Geochemical Characterization

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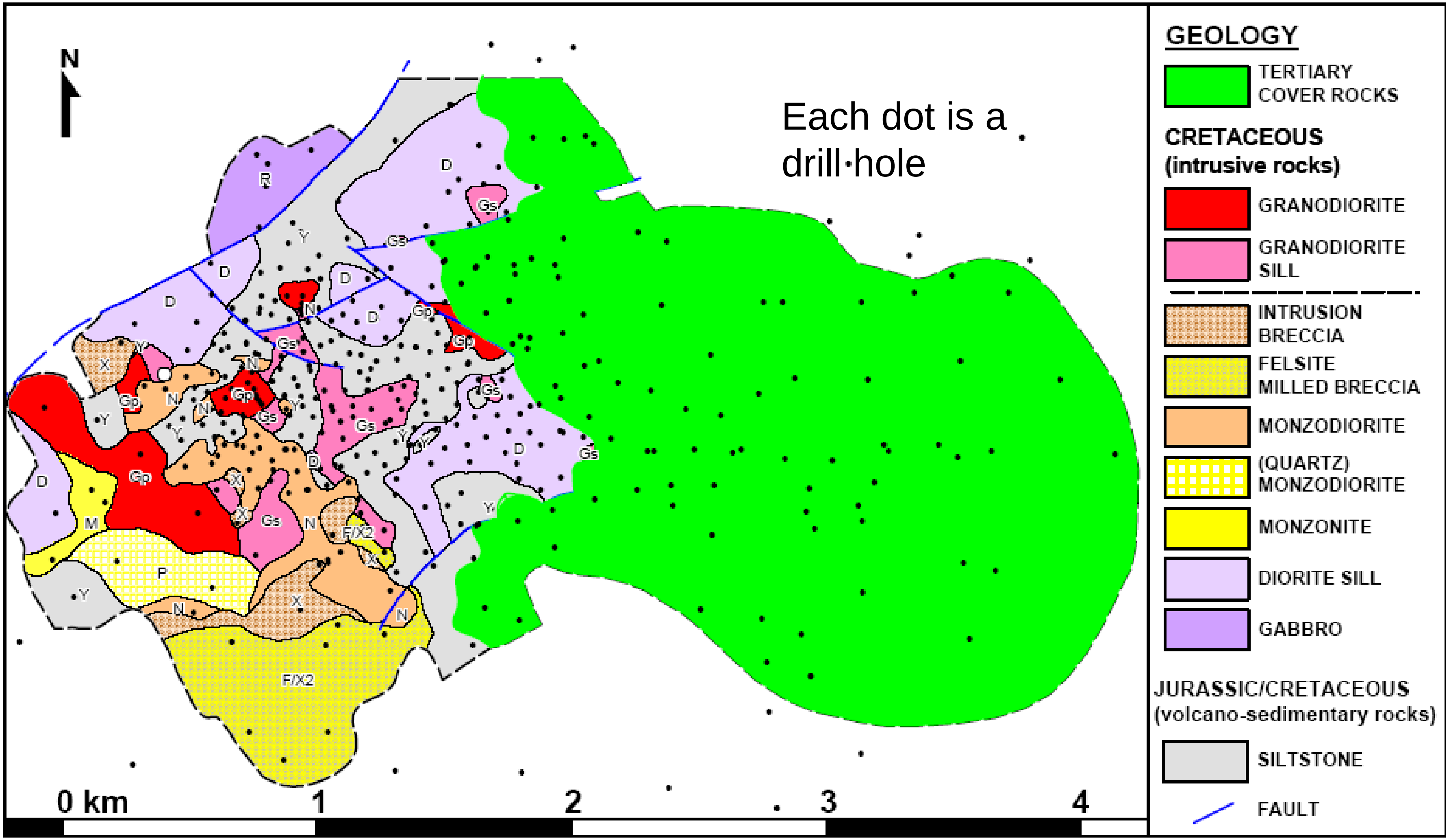
Anchorage

Outline

- Geological context
- Overall program objectives and design
- Geochemical characterization of waste rock

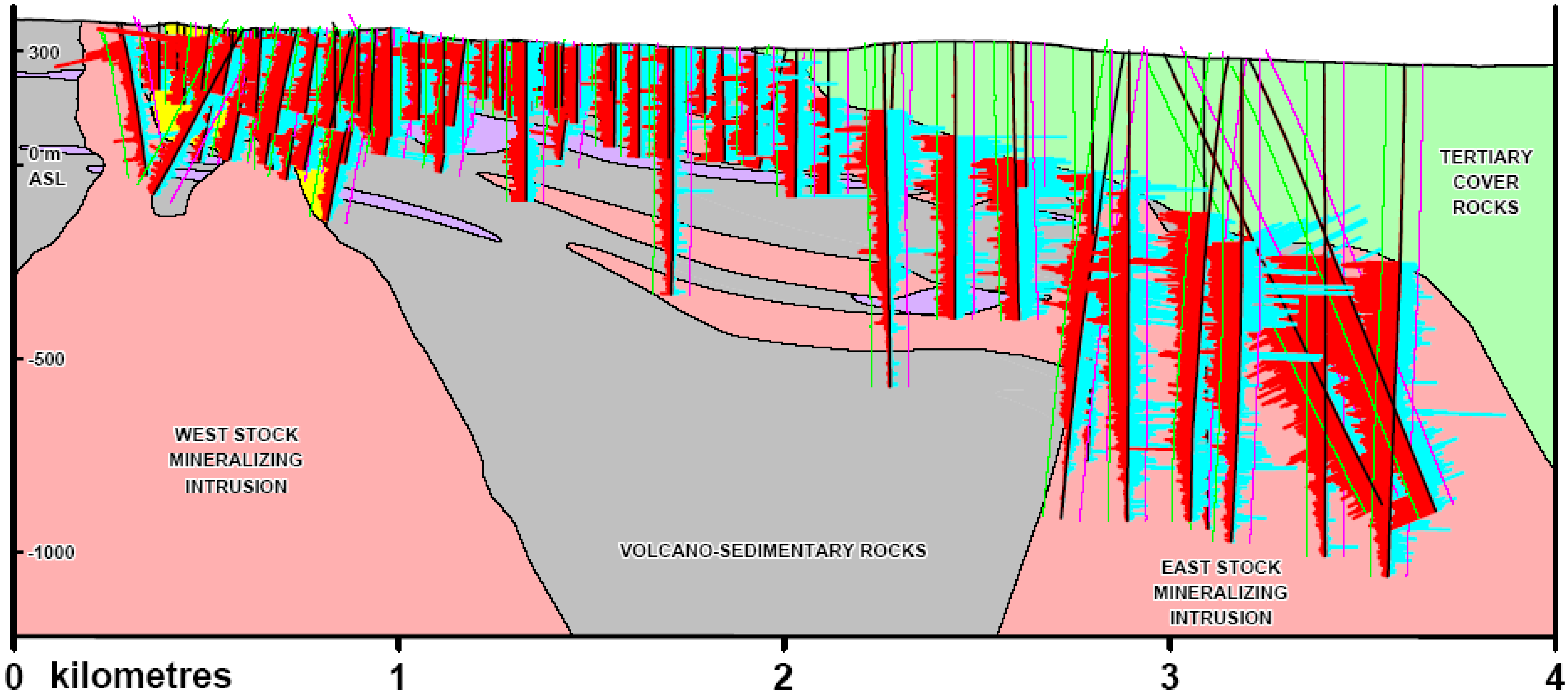
GEOLOGICAL CONTEXT

Geology Map



N
Each dot is a drill-hole
GEOLOGY
TERTIARY COVER ROCKS
CRETACEOUS (intrusive rocks)
GRANODIORITE
GRANODIORITE SILL
INTRUSION BRECCIA
FELSITE MILLED BRECCIA
MONZODIORITE
(QUARTZ) MONZODIORITE
MONZONITE
DIORITE SILL
GABBRO
JURASSIC/CRETACEOUS (volcano-sedimentary rocks)
SILTSTONE
FAULT
0 km
1
2
3
4

Geological Cross-Section



Program Objectives

- To characterize weathering and leaching behavior of materials that will be produced during mining and processing
- Inform engineering design of waste and water management plans

Study Design Questions

- Potential for metal leaching (ML) and acid rock drainage (ARD) - Static Tests:
  - Waste rock types (Pre-Tertiary, Tertiary)
  - Tailings
- Waste management criteria - Static and Kinetic Tests:
  - Reaction rates
- Water quality predictions - Static and Kinetic Tests:
  - Water management
  - Impact assessments

Tests Matrix

	West Zone		East Zone			Tailings	
Procedure	Pre-T	Tertiary	Pre-T	Tertiary	Over-burden	PWZ	PEZ
Acid-base accounting	485	145	200	200	26	36	12
Mineralogy	17	13	14	13	0	8	12
Extraction Tests	26	6	8	12	0	0	0
MWMP	0	27	0	0	9	0	0
Humidity Cells	21	15[1] + 3[2]	13	14 +3[2]	0	9	9
Bagged weathering tests	0	0	8	12	0	0	0
Subaqueous Columns	6	0	0	2	0	0	0
Aerated Columns	0	0	0	0	0	2	0
Field tests	4[1]	2[1] +3[2]	0	1+ 3[2]	0	0	0

