The Case for the Incorporating Mine Waste Characterisation and ML-ARD Into Mineral Resource Reporting Frameworks

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BC MEND ML/ARD ANNUAL WORKSHOP

The Science Behind Success

Controversial presentation warning...

- Non-ore materials characterisation should be considered as integral to mineral resource evaluation and reserve declaration

- Non-ore material characterisation should be included in the reserve declaration stage because, in addition to ore extraction and processing, managing these materials (including tailings) determines if the project as a whole will be financially viable.

  - PFS typically aims to put costs within +/- 25% whilst a DFS aims for +/-10%. A strong argument can be made that this is not achievable (at least for DFS) without thorough waste characterisation

- This places great importance on having a representative block model (and thus drill hole assay database) for non-ore parts of the deposit before a reserve can be declared.

- The focus should be on integrated mine planning driven by appropriate drill hole asssay database and block model development as part of resource-reserve development framework

- ML/ARD regulations and guidance, and existing mineral resource reporting frameworks together as they stand today are not sufficient to achieve the above in a consistent way

We have completed the study “with reference to”……

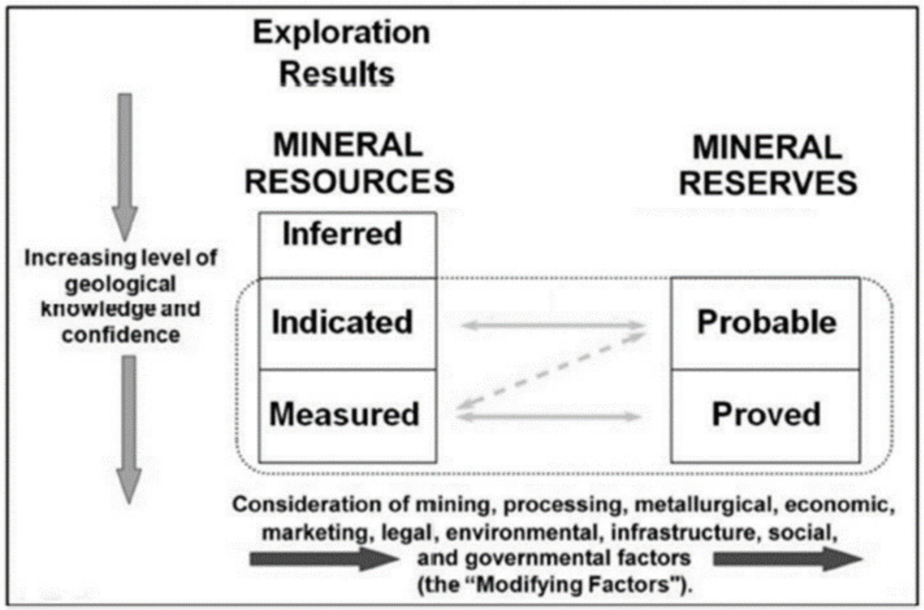
Type of document	Ireland	Finland	Sweden	Comments	Required implementation
EU legislation	IS EN	SFS EN	SS EN	Implemented by EU countries	Mandatory
Nationally-developed standards and legislation	NSAI	SFS:	SIS CEN	Includes technical reports and specifications on testing methods	Mandatory (in country)
Joint standards developed by CEN & ISO	EN-ISO			Not mandatory for EU countries, implemented case by case	Advisory standard method
International standards	ISO				
European guideline documents	BAT			Best available techniques	Advisory
International codes of practice	PERC			European equivalent of similar international documents (e.g. JORC/CIC)	Mandatory
International guides on testing and material characterisation	BAT			GARD guide, MEND guide	Advisory, different climates and legislative regimes

“The JORC Code provides a mandatory system for the classification of minerals Exploration Results, Mineral Resources and Ore Reserves according to the levels of confidence in geological knowledge and technical and economic considerations in Public Reports.” (https://jorc.org)“

How does waste characterisation fit with mineral resource framework

- In general this means increasing level of knowledge about ore zones not always waste zones

- However this phase provides much opportunity for ML/ARD study and to increase level of geochemical knowledge and confidence



Waste zones generally only become "important" when converting resources to reserves. Mine waste may be considered a "modifying factor"

ML/ARD as a "modifying factor"

Modifying Factors

PERC PAN-EUROPEAN RESERVES + RESOURCES REPORTING COMMITTEE

4.8.	***Definition***	**Modifying Factors are considerations used to convert Mineral Resources to Mineral Reserves. These include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social, governance ('ESG') and regulatory factors.**

The conversion of Mineral Resources to Mineral Reserves requires the consideration of the Modifying Factors. The estimation of Mineral Reserves must include consideration of all relevant Modifying Factors with input from a range of disciplines.

MINERAL RESERVE

MINERAL RESOURCE

Suitable waste characterisation and waste management risk assessment

By definition, to convert a mineral resource to a reserve then suitable waste characterisation, and waste management risk assessment is required as these are Modifying factors

Implications for non ore charactersiation

- Sufficient understanding of mine waste management is required to demonstrate a mine plan and schedule **is** technically achievable and economically viable.

- Understanding of the geochemistry of the waste should be sufficient to assume geochemical continuity between points of observation where data and sample are gathered (pertinent to spacing of boreholes)

CIM ICM

Geological evidence is derived from adequately detailed and reliable exploration, sampling and testing gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes, and is sufficient to assume geological and grade (or quality) continuity between points of observation where data and samples are gathered.

Underlying rational

- The process of ML/ARD assessment in the context of resource phase of project development could be considered as a bottom-up, rather than a top-down assessment

- Data driven process rather than a compliance driven process.

- The objectives for ML/ARD assessment can be thought of in terms of providing a set of requirements to provide an underlying suitable data set to facilitate future ML/ARD assessment

- From this bottom-up data-driven approach that consideration of ML/ARD within mineral resource/reserve definition frameworks becomes a practical, holistic and integrated consideration.

