Mining waste characterization and prediction of effluent quality

Mining Waste Management Methods (KaiHaMe)

Teemu Karlsson and Muhammad Muniruzzaman

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Introduction

- Low quality mine drainage from wastes, resulting from sulphide oxidation, is one of the biggest concerns in mining waste management
- The drainage chemistry should be predicted already in the planning phase of a mine
  - to assess potential environmental impacts of wastes and
  - to design relevant management and treatment methods for the waste facilities and their drainage,
- Finnish legislation on mining waste characterization is based on the EU legislation that has been implemented to Finland, especially on Directive 2009/360/EC
  - More info: http://wiki.gtk.fi/web/mine-closedure/wiki/-/wiki/Wiki/Legislation+regarding+characterisation+of+mining+waste
- Several methods are available to predict long-term behaviour of mining wastes and to assess their drainage quality
- Objectives: To assess the usability of several selected characterization methods in mine drainage prediction
- Materials: Waste rocks analysed from operating & closed mine sites with different characterization methods, drainage water sampling
- Investigations part of the ERDF funded KaiHaMe project

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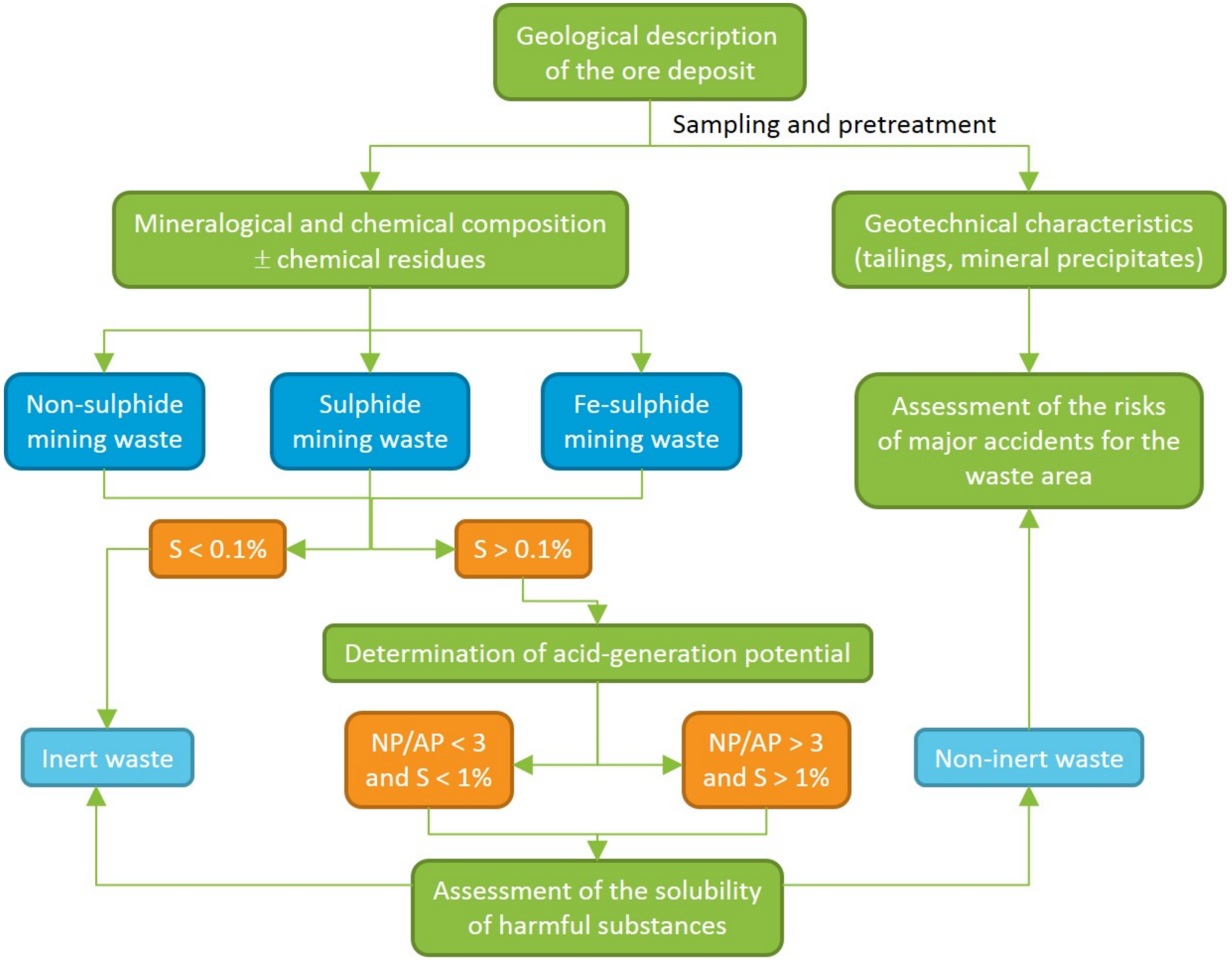
Characterization of mining wastes



