



2022

# Range Anxiety: Composition statistics of white mica and chlorite in hydrothermally altered rocks

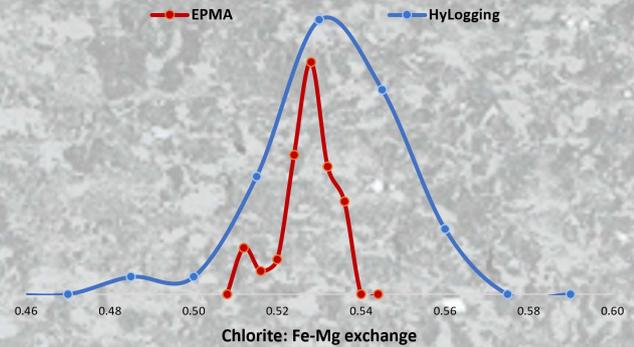
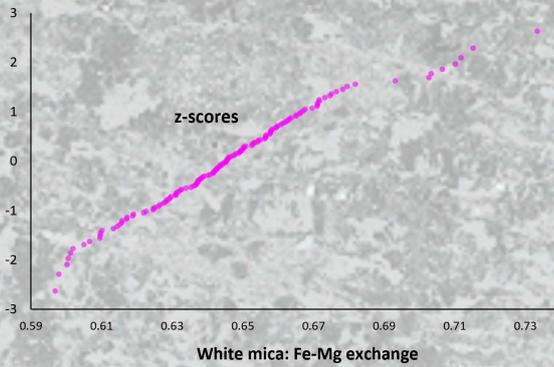
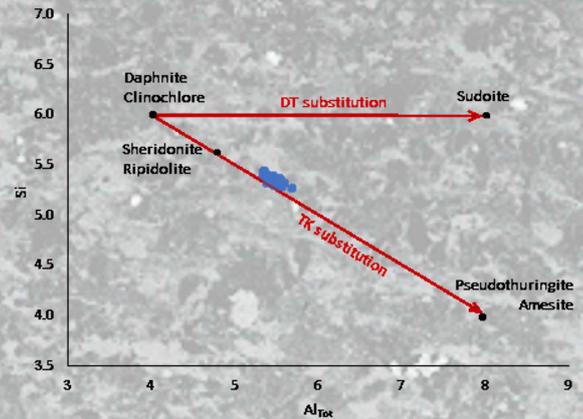
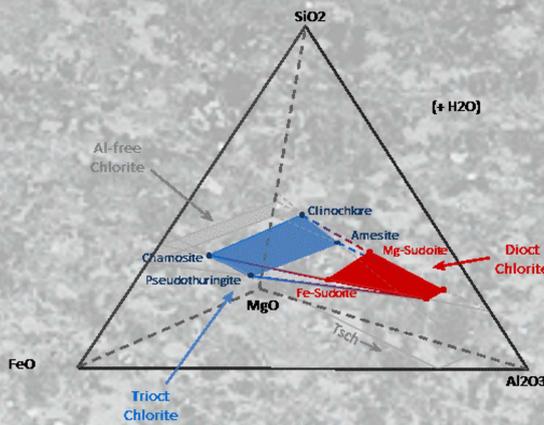
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REPORT No: TR29



Geological Survey  
Technical Report 29





Mineral Resources Tasmania  
Department of State Growth

## Geological Survey Technical Report 29:

### Range Anxiety:

### Composition statistics of white mica and chlorite in hydrothermally altered rocks

*by D. Green and T. Gallagher*

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I have an electric car, and I love it. However, although there's no reason for it, I'm often worried about how much charge is in the battery and how far I can drive.  
We call it Range Anxiety.

We generally assume that in a well-equilibrated assemblage, minerals have a single composition. However, as a metamorphic petrologist I had trouble measuring a typical composition of say, plagioclase in amphibolite grade schist, which would range by 10% Ab-An. I never had the time to get proper population statistics, and so I'd anxiously use the average of just a few analyses.  
I called it Range Anxiety.

And now in spectral geology I'm uneasy assuming that range of diagnostic wavelengths in a sample relates to the true range in mineral composition.  
It's Range Anxiety again.

David Green

April 2020

## 1. Introduction

The Rock Assemblage Library project initially analysed 25 samples to estimate mineral proportions by combining mineral compositions by EPMA (electron probe microanalysis) and whole rock lithochemistry from XRF (Moltzen and Bottrill 2018, Moltzen *et al.* 2020). The calculation was dependent on mineral compositions being well represented by the EPMA results. The extended project added 21 samples in which mineral proportions were measured using SEM MLA (Mineral Liberation Analysis) a method which has limited tolerance for variation in mineral composition (Green *et al.* 2021). It was noted in these projects that it would be desirable to check the results obtained by measuring the actual range of mineral compositions in individual samples.

Composition information for some minerals can also be estimated using the wavelength of diagnostic infra-red spectral features e.g. muscovite-phengite using the Al-OH absorption at about 2200nm. Calibrations have

been published for some common rock forming minerals such as white mica and chlorite and are commonly applied when seeking vectors to mineralisation (e.g. Pontual *et al.* 1997). While trends in composition can be used with some confidence, it is not known how the range of diagnostic wavelengths in any single sample or downhole location relates to the actual range in mineral composition.

In the current project we aimed to measure the population statistics of mineral compositions analysed by both EPMA and infra-red spectroscopy by HyLogger-3 scanning and to compare the two. The project targeted typical fine grained hydrothermal alteration containing significant proportions of minerals commonly subject to spectral analysis of composition, i.e. white mica, chlorite and plagioclase, and mineral assemblages amenable to validation, i.e. where analyses of non-targeted minerals and analyses indicating mineral mixtures can be efficiently filtered out.

## 2. Methods

### Mineral selection

Target minerals were selected based on the available mineral assemblages in the Rock Assemblage Library samples and those most commonly interpreted for composition using infra-red spectroscopy: white mica (muscovite – phengite), chlorite (Mg-chlorite – Fe-chlorite) and plagioclase (albite – anorthite).

### Sample selection

Three samples were selected for EPMA from 21 well-characterised samples previously analysed by MLA as part of the Rock Assemblage Library project (table 1). The selection criteria were:

- Significant modal proportions of any 2 of the minerals of interest: white mica, chlorite and plagioclase (table 2, figure 1).

- Hydrothermal alteration with a fine grain size, but coarse enough for EPMA, interpreted from backscatter electron imagery (figure 2).
- Absence of minerals that have the potential to confound EPMA results (by not being able to be unmixed from the target mineral) e.g. white mica without kaolinite, chlorite without amphibole and plagioclase without carbonate.
- Assemblages that include minerals easily distinguished from the target minerals e.g. white mica and carbonate, chlorite and white mica, plagioclase and white mica.

The samples were typically 10cm x 5cm, and homogeneous as indicated by HyLogging and MLA.

Table 1. Sample details. Start and end refer to TSG dataset sample id numbers. Spectra refers to the total number of HyLogger 4mm samples acquired from the face of the sample selected to be analysed by MLA. MRV – Mt Read Volcanics.

MRT Sample_ID	Target sub- assemblage	Lithology	Location	State	ddh id	Hole name	Start	End	Depth	Length (cm)	Spectra
G408245	Chlorite + Carbonate + White mica	Altered felsic volcanic	Mt Charter, MRV	Tas	13529	MCH1	73944	73949	533.75	4	160
G408248	K-feldspar + Plagioclase + White mica (+ Quartz)	Felsic volcanic	Hatfield River, MRV	Tas	8484	HAT7	38045	38050	146.6	4	323
G408266	Chlorite + Amphibole	Altered mafic volcanic	Cleveland	Tas	18532	C0631	77942	77964	283.31	8.8	147

Table 2. Mineralogy of samples from HyLogging (dCLST and uTSAS) and MLA (XMOD). SWIR results are provided in Appendix 1.

