FREEPORT-MCMORAN COPPER & GOLD

Quantitative Rietveld XRD Mineralogy of Copper and Molybdenum Ore Products

Doug Allen

April 24, 2012

FREEPORT-MCMORAN COPPER & GOLD

Safety Share – Watch the Ground – Even in the Parking Lot

Our Targets
Reduce Cost, Minimize Risk, Optimize Metallurgy

- **Profitable Cu Recovery**
- **Longevity of Lower Grade Resources**
- **Getting Maximum Value & Mine Life Out of Existing Resources & Core Assets.**

Mineralogy – The Driver for Ore Control & Processing

Concentrators

Comminution
Ore Hardness
Liberation/Locking
Reagent Use/Consumption
Selectivity
Middlings
Thickener Problems
Optimal Recovery
Slimes Generation

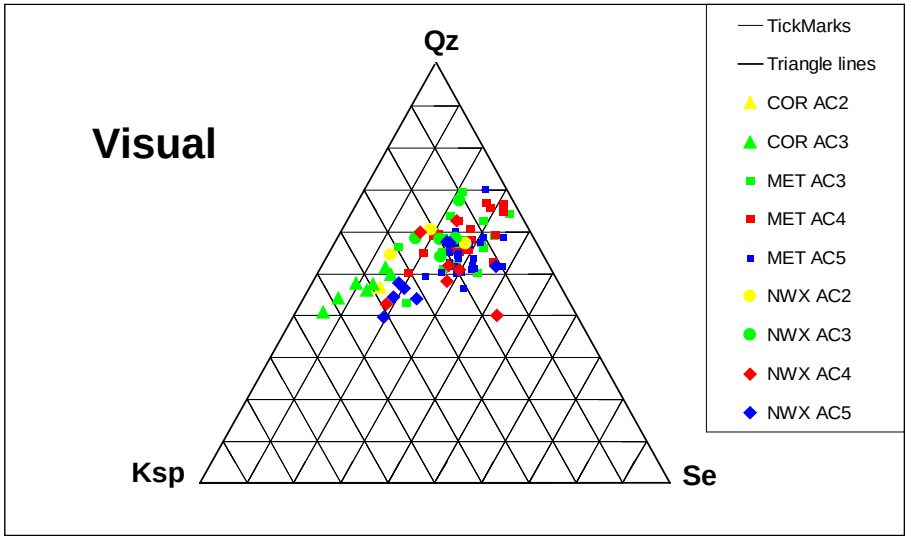
Heap/Stockpile Leaching

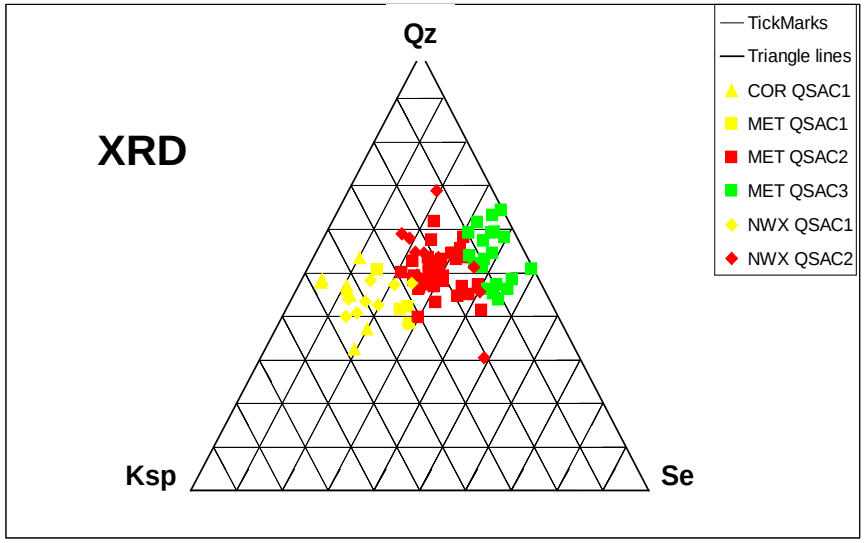
Crushing Response
Throughput
Agglomerate Quality
Moisture Addition
Liquid & Air Permeability
Cu Extraction
Salt Precipitation
Pyrite Content
PLS Impurities
Acid Consumption

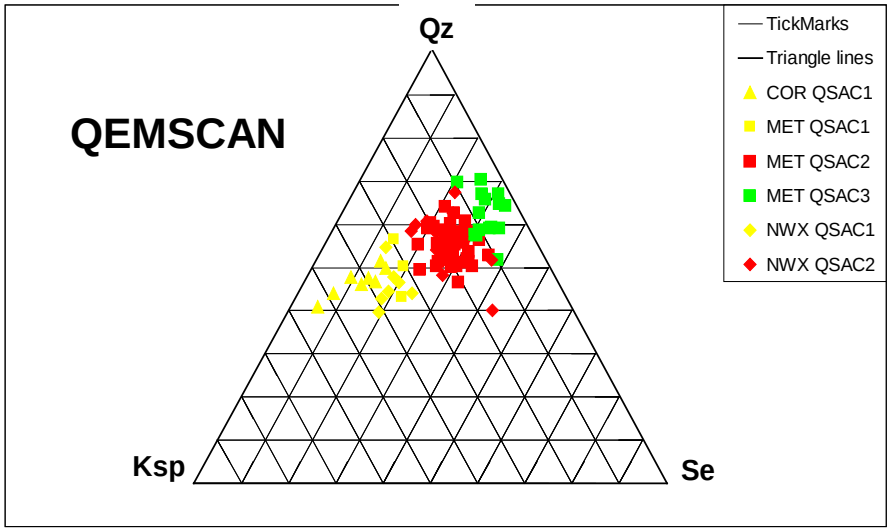
Mineralogical Parameters Affect All Of The Process Parameters

