Predicting ML/ARD from Low Acid Potential and Low Carbonate Neutralization Potential Rock

Baffinland Iron Mines, Mary River Project, Nunavut, Canada

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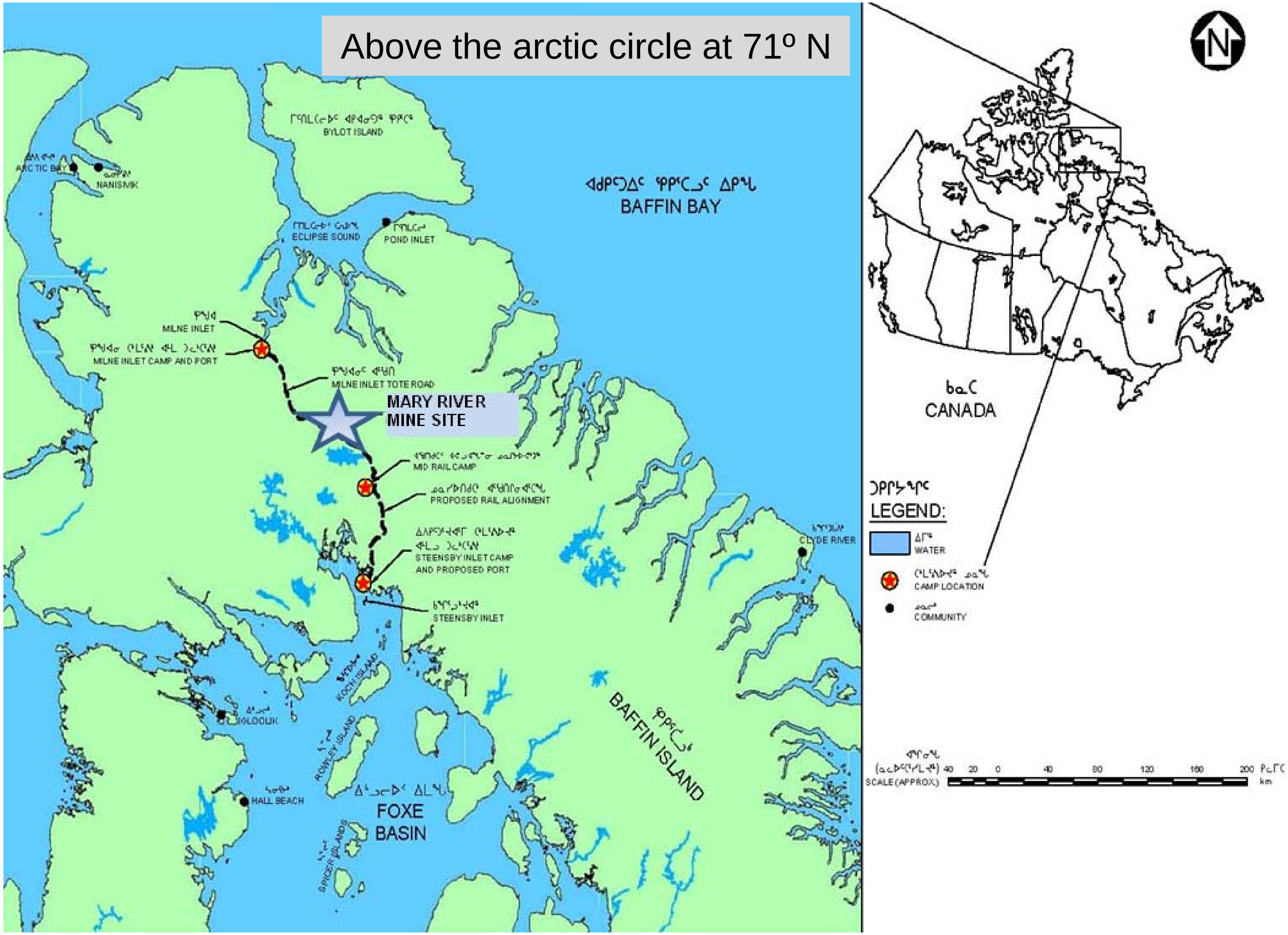
Acknowledgments

- Baffinland site support and geology staff.
- George H Wahl & Associates (modeling of waste types in pit).
- Knight Piésold (initial characterization work to 2009).

Outline

- Background
  - Site Location and setting.
  - Description of the ore.
- Waste rock geology and waste types.
- Summary of characterization work and results.
- Continuing and future work.

Site Location



Site Setting and Climate

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- Very cold temperatures that average -30º Celsius in winter.
- 24-hour darkness from November to January.
- Summers with 24-hour daylight from May to August, but continued cool to cold condition.
- Average annual precipitation is 220 mm/year with ~75% falling between May and October.
- Continuous permafrost
  - Precipitation between October and May as snow.
  - Short melt and drainage period between June and September.

Mary River Project - Ore

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- Estimated 365 Mt of high grade direct ship lump and fine iron ore.
- Algoma type iron formation consisting of hematite, magnetite and mixed hematite-magnetite-specular hematite.
- Deposit consists of a number of lensoidal bodies.
  - vary in their proportion of the main iron oxide minerals and impurity content of sulphur and silica (rarely Mn and P).

Summary of Sampling

- Estimated 566 Mt waste rock.
- Staged ML/ARD sampling.

Program	Waste Rock Samples
2006-2008	97
2010	180
2011	377
2012	230/489

Sampled Waste Rock Volume 2011

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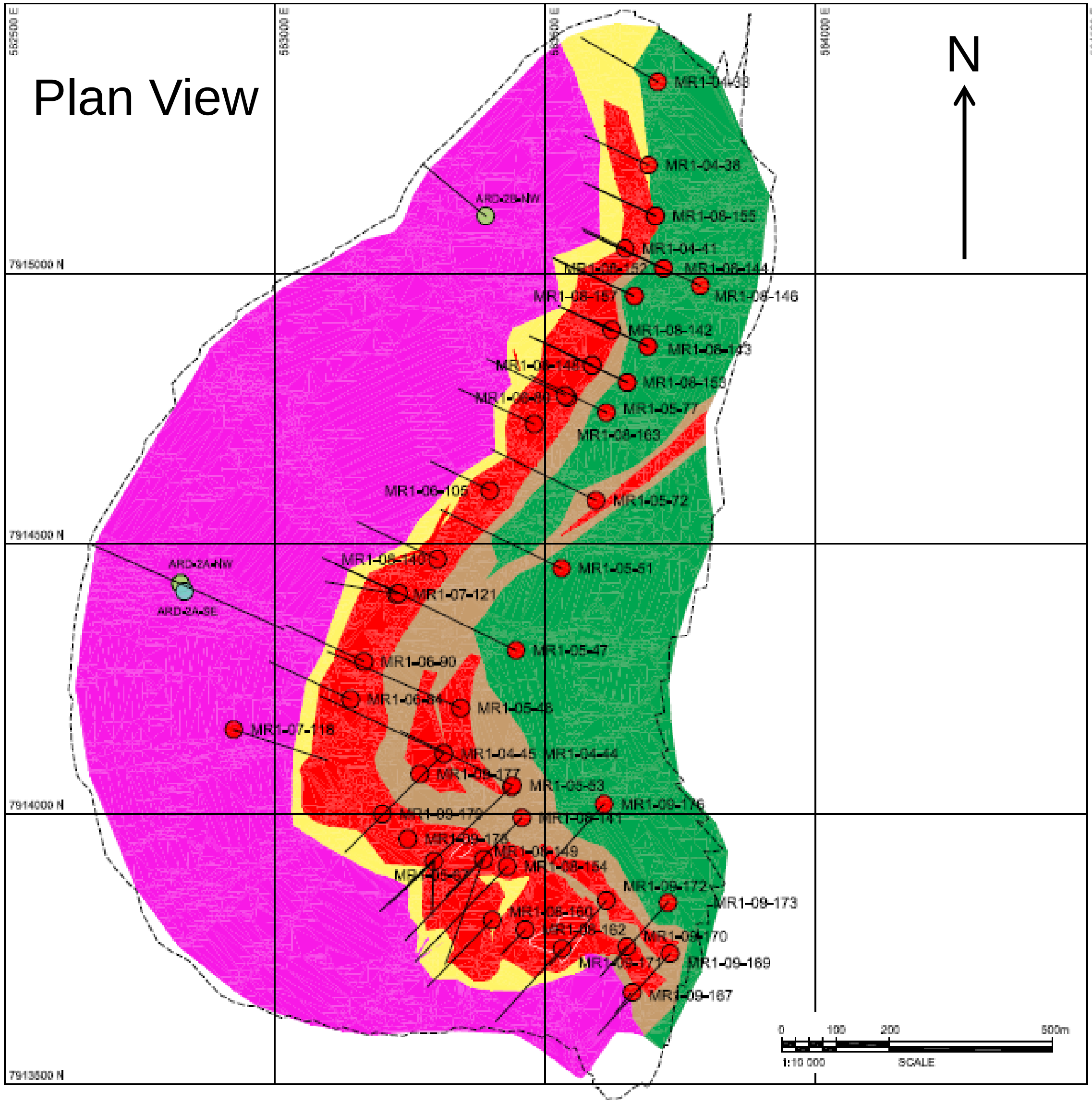

LEGEND:

- HIGH GRADE IRON FORMATION
- FOOT WALL SCHIST
- FOOT WALL WASTE (UNDIFFERENTIATED)
- HANGING WALL SCHIST
- HANGING WALL WASTE (UNDIFFERENTIATED)
- LIFE OF MINE PIT BOUNDARY

