Systematic soil sampling for copper-silver mineralization using a portable XRF.

- a case study from the Amazon foreland basin, eastern Peru -

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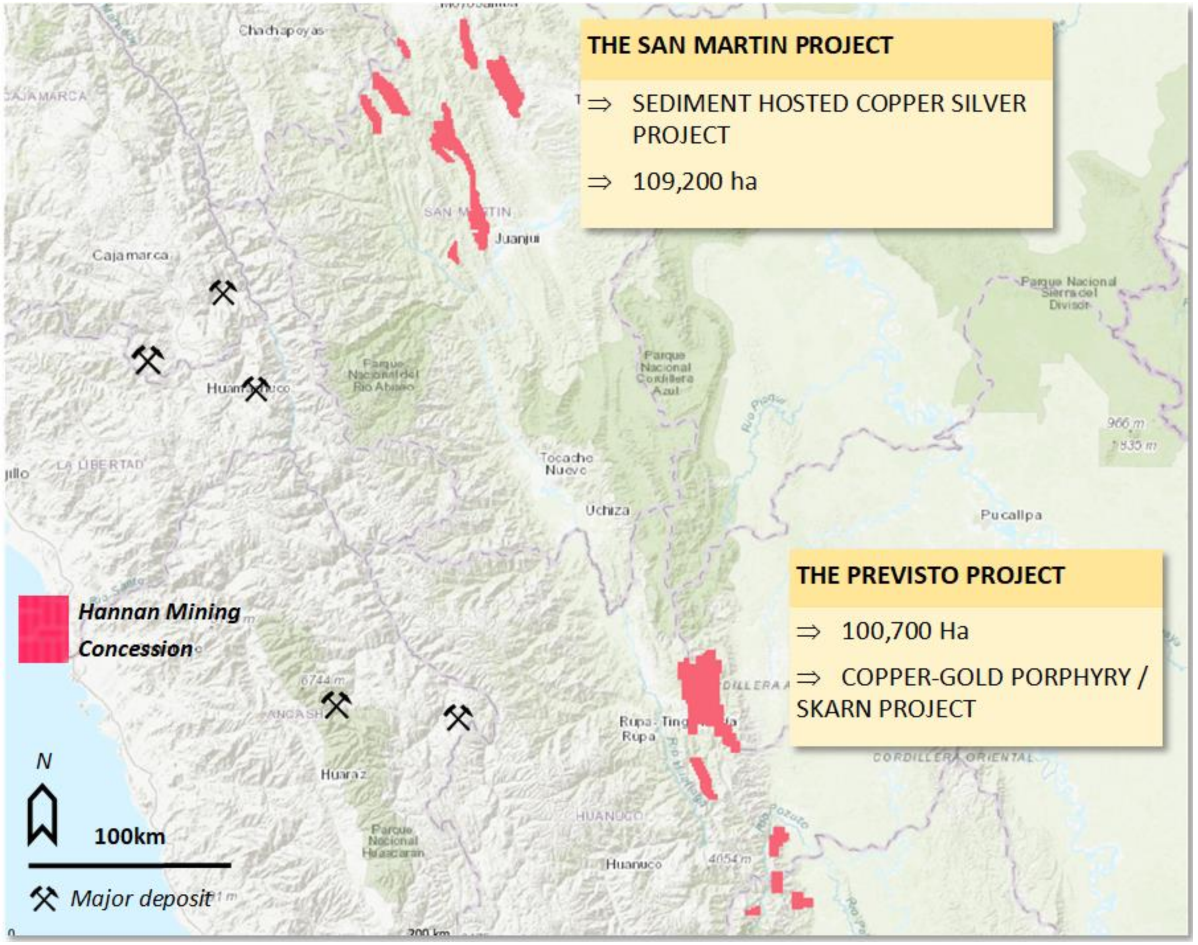
July 2021

Introduction

Hannan Metals Limited is a top 10 in-country Peru explorer with >2,000 sqkm of tenure

This case study will focus on the San Martin project: a sediment-hosted copper-silver target located in the Huallaga Basin of north central Peru.



Project Overview

- ✓ Stratabound sediment-hosted copper-silver target.
- ✓ New regional play with evidence of basin wide mineralizing system active over 100s of kilometers.
- ✓ Key characteristics of stratabound sediment-hosted copper deposits are high grade mineralization in shales that are a few decimeters to several meters thick and laterally extensive over 10s to 100s of kilometers.
- ✓ Hannan controls >1090 sq km of tenure.
- ✓ Challenge is to map mineralization undercover where <1% of the bedrock outcrops.

Project Overview

Climate and Vegetation

- ✓ Rainforest with a 4-5 month dry season.
- ✓ Steep topography, dense jungle

Logistics and field conditions

- ✓ Between 1-3h walk from "4x4 road" to field camp
- ✓ Renting houses in small settlements close to work areas.
- ✓ Conditions are basic but adequate.

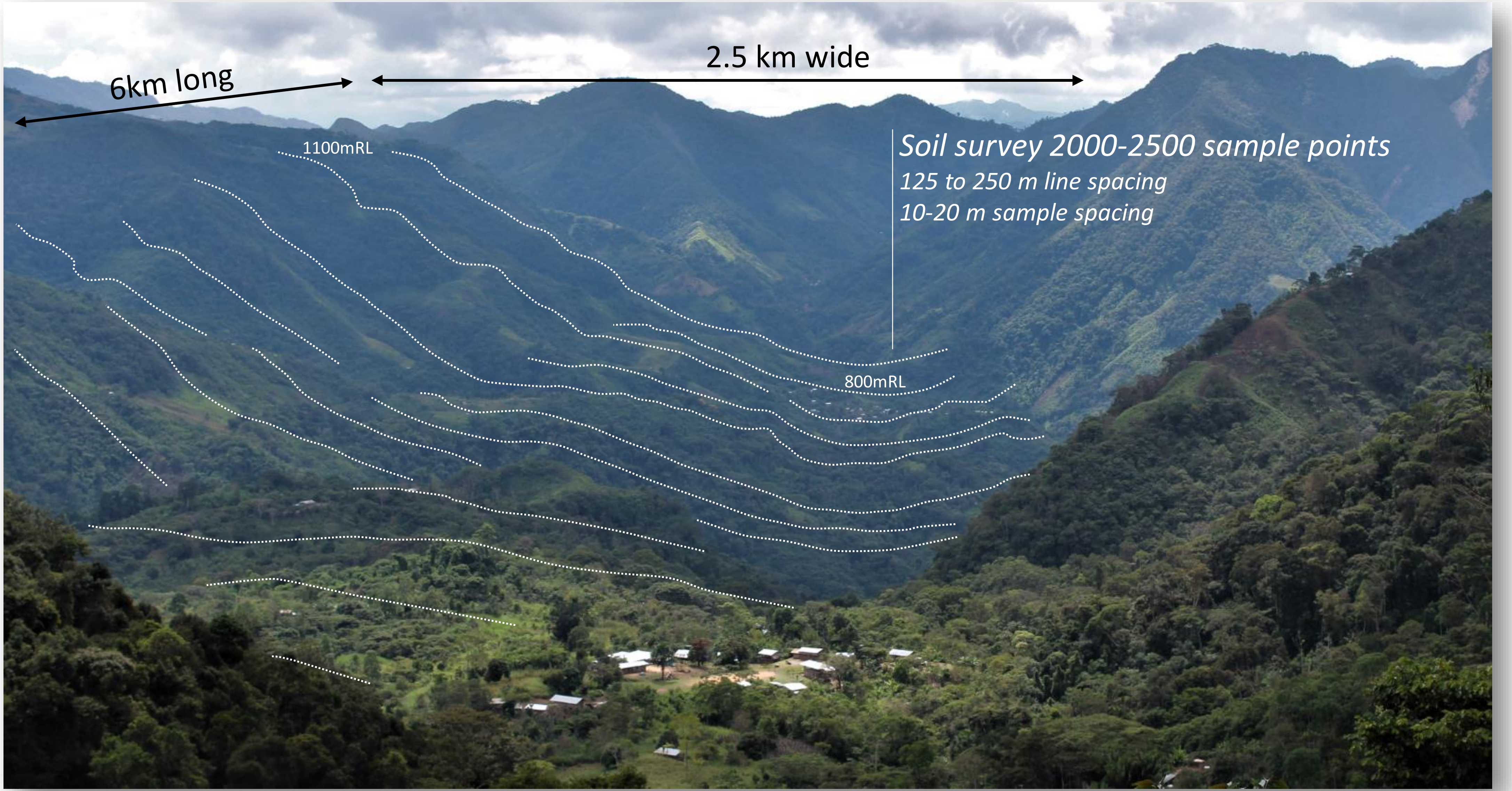
Project de-risking

- ✓ Prospecting creeks and stream sediment sampling are effective methods to reduce the search space.

- ✓ The dense vegetation in combination with very limited outcropping makes it challenging to prove the continuity of mineralization between outcrops

- ✓ Systematic soil sampling chosen to map mineralization undercover

Soil survey overview



Conventional soil sampling

- ✓ Slow and heavy - every two weeks up to 800kg of soil samples was transported by horse to 4x4 road.
- ✓ Slow decision times due to logistics and laboratory TAT
- ✓ Slow results meant difficulty to align work with first response social permitting teams
- ✓ Multiple mobilization to follow-up results meant additional costs
- ✓ Great quality data!

pXRF soil sampling

Early realization that the pXRF could replace the conventional soil sample at the project.

- needed to make sure we collected robust and fit-for-purpose data
- that our staff was appropriately trained
- that we had proper quality control programs in place

Fit-for-purpose data

The prize we were after was real time decision making during soil sampling and all the good things that follow:

- *Higher sampling rate = larger areas sampled*
- *Easier logistics*
- *Results that could be communicated in a timely manner to social teams and so on*

Listing key pathfinder elements:
Cu, Ag, Co, Zn, Pb, Mn, Ba, Sb, As, Ni, Hg, Re, Au, Pt, Pd, Li

The second purpose is to do lithological discrimination. We identified the following key elements:

K, Na, Ca, Mg, Si, Ba, Fe, Sc, Th, Ti, C, Zr, P, Nb, Al, V, Mo, U, Fe, S

Fit-for-purpose data

- ✓ Laboratory 4-acid ICP-MS outperforms the pXRF in most elements.
- ✓ The pXRF still produces fit-for-purpose data for many key pathfinders including copper as well as major elements.