Ore Control & Process Optimization Require New Tools

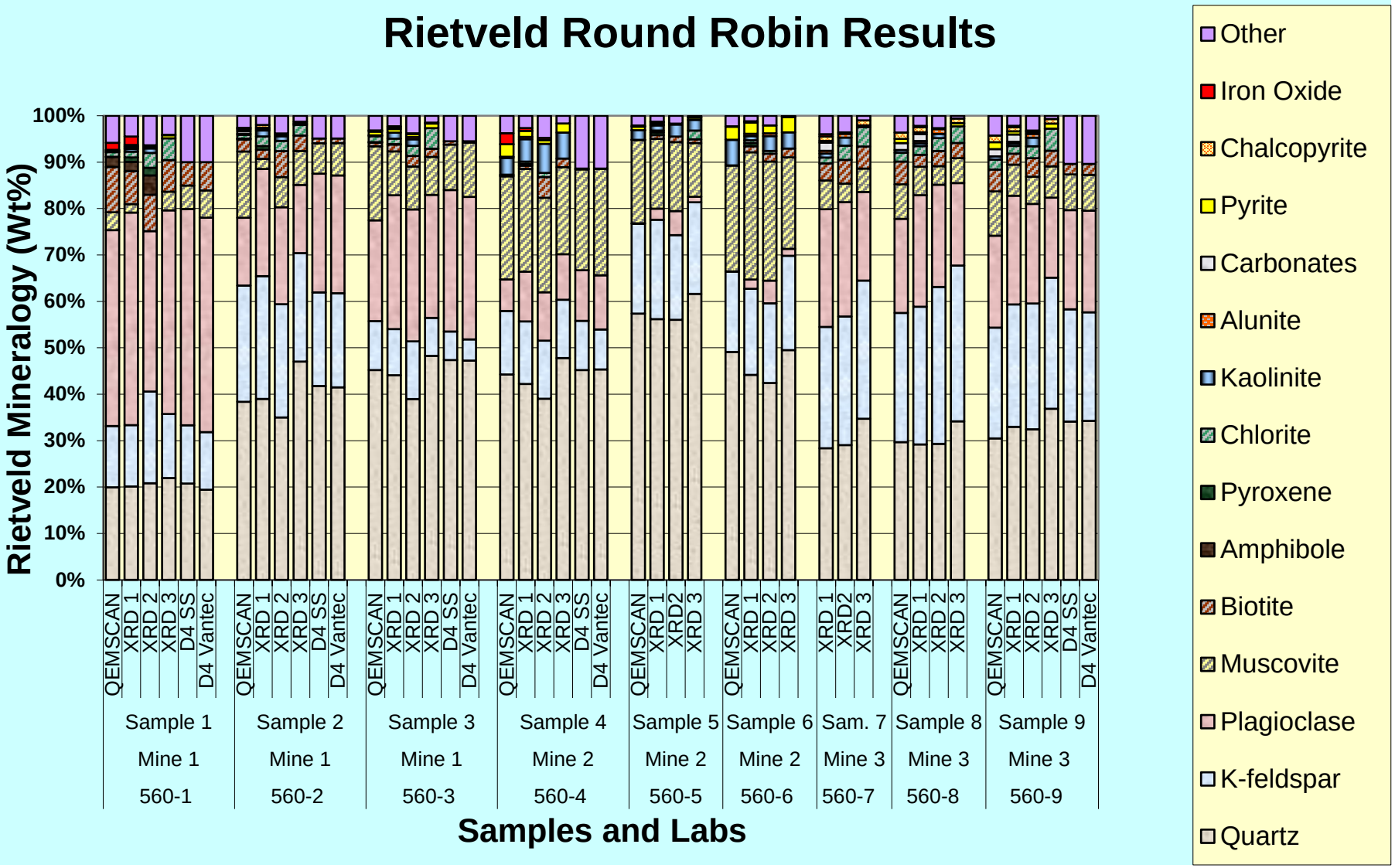
Ore Type Coding Comparison







Graphical Presentation of Data



FREEPORT-MCMORAN COPPER & GOLD

Freeport-McMoRan Technology Center XRD History

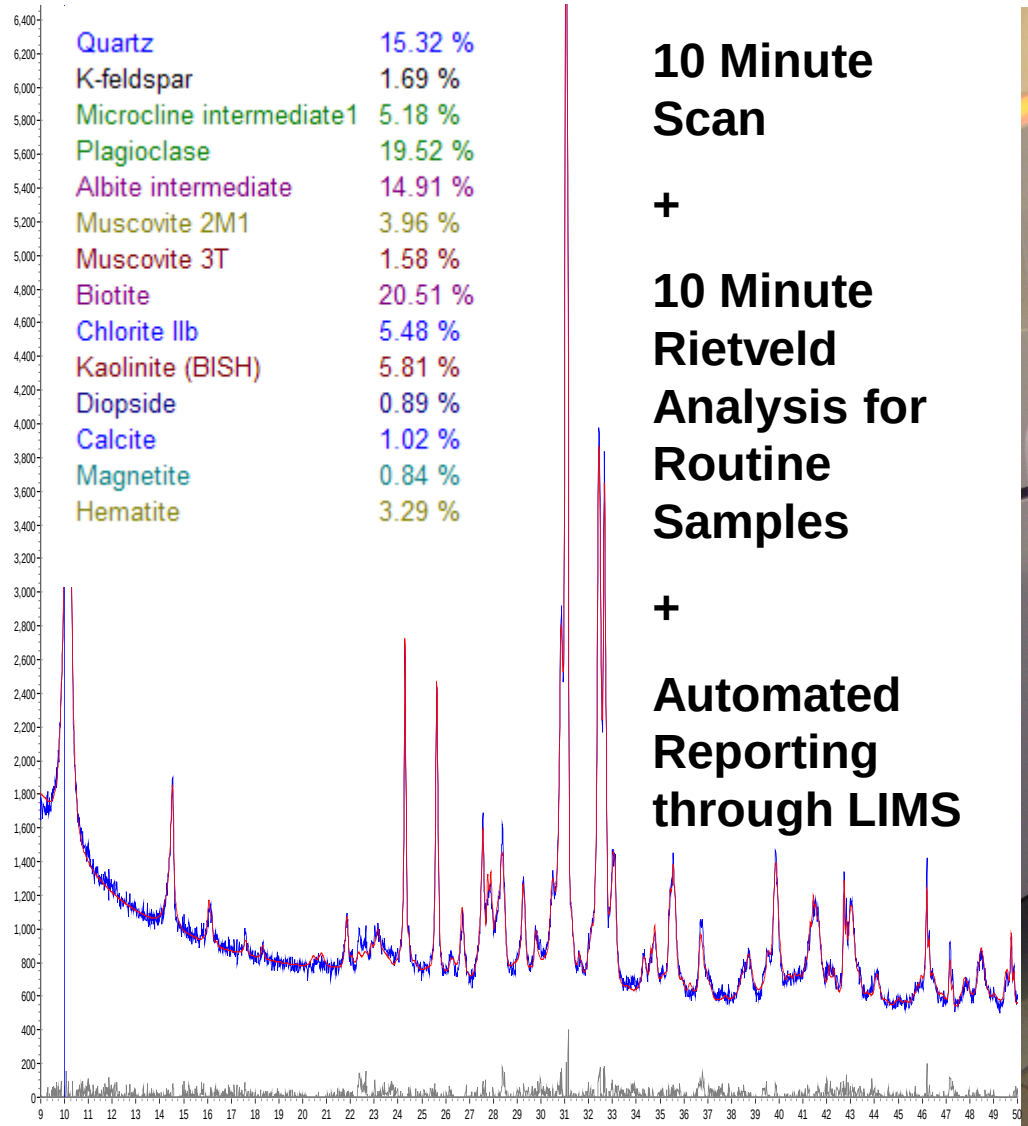
Year	Developments	Instru-ments	Miner-alogist	Tech-nician	XRD /Yr	NIR /Yr
2000	Occasional XRD by microscopists. Old orphaned Philips	1	0.2	0	~100	
2002	Rietveld by contract for NIR models. 1st Bruker D4	1	1	0	~100	
2003	Began in-house support of NIR Models	1	1	1	~1K	
2004	Began micronizing	1	1	2	~2K	
2005	Changed to Co Radiation. Phased out contract lab.	2	2	3	~3K	
2006	Earliest in-house automated Rietveld	2	2		~4K	
2007	Design of Automated AXN Lab	4	2		7K	
2008	Construction of AXN Lab	4	2	5	14K	
2009	Began AXN Operations	7	5	9	17K	100K
2010	Automated import of Resultls to Excel or LIMS	7	6	9	24K	110K
2011	Fully implemented automated Rietveld.	7	7.5	12	28K	168K
2012	Implemented chemistry reconciliation macro	7	7	13	36K	185K

XRD-NIR Design Capacity

- 500 Samples/Day + 50 QC Samples – XRD
- 700 Samples/Day + 50 QC Samples – NIR
- Turnaround 24-36 Hours
- 24 hour/day operation
- Automatic Transfer of Blast Hole Splits From Central Analytical Services Center (CASC)

FREEPORT-MCMORAN COPPER & GOLD

XRD Analysis



10 Minute Scan

+

10 Minute Rietveld Analysis for Routine Samples

+

Automated Reporting through LIMS

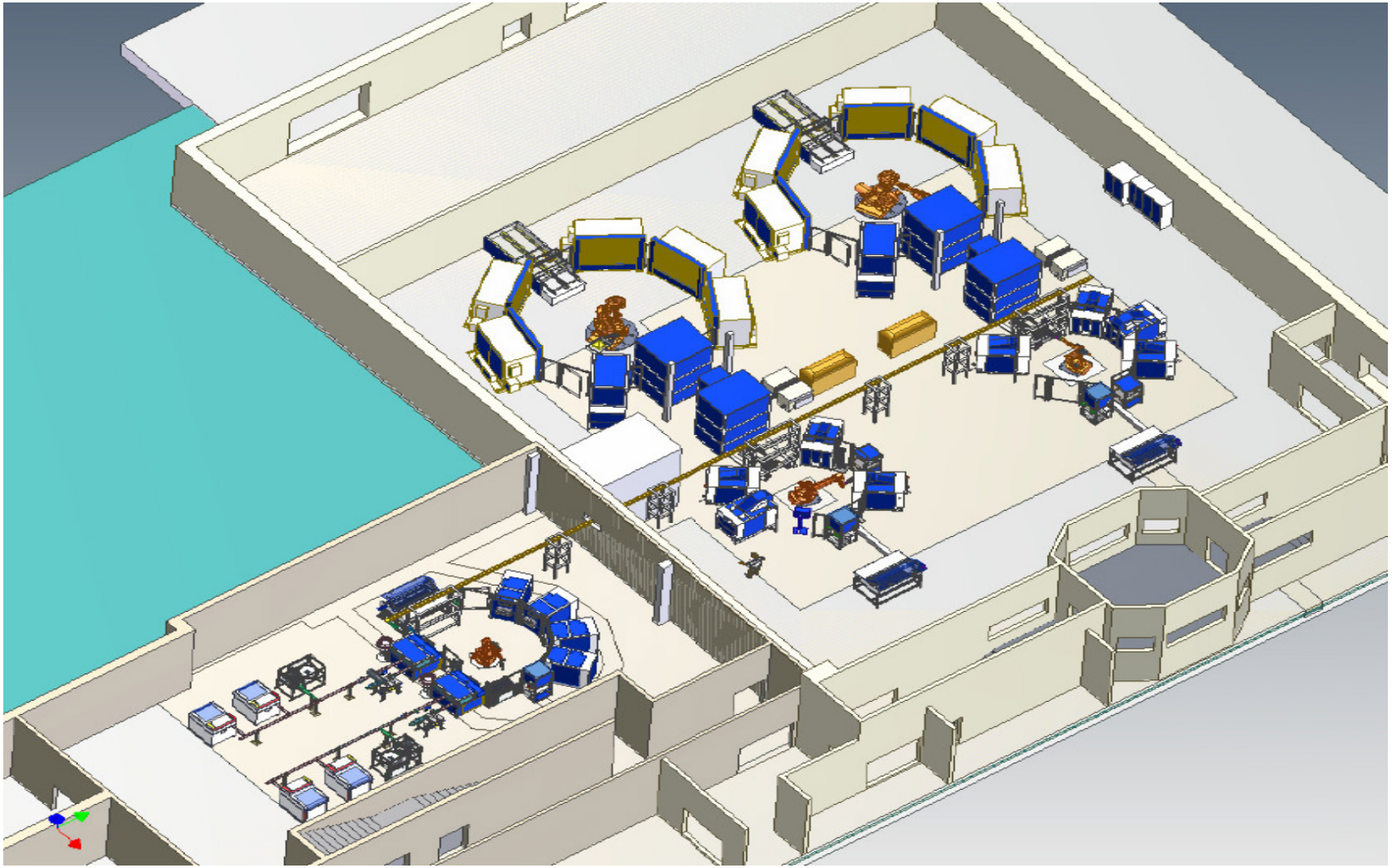
Near Infrared (NIR) at AXN Lab

- High Performance
- Extremely Fast Scanning Time 30 seconds
- Very User Friendly
- Analyzes for Clay and Alteration Minerals
- Excellent tool for Resource Control
- **Calibration Model Must be Constructed for Each Ore Body – 300 to 500 XRD Refinements**
- Non-destructive Testing
- NIR eliminates the need for the hazardous reagents and time consuming analysis