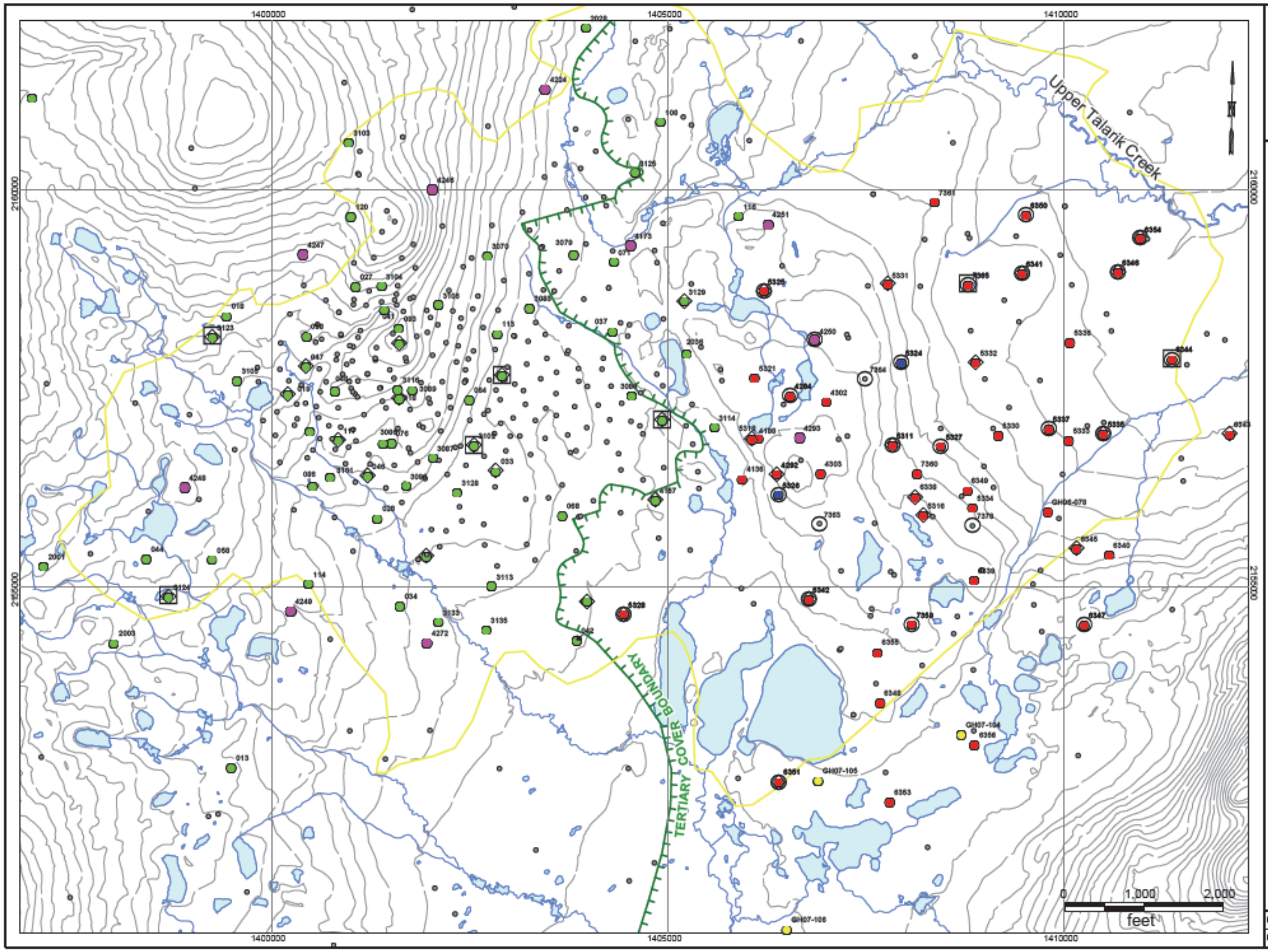
1. Includes some replicate tests.
2. Three field tests contain mixed West and East Zone Tertiary rock.

Chronology of Studies

	Number of kinetic tests running at end of each year (waste rock given as pre-Tertiary/Tertiary)				
	2005	**2006**	**2007**	**2008**	**2009**
Humidity cell tests (waste rock)					
PEZ	0	0	0	13/14	8/4
PWZ	17/15	5/10	2/9	6/9	6/4
PEZ+PWZ	0	0	0	0/3	0/3
Subaqueous columns (waste rock)					
PEZ	0	0	0	0/2	0/2
PWZ	6/0	4/0	4/0	4/0	1/0
Humidity cell tests (tailings)					
PEZ	0	0	0	9	5
PWZ	6	4	4	9	6

GEOCHEMICAL CHARACTERIZATION OF WASTE ROCK

Spatial Distribution Samples



LEGEND

- 2004 sampling programs (PWZ)
- 2004 supplemental sampling program (PWZ)
- 2005 sampling program (PWZ)
- 2007 sampling program (PEZ)
- 2007 sampling program (overburden)

PWZ: Pebble West Zone
PEZ: Pebble East Zone

- 2008 sampling program (stored bag tests)
- Other drillholes
- General deposit location

Kinetic tests

- Humidity cell
- Subaqueous column

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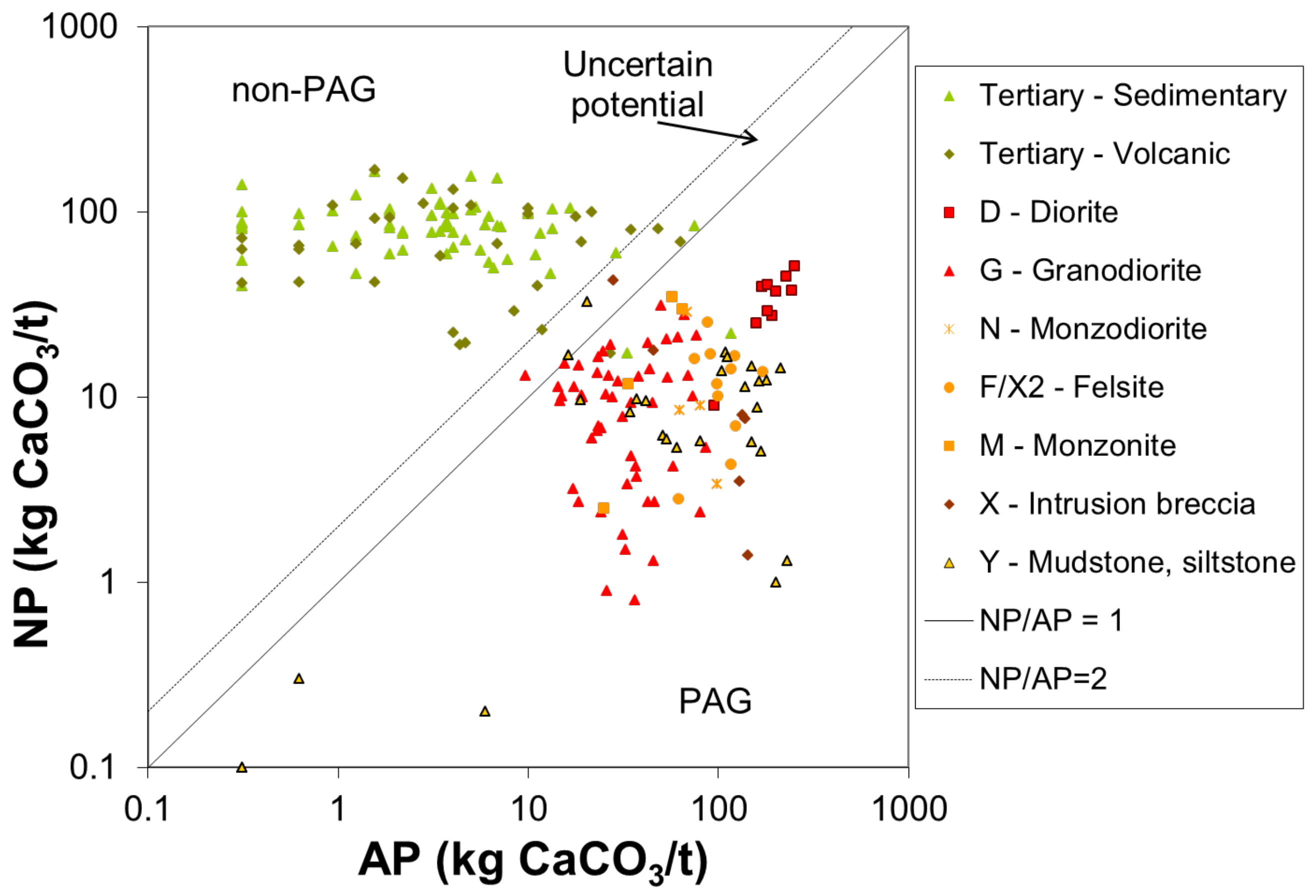
ARD POTENTIAL OF ROCK

ARD Potential

- Cretaceous mineralized rock is mainly PAG.
- Tertiary rock is mainly non-PAG.