Sulphur Speciation

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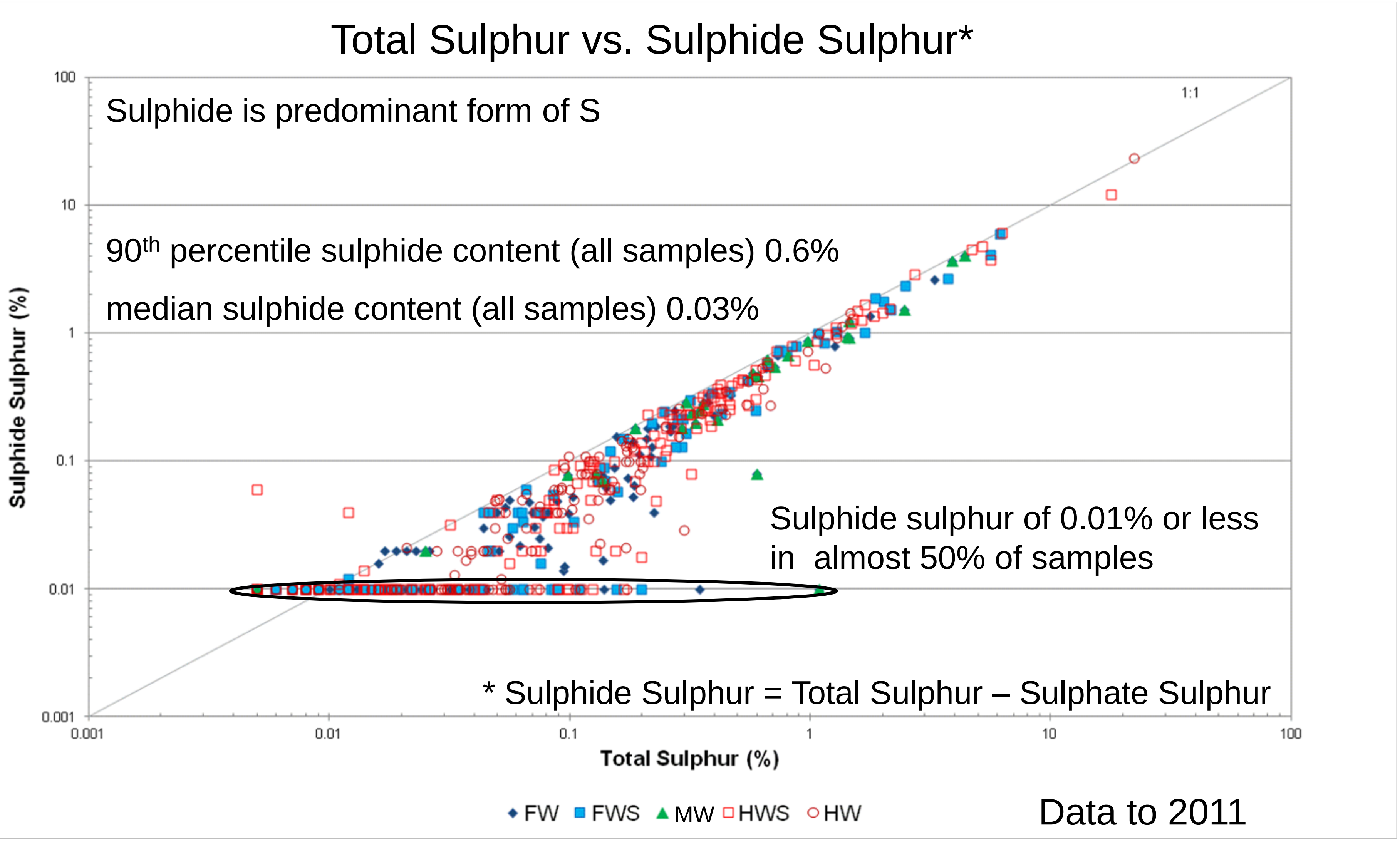
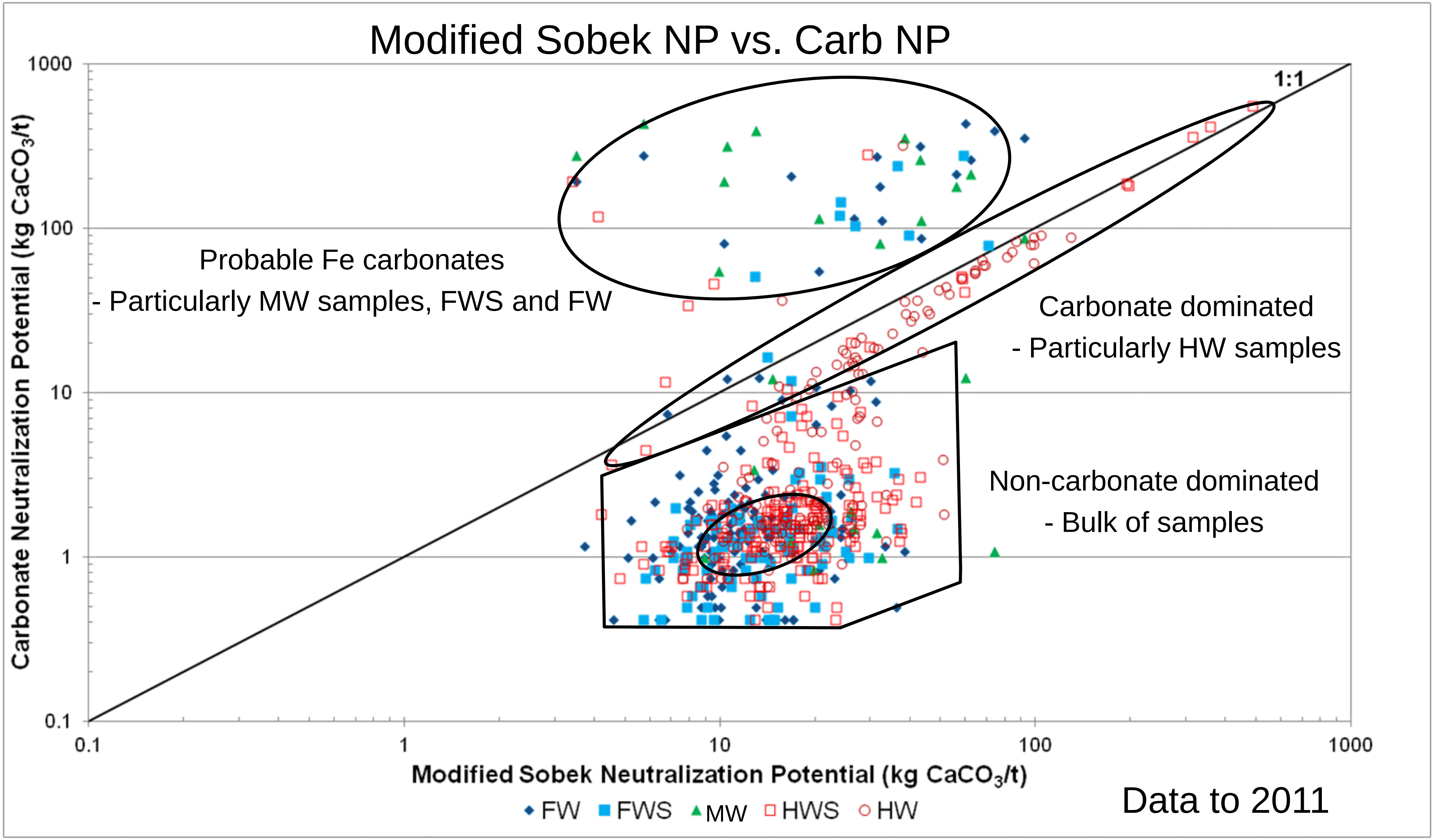
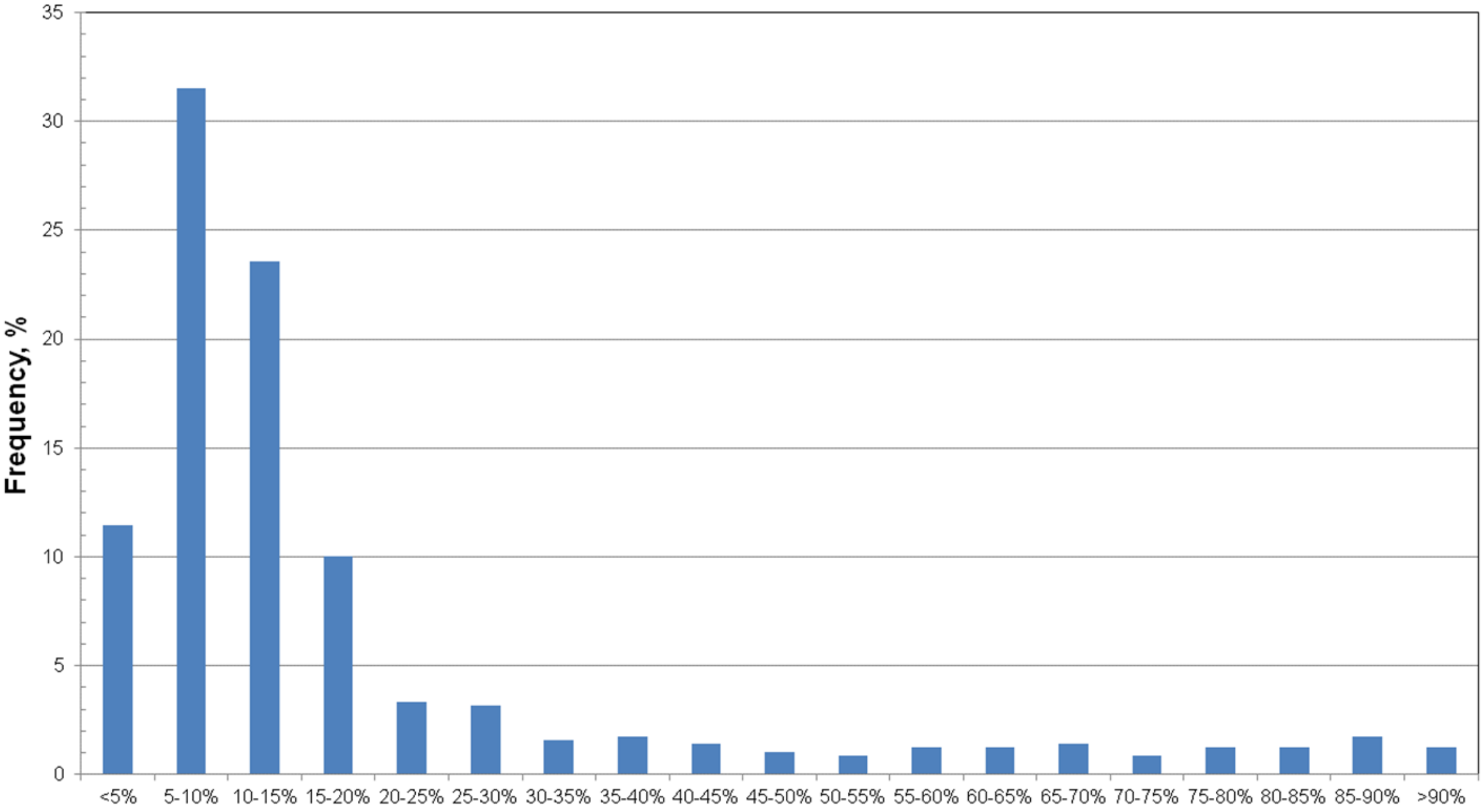