FREEPORT-MCMORAN COPPER & GOLD

Auto XRD-NIR (AXN) Lab Safford

High Throughput-Low Cost Mineralogical Ore Profiling



Auto XRD-NIR Lab Safford

High Throughput-Low Cost Mineralogical Ore Profiling

Modern "Bucking" Room

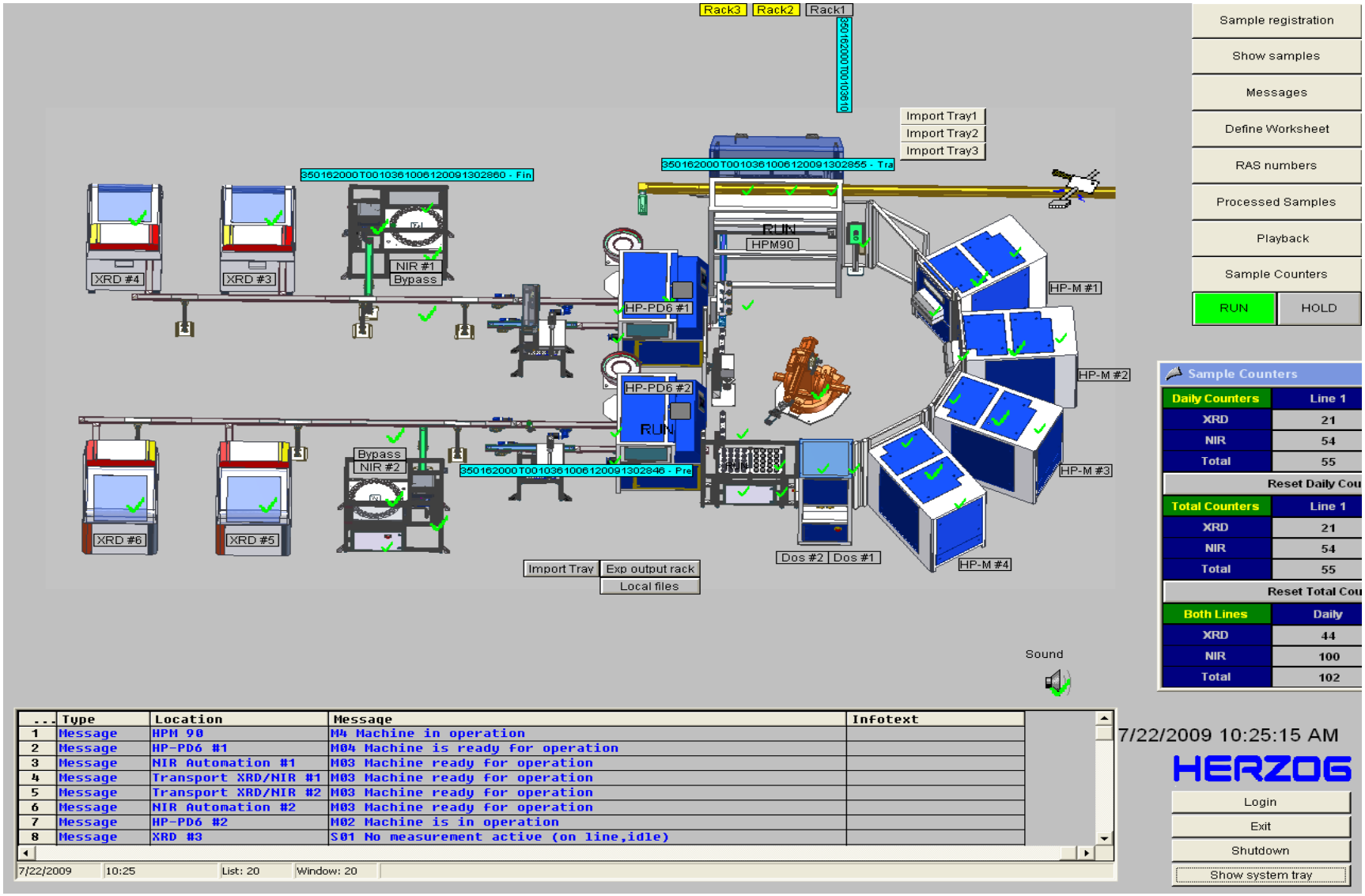
Automatic XRD and NIR Data Capture

FREEPORT-MCMORAN COPPER & GOLD

XRD-NIR Instrument Room

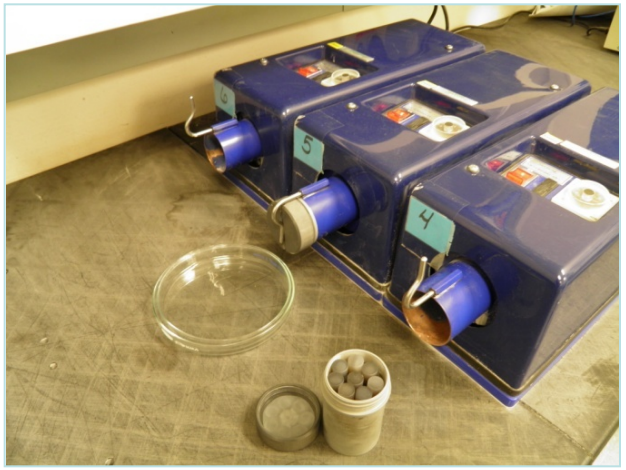
FREEPORT-McMoRan COPPER & GOLD

Prepmaster Control Software



FREEPORT-MCMORAN COPPER & GOLD

Micronizing Lab – Not Automated

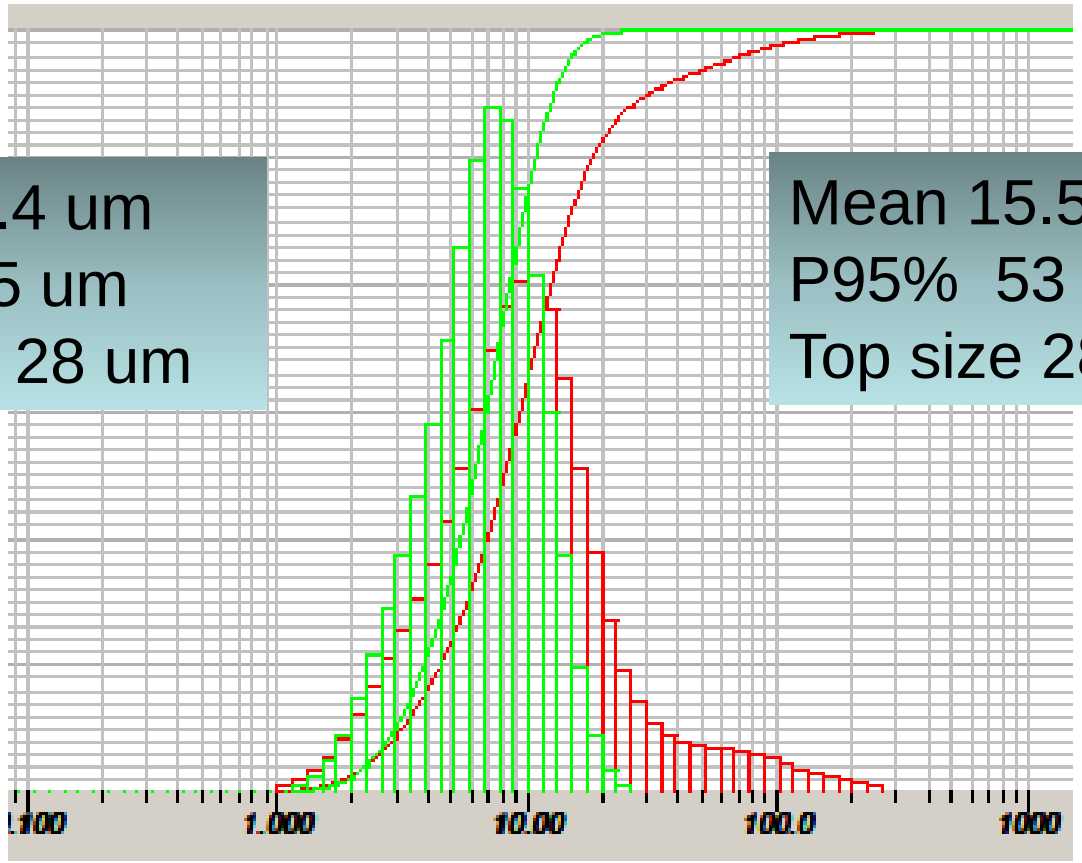


Typical Particle Size

Wet Micronize vs Auto Dry Grind

Mean 7.4 um
P95% 15 um
Top size 28 um

Mean 15.5 um
P95% 53 um
Top size 280 um



Diameter um

Press Requirements

Developing an automated press designed for XRD (not XRF) was the key to the automated circuit.

Back-Loading Against Frosted Surface

No Binder

Low Pressure

Minimize Preferred Orientation

Press Development

Manual Prototype

Herzog Automation

AXN QA/QC Overview

- NIST Corundum standard analyzed daily on each XRD
  - EVA peak position and area plotted on control chart
- Mylar Standard analyzed daily on NIR
- AXN Ore Standard (Granite) analyzed daily on each XRD
  - Synthetic standard being developed for XRD
  - Topas Rietveld refinement results for charting
- Site Specific Ore Standards analyzed daily on NIR
- Minimum of 5 % of samples are duplicated
- Blank (Glass) samples prepared daily to check for contamination
- Pulverizing mills checked daily to ensure proper particle size is produced

FREEPORT-MCMORAN COPPER & GOLD

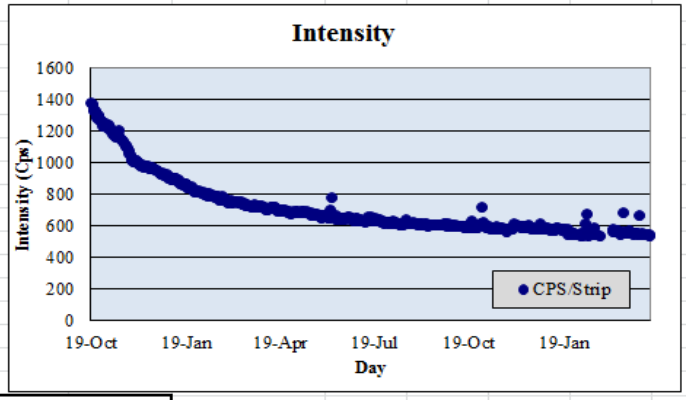
NIST 1976 Mounted in Bruker Ring
XRD # 4 Oct 2011 to Apr 2013

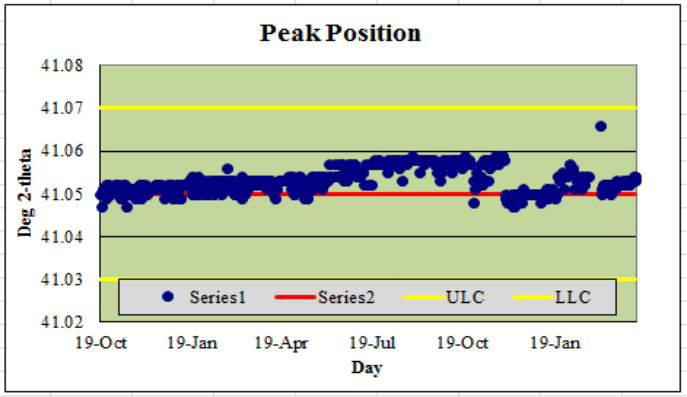
XRD 4 Control Charts

Tube installed:	10/18/2011
Nominal net height:	1058
Intensity average this week:	549
Tube strength(percent of initial):	51.85%
Average peak position this week:	41.053
End of Week PM counter:	7849

Comments:

