



**BUREAU  
VERITAS**

# **ANALYSIS OF MINING SAMPLES USING INFRARED SPECTROSCOPY AND MACHINE LEARNING**

**MATLAB CONFERENCE  
PERTH, MAY 2017**



# SUMMARY

01

**Who is  
Bureau Veritas?**

02

**Bureau Veritas  
Minerals Services**

03

**Infrared  
Spectroscopy**

04

**Machine Learning  
and Matlab**

05

**Summary**



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# 01 WHO IS BUREAU VERITAS

Established in 1828, Bureau Veritas is a global leader in Testing, Inspection & Certification services in the areas of Quality, Health & Safety, Environment and Social Responsibility across eight global businesses.



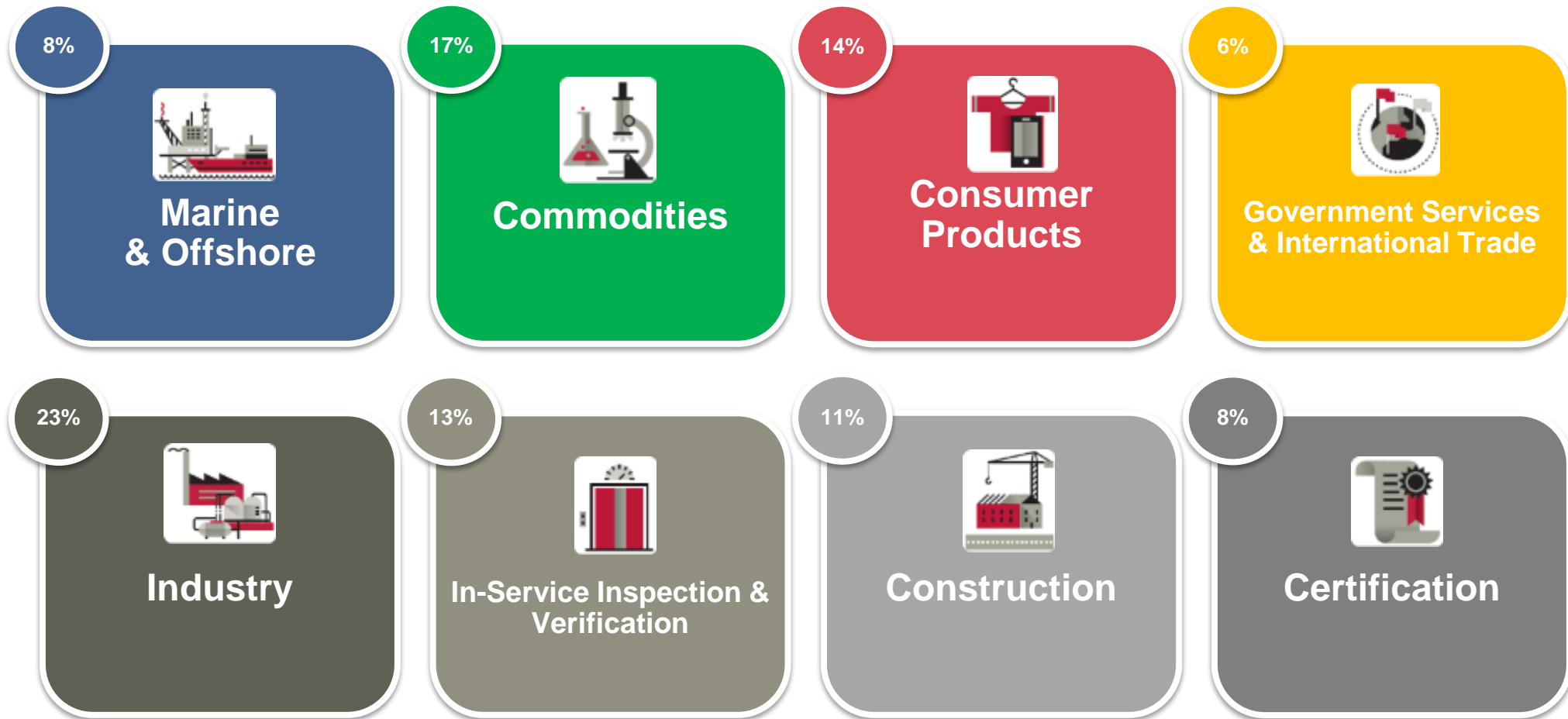
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# 8 GLOBAL BUSINESSES

## 2015 REVENUE: €4.6 BILLION

Global network comprising of 66,500 employees in 1400 offices and laboratories across 140 countries.







# 02 BUREAU VERITAS MINERALS SERVICES



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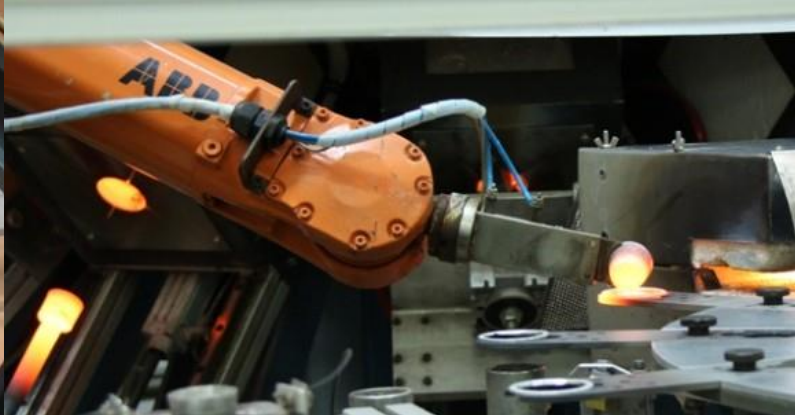
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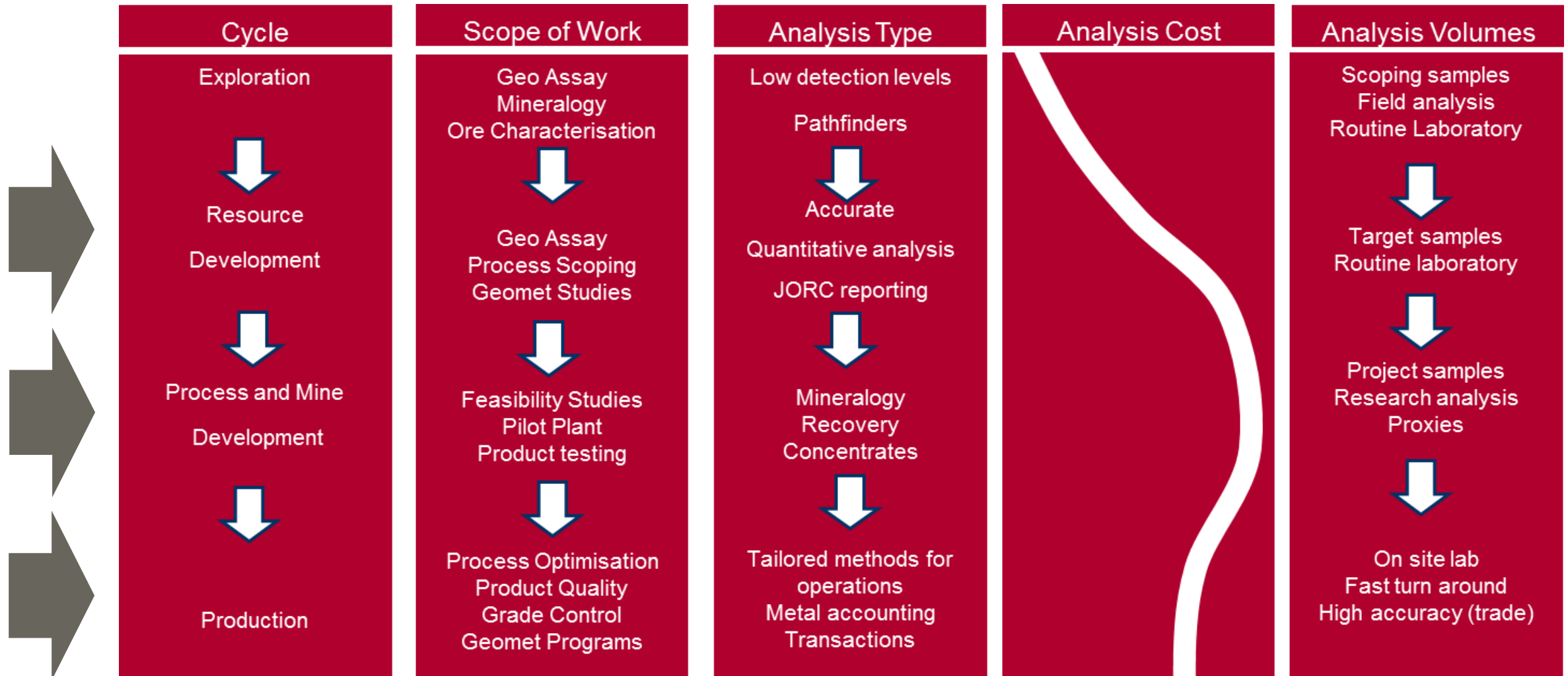