Understanding of the geochemistry of the waste should be sufficient to assume geochemical continuity between points of observation where data and sample are gathered

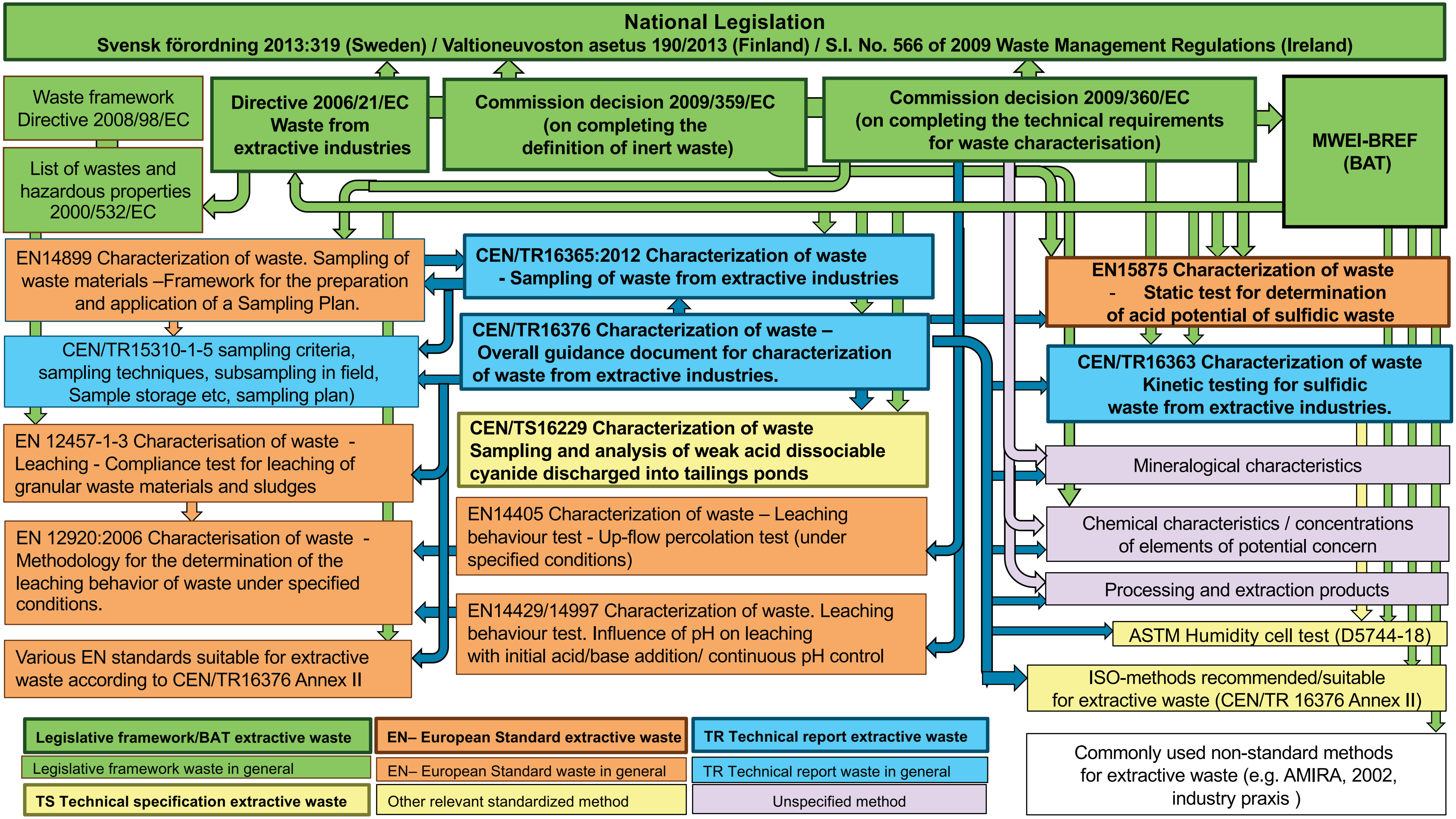
Implication for sampling requirements

- Conversion of Resources to Reserves - the declaration that a project is economic - cannot be completed without knowledge of waste management requirements and water treatment costs through operation, closure and post closure.

- It is necessary for investors, boards and directors to be informed of these costs in order to make fully informed investment decisions.

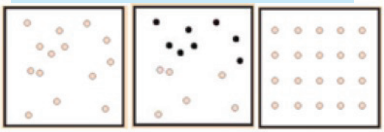
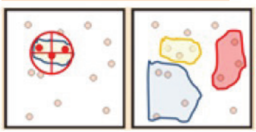
- Therefore we could make an argument that the number of samples required for waste characterisation at PFS stage for conversion of a resource to a reserve is:

- "Equal to that required to construct an ML/ARD block model that is suitable for use to develop a life of mine plan (including closure), mine waste schedule, and processing method that is technically achievable and economically viable"
    - This is not likely to be 50 or 100 samples.....Why? Because if a generic, non statistically justified sample number in ore zones is not acceptable for estimation as part of mineral reserve declaration then de-facto it should not be acceptable for waste characterisation "estimation" for any project proceeding to mining.


