



# Mineralogical Reconciliation of ore sample analyses

*using chemical assays, X-ray diffraction and  
automated mineralogy*

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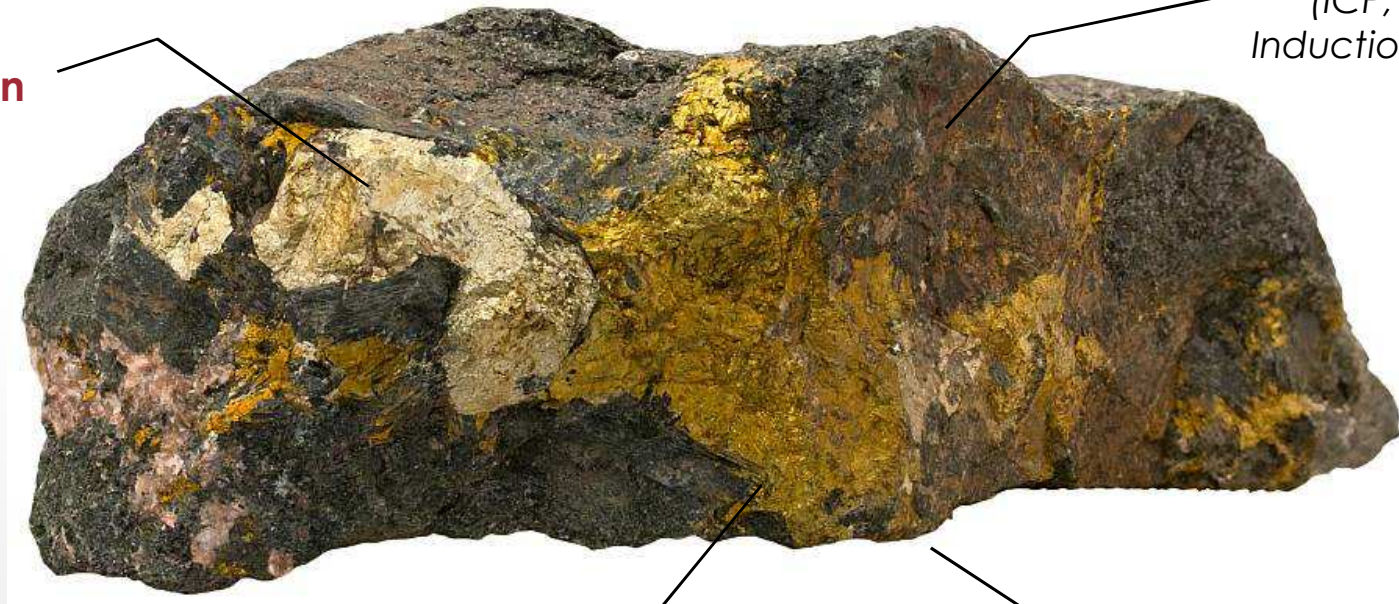
Betelehem SOLOMON, Thomas RIEGLER, Eric PIRARD

# Mineralogical Reconciliation

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- Multiple insights into the same sample

**X-ray Diffraction**



**Chemical Assays**  
(ICP, XRF, ...,  
Induction Furnace)

**Microscopy & Micro-analysis**  
Optical, SEM-based (EDS-EPMA),  
LA-ICP-MS

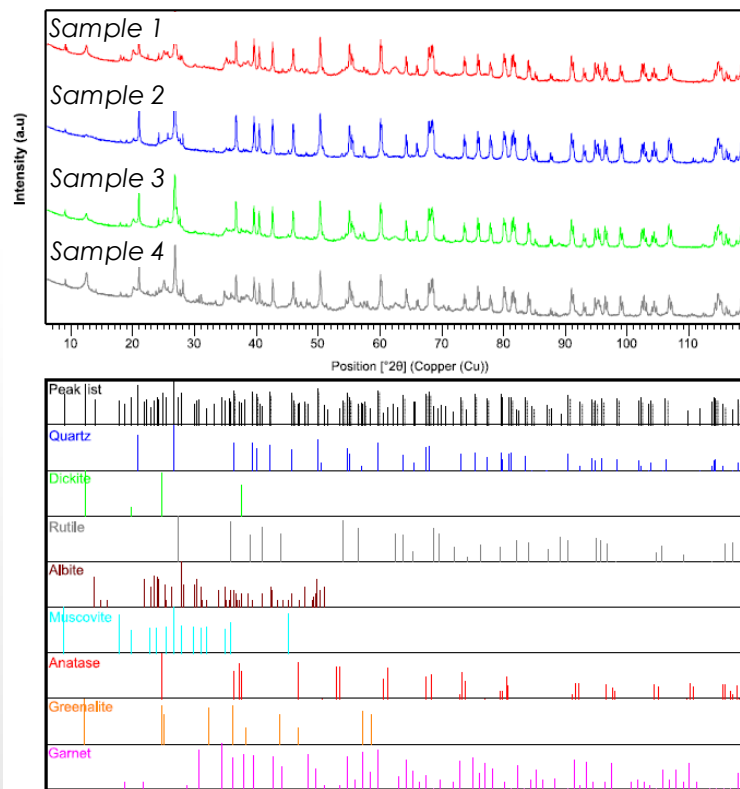
**Automated Mineralogy**  
(SEM-based,  $\mu$ XRF-based, ...)