pXRF fit-for purpose:
Cu, Zn, Mn, Fe, As, Ni
K, Ca, Mg, Ba, Si, Ti

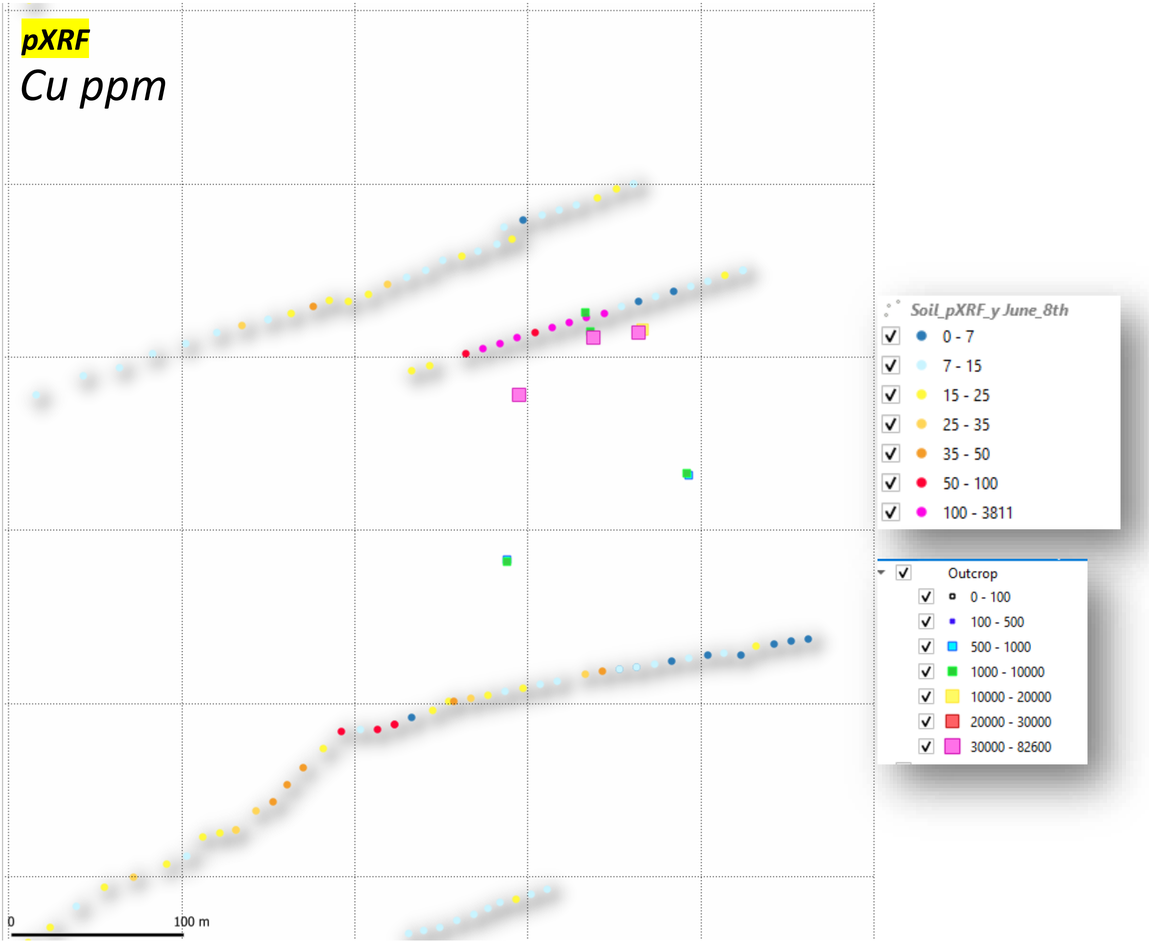
Importance	Trace element associated with	ALS data fit-for-purpose (single to multivariate	pXRF data fit-for-purpose (single to multivariate	pass QC FDUP (ALS	pass QC FDUP (pXRF	passing pXRF vs ALS comparison (XY-
1	Cu	yes	yes	yes	yes	yes* >10 ppm
1	Ag	close to DL/caution	no	close to DL/caution	no	no
1	Zn	yes	yes	yes	yes	yes > 30 ppm
1	Pb	yes	close to DL/caution	yes	close to DL/caution	no
2	Mn	yes	yes	yes	yes	yes*
2	Fe	yes	yes	yes	yes	yes*
3	As	yes	close to DL/caution	yes	yes	yes >9 ppm
3	Ni	yes	close to DL/caution	yes	close to DL/caution	yes
3	Co	yes	close to DL/caution	yes	close to DL/caution	caution
3	Sb	yes	no	yes	no	no*
3	Hg	not analyzed	not analyzed	not analyzed	not analyzed	not analyzed
3	Re	not analyzed	not analyzed	not analyzed	not analyzed	not analyzed
3	Cd	yes	no	yes	no	no
3	Au+PGE	not analyzed	not analyzed	not analyzed	not analyzed	not analyzed
	Major element assoicated with	**ALS data fit-for-purpose (single to multivariate analysis)**	**pXRF data fit-for-purpose (single to multivariate analysis)**	**pass QC (ALS results)**	**pass QC (pXRF results)**	**pass pXRF vs ALS comparison (XY-plot)**
1	K	yes	yes	yes	yes	yes*
1	Na	yes	not analyzed	yes	not analyzed with p	not analyzed with pXRF
1	Ca	yes	yes	yes	yes	yes*
1	Mg	yes	yes	yes	yes	yes*
1	Ba	yes	yes	yes	yes	yes*
1	Si	not analyzed	yes	not analyzed	yes	not analyzed with pXRF
	Other elements	**ALS data fit-for-purpose (single to multivariate analysis)**	**pXRF data fit-for-purpose (single to multivariate analysis)**	**pass QC (ALS results)**	**pass QC (pXRF results)**	**pass pXRF vs ALS comparison (XY-plot)**
	Ti	yes	yes	yes	yes	yes*
	Sc	yes	no	yes	not analyzed with p	not analyzed with pXRF
	V	yes	caution	yes	not analyzed with p	no
	Zr	yes	yes	yes	yes	no*
	Al	yes	yes	yes	yes	caution
	S	yes	yes	yes	yes	no
	Element for lithological discrimination (Halley)	**application**	**with ALS data**	**with pXRF data**		
	Ca - Mg	*limestone vs dolomite*	yes	yes		
	Sc vs Th, Ti, V, Zr, P, Nb	*provenance review*	yes	no		
	Ca vs Al	*quartz vs clay vs carbonate*	yes	yes		
	Ca-Al-Si ternary	*quartz vs clay vs carbonate*	no	yes		
	Fe vs Al	*sedimentary iron fm.*	yes	yes		
	Sc vs V	*organic carbon*	yes	no		
	V vs Mo, U, Cr	*organic carbon*	yes	no		
	Fe vs S	*diagenetic sulfides*	yes	no		
	K/Al vs Na/Al	*sericite vs albite*	yes	no		
	Ca-K-Na	*mineralogy*	yes	no		
	Al-K-Mg	*mineralogy*	yes	yes		
	Ca-Fe-S	*anhydrite*	yes	no		
	Cu/Sc	*Cu-sulfide anomalies and depletion*	yes	no		

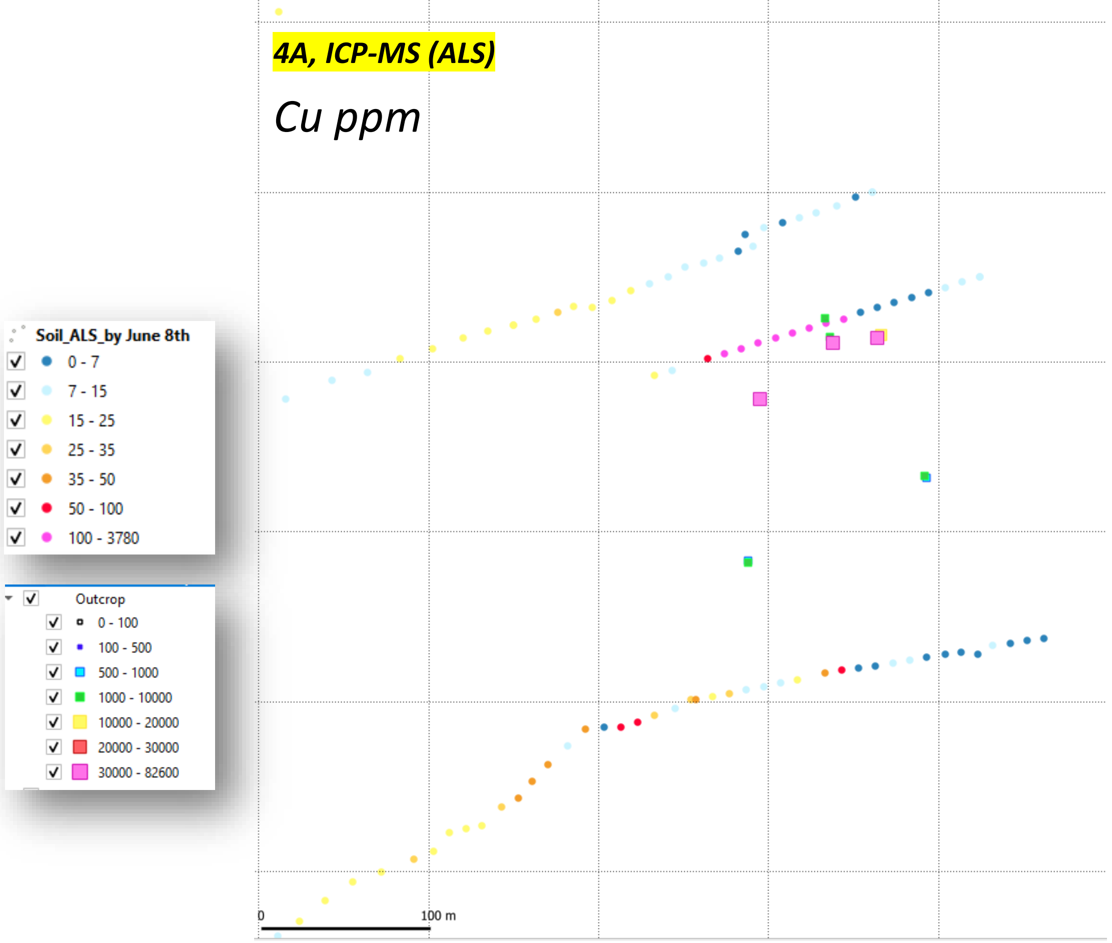
Orientation studies

To determine the most cost effective but fit-purpose sampling and pXRF assay protocol

Comparison to known sites of mineralization:

- ✓ *Excellent spatial correlation between ALS and pXRF copper data.*
- ✓ *Detection of the same anomalies, similar dynamic range of anomalies.*
- ✓ *Very good correlation with known outcrop mineralization*





Orientation studies

To nut out the most cost effective but still fit-purpose sampling and pXRF assay protocol

Comparison to known sites of mineralization:

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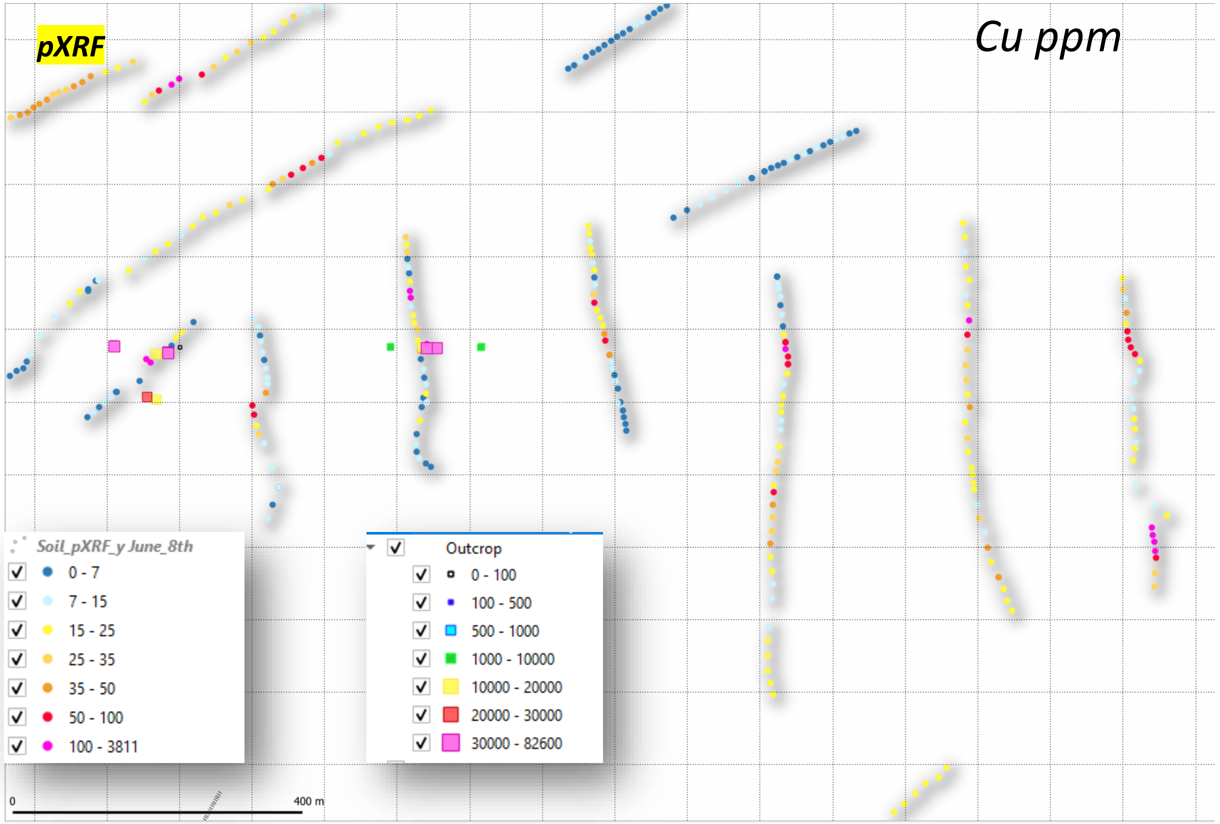
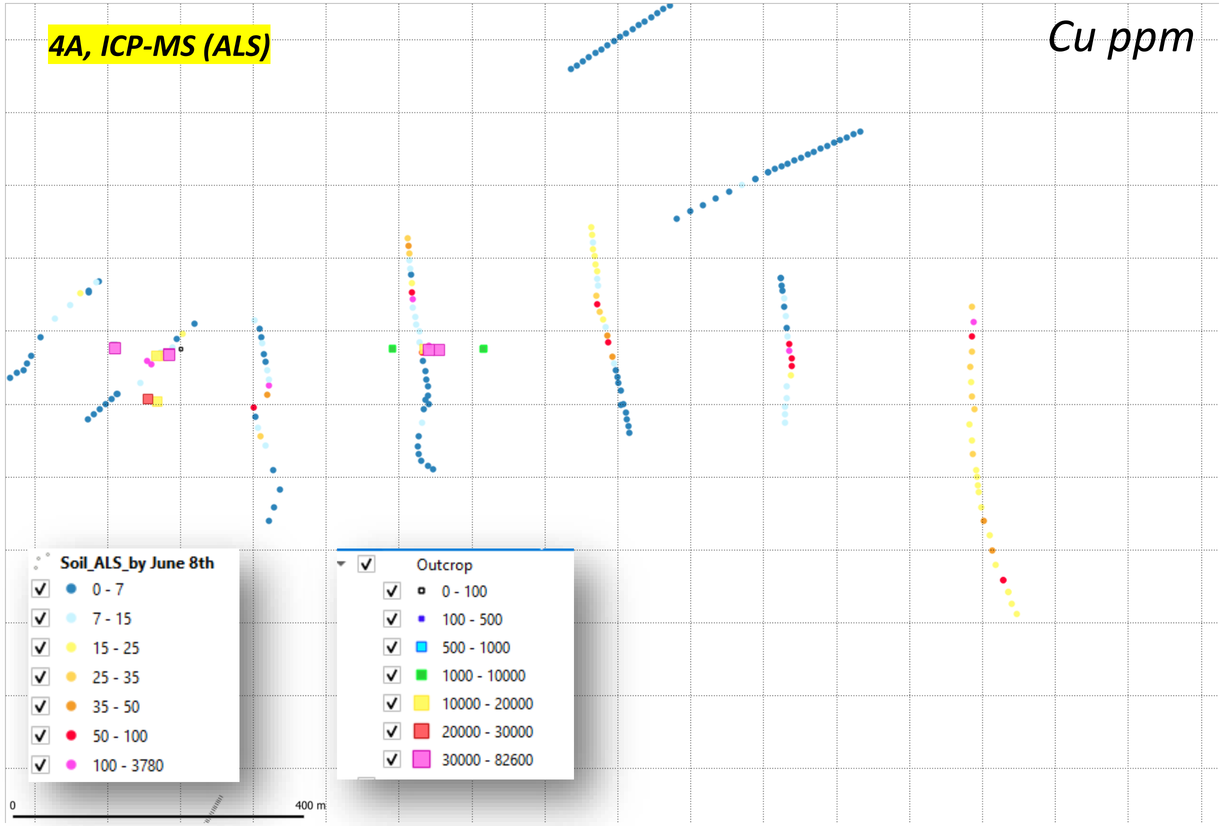




Orientation studies

To determine the most cost effective but still fit-purpose sampling and pXRF assay protocol

For best results we want to achieve a homogenous, compacted and dry sample (with minimal effort!)