No Data 4/6, 7





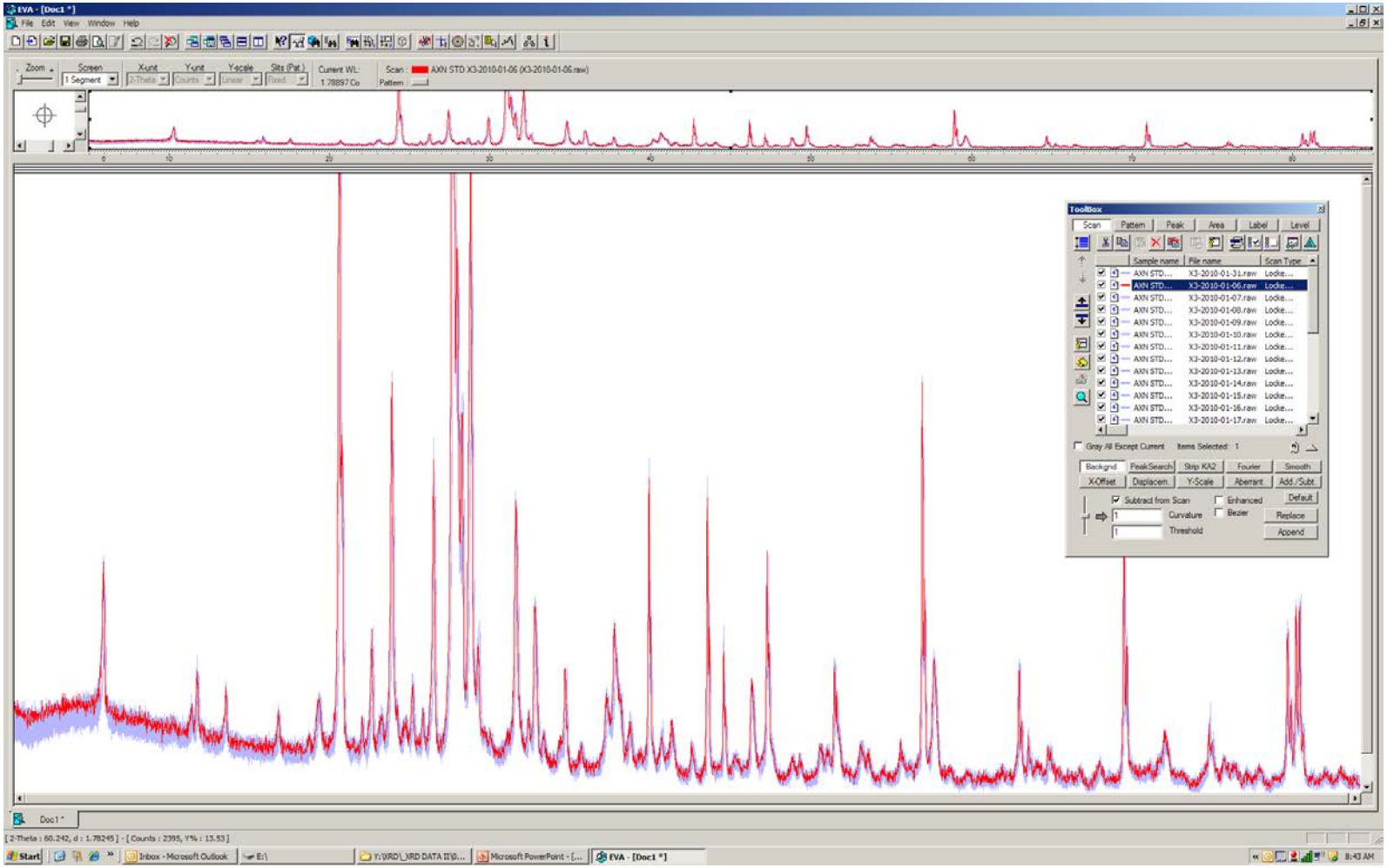
		NIST 1976					
	Creation Date/Time	Obs. Max (peak position	Net Height (intensit	FWHM (peak wid	Targeted Peak Position	ULC	LLC
515	3/20/2013 5:58	41.052	564	0.064	41.05	41.07	41.03
516	3/21/2013 5:55	41.051	567	0.064	41.05	41.07	41.03
517	3/22/2013 6:00	41.052	574	0.064	41.05	41.07	41.03
518	3/23/2013 5:38	41.053	567	0.063	41.05	41.07	41.03
519	3/24/2013 5:54	41.052	557	0.064	41.05	41.07	41.03
520	3/25/2013 5:50	41.052	560	0.064	41.05	41.07	41.03
521	3/26/2013 6:02	41.052	550	0.066	41.05	41.07	41.03
522	3/27/2013 6:17	41.052	561	0.065	41.05	41.07	41.03
523	3/28/2013 5:58	41.052	557	0.065	41.05	41.07	41.03
524	3/29/2013 6:25	41.053	557	0.064	41.05	41.07	41.03
525	3/30/2013 5:59	41.052	557	0.065	41.05	41.07	41.03
526	3/31/2013 5:57	41.052	555	0.064	41.05	41.07	41.03
527	4/1/2013 8:36	41.053	669	0.065	41.05	41.07	41.03
528	4/2/2013 5:47	41.053	554	0.066	41.05	41.07	41.03
529	4/3/2013 5:47	41.053	557	0.064	41.05	41.07	41.03
530	4/4/2013 5:48	41.053	549	0.066	41.05	41.07	41.03
531	4/5/2013 6:16	41.052	555	0.064	41.05	41.07	41.03
532	4/8/2013 13:10	41.053	550	0.065	41.05	41.07	41.03
533	4/9/2013 6:03	41.054	550	0.065	41.05	41.07	41.03
534	4/10/2013 5:48	41.054	547	0.065	41.05	41.07	41.03
535	4/11/2013 6:42	41.053	542	0.065	41.05	41.07	41.03

XRD 1 | XRD 2 | XRD 3 | XRD 4 | XRD 5 | XRD 6 | XRD 7

Ready 100%

FREEPORT-MCMORAN COPPER & GOLD

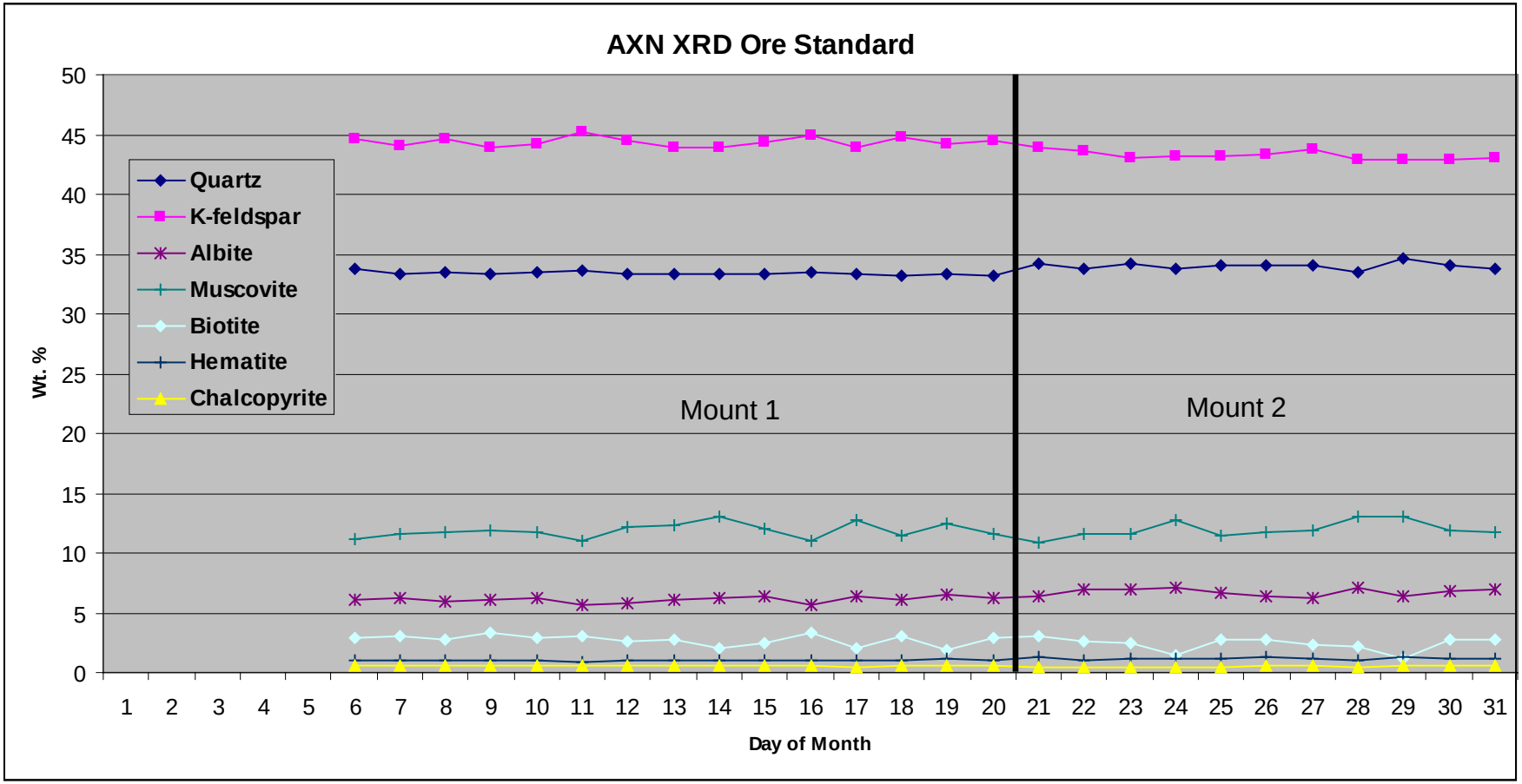
AXN XRD Granite Ore Standard XRD # 3 – January 2010



Sample analyzed daily on each XRD

FREEPORT-MCMORAN COPPER & GOLD

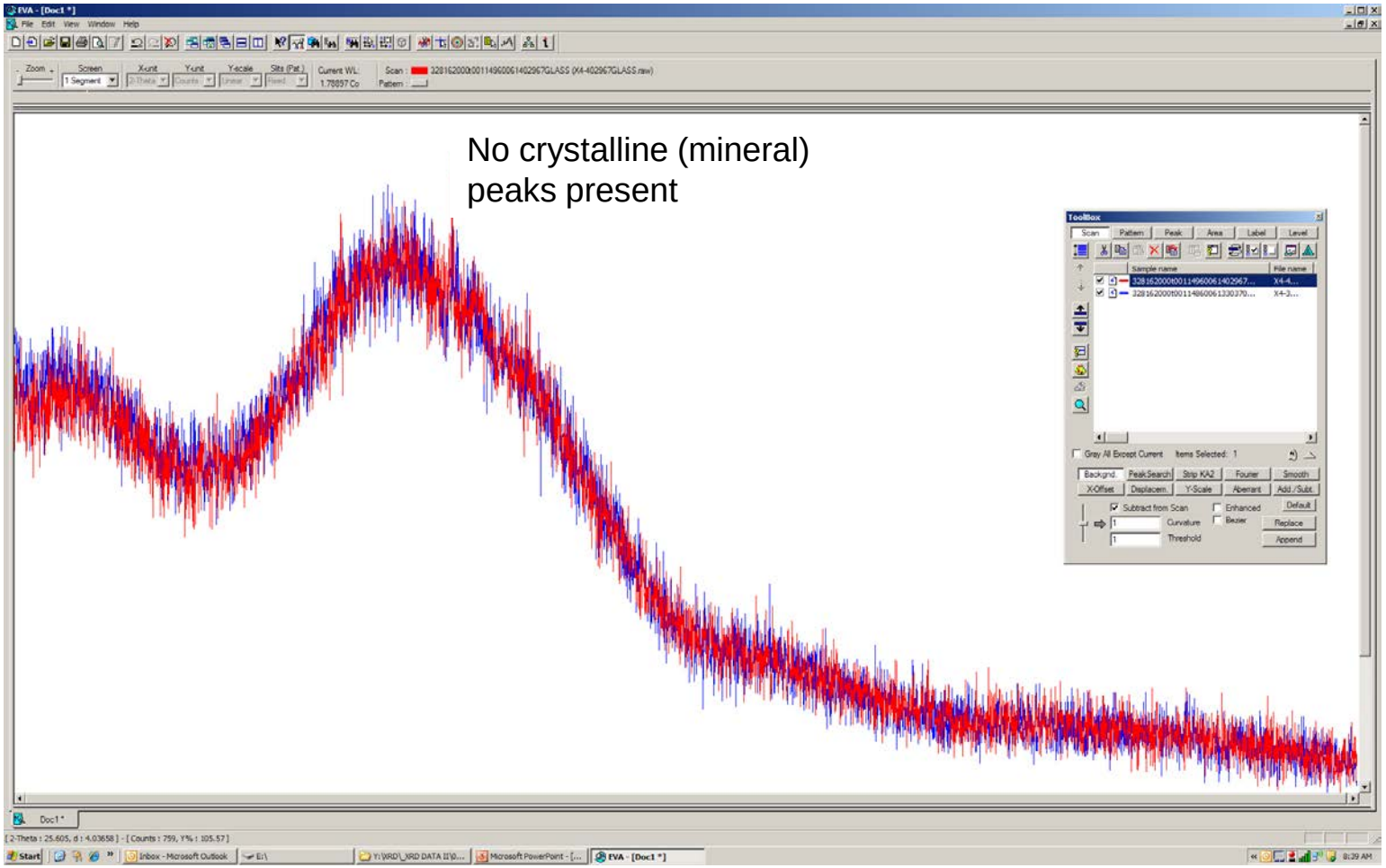
AXN XRD Ore Standard
XRD # 3 – January 2010



- Sample scanned every day on each individual XRD machines
- Mount replaced approximately every two weeks