National Legislation
Svensk förordning 2013:319 (Sweden) / Valtioneuvoston asetus 190/2013 (Finland) / S.I. No. 566 of 2009 Waste Management Regulations (Ireland)
Waste framework Directive 2008/98/EC
List of wastes and hazardous properties 2000/532/EC
Directive 2006/21/EC Waste from extractive industries
Commission decision 2009/359/EC (on completing the definition of inert waste)
Commission decision 2009/360/EC (on completing the technical requirements for waste characterisation)
MWEI-BREF (BAT)
EN14899 Characterization of waste. Sampling of waste materials –Framework for the preparation and application of a Sampling Plan.
CEN/TR16365:2012 Characterization of waste - Sampling of waste from extractive industries
EN15875 Characterization of waste - Static test for determination of acid potential of sulfidic waste
CEN/TR15310-1-5 sampling criteria, sampling techniques, subsampling in field, Sample storage etc, sampling plan)
CEN/TR16376 Characterization of waste – Overall guidance document for characterization of waste from extractive industries.
CEN/TR16363 Characterization of waste Kinetic testing for sulfidic waste from extractive industries.
EN 12457-1-3 Characterisation of waste - Leaching - Compliance test for leaching of granular waste materials and sludges
CEN/TS16229 Characterization of waste Sampling and analysis of weak acid dissociable cyanide discharged into tailings ponds
Mineralogical characteristics
EN14405 Characterization of waste – Leaching behaviour test - Up-flow percolation test (under specified conditions)
Chemical characteristics / concentrations of elements of potential concern
EN 12920:2006 Characterisation of waste - Methodology for the determination of the leaching behavior of waste under specified conditions.
Processing and extraction products
EN14429/14997 Characterization of waste. Leaching behaviour test. Influence of pH on leaching with initial acid/base addition/ continuous pH control
ASTM Humidity cell test (D5744-18)
Various EN standards suitable for extractive waste according to CEN/TR16376 Annex II
ISO-methods recommended/suitable for extractive waste (CEN/TR 16376 Annex II)
Legislative framework/BAT extractive waste
EN– European Standard extractive waste
TR Technical report extractive waste
Legislative framework waste in general
EN– European Standard waste in general
TR Technical report waste in general
TS Technical specification extractive waste
Other relevant standardized method
Unspecified method
Commonly used non-standard methods for extractive waste (e.g. AMIRA, 2002, industry praxis)

The purpose of the samples

- Difference between sampling to understand the geochemical behaviour of different types of waste (most ML/ARD studies) and that to construct a block model (Resource development)

	Details	Advantages	Application
Probabilistic sampling 	Random or regular grid – for example **resource or grade control drilling**	Statistical analysis is possible. Can quantify error	**Construct block model of waste** **Inform spot sampling**
Spot sampling  Most ML/ARD studies	Targeted sampling – understand the **ARD-ML behaviour** of a subset of samples	Detailed (often time-consuming and costly) tests used to characterise the selected materials	**Characterise waste** **Inform ARD-ML model – parameters that define waste classes**

Some of the ambiguity in discussions of number of samples required for waste definition stems from lack of clarity regarding the purpose of the samples. There is a difference between sampling to understand the geochemical behaviour of different types of waste and sampling required to construct a block model.

Describe probabilistic vs spot sampling using the table.

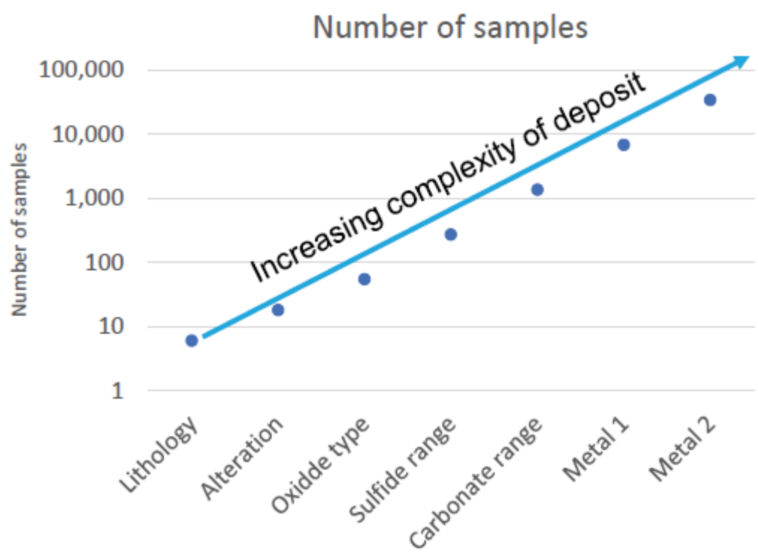
Crucially, both types of sampling are needed to create robust waste models that reflects the AMD behaviour accurately.

Sample selection principles

- Sampling is needed to obtain information
- The number of samples depends on the question that is being addressed and the detail/accuracy that the answer needs to deliver
- Generally, drilling gives random sampling type data. This information can be used to select targeted samples to understand specific combinations of parameters (for example sulfur content + carbonate mineralogy + specific alteration).
- Such targeted sampling provides information that allows application of the parameters collected for the larger randomly-selected dataset to predict material properties
- Validation testing requires once again a random sampling approach

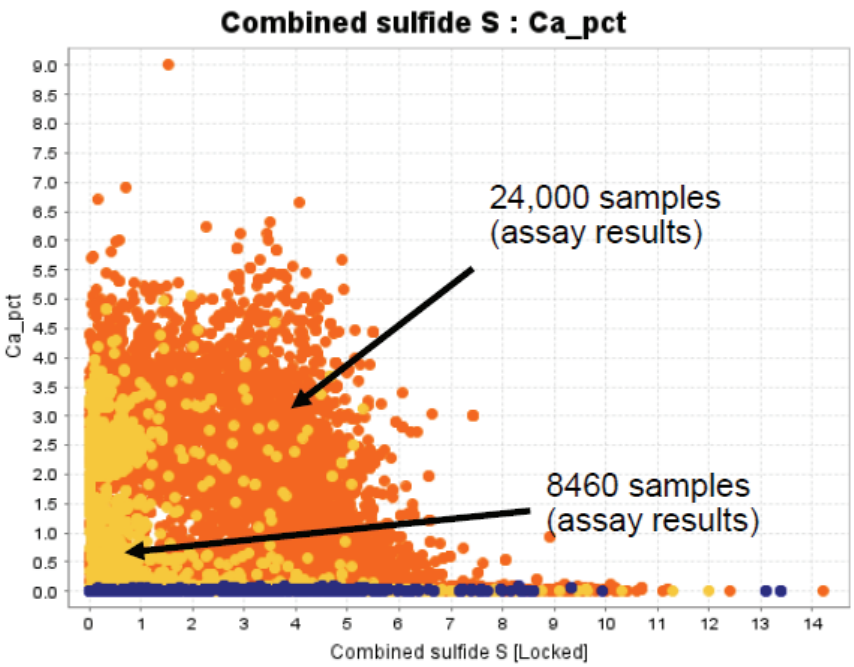
Geochemical properties relate to underlying complexity and number of relevant variables

