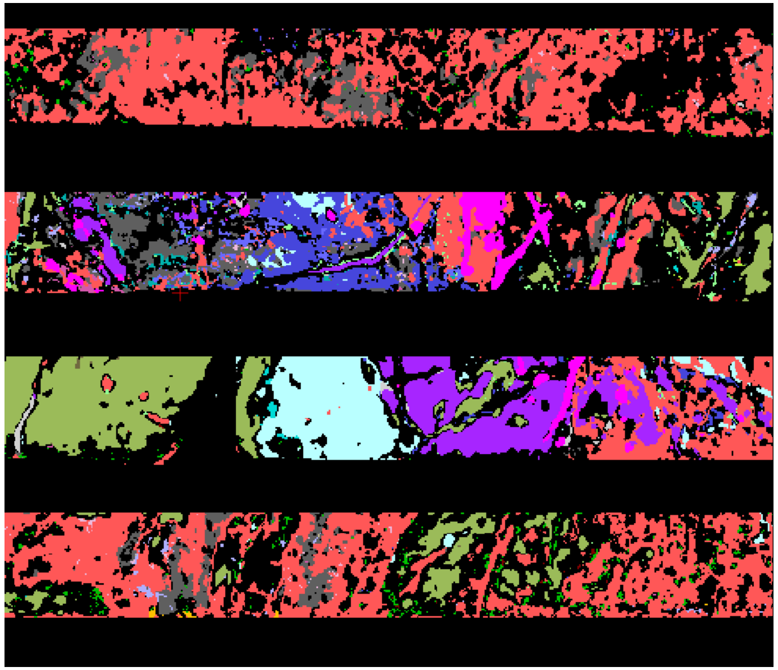
Mineral Mapping

Mineralogy Maps from SWIR data; what works, what doesn't work, and why.

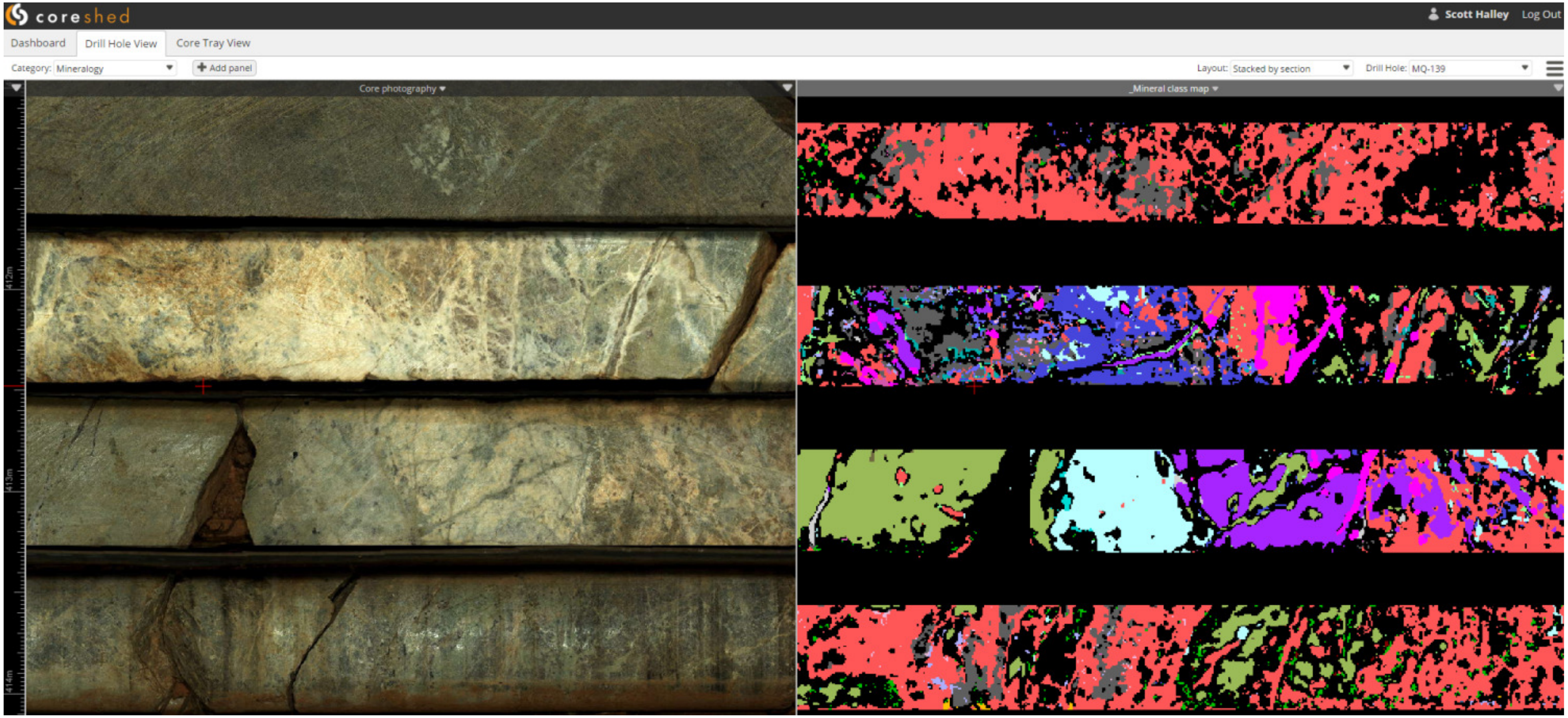


GeoConferences;
HYPERSPECTRAL ANALYSIS FOR EXPLORATION

Scott Halley
9th May 2016

How Representative is Terra Spec data?

This is a classified mineral map image from CoreScan.
Imagine you are measuring this drill core with a Terrra Spec; one measurement per meter of core.
Your field of view with the Terra Spec is about 1cm.
Which spots are you going to measure? How representative will it be?



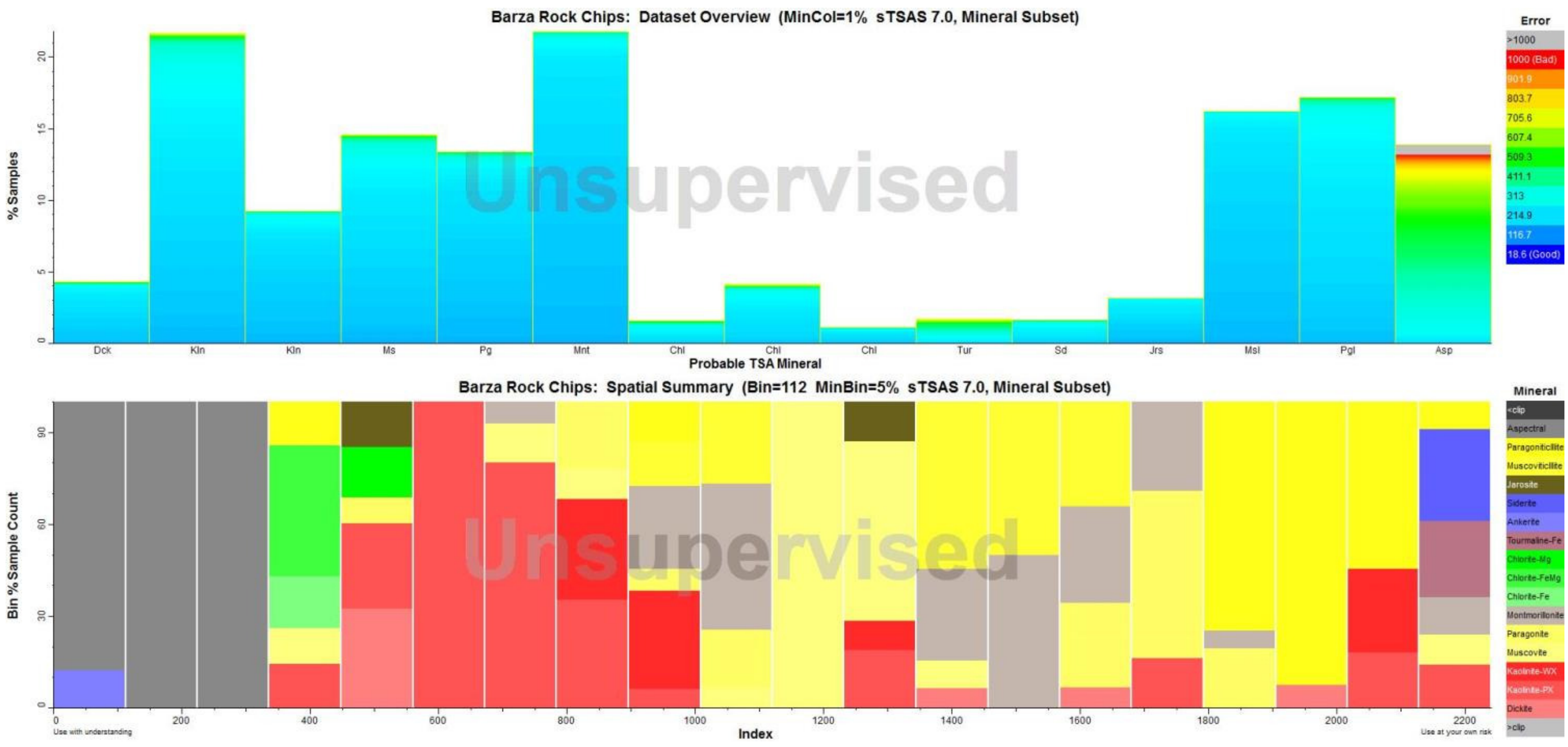
Case Study from a Porphyry Cu – Intermediate Sulfidation Epithermal system.

This is a case study that briefly shows the workflow I would use to interpret a Terra Spec data set. I also have ICP-MS/AES geochem from these samples. The SWIR interpretation has been plotted against the whole rock geochem to test the reliability of the SWIR. This highlights the limitations of the SWIR data, but also shows some graphical methods that can be used to improve the mineral classification.

Intuitive QAQC with Terra Spec and TSG

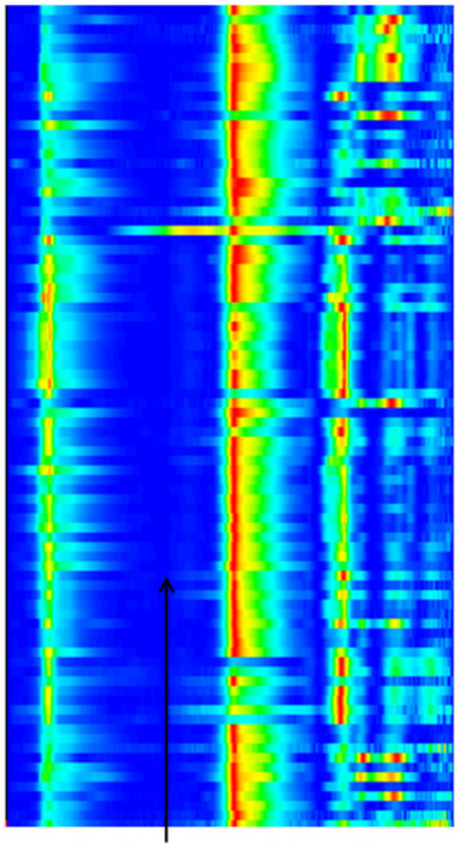
Most of us interpret Terra Spec data with TSG.

The initial screen looks like this. Check the Probable TSA Minerals. Look for runs of Aspectral data.

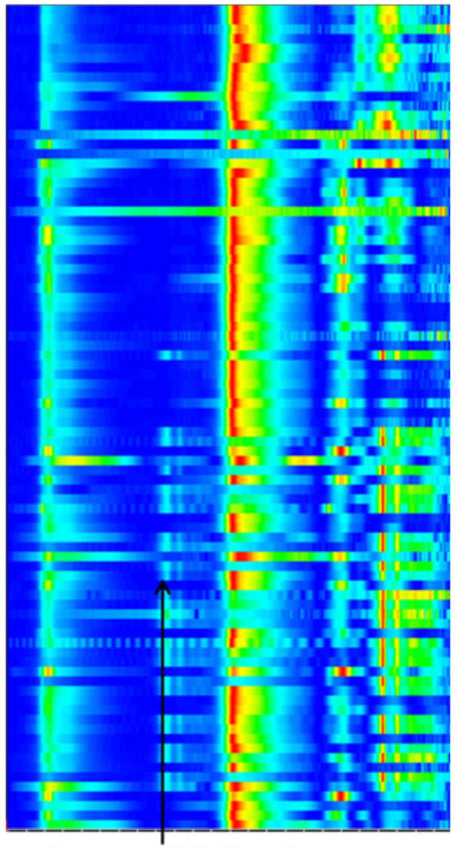


Intuitive QAQC with Terra Spec and TSG

Scroll through the log screen. Between 1500 and 1900nm, the normalized hull quotient should be a uniform deep blue colour. Noisey data or artifacts will show up clearly in this range. Are there blocks of poor data? If so, why; dark rocks?



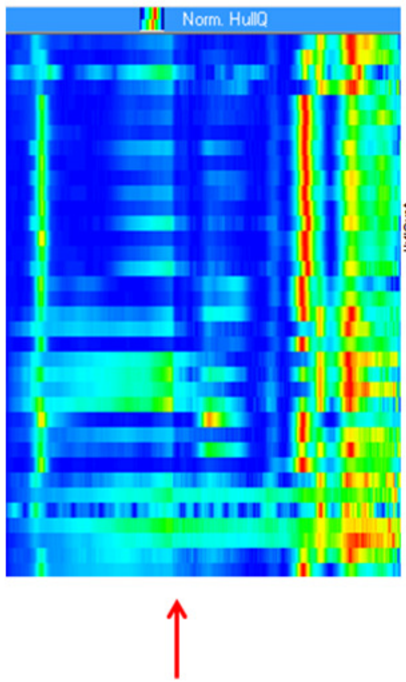
Good quality spectra with a uniform deep blue background

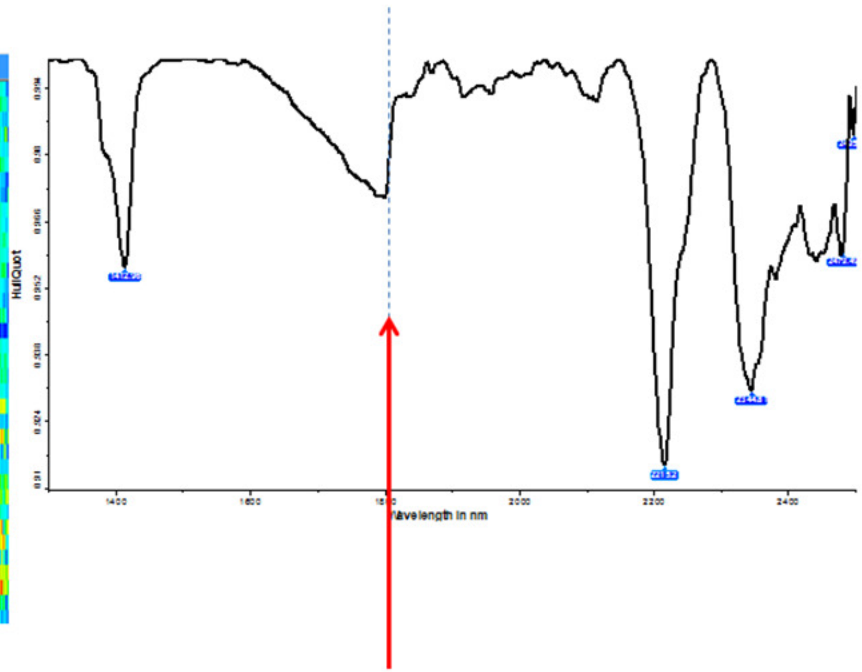


Noisy spectra full of artefacts

Intuitive QAQC with Terra Spec and TSG

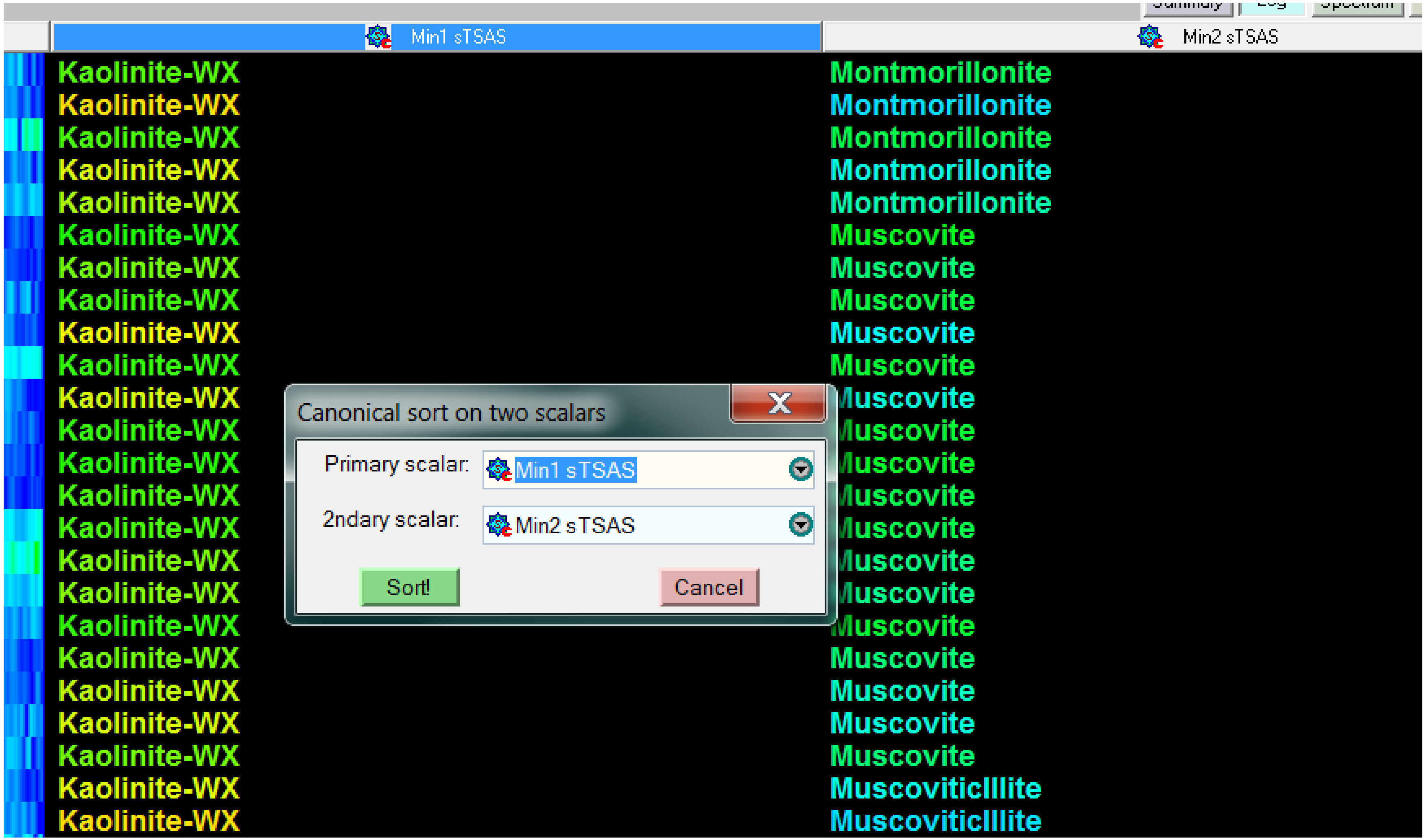
Watch out for artifacts like this; at 1800nm there is a break between sensor 2 and sensor 3. This will often cause TSG to give an “Aspectral” result. Someone wasn’t calibrating the ASD instrument frequently enough!





Intuitive QAQC with Terra Spec and TSG

Sort on Min1 and Min2. Scroll through the data and look for mineral species that do not belong in the mineral assemblage that you are expecting. When the software encounters poor quality spectra (usually in rocks with low reflectance) there are particular mineral names that it commonly assigns. In particular, don’t trust Ankerite, Siderite, Mg Chlorite, Tourmaline, Diaspore or Zoisite. You should go through and manually check these unreliable mineral picks.