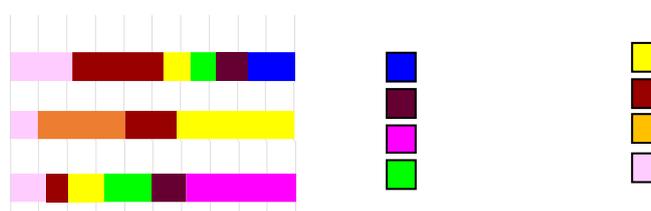
	<b>G408245</b> Chl+Carb+White mica Mt Charter, MRV	<b>G408248</b> K-feldspar+Plag+White mica(+Qtz) Hatfield River, MRV	<b>G408266</b> Chl+Amph Cleveland
Number of HyLogger spec	160	323	147
Number of MLA points	33404	64051	39994

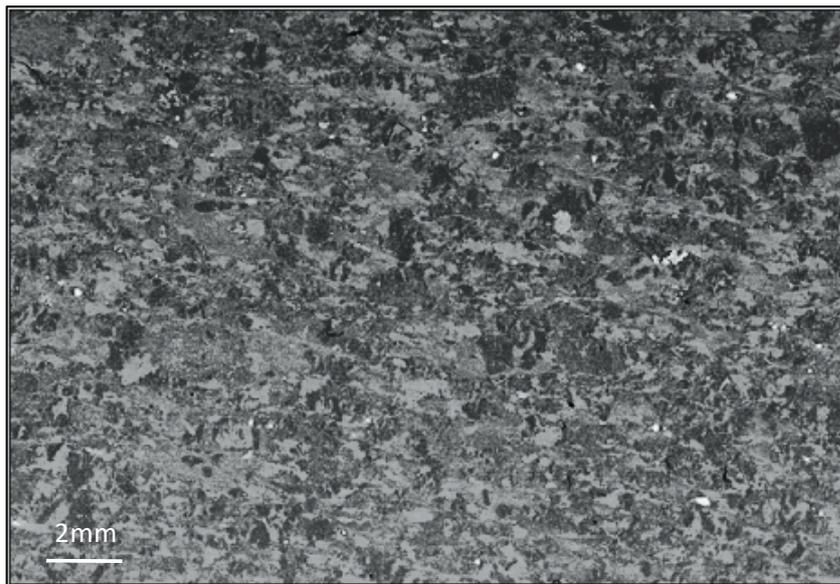
**TIR**

Groups	dCLST	XMOD	dCLST	XMOD	dCLST	XMOD
SILICA	23.7%	21.7%	13.6%	9.0%	16.6%	11.3%
K-FELDSPAR		0.1%	23.9%	28.9%		2.5%
PLAGIOCLASE	22.5%	31.8%	17.5%	16.7%		7.6%
WHITE-MICA	17.5%	9.4%	42.3%	38.6%		11.2%
CHLORITE	8.5%	9.1%	2.2%	1.4%	36.1%	15.3%
DARK-MICA		10.9%		2.6%	12.2%	11.3%
AMPHIBOLE		0.3%		0.0%	35.1%	35.4%
EPIDOTE						1.0%
CARBONATE	27.7%	16.3%	0.4%	0.7%		0.4%
PHOSPHATE		0.1%		0.3%		0.3%
OXIDE		0.0%		0.0%		2.8%
INVALID		0.3%		1.6%		0.5%

Minerals	dCLST	XMOD	dCLST	XMOD	dCLST	XMOD
Quartz	23.7%	22.7%	13.6%	9.2%	16.6%	11.9%
Microcline			23.9%			
Orthoclase		0.1%	0.0%	29.4%		2.6%
Albite	22.5%	23.3%	14.0%	12.8%		0.1%
Labradorite			0.1%			
Oligoclase		5.8%	3.4%	4.2%		7.9%
Muscovite	17.5%	0.8%	41.9%	2.8%		0.6%
Phengite		9.0%	0.4%	36.5%		11.2%
Chlorite-Fe	0.4%	9.4%	0.1%	1.5%	28.0%	16.0%
Chlorite-FeMg	8.1%	0.1%	2.2%		8.1%	0.0%
Biotite		11.4%		2.7%	11.5%	11.9%
Phlogopite					0.7%	
Actinolite		0.3%		0.0%	18.4%	37.1%
AmphiboleML48					0.3%	
Edenite					1.6%	
Hornblende					14.8%	
Siderite	17.2%		0.4%			
Calcite	10.5%	17.1%	0.0%	0.7%		0.4%
Apatite		0.1%		0.3%		0.3%

Figure 1.  
Summary bar  
chart of sample  
mineralogy from  
MLA.





G408245

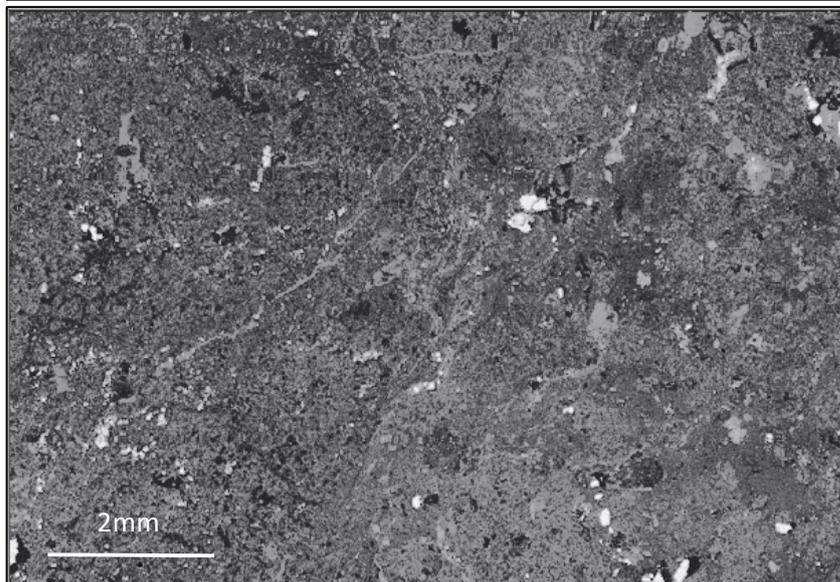
Large, lightest grey =  
carbonate

Darker matrix =  
plagioclase + biotite

Lighter matrix = chlorite+  
biotite ±

Small, dark crystals =  
biotite

Disseminated in matrix:  
quartz



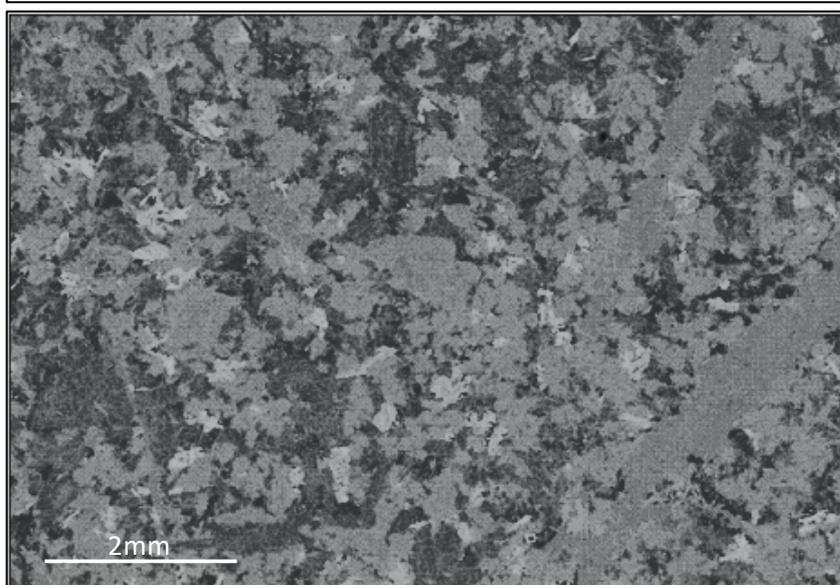
G408248

Darker grey patches = K-  
feldspar + white mica

Lighter grey patches =  
plagioclase + white  
mica

Veinlets = white mica

Disseminated in matrix:  
quartz



G408266

Large, light grey  
patches/crystals =  
amphibole

Darker grey patches =  
plagioclase + chlorite

Veinlets = chlorite

Disseminated in matrix:  
white mica, quartz  
and biotite

Figure 2. Backscatter electron images of samples, enhanced using a Gaussian stretch.

## EPMA

Initially, a pilot sample and mineral (white mica) was analysed by both energy dispersive x-ray spectroscopy (EDS) and wavelength dispersive x-ray spectroscopy (WDS) to establish the analytical requirements. This information informed the choice of analytical method for other samples and target minerals (with many of the considerations summarised in figure 3).

The analytes of interest included Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, Cl, F and H<sub>2</sub>O. It was found

that the most efficient analytical method was to run WDS and EDS simultaneously, the former far more time-consuming method for less concentrated elements (Ti, Fe, Mn, Mg, Na, K, Cl and F) and the latter for more concentrated elements or those with more easily integrated spectral peaks (Si, Al, Ca). This resulted in a total analysis time of about 3 minutes per spot.

Productivity, including time to move between locations on the sample and identify target minerals was 15 spots per hour.