Evaluation of NP



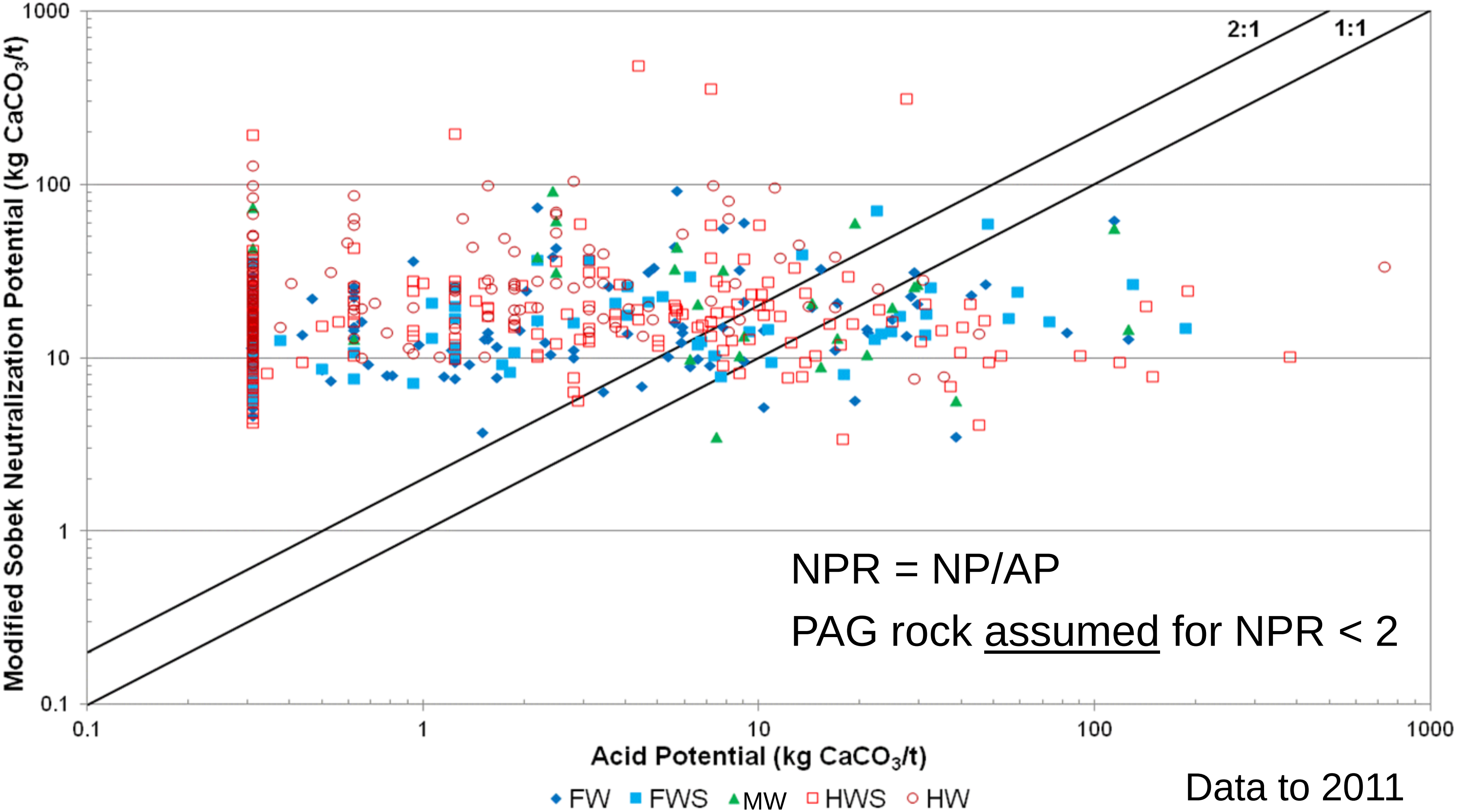
Carbonate is small portion of NP



Note: Based on 568 ABA samples.
Excludes 45 ABA samples with Carbonate NP > modified Sobek NP

Data to 2011

Neutralization potential ratio (NPR)