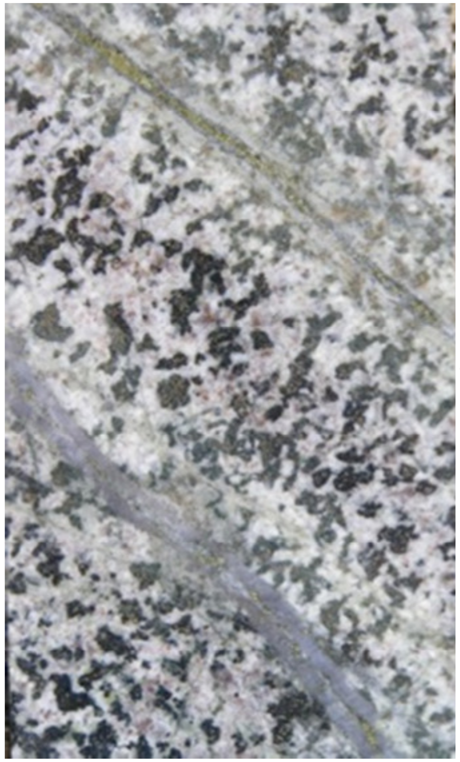


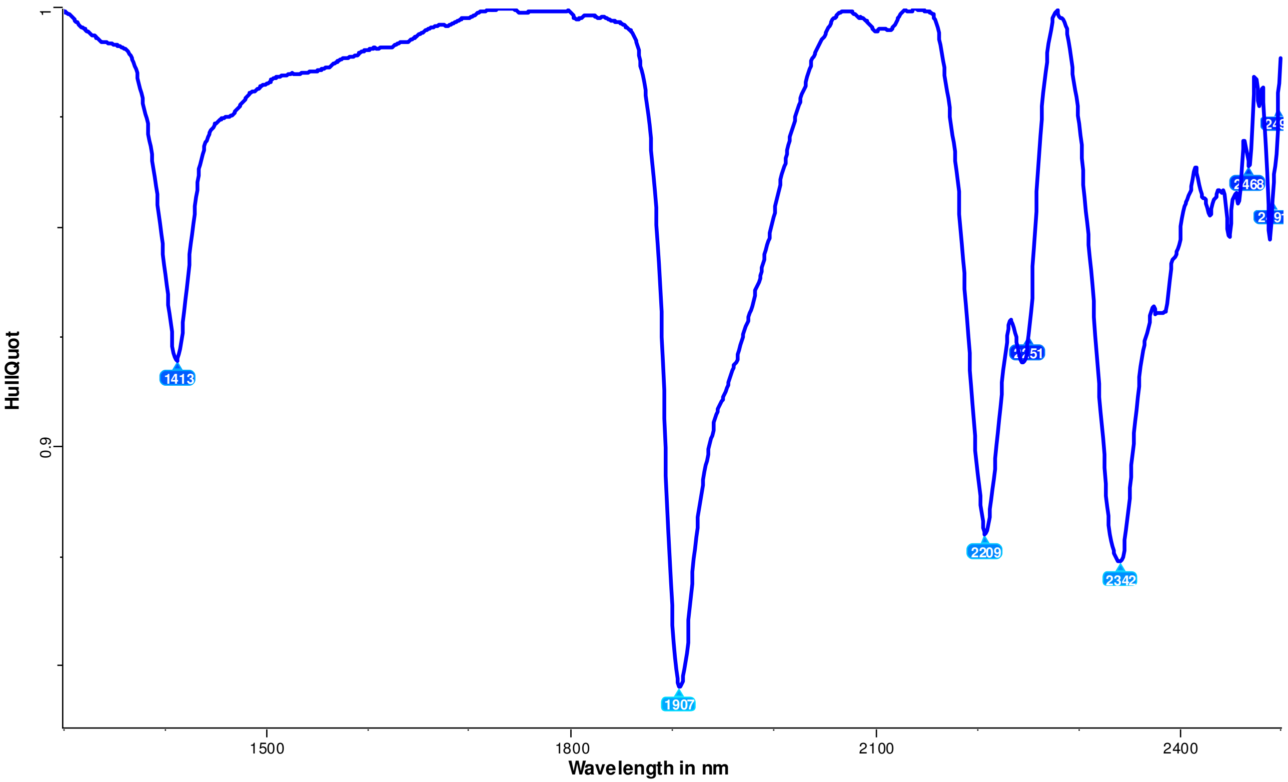
Intuitive QAQC with Terra Spec and TSG

Sort on Min1 and Min2. Scroll through the data and look for mineral species that do not belong in the mineral assemblage that you are expecting. When the software encounters poor quality spectra (usually in rocks with low reflectance) there are particular mineral names that it commonly assigns. **In particular, don't trust Ankerite, Siderite, Mg Chlorite, Tourmaline, Diaspore or Zoisite.** You should go through and manually check these unreliable mineral picks.

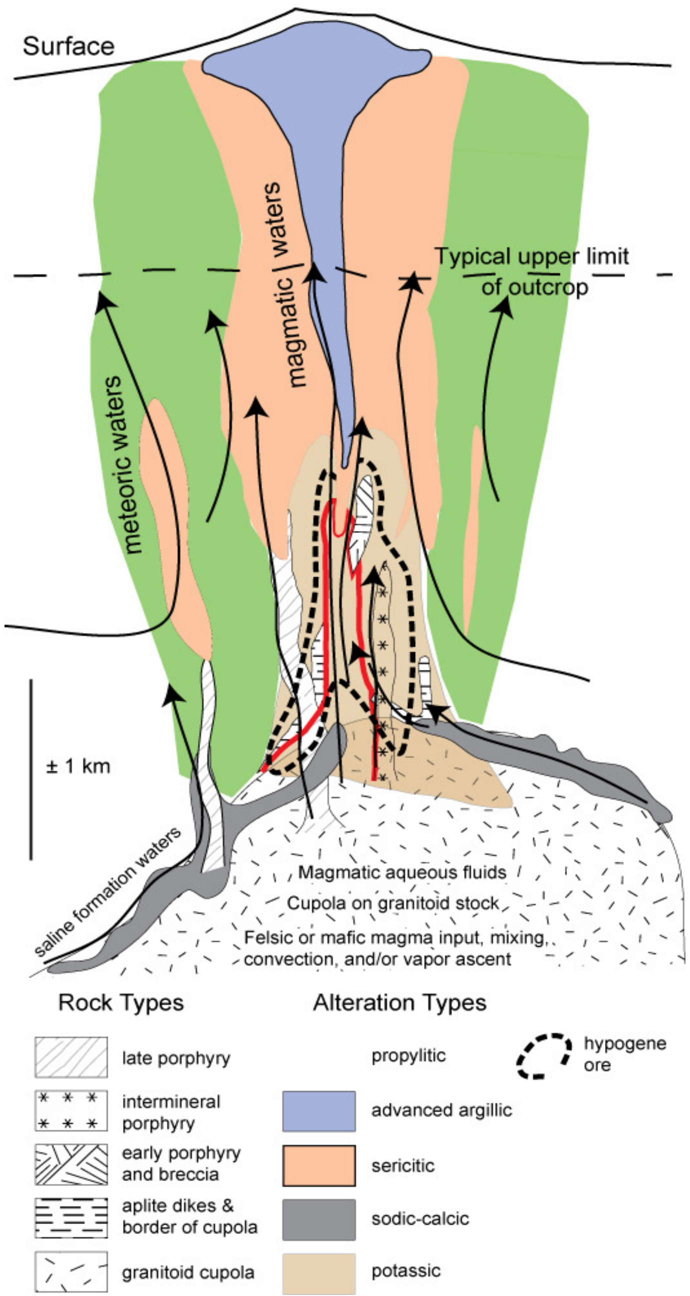
Min1 sTSAS	Min2 sTSAS
Siderite	Muscovite
Siderite	Vegetation-Dry
Siderite	Vegetation-Dry
Siderite	Vegetation-Dry
Siderite	Vegetation-Dry
Siderite	Vegetation-Dry
Siderite	Vegetation-Dry
Siderite	Vegetation-Dry
Tourmaline	NULL
Tourmaline-Fe	NULL
Tourmaline-Fe	NULL
Tourmaline-Fe	NULL
Tourmaline-Fe	NULL
Tourmaline-Fe	NULL
Tourmaline-Fe	NULL
Tourmaline-Fe	Ankerite
Tourmaline-Fe	Ankerite
Tourmaline-Fe	Ankerite
Tourmaline-Fe	Chlorite-FeMg
Tourmaline-Fe	Chlorite-FeMg
Tourmaline-Fe	Chlorite-FeMg
Tourmaline-Fe	Dickite
Tourmaline-Fe	Dolomite
Tourmaline-Fe	Jarosite
Tourmaline-Fe	Kaolinite-PX
Tourmaline-Fe	Magnesite
Tourmaline-Fe	Muscovite
Tourmaline-Fe	Muscovite
Tourmaline-Fe	Paragonite
Tourmaline-Fe	Paragonite
Tourmaline-Fe	Paragonite
Tourmaline-Fe	Paragonite
Tourmaline-Fe	Paragonite
Tourmaline-Fe	Paragonite
Vegetation-Dry	NULL
Vegetation-Dry	NULL
Vegetation-Dry	NULL
Vegetation-Dry	NULL
Vegetation-Dry	NULL

Overprinting relationships





This is another example of retrograde overprinting in a potassic zone, from Anne Mason, Yerington. This shows a biotite spectrum, however the feldspar is heavily dusted with low temperature illite-smectite. Feldspars are very reactive, however early high temperature micas are quite resistant to later overprinting.



Think about a hierarchy of diagnostic minerals for your particular mineral system.

The most abundant mineral is not necessarily the most critical.

Porphyry Cu?

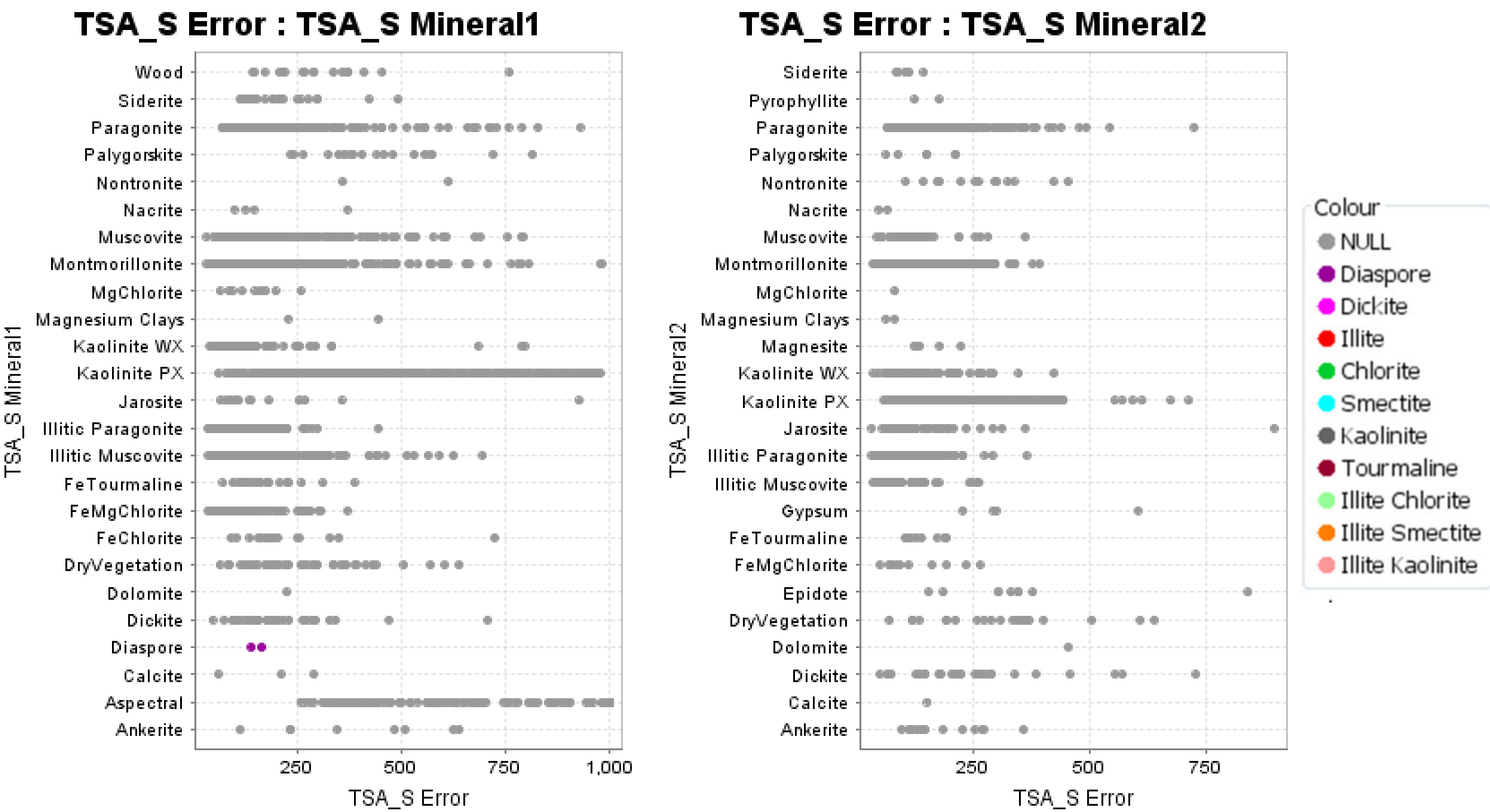
- Biotite
- Anhydrite
- Pyrophyllite
- Alunite
- Dickite
- Muscovite
- Chlorite

TSG processing

There is a standard list of spectral parameters that should be calculated for every data set; wavelengths, depths and widths of diagnostic absorption features.

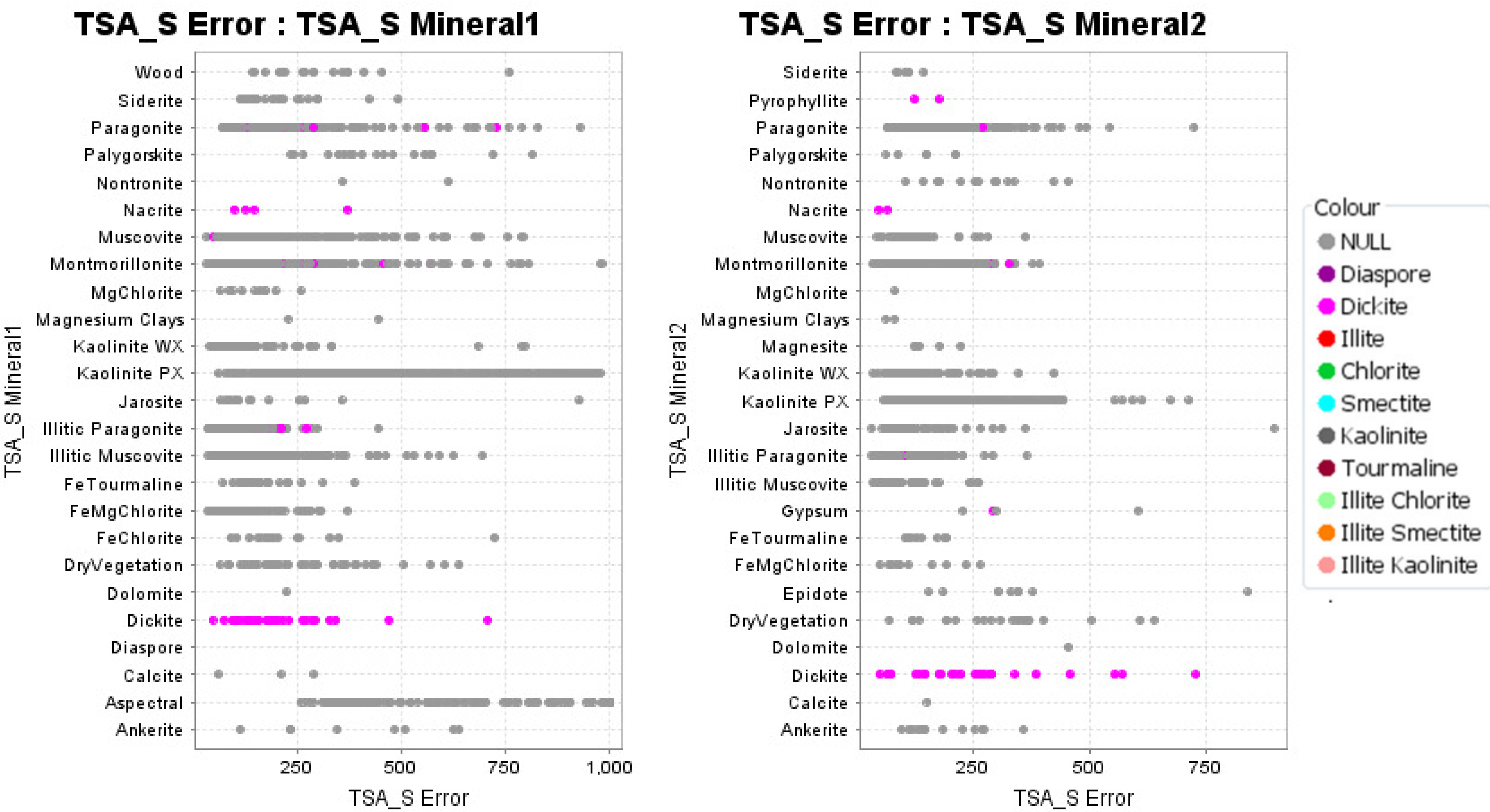
Creating a Mineral Classification

The Spectral Geologist creates a bewildering combination of min1 and min2 names. Set up a priority scheme for your project that picks the highest temperature and most important minerals sequentially. After you have selected each colour group in ioGAS, turn them off so that colour selection is not overwritten by later colour selections. In this case, I picked Diaspore first => indicative of a hot advanced argillic environment.



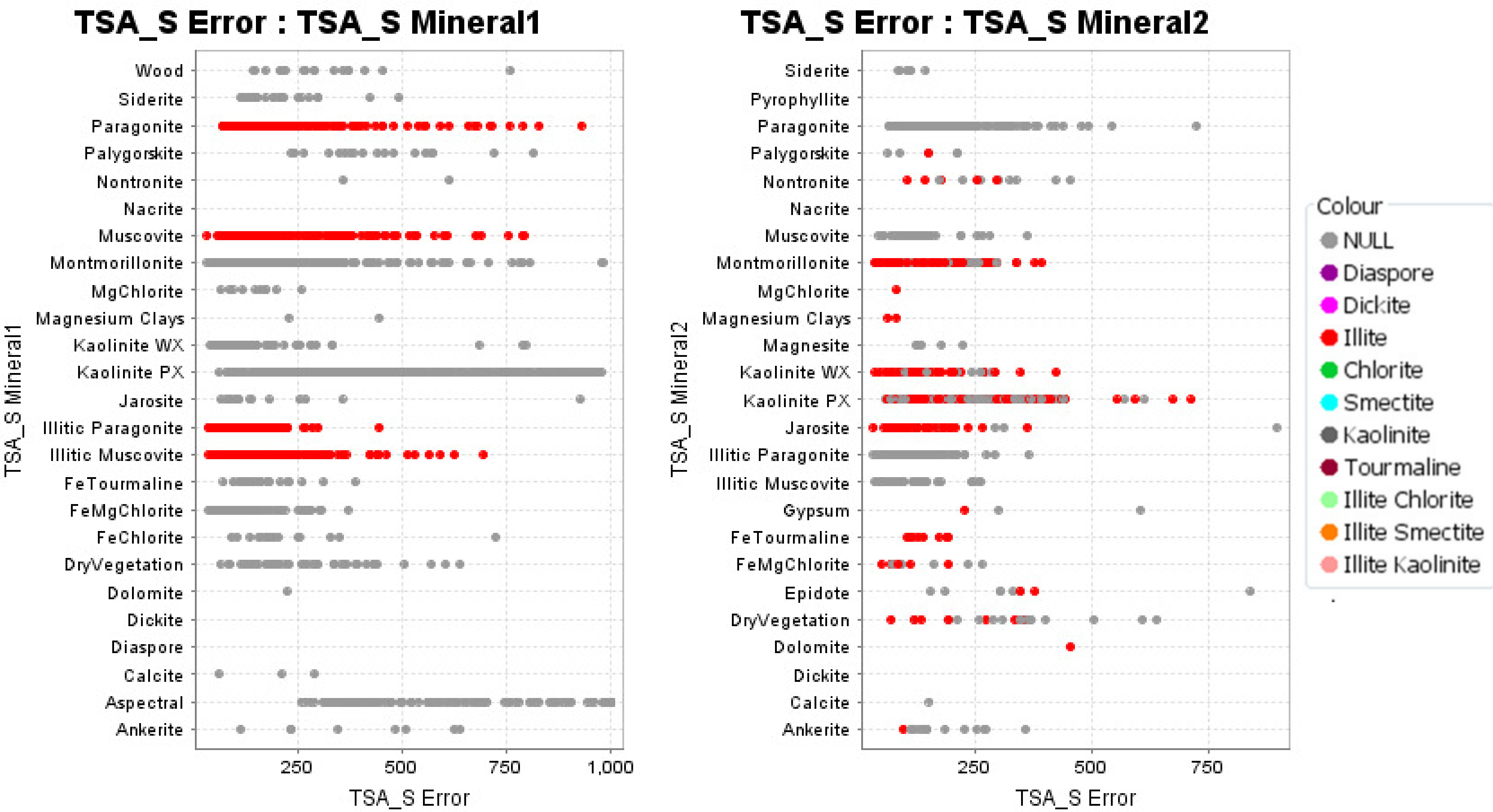
Creating a Mineral Classification

Set up a priority scheme for your mineral system that picks the highest temperature and most important minerals sequentially. Group together dickite AND nacrite as either Min1 or Min2. These are unambiguous spectra. Mid temperature range advanced argillic environment. The presence of these regardless of the relative abundance, is indicative of a very specific hydrothermal environment.