Assay directly in the sample hole ? Multiple spots and average possible. Easy logistics…

Great idea but not practical in the rain forest, over saturated soils and sudden showers will stop work

Orientation studies

To determine the most cost effective but still fit-purpose sampling and pXRF assay protocol

For best results we want to achieve a homogenous, compacted and dry sample (with minimal effort!)

- ✓ Works well but plastic film has impact on some elements.
- ✓ Sample is humid.
- ✓ Does not eliminate the logistics involved in conventional soil sampling.

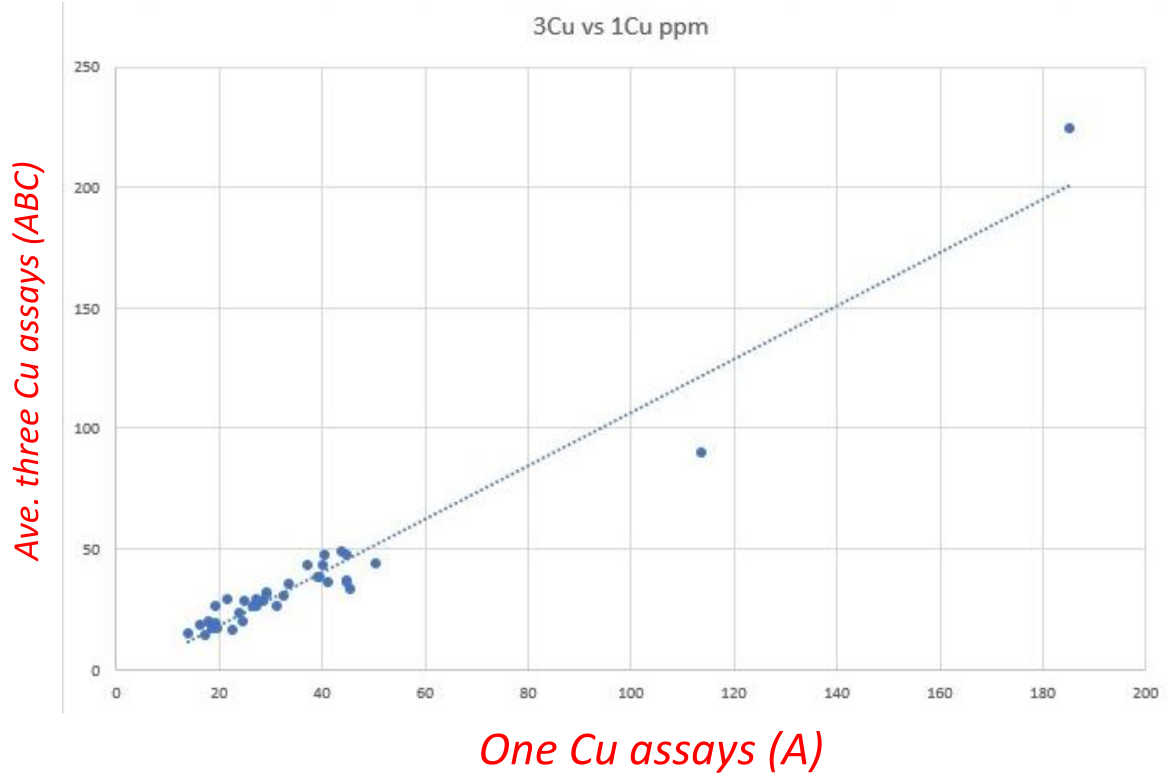
Orientation studies

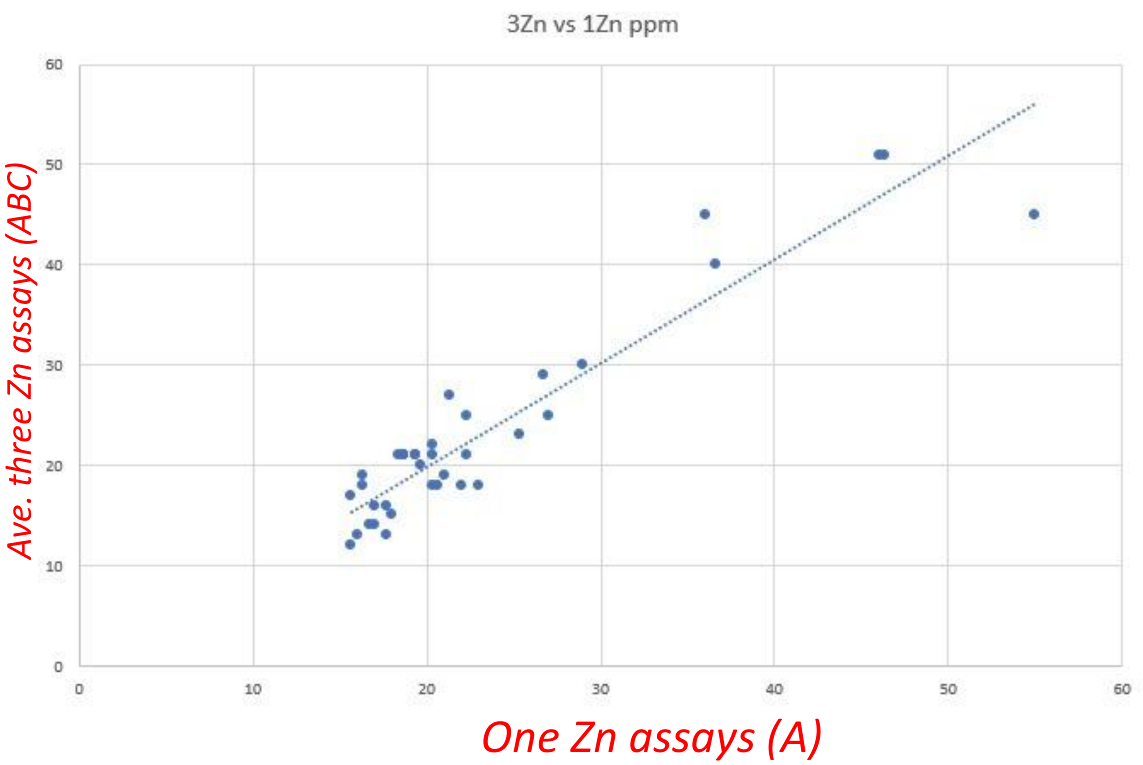
To determine the most cost effective but still fit-purpose sampling and pXRF assay protocol

✓ Three times the work without major data uplift.

Procedure

- *3 unique samples from the same sample hole A/B/C*
- *Pellets of A/B/C -> Dry in microwave*
- *Analyze of 3 beams for 30s.*





Key learnings for fit-for-purpose data

1 Sampling

- ✓ Remove rock fragment and homogenize the soil in the hole prior to sampling
- ✓ Sample at least 9 different parts of the hole with a small teaspoon.

Key learnings for fit-for-purpose data

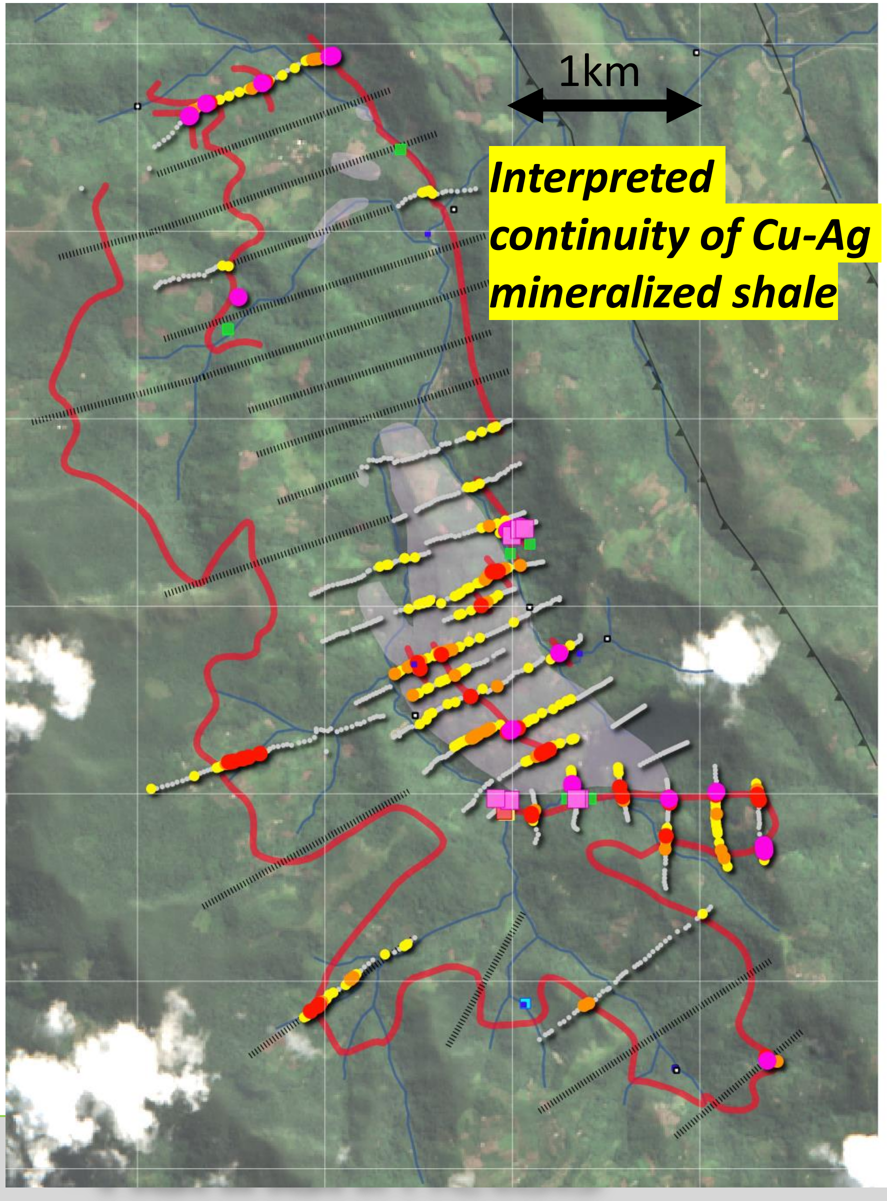
2 Assay

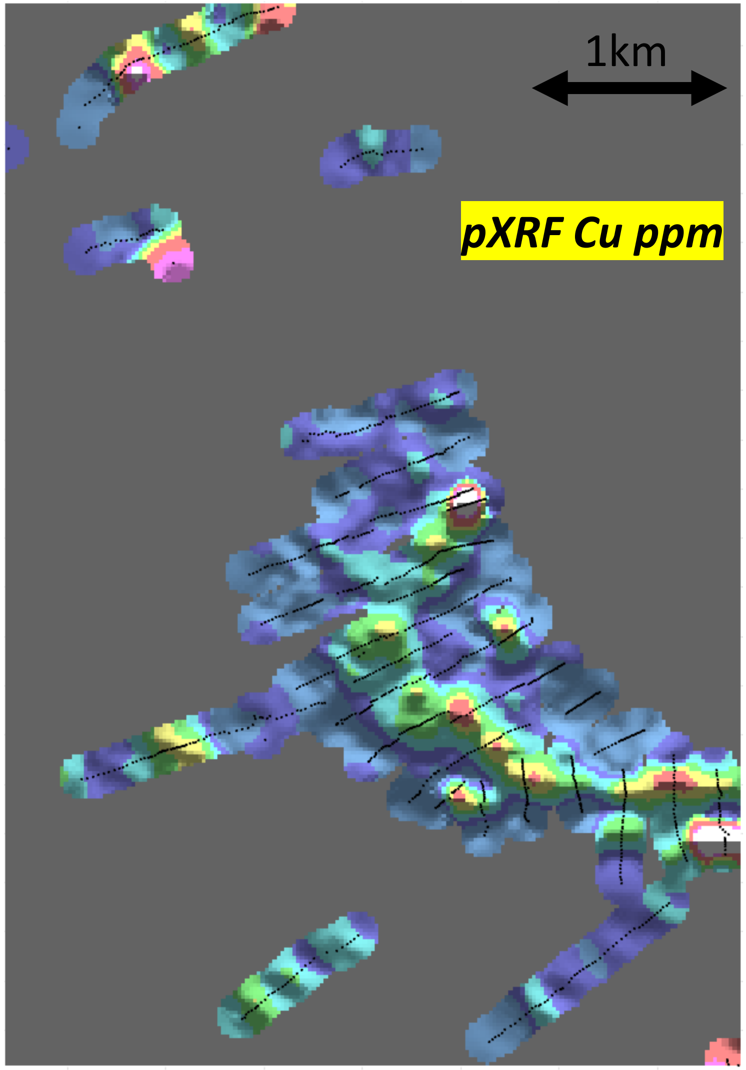
Use bottle caps to make a soil pellet

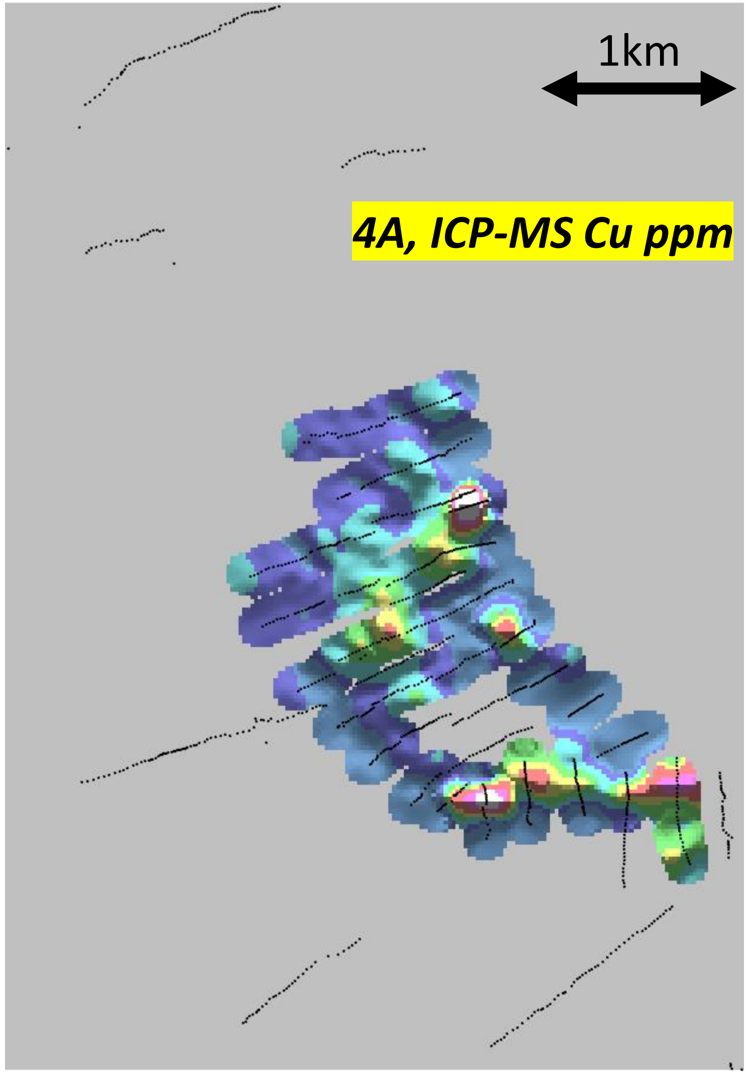
Dry the sample in a microwave

Use the Olympus workstation for safe sample handling

Data interpretation and decision making







Summary

Fit-for-purpose data is achievable for key pathfinder elements and major elements.