# MINING DEVELOPMENT



# 03 INFRARED SPECTROSCOPY





# INFRARED SPECTROSCOPY

Sample is presented to a light source. – No special preparation

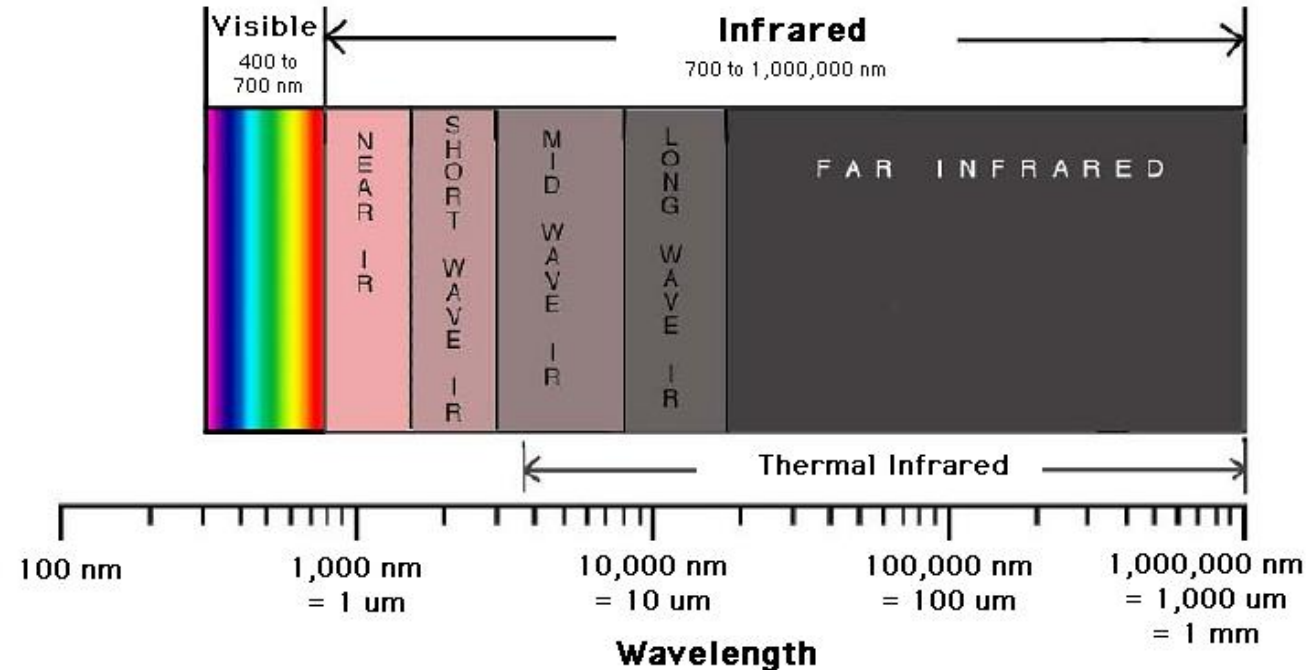
The response from the sample is measured by a detector.

- Near Infrared, Short Wave Infrared
- FTIR – Fourier Transform Infrared Spectroscopy – Mid to Thermal Infrared

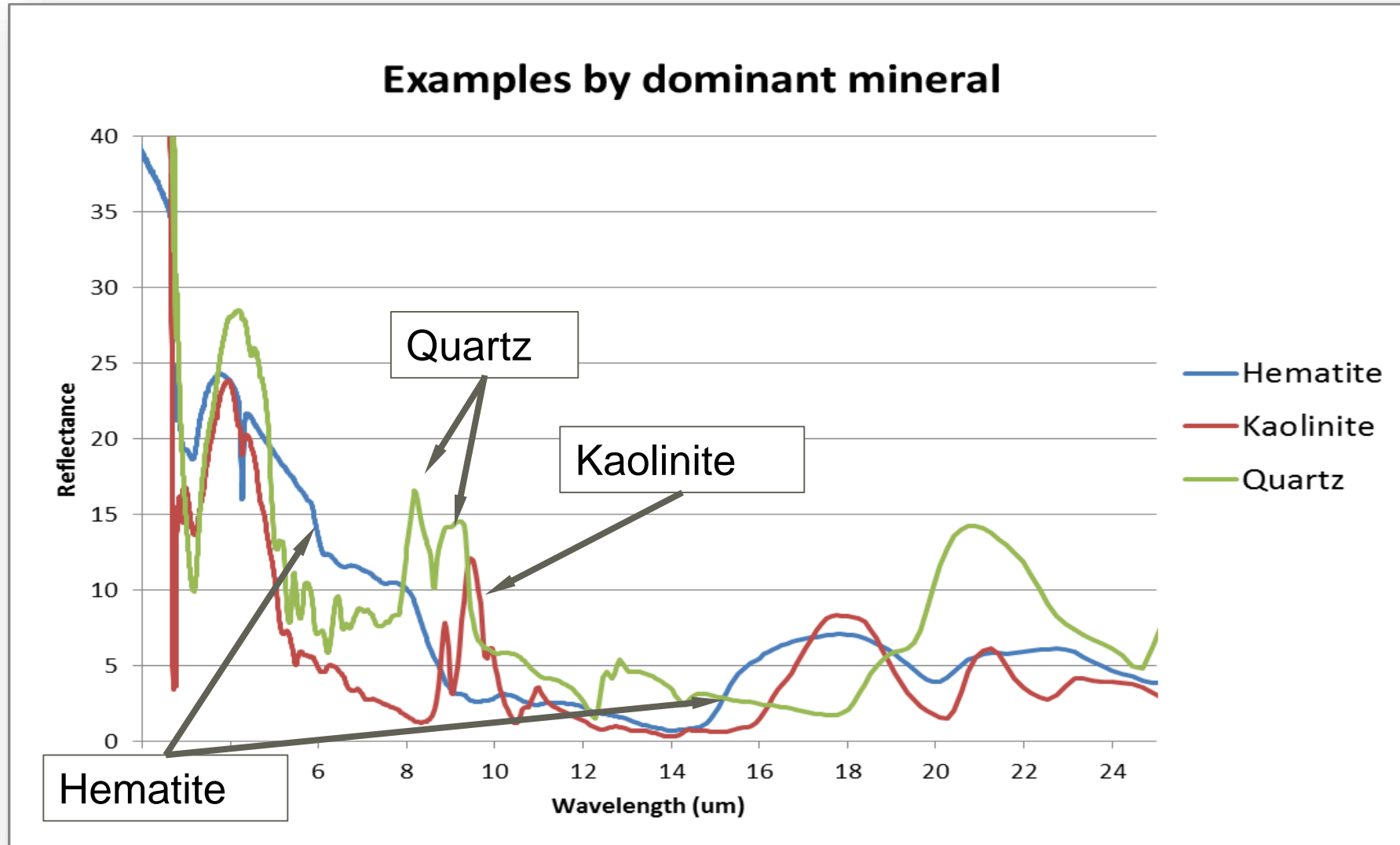
Spectra is representative of the molecular bonding in the sample