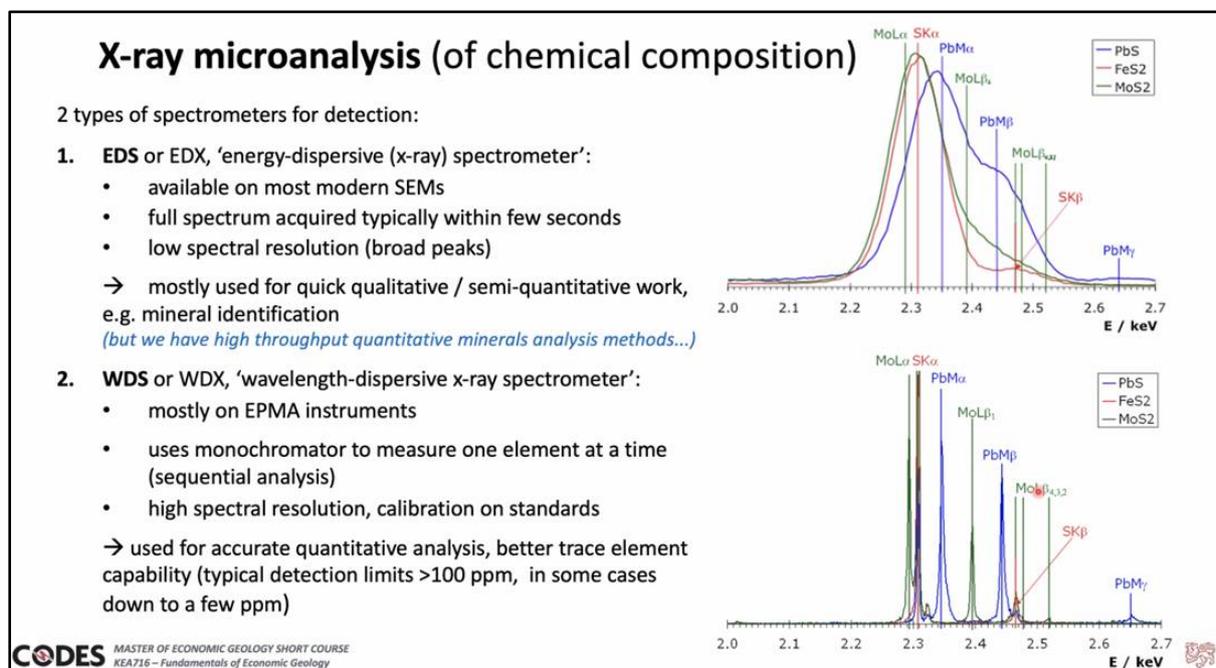


Figure 3. Comparison of the X-ray spectra from EDS and WDS. The WDS peaks are much better resolved leading to better precision (and to a slightly lesser degree, accuracy) of the measured compositions. (Image courtesy of Karsten Goeman.)

The analyses were acquired on an electron EPMA equipped with 5 tunable wavelength dispersive spectrometers and a Thermo NSS or PF EDS system at the Central Science Laboratories at the University of Tasmania. Operating conditions were 40 degrees take-off angle, a beam energy of 15 keV with a beam current of 10 nA and beam diameter of 10 microns. WDS analytical sensitivity at the 99% confidence level ranged from 0.02 wt% (for Mg) to 0.15 wt % (for Fe). EDS analytical

sensitivity at the 99% confidence level ranged from 0.08% (for Si) to 0.11% (for Ca). Analytical uncertainty was obtained by multiple analysis of standards. Oxygen and hydrogen were calculated by cation stoichiometry and included in the matrix correction.

The target number of EPMA analyses for each sample was that which would be comparable to the number obtained from HyLogging i.e. ~80 independent analyses.

Whilst selecting samples with a fine grain size is more representative of typical hydrothermally altered rocks, it is a challenge for analysis, where the analytical volume may often include a mineral mixture. All analyses were filtered to exclude those with indications of additional minerals. This was made simpler by the initial screening of sample mineral assemblages to exclude those with minerals that could not be readily unmixed from the target mineral e.g. white mica and kaolinite, but allowing minerals easily distinguished from the target minerals e.g. white mica and carbonate.

### Mineral composition from EPMA

Compositions of white mica and chlorite were calculated by transforming cation proportions to a base mineral + cation coupled exchange proportions (Thompson 1980), i.e.

- muscovite + Tschermak exchange ( $\text{MgSiAl}_2$ ) +  $\text{FeMg}_{-1}$  +  $\text{NaK}_{-1}$
- clinocllore + Tschermak exchange ( $\text{MgSiAl}_2$ ) + dioctohedral-trioctahedral

exchange ( $\text{Al}_2 \square \text{Mg}_{-3}$ ) +  $\text{FeMg}_{-1}$  (figure 4).

The transformation was calculated using least squares linear algebra, solving for X in the system  $Y = AX$ , where Y is a vector listing the cation proportions, X is a vector listing the mineral and exchanges proportions and A is a transformation matrix (table) expressing mineral and exchanges in terms of cations, using the solution  $X = (A^T A)^{-1} A^T Y$  (Thompson 1982). The system is overdetermined: there are more cations than minerals + exchanges, so the transformation is a dimension reduction or projection, relying on stoichiometric constraints and the reality of the exchanges for validity. The strengths of the method over stepwise methods are that the solution is simultaneous, unbiased and minimises error. It does not prioritise the assignment of cations to specific sites over others. Cation proportions were initially simplified (reducing dimensions) by combining Si and Ti, and Fe and Mn and calculating  $\text{FeMg}_{-1}$  and  $\text{NaK}_{-1}$  directly from cations.

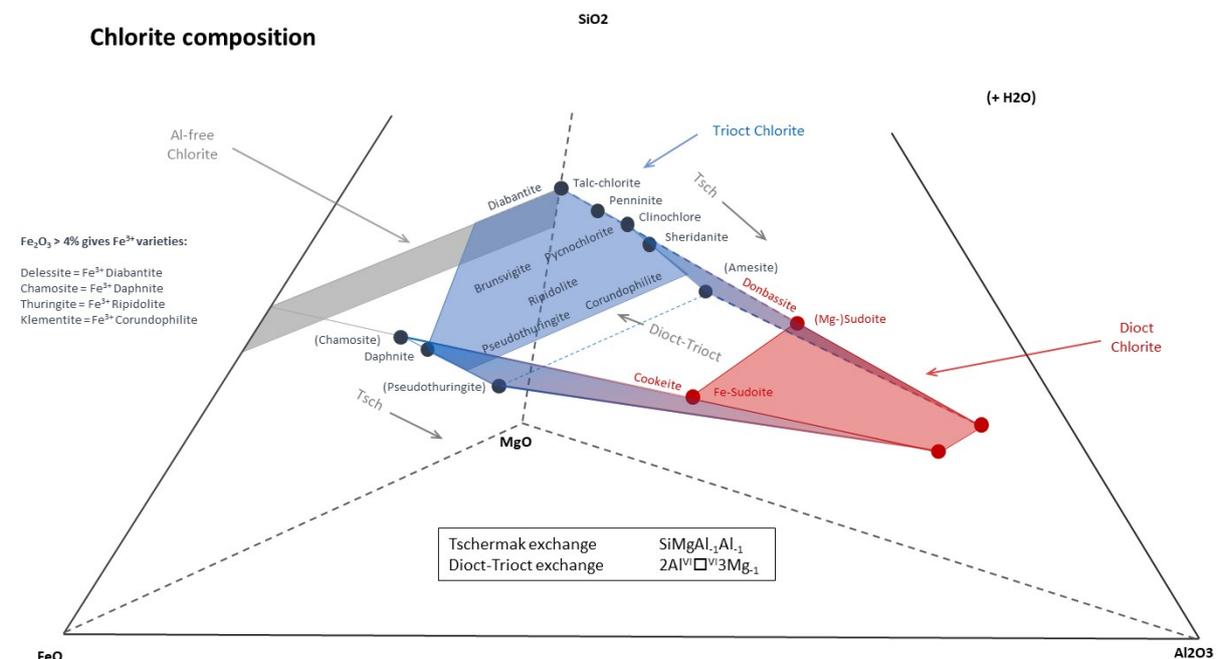


Figure 4. Composition space of chlorite showing mineral names and illustrating the three main cation coupled exchanges:  $\text{FeMg}_{-1}$ , Tschermak exchange ( $\text{MgSiAl}_2$ ) and dioctohedral-trioctahedral exchange ( $\text{Al}_2 \square \text{Mg}_{-3}$ ). Chlorite mineral species can be interpreted as clinocllore plus (or modified by) linear combinations of the cation exchanges.