Real time decision making to determine infill or extension of sample traverses.

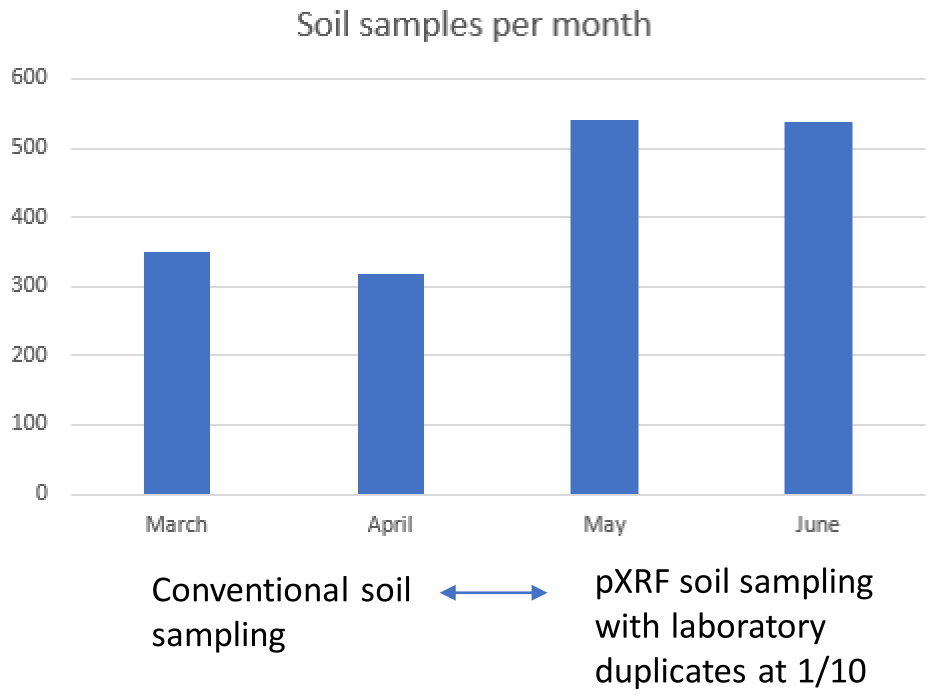
Controlled office laboratory with QAQC program of:

- ✓ *Duplicate 1/10 sample: 2 kg of soil sample to send to ALS for 4A + ME-MS61*
- ✓ *Field duplicate 1/20 pXRF sample*
- ✓ *Measurement of CRM NIST 2711a every 1/20*

60 % faster sampling

Payback time of one unit is ~4months at current sampling rate (only accounting for hard assay costs)

The bigger area surveyed the greater chance for a discovery.



Results from lab duplicates

Comparison of result of pXRF vs laboratory ICP-MS, four acid digest.

3 beams x 30s
"dry sample"

VS

SAMPLE PREPARATION	
ALS CODE	DESCRIPTION
WEI-21	Received Sample Weight
DRY-22	Drying – Maximum Temp 60C
BAG-01	Bulk Master for Storage
PUL-QC	Pulverizing QC Test
LOG-22	Sample login – Rcd w/o BarCode
SCR-41	Screen to -180um and save both
PUL-31	Pulverize up to 250g 85% <75 um

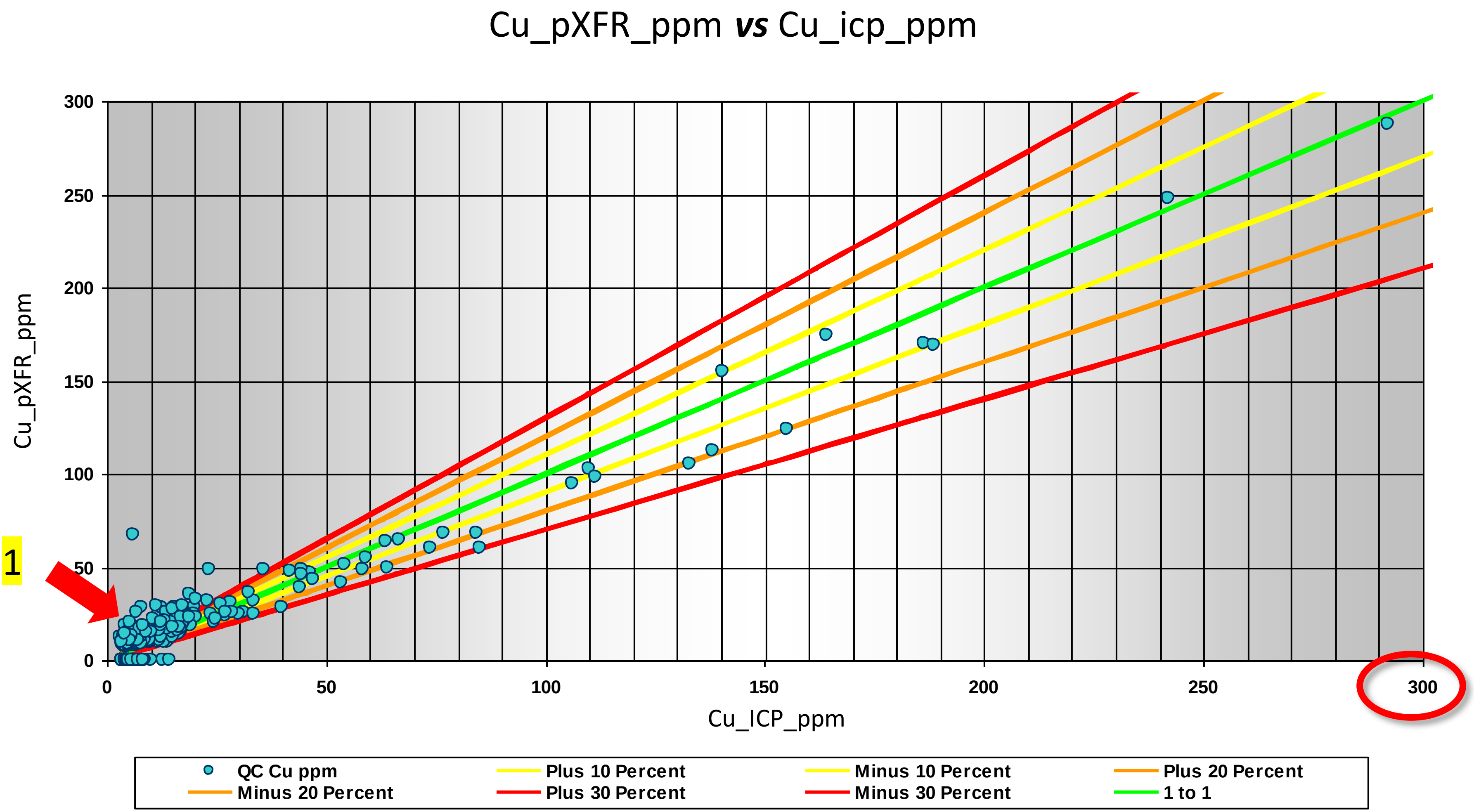
ANALYTICAL PROCEDURES		
ALS CODE	DESCRIPTION	INSTRUMENT
ME-MS61	48 element four acid ICP-MS	

~2kg sample

N=400 samples analysed both with pXRF and ME-MS61 (4A)

ICP vs pXRF

Cu results (<300 ppm)



1: closer to the DL the reproducibility is reduced of the pXRF

ICP vs pXRF

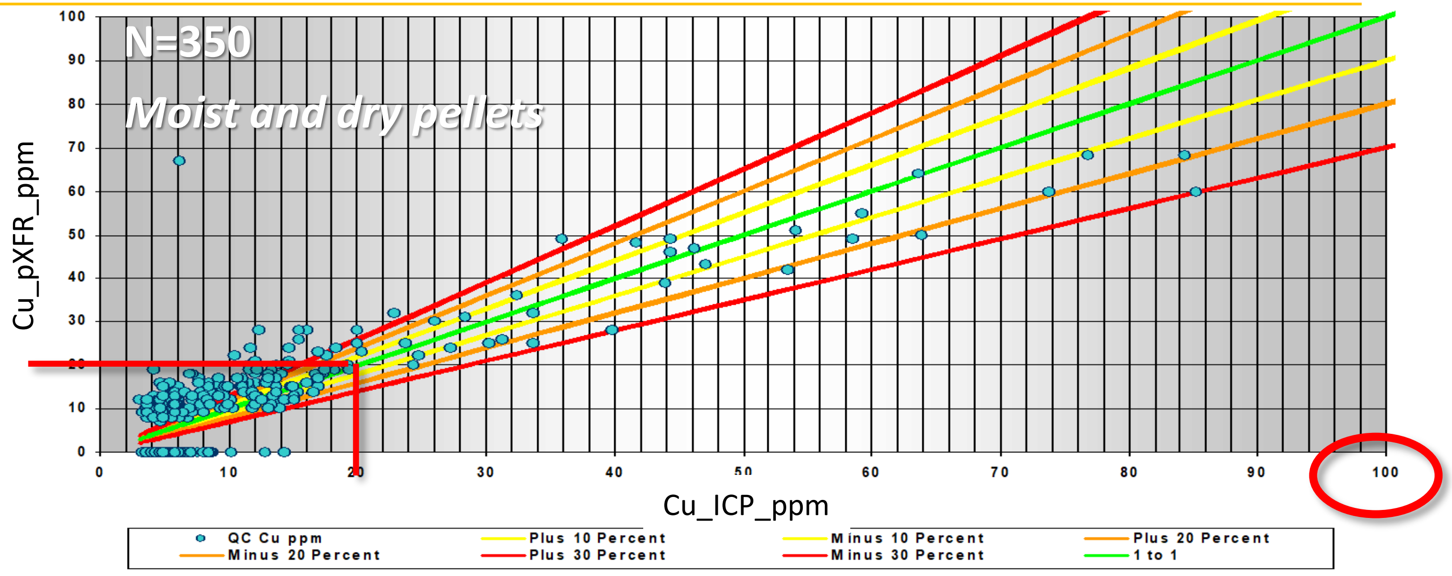
Cu results (<100 ppm)

>20 ppm Cu is considered anomalous

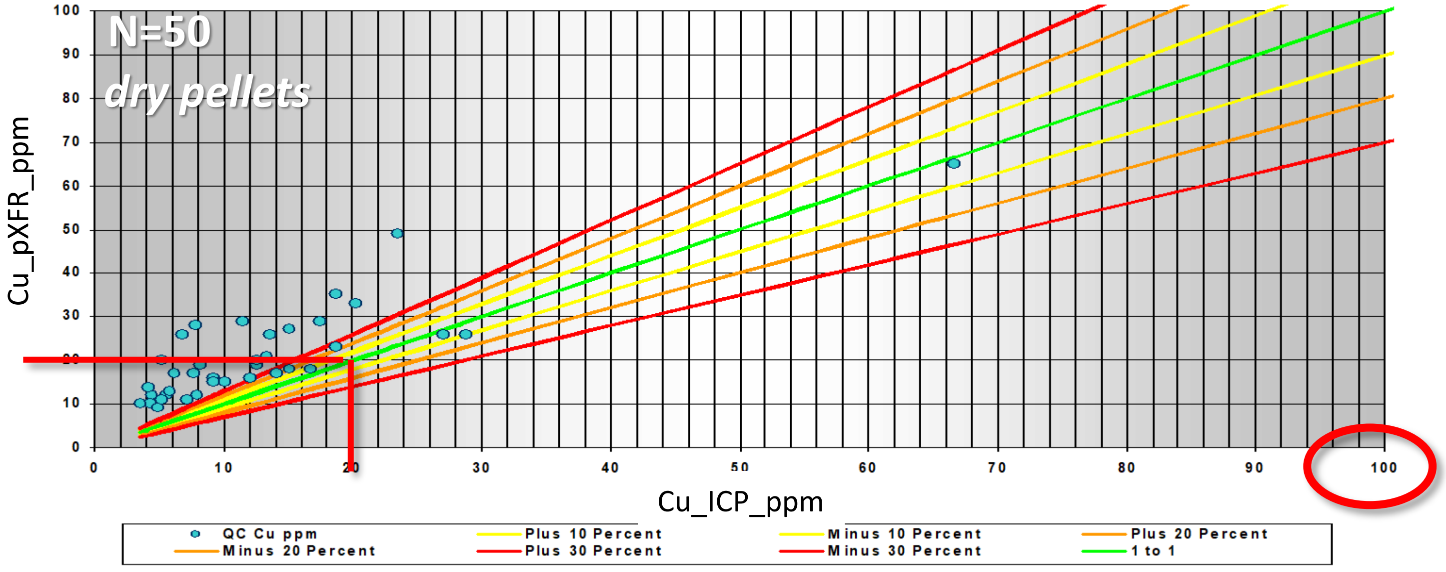
Data <15 ppm is ”noisier” but difficult to improve due to limitations of the pXRF.