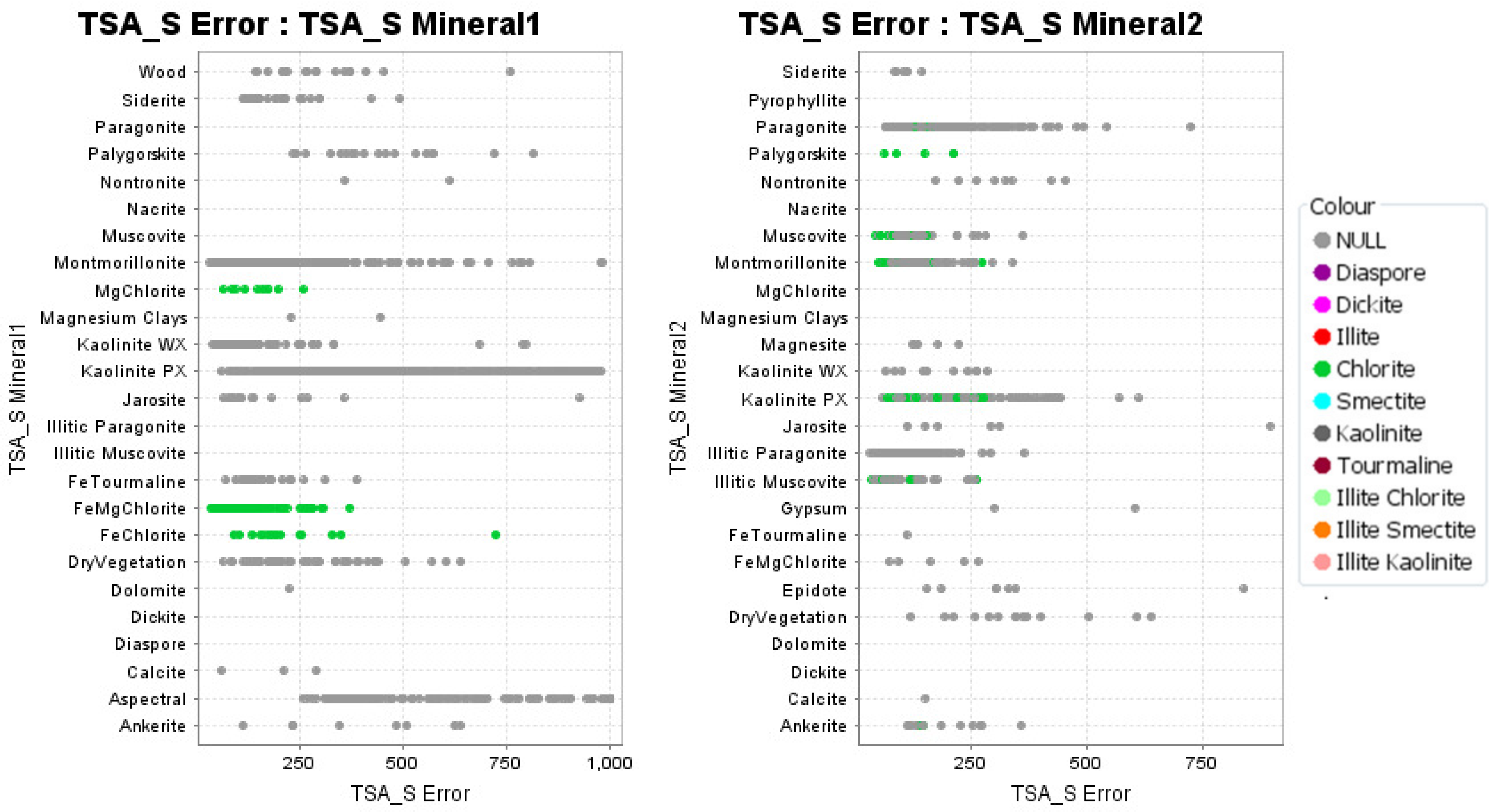
Creating a Mineral Classification

Set up a priority scheme for your mineral system that picks the highest temperature and most important minerals sequentially. Group ALL of the white mica types from Min1 together as “Illite”.



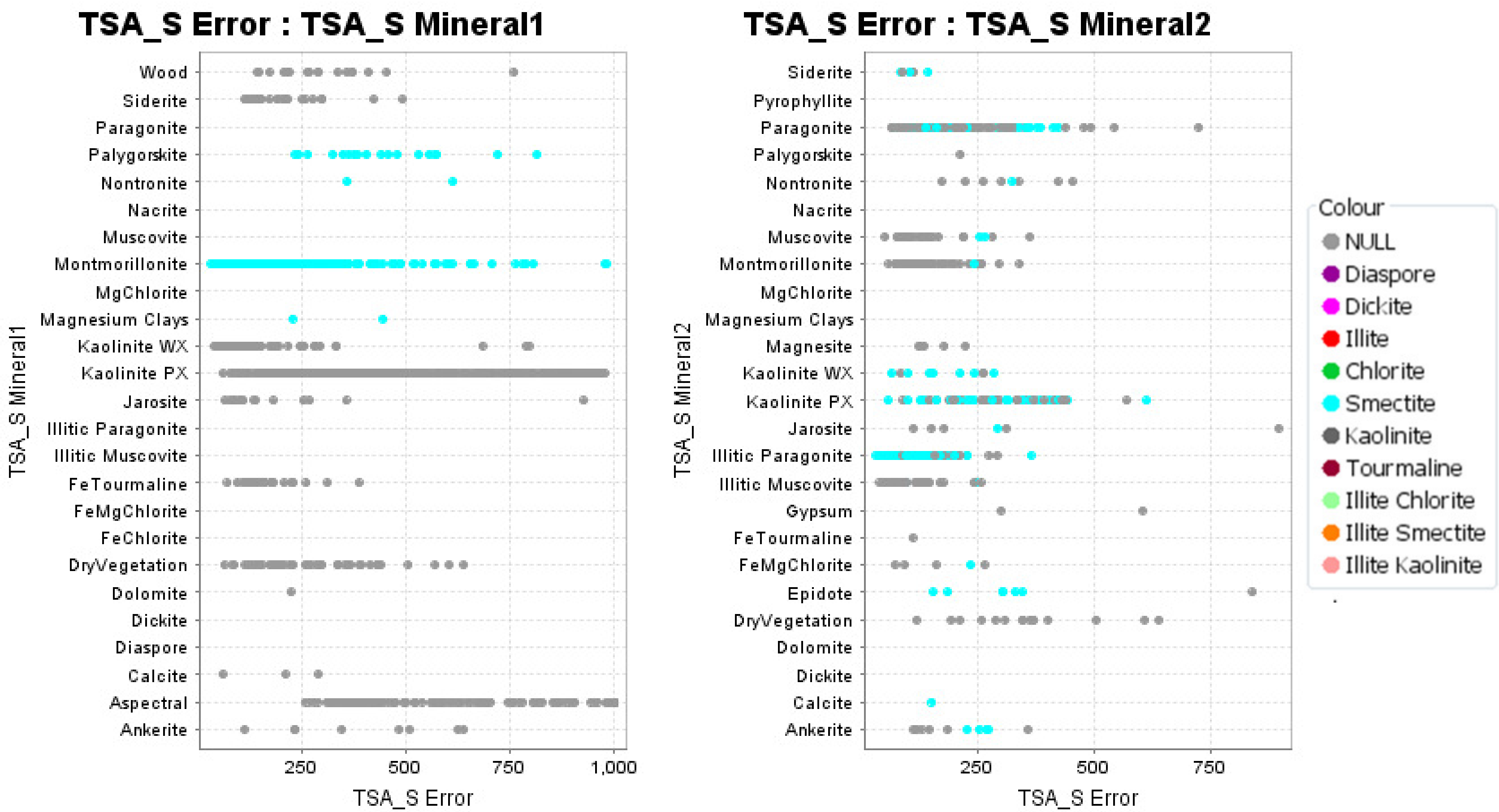
Creating a Mineral Classification

Set up a priority scheme for your mineral system that picks the highest temperature and most important minerals sequentially. Group ALL of the chlorite types from Min1 together as “Chlorite”.



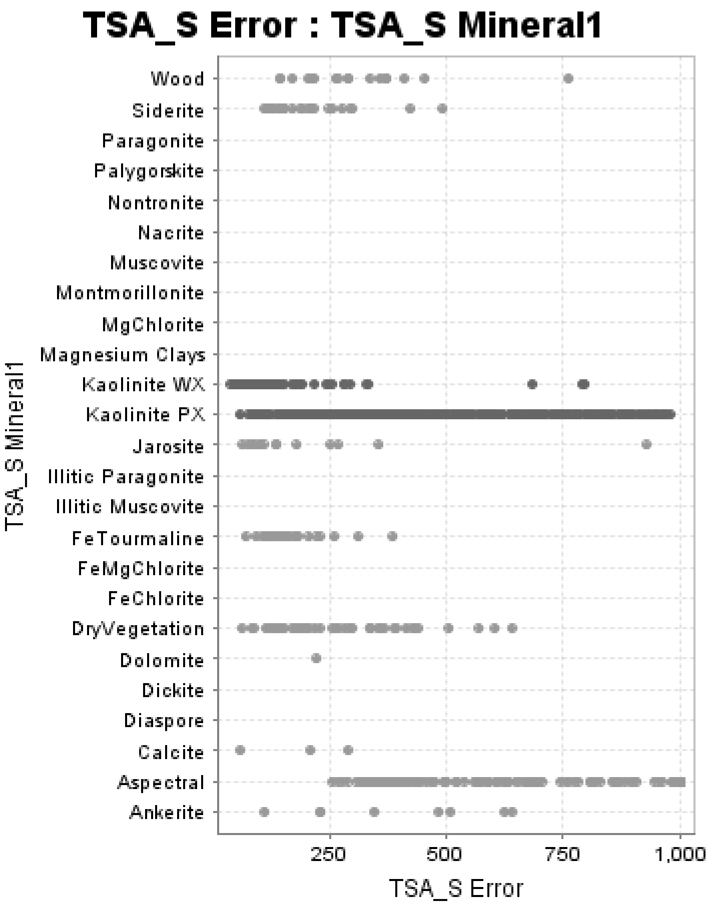
Creating a Mineral Classification

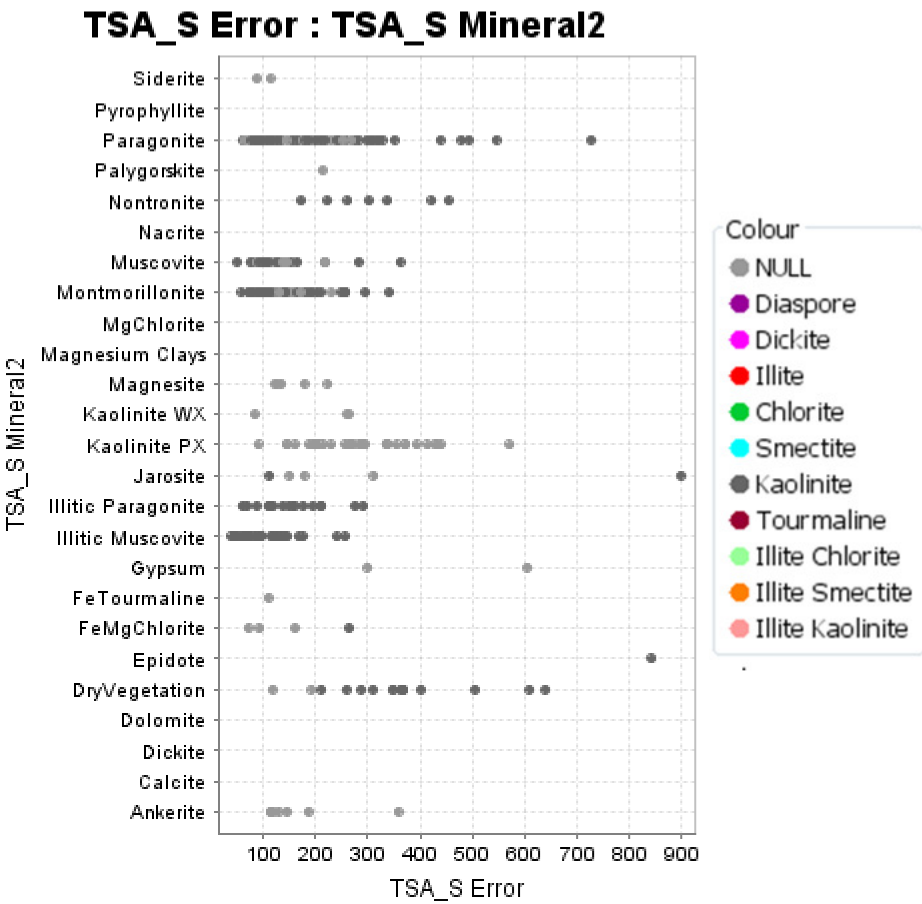
Set up a priority scheme for your mineral system that picks the highest temperature and most important minerals sequentially. Group ALL of the smectite types from Min1 together as “Smectite”.



Creating a Mineral Classification

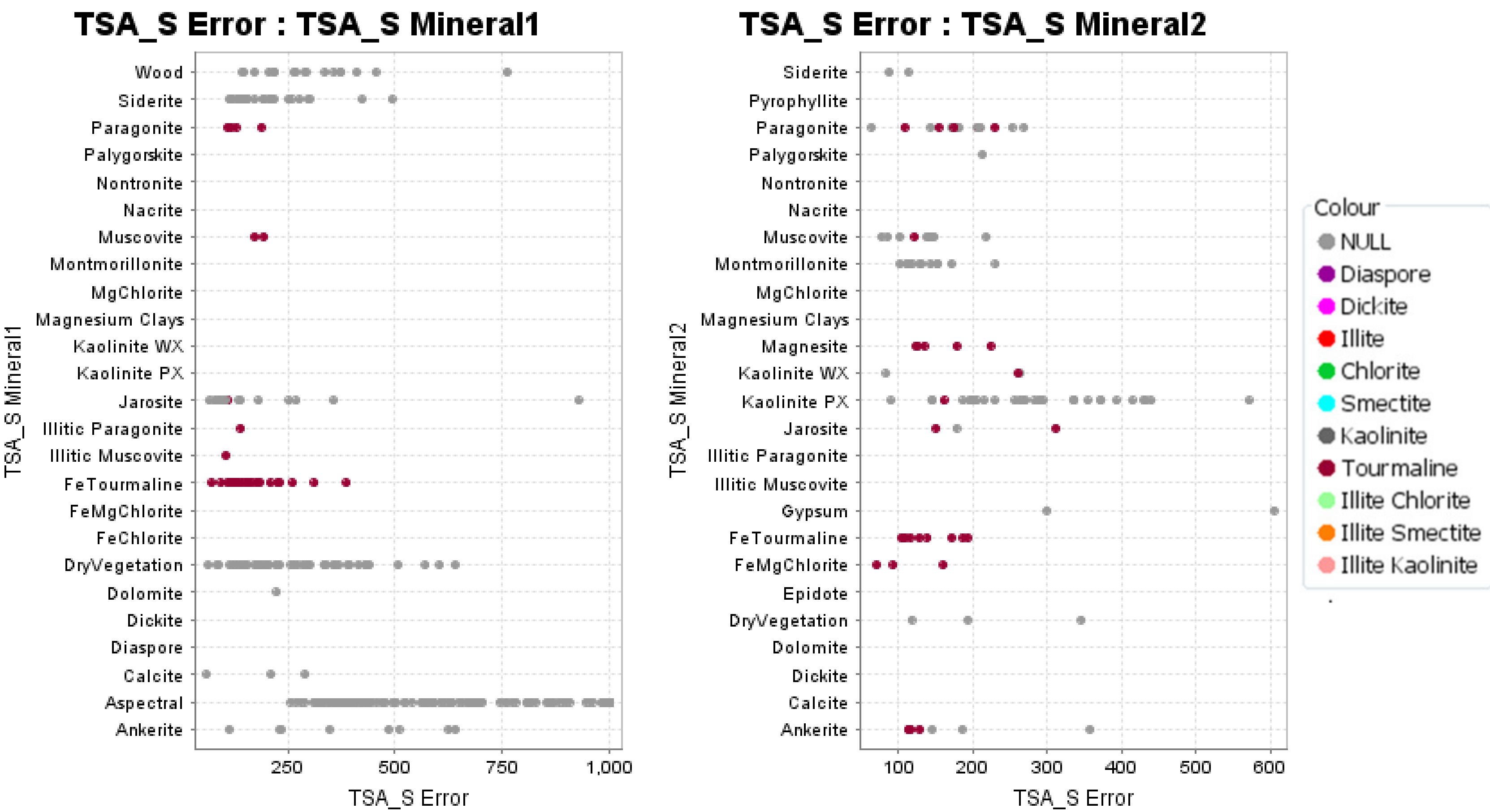
Set up a priority scheme for your mineral system that picks the highest temperature and most important minerals sequentially. Group ALL of the kaolinite types from Min1 together as "Kaolinite".





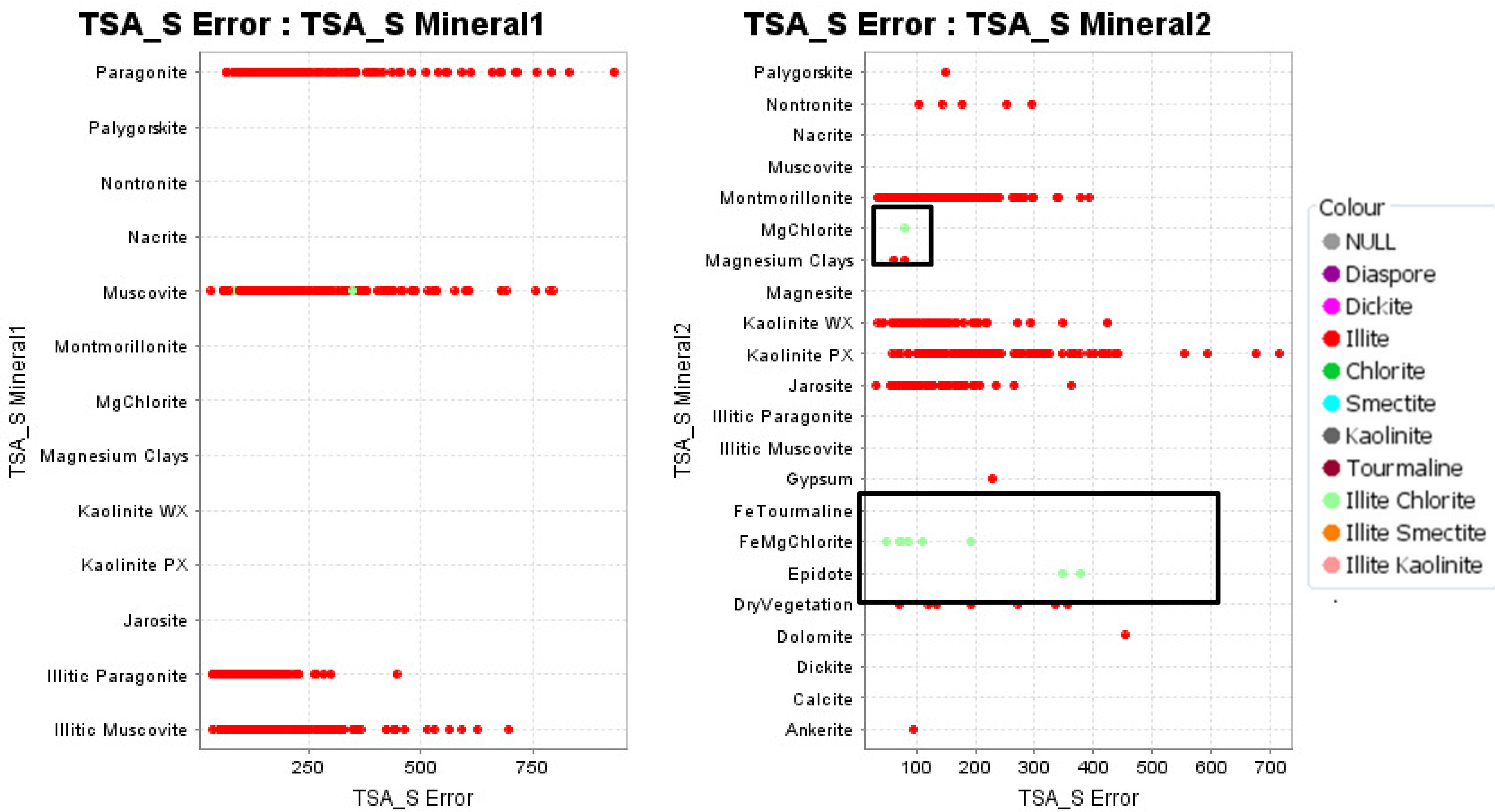
Creating a Mineral Classification

Select all of the tourmaline from min1 AND min2, but ONLY after manually checking the spectra to verify that it really is tourmaline!!