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# Revealing the problem

# Revealing the problem

- X Ray Diffraction
  - Provides a list of minerals (> 1% W<sub>w</sub>) w/o quantification



Rutile (TiO<sub>2</sub>)

Anatase (TiO<sub>2</sub>)

Albite (NaAlSi<sub>3</sub>O<sub>8</sub>)

Muscovite (KAl<sub>2</sub>(Si<sub>3</sub>Al)O<sub>10</sub>(OH,F)<sub>2</sub>)

Quartz (SiO<sub>2</sub>)

Greenalite (Fe,Fe)<sub>2</sub>-3Si<sub>2</sub>O<sub>5</sub>(OH)<sub>4</sub>

Garnet (X<sub>3</sub>Y<sub>2</sub>(SiO<sub>4</sub>)<sub>3</sub>, X:Mg, Fe, Mn, Ca, Y:Al, Fe, Cr)

Dickite (Al<sub>2</sub>Si<sub>2</sub>O<sub>5</sub>(OH)<sub>4</sub>)

# Revealing the problem

- XRF Bulk Chemistry
  - Provides a complete list of elements with accurate quantification and low detection limits

	Sample 1	Sample 2	Sample 3	Sample 4	
<b>Si</b>	39.8	45.7	42.9	38.2	
<b>Al</b>	3.65	0.41	1.61	4.47	
<b>Fe</b>	0.72	0.16	0.27	1.6	Usually in silicates
<b>K</b>	0.29	0.04	0.12	0.09	
<b>Mg</b>	0.1	0.1	0.1	0.1	Possibly in Albite, Muscovite, Quartz, Greenalite, Garnet, Dickite,...
<b>Na</b>	0.1	0.1	0.1	0.16	
<b>Mn</b>	0.07	0.07	0.07	0.11	
<b>Ca</b>	0.03	0.03	0.03	0.19	
<b>Ti</b>	1.43	0.32	0.79	2.16	Ti-bearing minerals Possibly in Anatase, Rutile,...
<b>Zr</b>	0.08	0.05	0.05	0.06	Zircon (was not identified by XRD)
<b>S</b>	0.011	0.08	0.033	0.059	
<b>P</b>	0.01	0.01	0.01	0.01	
<b>V</b>	0.01	0.01	0.01	0.01	None
<b>Nb</b>	0.1	0.1	0.1	0.1	No mineral containing these elements has been identified by XRD

# Revealing the problem

- Automated Mineralogy
  - Provides a modal analysis of user-identified minerals (SIP)

	Sample1	Sample 2	Sample 3	Sample 4	
Quartz	79.7	95.46	88.07	63.89	
Phyllosilicates	8.83	1.4	7.06	10.68	
Tourmaline	1.19	0.29	0.71	0.78	
Staurolite	0.06	0.04	0.06	0.64	
Epidote	0.25	0.03	0.11	0.07	Minerals related to Si, Al, Fe, K, Mg, Na, Mn and Ca
Garnet	0.09	0.01	0.02	9.97	
Autres porteurs Al	1.33		0.84	0.38	
Other silicates	0.48	0.08	0.21	1.78	
Others	0.72	0.13	0.54	0.46	
Hydroxides Fe-Al	0.02	0.01	0.02	0.06	
Magnetite	0	0	0	0.71	
Rutile	1.42	1.39	1.18	4.84	Minerals related to Ti
Pseudorutile	0.19	0.07	0.06	0.2	
Anatase	0.12	0.04	0.04	0.08	
Ilmenite	0.04	0.02	0.01	0.18	
Zircon	5.29	0.51	0.92	0.52	Mineral related to Zr
Phosphates	0.13	0.05	0.04	0.15	Mineral related to P

No mineral to explain the presence of S?