Drying of pellets seems to improve the data with less ”ND” results of the duplicate sample.

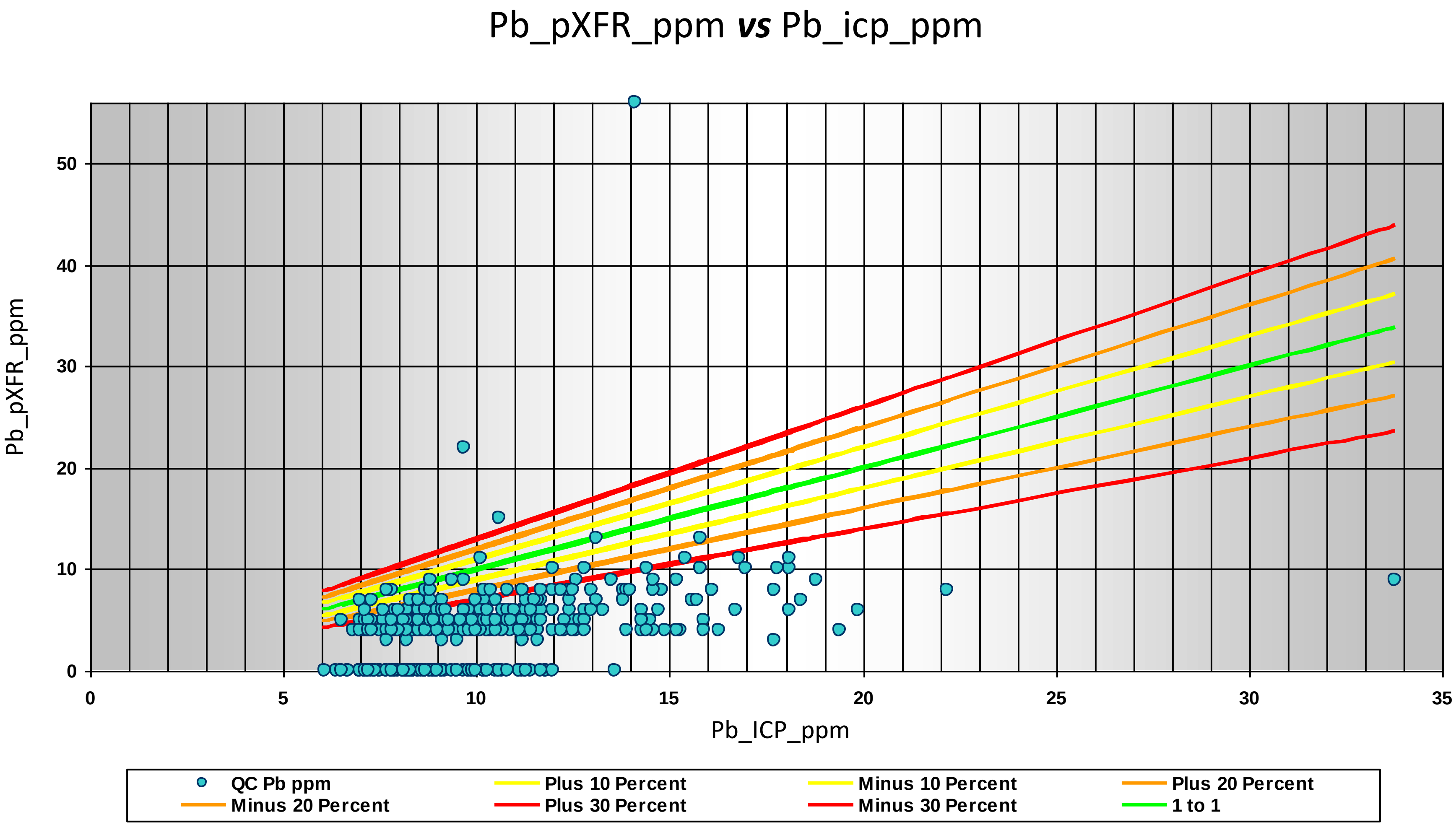
Cu_pXFR_ppm ***vs*** Cu_icp_ppm



Cu_pXFR_ppm ***vs*** Cu_icp_ppm

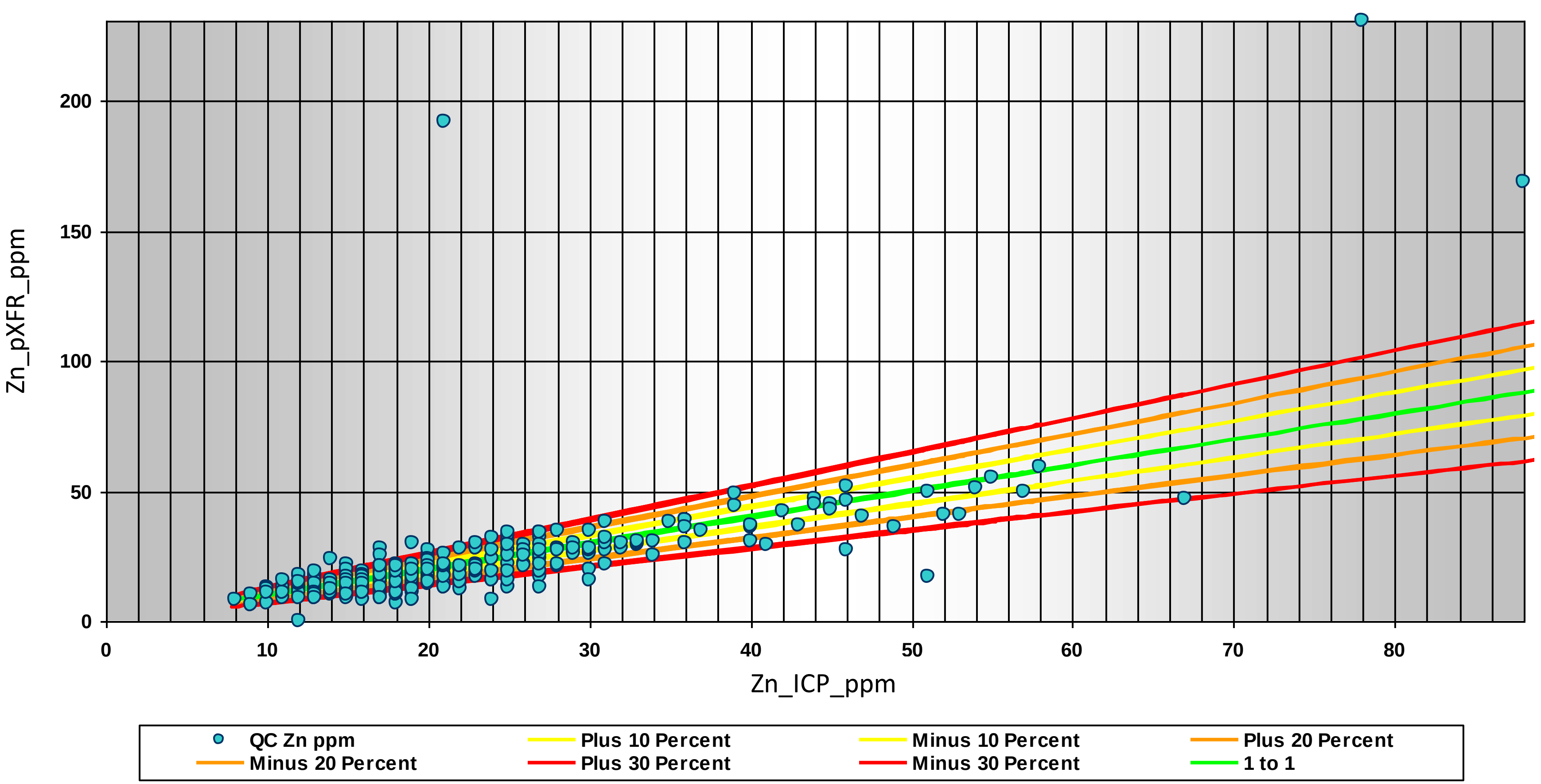


Pb results

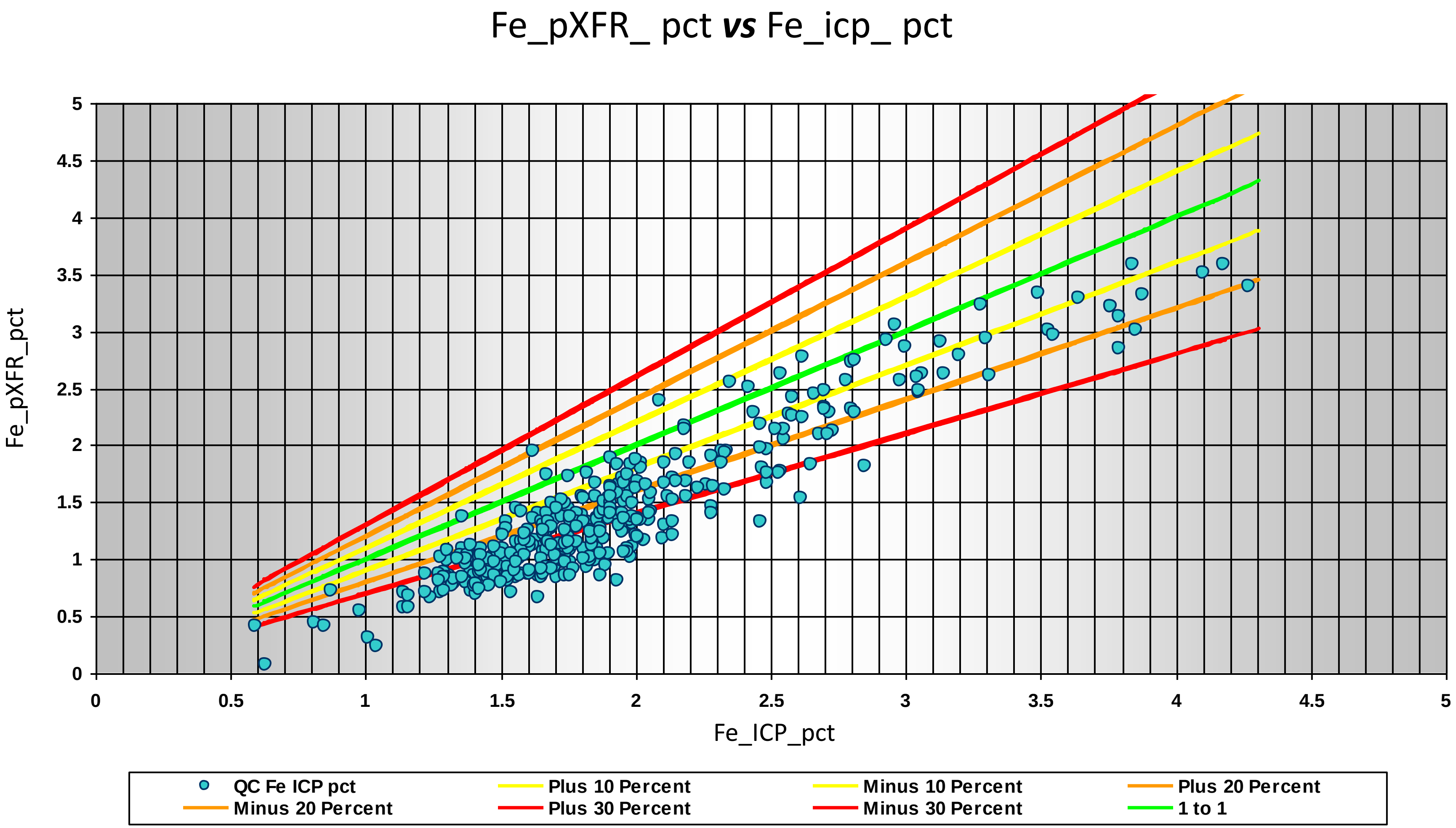

Pb_pXFR_ppm *vs* Pb_icp_ppm
Pb_pXFR_ppm
Pb_ICP_ppm
0
10
20
30
40
50
0
5
10
15
20
25
30
35
QC Pb ppm
Plus 10 Percent
Minus 10 Percent
Plus 20 Percent
Minus 20 Percent
Plus 30 Percent
Minus 30 Percent
1 to 1