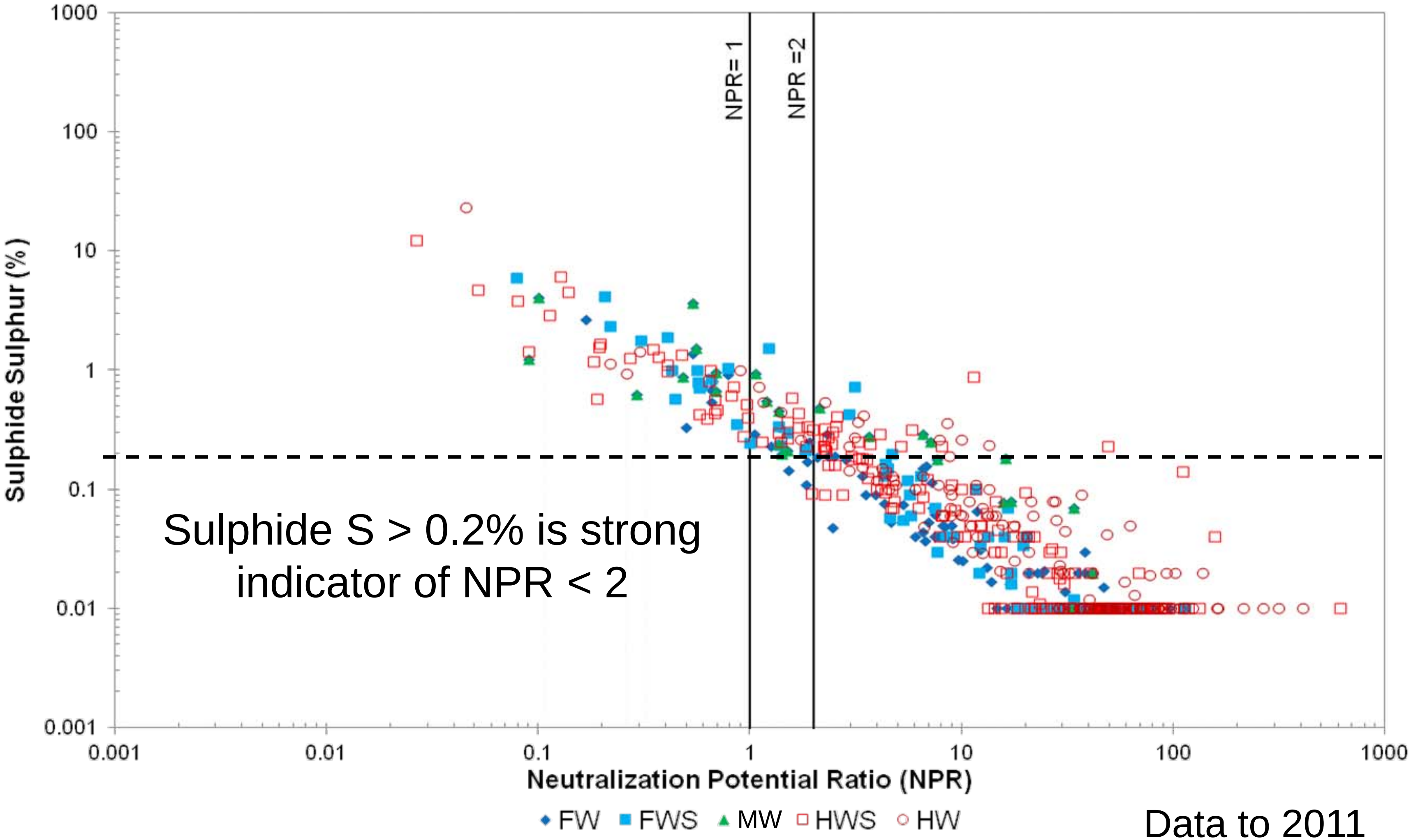


NPR = NP/AP

PAG rock <u>assumed</u> for NPR < 2

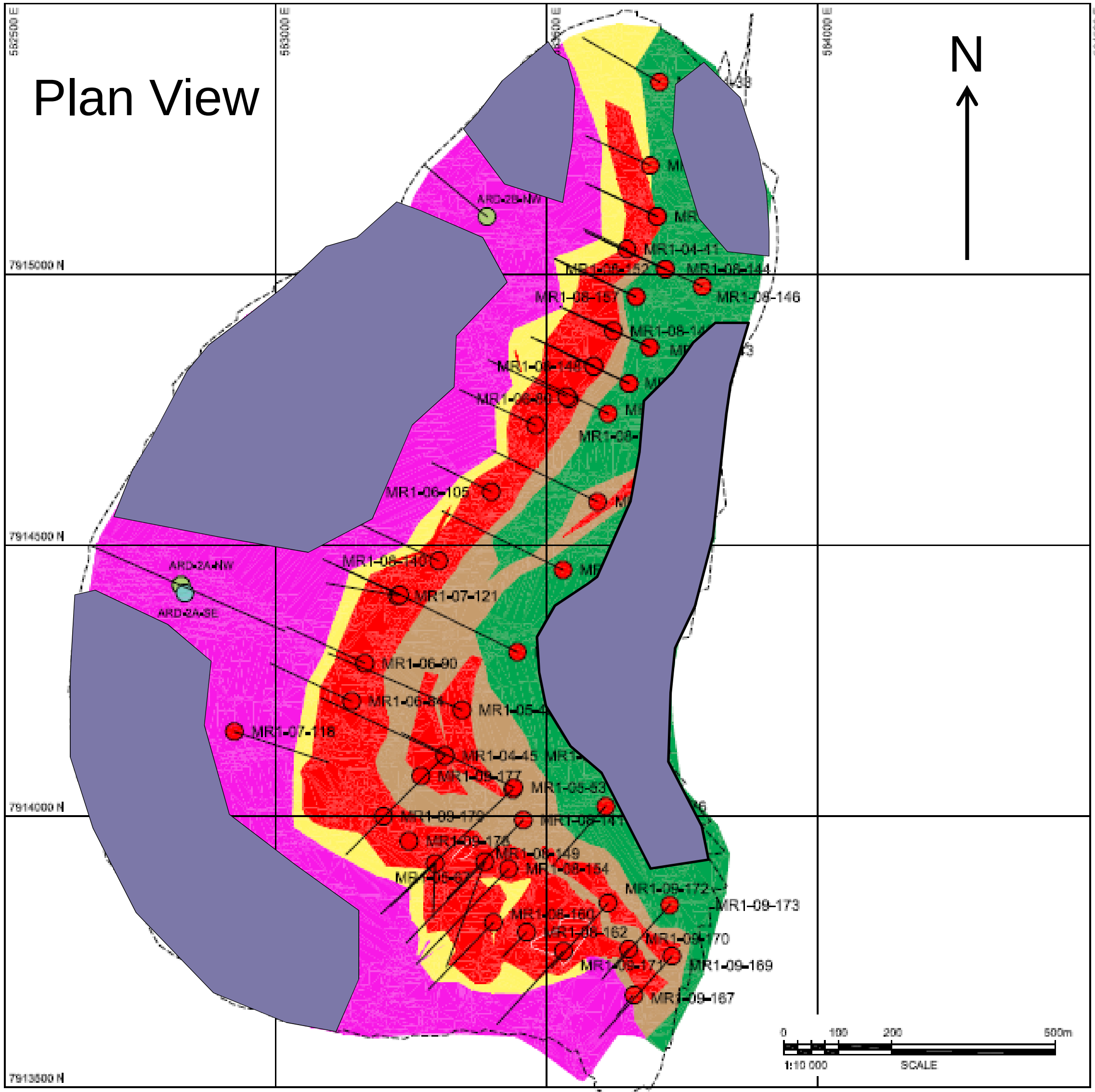
Data to 2011

NPR vs. Sulphide S



Data to 2011

Sampled Waste Rock Volume 2011



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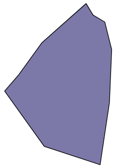
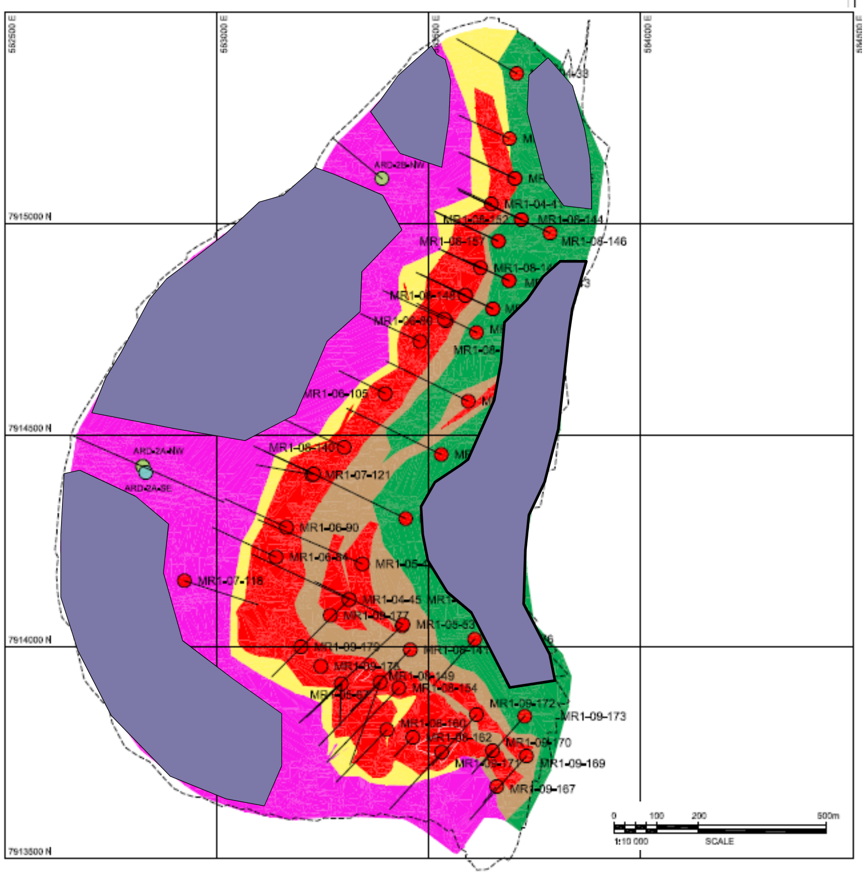
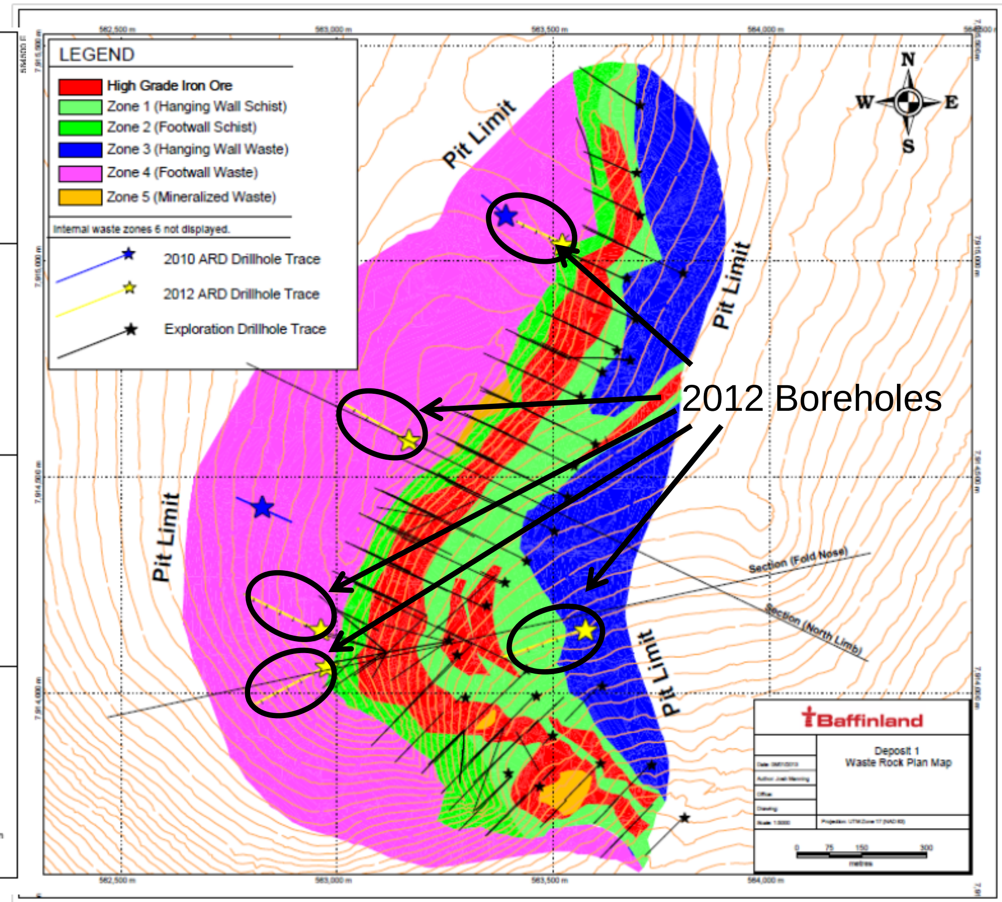


Unsampled regions of pit

- Estimated 15% PAG rock overall.