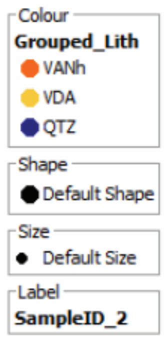
- Given the following deposit characteristics how many samples are required to characterise geochemical properties?
  - 6 rock types (dacite, andesite, breccia)
  - 3 alteration types (silicic, argillic, advanced argillic)
  - 3 oxide types (oxide, transition, sulfide)
  - 5 key sulfide ranges (e.g. 0-0.15%, 0.15-0.3%...)
  - 5 key carbonate grade ranges
  - 2 key metal species (not correlated e.g. As and Mn), for each metal species 5 key metal concentration ranges (e.g. 0-100ppm, 100-250ppm etc)

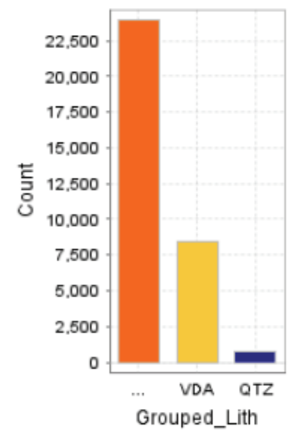


Maximum potential combinations of properties = <u>33,750 i.e. likely tens of thousands of different geochemical compositional outcomes that may be sampled.</u>

What is the level of confidence in the underlying distributions of key parameters in the entire resource?