## Hyperspectral scanning

Samples were scanned with the MRT HyLogger-3 (visible, NIR, SWIR and TIR; Schodlok *et al.* 2016) with a sample spacing of 4mm in both the down track and cross track directions (i.e. sampling chunked by 1 with tray sections separated by 4mm). This resulted in ~80 independent spectra for each sample (as discussed in Green *et al.* 2021 and below).

## Mineral composition from spectroscopy

The wavelength positions of diagnostic absorptions of white mica and chlorite relate to their composition (e.g. Pontual *et al.* 1997):

- The white mica Al-OH 2200nm feature wavelength is linearly related to Tschermak exchange:

2200nm = muscovite, 2220nm = phengite = muscovite + Tschermak exchange

- The chlorite (Fe,Mg)-OH  $\nu+\delta$  2350nm feature wavelength is linearly related to FeMg<sub>1</sub>:  
2325nm = chlinochlore, 2360nm = chamosite = chlinochlore + FeMg<sub>1</sub>.

Compositions in terms of Tschermak exchange in white micas and FeMg<sub>1</sub> in chlorites were calculated from the diagnostic feature wavelengths by linear interpolation from the diagnostic wavelengths of end members. Feature wavelengths (white mica 2200nm and chlorite 2350nm) were modelled using the PFit method in The Spectral Geologist software using reflectance with a hull envelope continuum for white mica (figure 5) and hull quotient with no continuum for chlorite.

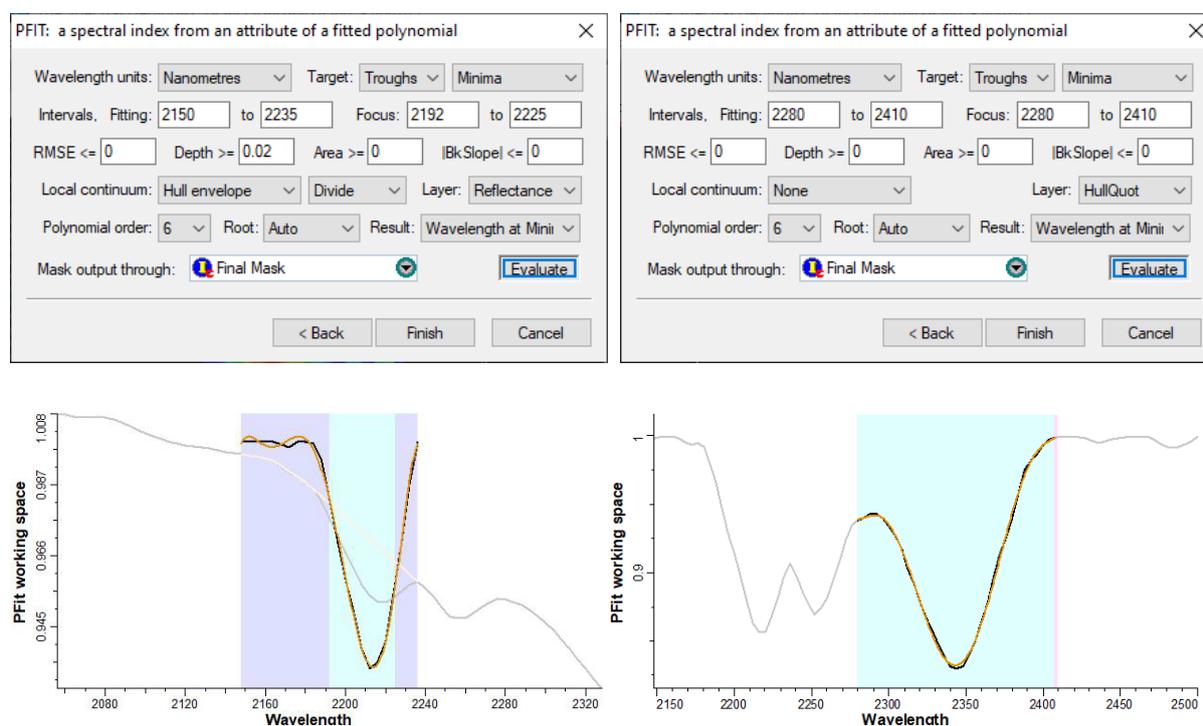


Figure 5. PFit parameters used to model the AlOH and FeOH absorption features in the The Spectral Geologist software. PFit evaluation plots illustrate typical scaled fits (in orange) to data (in grey) within the scope of the model (coloured background), superimposed on a full SWIR spectrum (in grey).

### 3. Results

EPMA analysis was not straight forward, with 61% of the 594 analyses interpreted as mixtures of minerals. Sample G408245 was the most productive, returning 60 chlorites and 24 white mica analyses. Sample G408248b returned 148 chlorite analyses, but all white mica and Ca-bearing plagioclase appeared to be mixtures with other minerals. In sample G408266 all 146 analyses contained significant

concentrations of Ca, Na and K and were interpreted as mineral mixtures.

EPMA results are provided in Appendix 1 and summaries of chemical compositions illustrating the range of results and analytical error are shown in figures 6, 7 and 8. Hyperspectral results are included in graphs comparing EPMA and HyLogging results as part of the discussion.

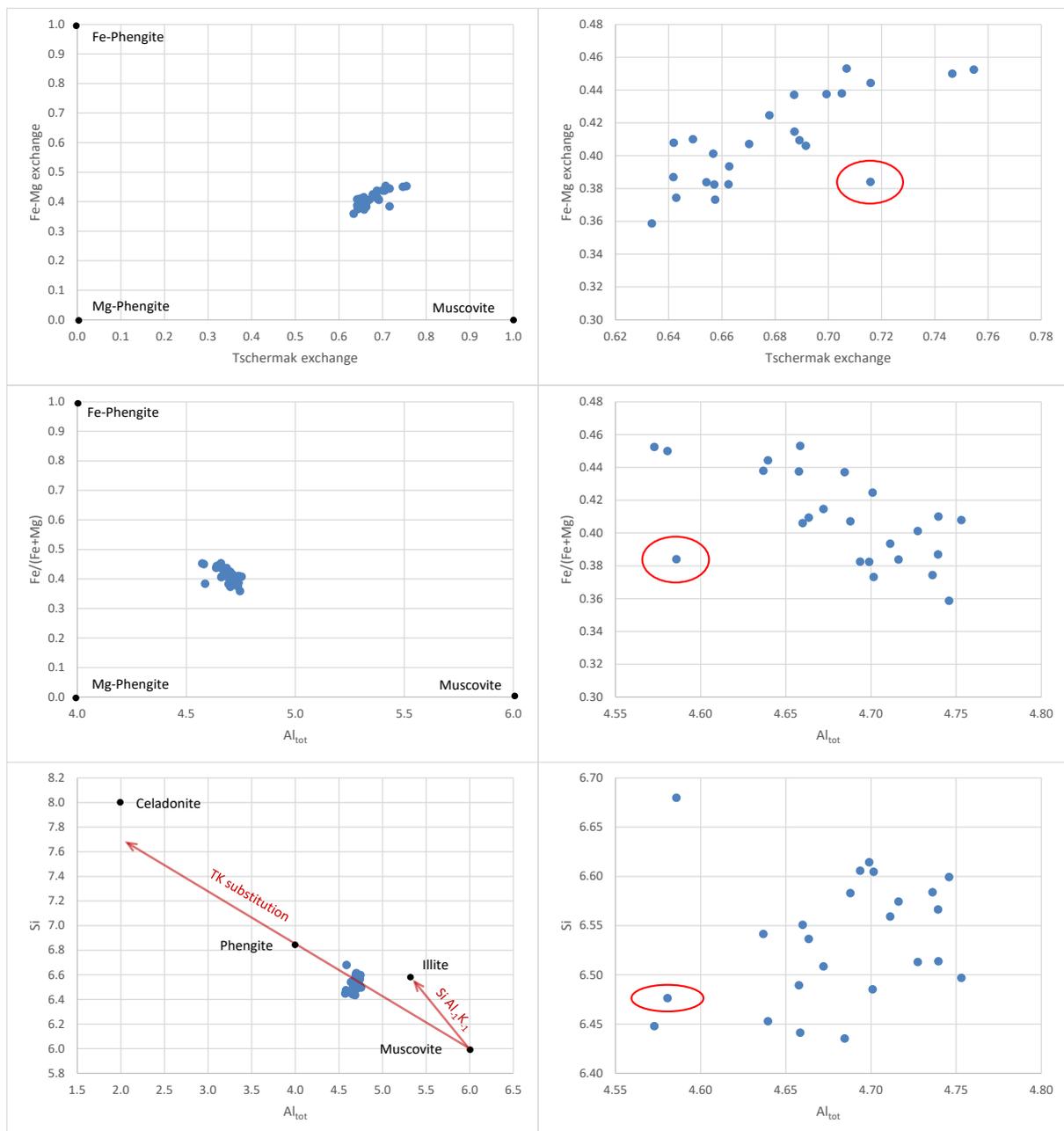


Figure 6. EPMA results for white mica in G408245 showing 2σ analytical uncertainty ellipses.