Waste Rock Drilling 2012





Modeled Waste Distribution in Pit 2013

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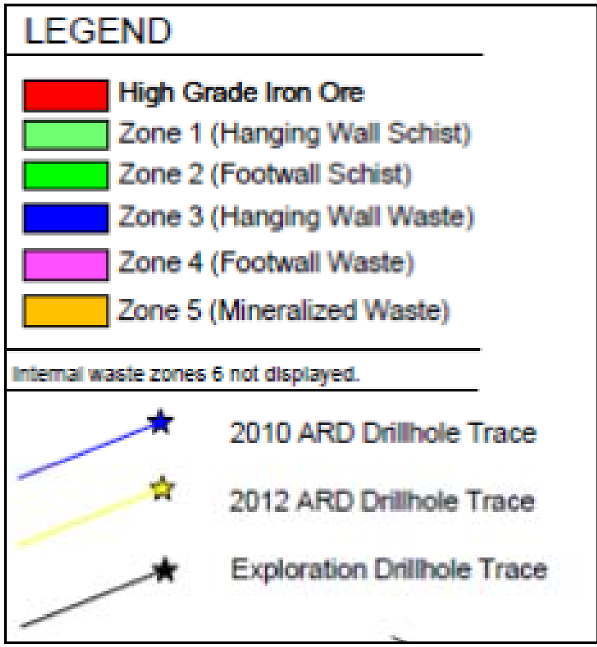
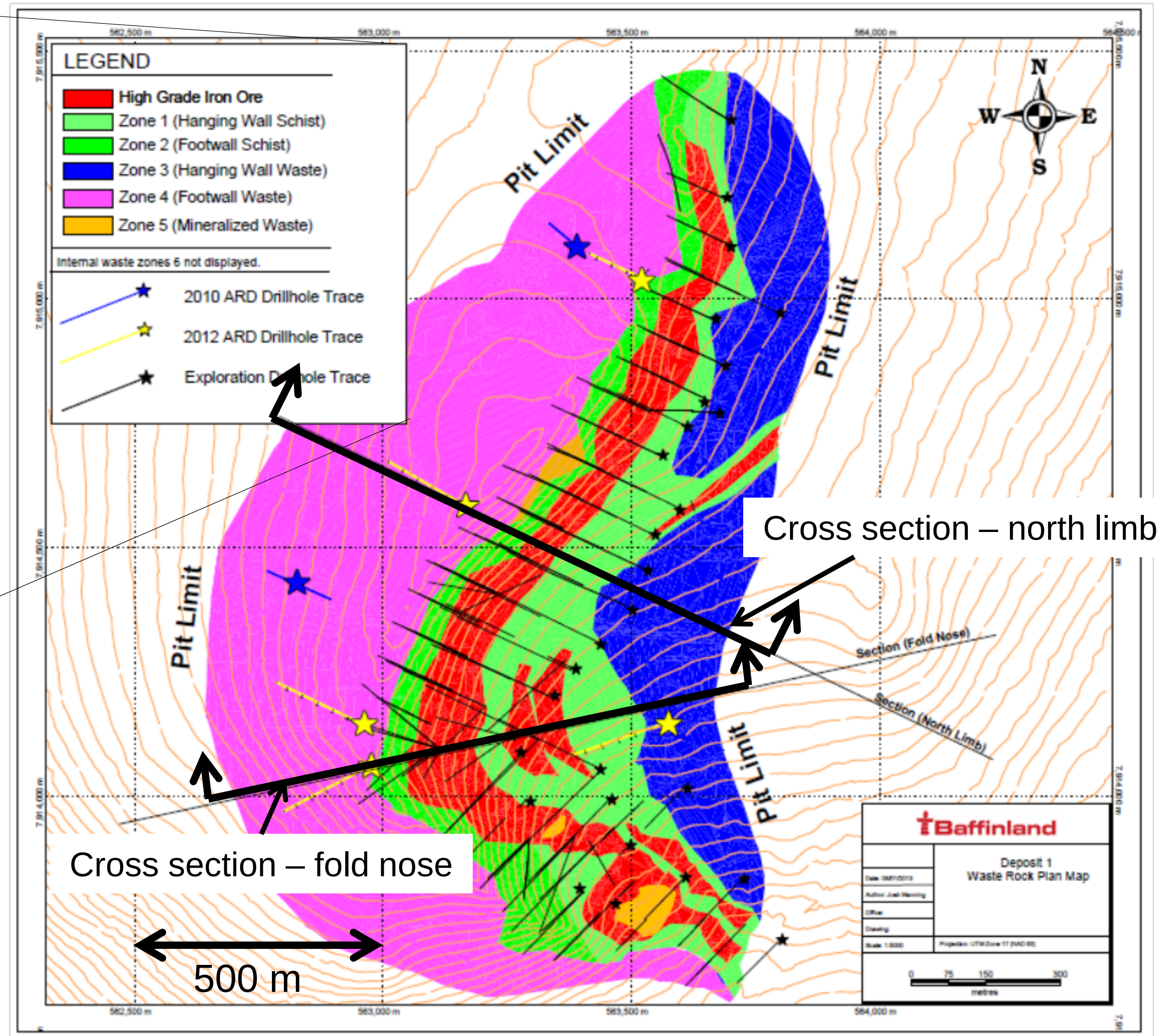
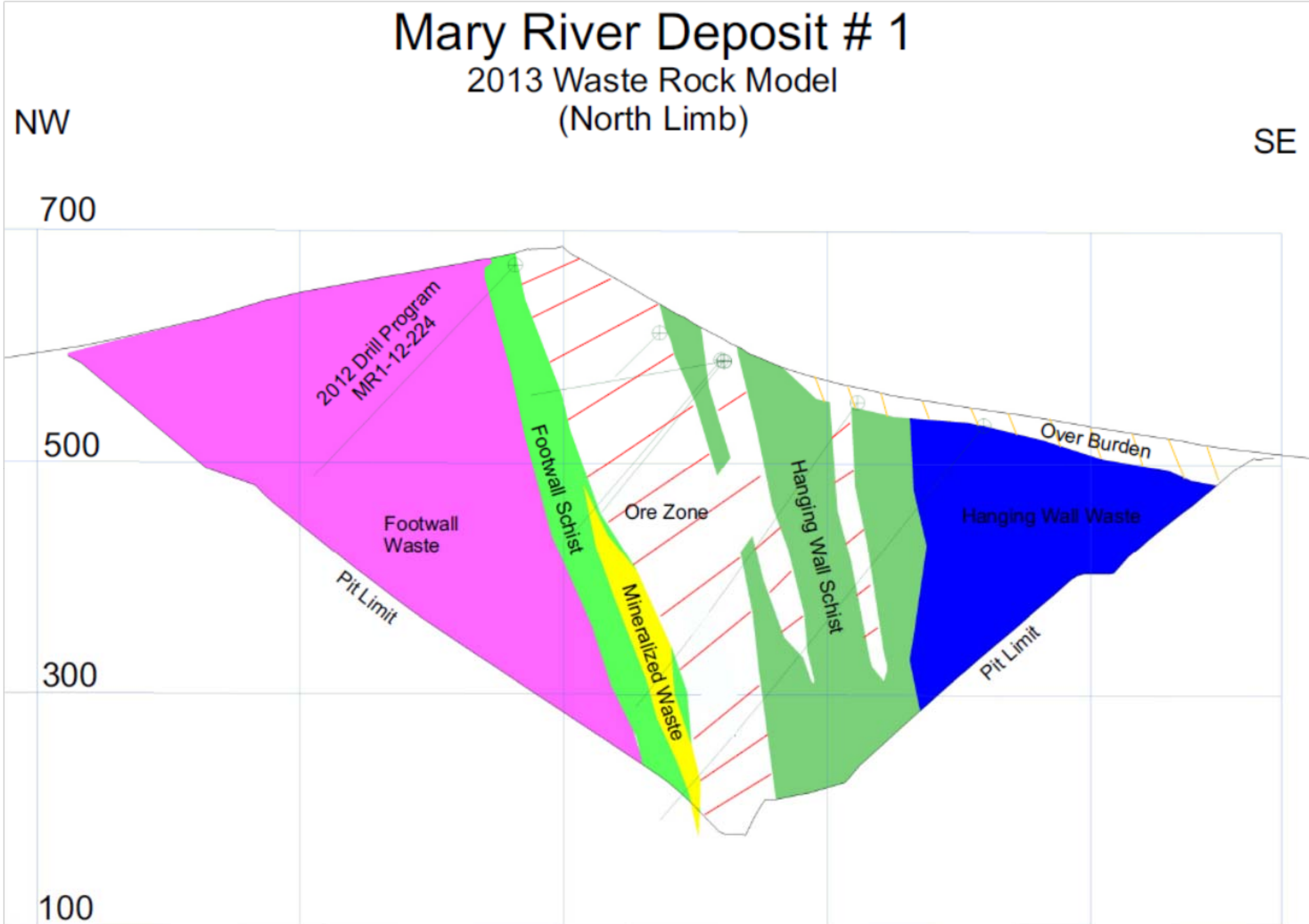