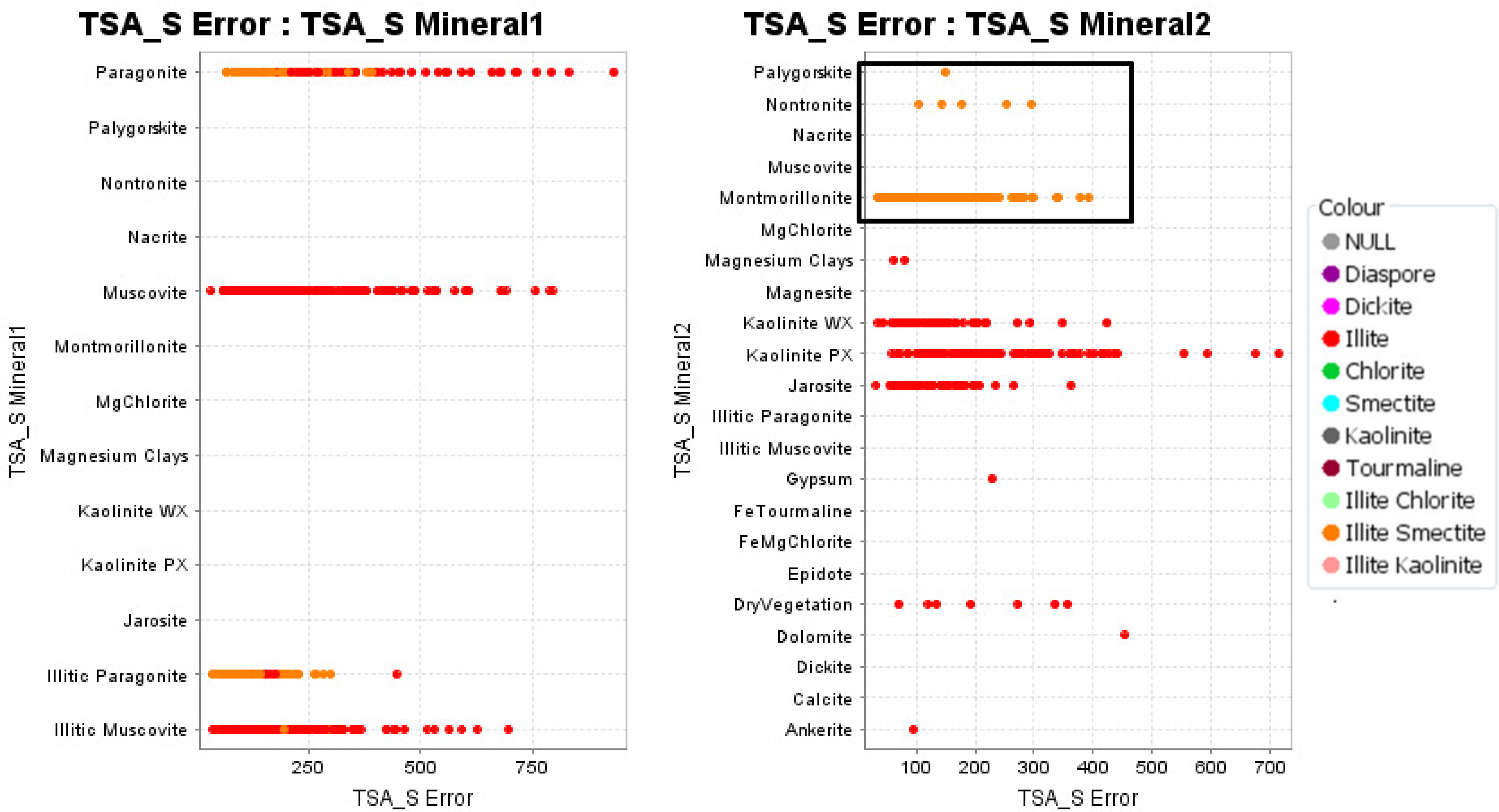
Picking Mineral Mixtures

Find all of the occurrences where an illite mineral is min 1 AND a chlorite mineral is min 2; add them to a group called "Illite Chlorite". Then find chlorite as min 1 and illite as min 2 and them to "Illite Chlorite" as well.



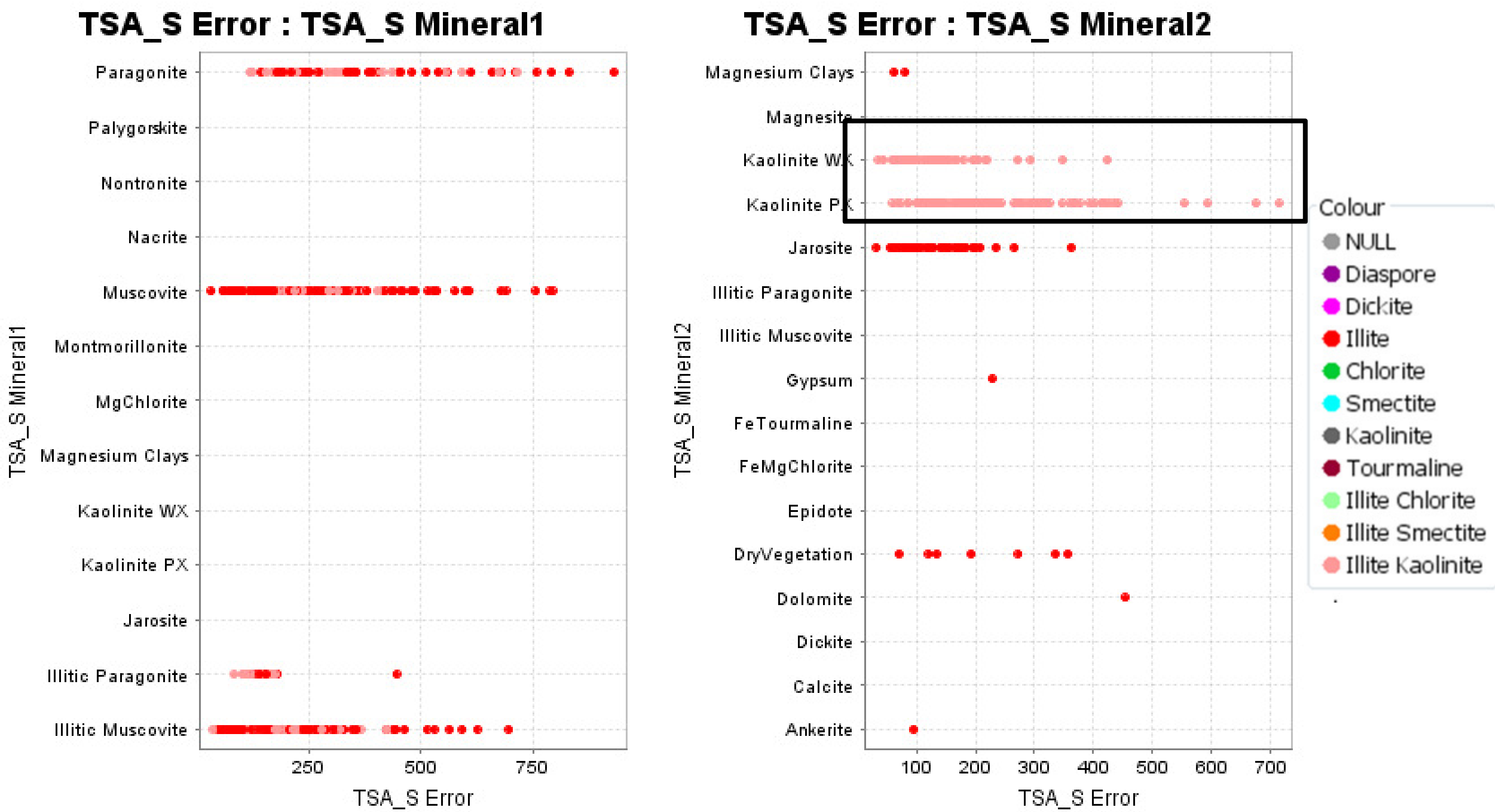
Picking Mineral Mixtures

Find all of the occurrences where an illite mineral is min 1 AND a smectite mineral is min 2; add them to a group called "Illite Smectite". Then find smectite as min 1 and illite as min 2 and them to "Illite Smectite" as well.

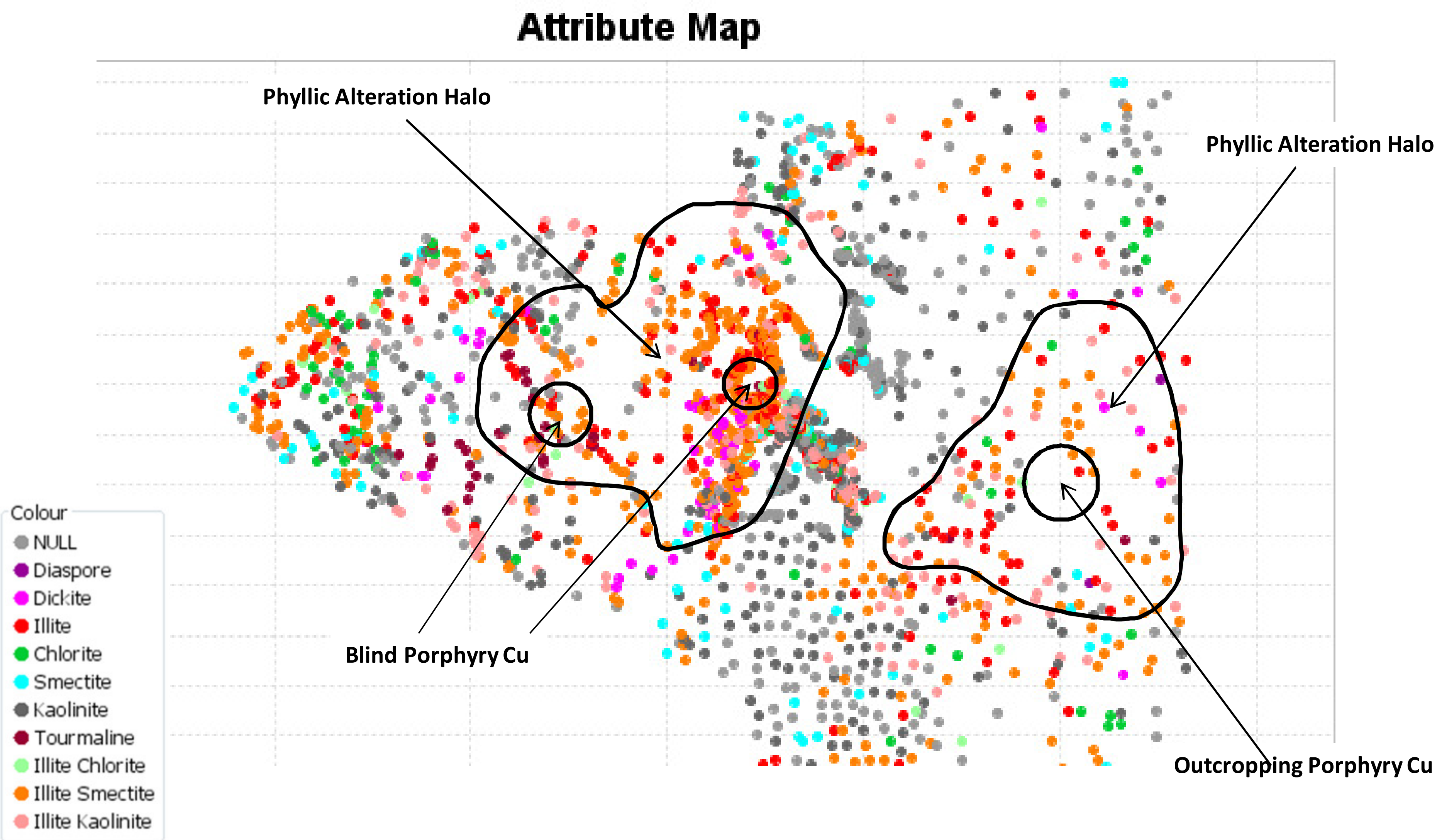


Picking Mineral Mixtures

Find all of the occurrences where an illite mineral is min 1 AND a kaolinite mineral is min 2; add them to a group called “Illite Kaolinite”. Then find kaolinite as min 1 and illite as min 2 and them to “Illite Kaolinite” as well.

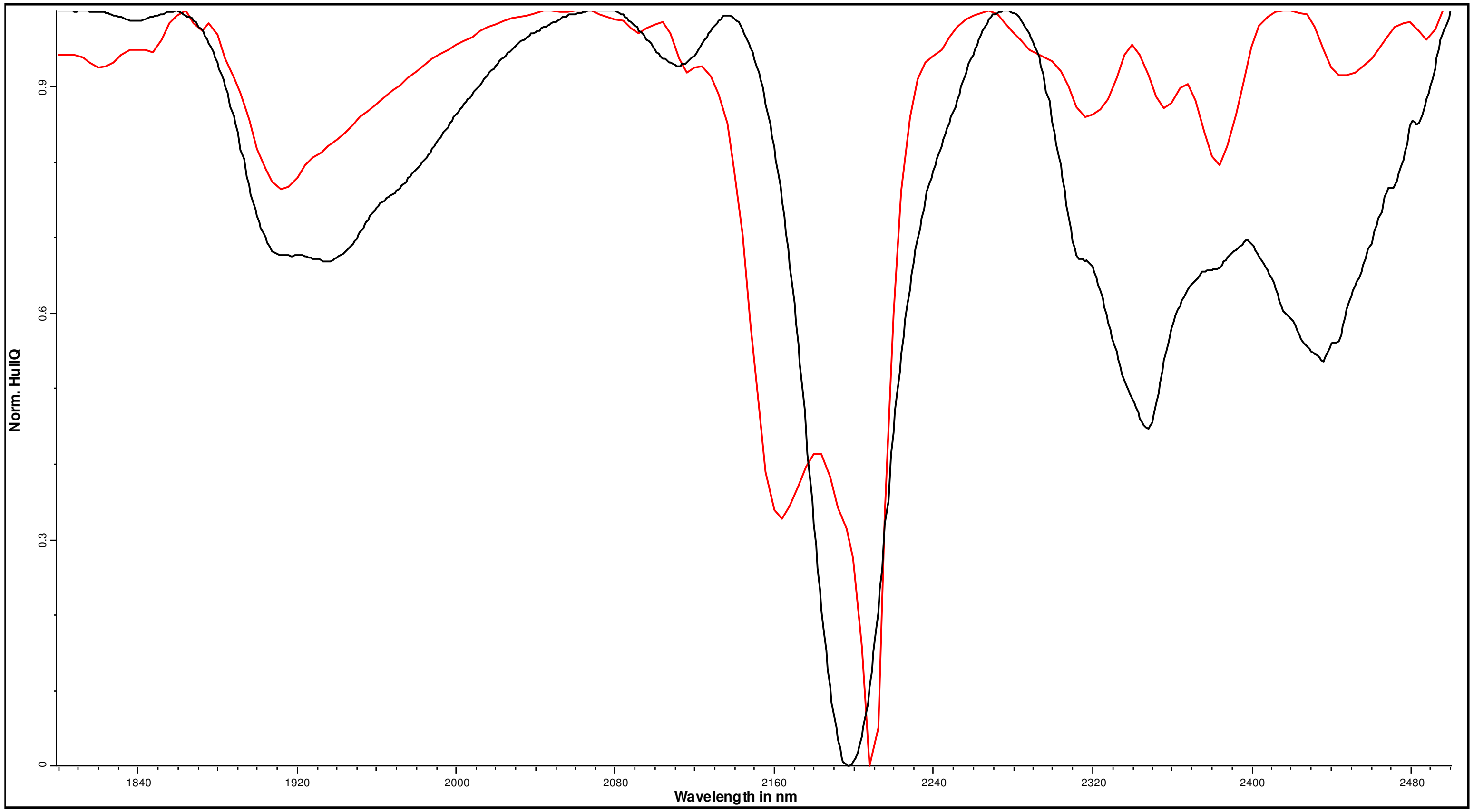


Plot the “preliminary” map



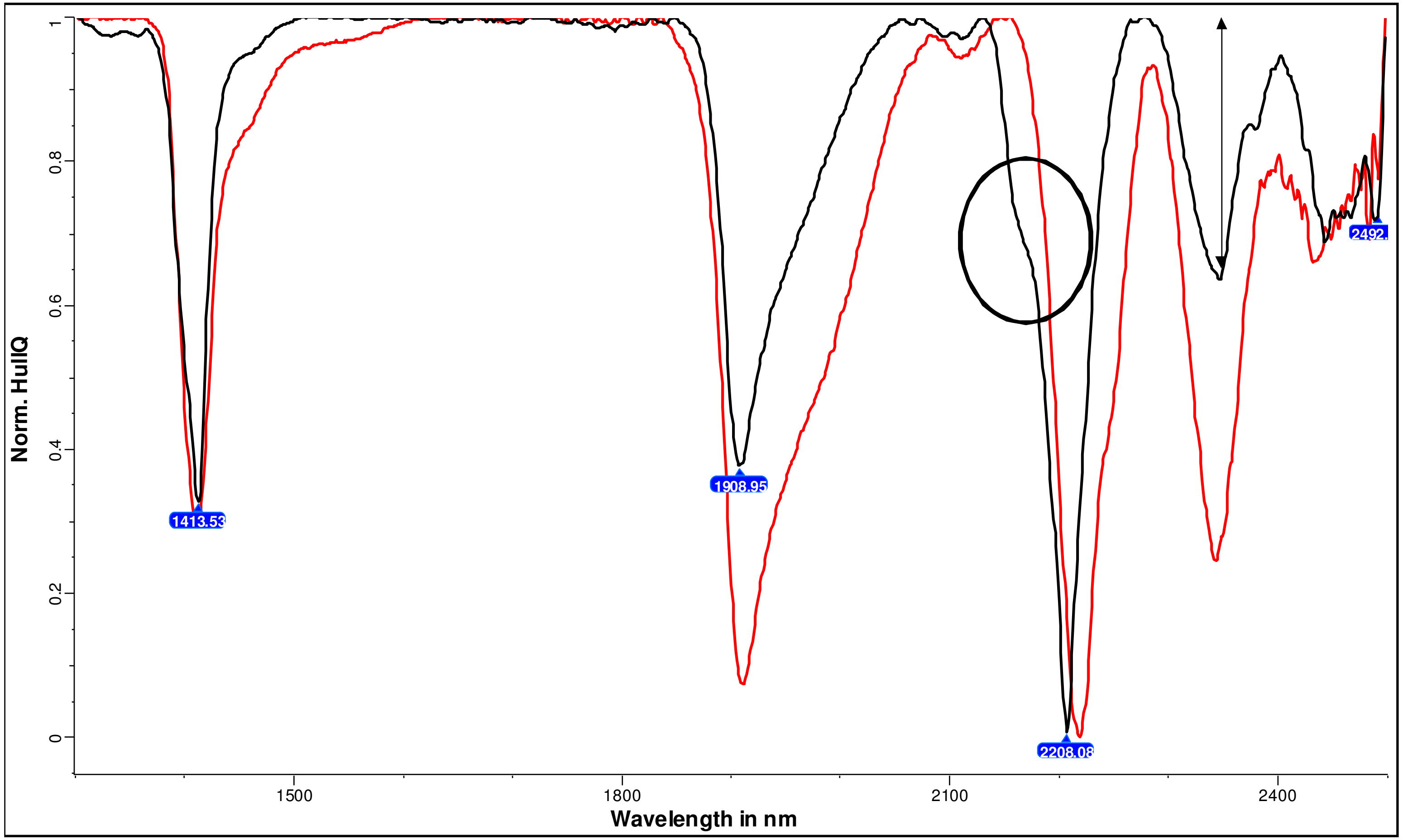
Mixed Spectra

This plot shows a sericite spectrum in black and a kaolinite spectrum in red. The characteristic absorption feature is located at about 2200nm. In sericite, this feature is relatively broad, rounded, and symmetric and has a variable wavelength at the minimum point. In kaolinite, this feature is relatively narrow, sharp, asymmetric, and has a fixed wavelength at 2207nm.



Mixed Spectra

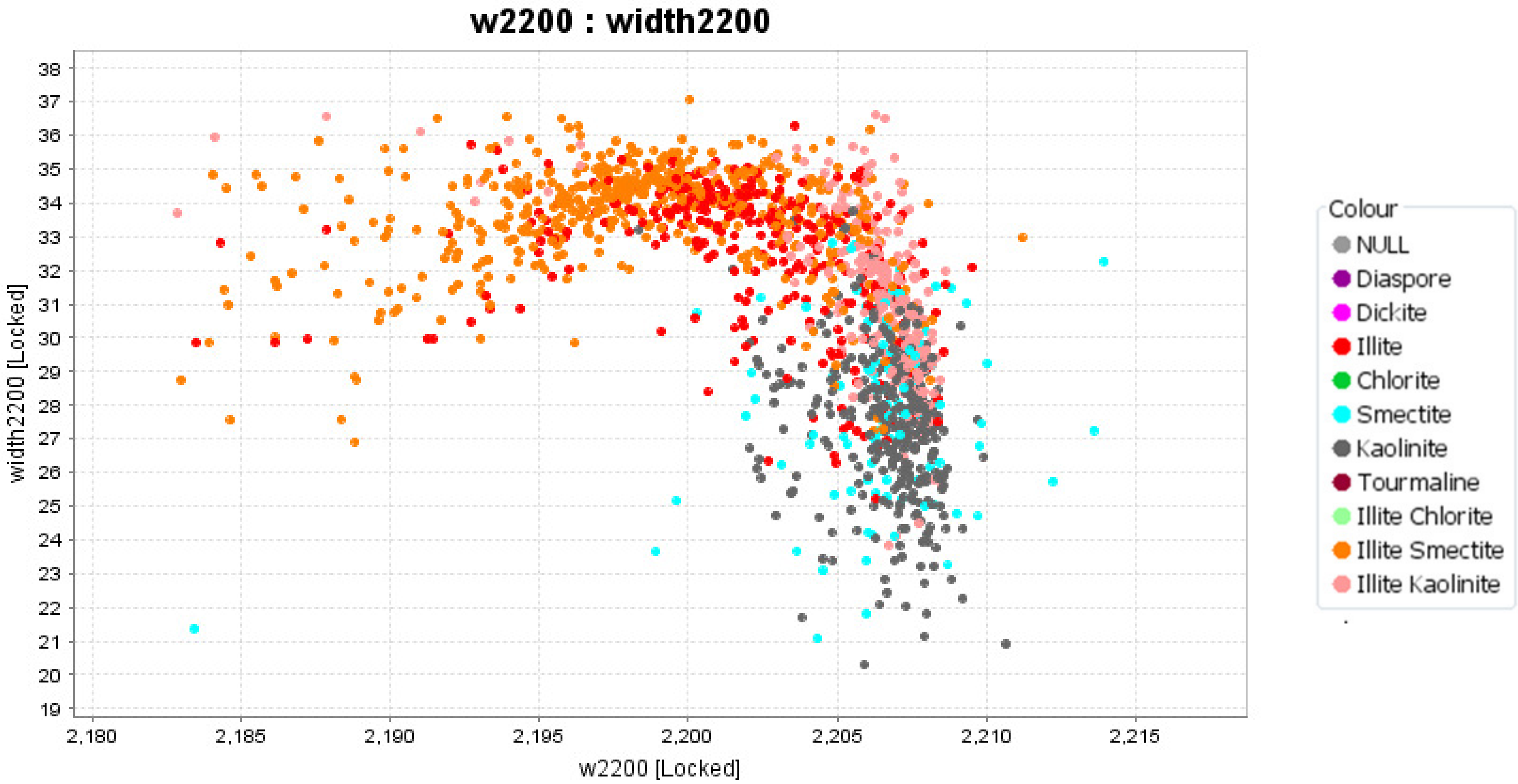
This plot shows a sericite spectrum in red, superimposed on a black spectrum showing a mixture of sericite with a small amount of kaolinite. Rather than having a distinct kaolinite doublet at 2160nm, the mixed sample now just shows a small inflection (circled), and the absorption feature is narrower with a minimum point at 2208. These can be recognised graphically by plotting the wavelength of the 2200nm feature against the relative width of the feature.