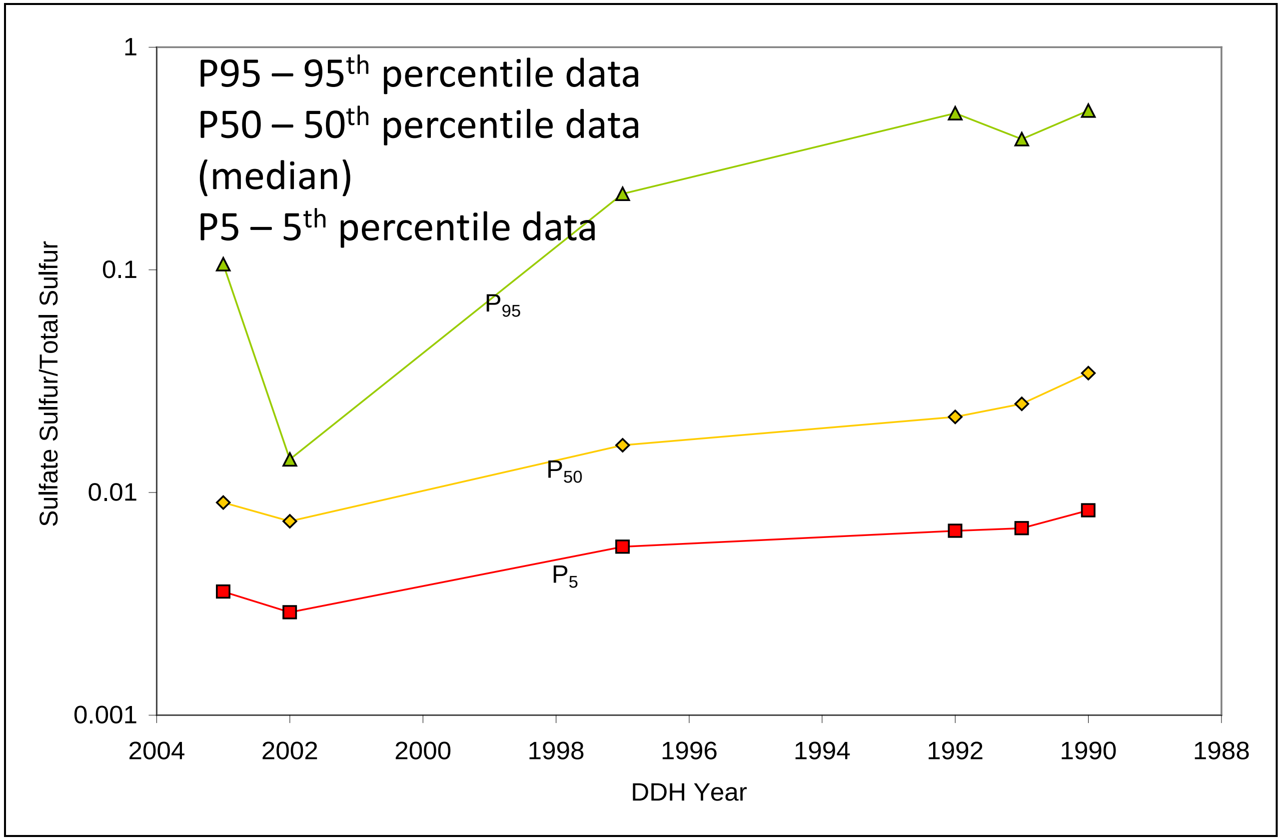


- Charts show West Zone data
- East Zone shows similar results to West Zone

REACTION RATES FOR EXPOSED ROCK

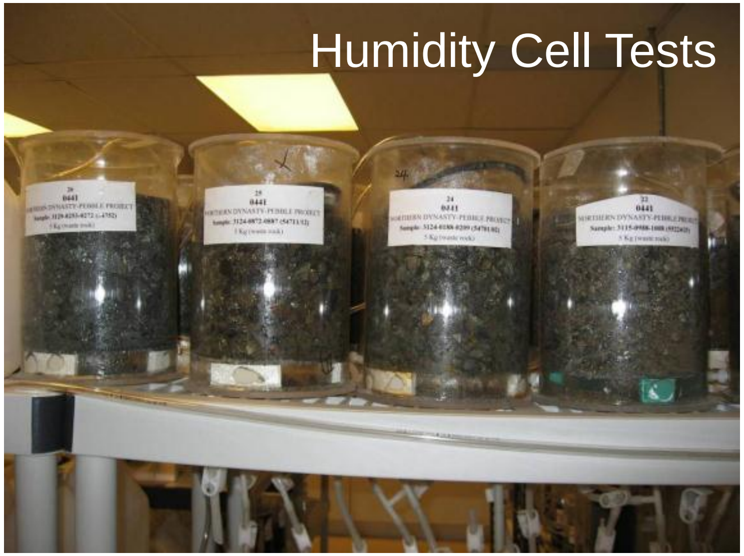
Core Aging Effects

- Increase in sulfate sulfur relative to sulfur as the age of the core increased
- Coincident reduction in NP, development acidic paste pH
- Estimated timescale to acid onset, up to 40 years

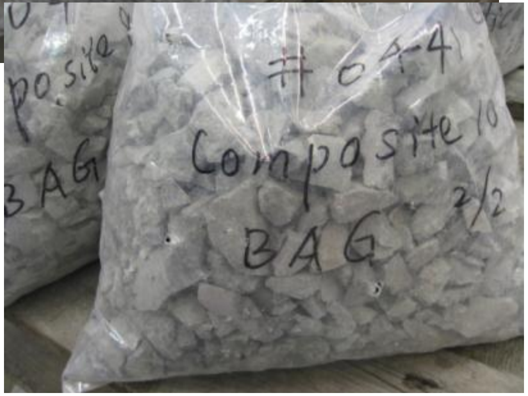


Data shown for PWZ pre-T mineralised rock (stored at site)

Lab Kinetic Test Methods: Rock


Humidity Cell Tests


Subaqueous Columns



Bagged Weathering Tests

Humidity Cell Tests

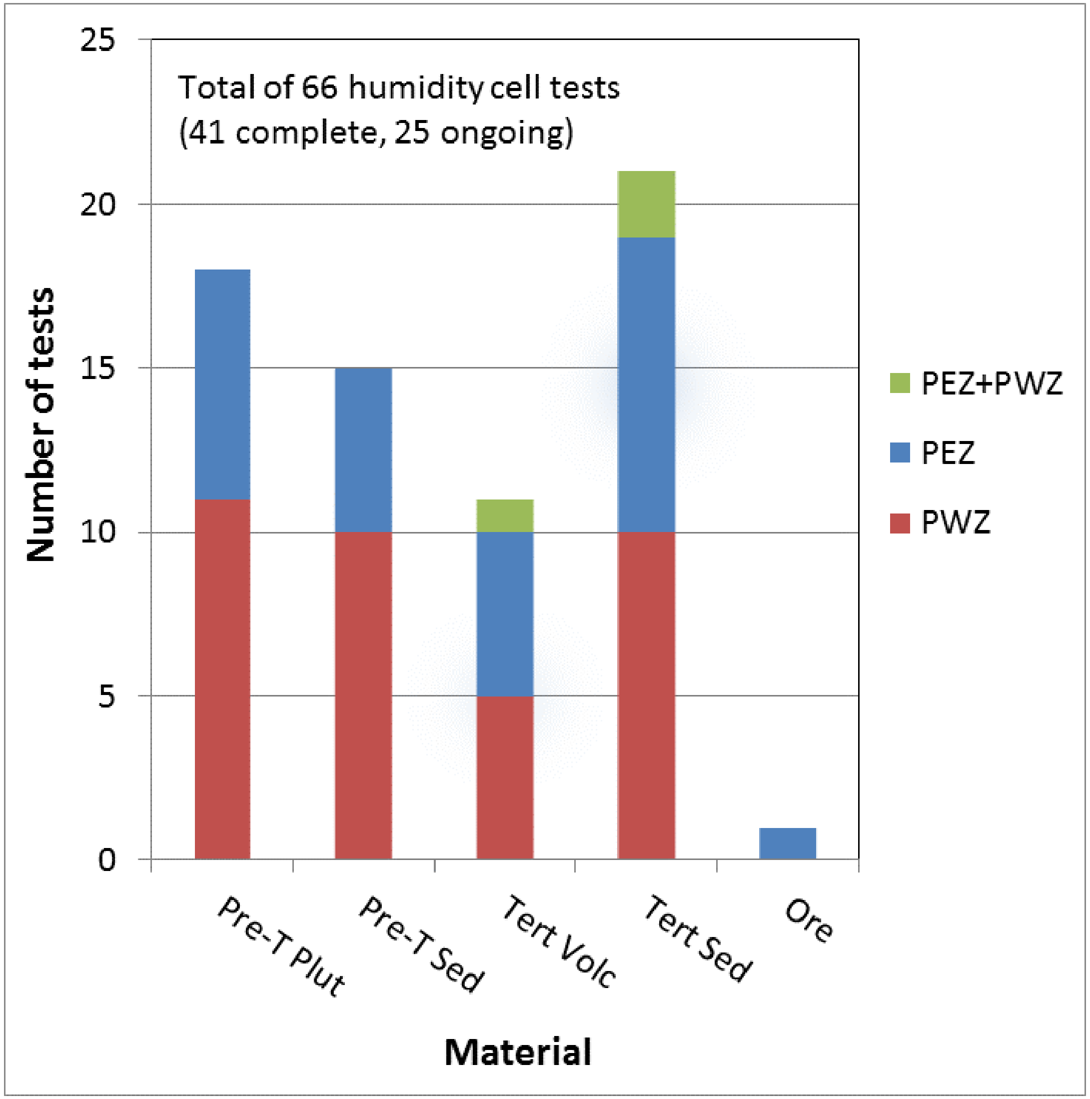
To estimate reaction rates under aerobic conditions

Data relevant to:

- Waste rock dumps, pitwalls, stockpiles

Samples were selected to cover range of:

- Rock types
- S contents
- Sample ‘age’ (old core versus fresh core)



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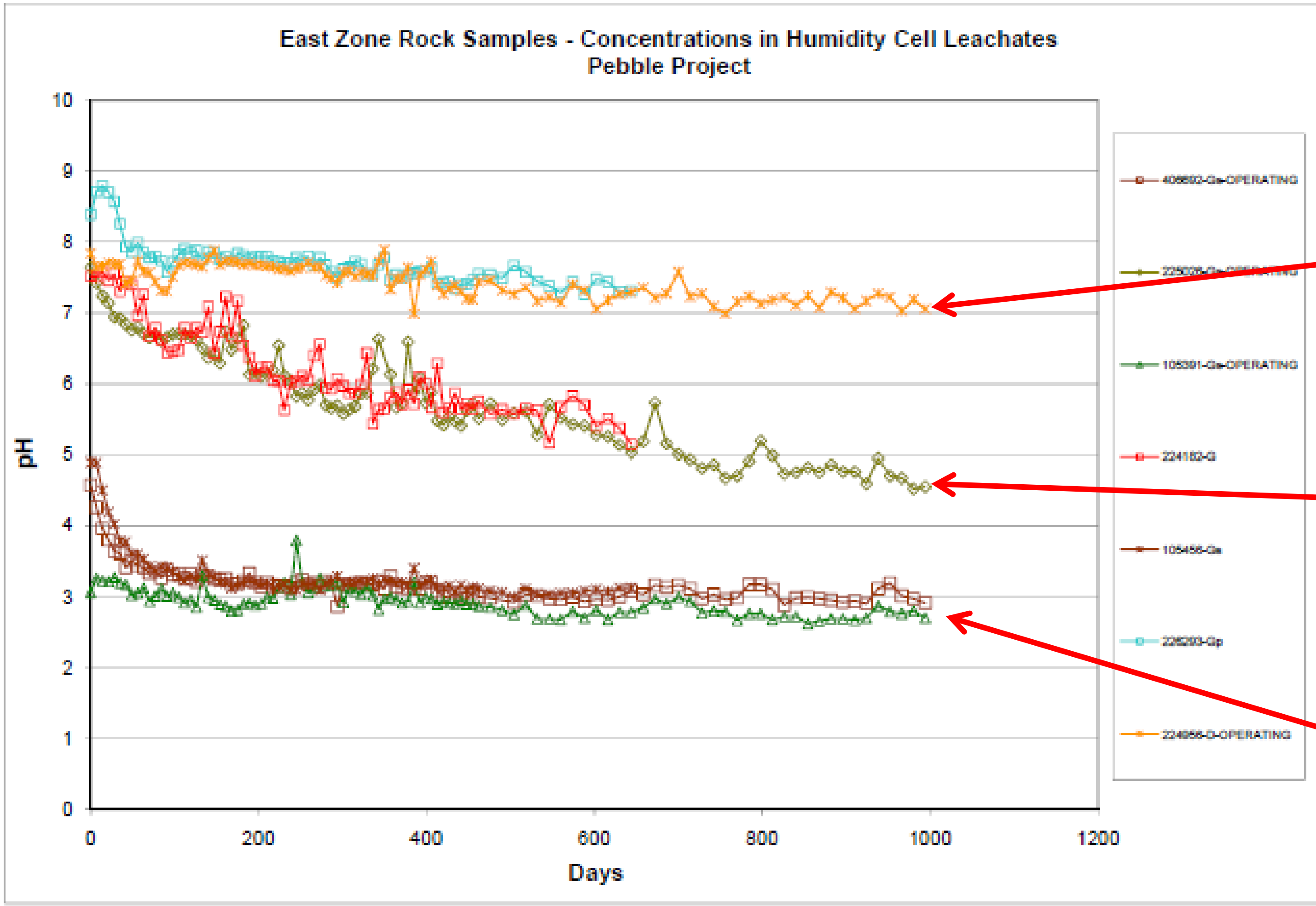
Humidity Cell Tests: Example Results