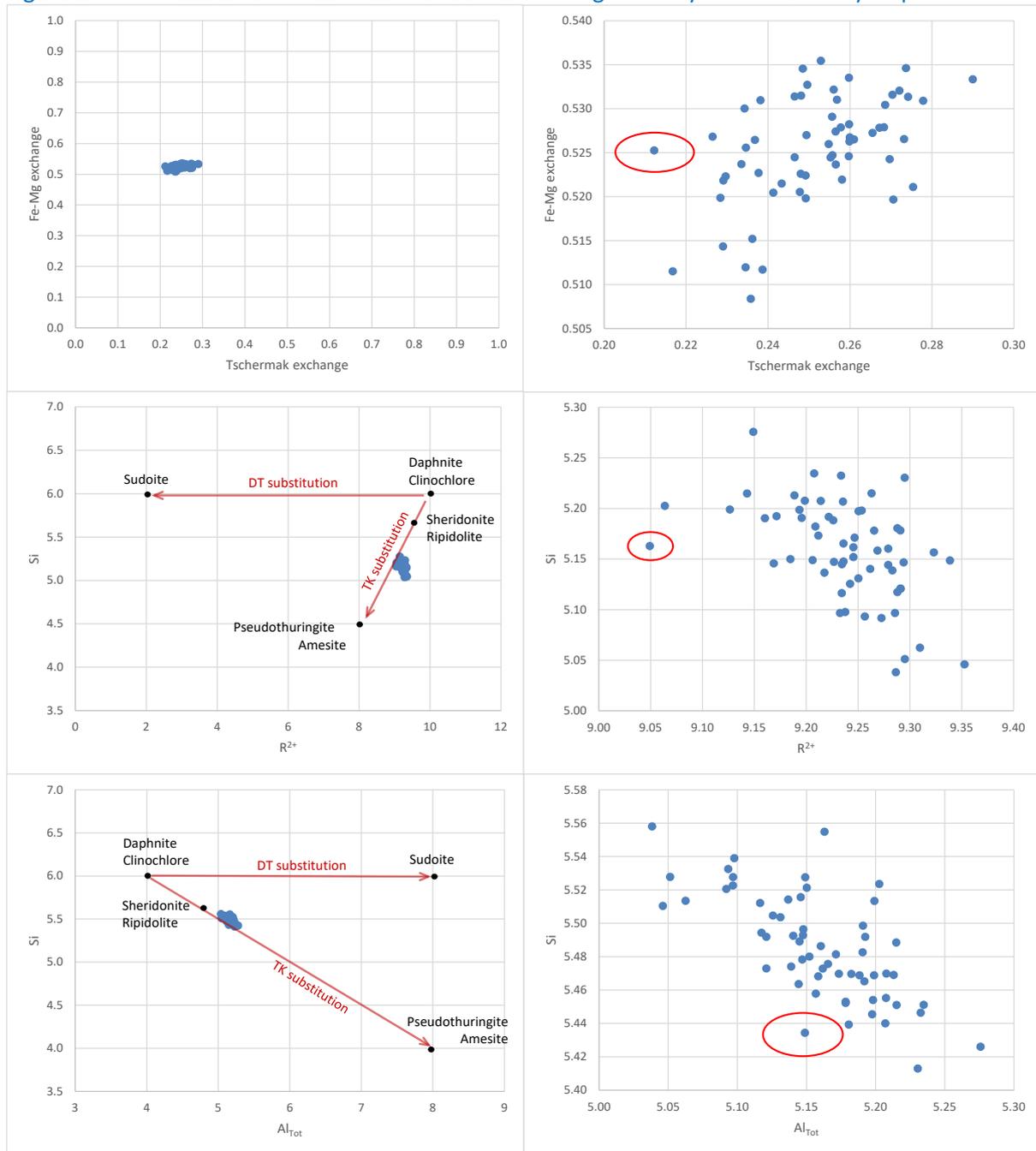


Figure 7. EPMA results for chlorite in G408245 showing 2σ analytical uncertainty ellipses.



Figure 8. EPMA results for chlorite in G408248b showing  $2\sigma$  analytical uncertainty ellipses.

## 4. Discussion

### Composition from EPMA analysis

The white mica in G408245 averaged  $\text{Si} = 6.5$ ,  $\text{Al}_{\text{tot}} = 4.7$ ,  $\text{Al}^{\text{IV}} = 1.3$ ,  $\text{Al}^{\text{VI}} = 3.2$ ,  $\text{Mg} + \text{Fe} = 1.0$ , corresponding to muscovite with 0.68 Tschermak exchange toward (and ultimately celadonite) phengite, i.e.  $\text{phe}_{68}\text{mus}_{38}$ , 0.41  $\text{FeMg}_{-1}$  and 0.02  $\text{NaK}_{-1}$  toward paragonite (figure 7). Illite exchange ( $\text{Si}\square\text{Al}_{-1}\text{K}_{-1}$ ) was not modelled because it is at a low angle to Tschermak exchange, which is the main focus of the analysis. An alternative analysis could account for both Tschermak and illite exchange using a less realistic exchange toward illite that is perpendicular to Tschermak exchange i.e.  $\text{Si}_{0.27}\text{Al}_{0.16}(\text{MgFe})_{-0.43}\text{K}_{-0.7}$ .

The chlorite in G408245 averaged  $\text{Si} = 5.5$ ,  $\text{Al}_{\text{tot}} = 5.1$ ,  $\text{Al}^{\text{IV}} = 2.5$ ,  $\text{Al}^{\text{VI}} = 2.6$ ,  $\text{R}^{2+} = 9.2$ , corresponding to clinocllore with 0.25 Tschermak exchange toward ripidolite (and ultimately amesite or pseudothuringite) i.e.  $\text{clino}_{88}\text{ames}_{12}$ , 0.53  $\text{FeMg}_{-1}$  toward chamosite i.e.  $\text{clino}_{47}\text{cham}_{53}$  and 0.04 dioctohedral-trioctahedral exchange ( $\text{Al}_2\text{Mg}_{-3}$ ) toward sudoite i.e.  $\text{clino}_{98}\text{sudo}_2$  (figure 7).

The chlorite in G408248b averaged  $\text{Si} = 5.4$ ,  $\text{Al}_{\text{tot}} = 5.5$ ,  $\text{Al}^{\text{IV}} = 2.6$ ,  $\text{Al}^{\text{VI}} = 2.8$ ,  $\text{R}^{2+} = 11.9$ , corresponding to clinocllore with 0.32 Tschermak exchange toward ripidolite, 0.65  $\text{FeMg}_{-1}$  toward chamosite and 0.05

dioctohedral-trioctahedral exchange ( $\text{Al}_2\text{Mg}_{-3}$ ) toward sudoite (figure 8).

Deviation from an ideal model, where the measured composition is an exact linear combination of the mineral + cation exchanges, arises from unaccounted cation exchanges (e.g.  $\text{Fe}^{3+}\text{Fe}^{2+}_{-1}\text{H}^{+}_{-1}$ , Masci *et al.* 2019 and illite exchange  $\text{Si}\square\text{Al}_{-1}\text{K}_{-1}$ ) and traces of spurious cations (e.g. Ca), together indicating non-ideal modelling and/or stoichiometry, and analytical error. Sums of residuals squared ( $\sum(\text{Y}^{\text{T}} - \text{XA})^2$ ) was of the order of 0.15, indicating ~1% deviation from an ideal model excluding illite exchange. EPMA analytical uncertainties (figures 7 and 8) indicate that 90% of the deviation from ideal is stoichiometric.

### Shape of composition distribution

The EPMA composition histograms, especially those with the greatest number of samples, are symmetric, unimodal distributions (figures 9, 10 and 11), and are Gaussian-like (as indicated by the normal probability plot in figure 11). This indicates a single population with statistics compatible with a normal analytical uncertainty distribution and may be representative of altered rocks commonly scanned with the HyLogger.