Mixed Spectra

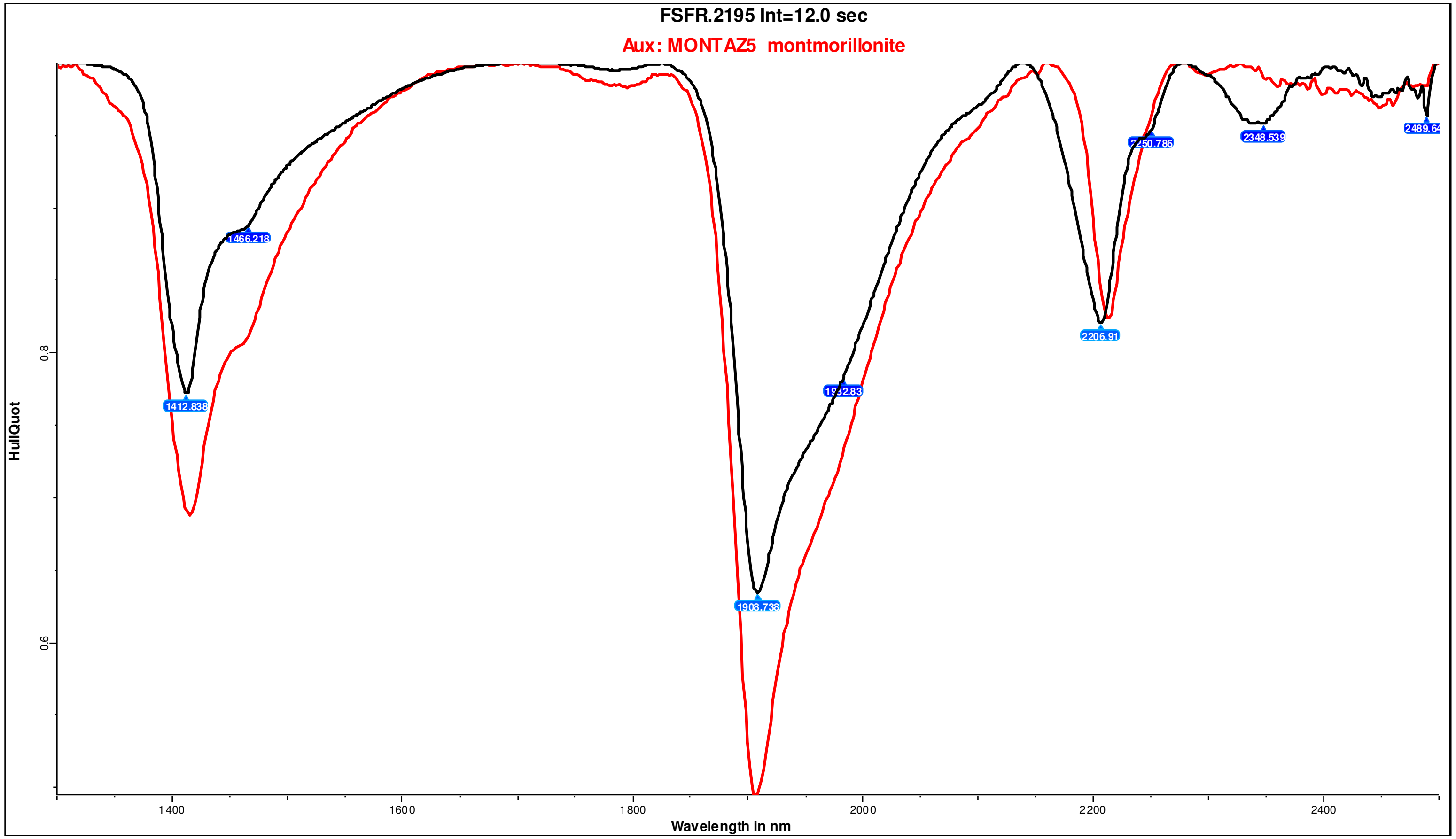
Plot w2200 versus width2200. The kaolinite points have a narrow feature at 2207nm. The mixed illite kaolinite samples are slightly broader, but still at 2207nm. The red points overlapping with the illite-kaolinite should be reclassified. The orange points between 2200 and 2205 have a character more like illite than smectite. The orange points <2192nm are likely to be a different smectite mineral (beidellite) not in the TSG library.

This is a really useful plot for picking mis-classifications in TSG.



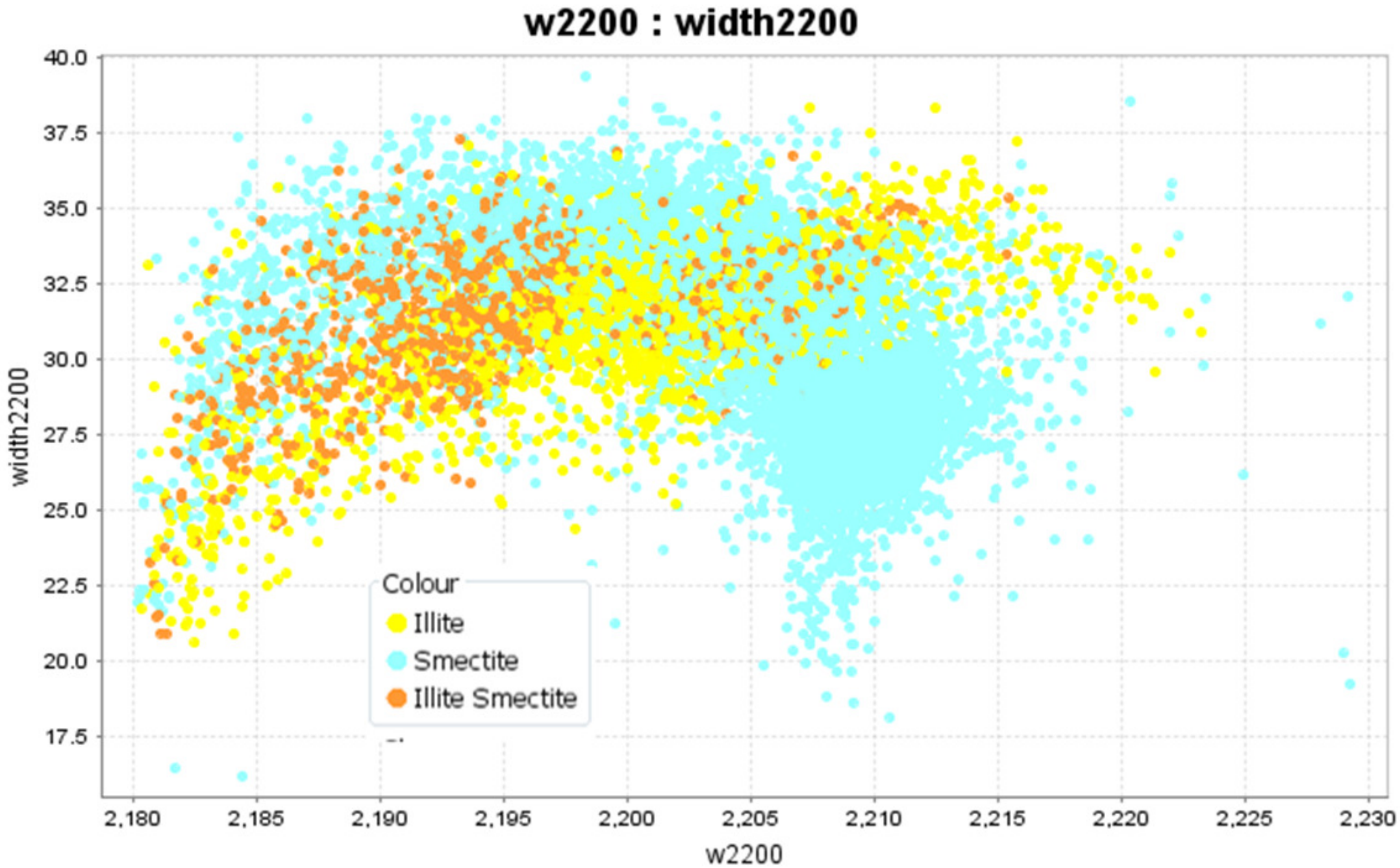
Mixed Spectra

This plot shows a montmorillonite spectrum in black, compared with a USGS spectral library montmorillonite in red. Montmorillonite always has relatively narrow and sharp, but symmetric feature at 2206nm.



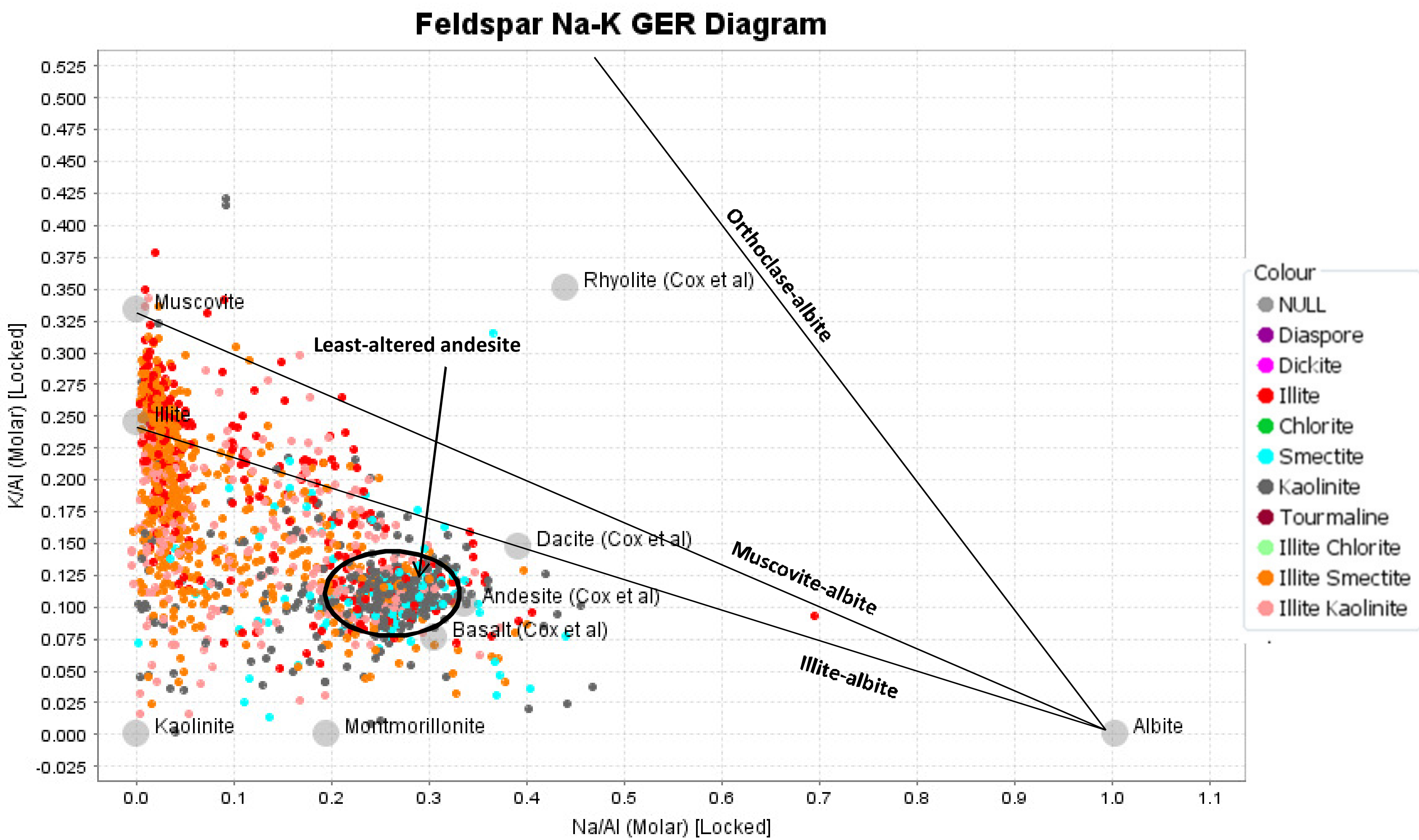
Mixed Spectra

TSG commonly does a poor job picking real smectites, especially when they are mixed with other minerals. This is a plot from a different data set, but it highlights the point. The big cluster of cyan points at 2206nm is real montmorillonite. The cyan points between 2205 and 2185 are likely to be illite rather than montmorillonite.



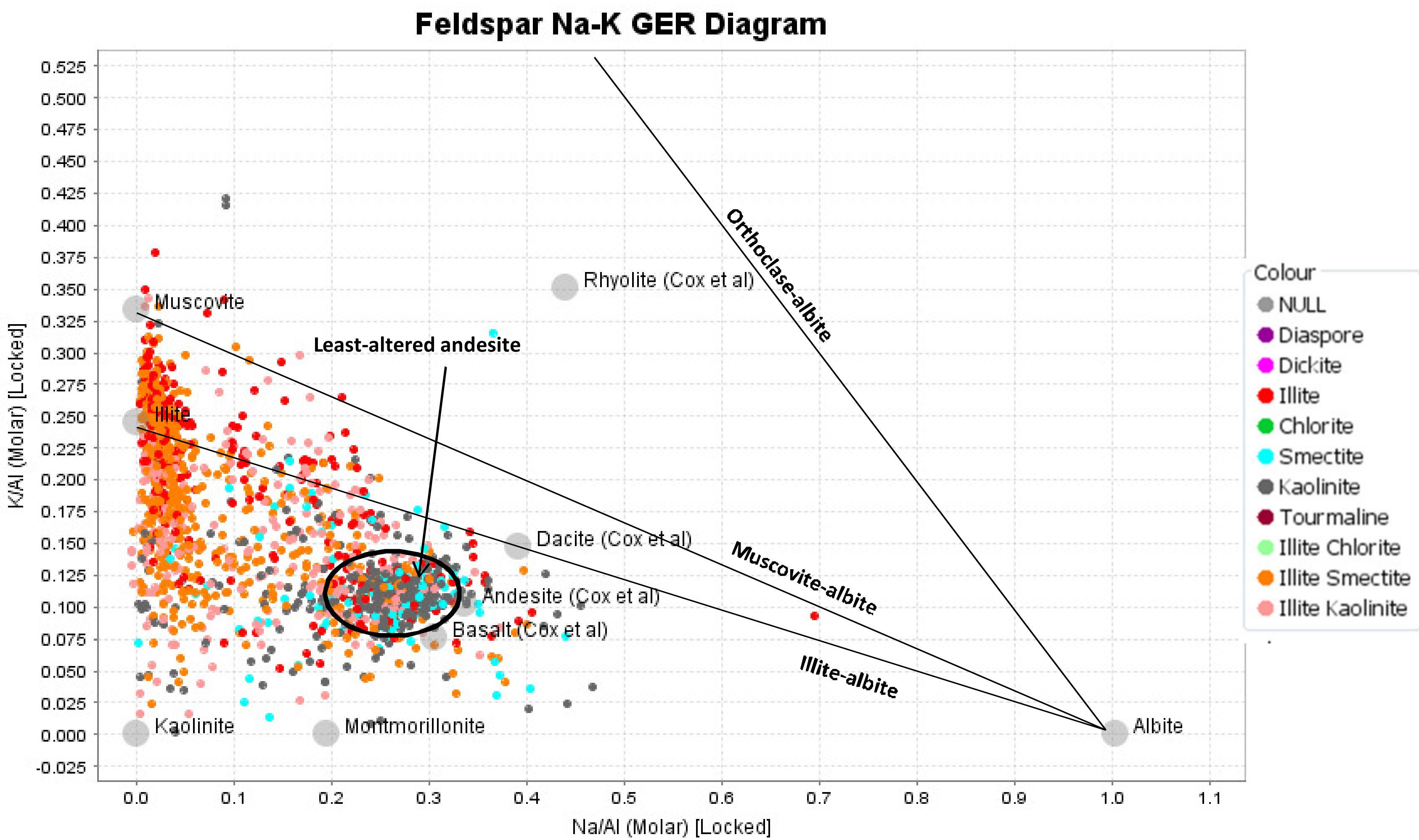
Compare ASD mineralogy with whole rock geochem

With a 4 acid digest method, the changes in whole rock chemistry due to hydrothermal alteration reactions can be investigated. Consider a rock that is totally sericitized. The mineralogy of the rock might be muscovite-quartz-carbonate-pyrite. All of the K and Al in that rock will be within sericite. Muscovite has a composition of $KAl_3Si_3O_{10}(OH)_2$. Therefore the ratio of K:Al in the sericitized rock is 1:3. Similarly, a totally K feldspar ($KAlSi_3O_8$) altered rock will have a K:Al ratio of 1:1. In the same way, albitisation can also be tracked. Albite is $NaAlSi_3O_8$: Na:Al =1:1.



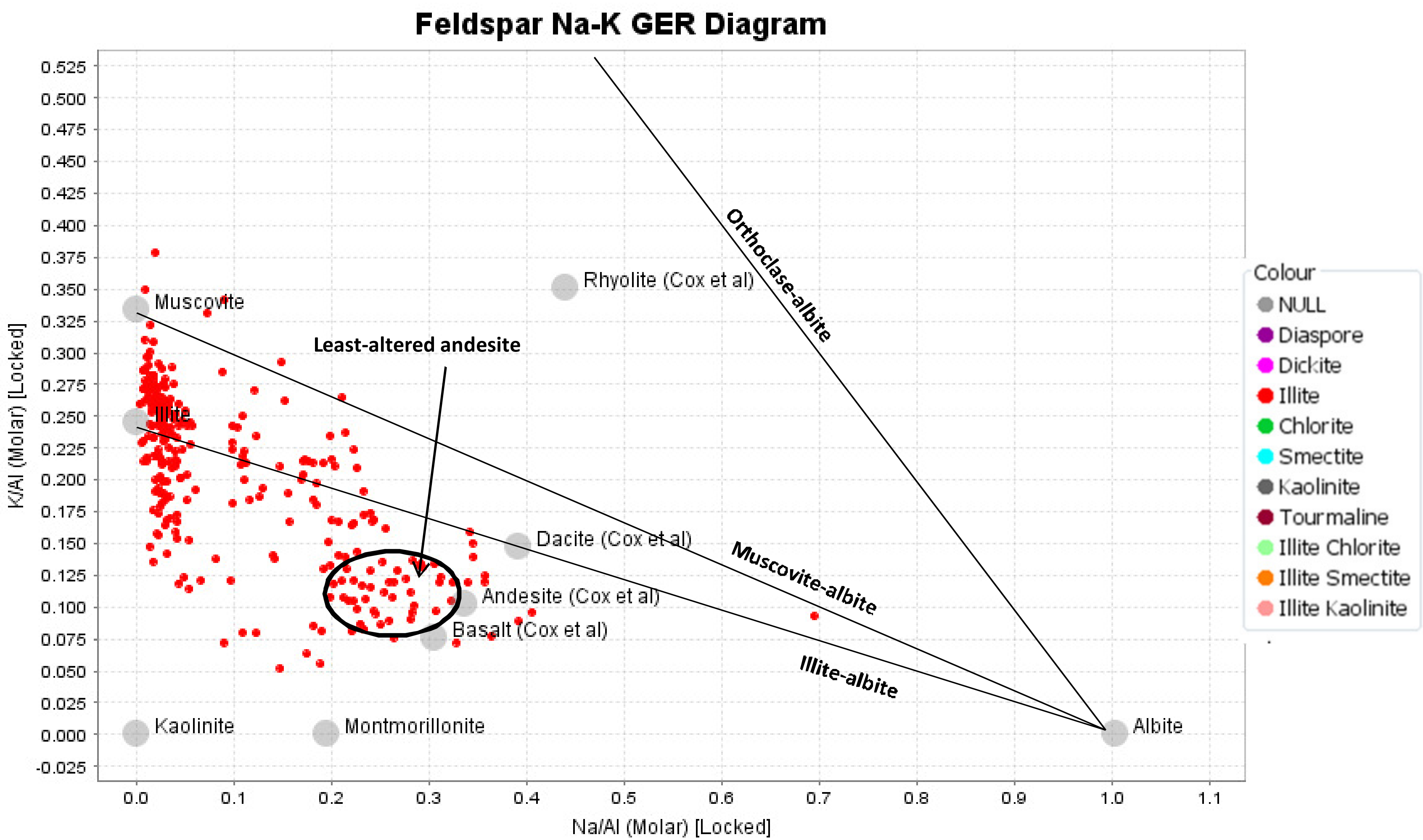
Compare ASD mineralogy with whole rock geochem

From this plot, we *should* see the various colour classifications grouped around the projected compositions of the end member minerals, but instead they are overlapping right across the plot. In particular, relatively unaltered host rocks still report a dusting of clay minerals; these points are quite misleading.