Absorption of incident light at specific characteristic wavelengths

Bond vibration, bending and stretching

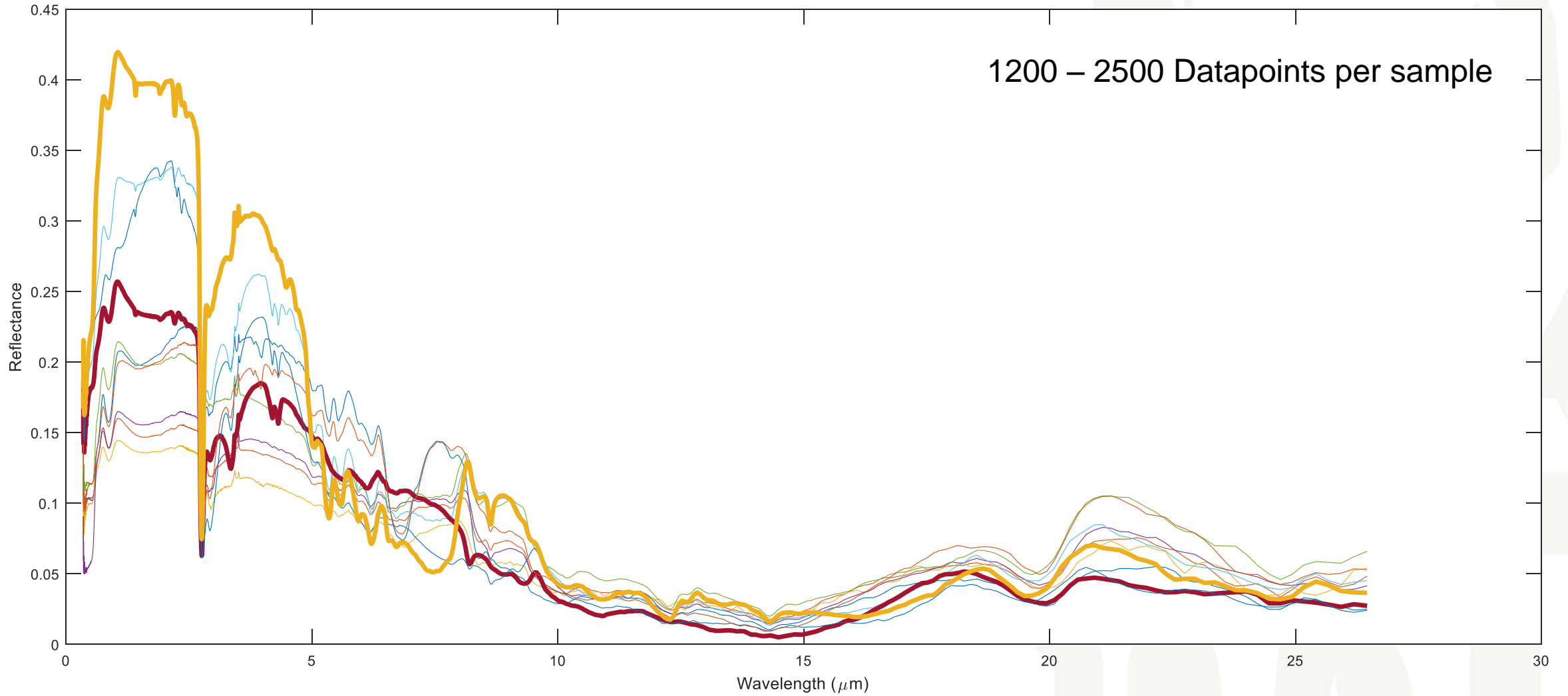


# SPECTRA OF IRON ORE SAMPLES



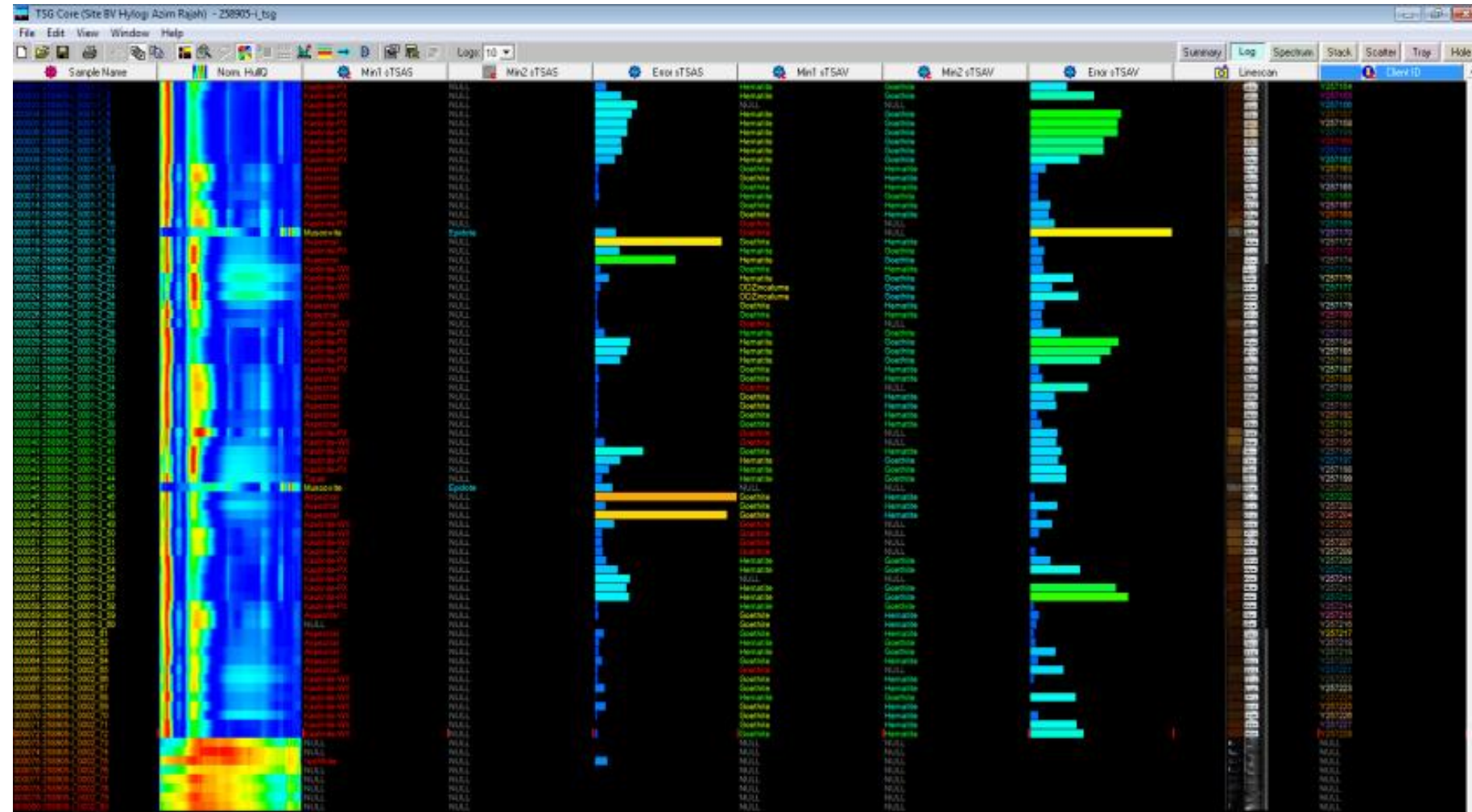


# EXAMPLE SPECTRA



# SPECTRAL INTERPRETATION

- ▶ Spectral Library
- ▶ Analyse Features for  
DEPTH  
LOCATION  
SHAPE
- ▶ Major Minerals Only





A large orange industrial robotic arm is shown in a factory setting, positioned over a workbench. The arm is complex, with multiple joints and cables. The background is slightly blurred, showing other industrial equipment and a green wall. A red vertical bar is on the right side of the image.

# 04 MACHINE LEARNING AND MATLAB



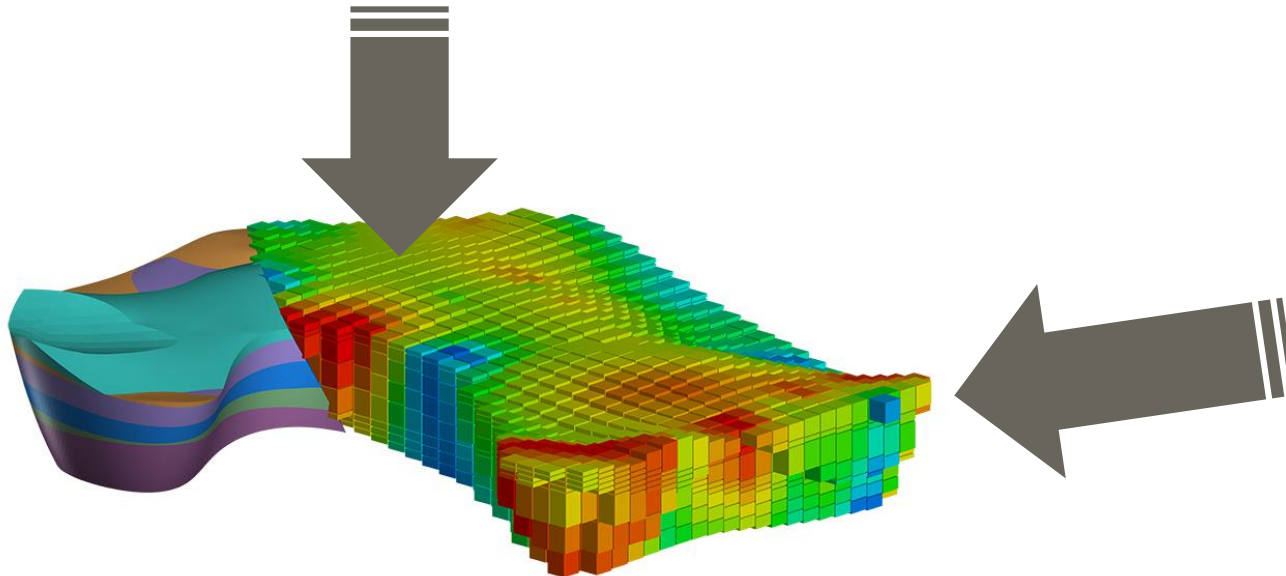
## *Spectral Process Overview – Value Proposition*

### **1. *Mineralogy and Proxies***

- Mineralogy drives block model design
- Metallurgical testing is expensive
- Proxies are unreliable