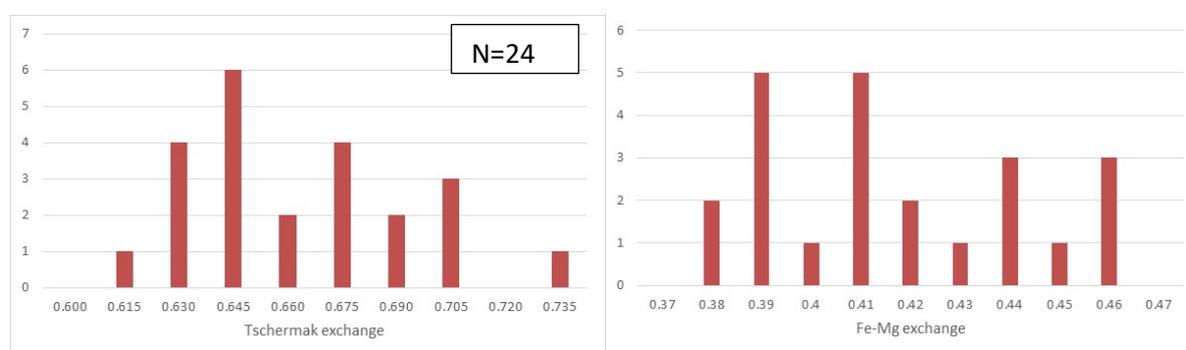


Figure 9. Histograms of white mica composition from EPMA results for G408245.

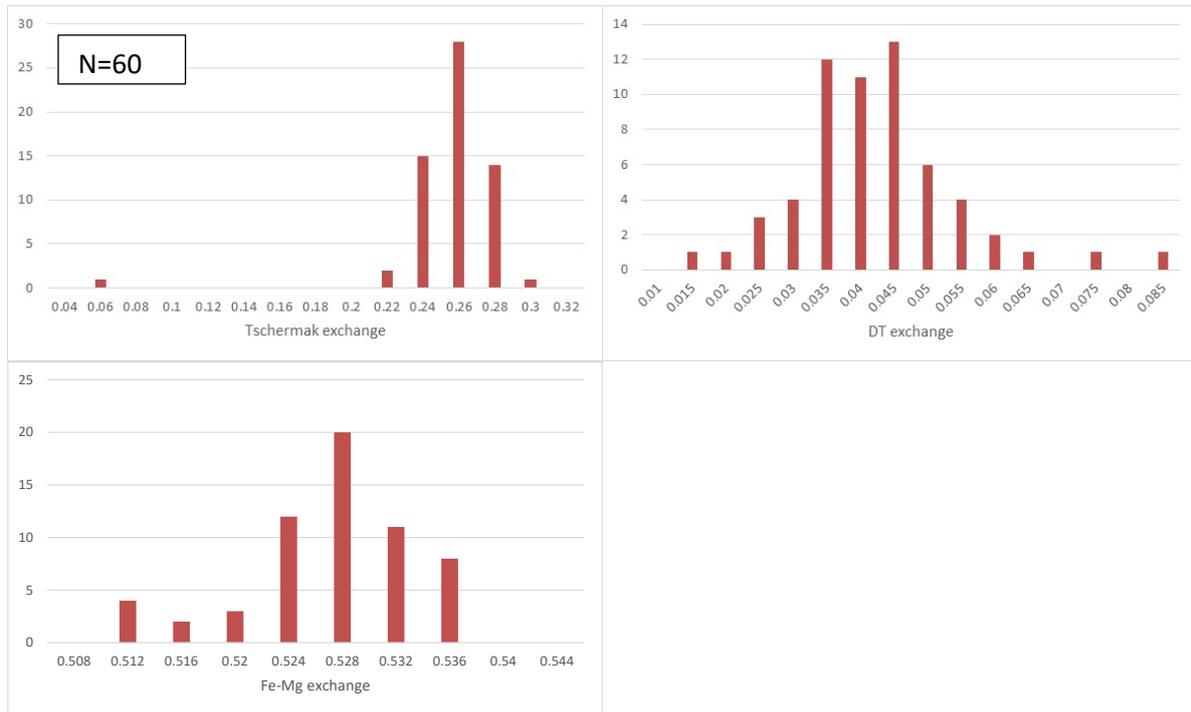


Figure 10. Histograms of chlorite composition from EPMA results for G408245.

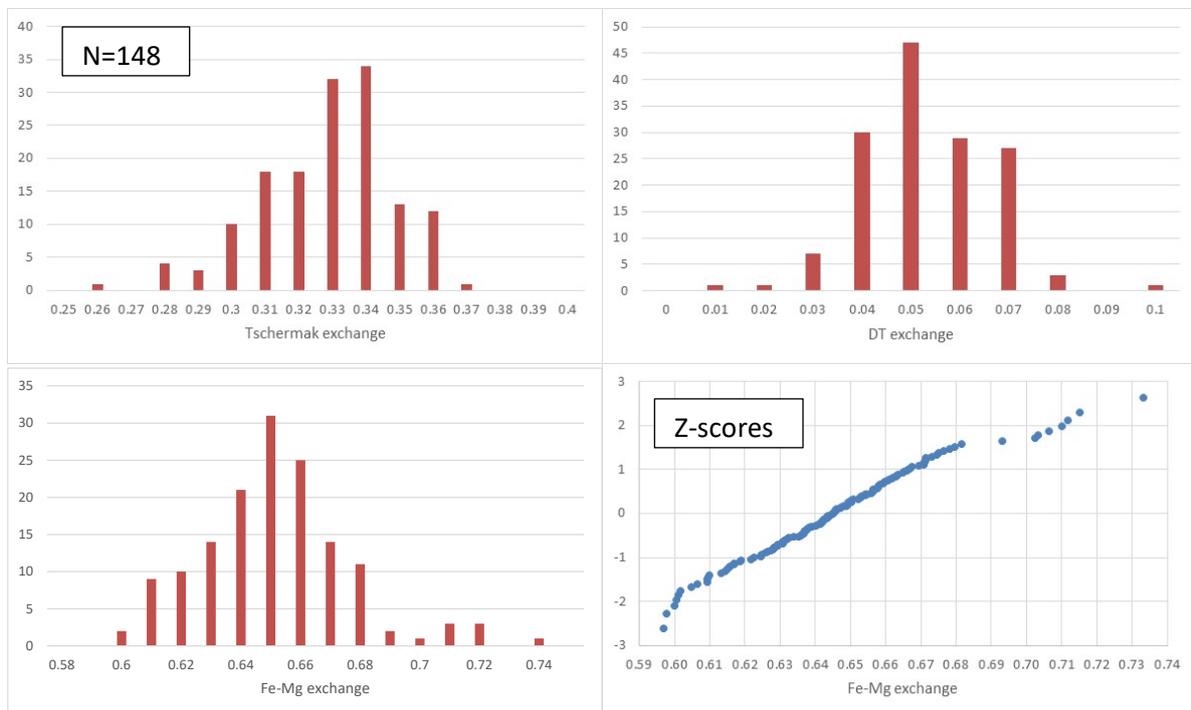


Figure 11. Histograms of chlorite composition from EPMA results for G408248a. A normal probability plot is shown for the Fe-Mg exchange.

The hyperspectrally-derived composition histograms contain more samples than analysed by EPMA, although there is significant overlap in the sample volumes. There is a 63% SWIR signal overlap between adjacent samples 4mm apart (from a project measuring the instantaneous field of view of the HyLogger-3 by D Green in 2016). This indicates that for

example, 100 samples represent 37 spatially independent samples. Linear trends in normal probability plots for white mica and chlorite feature wavelengths in G480245 indicate Gaussian-like distributions, but chlorite feature wavelengths in G480248a were significantly different from Gaussian with an asymmetric tail at short wavelengths (figure 12).