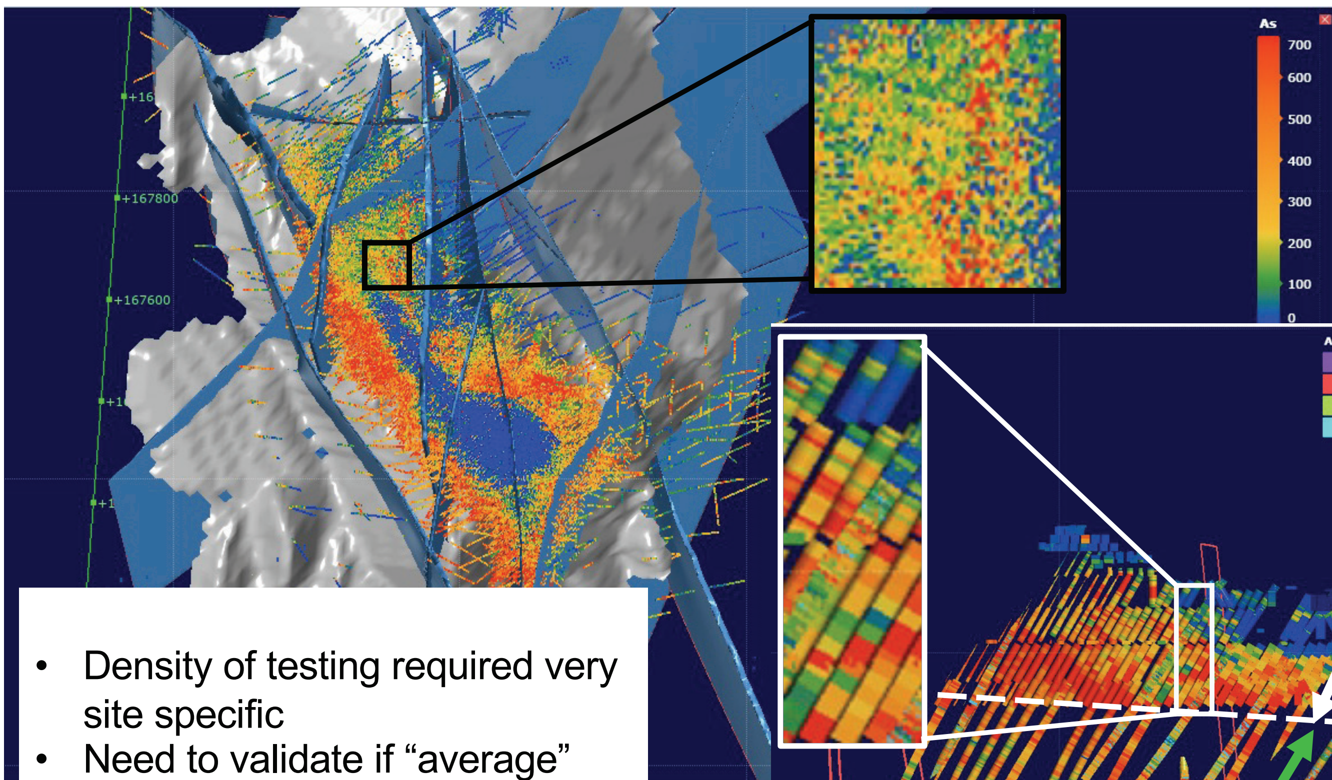




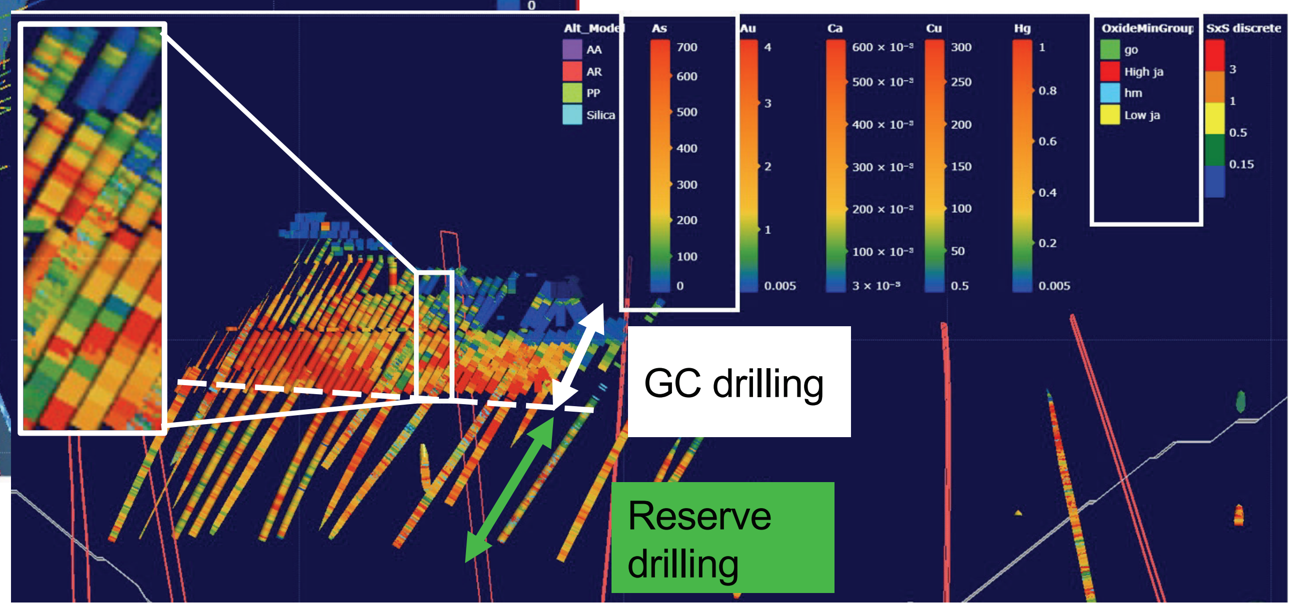


- Are the distributions a function of real differences by lithology or a function of number of samples taken?
- How many samples are needed to understand the distribution to a meaningful level of statistical certainty?
- How should sampling strategy for ARD/ML be developed and validated?

Real life complexity from high density grade control drilling ~260,000 results for arsenic



Layered complexity:
- Rock type
- Alteration type
- Oxidation state
- Mineralisation type
- Mineral grade



- Density of testing required very site specific
- Need to validate if “average” grade approach appropriate for block models of waste zones.

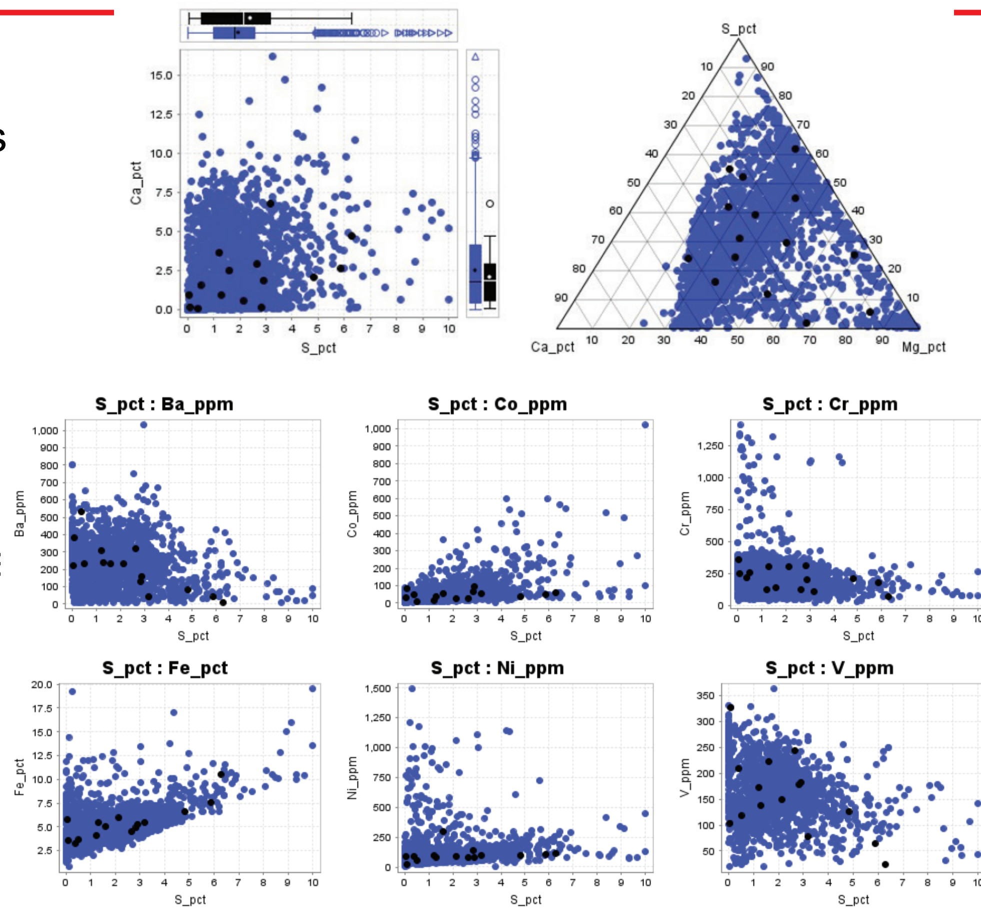
Sample selection: the unknown unknows...

- Targeted sample selection aims to provide information for the key combinations of parameters that may be encountered, while capturing some of the variability of the depost.