### **2. *Infrared Red Spectra***

- Simple and low cost
- Laboratory Workflow
- Spectral fingerprint



Machine Learning

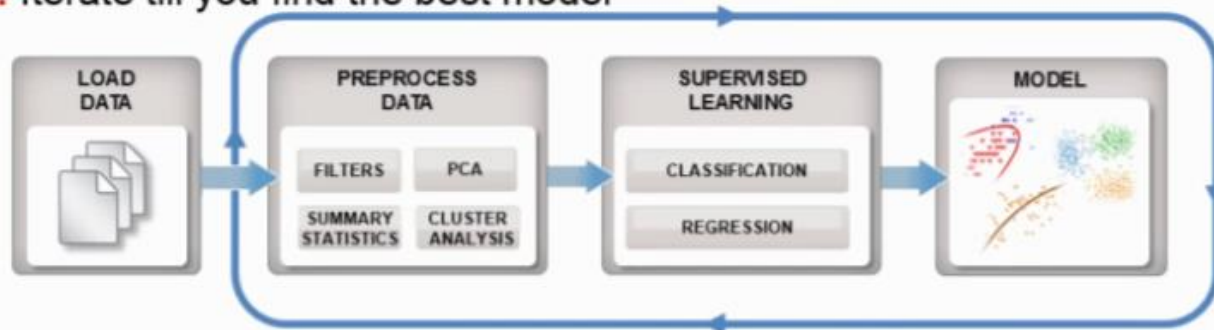


# MACHINE LEARNING

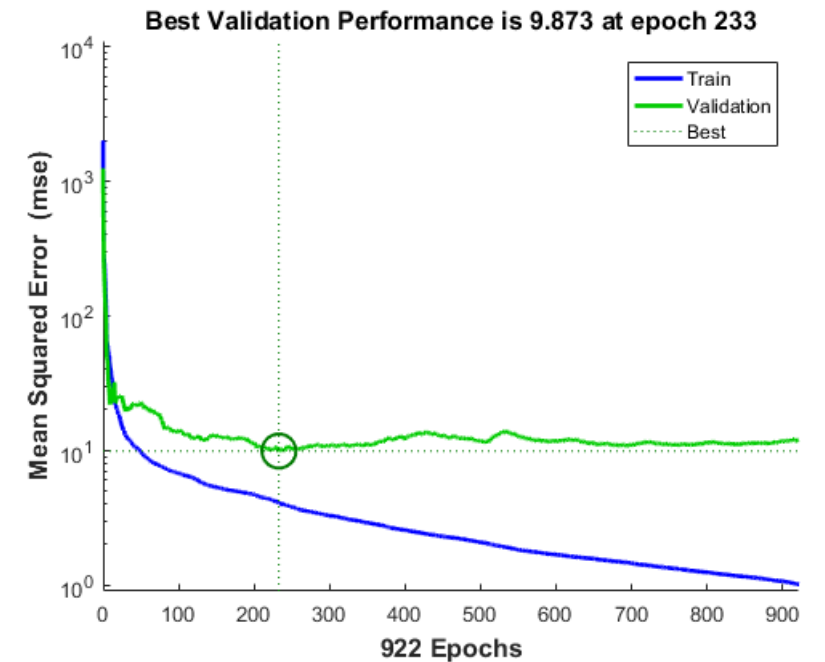
*How do we use this data for routine analysis?*

Two step process:

**Train:** Iterate till you find the best model



**Predict:** Integrate trained models into applications



## ▶ Mineralogy

- Hematite, Goethite, Gibbsite, Kaolinite, Talc, Mica, Quartz

## ▶ Physical properties

- LOI, SG, Bulk Density

## ▶ Ore processing properties

- Comminution energy, recovery, acid consumption

## ▶ Chemistry

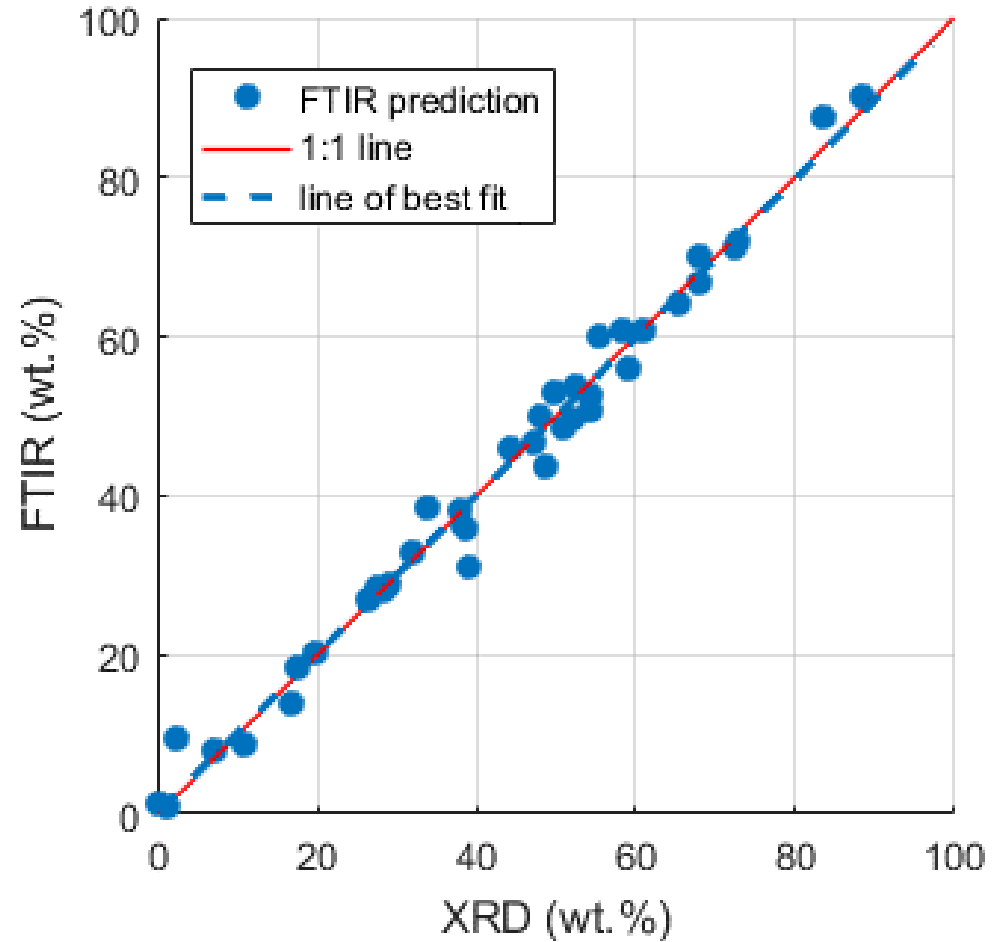
- Fe, Al, Si for laterites and Cu, Ni, Pb, Zn for base metal ores