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# Cross-validation

# Automated Mineralogy vs. XRD

- Detected by both

	QEMscan Modal Mineralogy					
	QEMscan	XRD	Sample 1	Sample 2	Sample 3	Sample 4
Quartz	x	x	79.7	95.46	88.07	63.89
Rutile	x	x	1.42	1.39	1.18	4.84
Garnet	x	x	0.09	0.01	0.02	9.97
Anatase	x	x	0.12	0.04	0.04	0.08

- Only QEMscan

Phyllosilicates	x		8.83	1.4	7.06	10.68
Tourmaline	x		1.19	0.29	0.71	0.78
Zircon	x		5.29	0.51	0.92	0.52
Ilmenite	x		0.04	0.02	0.01	0.18
Staurolite	x		0.06	0.04	0.06	0.64
Phosphates	x		0.13	0.05	0.04	0.15
Pseudorutile	x		0.19	0.07	0.06	0.2
Epidote	x		0.25	0.03	0.11	0.07
Hydroxides Fe-Al	x		0.02	0.01	0.02	0.06
Magnetite	x		0	0	0	0.71
other silicates	x		0.48	0.08	0.21	1.78
Others	x		0.72	0.13	0.54	0.46
Autres porteurs Al	x		1.33		0.84	0.38

- Only XRD

Albite		x
Muscovite		x
Greenalite		x
Dickite		x



# Automated Mineralogy vs. XRF

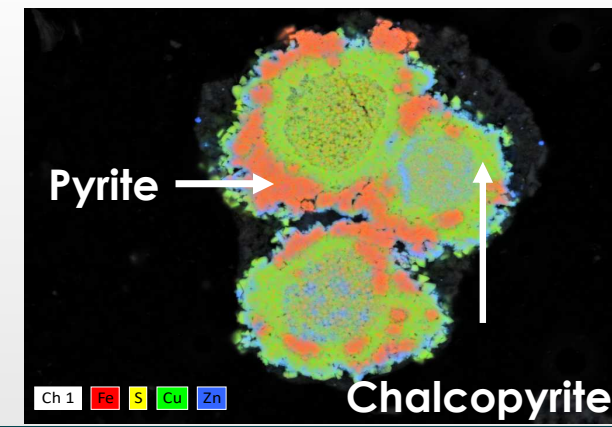
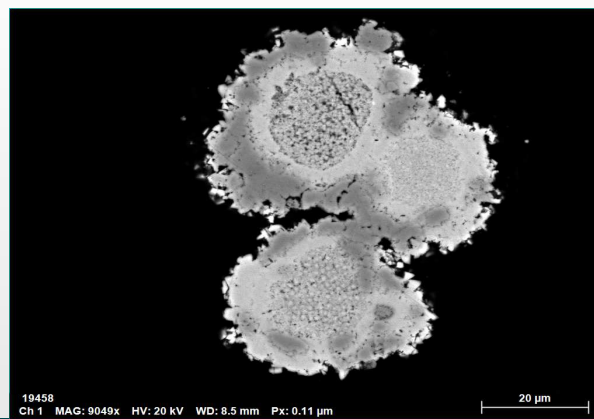
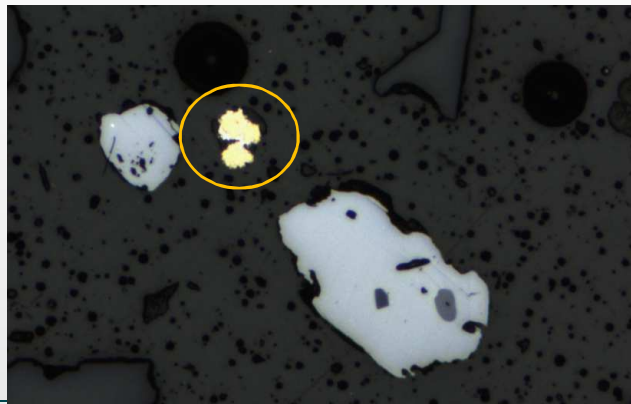
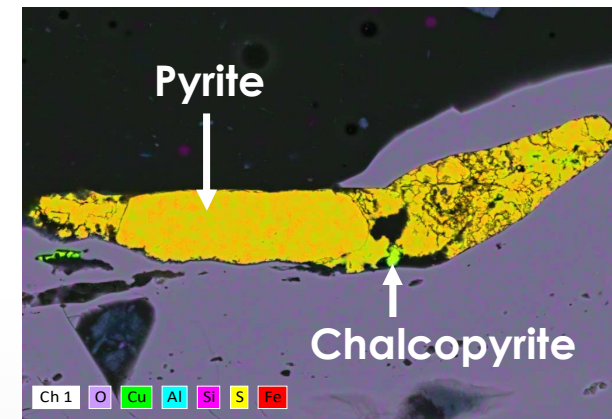
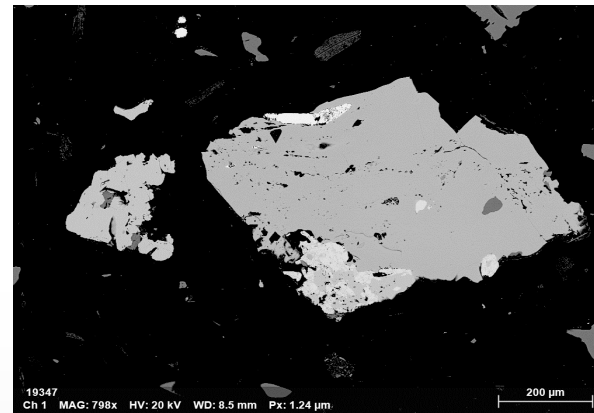
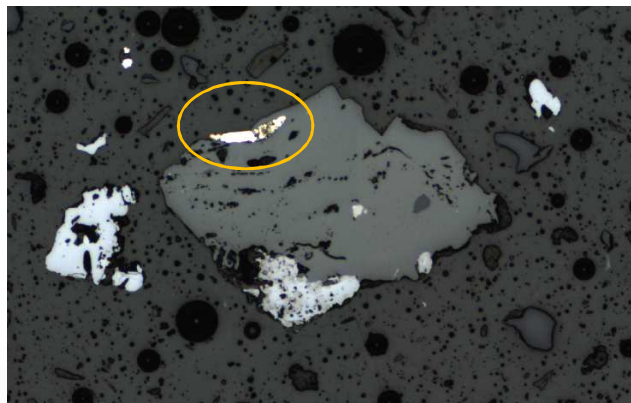