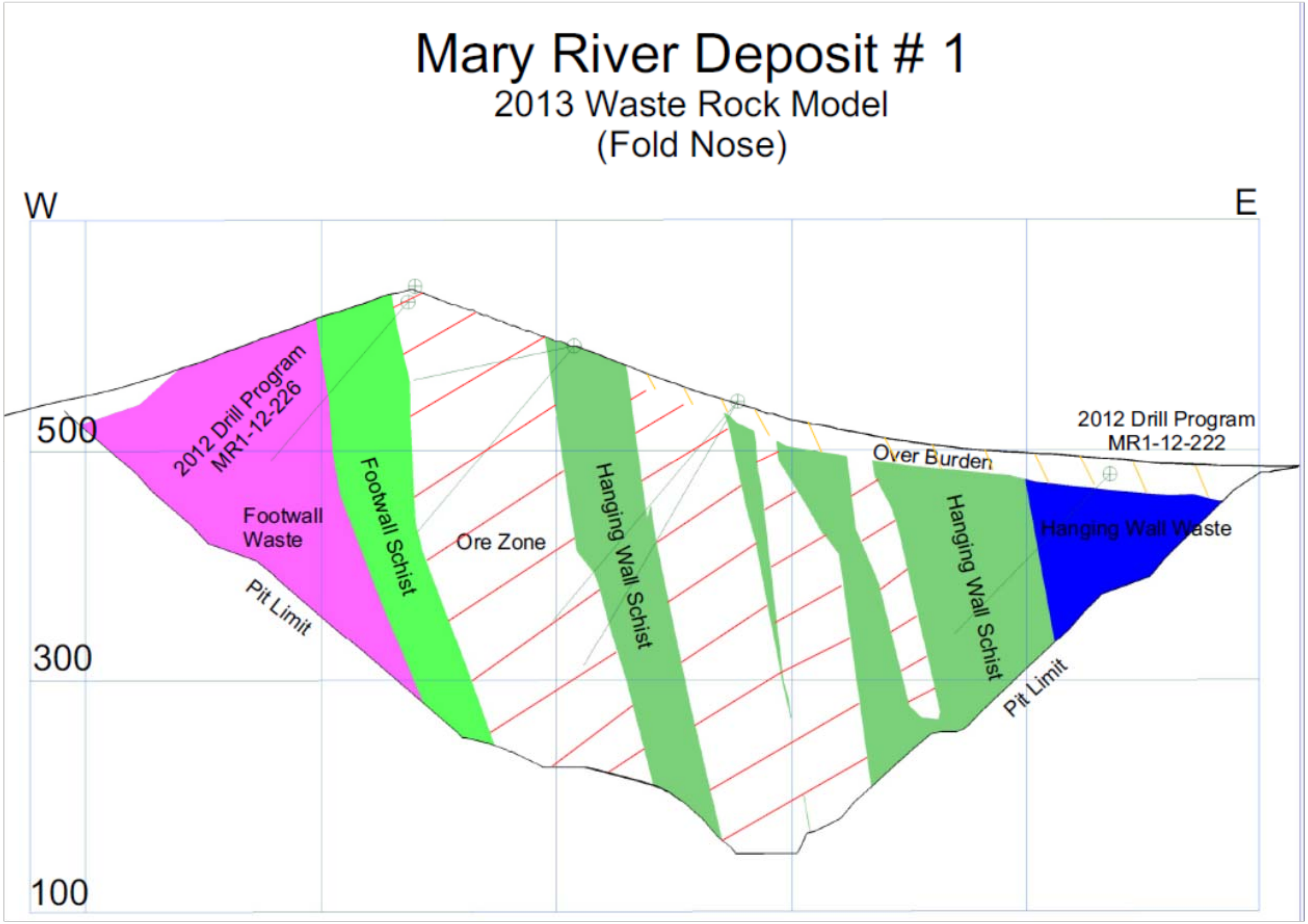


Plan View

Cross Section North Limb



Cross Section – Fold Nose

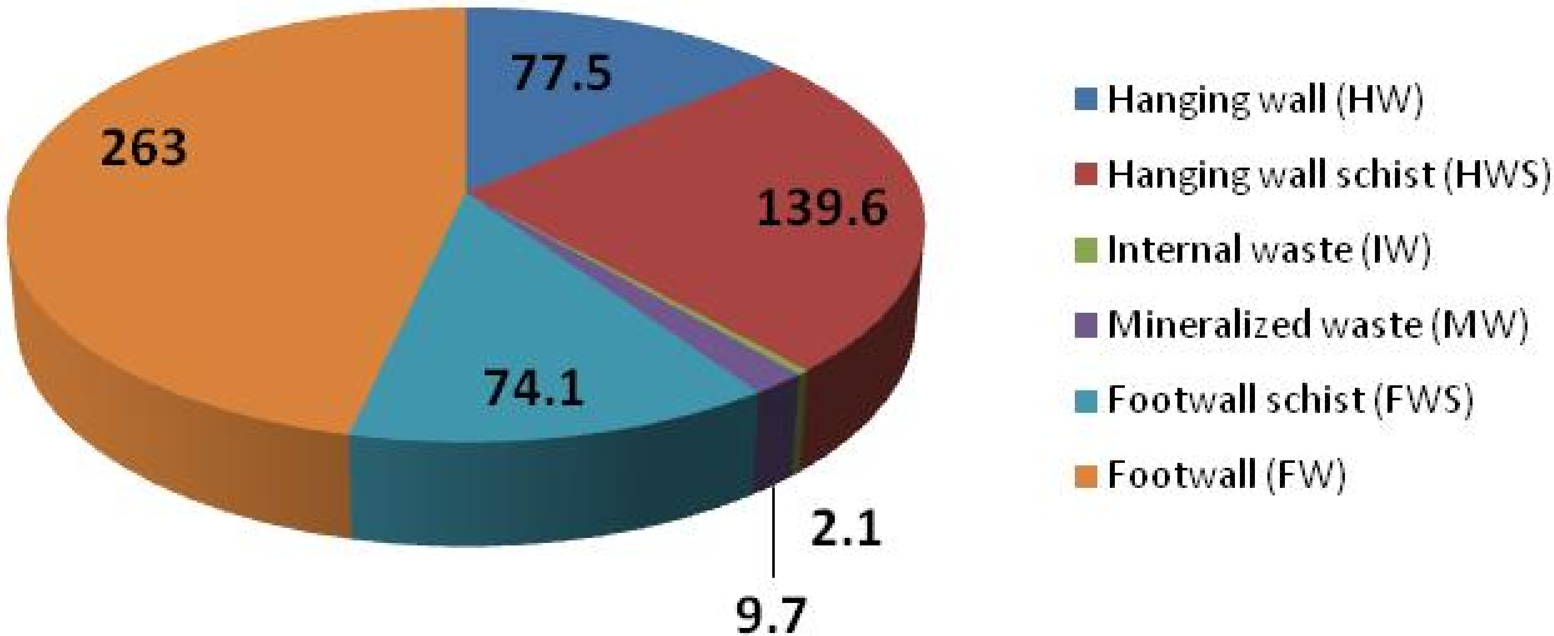


Mary River Deposit 1 - Waste

Waste Type	In-Pit Tonnage (Mt)	Waste (%)	Lithologies (in approximate order of abundance)
Hanging wall (HW)	77.5	14	**meta-volcanic (tuff); greywacke;** amphibolite; chlorite, mica or amphibole schist; ultramafite; and gneiss
Hanging wall schist (HWS)	139.6	25	**chlorite, mica, or amphibole schist**; amphibolite; greywacke; and meta-volcanic (tuff); inter-bedded zones of banded iron formation
Internal waste (IW)	2.1	0.4	schist; amphibolite; and meta-volcanic (tuff)
Mineralized waste (MW)	9.7	1.7	high grade iron formation (elevated Mn, S or P); and banded iron formation
Footwall schist (FWS)	74.1	13	**chlorite, mica, or amphibole schist; gneiss; greywacke**; amphibolite; and meta-volcanic (tuff); inter-bedded zones of banded iron formation
Footwall (FW)	263.0	46	**gneiss; metasediments (e.g., greywacke**); chlorite, mica or amphibole schist; and amphibolites
Total	566	100	

- Generally little primary or structural carbonate.