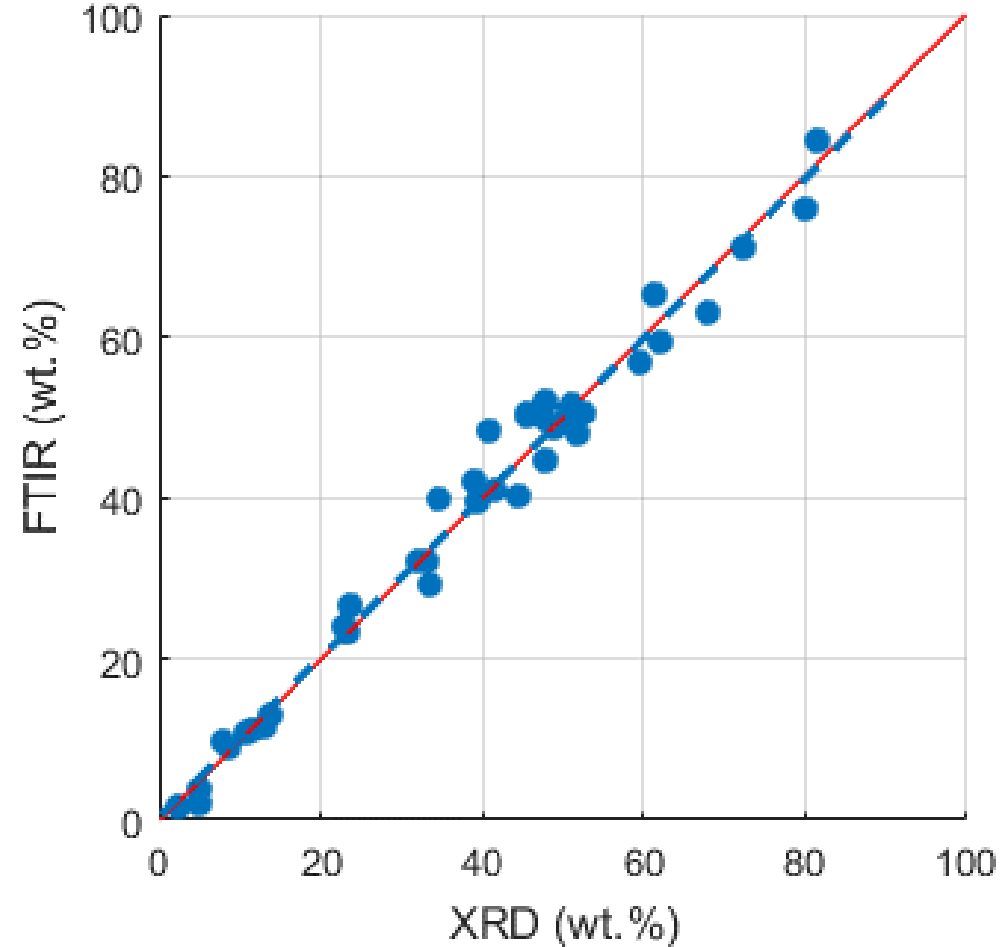
# RESULTS

## Matrix/dominant minerals – Fe ore

### Hematite



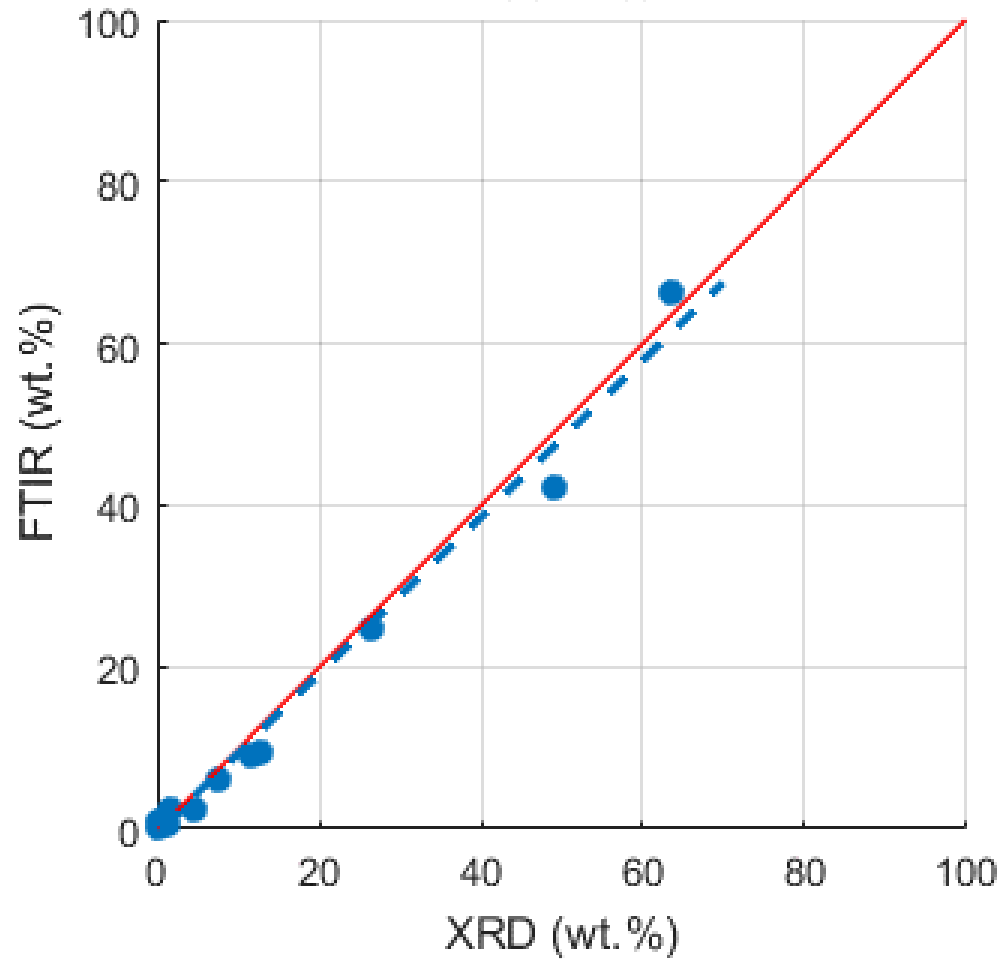
### Goethite



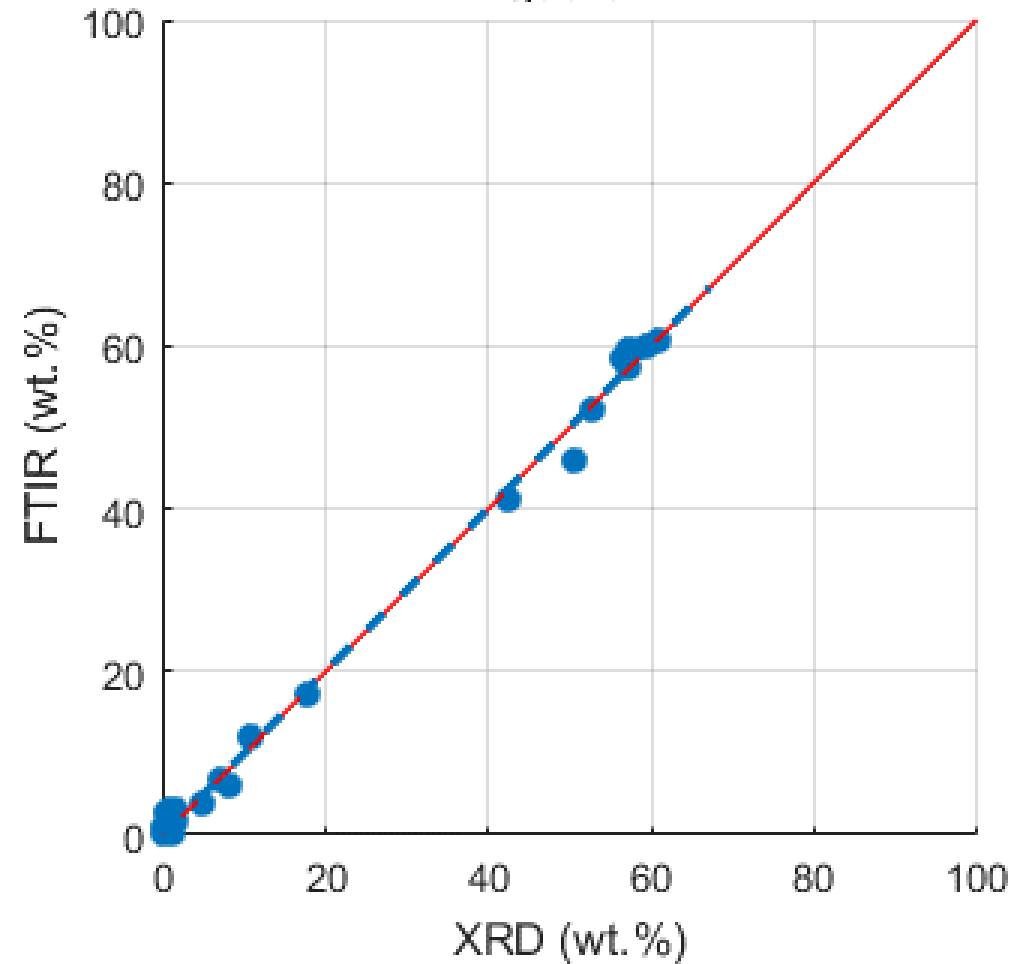