	QEMscan						XRF				
	Qemscan	XRD	S1	S2	S3	S4		S1	S2	S3	S4
Quartz	x	x	79.7	95.46	88.07	63.89	Si	39.8	45.7	42.9	38.2
Garnet	x	x	0.09	0.01	0.02	9.97	Al	3.65	0.4	1.61	4.47
Phyllosilicates	x		8.83	1.4	7.06	10.68	Fe	0.72	0.16	0.27	1.6
other silicates	x		0.48	0.08	0.21	1.78	Mg	0.7	0.1	0.1	0.1
Others	x		0.72	0.13	0.54	0.46	Mn	0.07	0.07	0.07	0.1
Autres porteurs							Ca	0.03	0.03	0.03	0.19
Al	x		1.33		0.84	0.38	V	0.01	0.01	0.01	0.01
Dickite		x									
Tourmaline	x		1.19	0.29	0.71	0.78					
Stauralite	x		0.06	0.04	0.06	0.64					
Pseudorutile	x		0.19	0.07	0.06	0.2					
Epidote	x		0.25	0.03	0.1	0.07					
Hydroxides Fe-Al	x		0.02	0.01	0.02	0.06					
Magnetite	x		0	0	0	0.71					
Greenalite		x									
Rutile	x	x	1.42	1.39	1.18	4.84	Ti	1.43	0.32	0.79	2.16
Anatase	x	x	0.12	0.04	0.04	0.08					
Ilmenite	x		0.04	0.02	0.01	0.18					
Zircon	x		5.29	0.51	0.92	0.52	Zr	0.08	0.05	0.05	0.06
Phosphates	x		0.13	0.05	0.04	0.15	P	0.01	0.01	0.01	0.01
Albite		x					Na	0.1	0.1	0.1	0.16
Muscovite		x					K	0.29	0.04	0.12	0.09
							S	0.011	0.08	0.033	0.059

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# Exploration & Reconciliation