Proportions of Waste Types



Quantities - Mt

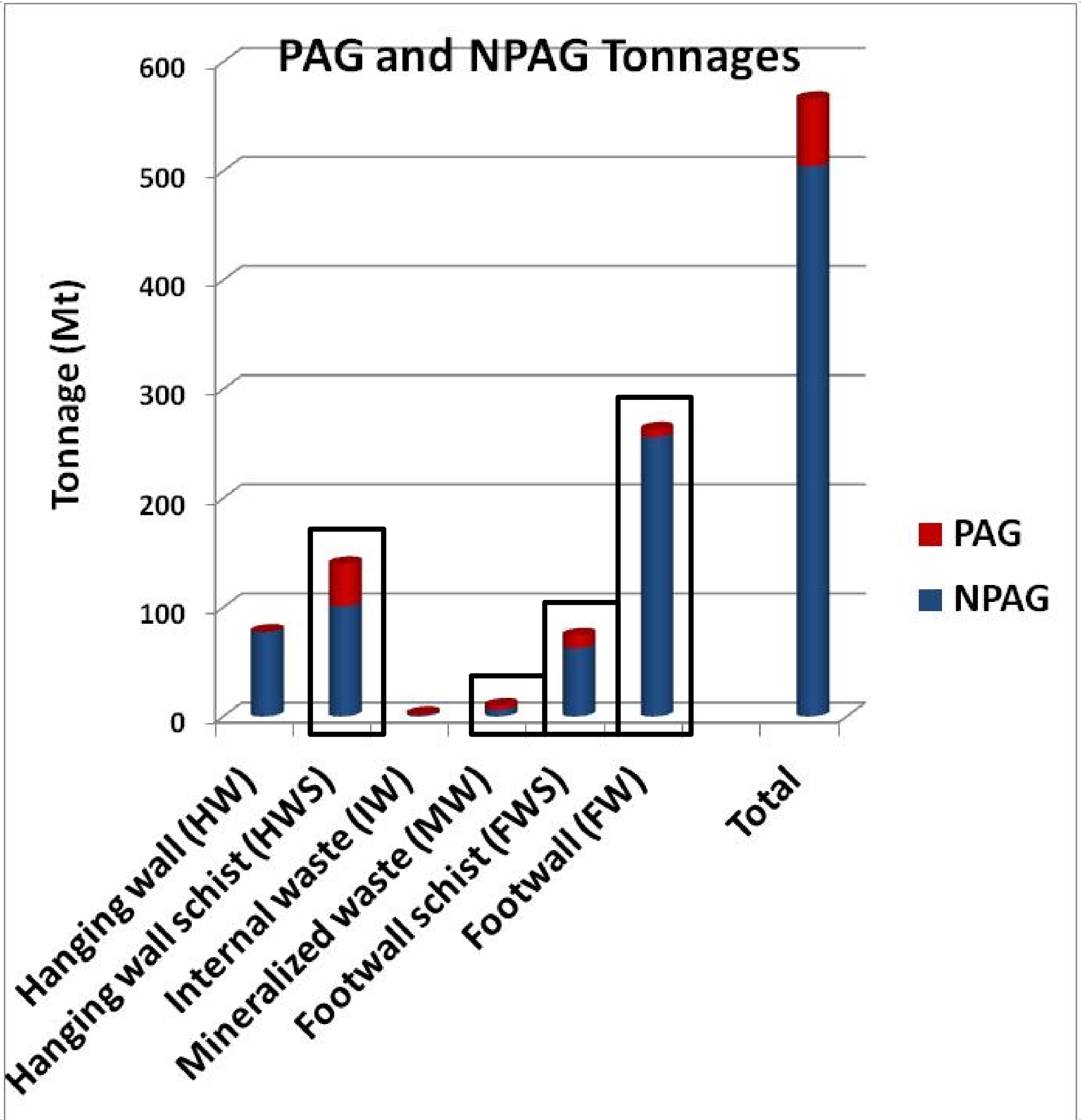
Inferred PAG Tonnage

Waste Rock Domain	Tonnage (Mt)	No. Samples	Mean S %	Mean NPR**	% Samples NPR <2	PAG tonnage (Mt)
HW	77.5	61	0.10	17.7	0.0	0.0
HWS	139.6	260	0.68	1.6	27.7	38.6
IW	2.1	7	0.31	1.5	42.9	0.9
MW	9.7	21	1.06	1.3	38.1	3.7
FWS	74.1	161	0.30	2.4	15.5	11.5
FW	263.0	449	0.06	15.7	2.7	7.0
Total	566	959				61.8

* Assumed NPR < 2 represents PAG rock, ** NPR = Modified Sobek NP/AP

- Estimated PAG tonnage for waste rock regions based on % PAG samples within each domain.
- Updated estimate is that PAG* rock represents 10.9% of the total waste rock (based on additional 2012 drilling).

Proportions of PAG and NPAG

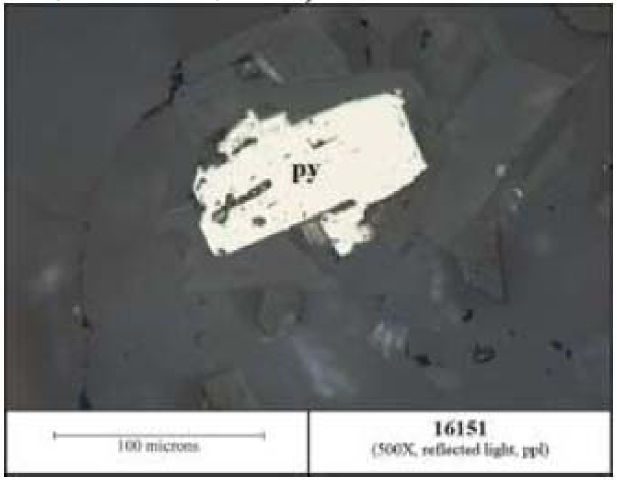


- HWS and FWS contain largest quantities of PAG.
- FW is largest overall tonnage of material (almost 50% of rock) with low % PAG.
- MW is low tonnage with high % PAG.

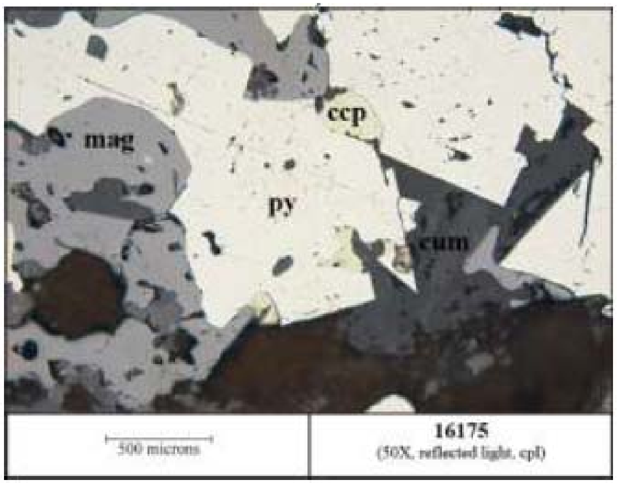
Sulphide Mineralogy

- Pyrite (FeS_2) is the most common sulfide mineral and typically occurs as disseminated anhedral to euhedral grains.
  - Analysis of pyrite grains did not identify arsenic or mercury above detection limits.
- Chalcopyrite ($CuFeS_2$) is the next most common sulfide.
- NAG Leachate results are consistent with range of sulphides observed.

Images courtesy of Rod Johnson & Associates



Euhedral to subhedral pyrite (py).

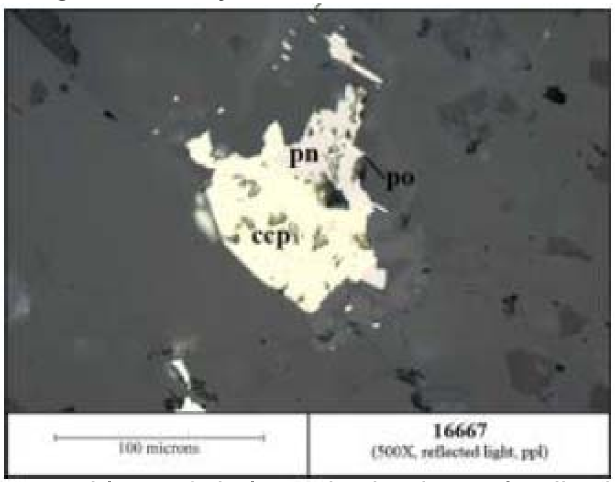


Coarse euhedral to subhedral pyrite (py) and anhedral chalcopyrite (ccp).

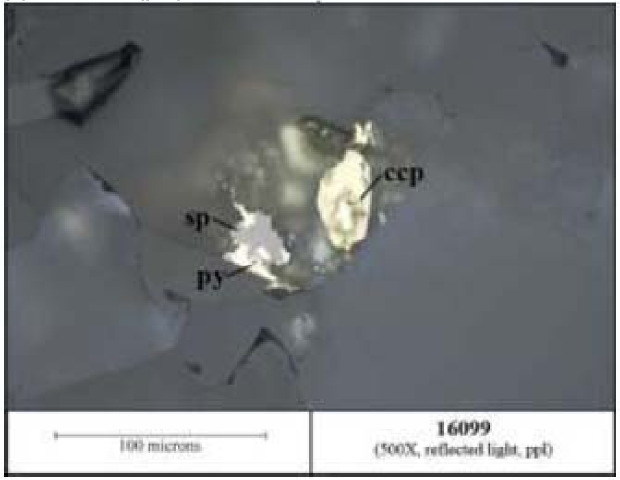
Sulphide Mineralogy

- The sulfide assemblage pyrrhotite ($Fe_{1-x}S$), chalcopyrite, and pentlandite $(Fe,Ni)_9S_8$ was identified in three of 20 samples.
  - Analysis of pyrrhotite identified measureable levels of nickel.
  - Pentlandite sometimes contained elevated cobalt.
- Sphalerite identified in 2 of 20 samples contained measurable amounts of cadmium.
- Marcasite (FeS_2) identified in a single sample contained measureable amounts of nickel and copper.

Images courtesy of Rod Johnson & Associates



Assemblage of chalcopyrite (ccp), pentlandite (pn) and pyrrhotite (po).



Assemblage of chalcopyrite (ccp), pyrite (py) and sphalerite (sp).