pH-neutral for duration of tests

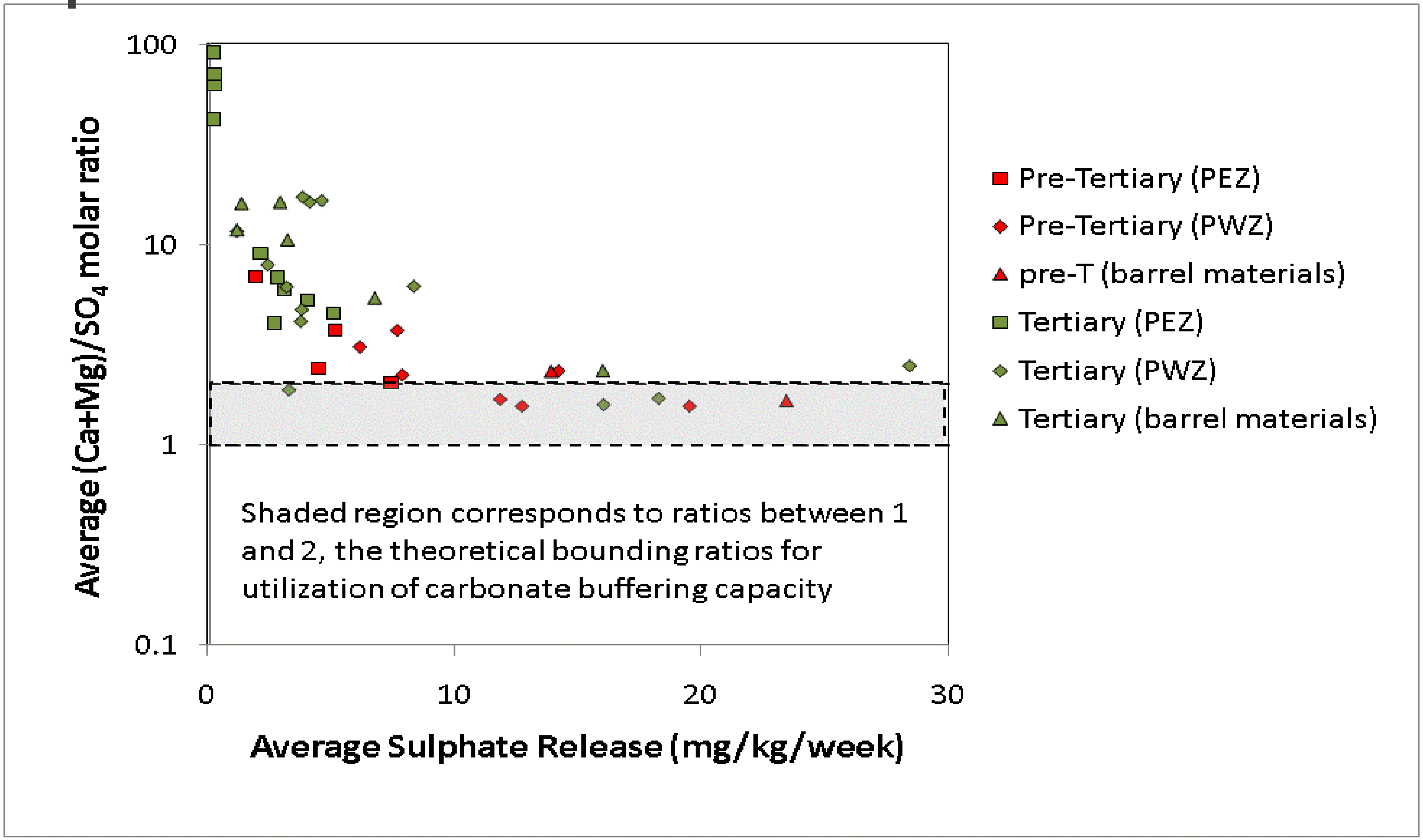
Initially pH-neutral, tending toward acidic pH with time

Immediately acidic

pH plotted as a function of time (days)

Humidity Cell Tests: Rocks

Site-Specific Criterion for PAG rock



Pebble site-specific NP/AP criteria:1.6

Equivalent for pre-T and T rock

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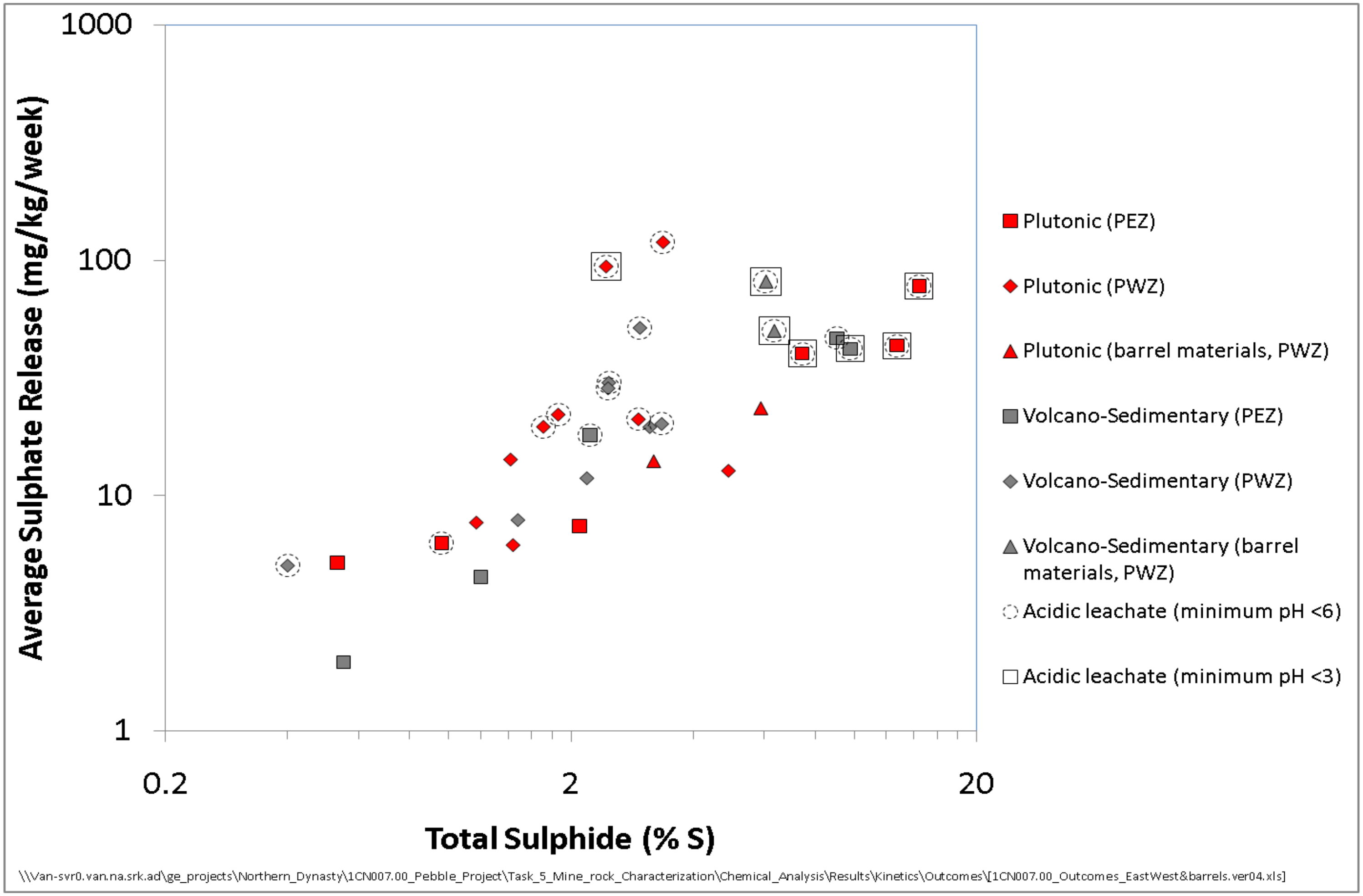
Humidity Cell Tests: Rocks

Release Rates Compared to Composition - Sulfate

Relationship independent of rock type, leachate pH



Only pre-T data shown

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Humidity Cell Tests: Rocks

Timing of Onset to Acid Conditions

- HCT testing (laboratory conditions):