# RESULTS

## Matrix/dominant minerals – Fe ore

### Kaolinite



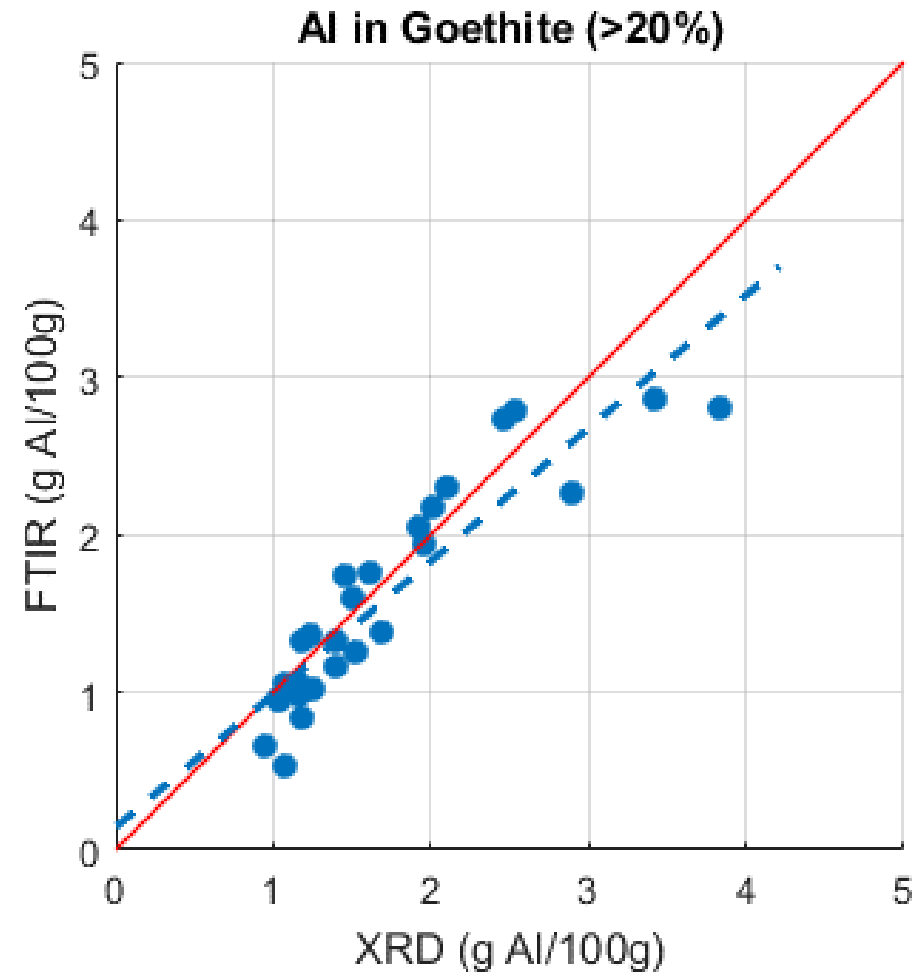
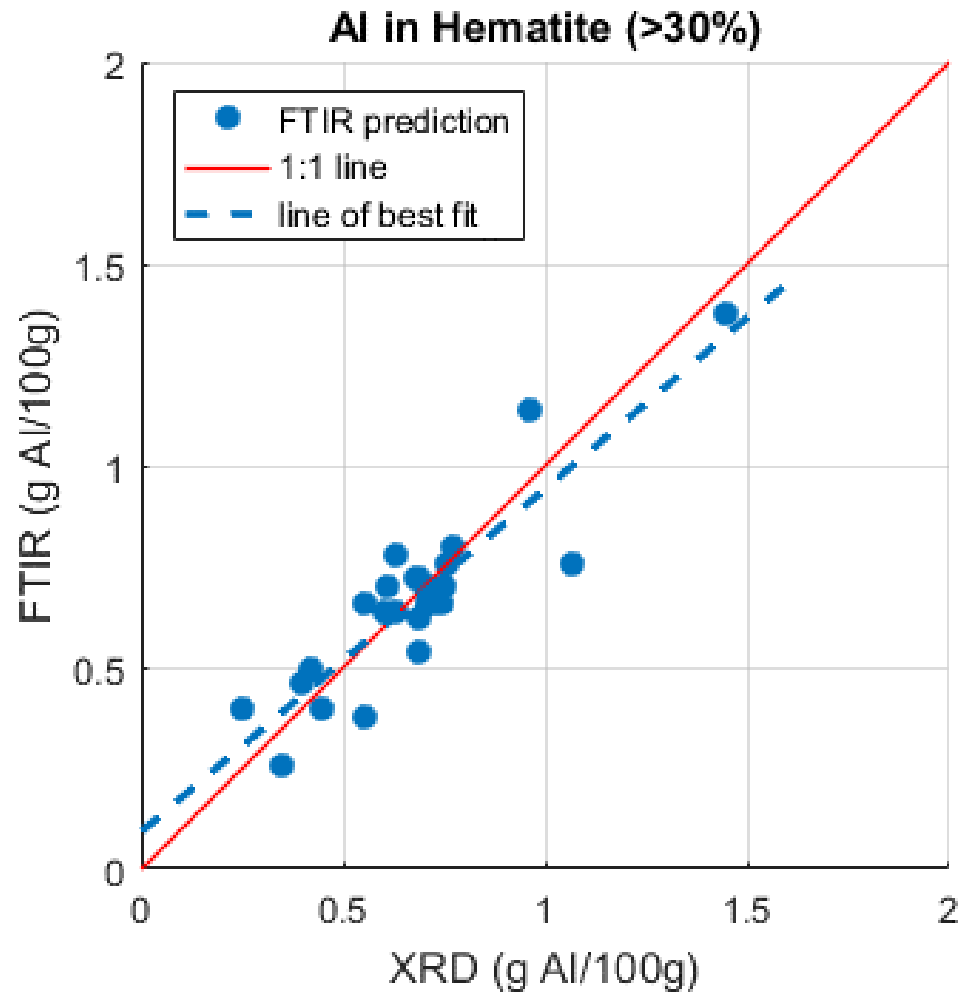
### Quartz