Zn results

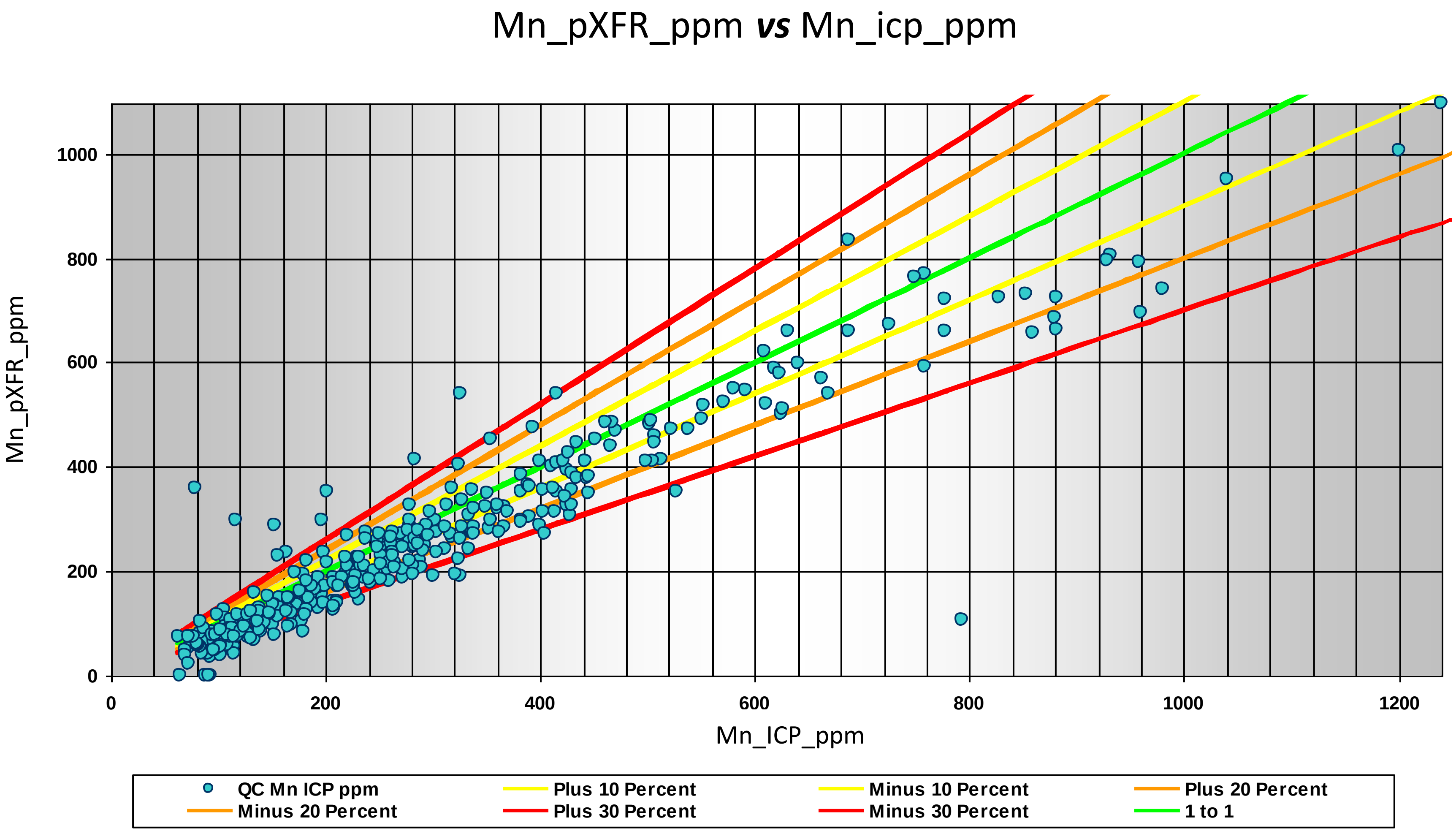
Zn_pXFR_ppm ***vs*** Zn_icp_ppm



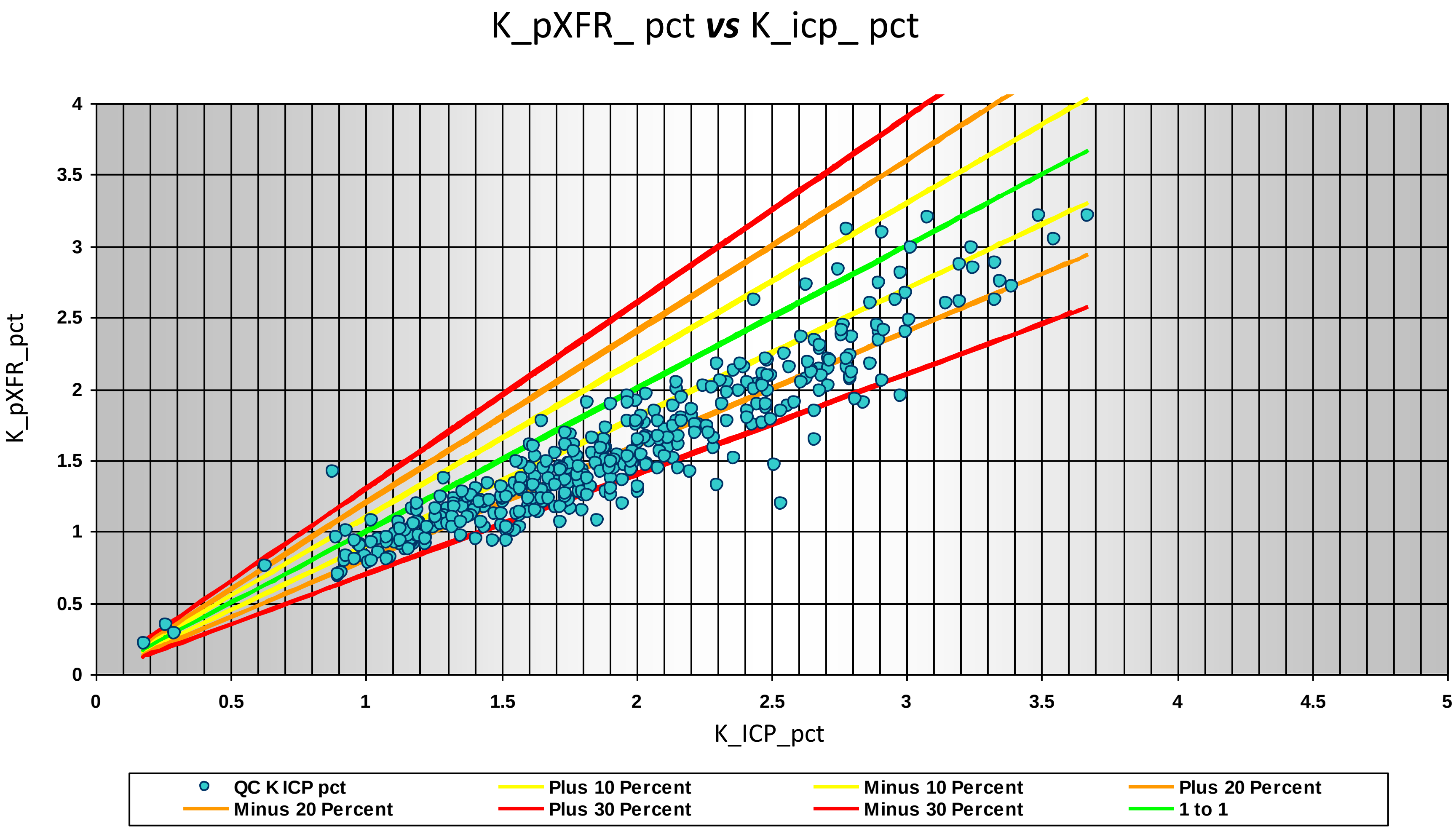
Fe results


Fe_pXFR_ pct vs Fe_icp_ pct
Fe_pXFR_pct
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Fe_ICP_pct
QC Fe ICP pct
Plus 10 Percent
Minus 10 Percent
Plus 20 Percent
Minus 20 Percent
Plus 30 Percent
Minus 30 Percent
1 to 1

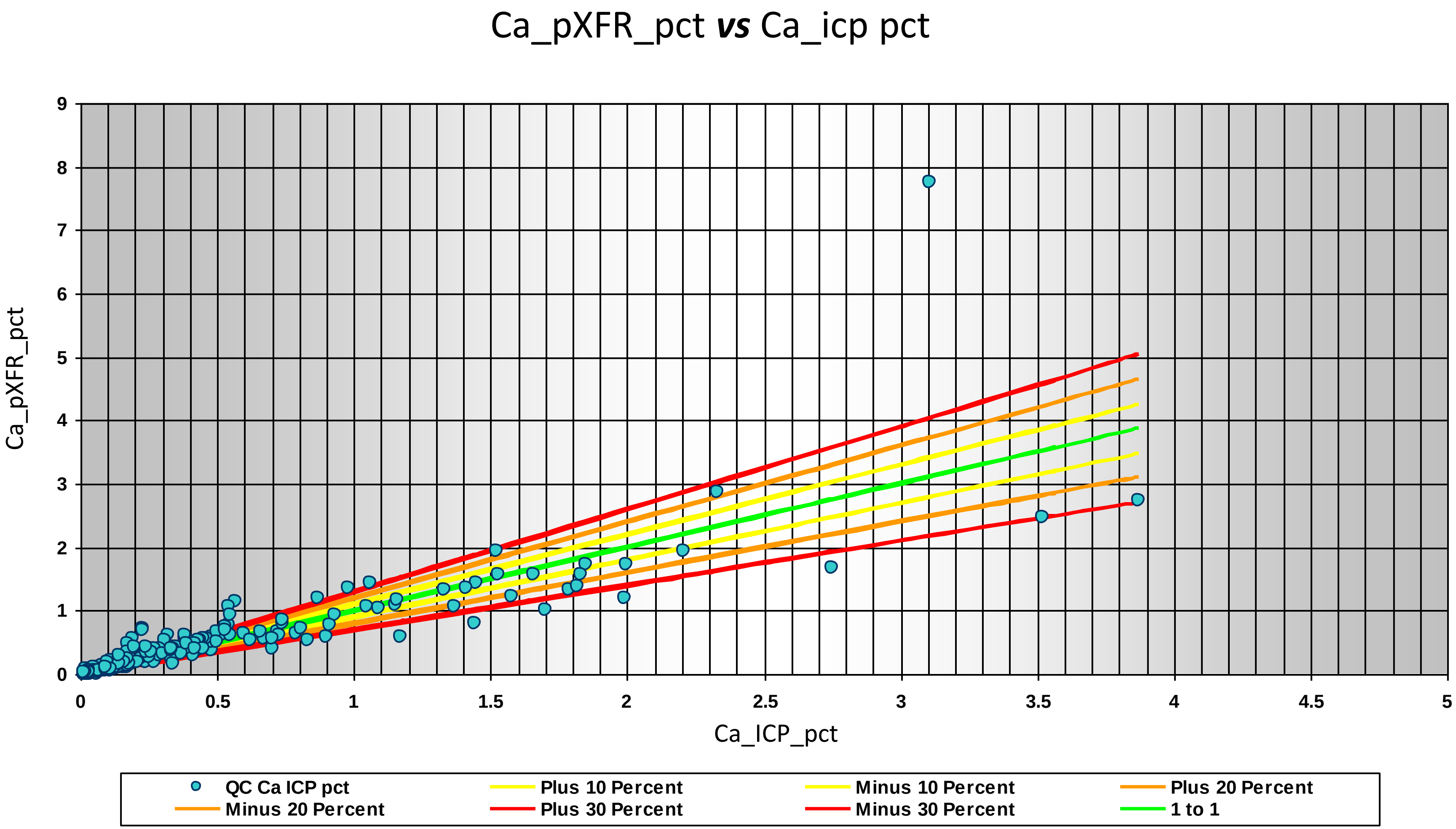
Mn results


Mn_pXFR_ppm vs Mn_icp_ppm
Mn_pXFR_ppm
0
200
400
600
800
1000
0
200
400
600
800
1000
1200
Mn_ICP_ppm
QC Mn ICP ppm
Plus 10 Percent
Minus 10 Percent
Plus 20 Percent
Minus 20 Percent
Plus 30 Percent
Minus 30 Percent
1 to 1

K results

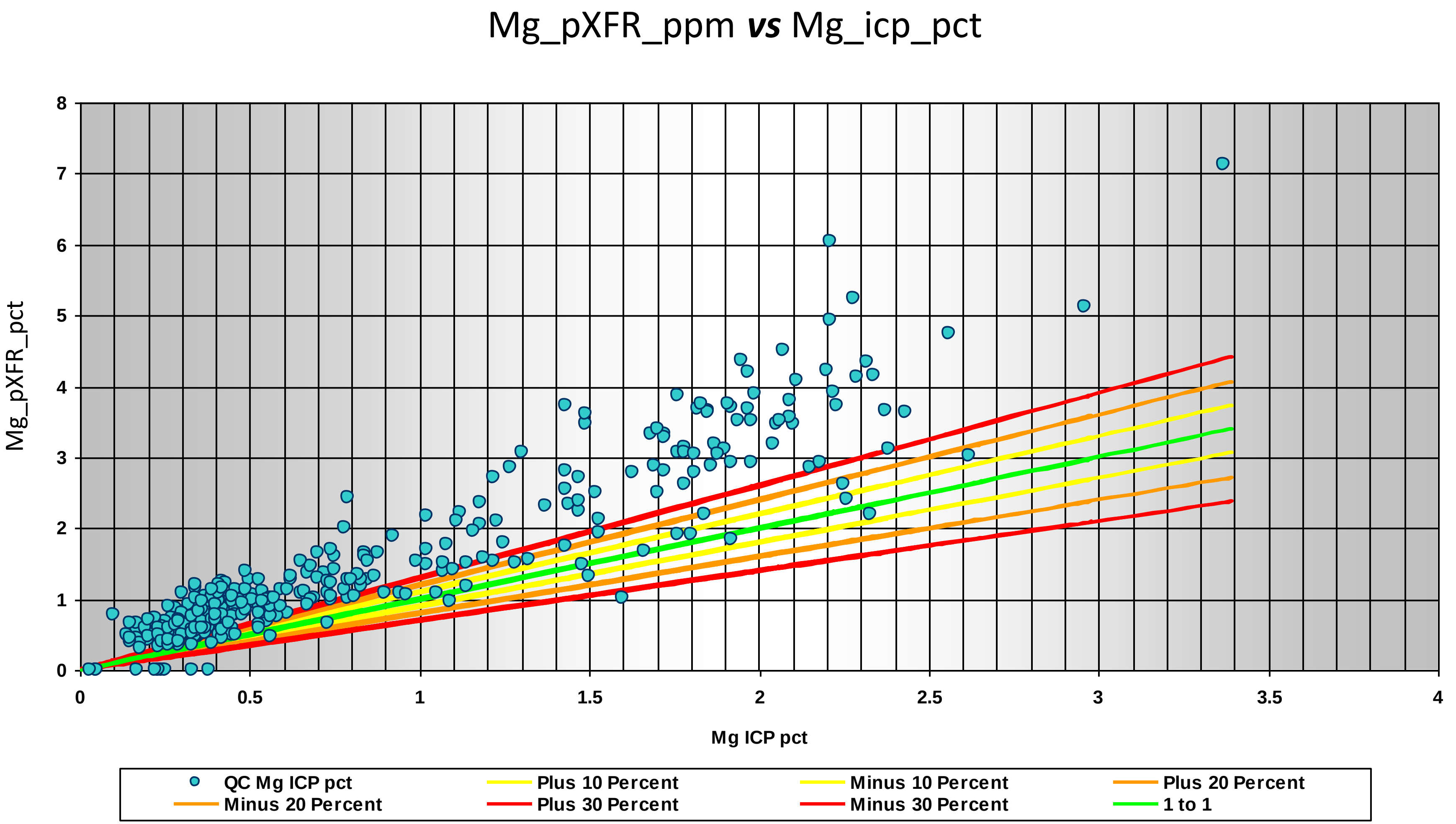

K_pXFR_ pct vs K_icp_ pct
K_pXFR_pct
K_ICP_pct
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
QC K ICP pct
Plus 10 Percent
Minus 10 Percent
Plus 20 Percent
Minus 20 Percent
Plus 30 Percent
Minus 30 Percent
1 to 1