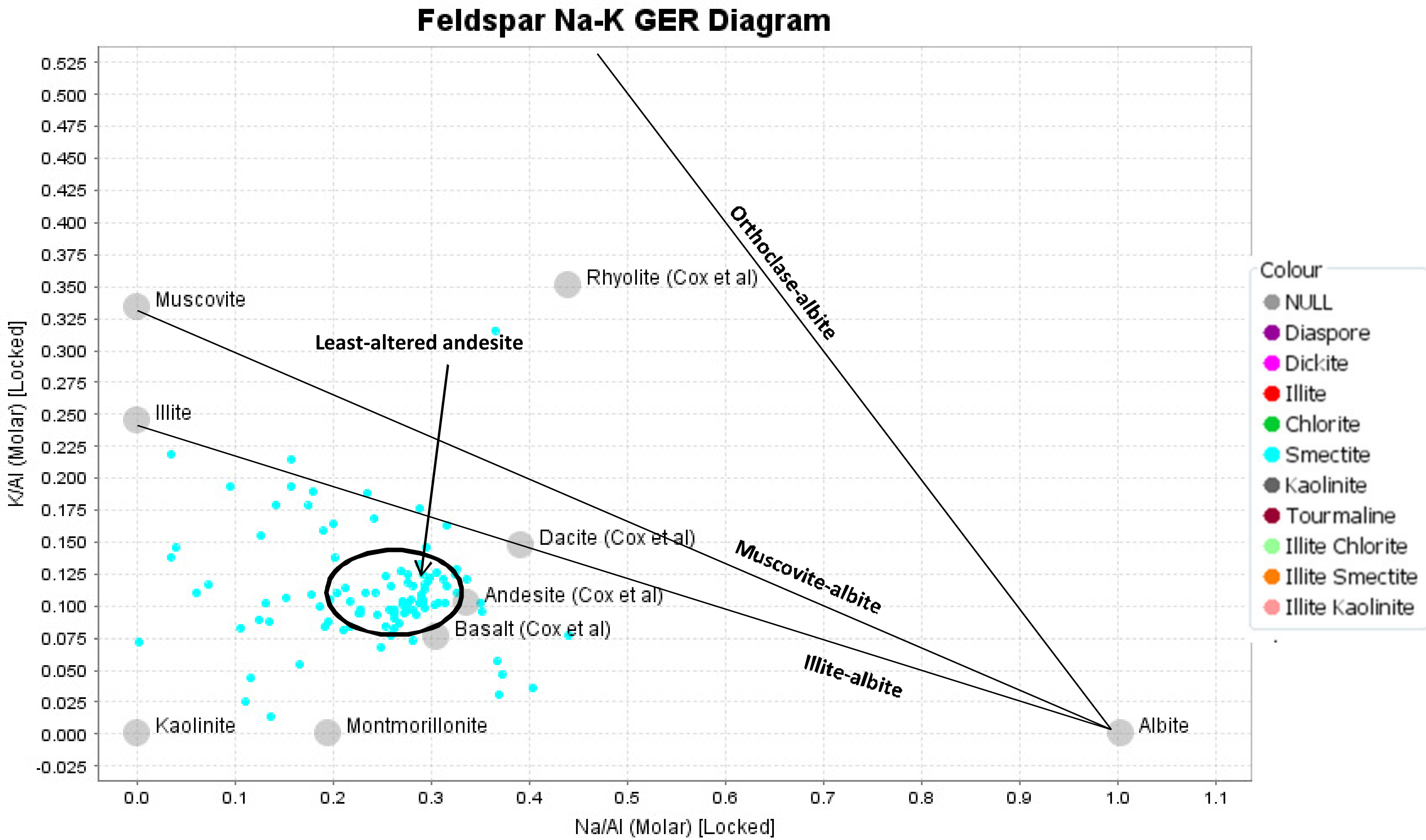
Reported Illite

Most of these cluster around the composition of illite, but some samples have just partial illite alteration, and some are just a dusting in unaltered rocks.



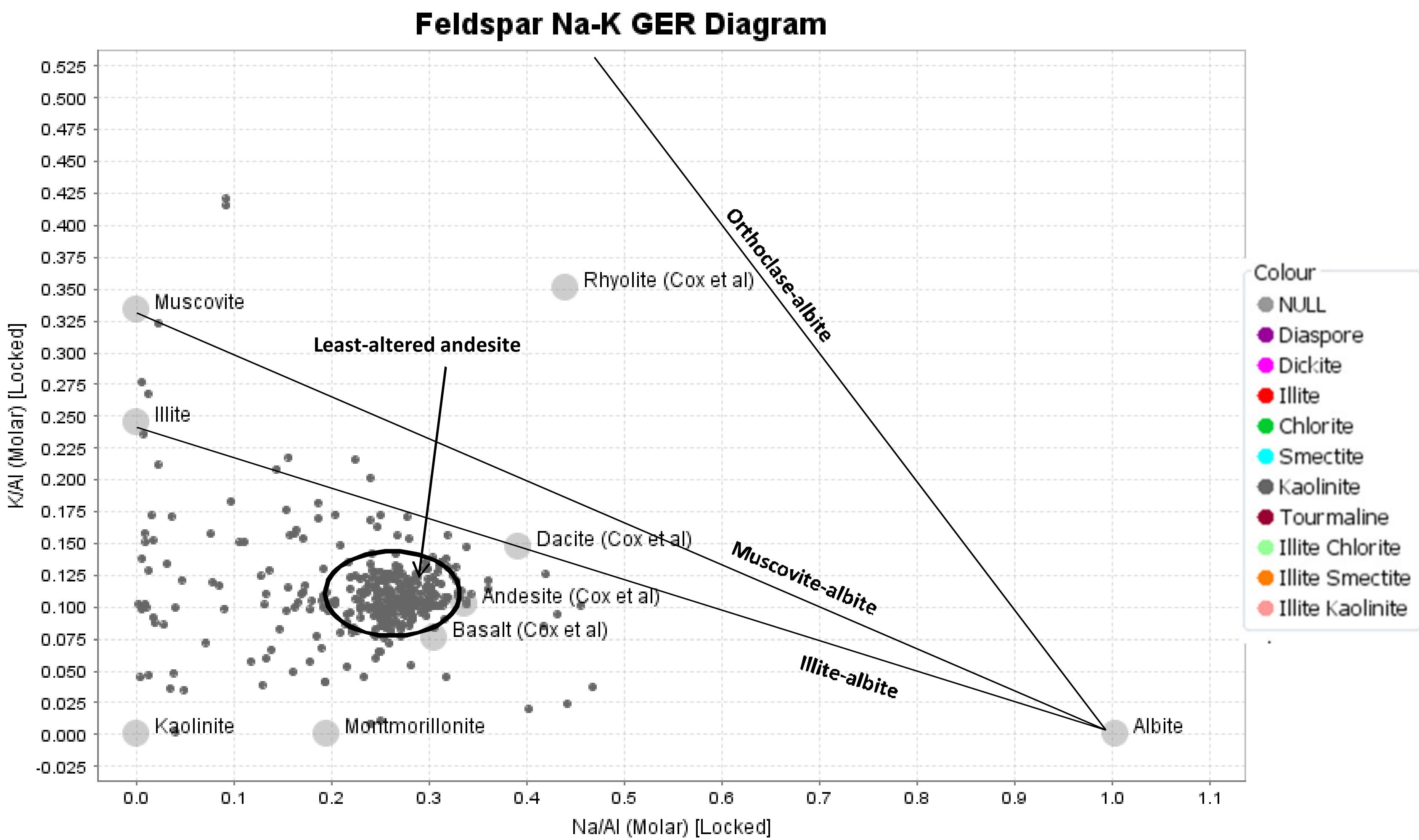
Reported Montmorillonite

Virtually all of the montmorillonite is a dusting in unaltered rocks. These rocks *could* be albite-chlorite-smectite, but the alteration was not strong enough to change the bulk alkali content.



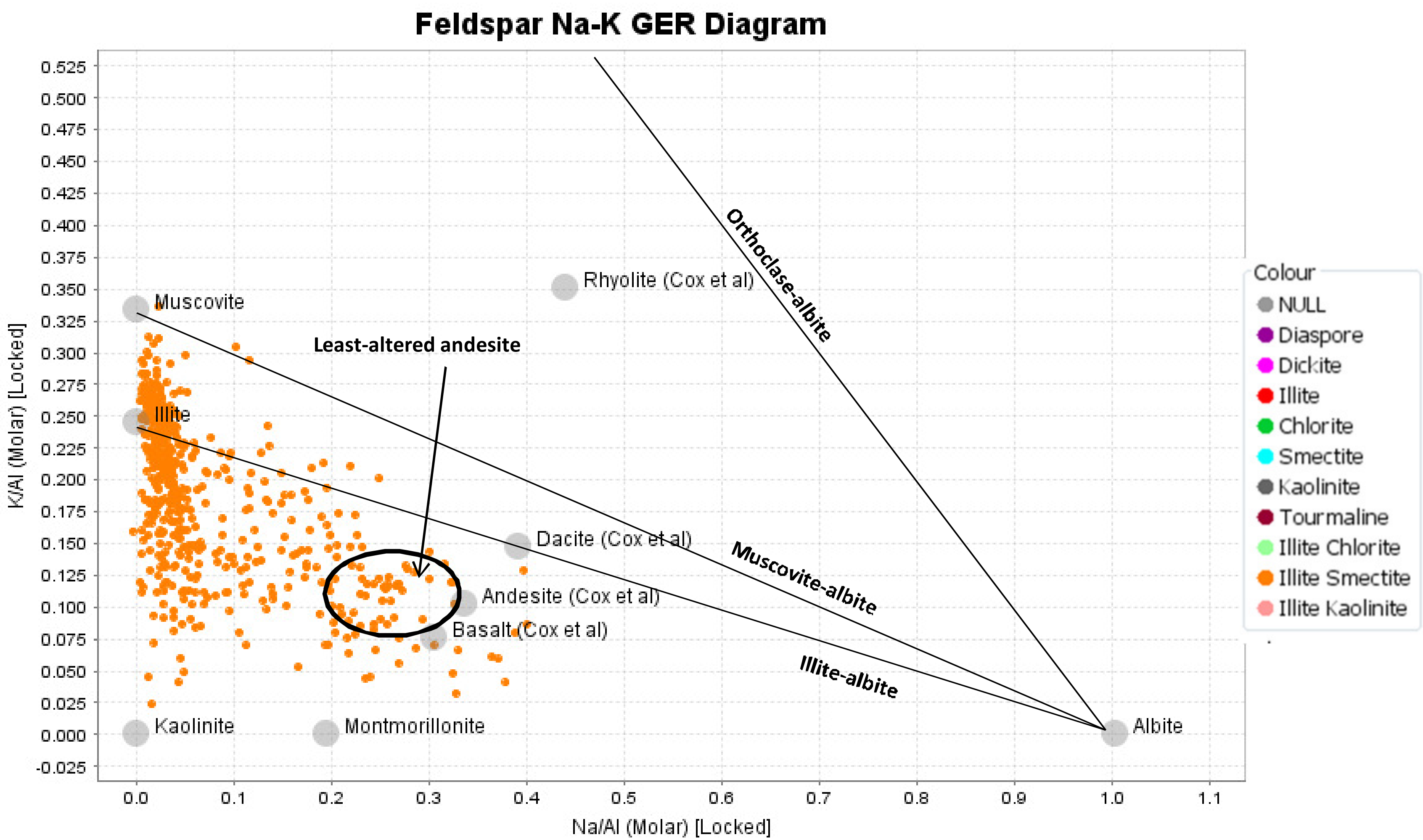
Reported Kaolinite

Most of the kaolinite is a dusting in unaltered rocks. There is a small percentage of strongly Na-depleted kaolinite-bearing samples.



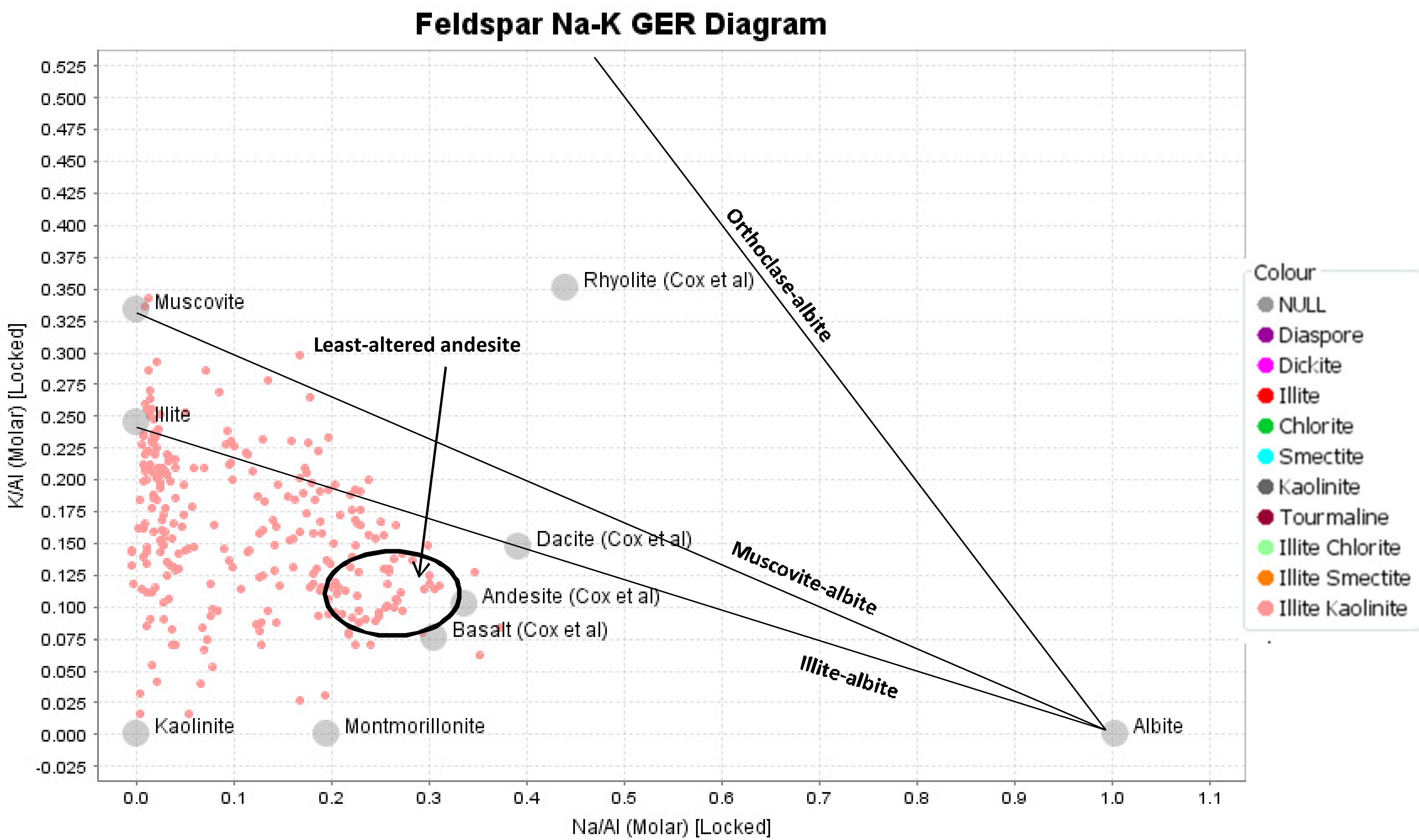
Reported Illite Smectite

80% of the "illite smectite" samples plot on and around the projected position of illite. These points DO NOT form a trend towards the projected composition of montmorillonite. TSG massively over-estimates montmorillonite.



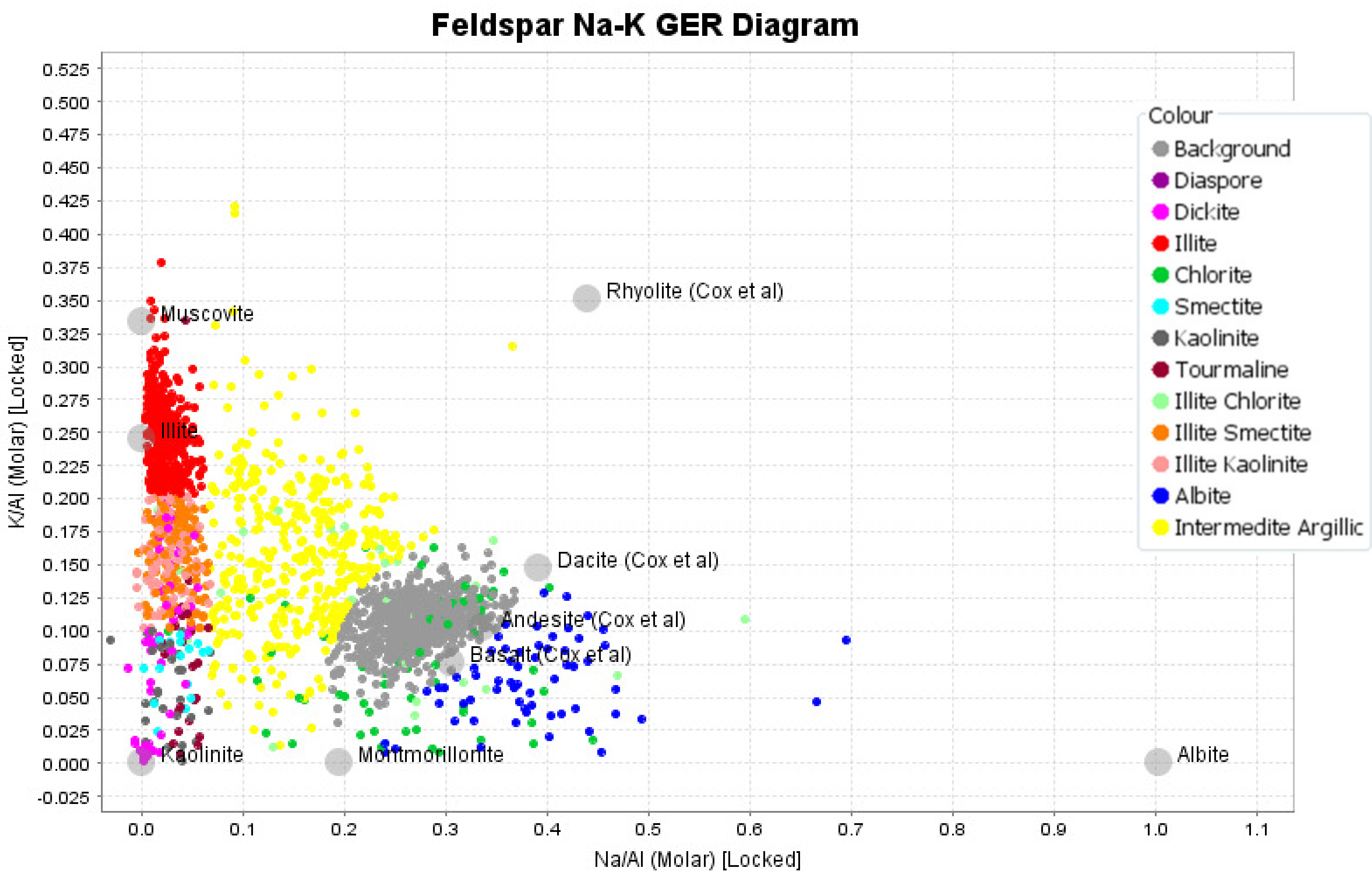
Reported Illite Kaolinite

Some of the “illite kaolinite” samples plot on and around the projected position of illite. There is a trend towards the projected composition of kaolinite. Some of these samples are incompletely altered and some are just a dusting in unaltered rocks.