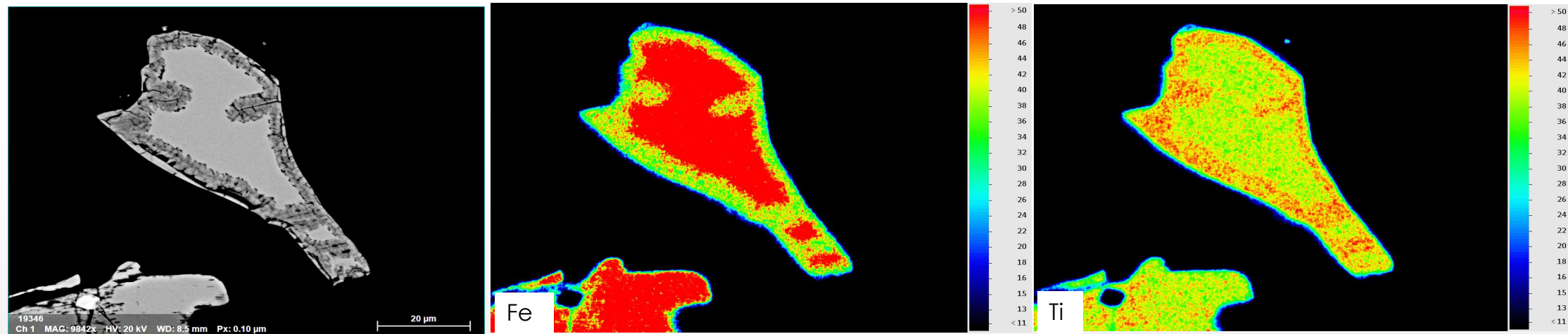
# Exploration & Reconciliation

- Making use of microscopy (OM – BSE – EDX Maps)



# Exploration & Reconciliation

- Making use of microscopy (OM – BSE – EDX Maps)



Ti content in ilmenite is reduced by 10%

# Exploration & Reconciliation

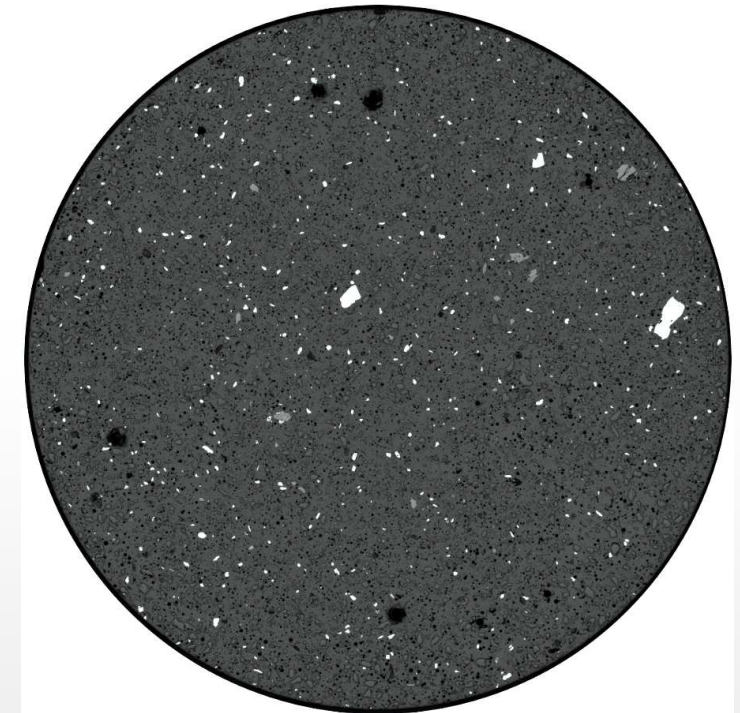
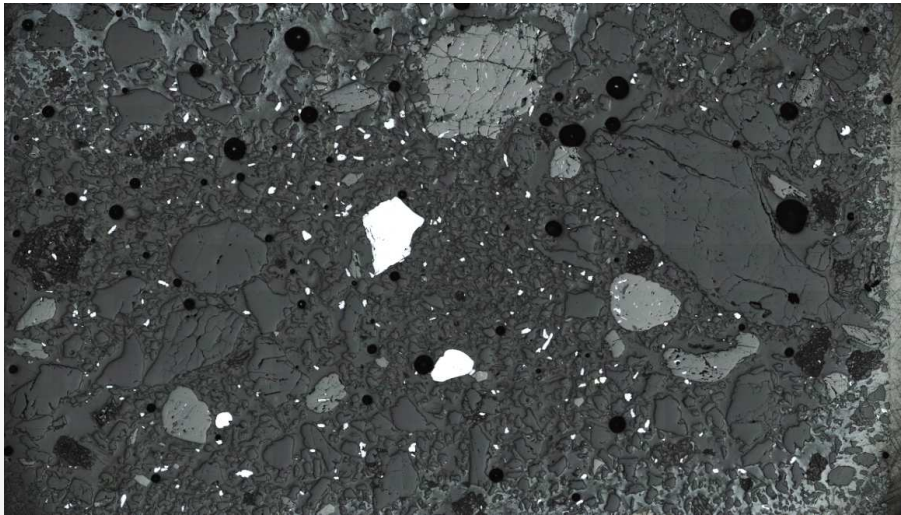
- Comparing QEMScan / Zeiss Mineralogic
  - 5000 to 15000 particles with Zeiss Mineralogic!