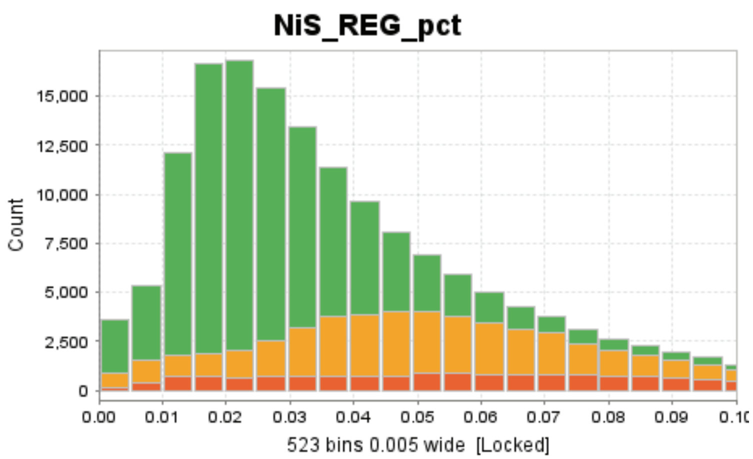
- Usually, it is aimed to have similar distribution of lithologies in the subset of detailed samples as in the deposit

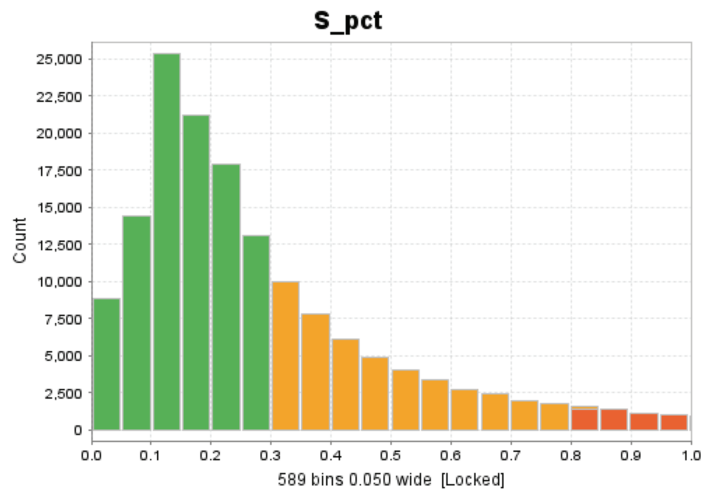
- Targeted testing requires samples from different depths and parts of the pit so that it is representative of the rock in the deposit as a whole

- <u>Balancing the geochemical distribution of the deposit can be challenging if very few samples are selected</u>