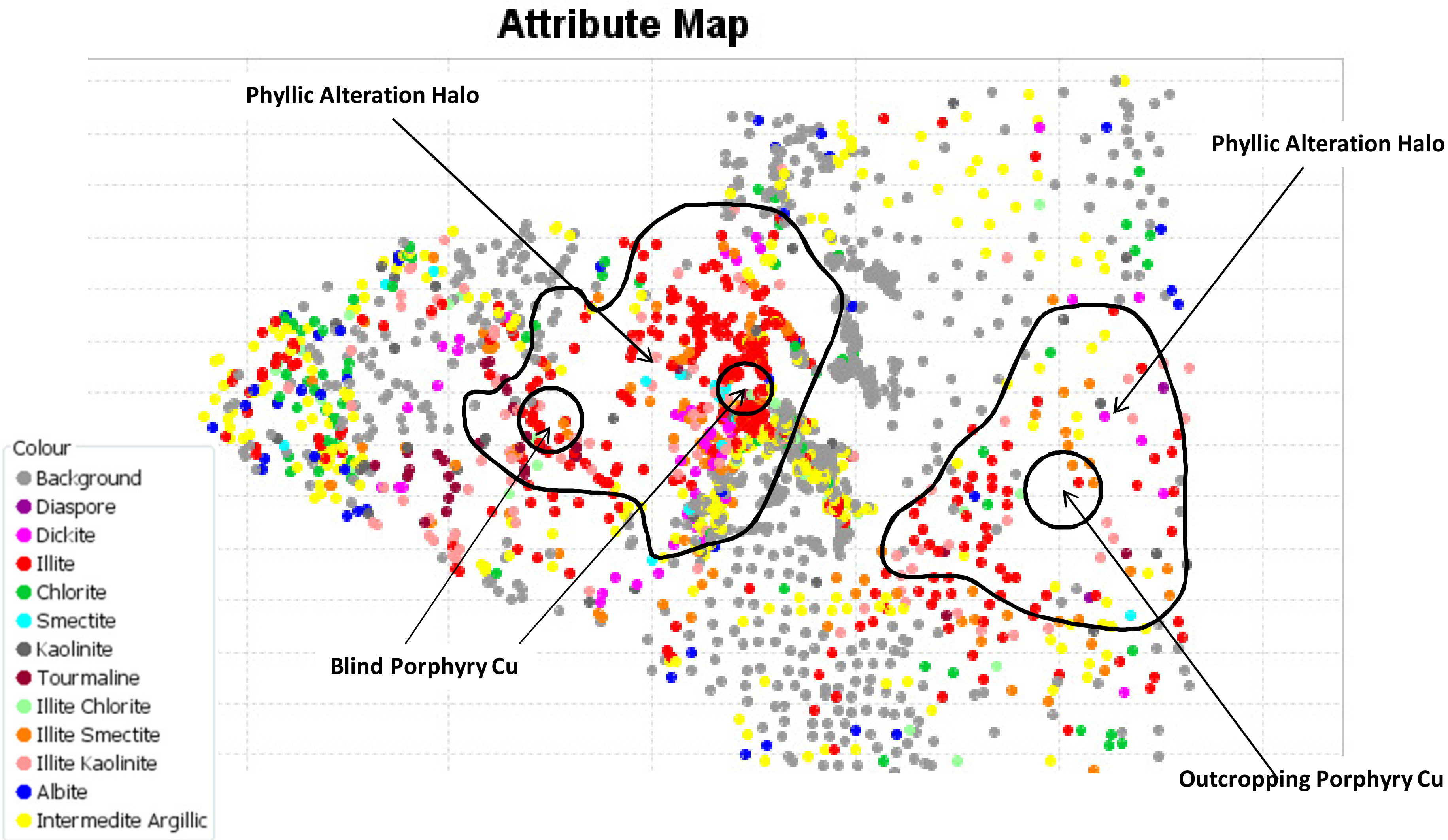


Integrate ASD mineralogy with whole rock geochem

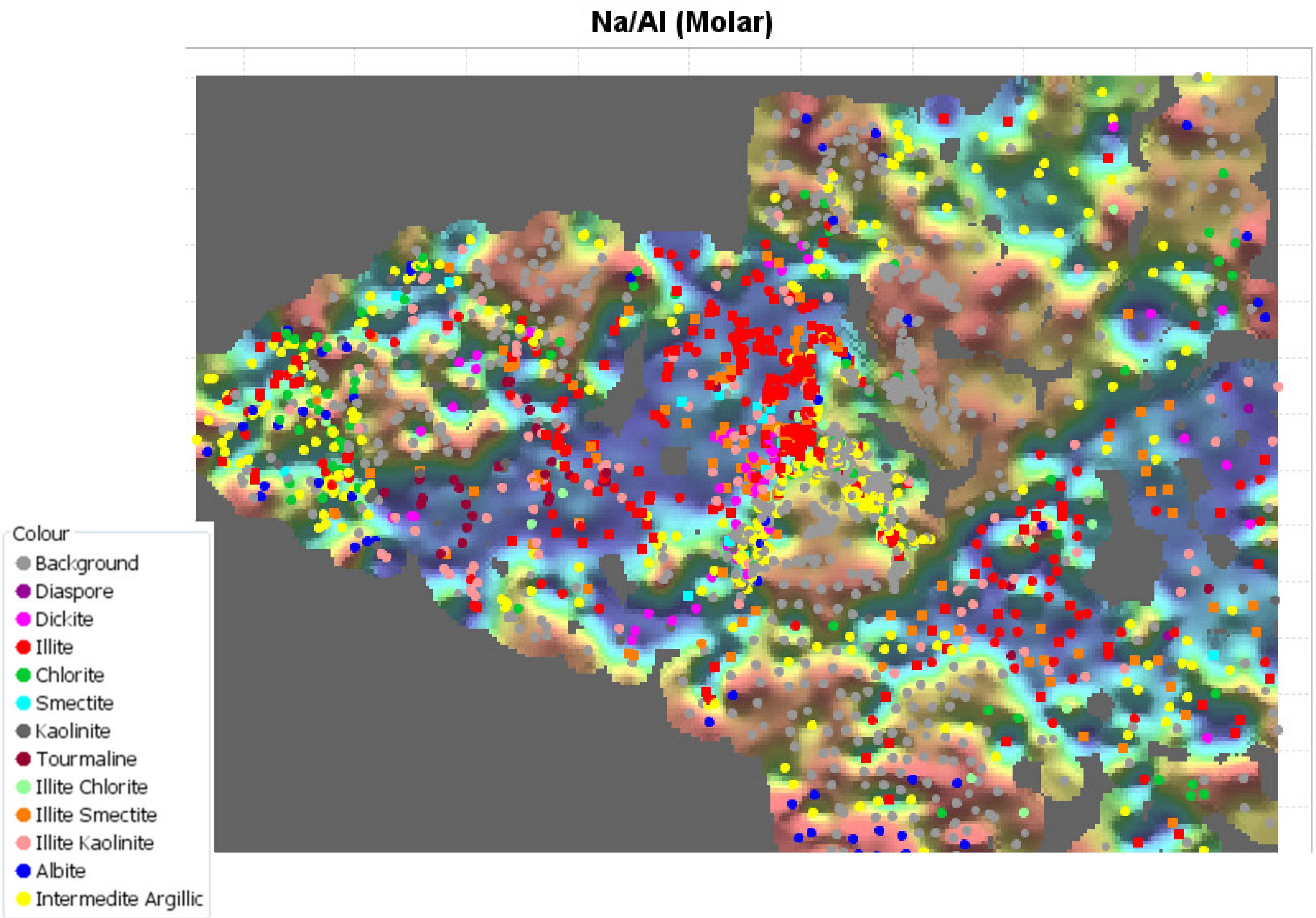
Consider the Na-depleted samples plotting between the projected composition of muscovite and kaolinite. Divide this into 3 equal ranges of K/Al. These points can then be assigned as dominantly illite, dominantly clay (kaolinite or smectite), or mixed illite-clay (kaolinite or smectite). Clay minerals that fall on top of the least-altered andesite composition were reassigned as “background”. The partially altered samples are mixtures of illite, smectite and kaolinite. These were lumped together as intermediate argillic alteration. An albite group was also picked out. This should be a quite accurate representation of the mineralogy.



Final Mineralogy map

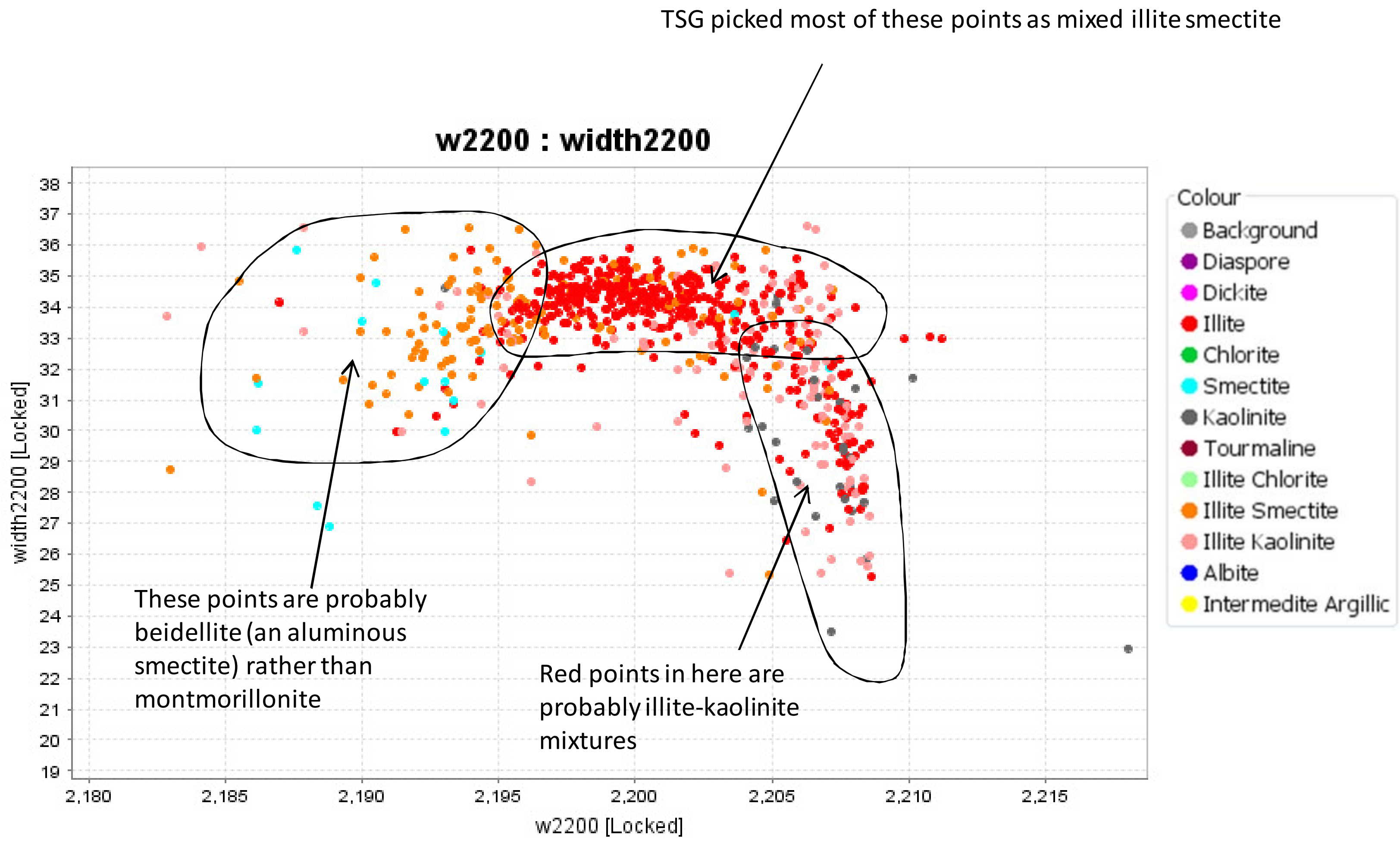


Mineralogy classification overlaid on a gridded image of Na/Al molar ratio



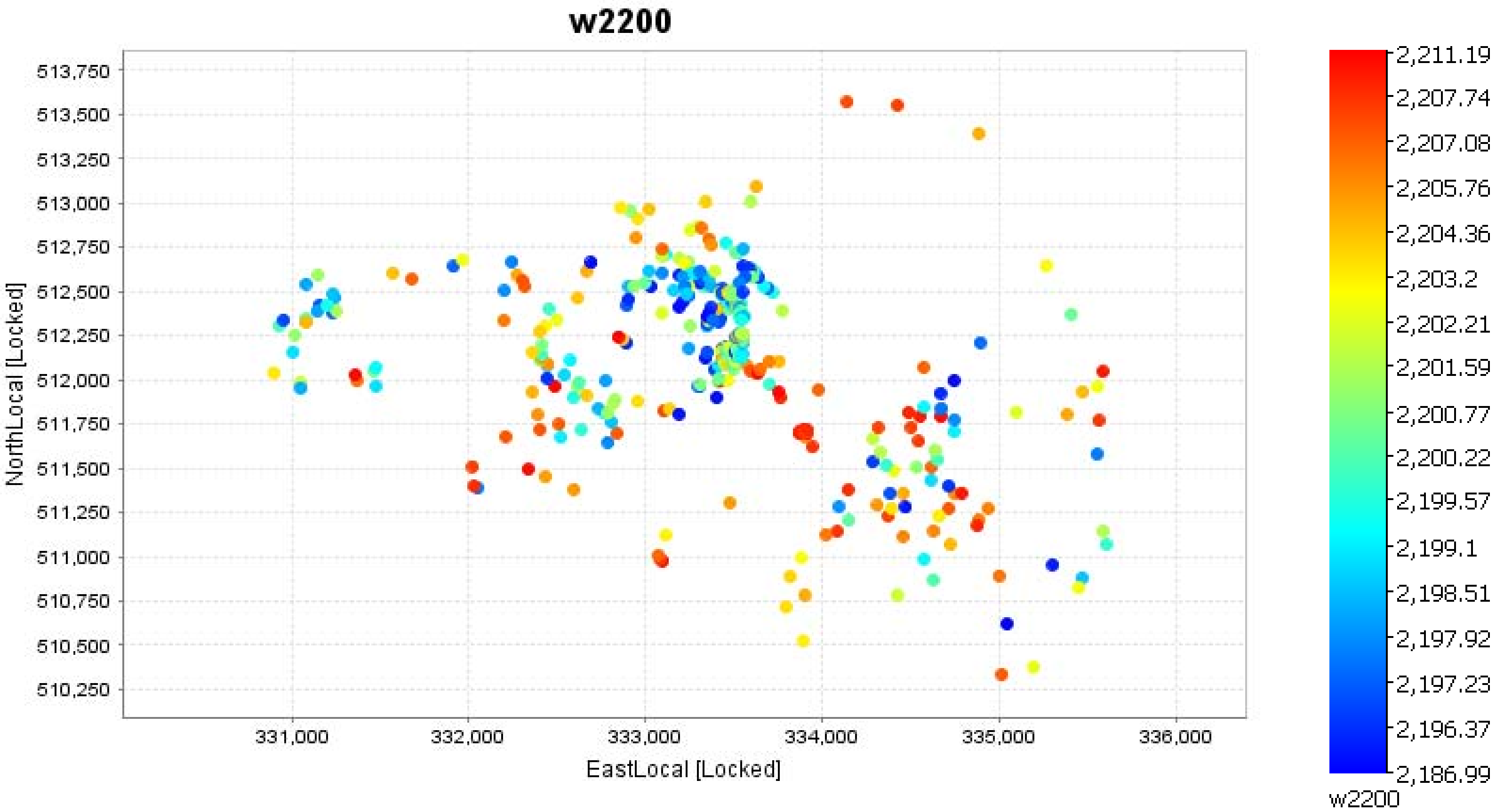
Mixed Spectra

Revisit the w2200 vs width 2200 plot now that points are reclassified using the assays. Without having the benefit of the geochem this plot could have been used to significantly improve the classification of the mineralogy.



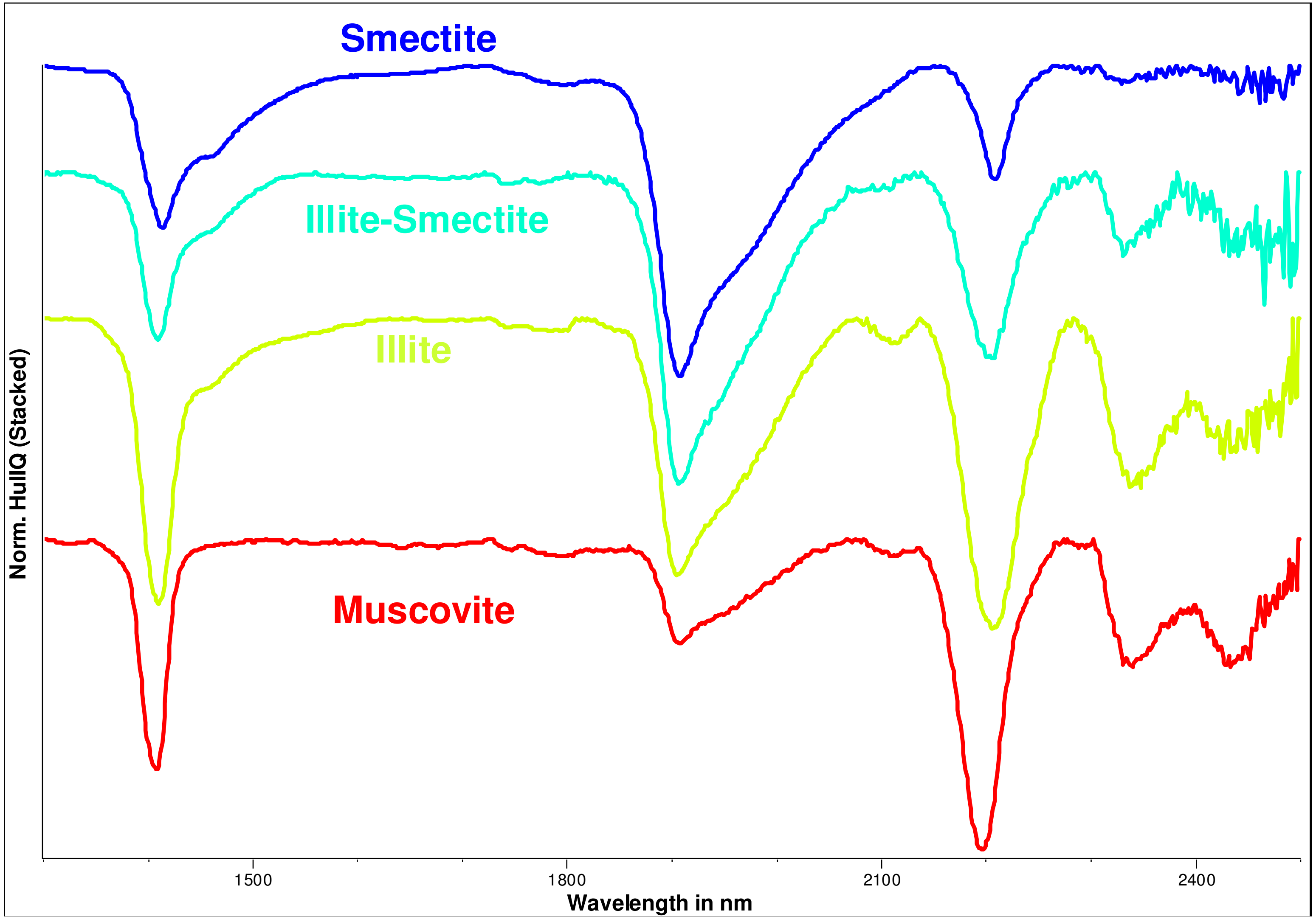
White mica compositions

Select ONLY the samples that are classified as Illite or Illite Chlorite. The presence of kaolinte or smectite shifts the wavelength at the minimum point. Plot ranges of the 2200nm wavelength. In Porphyry systems the most intense/proximal phyllic alteration has the shortest wavelengths.



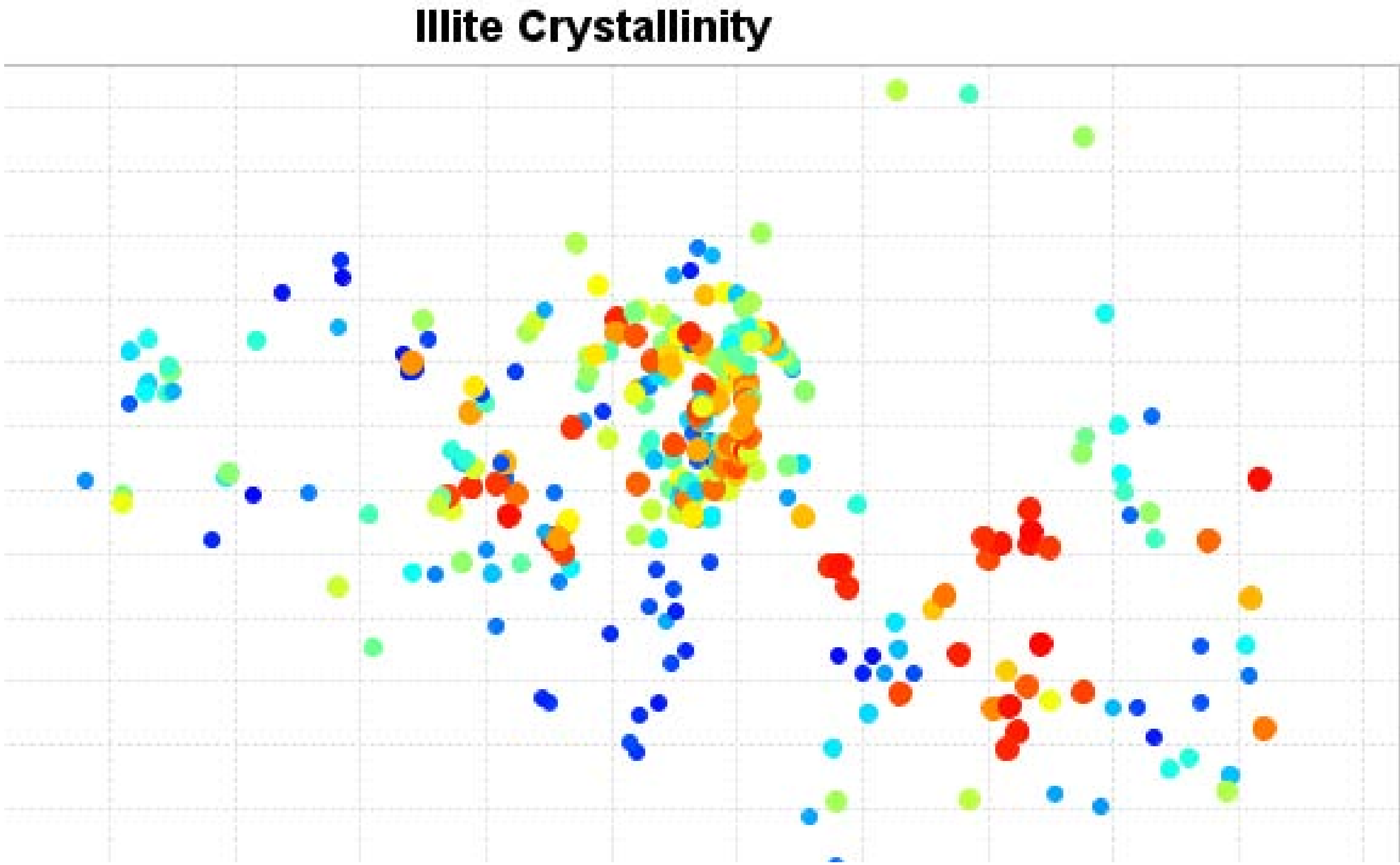
Illite Crystallinity

In a spectral sense there is a complete continuum between muscovite and montmorillinite. There is also a compete continuum in an alteration process, running down a temperature gradient. A proxy for mapping this is a ratio of the depth of the 2200nm feature to the 1900nm feature. Note also how the shape of the 1400nm -OH feature changes. The sidth of the 1400 feature can also be used as an Illite crystallinity index.