Ref: Kauppila et al. 2013: Best environmental practices for metal mining

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Mine waste characterization

- Several laboratory and field methods have been developed to characterize mine waste materials and to predict their long-term behaviour.
  - Static tests: short term laboratory analyses, usually good for preliminary investigation and screening.
  - Kinetic tests: longer term tests, reveal information also about the time scale of drainage events. Kinetic tests are usually more expensive, time consuming and with larger test settings.
  - Results of the static tests and geochemical analyses can be used to select suitable samples for kinetic testing, and they can also provide threshold data for modelling (e.g. whole rock composition).

- Several modelling tools have been developed
- Prediction of the effluent quality is, however, a challenging task due to several reasons.
  - For example, mineral weathering processes resulting in low quality drainage from mining wastes are very complex and long-term

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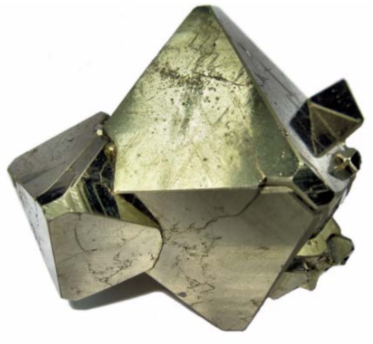
ARD prediction



- Acidity of the drainage depends on the ratio of acid producing and neutralising minerals in the waste.
  - Sulphide minerals, especially iron sulphides such as pyrrhotite and pyrite are acid producing minerals, whereas carbonates are the most effective neutralizing or acid buffering minerals.
- ABA: Acid-Base Accounting
  - Includes the determination of sulphur/sulphide content of waste to calculate acid potential (AP) of the waste. The neutralisation potential (NP) depends on the amount of carbonates and other alkaline material. Measured usually in EU based on standard CEN prEN 15875: 2008.
- NAG: Net Acid Generation
  - Based on the reaction of a sample with hydrogen peroxide, which accelerates the oxidation of sulphide minerals in the sample (AMIRA 2002). Acid producing and neutralizing reactions occur simultaneously.

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ARD prediction

- Known problems related to commonly used ARD prediction methods, e.g.:
  - APP may be overestimated if there are other sulphide or sulphur containing minerals than rapidly acid producing ones
  - APP may be underestimated if waste contains much easily dissolvable and acid generating iron sulphate minerals or siderite
  - NP may be underestimated if the weathering of silicate minerals is not considered in APP estimations
- AP and NP can also be calculated based on mineralogy (Lawrence and Scheske 1997) and relative reactivities of minerals (Sverdrup 1990)
  - See: http://wiki.gtk.fi/web/mine-closedure/wiki/-/wiki/Wiki/Mineralogical+calculation+of+AP+and+NP
- Commonly used factor to calculate AP from S content is 31.25, but in some cases, especially when predicting if pH will be around neutral, the use of AP factor of 61.5 is justified (Dold 2017)

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Comparison of static ARD tests to actual drainage pH