Ca results



Ca_pXFR_pct vs Ca_icp pct
Ca_pXFR_pct
Ca_ICP_pct
9
8
7
6
5
4
3
2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
QC Ca ICP pct
Plus 10 Percent
Minus 10 Percent
Plus 20 Percent
Minus 20 Percent
Plus 30 Percent
Minus 30 Percent
1 to 1

Mg results



Mg_pXFR_ppm vs Mg_icp_pct
Mg_pXFR_pct
Mg ICP pct
0
1
2
3
4
5
6
7
8
0
0.5
1
1.5
2
2.5
3
3.5
4
QC Mg ICP pct
Plus 10 Percent
Minus 10 Percent
Plus 20 Percent
Minus 20 Percent
Plus 30 Percent
Minus 30 Percent
1 to 1

Field duplicates pXRF

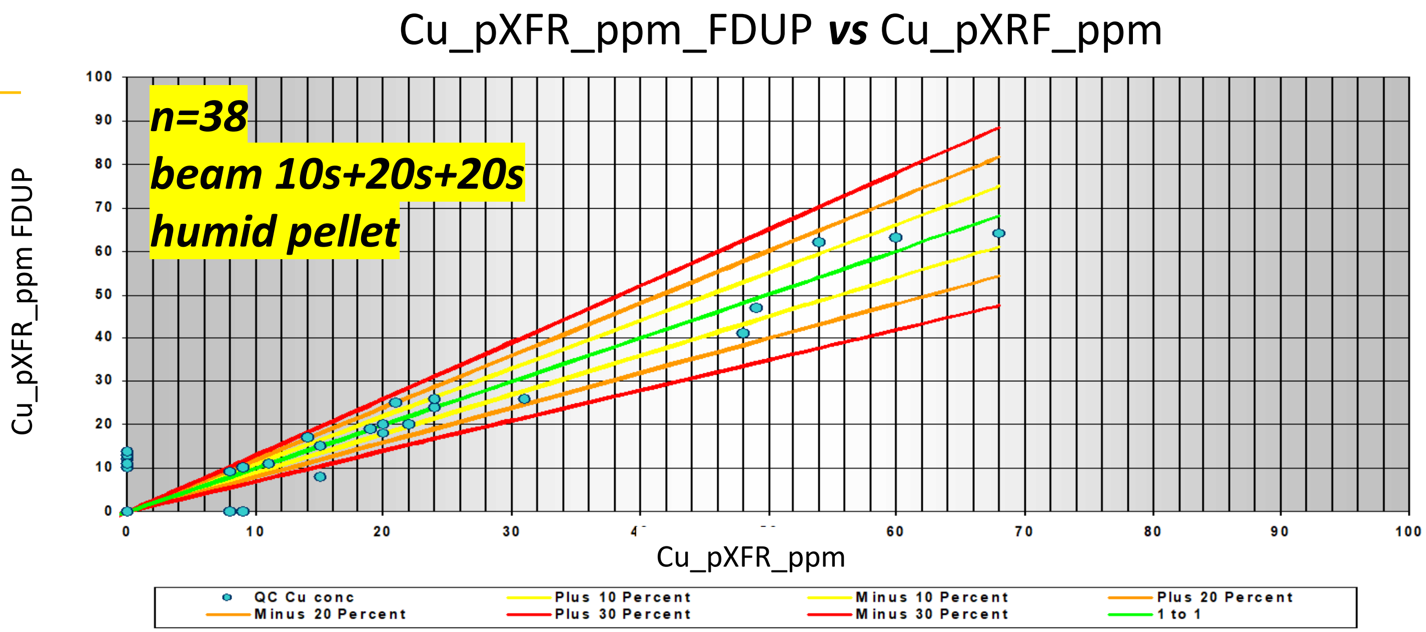
2^{nd} sample from the same sample hole.