FREEPORT-MCMORAN COPPER & GOLD

AXN Glass Sample



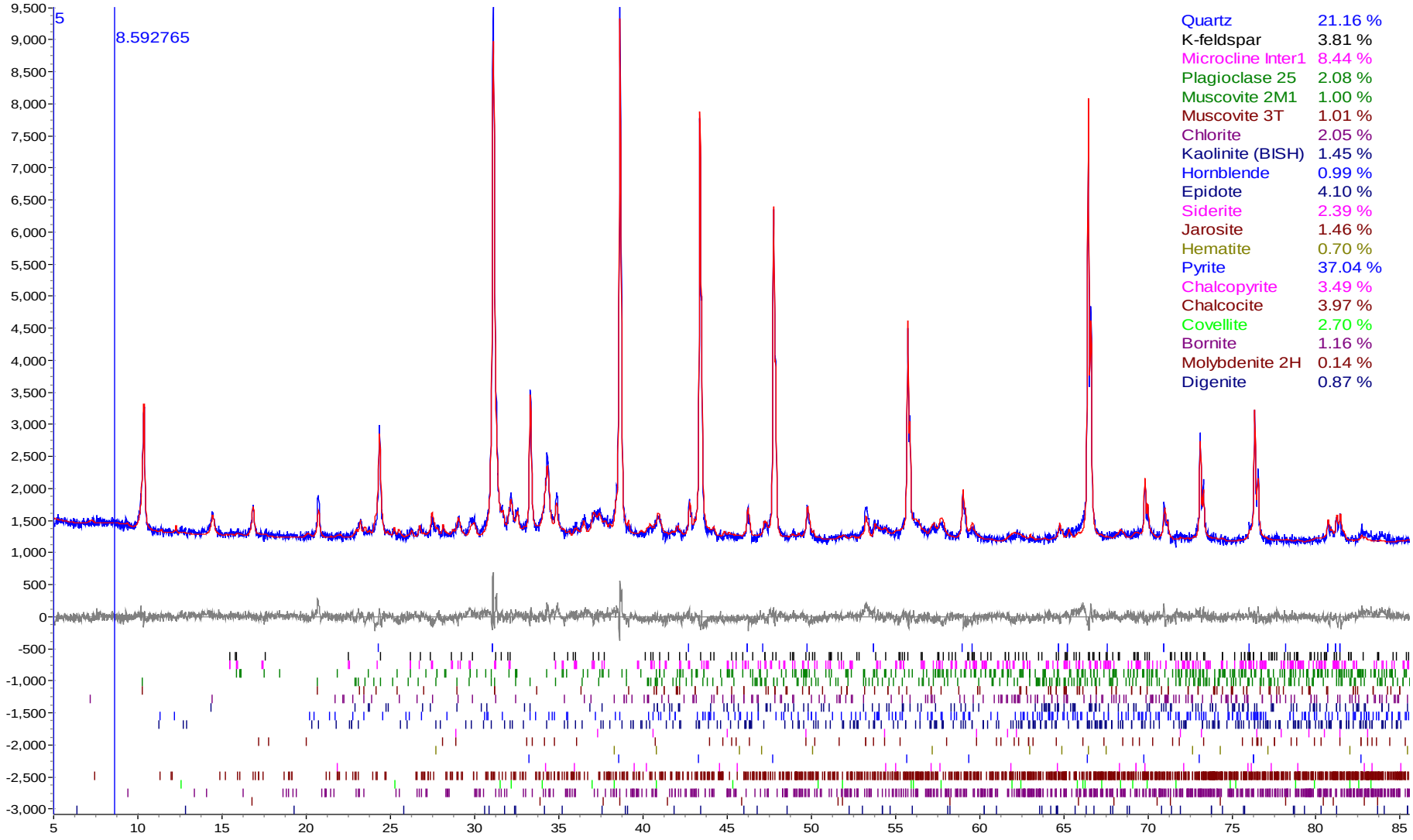
Scanned daily to check for contamination from the XRD mills

Bulk of Freeport-McMoRan XRD

- Most Freeport-McMoRan samples are not complete unknowns.
  - Blasthole Samples.
  - Mill Feeds, Concentrates, Tailings.
  - Exploration Drill Core or Cuttings.
  - Leach Pile Feed & Residue Samples.
- We have a good idea of the minerals that are present in each project.
- Most large projects have very similar samples with variations in Wt%.
- Some sample types, however, are very complex.