Mine site	S	AP factor: 31.25				AP factor: 62.5					
		NNP	**NPR**	**NNP**	**NPR**	**NNP**	**NPR**	**NNP**	**NPR**	**NAG pH**	**Drainage**
	%	NP-AP	NP/AP	minNP- minAP	minNP/minAP	NP-AP	NP/AP	minNP-minAP	minNP/minAP		
Pampalo	0.10	68.4	22.9	62.0	282.9	65.3	11.4	61.8	141.4	9.2	**6.7**
Siilinjärvi old	0.07	256.8	118.4	306.3	5106.0	254.6	59.2	306.2	2553.0	10.8	**6.5**
Siilinjärvi new	0.17	107.7	21.3	61.7	14.9	102.4	10.6	57.3	7.5	10.5	**7.0**
Horsmanaho old	1.41	-2.4	0.9	146.5	8.1	-46.4	0.5	125.9	4.1	7.5	**7.3**
Horsmanaho new	2.27	-24.6	0.7	133.7	4.8	-95.6	0.3	98.7	2.4	3.8	**7.7**
Kylylahti	4.32	-72.8	0.5	-120.7	0.2	-207.8	0.2	-271.1	0.1	9.0	**7.1**
Hitura 2014	3.35	-66.4	0.4	-48.1	0.3	-171.1	0.2	-121.0	0.2	2.6	**3.5**
Hammaslahti	1.61	-36.9	0.3	-2.4	0.7	-87.2	0.1	-11.6	0.4	3.0	**3.9**
Hitura 2016	2.47	-72.6	0.1	-14.2	0.5	-149.8	0.0	-42.0	0.2	2.6	**4.0**
Särkiniemi	1.69	-39.6	0.2	1.9	1.1	-92.4	0.1	-15.9	0.6	2.7	**3.3**
Hällinmäki	0.37	-1.9	0.8	18.6	12.1	-13.4	0.4	16.9	6.0	4.1	**6.7**
Laiva	0.10	6.8	3.1	8.1	14.8	3.6	1.6	7.5	7.4	7.5	**7.0**
Kevitsa	0.31	48.1	6.0	170.7	132.3	38.6	3.0	170.7	66.4	9.1	**7.4**

- Non-acid generating
- Potentially acid generating
- Uncertainty zone; slightly non-acid generating
- Uncertainty zone; slightly acid generating
- Uncertainty zone

Disclaimer: Does the waste rock sample and drainage water sample represent the whole pile? Age of pile!

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Geochemical characterization and element mobility prediction

- Geochemical characterization is carried out to define total chemical composition of mine wastes
  - to identify primary contaminants and other elements of concern and to assess leachability of elements from the wastes.
- Example methods:
  - XRF: total element concentrations
  - Aqua Regia extraction: acid soluble elements, elements bound to mica, clay, salt and sulphide minerals
  - NAG test leachate: not very widely used, but has been suggested
  - Shake flask test (SFS-EN 12457-3): weak leaching test recommended by the European mining waste characterization standard