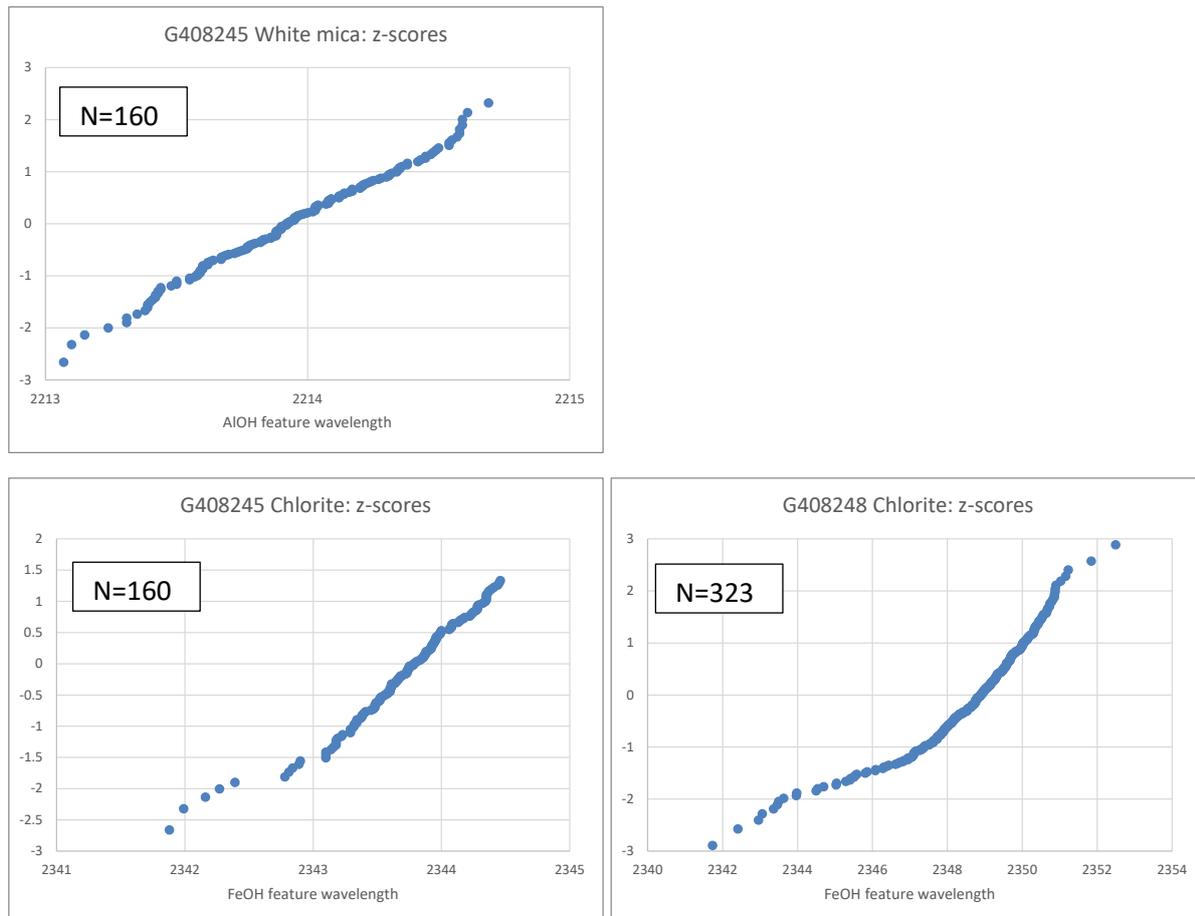


Figure 12. Normal probability plots of white mica and chlorite composition from HyLogging results.

## Composition error

Summaries of the EPMA and HyLogging results are combined in figure 13. The average compositions from EPMA and HyLogging differ only very slightly:

- White mica Tschermak exchange is overestimated by HyLogging by 2% (G408245).

### G408245 White mica

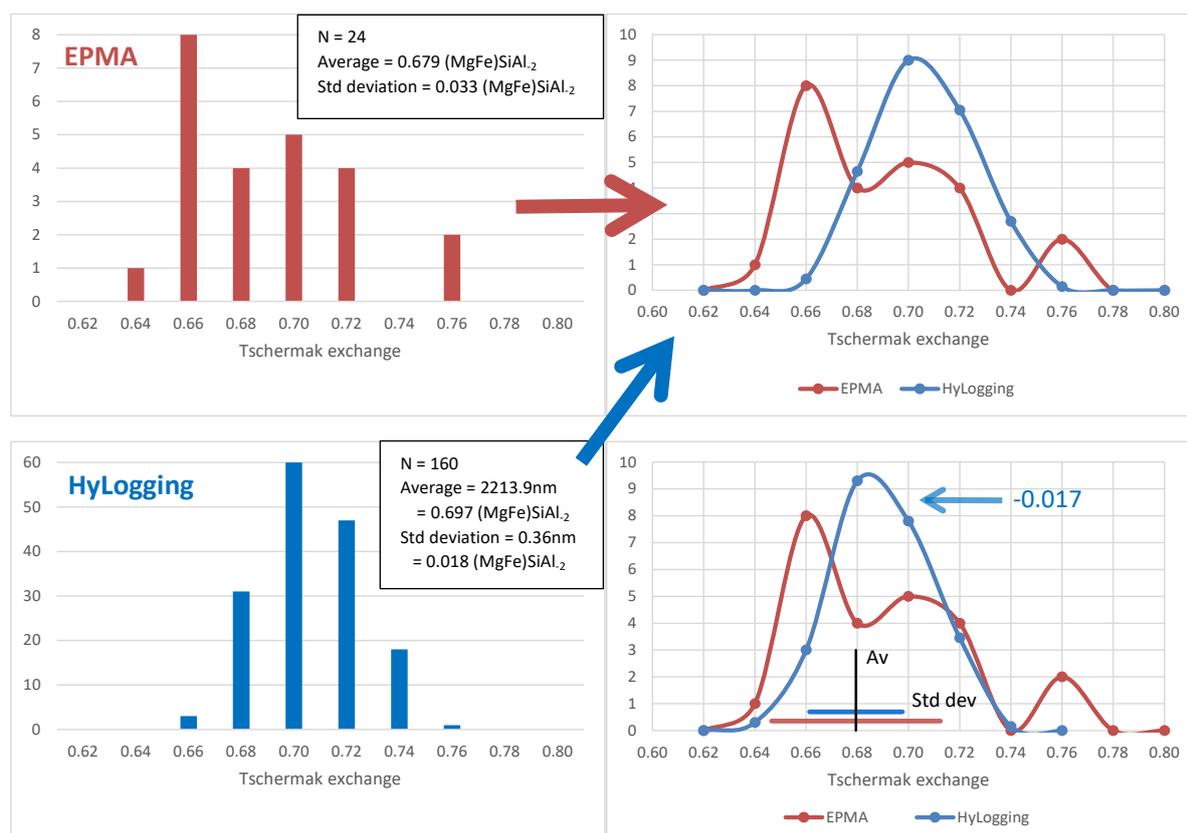
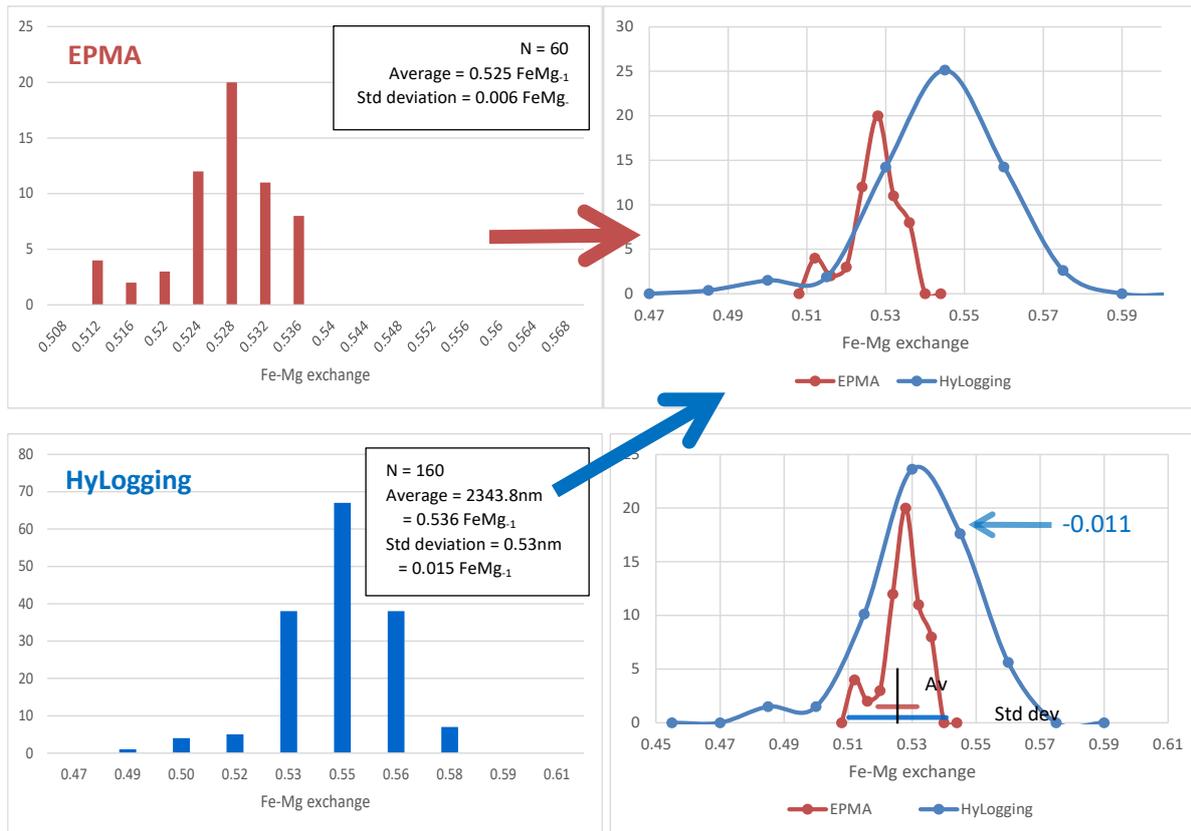


Figure 13 (above and on next page). Composition histograms for white mica and chlorite from EPMA and HyLogging are compared by combining the bar plots (left) into a scatter plot in which frequencies are scaled according to the total number of samples/analyses/spectra (top right). The histogram from the HyLogging results is translated with respect to that of the EPMA results so the averages coincide (bottom right). The vertical black line is the average and the two horizontal bars indicate -1 standard deviation to +1 standard deviation (red for EPMA, blue for HyLogging).