Qemscan				
	S1	S2	S3	S4
Quartz	79.7	95.46	88.07	63.89
Rutile	1.42	1.39	1.18	4.84
Zircon	5.29	0.51	0.92	0.52
Staurolite	0.06	0.04	0.06	0.64
Epidote	0.25	0.03	0.11	0.07
Ilmenite	0.04	0.02	0.01	0.18
Garnet	0.09	0.01	0.02	9.97
Other silicates	0.48	0.08	0.21	1.78
Phyllosilicates	8.83	1.4	7.06	10.68
Tourmaline	1.19	0.29	0.71	0.78
Others	0.72	0.13	0.54	0.46
Pseudorutile	0.19	0.07	0.06	0.2
Phosphates	0.13	0.05	0.04	0.15
Anatase	0.12	0.04	0.04	0.08
Hydroxides Fe-Al	0.02	0.01	0.02	0.06
Magnetite	0	0	0	0.71
Others with Al	1.33		0.84	0.38

Mineralogic				
	S1	S2	S3	S4
Quartz	78.56	95.71	87.83	63.33
Rutile	2.26	2.40	4.22	11.91
Zircon	0.14	0.03	0.22	0.37
Fe-Kaolinite (Staurolite)	12.06	0.59	3.51	2.03
Epidote	0.001		0.004	0.04
Ilmenite	0.09	0.03	0.07	0.69
Pyrope / Almandine	0.37	0.003	0.02	3.53
Aulres silicates	1.95	0.22	0.58	0.60
Kaolinite / Dickite	2.97	0.43	1.77	4.39
Kyanite	0.35	0.24	0.62	10.02
Fe-Rutile	0.18	0.06	0.18	0.12
Al-Ilmenite	0.24	0.07	0.19	0.36
Sphene	0.0004	0.0003		0.0007
Albite	0.01	0.00	0.05	1.80
Muscovite / Orthoclase	0.78	0.22	0.74	0.67
Al-Oxyde	0.005	0.0008	0.002	0.0003
Fe-Oxyde	0.01		0.0007	0.0036
Pyrite			0.001	0.09
Chalcopyrite				0.010
Chalcocite				0.0004
Monazite	0.002			0.03

# Exploration & Reconciliation

- Comparing Sample Preparation for Automated Mineralogy
  - Transversal section vs. carbon black randomized suspension
    - Same scale!