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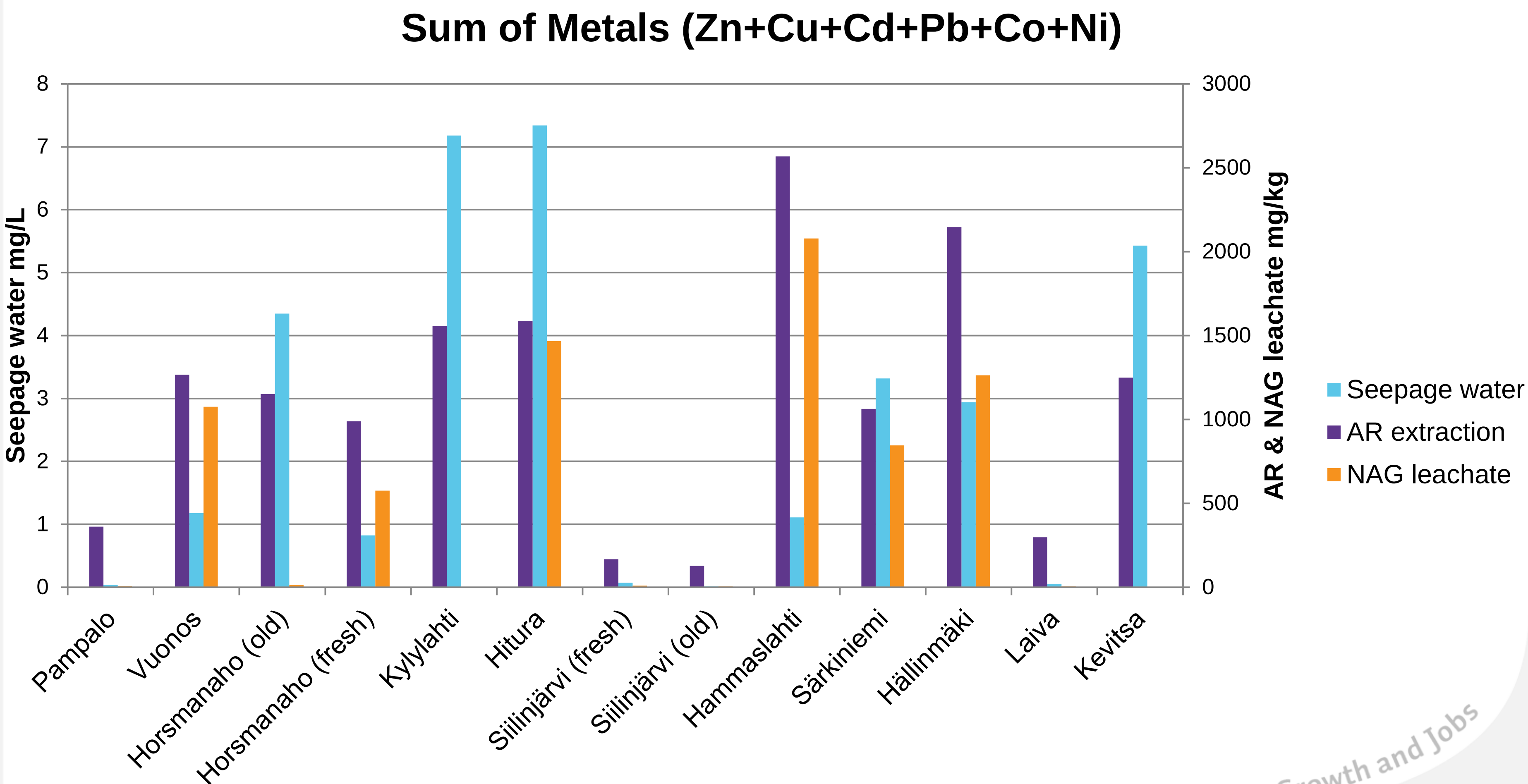
Comparison of Aqua Regia and NAG test leachates



Aqua Regia: quite good correspondence with drainage

NAG leachate: doesn't show up in some cases

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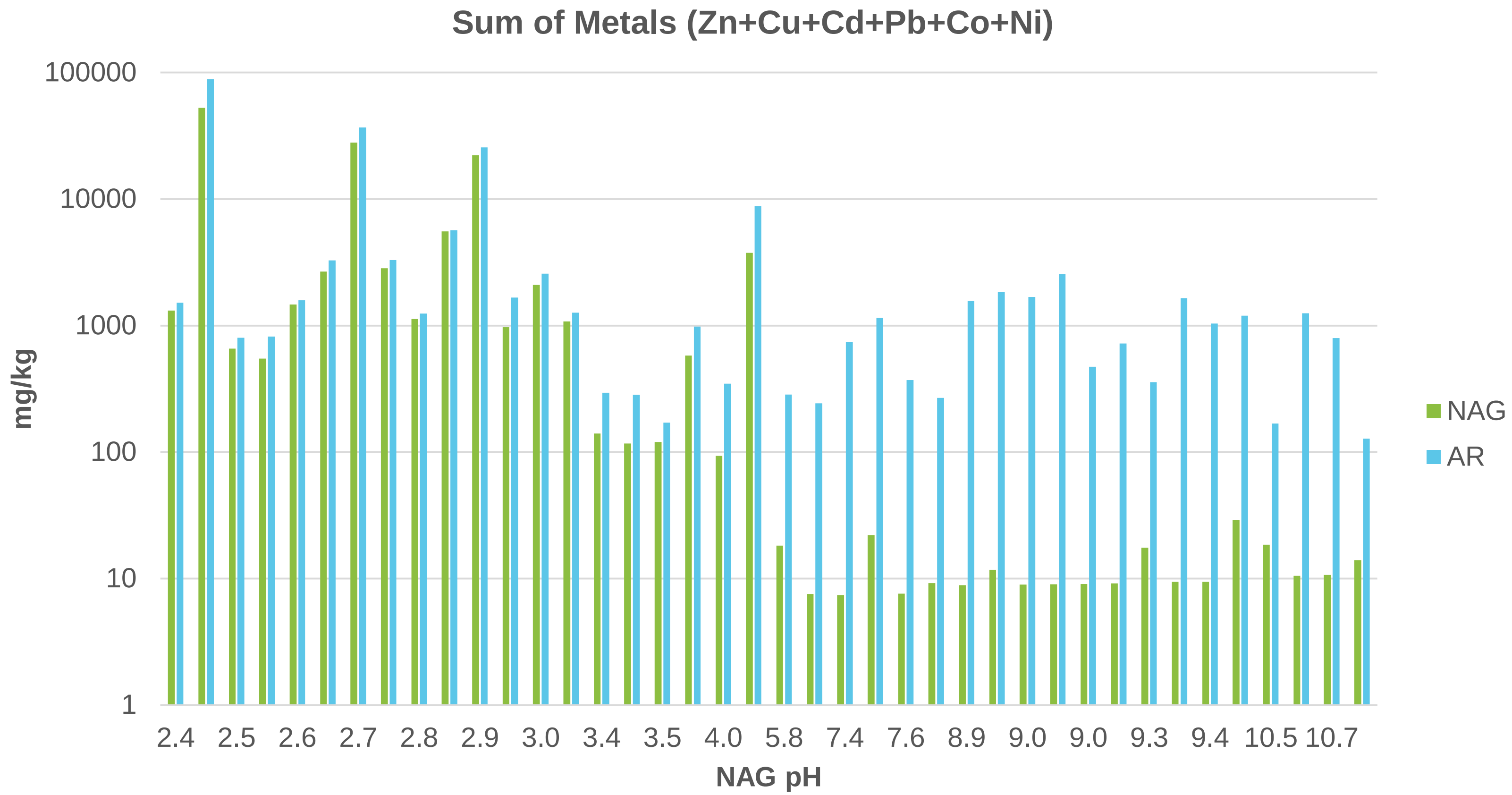
NAG test leachate analysis