Distributions in assay database against classifications

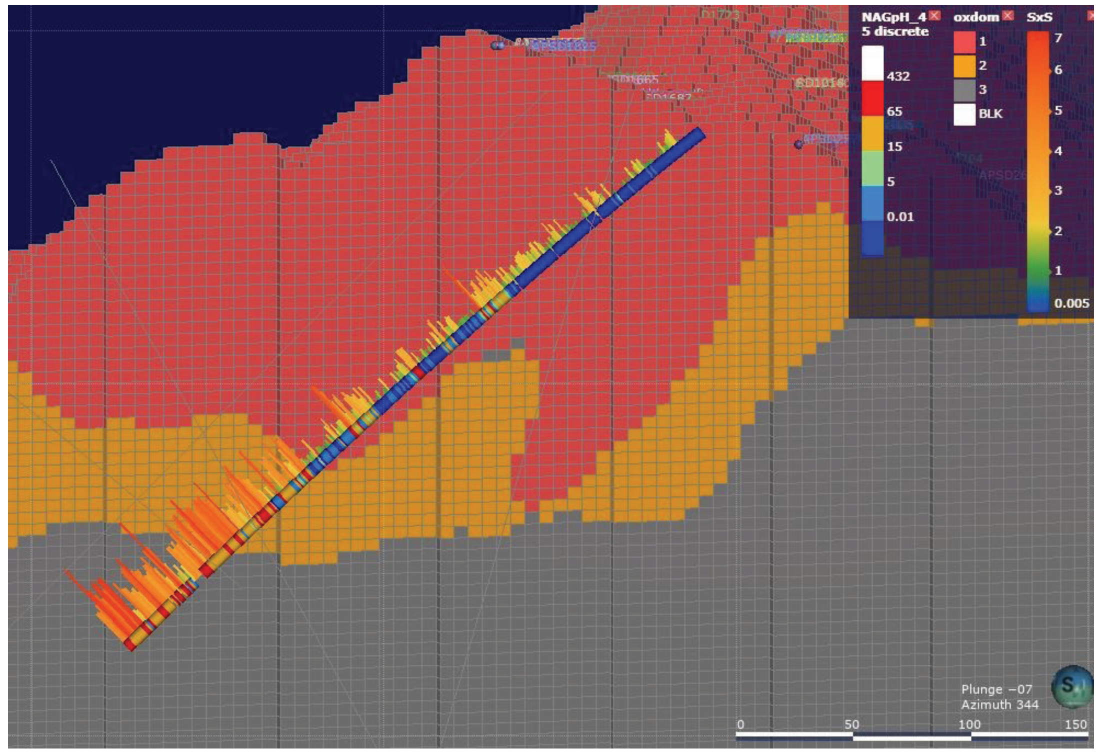




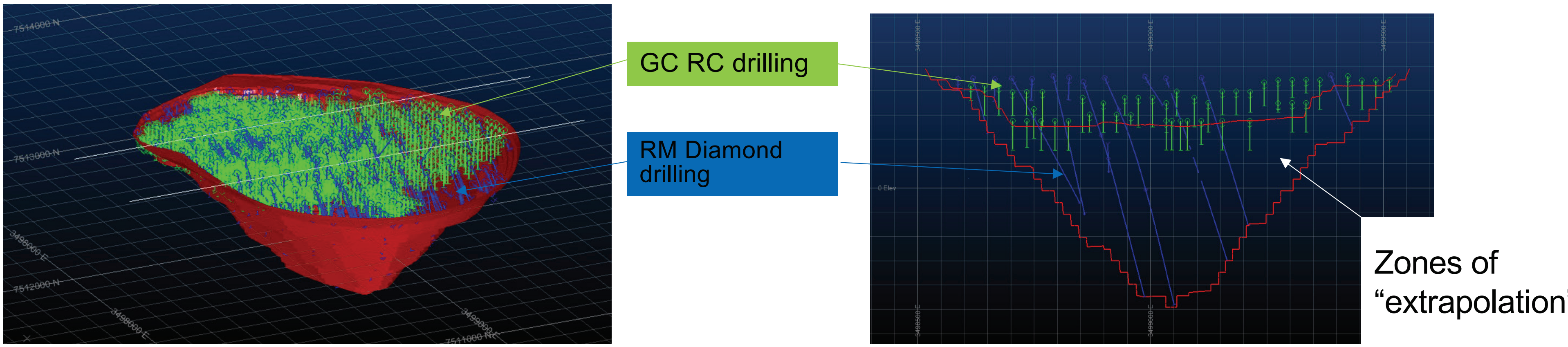
Parameters are not always directly correlated meaning without a lot of data it can be difficult to determine what the distributions are for a given waste material classification

Datasets vs models and validation

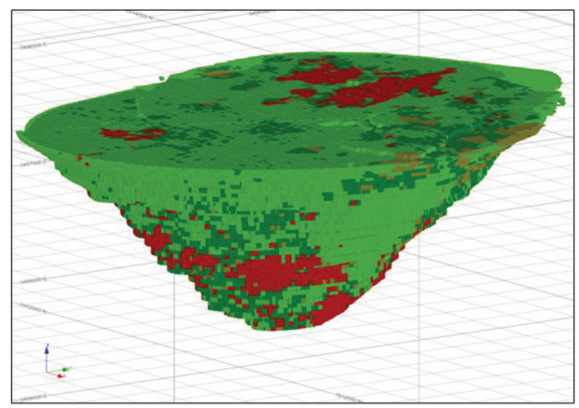
- Drill data is used to construct the model:
  - Where more than one interval data point is present for the block, the assay data has to be combined in some way (for example grade weight average or top cut value)
  - Where no borehole intercepts the block, data has to be interpolated between nearest data points, making an assumption about the grade and geology being similar to that of the locations of the boreholes, or be predictably grading between the two.



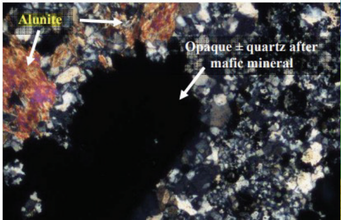
Block model construction



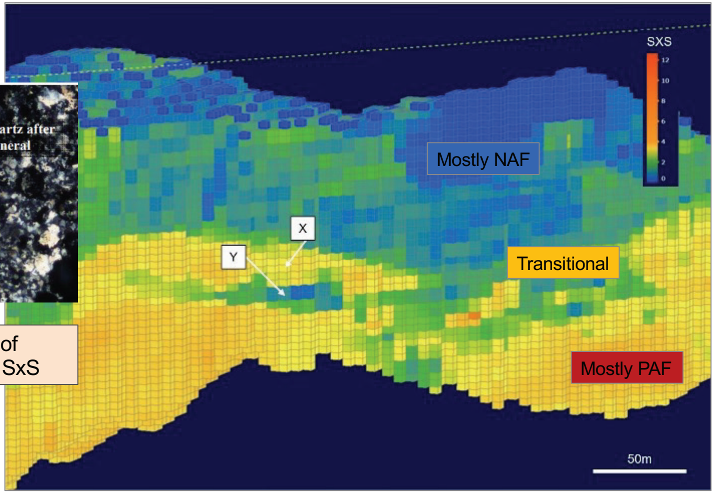
Parameter	Resource Model	Grade control Model
Block size (m)	30*40*24	10*10*12
Drill data	Diamond and RC	RC
Estimation	Indicator Kriging & Ordinary Kriging	Indicator Kriging & Ordinary Kriging
Assay data	Metals, Sulfide sulfur	Metals/sulfide sulfur/XRD/AMD



High-resolution, low certainty model



Alunite can make up >30% of rocks = 1.5% false uplift on SxS



X = Elevated Sulfur Reduced zone, Y = Low Sulfur Oxide Zone

- Looks great, and model based on proxies from routine assay can have >260,000 datapoints. **<u>BUT</u>** SxS is impacted by Alunite, a source of sulfate sulfur also picked up in SCIR measurements
- Therefore the model requires corrections in zones of elevated alunite
- Alunite Min-1 on ASD and confirmed with XRD on selected validation boreholes

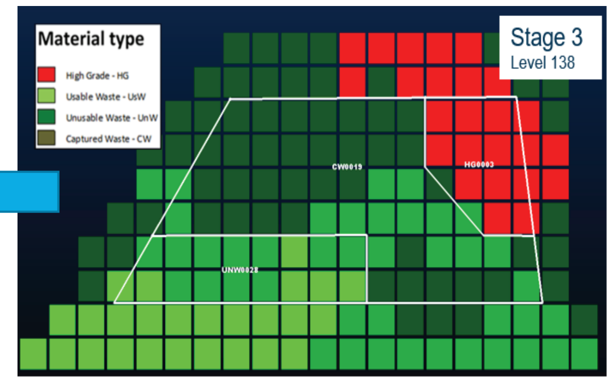
Changes from model to mining

Blast movement

Blast/dig plan

	Block Tonnes	Ni	NiS	Cu	CuS	Au	Pt	Pd	S	NICUEQ_	POPNRAT_	CUNISRAT_	Talc_	Amphibole
CW	174,830	0.07	0.05	0.07	0.06	0.022	0.03	0.02	1.33	0.10	20.03	1.33	0.01	29.85
CW0019	174,830	0.07	0.05	0.07	0.06	0.022	0.03	0.02	1.33	0.10	20.03	1.33	0.01	29.85
UNW	60,770	0.06	0.03	0.04	0.03	0.014	0.04	0.02	0.36	0.06	7.44	1.17	0.00	40.70
UNW0028	60,770	0.06	0.03	0.04	0.03	0.014	0.04	0.02	0.36	0.06	7.44	1.17	0.00	40.70
HG	45,380	0.16	0.13	0.28	0.25	0.072	0.09	0.06	1.53	0.31	7.84	2.12	0.02	18.94
HG0003	45,380	0.16	0.13	0.28	0.25	0.072	0.09	0.06	1.53	0.31	7.84	2.12	0.02	18.94
Grand Total	280,980	0.08	0.06	0.10	0.09	0.028	0.04	0.02	1.15	0.13	10.80	1.77	0.01	30.43