NP/AP	Time to acid onset
<0.1	< 2 years
0.1 to 0.3	3 to 10 year
1.0	> 20 years

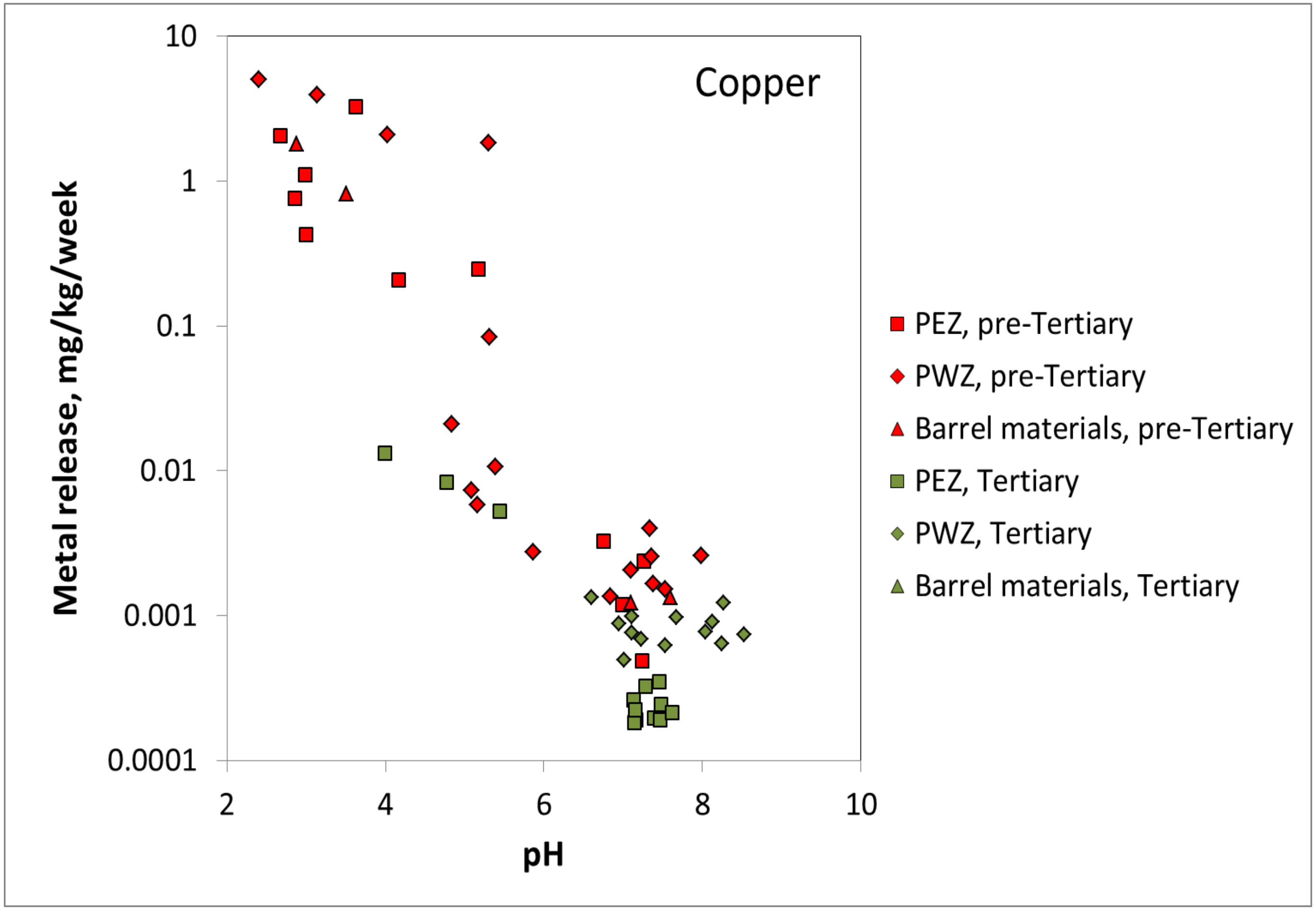
- Consistent with core aging effects (site conditions)

Humidity Cell Tests: Rocks
Controls on Metal Release

Main control, leachate pH, higher release at acid pH

Potential for release linked to PAG materials

Oxyanions: (As, Mo, Se) - significant release at neutral pH



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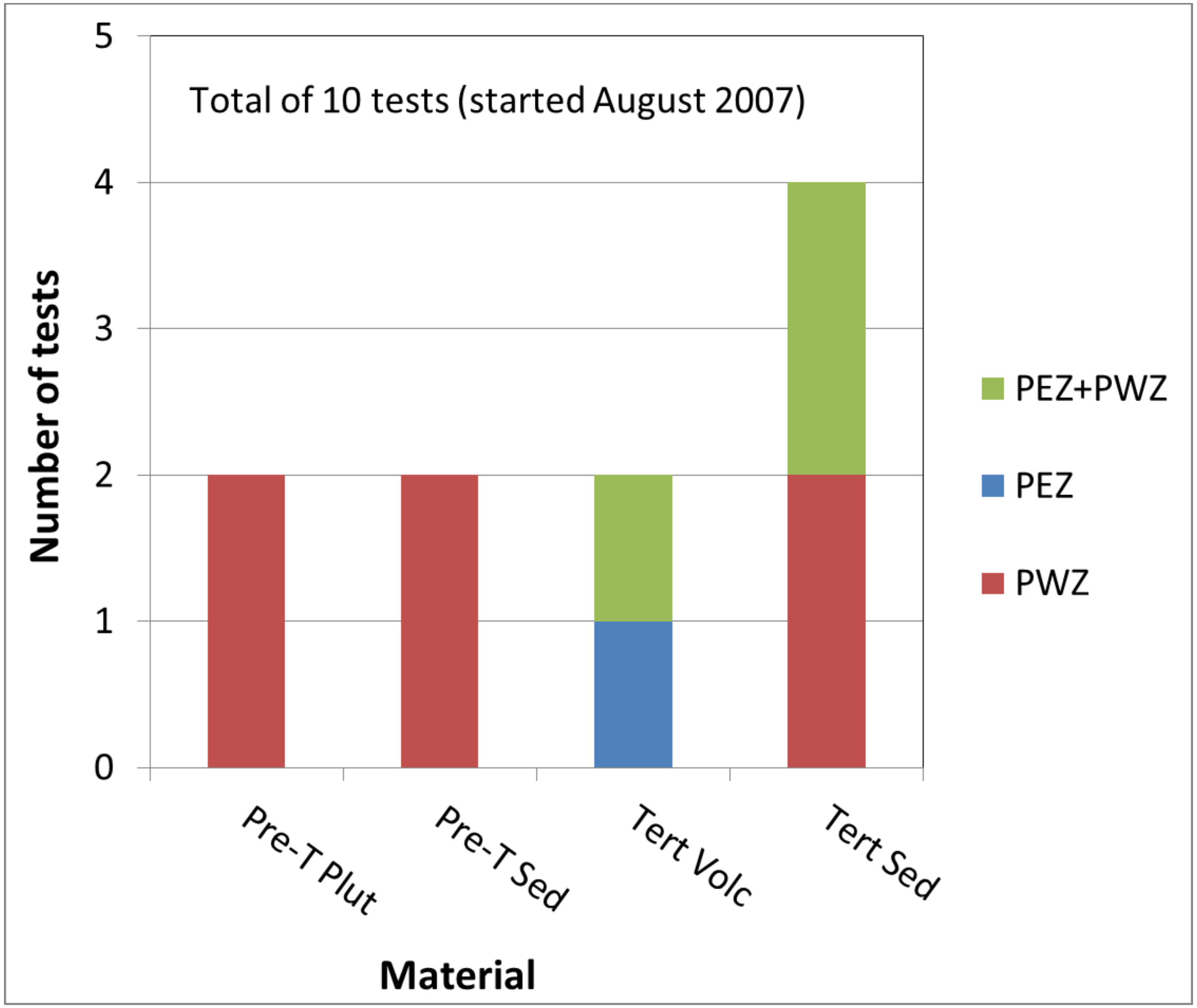
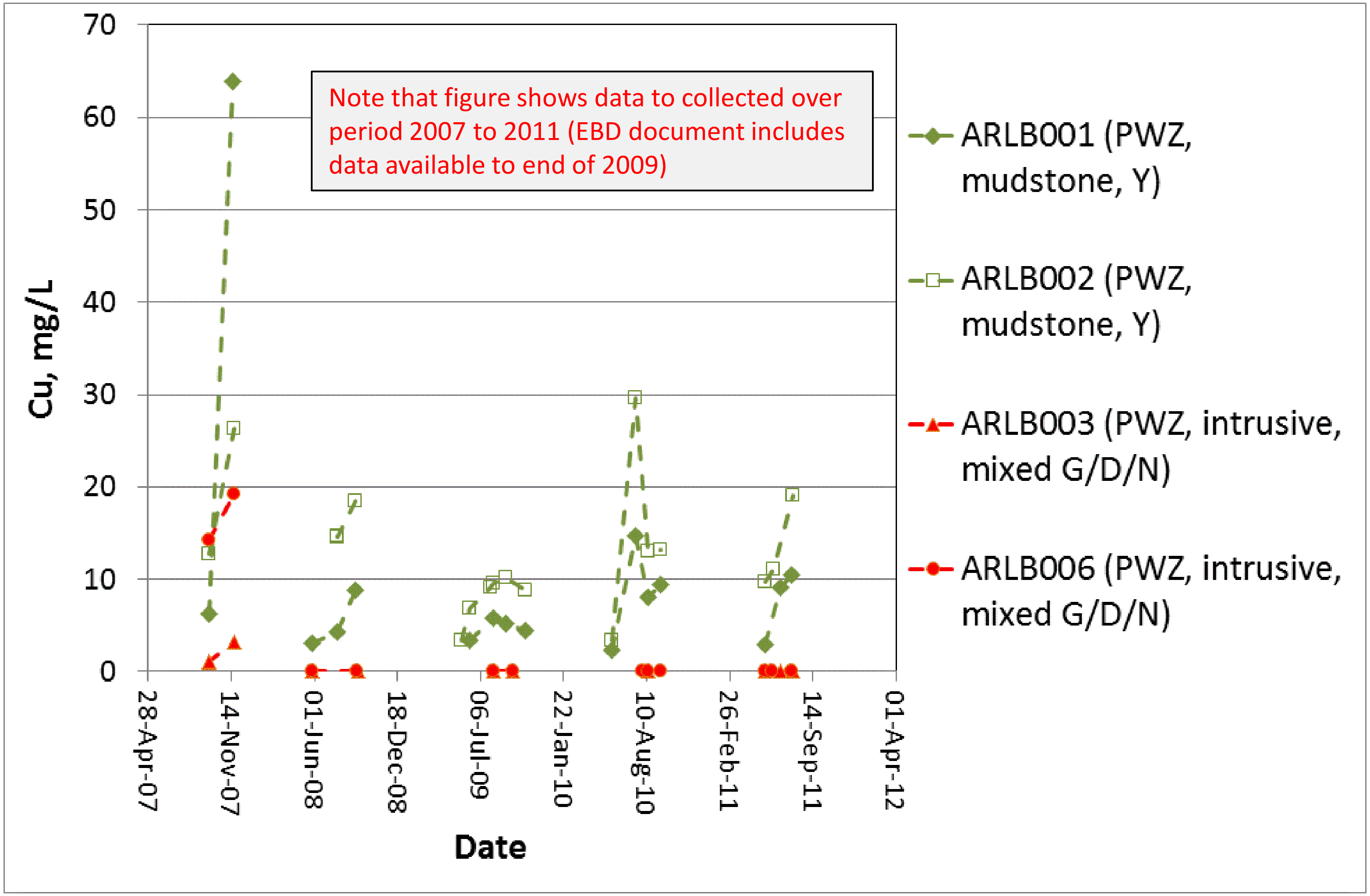
Field Weathering Tests

Field Weathering Tests

- To evaluate leaching behavior under field conditions
- Comparison with laboratory conditions
- Focus on Tertiary and West Zone Pre-Tertiary.