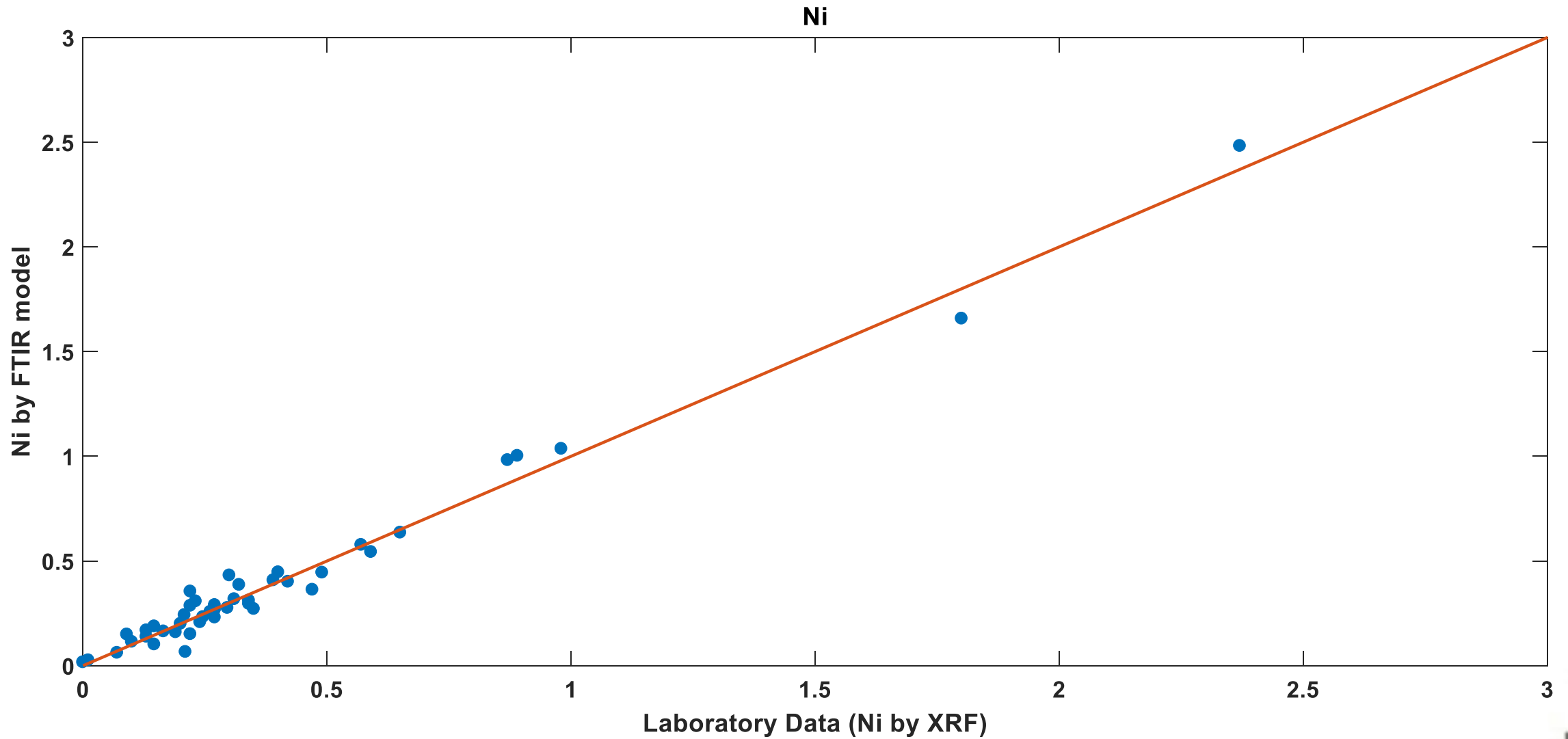
# RESULTS

## Substitution Analyte – Fe ore



# RESULTS

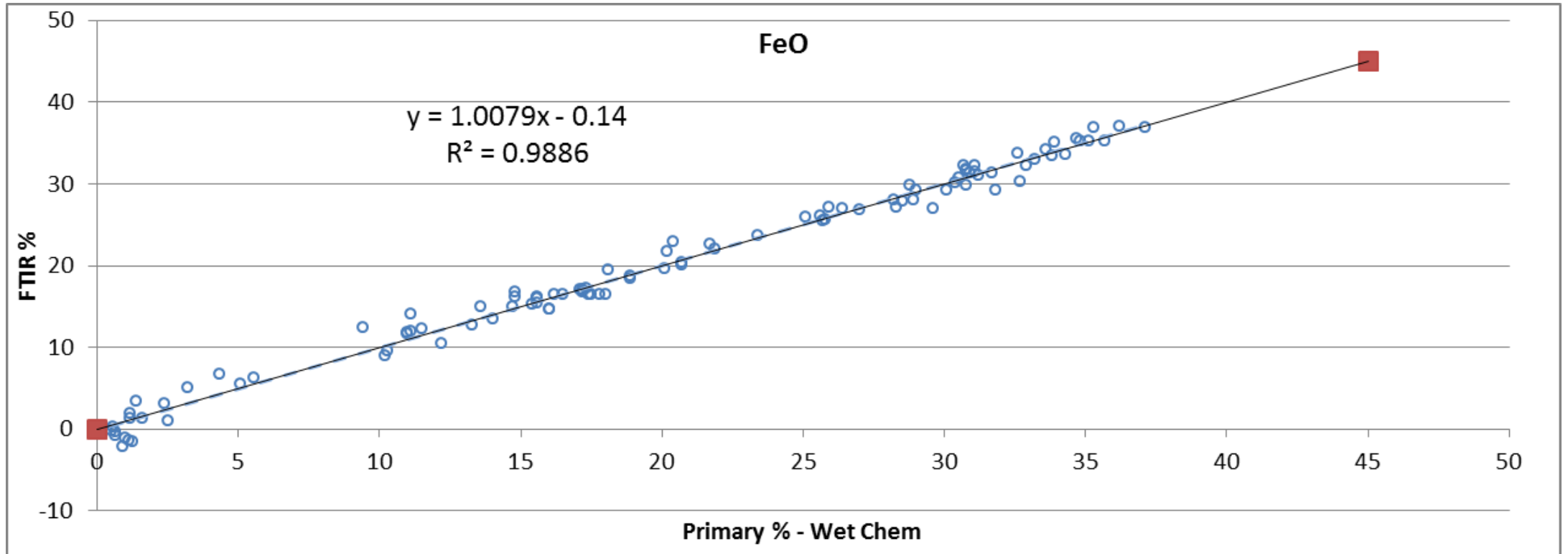
Element – Ni laterite





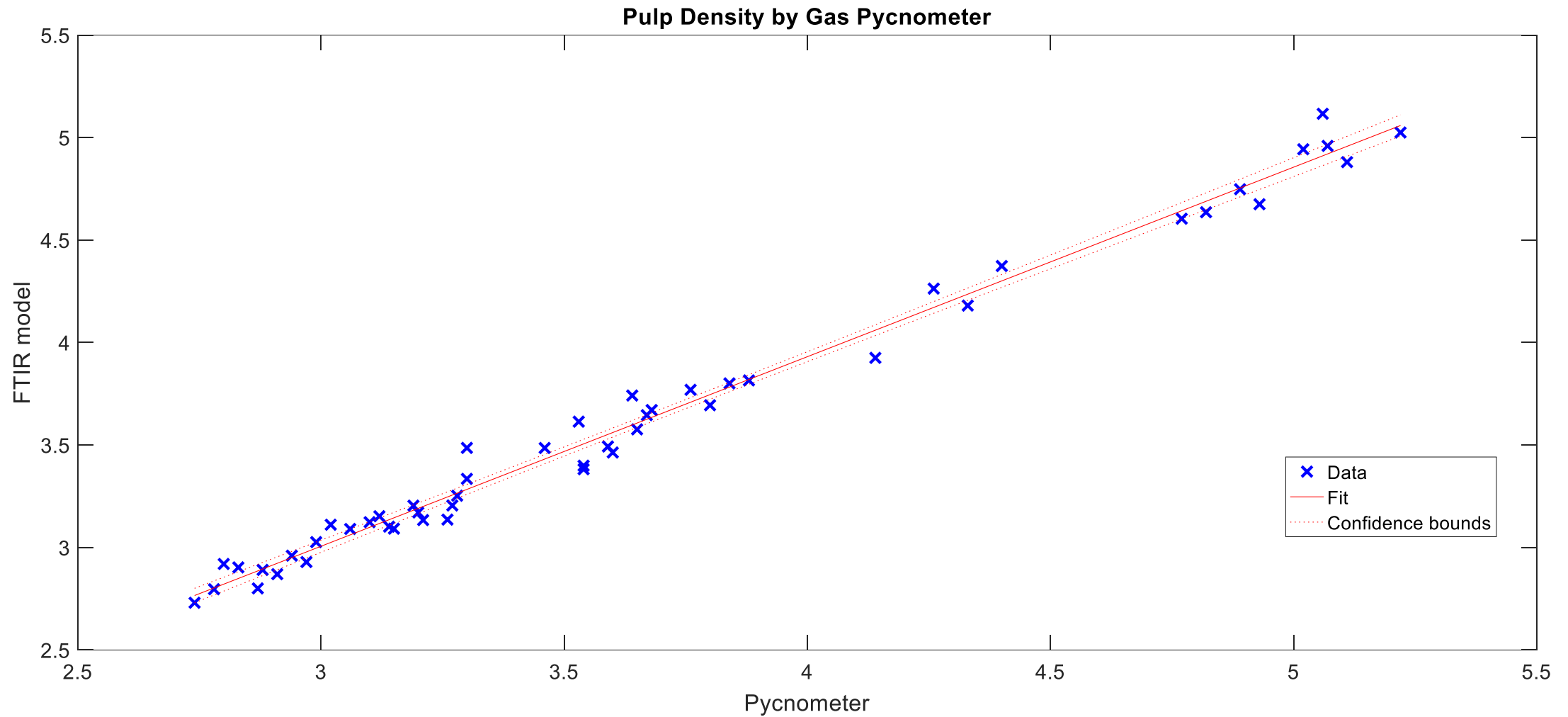
# RESULTS

## Element speciation – Fe<sup>2+</sup>

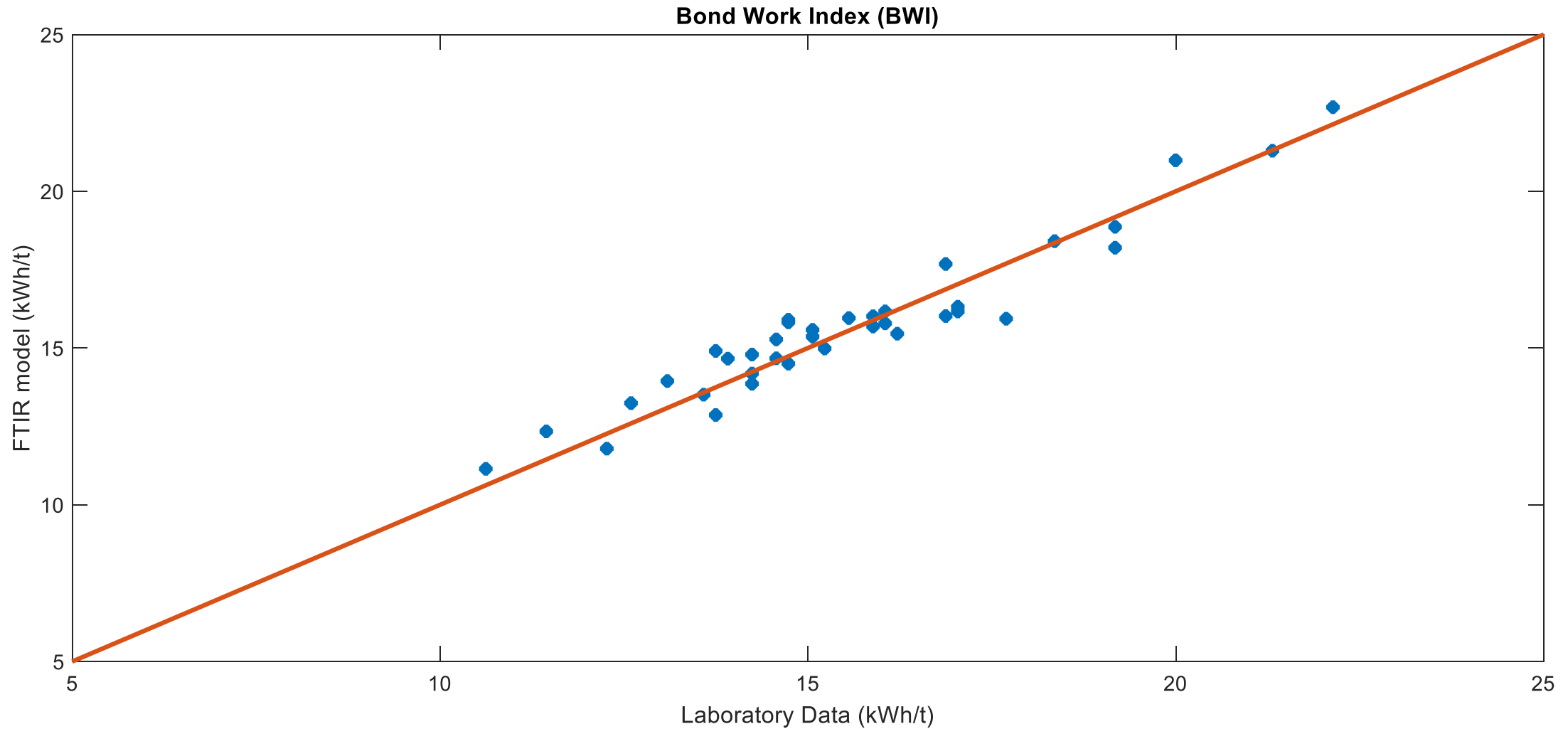


# RESULTS


## Physical property - Density







# 04 APPLICATION DEPLOYMENT - OPERATIONS



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QC Summary

Warnings Count

Sample Barcodes Dup  
**Passed**

QA/QC Storage  
**Disabled**

### File Control Settings

**Spg File List**

- 269034.h p1x4.SPG
- 269034.h p2x4.SPG
- 269034.h p3x4.SPG
- 269034.h p4x4.SPG

Barcode Exchange File

Output Folder  
C:\Users\jcarter\Desktop\Test

Files Count  
1

Output Options

- Single File (\*.csv)
- Multiple File (\*.csv)
- Single Matlab File (\*.mat)