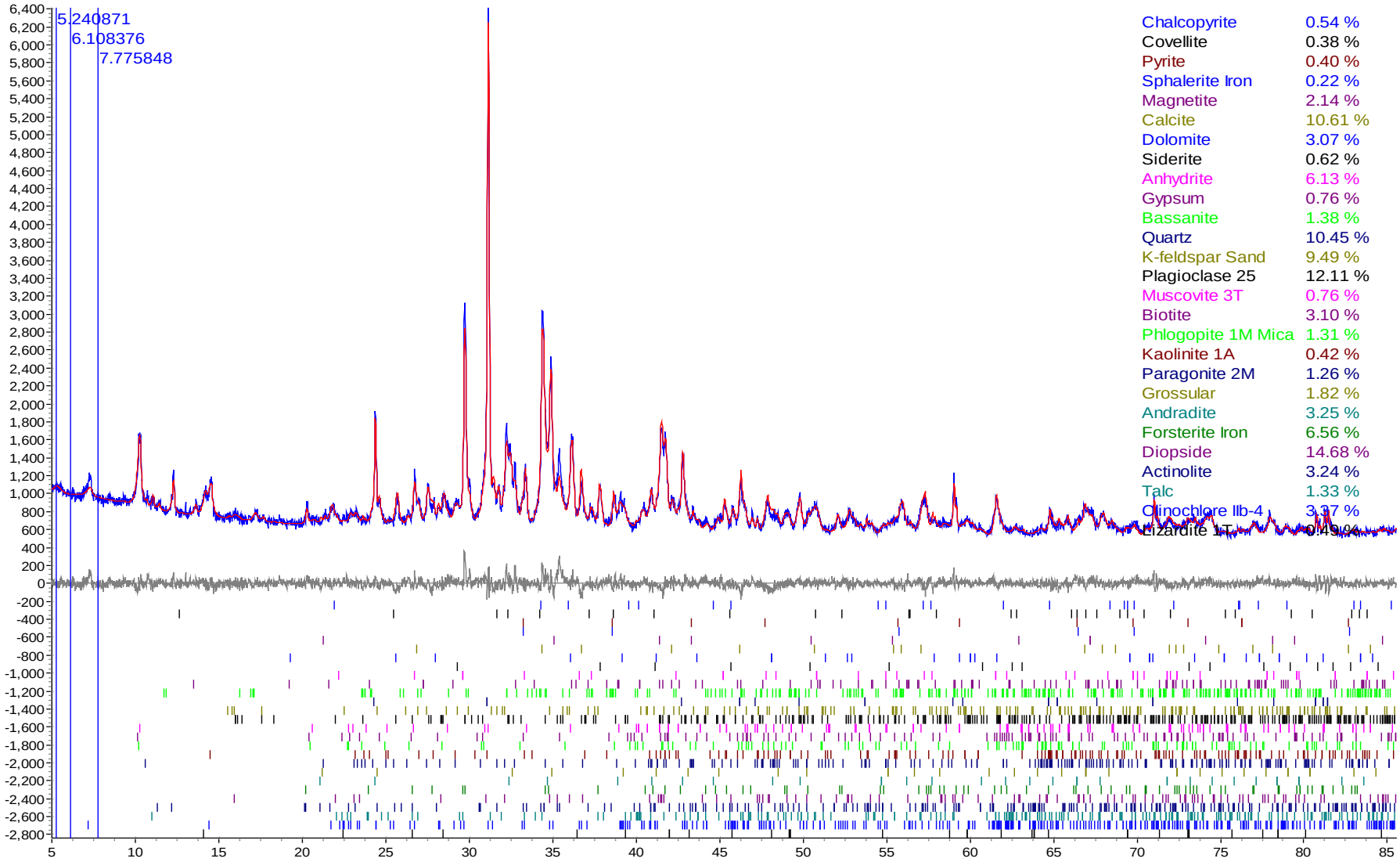
FREEPORT-MCMORAN COPPER & GOLD

Typical Sample
Copper Rougher Concentrate



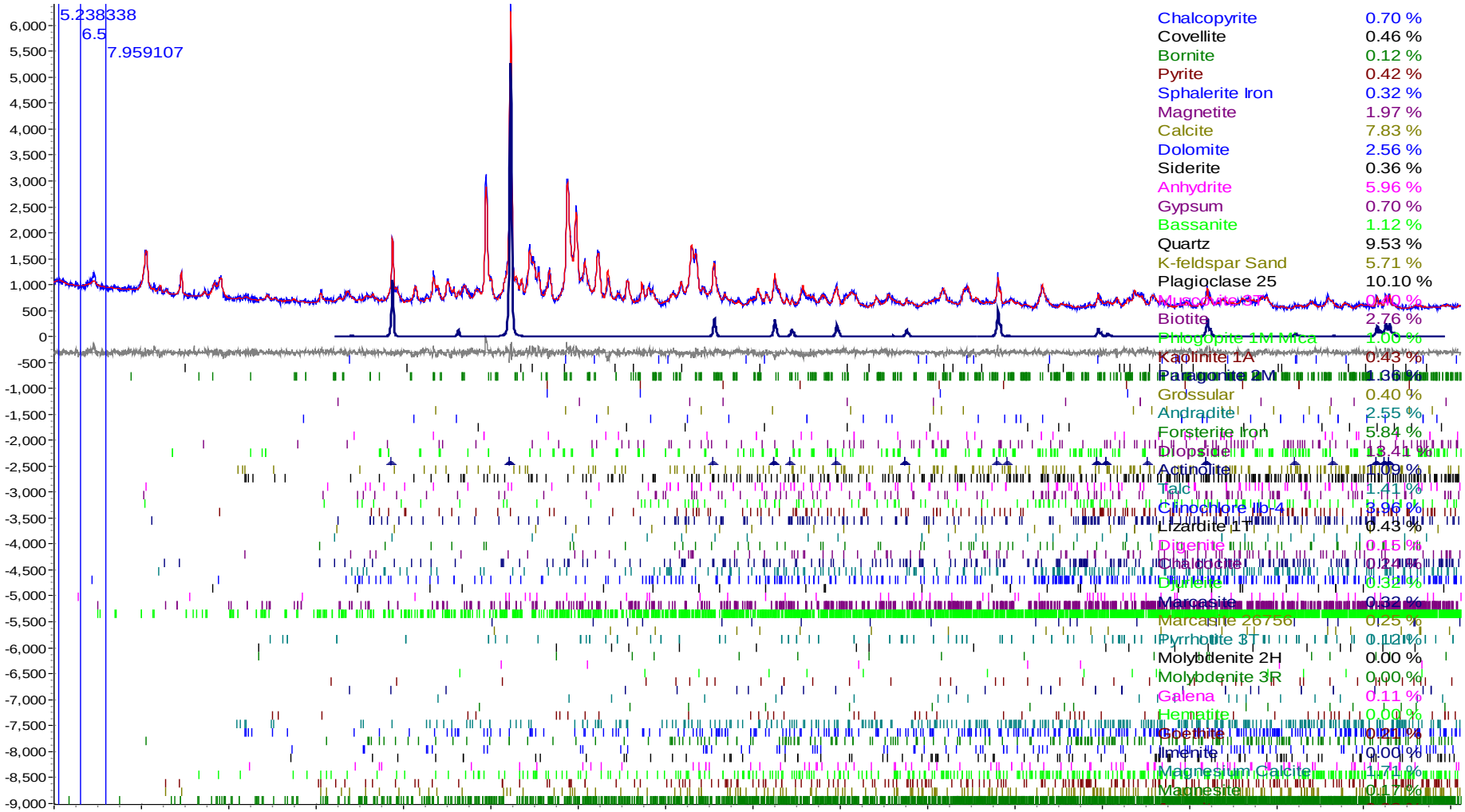
FREEPORT-MCMORAN COPPER & GOLD

A More Complex Mill Feed Composite



FREEPORT-MCMORAN COPPER & GOLD

Full List of Minerals Pushes Topas Limits But It Still Converges



42 of 53 phases displayed

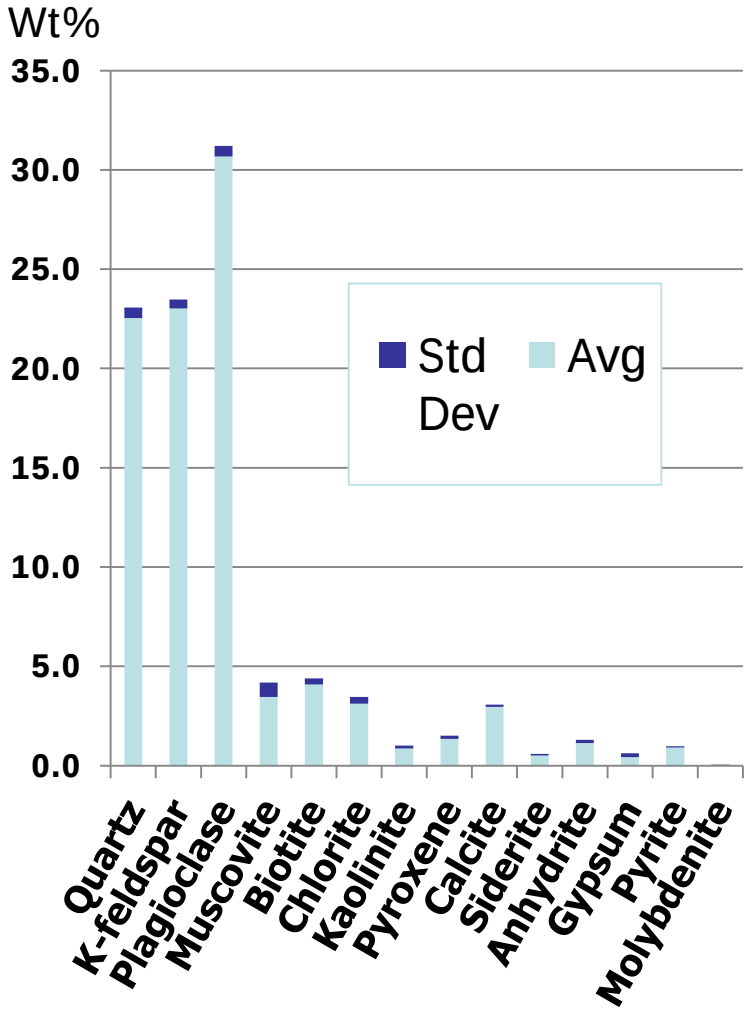
FREEPORT-MCMORAN COPPER & GOLD

Typical Variability

Mill Feed Composites

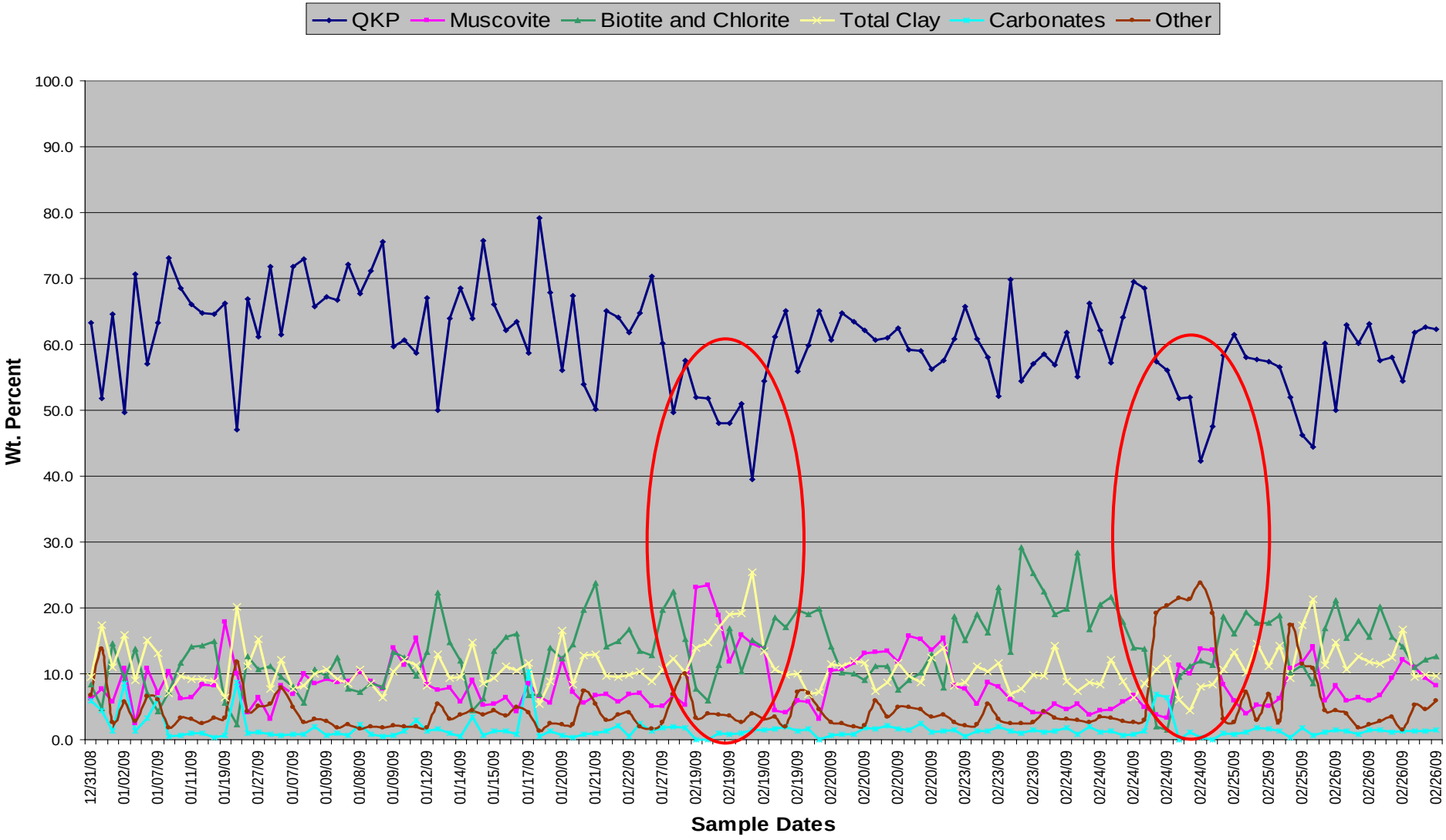
- Aug 2009 through April 2010.
- Two shift composites/day.
- Variability measured on 29 pairs of duplicates.

Mineral	Avg	Std Dev
Quartz	22.5	0.53
K-feldspar	23.0	0.46
Plagioclase	30.7	0.52
Muscovite	3.5	0.72
Biotite	4.1	0.31
Chlorite	3.1	0.33
Kaolinite	0.9	0.15
Pyroxene	1.3	0.17
Calcite	3.0	0.11
Siderite	0.5	0.08
Anhydrite	1.1	0.16
Gypsum	0.4	0.19
Pyrite	0.9	0.08
Molybdenite	0.04	0.015