Field Weathering Tests:
Example Results



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Field Weathering Tests:
Summary of Data from 2007 to 2011

	Barrel #	Rock Type	Zone	pH	Average concentration, mg/L				
					SO_4	As	Mo	Se	Cu
Pre-Tertiary	B03	G/D/N	West	7.67	1418	0.0009	0.03	0.2	0.5
Pre-Tertiary	B06	G/D/N	West	7.55	764	0.002	0.1	0.2	2.8
Pre-Tertiary	B01	Y	West	4.38	566	0.0004	0.0001	0.06	10.1
Pre-Tertiary	B02	Y	West	4.50	769	0.0005	0.00006	0.03	13.0
Tertiary	B10	TA+TB	East	7.85	33	0.001	0.05	0.001	0.002
Tertiary	B09	TD	East+West	7.85	12	0.001	0.05	0.001	0.002
Tertiary	B07	TC/TF	West	8.46	827	0.0006	0.02	0.01	0.002
Tertiary	B08	TC/TF	West	8.50	329	0.0005	0.1	0.03	0.001
Tertiary	B04	TW	East+West	8.48	315	0.004	0.2	0.1	0.004
Tertiary	B05	TY	East+West	7.87	661	0.007	0.1	0.1	0.003

Note that calculations are based on data to 2011 (EBD document based on data to 2009)

Highest Cu, coincident with acid pH

Field Tests: Observations

Two barrels have acidic leachate

- Barrels #1 and #2 – Pre-T sedimentary rock.
- Similar result in lab tests.

Broadly similar leachate chemistry for field and lab tests

- As, Mo, Se associated with leaching of Pre-Tertiary and Tertiary.
- Higher metals (e.g. Cu) associated with Pre-T materials.

REACTION RATES FOR SUBMERGED ROCK

Reactions Underwater: Study Design

Mine Feature

Test Strategy

PAG waste rock

Immediate storage underwater

Subaqueous column using ‘fresh’ rock

Rock exposed underground

Pit walls

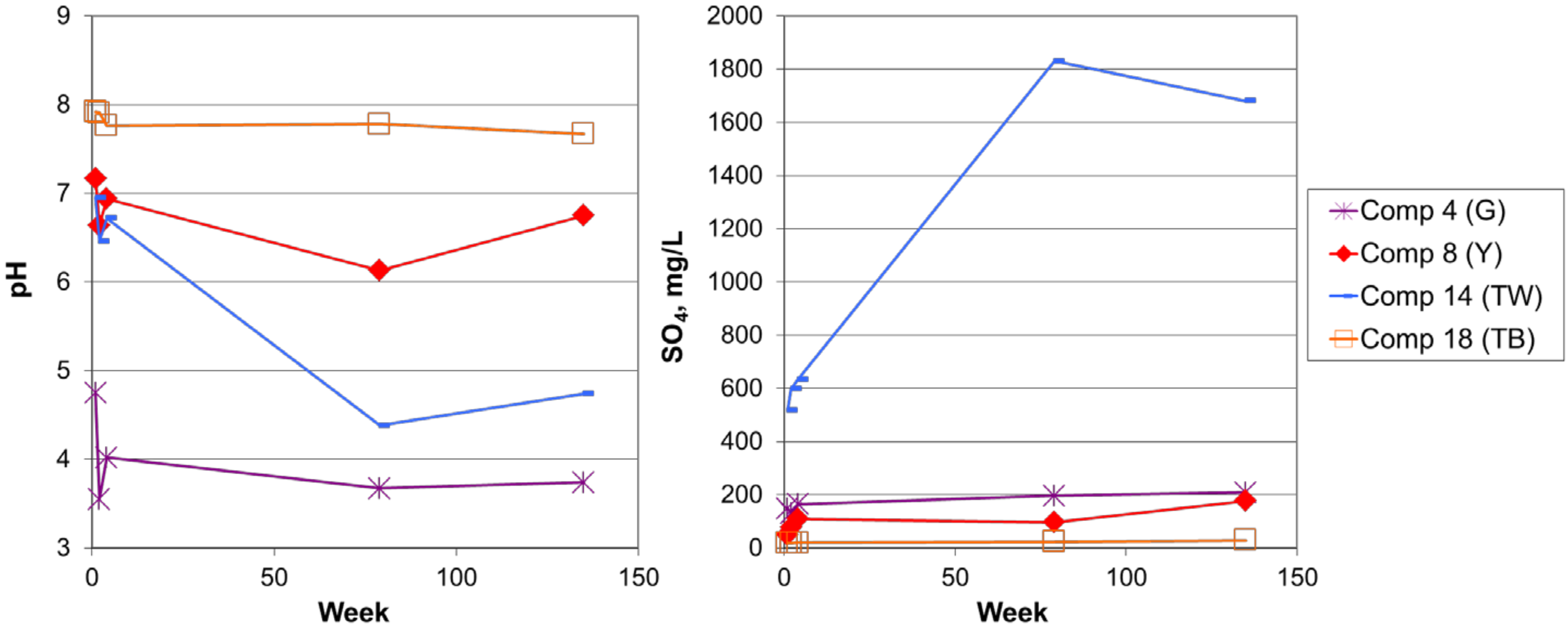
Weathering and oxidation while rock exposed

Bagged weathering tests

Later submergence following flooding

Subaqueous column using ‘weathered’ rock

Stored Bag Tests: Example Results



Shake flask extraction tests as a function of time:

- Some tests indicate production of acidic reaction products in the stored bags
- Coincident increase in soluble sulfate

Note that EBD document gives data to Week 4 (data available in 2009). Figures above show data for subsequent extraction tests in 2010 and 2011

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Underwater Reaction Rates Subaqueous Columns

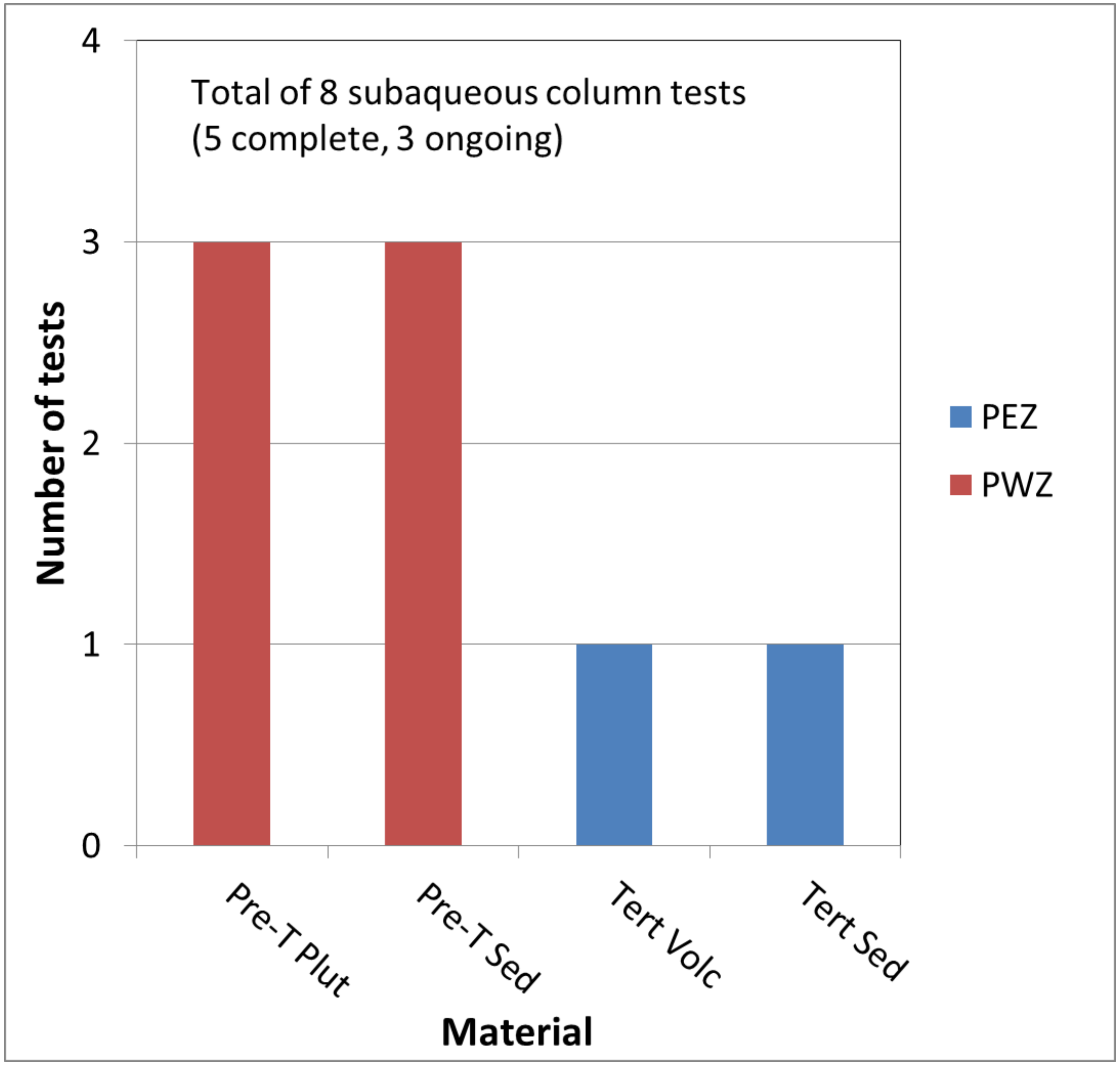
THE pebble PARTNERSHIP

Subaqueous Columns: Waste Rock

To estimate reaction rates under saturated conditions

Samples selected to cover range of:

- Rock types
- Sulfur contents



Subaqueous Columns: Design Aspects

Bagged Weathering Test

Periodic removal of sub-samples

Shake Flask Extraction Test

To quantify readily soluble salts

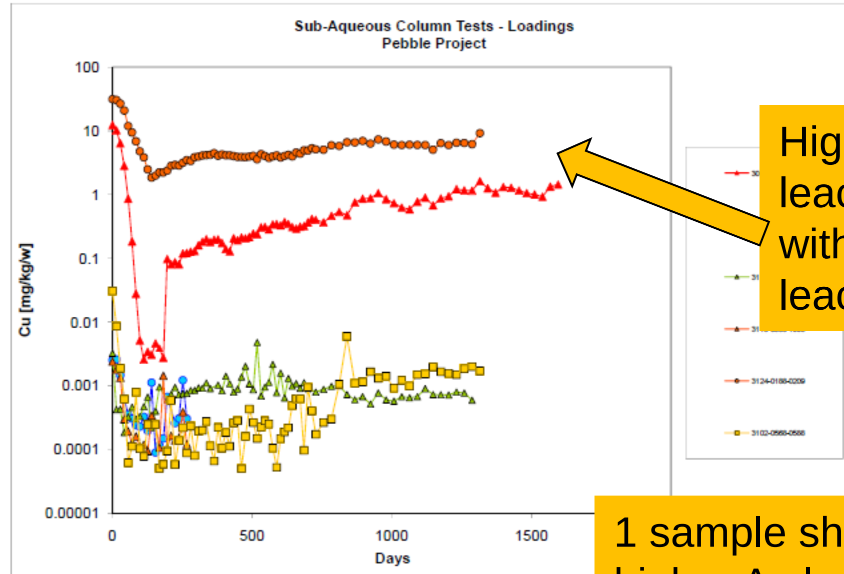
As accumulation of salts decreases

Subaqueous Columns

Stored in moist, aerobic conditions
Aeration holes to ensure O_2 and H_2O availability

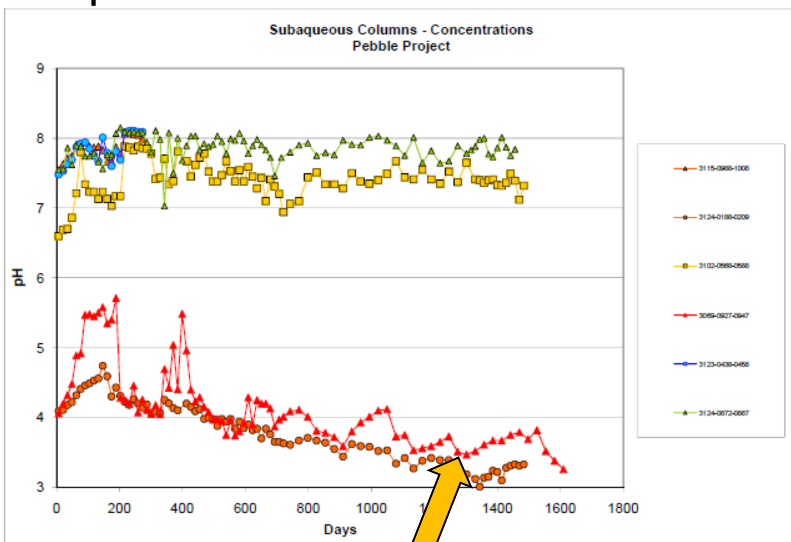
Subaqueous Columns:
Outcomes Fresh PAG Rock Tests

Cu



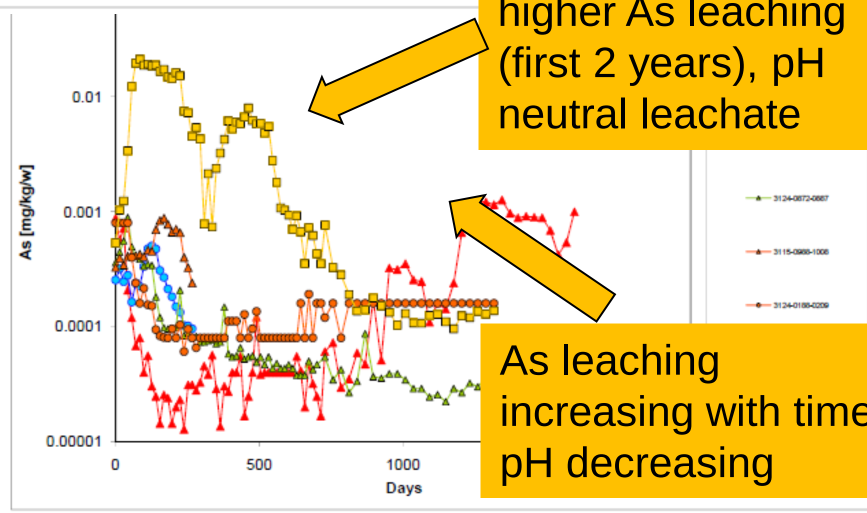
Higher Cu leaching with acid leachate

pH



1 sample showed higher As leaching (first 2 years), pH neutral leachate

As



2 samples acidic when submerged

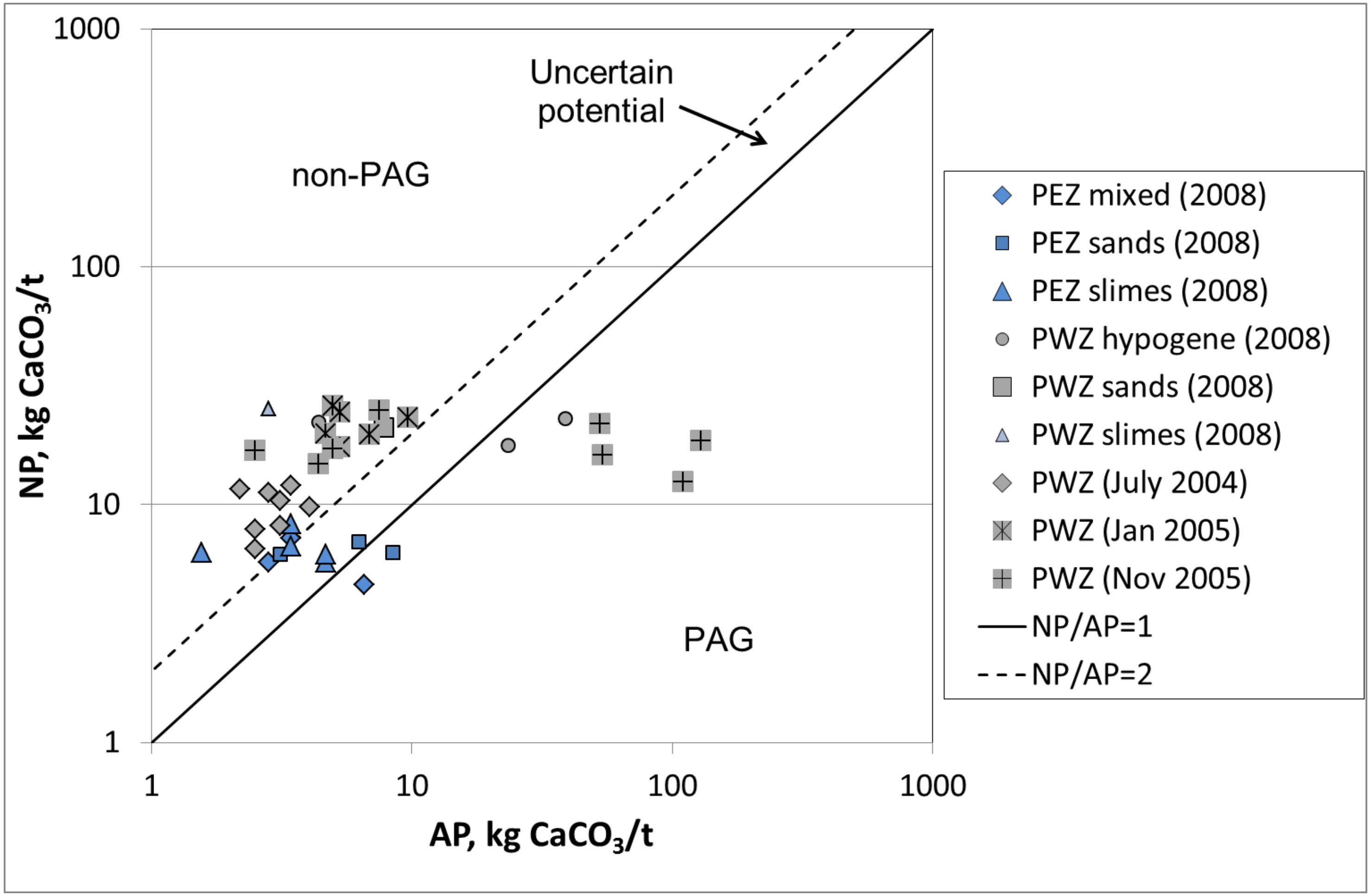
As leaching increasing with time, pH decreasing

Only PWZ tests shown

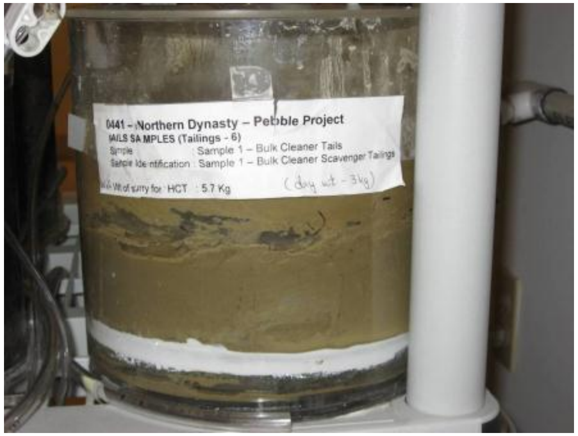
GEOCHEMICAL CHARACTERIZATION OF BULK TAILINGS

ABA (Bulk Tailings)