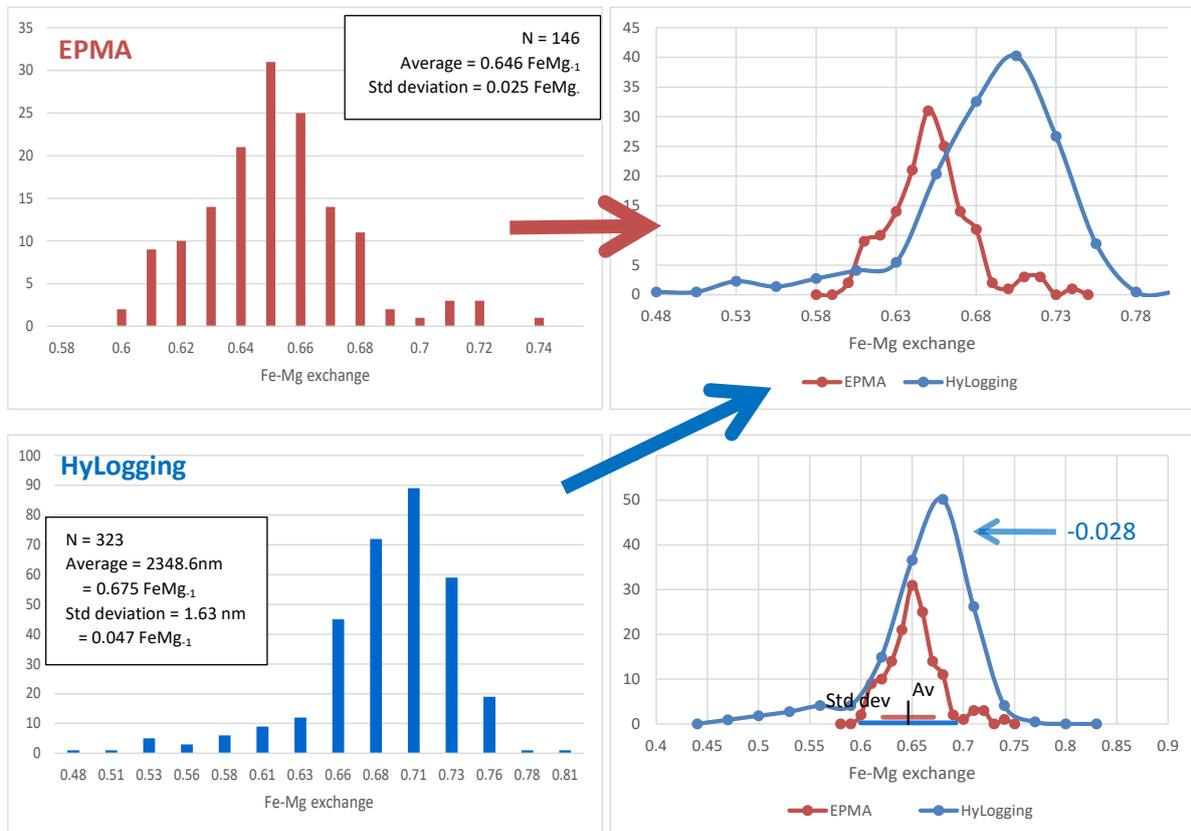
- Chlorite FeMg-1 is overestimated by HyLogging by 1% (G408245) and 3% (G408248a), although the population of the latter is skewed by a long tail and the difference in medians provides a better error estimate of 6%.

This result appears excellent, but the significance is diminished because the calculation of composition from spectral features is dependent on the choice of feature fitting algorithm and end member feature wavelengths.

G408245 Chlorite



G408248b Chlorite



### Compositional range

The range of Tschermak compositions measured by EPMA was 0.132 (width of 2 standard deviations either side of the mean) for white mica and 0.024 and 0.100 for chlorite. The uncertainty arising from analytical error was 0.012 ( $2\sigma$ ) for white mica and 0.006 for chlorite. Figures 6, 7 and 8 show the compositional ranges and analytical uncertainties, illustrating their relative magnitude and indicating the veracity of the compositional ranges.

The range Tschermak compositions measured by HyLogging was 0.072 for white mica, 0.6 times that measured from EPMA. This is a surprising result and may indicate that spectral analysis is more precise than EPMA or many of the EPMA analytical sample volumes were variably contaminated.

The range of Fe-Mg compositions measured by EPMA was 0.112 for white mica and 0.024 and 0.100 for chlorite. The uncertainty arising from analytical error was 0.009 for white mica and 0.006 for chlorite.

The range of Fe-Mg compositions measured by HyLogging was 0.060 and 0.188 for chlorite, 1.9 and 2.5 times that measured EPMA. This indicates that HyLogging is a good measure of compositional range.

The range of Na-K compositions measured by EPMA was 0.056.

The range of dioctahedral-trioctahedral compositions measured by EPMA was 0.048 for chlorite. The uncertainty arising from analytical error was 0.003.

In summary, the compositional ranges encompassing 90% of white micas and chlorites are 2-13% across all measures.

### Analytical uncertainty

The range of chlorite compositions from HyLogging results was significantly wider than those from the EPMA: standard deviations for  $\text{FeMg}_{-1}$  in chlorite were ~2 times larger for HyLogging compared to EPMA. This indicates that the EPMA returns better analytical uncertainty than the HyLogging system. The degree of additional spread in the HyLogging results informs us about the relative precision (and maybe accuracy) of the techniques.

The compositional range measured for white mica was tighter in the HyLogging results: the standard deviation for Tschermak exchange in white mica was almost 2 times larger for EPMA compared to HyLogging. This was an unexpected result and indicates that spectral analysis is more precise than EPMA. This is supported by the large size of EPMA uncertainty ellipses relative to the range of compositions, illustrated in figure 6. As discussed above, this result may also indicate that many of the EPMA analytical sample volumes were slightly contaminated by other minerals.

## 5. Conclusions

The aim of the project was to address questions relating to 'Range anxiety':

- **Are the population statistics of mineral compositions in altered rocks simple and do the compositions have a narrow range?** The answer is yes to both questions, with compositions showing a unimodal, non-skewed and Gaussian distribution and with narrow ranges (2-13% of typical measures).
- **Is the range of compositions indicated by spectral analysis true?** The answer is that it is at least consistent with EPMA analysis, with the proviso indicated by chlorites that the range can be more spread than the truth (by a factor of 2).

Our conclusions in detail include:

- EPMA analytical volumes (~10  $\mu\text{m}$ ) typically included more than a single mineral in typical hydrothermal alteration textures.
- Histograms of white mica and chlorite compositions from EPMA and hyperspectral analysis tended toward being unimodal, non-skewed and in some cases Gaussian-like as the number of samples was increased.
- Within each sample,
  - the range of Tschermak compositions was limited to 13% of the full muscovite-phengite range and 2-10% of the clinocllore-amesite range.
  - the range of Fe-Mg compositions was limited to 11% of the full range in white mica and 2-10% of the clinocllore-chamosite range.
  - the range of Na-K compositions was limited to 5% of the muscovite-paragonite range.
  - the range of dioctahedral-trioctahedral compositions was limited to 5% of the clinocllore-sudoite range.
- The range of compositions measured by EPMA was well estimated by the range of spectral feature wavelengths in white mica (actually surprisingly under-estimated by a factor of 0.55) and was 2 times wider in chlorite.
- Spectral analysis estimated the Tschermak composition of white mica and Fe:Mg of chlorite to within 6%, but this accuracy was dependent on the choice of feature extraction algorithms and end member feature wavelengths.

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# APPENDIX 1

## Excel files - MLA data - TSG datasets



File Download

<https://www.mrt.tas.gov.au/mrtdoc/dominfo/download/TR29/>



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