*Randomized sections (no very large),  
more abundant fine rutile in sections*

# Exploration & Reconciliation

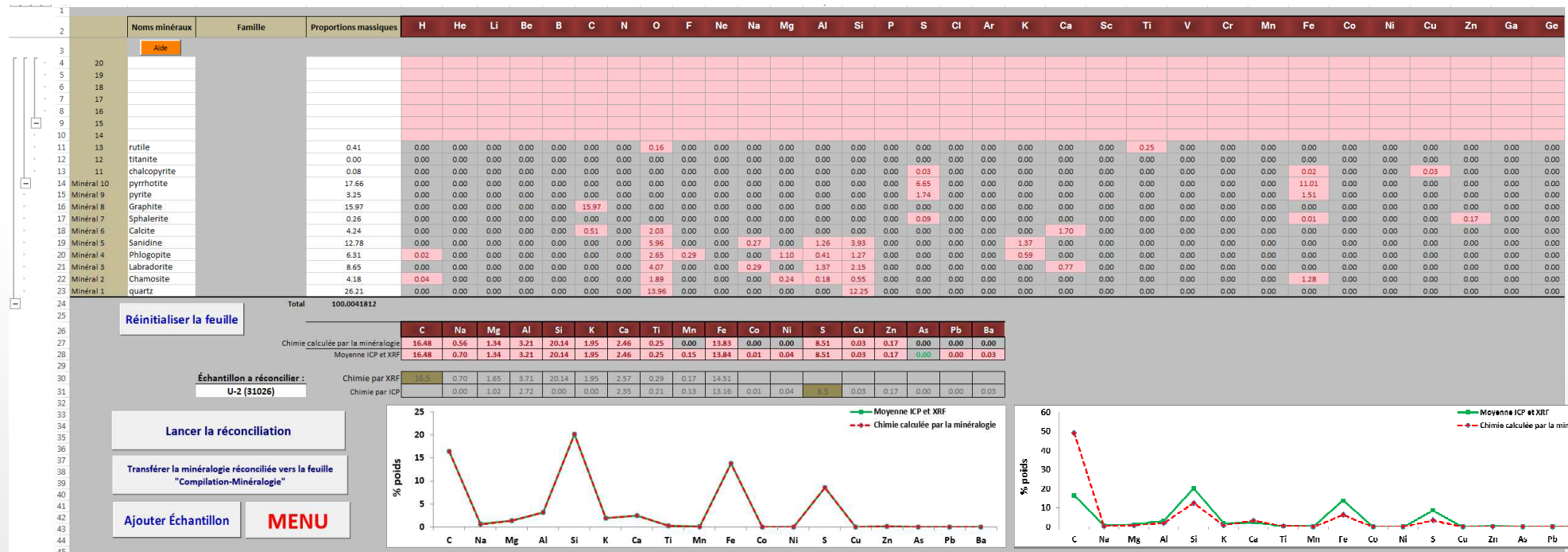
- Comparing XRF/ Mineralogic

	Mineralogic				XRF				
	S1	S2	S3	S4	S1	S2	S3	S4	
Quartz	78.56	95.71	87.83	63.33	Si	37.1	45.3	42.7	37.6
Pyrope / Almandine	0.37	0.003	0.22	3.53	Al	8.01	1.16	3.41	7.4
Cyanite	0.35	0.24	0.62	1.02	Fe	0.999	0.0962	0.265	1.28
Other silicates	1.95	0.22	0.58	0.60	Mg	0.144	0.0204	0.0794	0.0692
Kaolinite / Dickite	2.97	0.43	1.77	4.39	Mn	0.0053		0.00397	0.0831
Fe-Kaolinite (Staurolite)	12.08	0.59	3.5	2.03	Ca	0.0196	0.015	0.0851	0.191
Epidote	0.001		0.004	0.04	V	0.01	0.01	0.01	0.01
Sphene	0.0004	0.0003		0.0007					
Al-Oxide	0.005	0.0008	0.002	0.0003					
Fe-Oxide	0.0		0.0007	0.0036					
Rutile	2.26	2.40	4.22	1.91	Ti	1.53	0.336	0.543	1.49
Fe-Rutile	0.18	0.06	0.18	0.12					
Ilmenite	0.09	0.03	0.07	0.69					
Al-Hmenite	0.21	0.07	0.19	0.36					
Zircon	0.14	0.03	0.22	0.37	Zr	0.07	0.01	0.02	0.05
Albite	0.01	0.00	0.05	1.80	Na	0.199	0.0316	0.0592	0.137
Muscovite / Orthoclase	0.78	0.22	0.74	0.67	K	0.619	0.0962	0.258	0.141
Pyrite			0.001	0.09	S	0.0241	0.014	0.0869	0.0706
Chalcopyrite				0.010	Cu	0.00235	0.00232	0.00376	0.00648
Chalcoite				0.0004					
Zn in Cpy					Zn	0.0033	0.00183	0.00331	0.0104
Monazite	0.002			0.03	Ce				0.0116