Illite Crystallinity

The Illite Crystallinity index should be used ONLY for those samples that contain just white mica minerals and/or montmorillonite. Every other mineral contributes to the depth of the 1900 feature, so those mixed-mineral spectra should NOT be included in the IC index.



Illite Crystallinity

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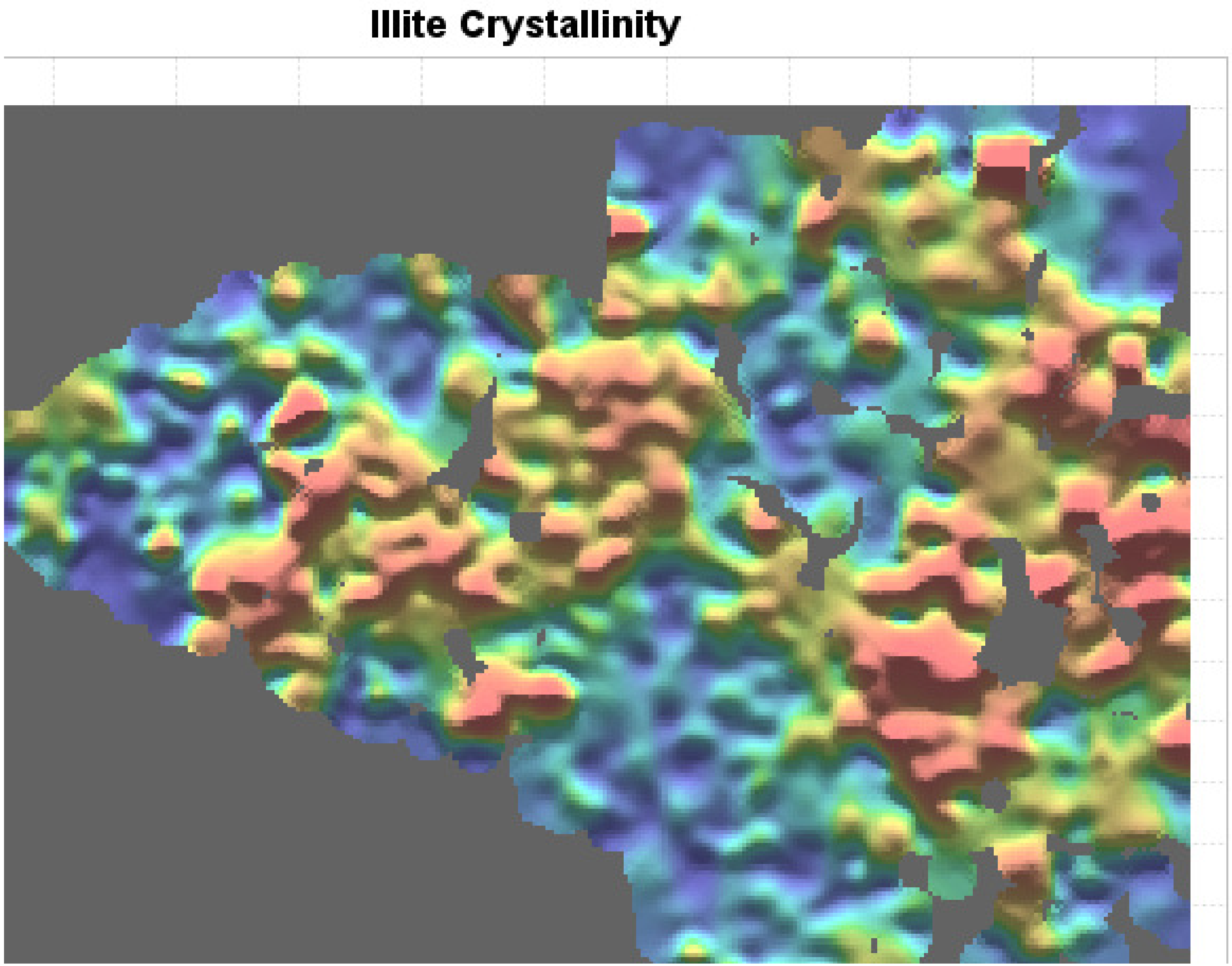
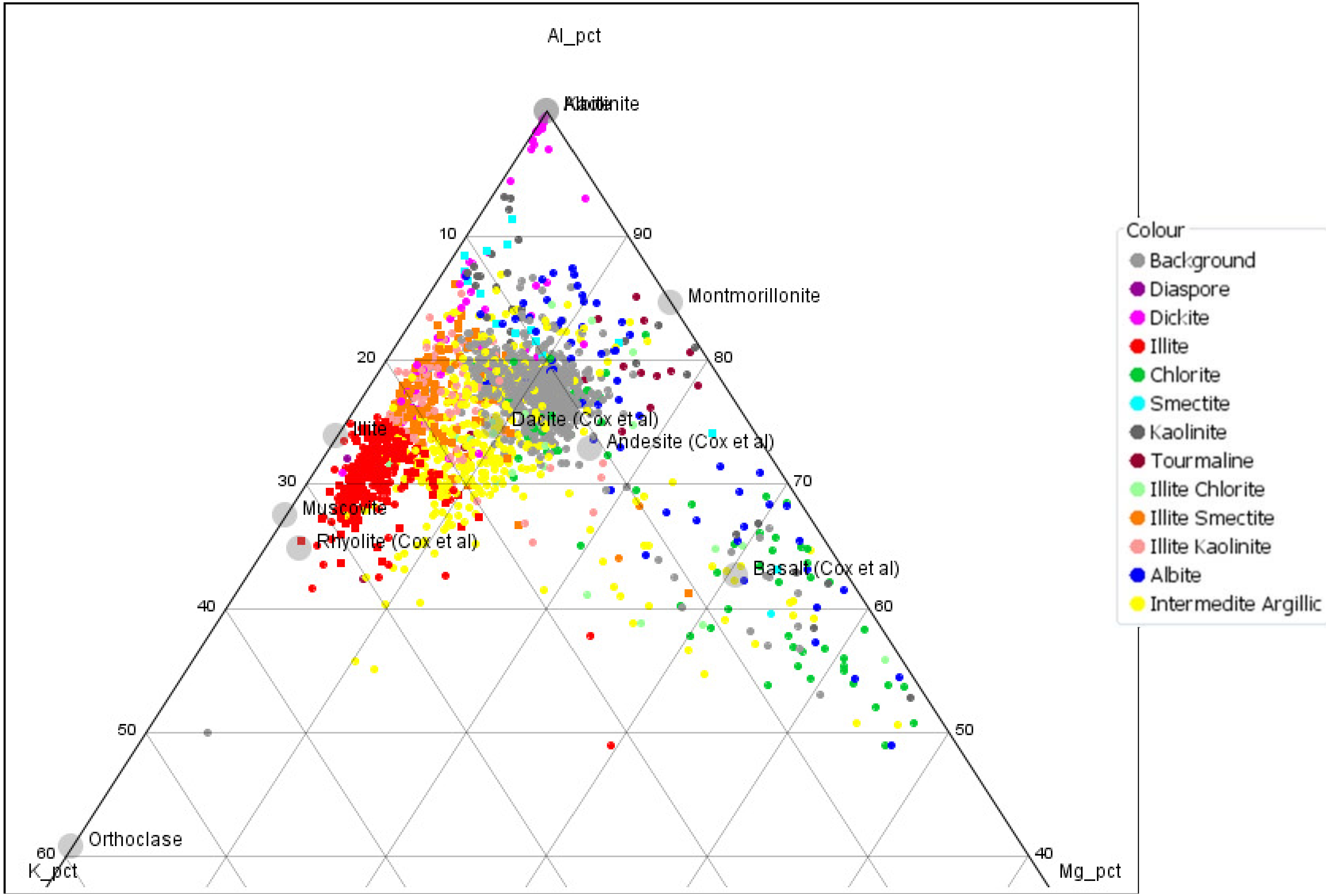


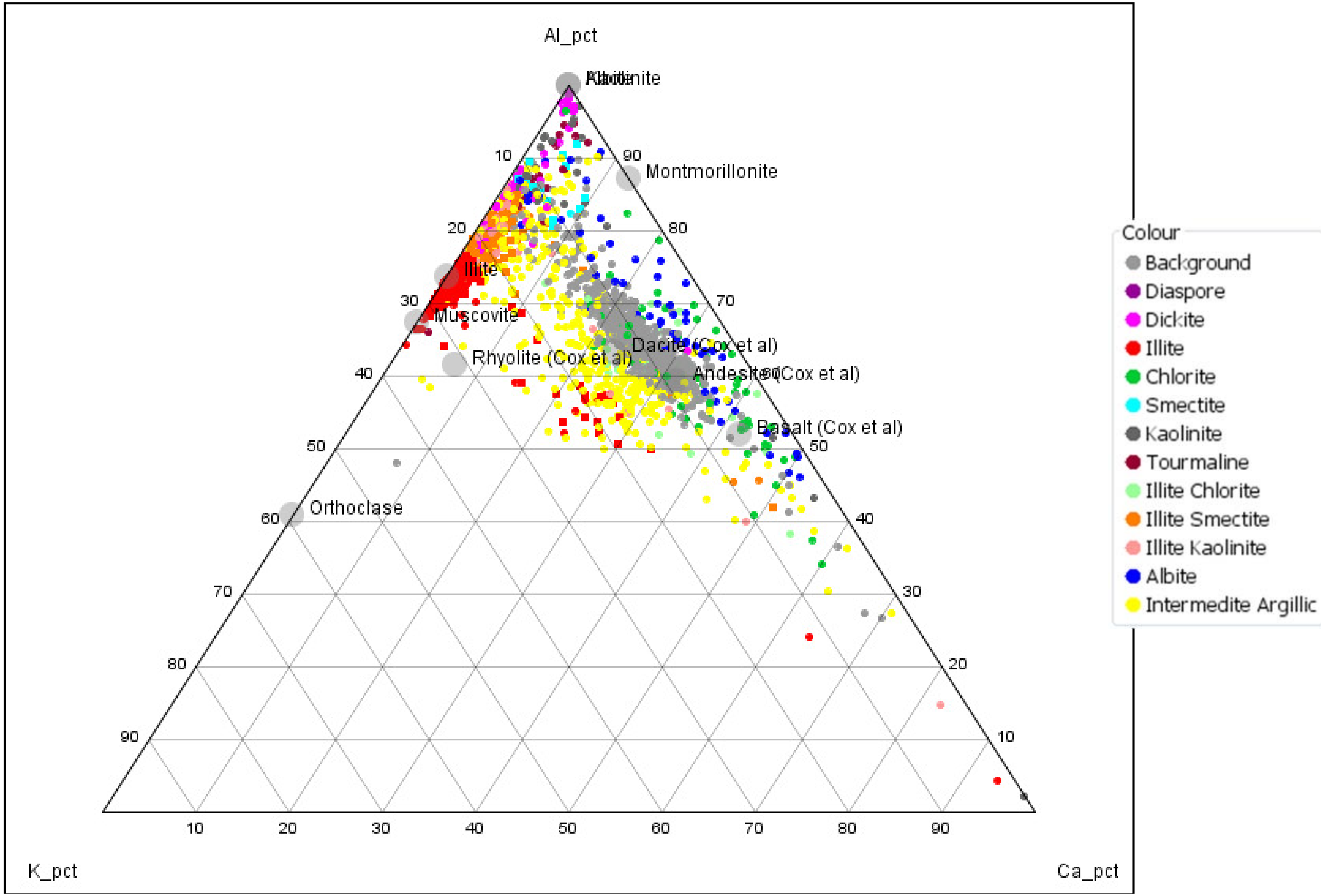
Other useful geochem plots; Al-K-Mg ternary

Where assay data is available, always plot an Al-K-Mg ternary plot. Chlorite-destructive alteration causes depletion of Mg. Intense illite alteration, illite kaolinite and kaolinite, as well as other types of advanced argillic, will be Mg-depleted. Mg is usually retained in smectitic zones.



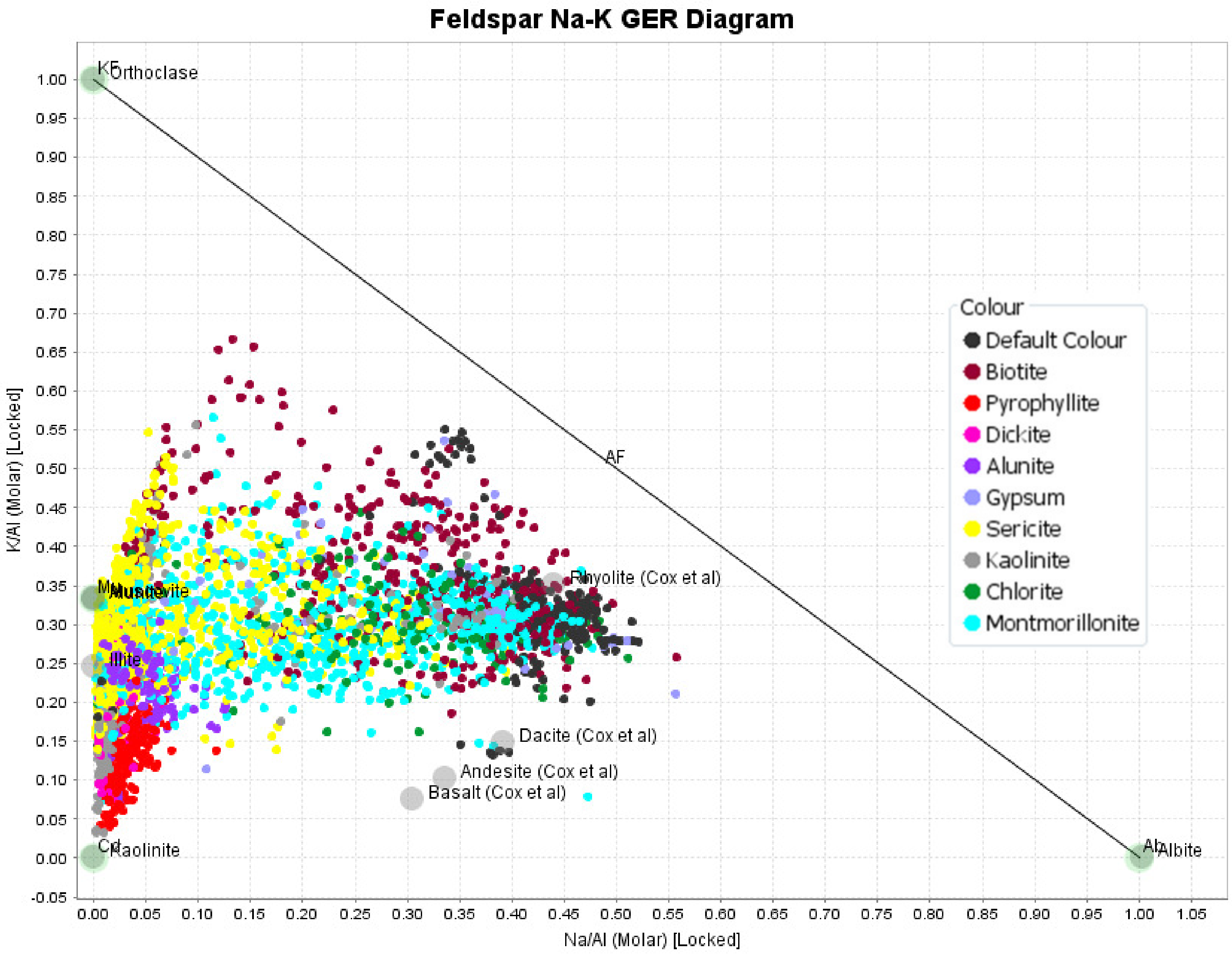
Other useful geochem plots; Al-K-Ca ternary

Plot an Al-K-Ca ternary plot. In feldspar-destructive alteration, calcic plagioclase is broken down early in the process. Calcium is removed in acid environments. These plots suggest that we are still overestimating the montmorillonite abundance.



Comparison with CoreScan

Corescan measures spectra with a 0.5mm by 0.5mm resolution. This data has been composited to match assay intervals; the dominant spectral mineral signal was assigned to each interval. In contrast to the point ASD measurements, this shows an excellent correlation with the geochemistry. The partial clay overprint (illite-smectite-kaolinite) on feldspathic rocks I still problematic, but this will be resolved with the introduction of TIR. More importantly, Corescan is picking up the critical minerals that are present with just low abundances, eg in this case, the biotite!



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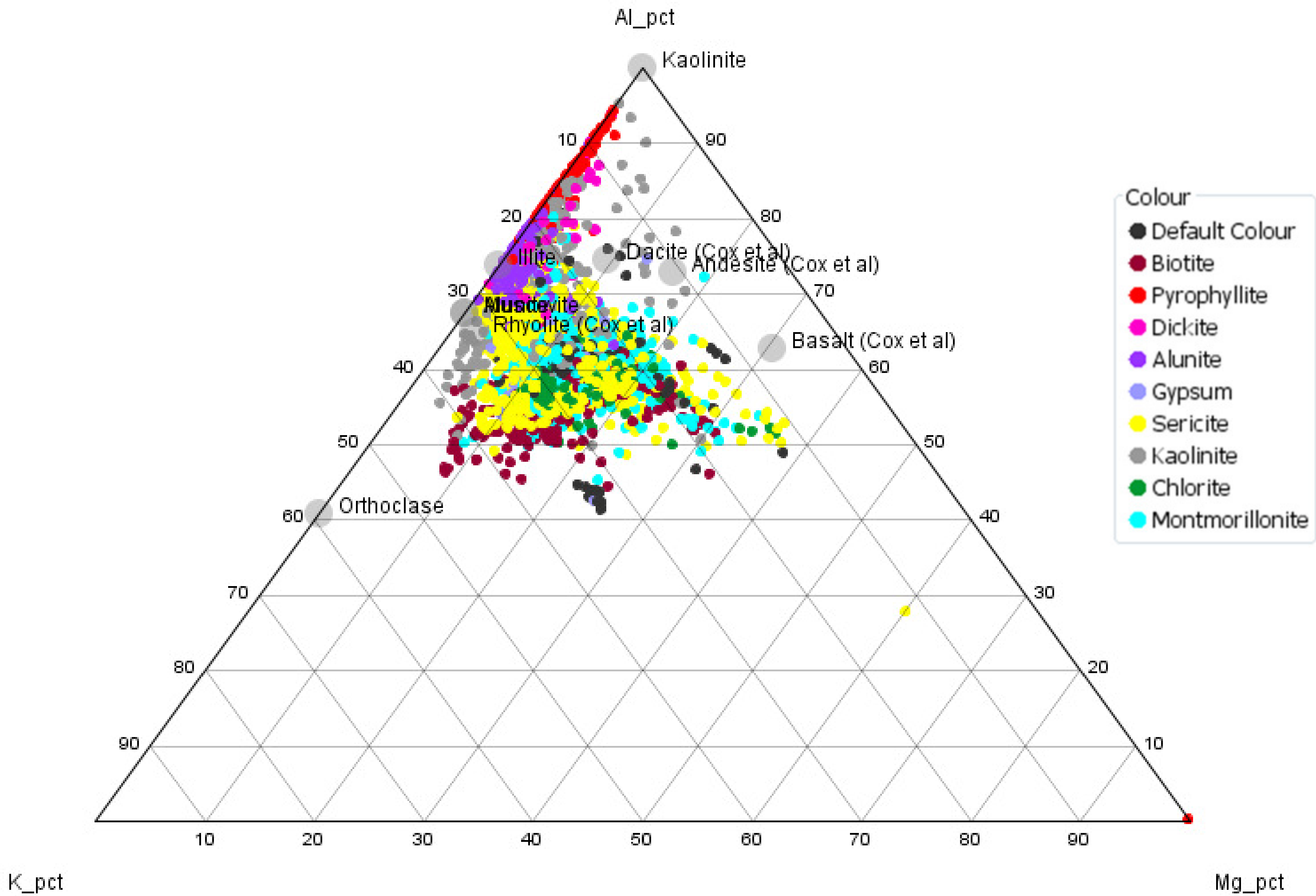

Conclusions

- TerraSpec is low-resolution data. There is a lot of ambiguity in interpreting mixed mineral spectra. An analogy is assaying gold with a precision of 1ppm, but quoting results to 2 decimal places. We tend to over-interpret individual spectra. This is quite meaningless when we would have got a very different answer if we had measured a spot 1cm away.

- A lot of data is needed to see patterns through the inherent variability of natural hydrothermal systems.

- Familiarize yourself with the “quirks” of TSG. There are some mineral picks that should not be trusted, and there are simple scalar plots that can be used to check the TSG results.

- Calibrate your spectral interps against whole rock geochem where possible.