Non-PAG tails low S tailings have been produced

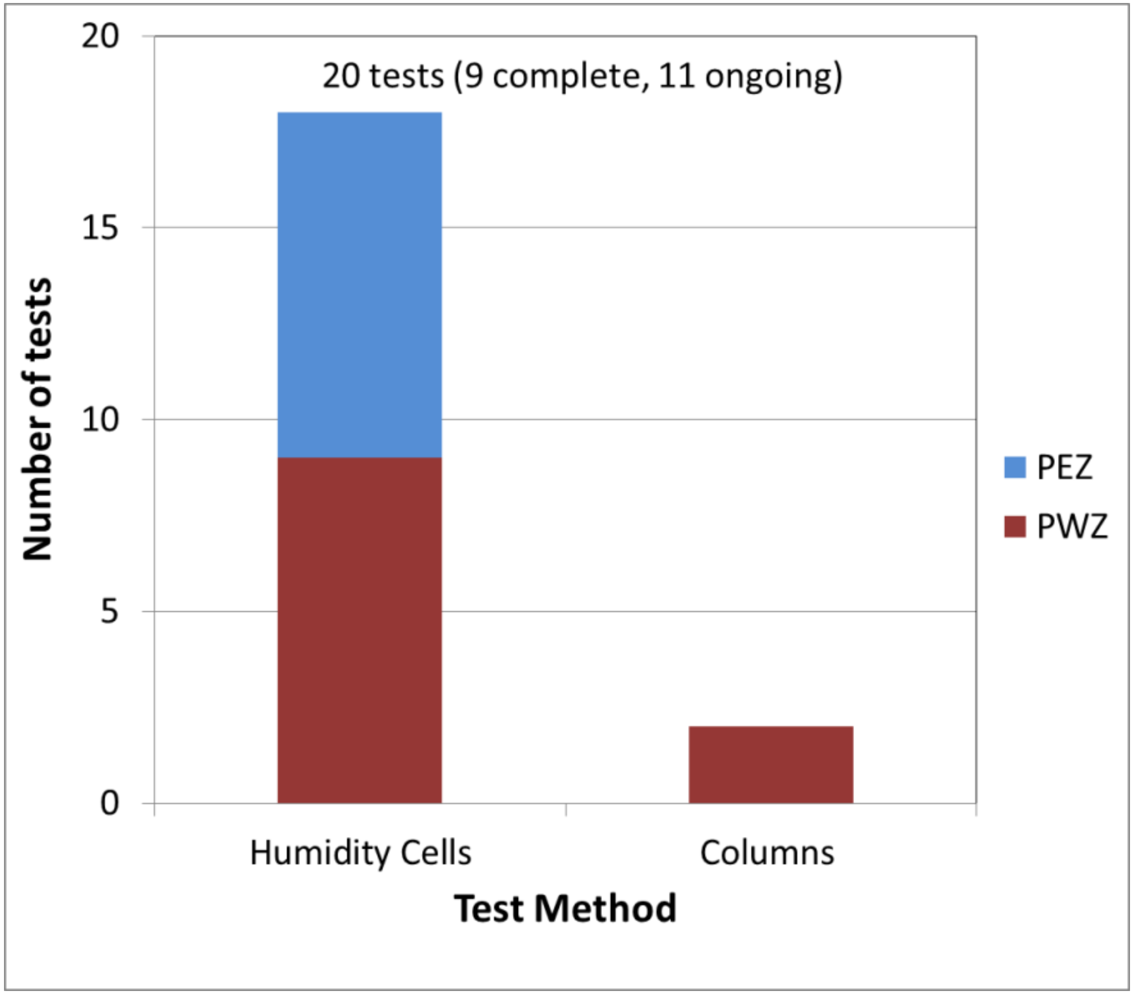


Kinetic Test Methods: Tailings



Humidity Cell Tests

Leach Columns



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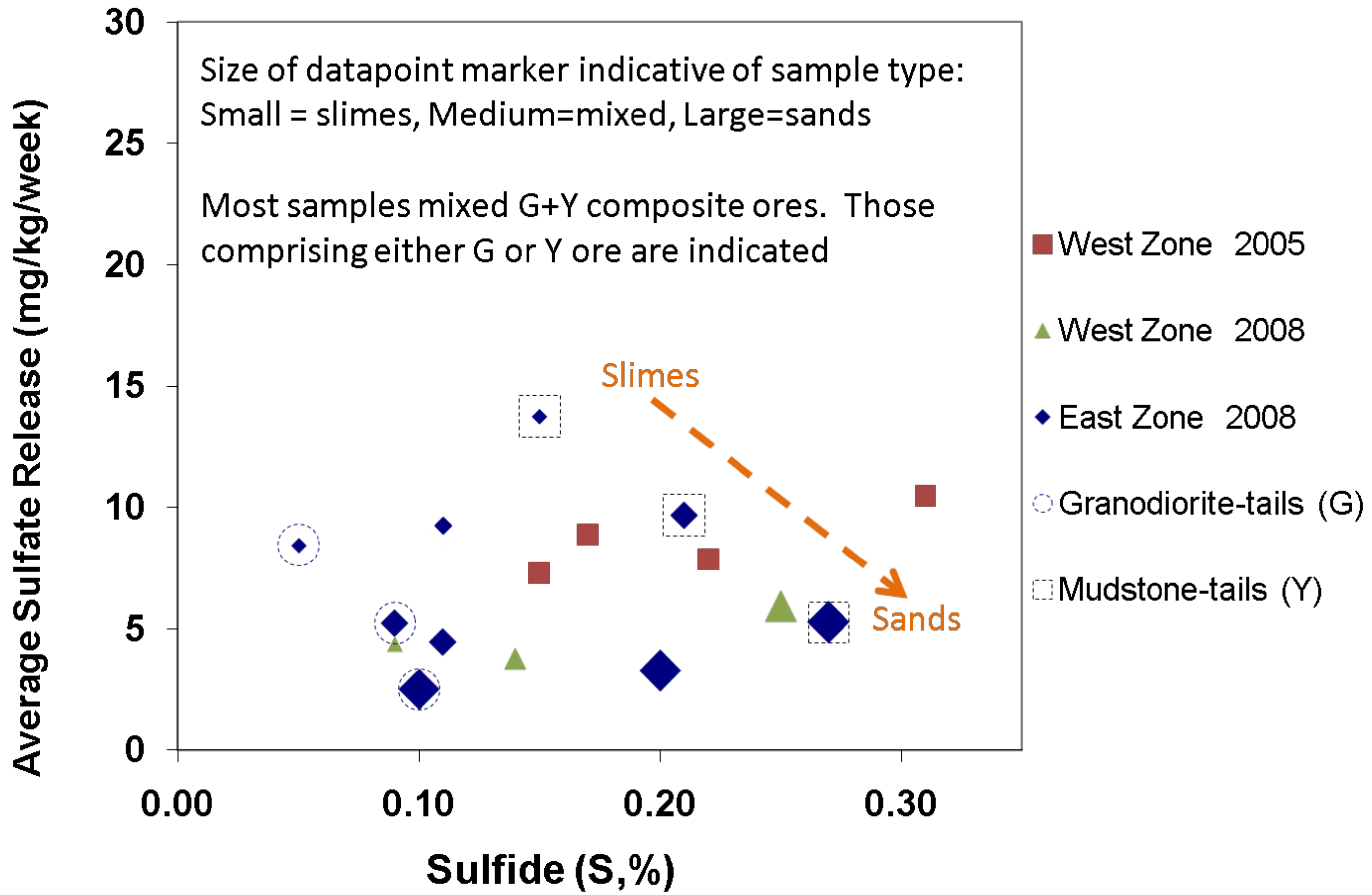
Humidity Cell Tests: Tailings

- Oxidation rates related to S content and particle size.
- To-date, no acidic leachates



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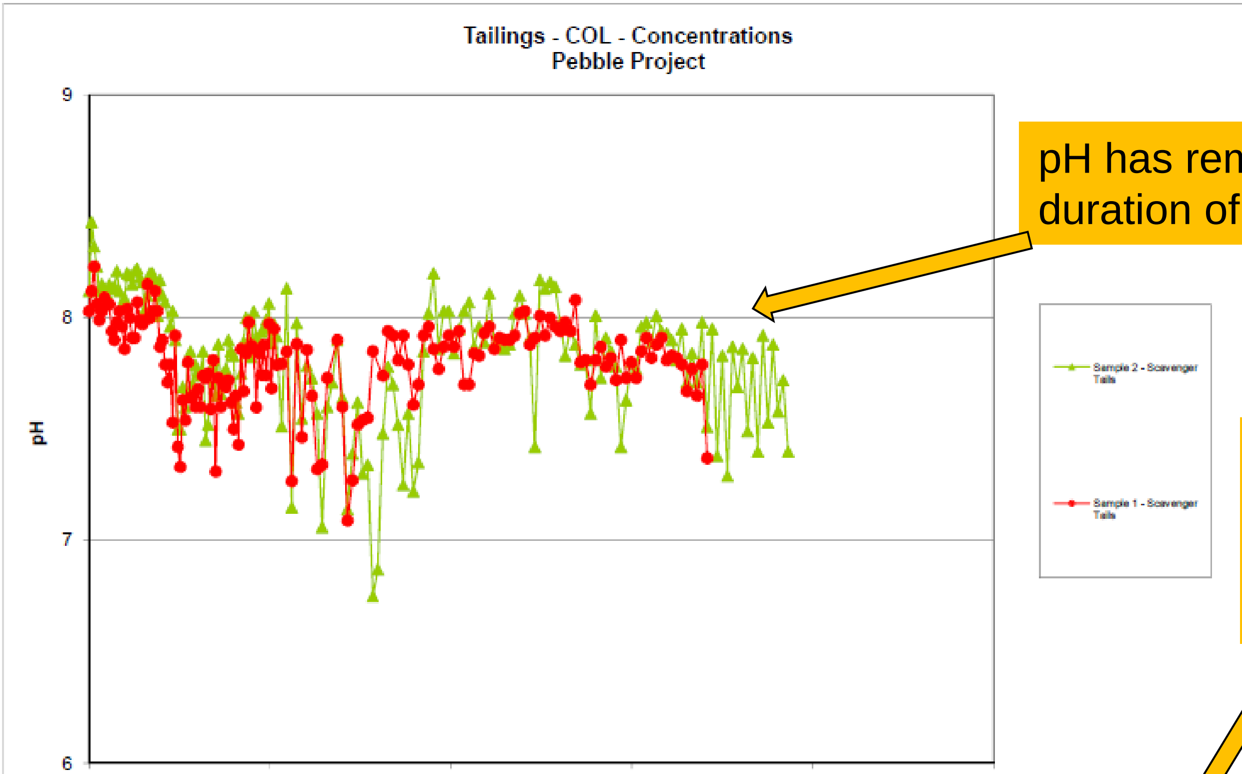
Leach Columns: Outcomes

pH



pH has remained near-neutral for duration of tests

Sulfate release towards low end of range shown by humidity cell tests

	SO_4 mg/kg/week
S2-Scavenger Tails	3.57
S1-Scavenger Tails	2.94

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Summary

- Waste rock
  - Large database of static test data have demonstrated distinctive characteristics of waste rock type.
  - Kinetic test data are suitable for input into waste rock management planning and water quality predictions.
  - Comparative data from field tests allow lab test data to be linked to field conditions.
- Tailings
  - Testing of simulated tailings indicates low ARD potential of bulk tailings.