# Exploration & Reconciliation

- Using XLS Solver
  - Iterative fitting of Modal Mineralogy to XRF





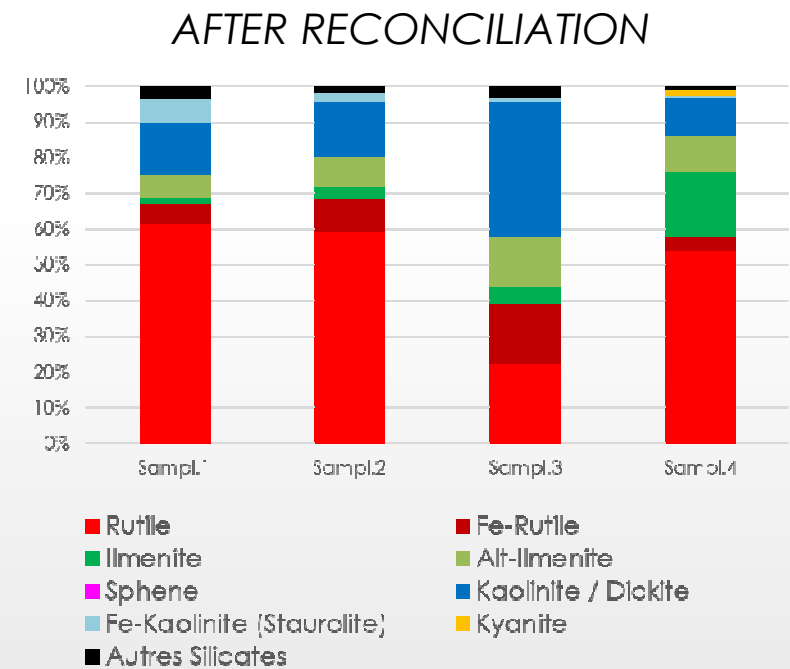
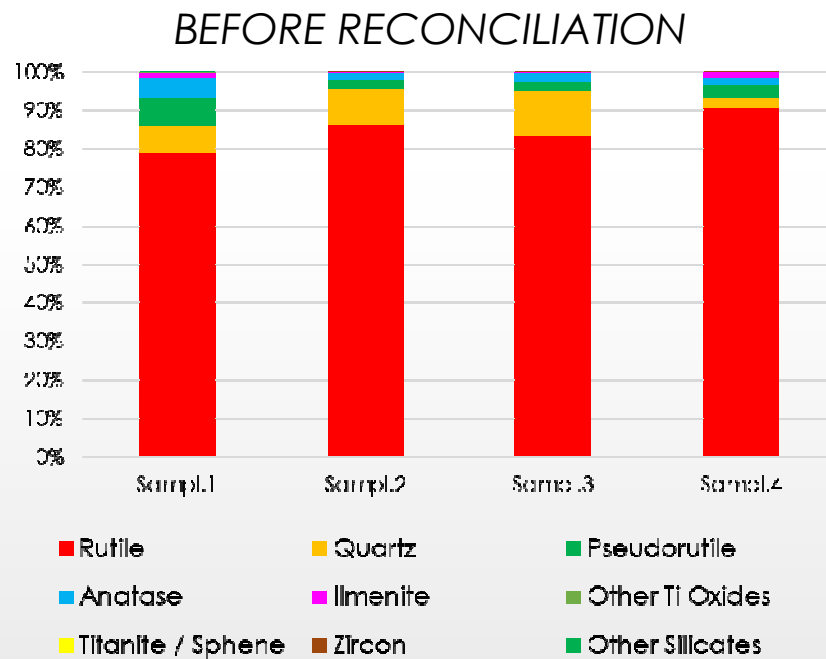
# Exploration & Reconciliation

- Corrected Modal Mineralogy

	S1	S2	S3	S4
Quartz	61.25	94.31	84.41	65.60
Pyrope / Almandine	0.37	0.003	0.02	3.58
Kyanite	0.35	0.24	0.62	15.94
Other silicates	1.95	0.22	0.58	0.60
Kaolinite / Dickite	10.86	2.36	9.51	7.33
Fe-Kaolinite (Staurolite)	14.09	0.98	0.61	1.10
Epidote	0.00			
Sphene	0.0004	0.0003		0.0007
Al-Oxyde	0.005	0.0008	0.002	0.0003
Fe-Oxyde	0.0		0.0007	0.004
Rutile	1.56	0.31	0.19	1.25
Fe-Rutile	0.18	0.06	0.18	0.12
Ilmenite	0.09	0.03	0.07	0.70
Alt-Ilmenite	0.24	0.07	0.18	0.36
Zircon	0.17	0.03	0.05	0.11
Albite	2.40	0.38	0.71	1.65
Muscovite / Orthoclase	6.3	0.98	2.63	1.44
Pyrite	0.04	0.02	0.16	0.12
Chalcopyrite	0.0	0.01	0.01	0.02
Chalcocite				0.00
Monazite	0.13	0.02	0.07	0.12

# Exploration & Reconciliation

- Corrected Modal Mineralogy
  - Impact on Ti Department



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# Conclusions

# Conclusions

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- Sample Preparation
- Reconciliation
- Do more without AM
- Closely supervise your Automated Mineralogy

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Thank You!