Sorby Connection Panel

Jobnumber to call: u269034

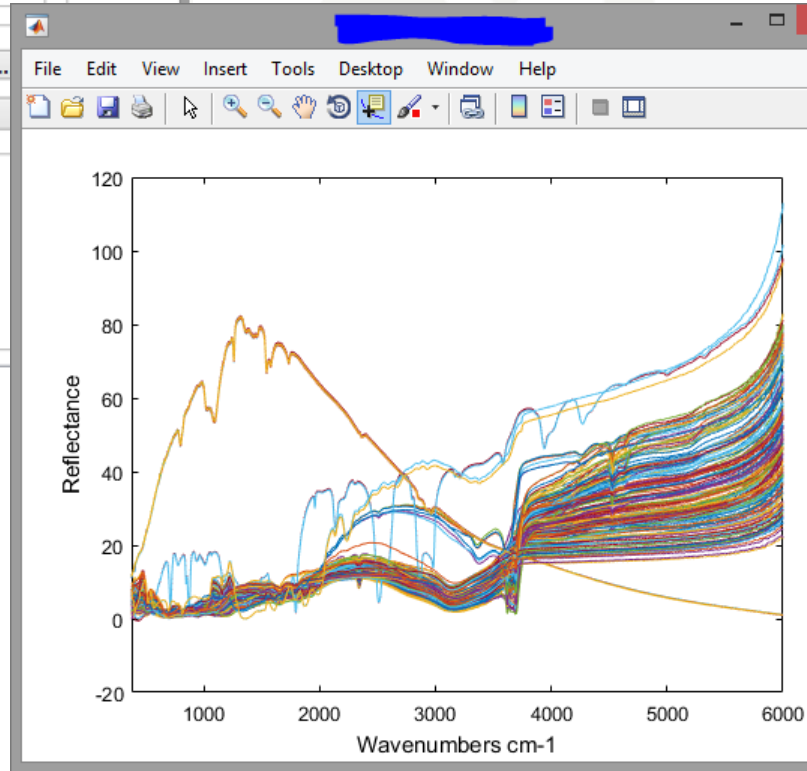
Sorby Minerals Service Node Status

Samples Count

From SPOs: 167

From Sorby: 167

Barcode	SampleID	Status	pFe	FE_X	pSiO2	SiO2	pAl2O3	AL2O3	pLOI	LOI	Warnings	IncExcl
			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		<input checked="" type="checkbox"/>
	ICD		53.5122	58.35	6.9323	5.58	3.4375	2.58	8.9585	7.71		<input checked="" type="checkbox"/>
	ICD		57.3696	60.84	3.6732	4.44	2.2112	1.37	8.4935	6.65		<input checked="" type="checkbox"/>
			56.0529	60.94	4.954	4.53	2.3557	1.27	8.0768	6.47		<input checked="" type="checkbox"/>
			59.163	61.63	3.922	4.30	1.3071	0.87	7.6689	6.23		<input checked="" type="checkbox"/>
			56.9606	58.59	4.8018	4.78	1.8491	1.77	10.5594	9.28		<input checked="" type="checkbox"/>
			57.5209	58.19	4.0853	4.62	2.0413	2.28	11.076	9.59		<input checked="" type="checkbox"/>
			44.4145	42.42	22.6904	27.44	2.6616	3.07	9.2985	8.22		<input checked="" type="checkbox"/>
			30.1172	28.62	54.1863	53.58	0.59603	1.13	4.5655	3.88		<input checked="" type="checkbox"/>
			50.3799	57.39	6.2527	4.33	5.7391	4.98	9.037	7.99		<input checked="" type="checkbox"/>
			55.5026	61.41	3.3863	3.13	3.2464	2.31	7.4949	6.34		<input checked="" type="checkbox"/>
	ICB	<DL	2.18	72.5259	70.33	13.9748	14.80	4.8855	0.77			<input checked="" type="checkbox"/>
	ICS		52.5467	54.42	5.8277	7.89	4.3511	4.85	9.7111	8.53		<input checked="" type="checkbox"/>
			55.2728	59.60	4.8592	4.07	3.1943	2.46	8.7405	7.82		<input checked="" type="checkbox"/>
			57.2003	60.61	2.8795	2.27	2.8397	2.54	9.1149	7.91		<input checked="" type="checkbox"/>



Command Echo

```
Sorby Exchange file =
Converted files will output to =C:\Users\jcarter\Desktop\Test
Reading Spectra From Binary
Finished Reading Spectra From Binary
Exchanging Barcodes
Testing Connection to Sorby..
Calling to Sorby..
Successful call made.
```

Comparisons

Start



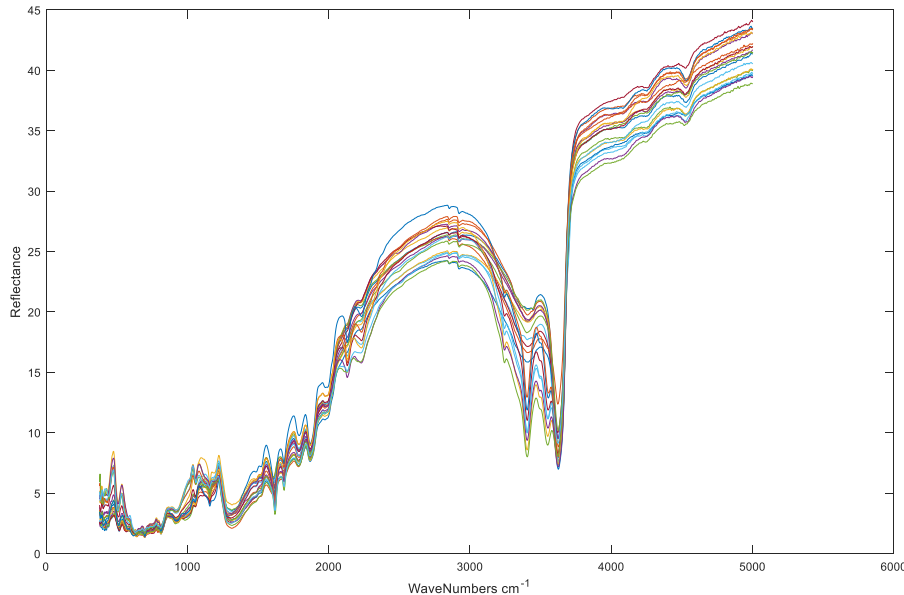
# 05 SUMMARY



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10.66	2.97	0.138	0.017	0.013	0.011
11.54	2.71	0.187	0.021	0.016	0.008
21.63	1.60	0.035	0.019	0.015	0.006
21.68	1.59	0.035	0.020	0.015	0.005
21.51	1.58	0.034	0.018	0.014	0.054
28.42	1.65	0.063	0.021	0.016	0.008
69.40	14.33	0.336	0.050	0.039	1.640
4.64	0.13	0.050	0.020	0.015	0.015
4.66	0.14	0.049	0.020	0.015	0.015

- ▶ Low cost analysis (Spectral <\$10 per sample vs XRD >\$100 per sample)
- ▶ Obtain complete mine picture from a routine laboratory workflow
- ▶ Predict future processing conditions – high value data !!
- ▶ Create a digital mine record.

*Bi-Annual premier iron ore conference – July 2017*

## **Determination of Iron Ore Mineralogy using Fourier Transform Infrared Spectroscopy: a Chemometric Approach.**

J Carter, K Auyong and L Dixon

Fourier Transform Infrared (FTIR) spectroscopy and other NIR tools have been used in the bauxite industry for many years. Infrared spectroscopy exploits the differences in chemical composition and lattice structure to produce a characteristic response. Spectral devices, such as those from ASD Inc. and the Hylogger™, provide qualitative mineralogical data targeted towards hydrated minerals detected in the near and short wave infrared region. The FTIR spectrum extends into the mid and thermal infrared range and can therefore respond to the presence of silicates and oxides, in addition to hydrates and carbonates.

The key to successful utilisation of infrared spectra, however, is the interpretation methodology. In this study, FTIR spectra were calibrated against quantitative x-ray diffraction data for the determination of the mineralogy of iron ore. A full pattern machine learning technique was utilised for the calibration, and the assessment of the regressions determined from an independent validation set. The abundance of key minerals - hematite, goethite, kaolinite and quartz - were determined and the results correlated against X-ray fluorescence assays and loss on ignition data. The results of the study indicate that spectral techniques using a full pattern machine learning approach and artificial neural networks can be used successfully to obtain objective and quantitative mineralogical data to support field observations and analytical results for iron ore resource modelling. A comparison of this technique to the cost, quality and timeliness of other quantitative mineralogy tools is also made.



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***Move Forward with Confidence***