Element concentrations drop in NAG test leachate when pH gets higher!

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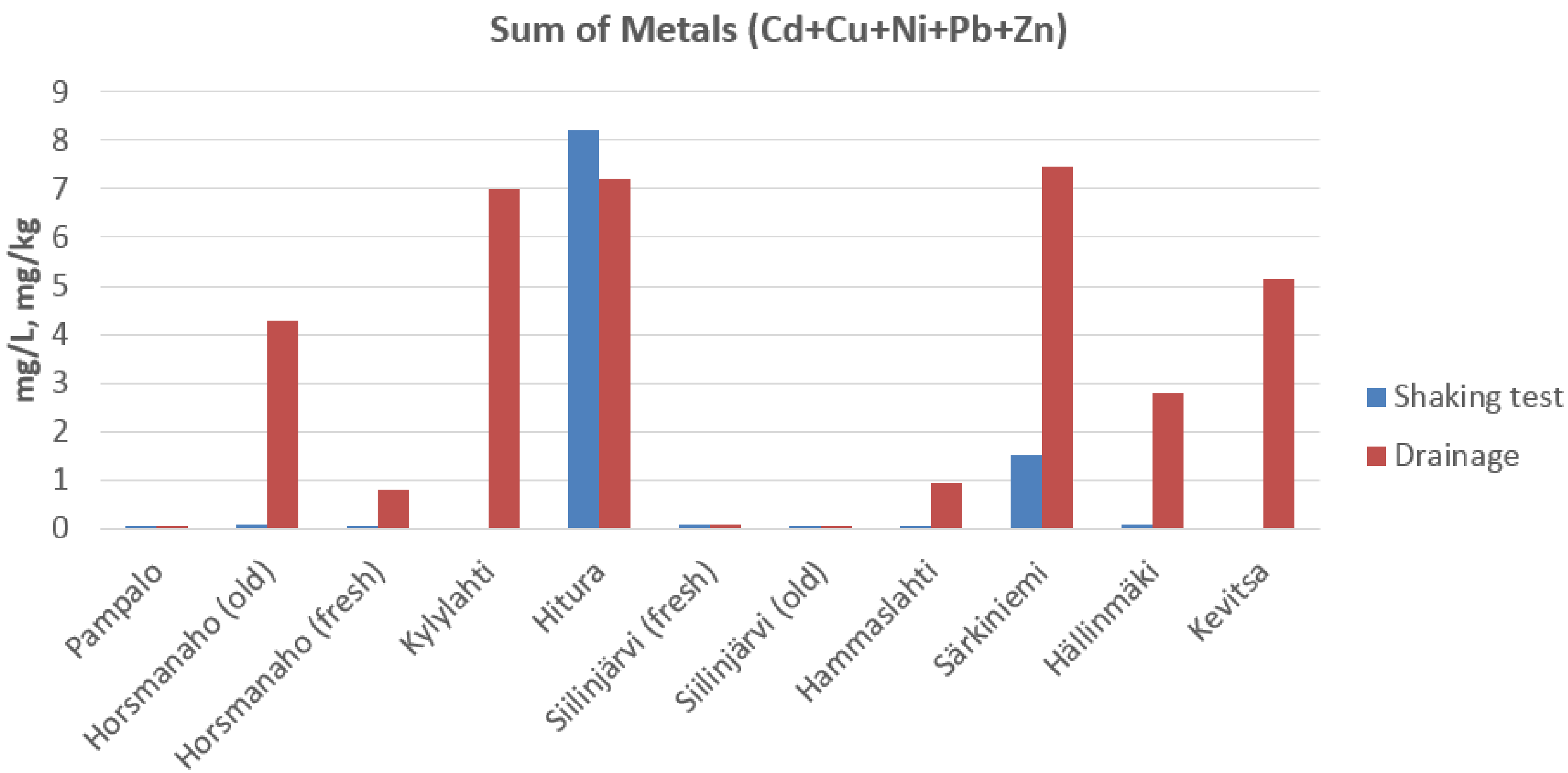
Shake flask test