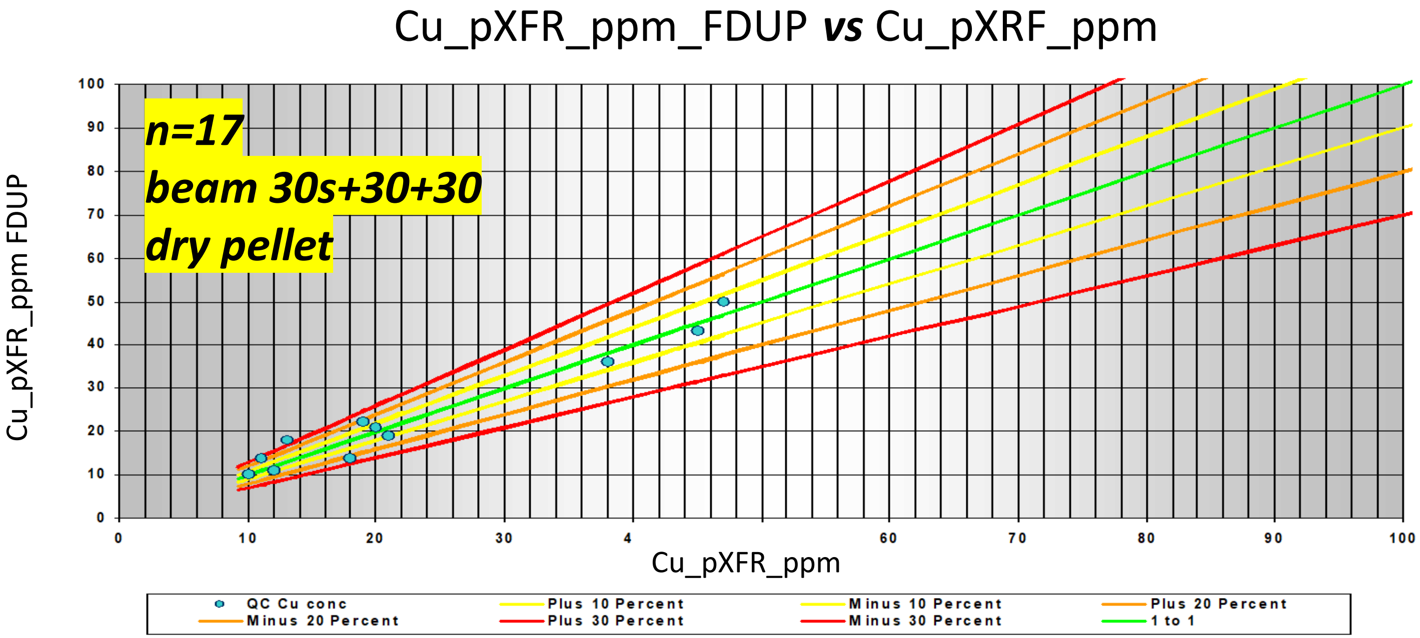
n= 55

Frequency 1 in 20

Fdup pXRF vs pXRF

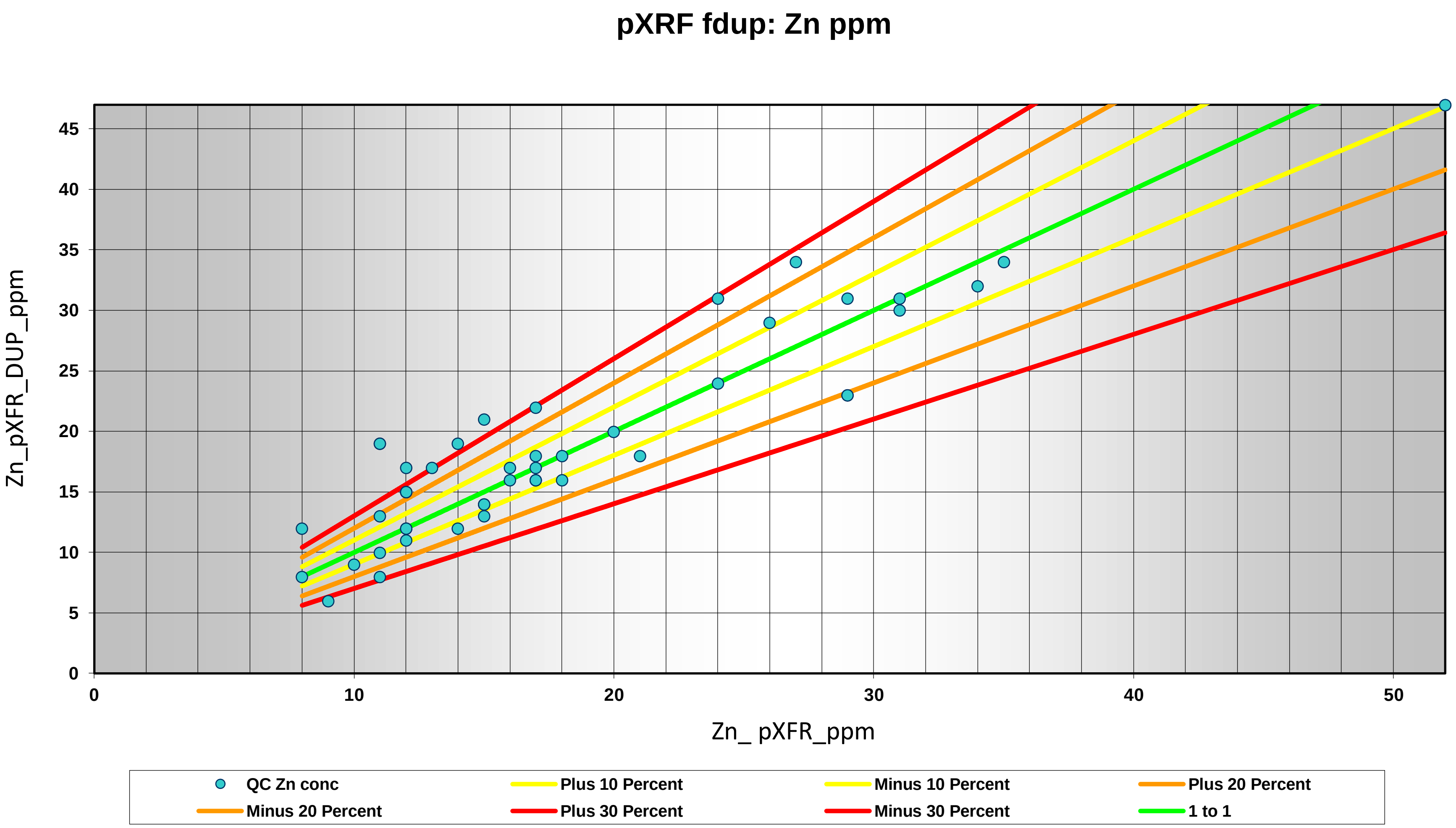
Cu results





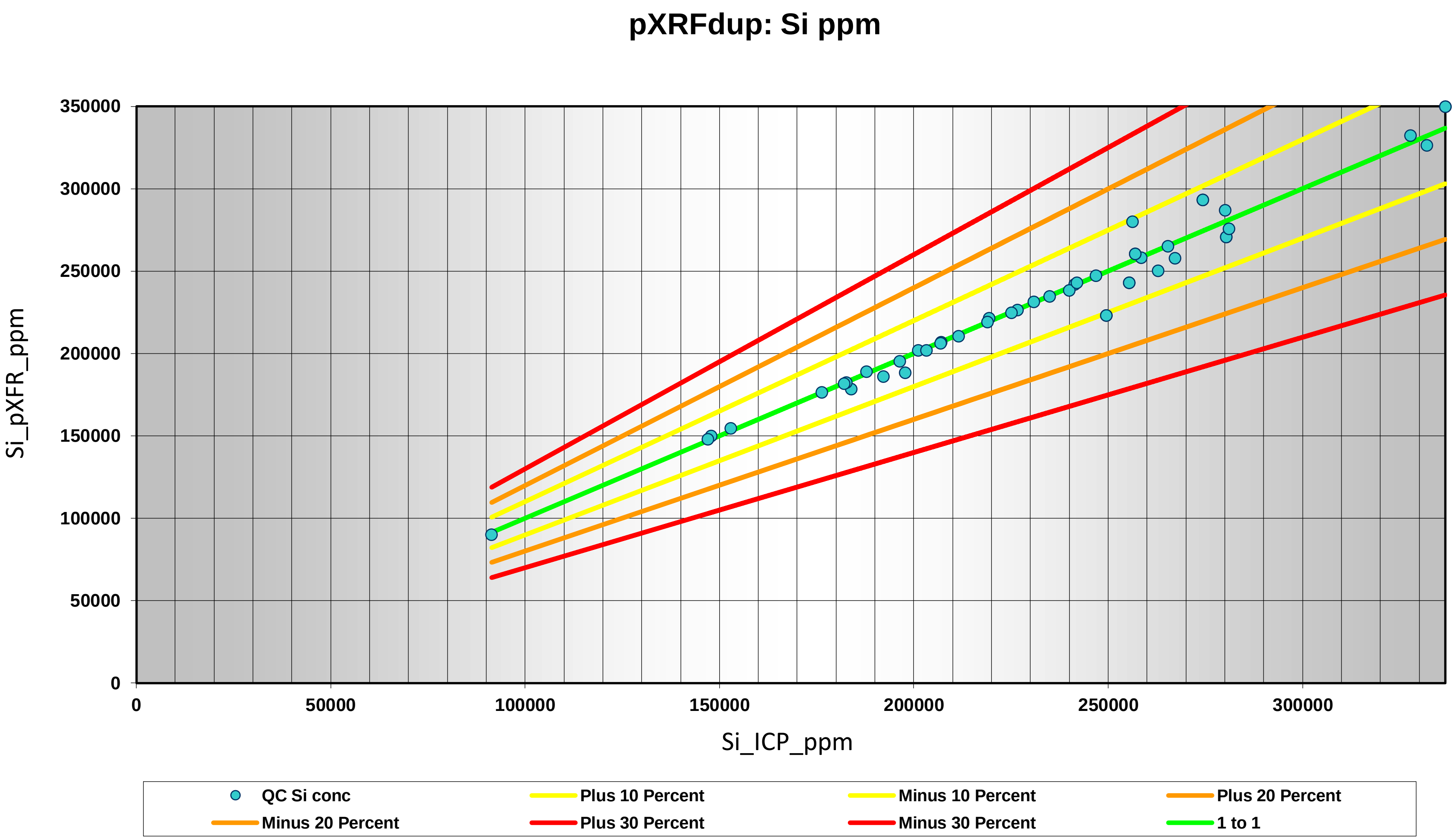
Fdup pXRF vs pXRF

Zn results



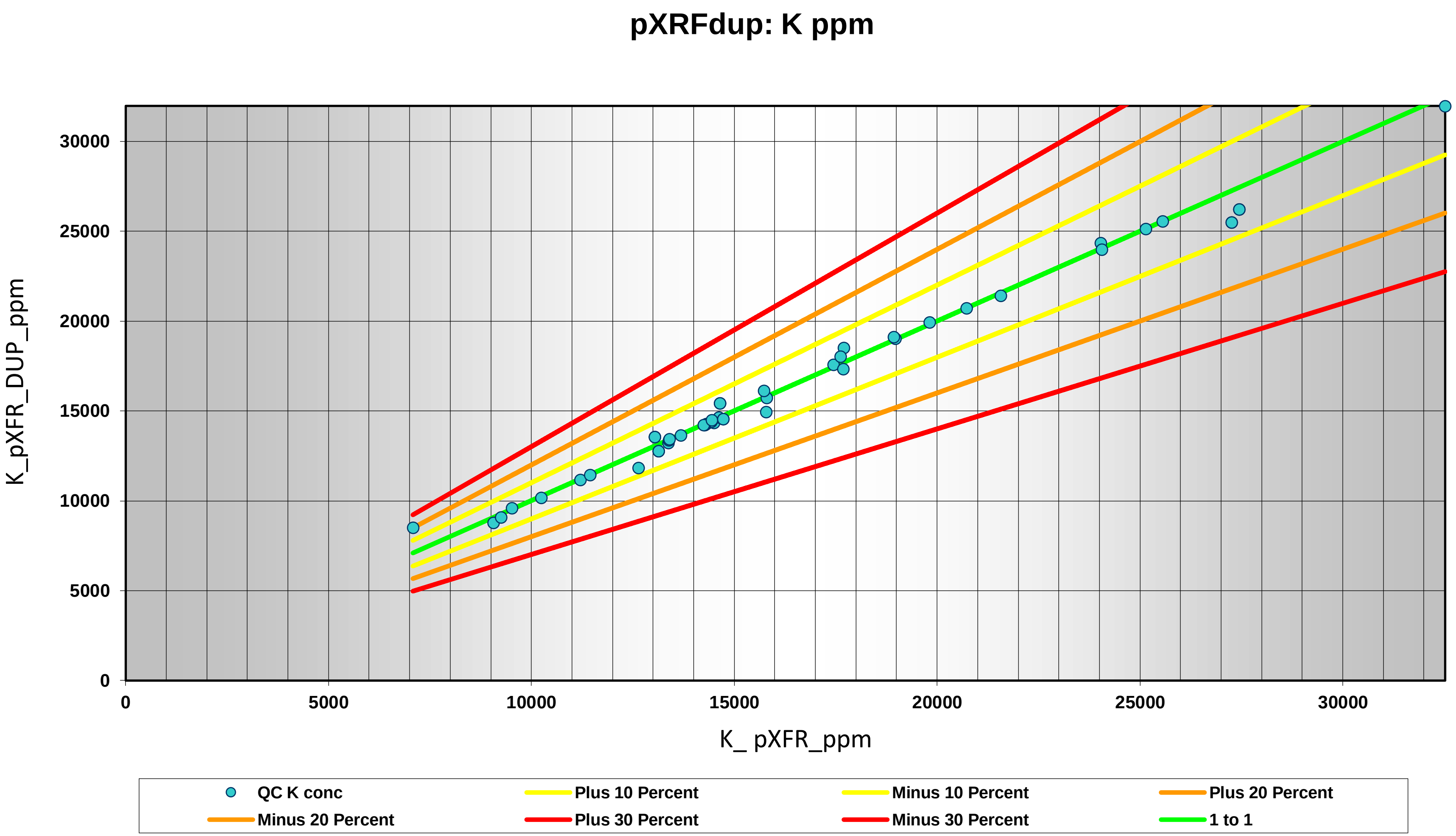
Fdup pXRF vs pXRF

Si results



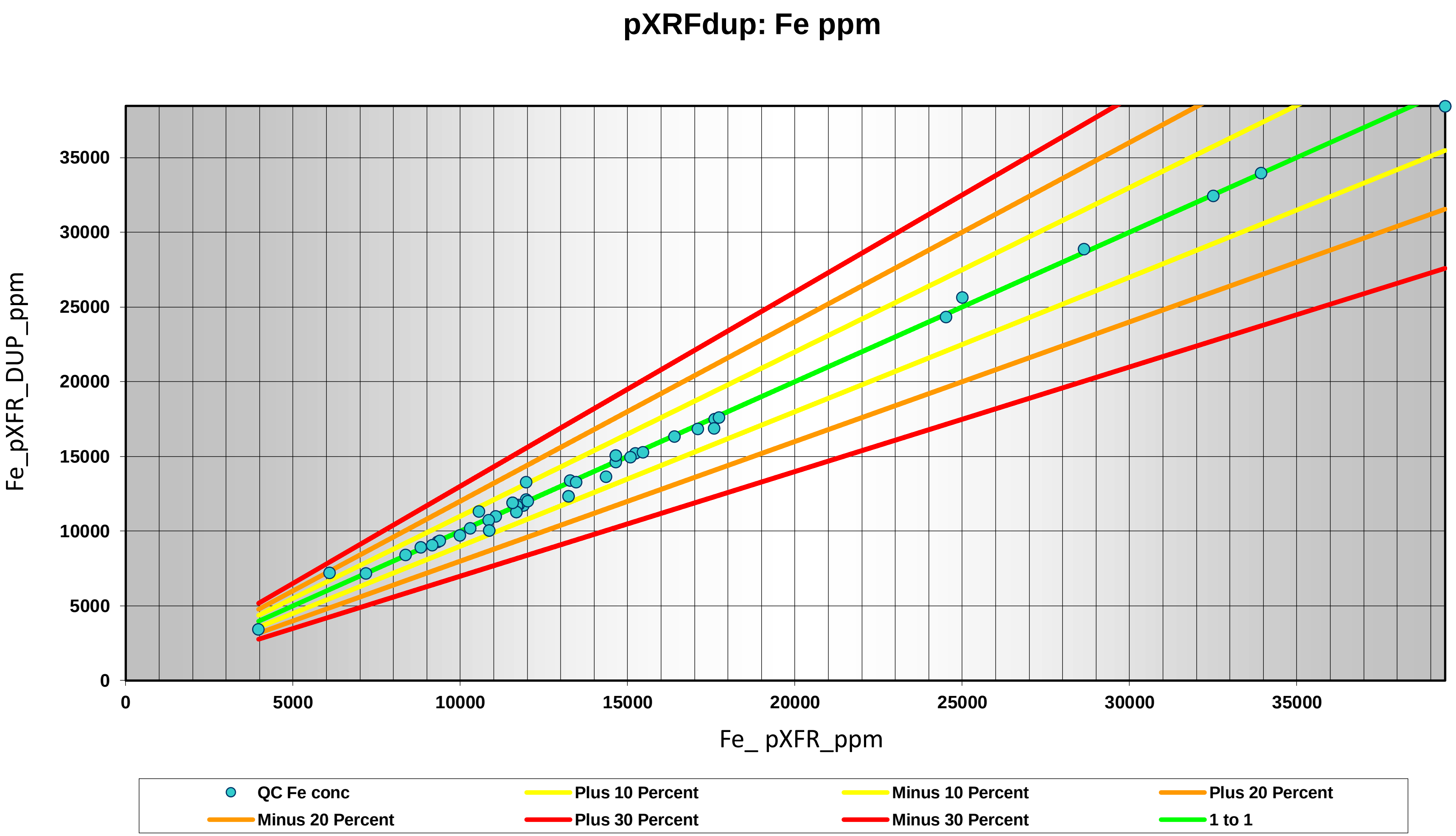
Fdup pXRF vs pXRF

K results

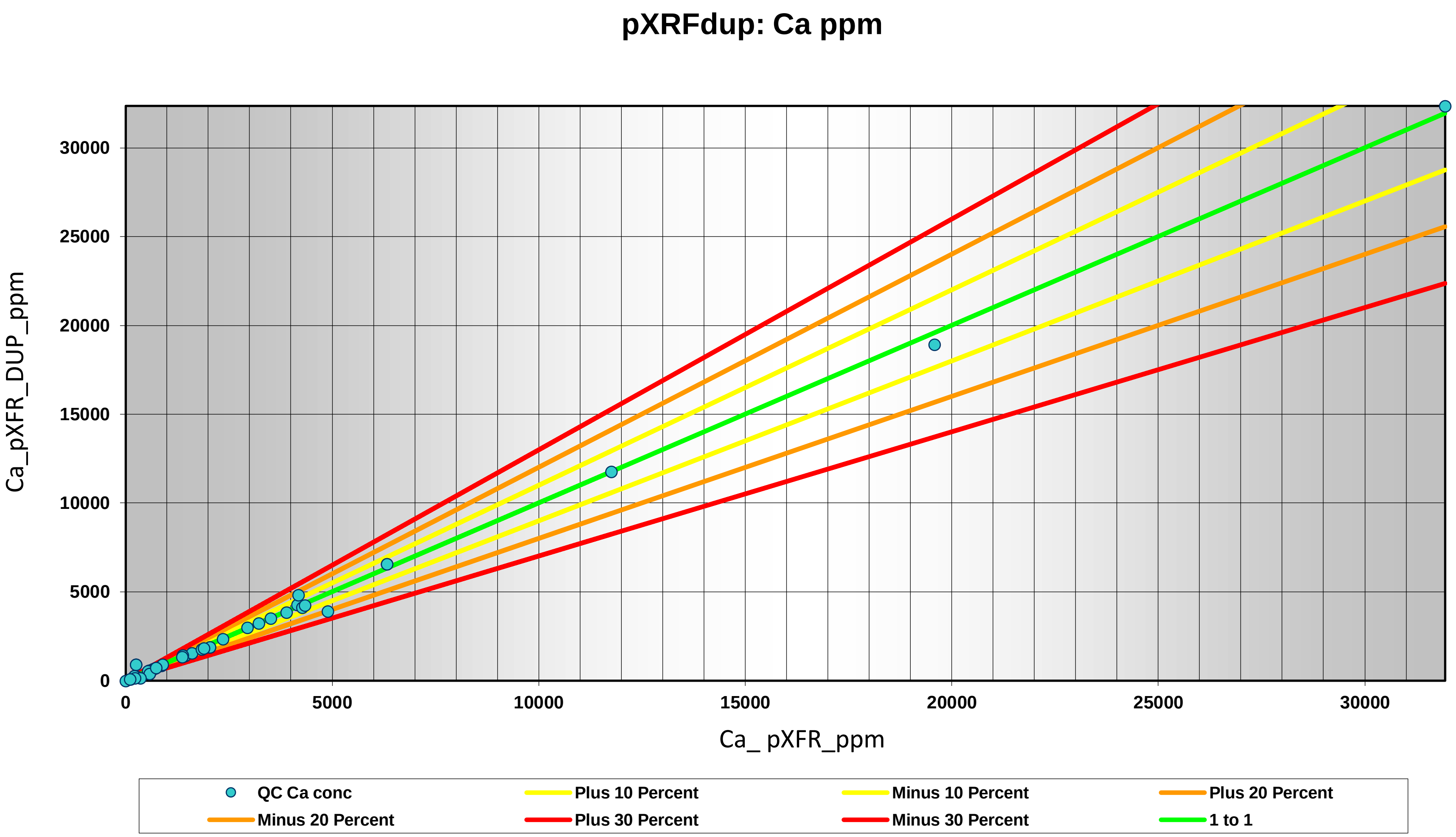


Fdup pXRF vs pXRF

Fe results



Ca results


pXRFdup: Ca ppm
Ca_pXFR_DUP_ppm
Ca_ pXFR_ppm
0
5000
10000
15000
20000
25000
30000
QC Ca conc
Plus 10 Percent
Minus 10 Percent
Plus 20 Percent
Minus 20 Percent
Plus 30 Percent
Minus 30 Percent
1 to 1

Fdup pXRF vs pXRF

Mg results