FREEPORT-MCMORAN COPPER & GOLD

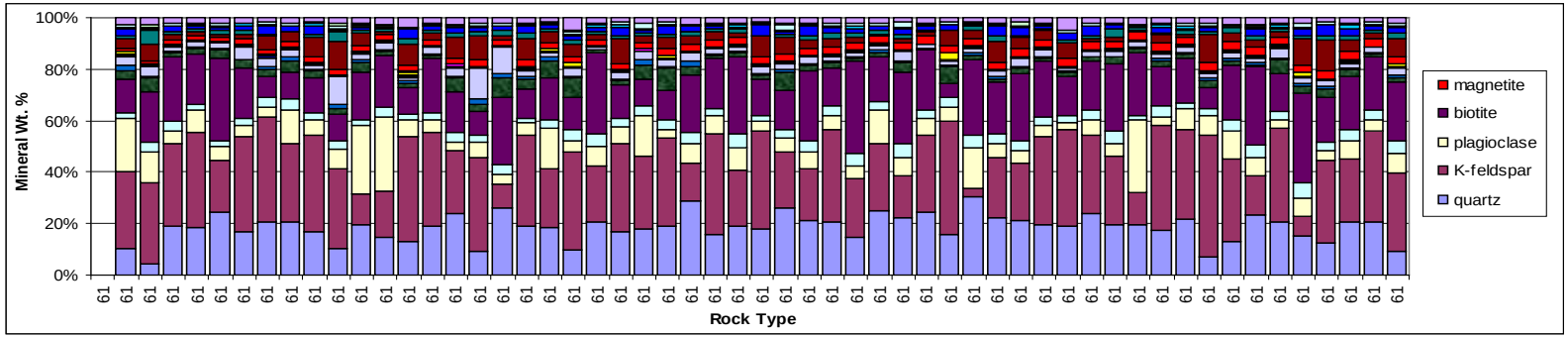
One Month Daily Blast Hole Analysis

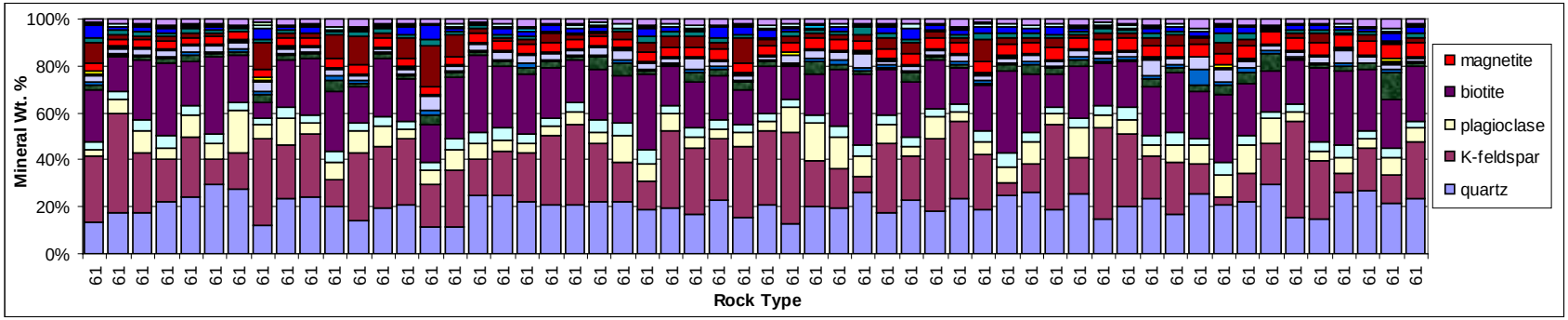


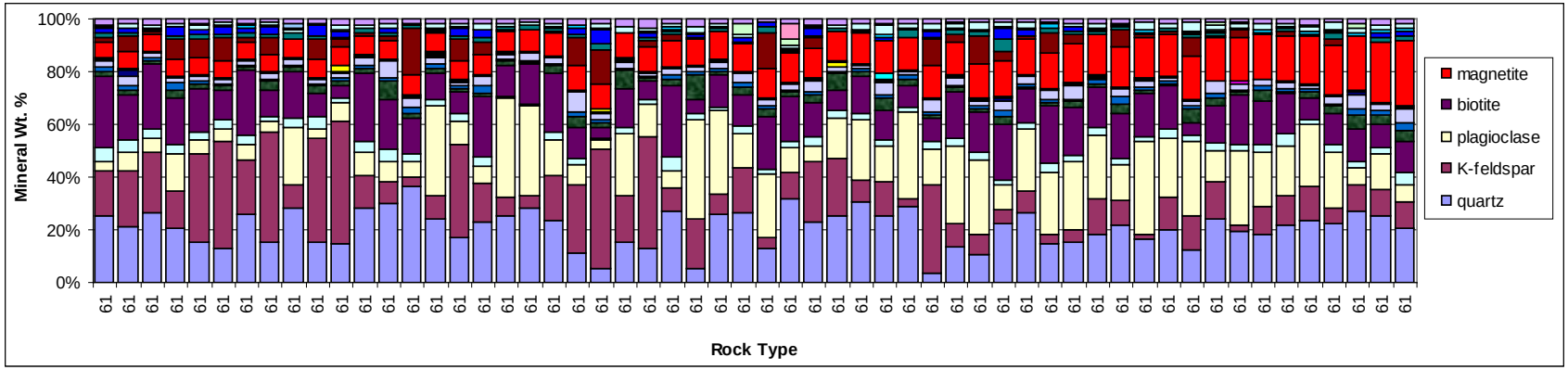
FREEPORT-MCMORAN COPPER & GOLD

XRD Mineralogy of Ore Logged as Type 61

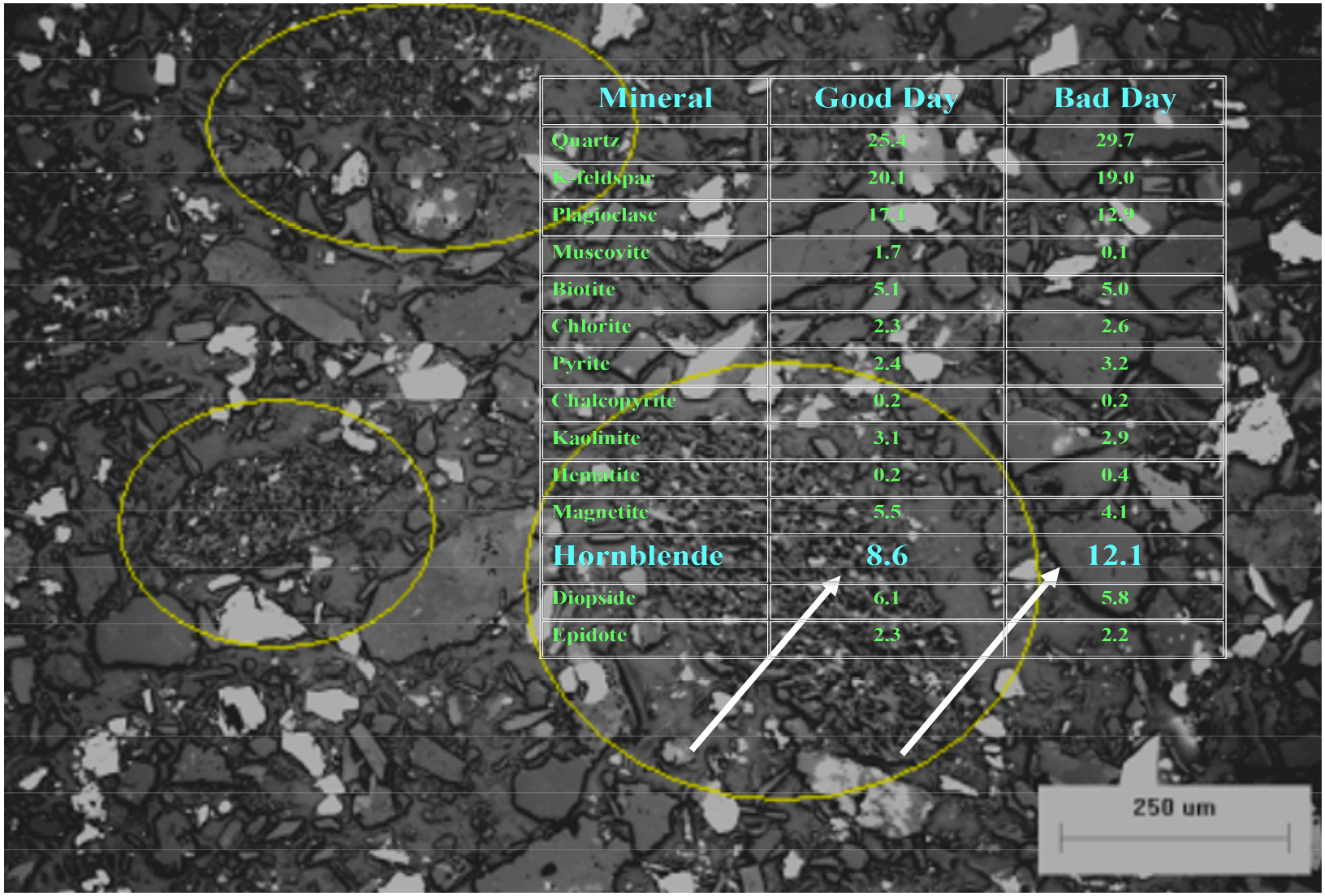
Typically 75% of Mill Feed





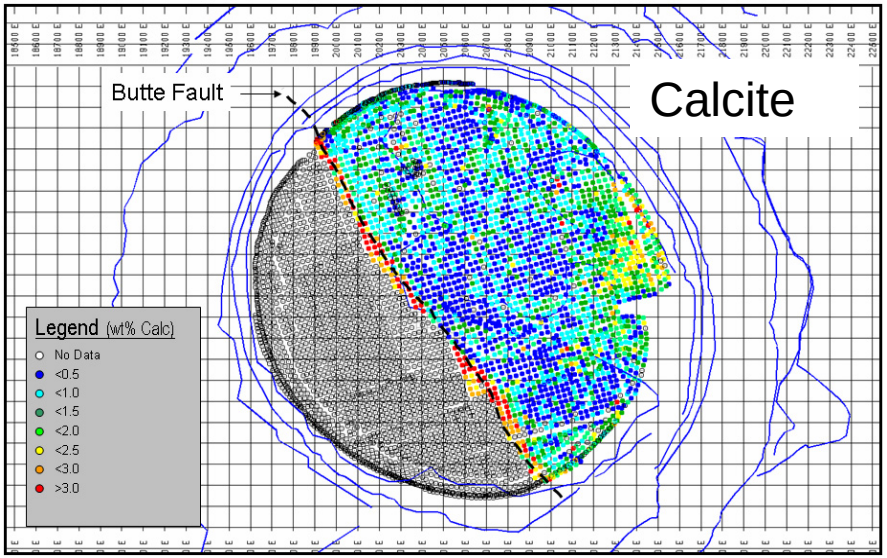


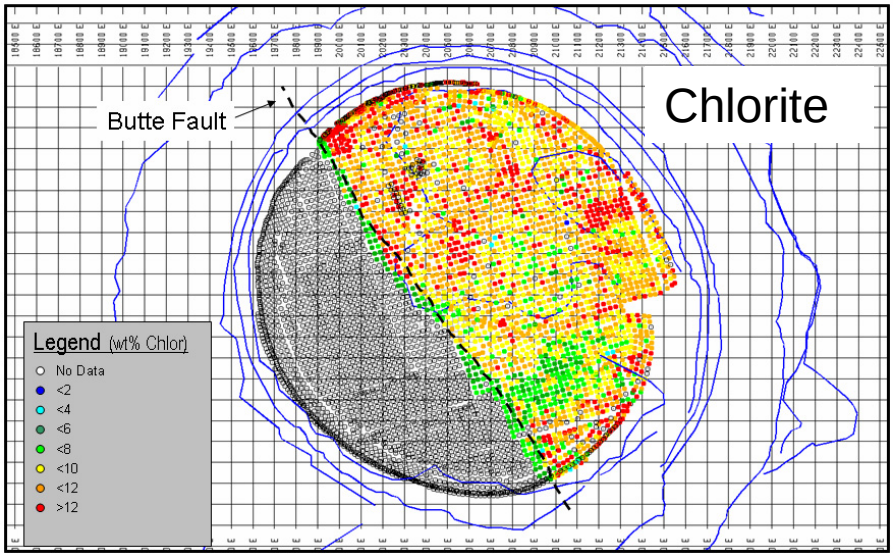
Tailing Thickener Product
High Settling/Rake Breakdown

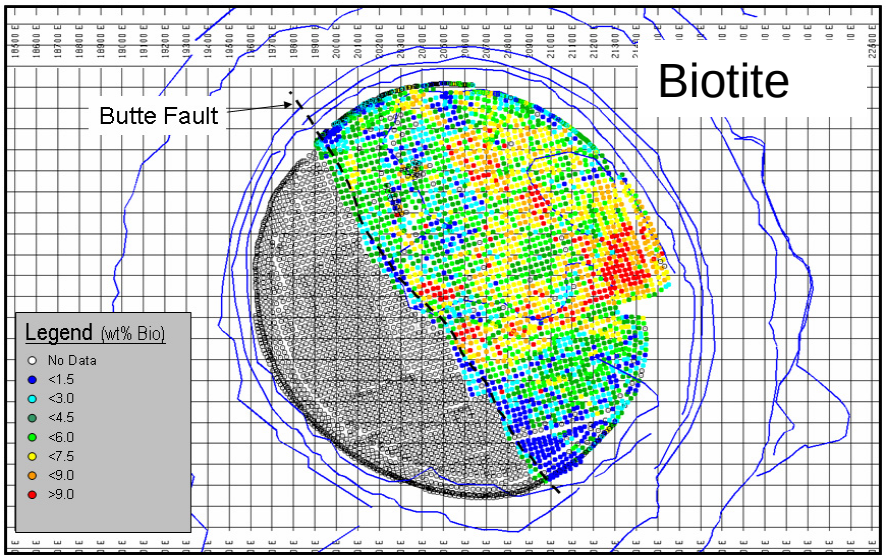


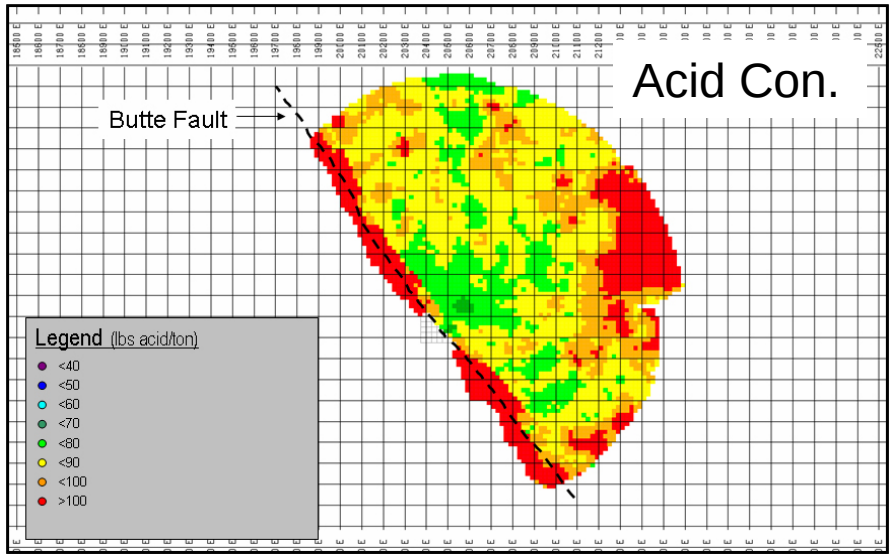
Mineral	Good Day	Bad Day
Quartz	25.4	29.7
K-feldspar	20.1	19.0
Plagioclase	17.1	12.9
Muscovite	1.7	0.1
Biotite	5.1	5.0
Chlorite	2.3	2.6
Pyrite	2.4	3.2
Chalcopyrite	0.2	0.2
Kaolinite	3.1	2.9
Hematite	0.2	0.4
Magnetite	5.5	4.1
Hornblende	**8.6**	**12.1**
Diopside	6.1	5.8
Epidote	2.3	2.2