Not very good in drainage quality prediction for fresh waste rock (OK for some clearly weathered waste material)

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Modelling

- Accurate data is needed for modelling
- Major controlling processes must be identified
- The overall system behaviour (hydrogeology and geochemistry) should be properly understood
- ”Minimum” data required for reliable predictions:
  - Mineralogical composition and weathering rates
  - Recharge and ambient environmental conditions
  - Main fluid migration pathways and solute transport within the waste facilities and in the surrounding receptor water bodies
  - Heterogeneties regarding physicochemical properties
  - Representative quantity and quality of data
  - Spatially and temporally resolved data (e.g. depth profiles, time series) are always more helpful

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Modelling

- Useful codes:
  - PHREEQC
  - MIN3P
  - CrunchFlow
  - Geochemist's Workbench
  - TOUGHREACT
  - HPx
  - HYDROGEOCHEM
  - PFLOTRAN
  - OpenGeoSys
- For more details, see soon to be published KaiHaMe report "*Water quality prediction of mining waste facilities based on predictive models*" (Muniruzzaman et al. 2017)

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Conclusions

- ABA and NAG tests
  - May underestimate/overestimate NRP, e.g. do not consider silicate NP
- Mineralogical ARD prediction
  - Silicate NP can be taken into account – seems to be more realistic in ARD prediction, if sufficient mineralogical data is available
- Aqua Regia
  - Good correspondence with actual seepage water quality in predicting which elements will be present in the effluents, too pessimistic with some elements
- Shake flask test
  - Doesn't work with fresh waste rocks, may indicate drainage quality when analysing old weathered rock material
- NAG test leachate
  - Similar to AR results, but only if NAG test pH is below 3.5-4
  - Method development needed!

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Conclusions

- Study site should be characterised as detailed as possible
  - System understandings are inevitable for meaningful model predictions
- Quantity and quality of data will ultimately determine the quality of predictive modelling
  - Sufficient budget should be allocated in detailed site characterisation
  - Good communication between the experimentalist and the modeller during the planning phase of a data collection campaign can be more efficient
  - Periodic monitoring helps validating and improving model performances
  - Accuracy of predictive modelling is primarily limited by the system understading rather than codes' capabilities
- Numerical codes should be selected based on:
  - Capabilities
  - Numerical methods and their accuracies
  - Visualization packages and graphical user interfaces
  - Availability to the public

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Thank you!

teemu.karlsson@gtk.fi (characterisation)
md.muniruzzaman@gtk.fi (modelling)

http://projects.gtk.fi/KaiHaMe

Additional information on the mine waste characterization methods is available in the GTK's Wiki page: mineclosure.gtk.fi

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