Block model

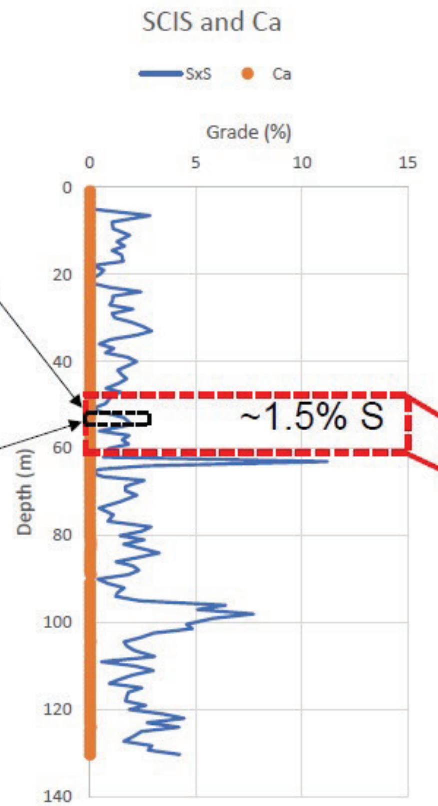


- Scale of mining may not be equal to block model.
- Bulk mining means that “isolated” blocks may be lumped in with others
- Grade weighting at the mine plan scale means that mixing/blending of blocks together likely to occur
- After blasting boundaries between blocks/dig areas move meaning that mixing occurs across boundaries during mining process (unless offsets are applied at boundary zones)

Grade weight averaging

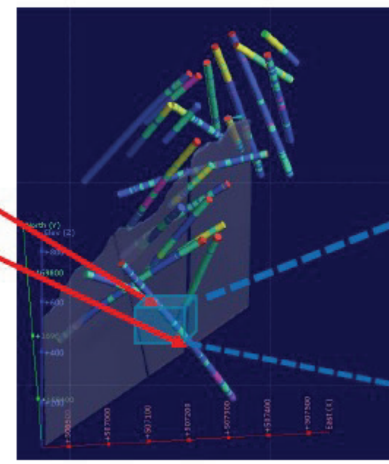
1m drill core intervals

3m composite sample for sulfide sulfur analysis



130m drill hole profile sulfide sulfur/calcium assay data

Designed for resource assessment (entire block will be processed), not for environmental evaluations where the range of values may be more important than the average.

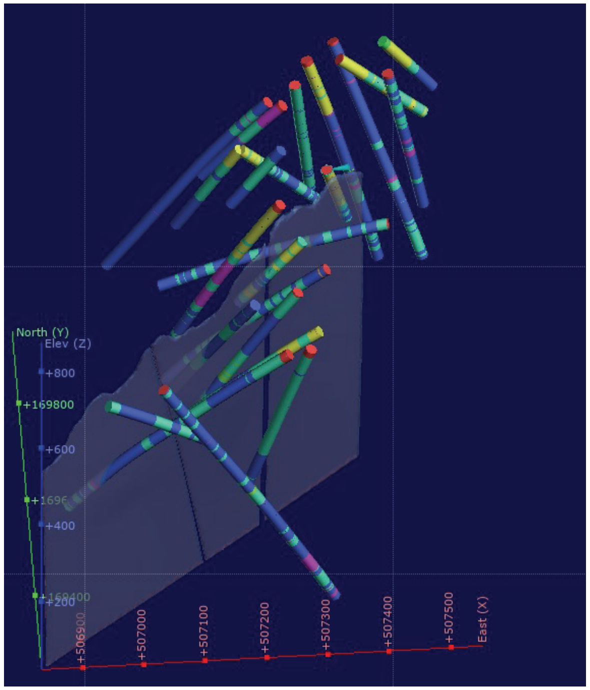


25*10m block area in resource model

Grade weighted average block value based on model estimation

Conclusion: better understanding underpins better outcomes

- Mines produce waste more than anything else (volumetrically)
- Sampling and modelling of this waste should be developed using a similar approach as carried out in the ore zone
- Early detailed geochemical characterisation can identify the key ML/ARD risk indicators so that they are included in the testing and used for modelling from the onset.
- This will improve the accuracy of planning, scheduling, estimation of future risks from the waste and economic evaluation.



25*10m block area in resource model

Conclusions

- Where ML/ARD assessment is considered as a separate technical exercise to mineral resource assessment, missed opportunities can be identified with respect to both the development of the underlying data set used for ML/ARD assessment, and consequently managing project risks related to ML/ARD.
- Development of an integrated framework that better describes the integration of ML/ARD into resource definition project workflow and resource reporting is considered to be a significant opportunity for the mining industry to present ML/ARD related risks and develop transparent ML/ARD related mitigation strategies
- Considerations of circular economy, and reduce-reuse-recycle mantras, consideration of integrating ML/ARD into resource development and reporting can assist with determine “value” to non-ore blocks as well as ore blocks within a mine model.
  - For this to be practicable the underlying data set is required to be developed during the resource development phase to include appropriate parameters to allow the construction of a non-ore block model

Thank you

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