Kinetic Testing

- Ten standard humidity cells initiated in 2008 and operated for 53 weeks.
  - Range of major lithology sub-types and NP/AP (7 samples with NPR < 2).
- Nine additional standard humidity cells and eight carbonate depleted humidity cells initiated in 2011.
  - Standard cells selected to cover NPR range <1 to >2 (Carbonate NPR much less).
  - Carbonate NP depleted cells prepared by Na acetate leach (pH 4.5) until >80% of inorganic carbon is removed.
  - NP depleted cells selected to measure drainage from non-carbonate waste rock (non-carbonate NPR between 1 and just over 2).
  - More than 80 and 64 weeks of data for standard and carbonate depleted cells respectively.

pH of Standard Cells

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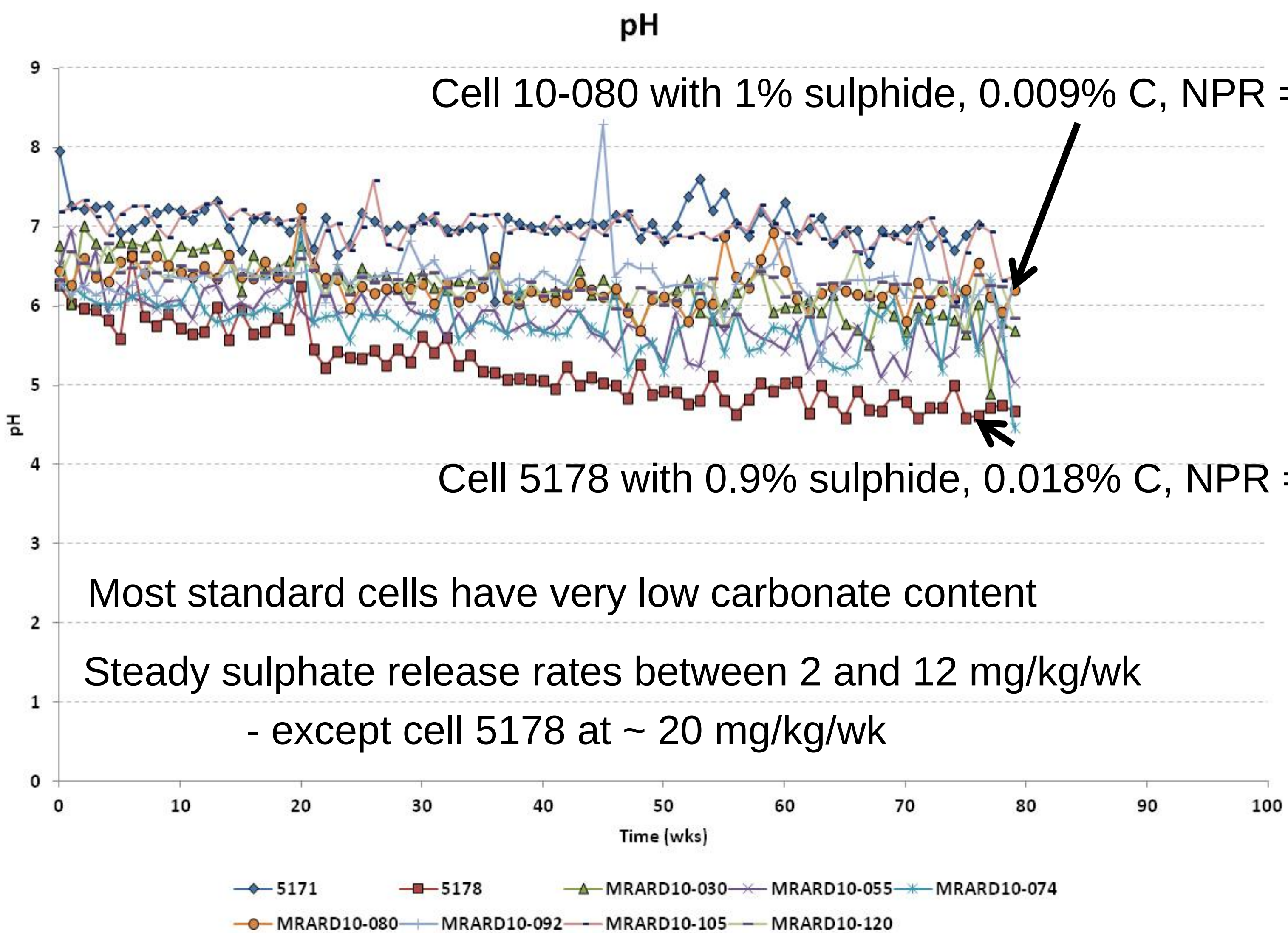


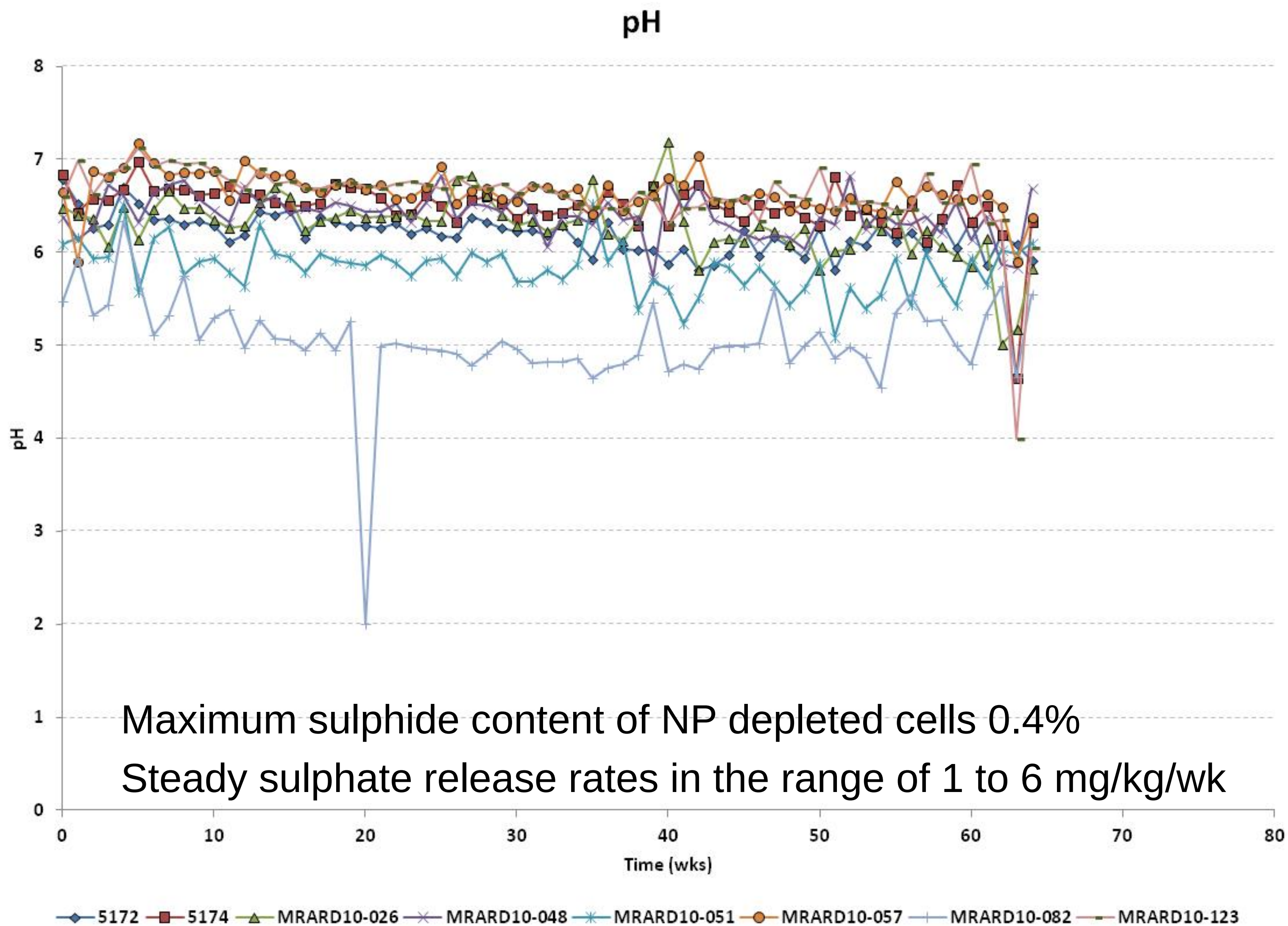
Cell 10-080 with 1% sulphide, 0.009% C, NPR = 0.6

Cell 5178 with 0.9% sulphide, 0.018% C, NPR = 0.8

Most standard cells have very low carbonate content

Steady sulphate release rates between 2 and 12 mg/kg/wk
- except cell 5178 at ~ 20 mg/kg/wk

pH of Carbonate Depleted Cells



Maximum sulphide content of NP depleted cells 0.4%

Steady sulphate release rates in the range of 1 to 6 mg/kg/wk

Challenges

- Predicting long-term behaviour of sulphide-bearing rock when mechanisms of neutralization at low AP are not well understood.
  - For static tests Modified ABA and NAGpH are supportive of each other.
  - Get carefully selected and prepared humidity cells running early and keep running.
  - Build mineralogical understanding of samples and look for links to static and kinetic data for both AP and NP.
- Modeling water quality
  - Lack of acidic drainage from testing is a particular limitation.
  - What is representative acidic drainage for these low reactive materials and how is it best determined.
  - Utilize conservative assumptions in the absence of the defendable long-term rock behaviour while data is being gathered.

Continuing and Future Work

- Continuation of humidity cells.
- Planning for set up of field test pads.
- Additional detailed mineralogical assessment is being completed to better understand sources of NP and AP in relation to static and kinetic testing results.
  - 30 carefully selected samples from static data set by lithology, NPR, Carb NPR and NAGpH.
  - Mineral liberation analysis (MLA) being considered for selected humidity cell subsamples to relate quantitative mineralogy to available AP (occlusion) and possible non-carbonate NP sources based on mineral type and texture.