3750 Bench
NIR Blasthole Data









Recent Developments

- Automated Refinement in Batch Mode
- Refinement Reconciliation with Chemical Assay
- Automated Results Import into LIMS/Business Objects

FREEPORT-MCMORAN COPPER & GOLD

Batch Rietveld Automation

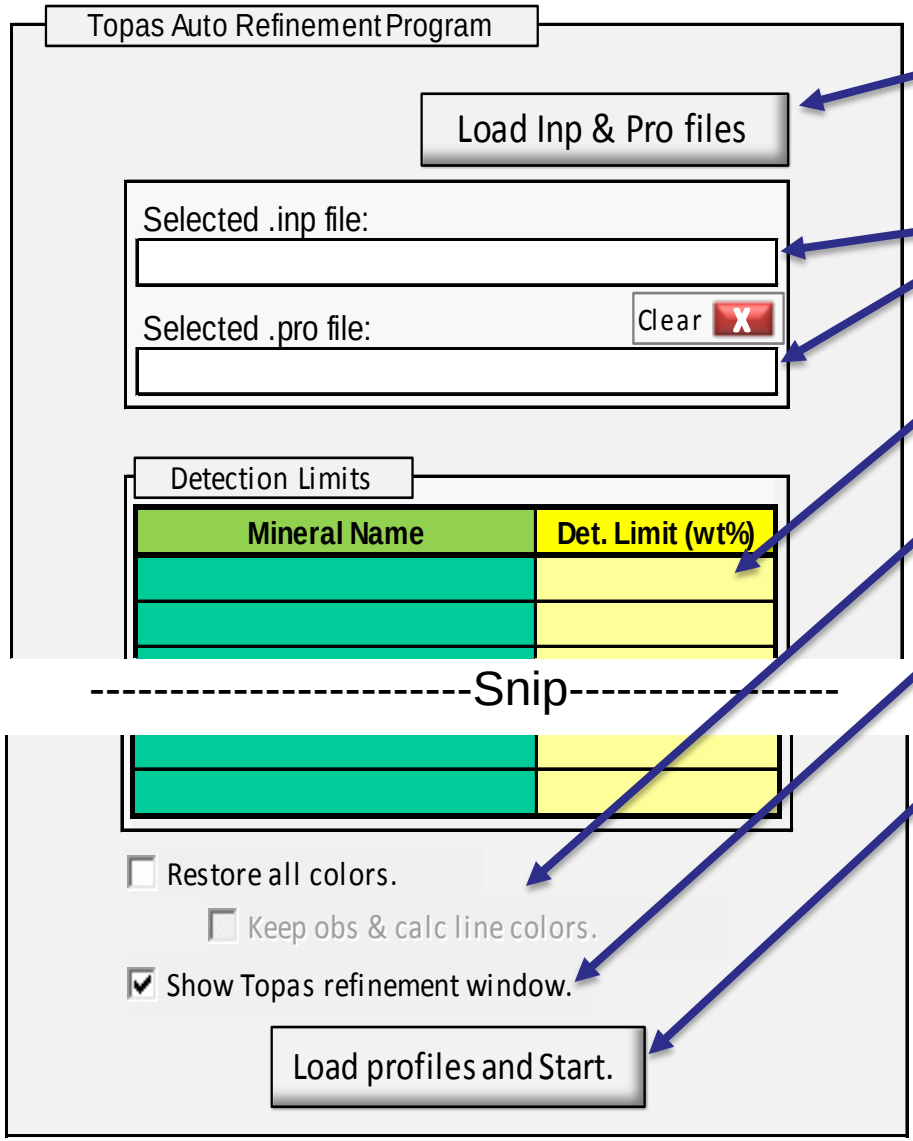
We rejected TOPAS BBQ Option

- Refinements are run automatically and reported
- It has no facility to check refinements visually and rerun
- Has been successful in cement industry

Developed an in-house automated refinement program

- Visual Basic macros in MS Excel
- Runs repeated samples using the same start file in batch mode
- Results are (.pro) files that can be opened in Graphical User Interface (GUI)
- Mineralogists or expert techs can rapidly open each (.pro) file in the GUI for a final check and/or make any adjustments needed.

Batch Rietveld Automation



Browse to directory with saved (.inp) file exported from start.pro file.

Filenames are copied into macro.

Optional detection limits can be set.

Plotting options for output (.pro) file.

Controls whether “DOS” window is visible.

Opens startfile directory (or browse); Select and open any number of (.raw) files; Creates (.inp) file for each (.raw) file; runs tc.exe for each, turns off phases <DL, reruns from start conditions; converts (.out) file to (.pro) file for use in GUI

Chemical Assay Reconciliation

Screenshot of chemistry setup page

	A	B	C	D
7	C	Calcite, Mg	0.1200	Strong XRD overlap with chalcopyrite
8	C	Calcite, Mg-Calcite	0.1200	
9	C	Magnesium Calcite	0.1200	
10	C	Cerussite	0.0449	
11	C	Dolomite	0.1303	
12	C	Magnesite	0.1425	
13	C	Malachite	0.0543	
14	C	Pyroaurite	0.0182	
15	C	Rhodochrosite	0.1045	
16	C	Siderite	0.1037	
17	C	Smithsonite	0.0958	
18	Cu	Antlerite	0.5375	
19	Cu	Azurite	0.5532	
20	Cu	Bonattite	0.2975	
21	Cu	Bornite	0.6332	
22	Cu	Bornite F23	0.6332	
23	Cu	Brochantite	0.5621	
24	Cu	Carrollite	0.2052	
25	Cu	Chalcanthite	0.2546	
26	Cu	Chalcocite	0.7986	
27	Cu	Chalcocyanite	0.3982	
28	Cu	Chalcopyrite	0.3463	Strong XRD overlap with calcite
29	Cu	Copper	1.0000	

AssayVsXRD | Results0 | Assay Results | External Assay | Sample List | **Chemistry Calc Configuration** | Lims Mineral List Prod | Lims Mineral List PTC L

Ready

Chemical Assay Reconciliation

Screenshot of XRD – Assay Comparison Page

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Reimport Calc	SC	C				Cu		Pb		Zn		Mo		
2			XRD	Assay	XRD Su	Calcula	XRD	Assay	XRD	Assay	XRD	Assay	XRD	Assay	
49	3274-0043	0.95	0.30	0.37	2.57	2.96	0.33	0.34	0.00	0.01	0.00	0.02	0.00	ULTIVALUE	
50	3274-0044	1.45	0.32	0.34	2.68	2.72	6.48	7.41	0.00	0.21	0.32	0.31	0.02	0.04	
51	3274-0045	2.81	0.55	0.55	4.59	4.40	2.67	3.24	0.00	0.10	0.17	0.18	0.00	0.02	
52	3274-0046	3.54	0.56	0.61	4.72	4.88	0.65	0.80	0.00	0.03	0.00	0.07	0.00	0.01	
53	3274-0047	3.15	0.55	0.59	4.65	4.72	0.21	0.23	0.00	0.01	0.00	0.03	0.00	0.01	
54	3274-0048	0.78	0.28	0.32	2.34	2.56	0.00	ULTIVAL	0.00	0.00	0.00	<0.0 %	0.00	)ES MS	
55	3274-0049	0.99	0.33	0.35	2.71	2.80	0.34	0.32	0.00	0.01	0.00	0.02	0.00	)ES 0 MS	
56	3274-0050	1.90	0.26	0.34	2.26	2.72	7.32	8.51	0.00	0.24	0.37	0.38	0.03	0.04	
57	3274-0051	2.87	0.55	0.53	4.57	4.24	2.14	2.52	0.00	0.07	0.20	0.15	0.00	0.02	
58	3274-0052	3.31	0.56	0.57	4.70	4.56	0.49	0.50	0.00	0.02	0.00	0.04	0.00	0.01	
59	3274-0053	3.58	0.47	0.58	3.90	4.64	0.15	0.19	0.00	0.01	0.00	0.02	0.00	0.01	
60	3274-0054	0.74	0.30	0.33	2.62	2.64	0.00	ULTIVAL	0.00	0.00	0.00	<0.0 %	0.00	ULTIVALUE	
61	3274-0055	1.03	0.33	0.36	2.79	2.88	0.26	0.34	0.00	0.01	0.00	0.02	0.00	ULTIVALUE	
62	3274-0056	1.69	0.36	0.37	2.95	2.96	6.58	7.31	0.00	0.20	0.36	0.32	0.09	0.05	
63	3274-0057	2.82	0.51	0.54	4.26	4.32	1.75	2.16	0.00	0.07	0.00	0.14	0.00	0.02	
64	3274-0058	3.29	0.46	0.59	3.87	4.72	0.44	0.49	0.00	0.02	0.00	0.06	0.00	0.01	
65	3274-0059	3.52	0.46	0.57	3.82	4.56	0.17	0.16	0.00	0.01	0.00	0.03	0.00	0.01	
66	3274-0060	0.80	0.27	0.33	2.25	2.64	0.00	ULTIVAL	0.00	0.00	0.00	<0.0 %	0.00	ULTIVALUE	
67	3274-0061	0.95	0.29	0.34	2.44	2.72	0.35	0.35	0.00	0.01	0.00	0.02	0.00	ULTIVALUE	
68	3274-0062	1.43	0.36	0.36	3.01	2.88	7.23	7.92	0.00	0.24	0.62	0.46	0.00	0.04	

AssayVsXRD | Results0 | Assay Results | External Assay | Sample List | Chemistry Calc Configuration | Lims Mineral List Prod | Lims Mineral List P

Ready

Continuing Issues

- **Automated Micronizing**
- **Eliminating Preferred Orientation**
- **Modeling Highly Variable Disordered Clays (including Chrysocolla)**

Thank You

Questions or Suggestions?