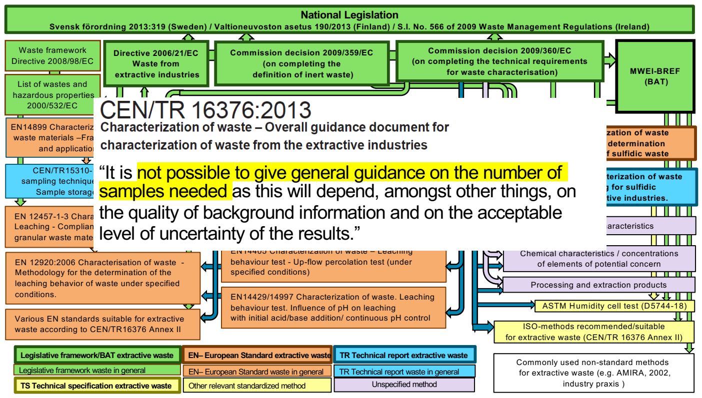
**Presentation by Diana Brookshaw, Tim Wright and Steven Pearce (Mine Environment Management) and Janjan Hertrijana and Ken Grohs, (PT Agincourt Resources)**



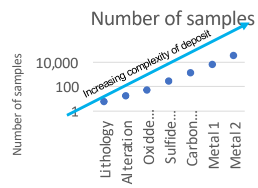

CEN/TR 16376:2013

**Characterization of waste – Overall guidance document for characterization of waste from the extractive industries**

"It is not possible to give general guidance on the number of samples needed as this will depend, amongst other things, on the quality of background information and on the acceptable level of uncertainty of the results."

Thought experiment – how many samples?

- 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>**

**The "appropriate" number of samples is entirely <u>site specific</u>, there is <u>no "standard" number that can be used with any amount of confidence</u>.**

Notes: Waste characterisation is often viewed as a "regulatory requirement" or as an "environmental study". This perspective often drives the narrative when discussions are had about how many samples are needed for ARDML. However, if we approach the question from the perspective of understanding how waste characterisation fits into mineral reserve definition, then this allows a different narrative to drive the discussion.

## From another perspective: How does waste characterisation fit into mineral reserve definition?

JORC The JORC Code 2012 Edition

PERC PAN-EUROPEAN RESERVES + RESOURCES REPORTING COMMITTEE

CIM ICM

An 'Indicated Mineral Resource' is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit.

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.

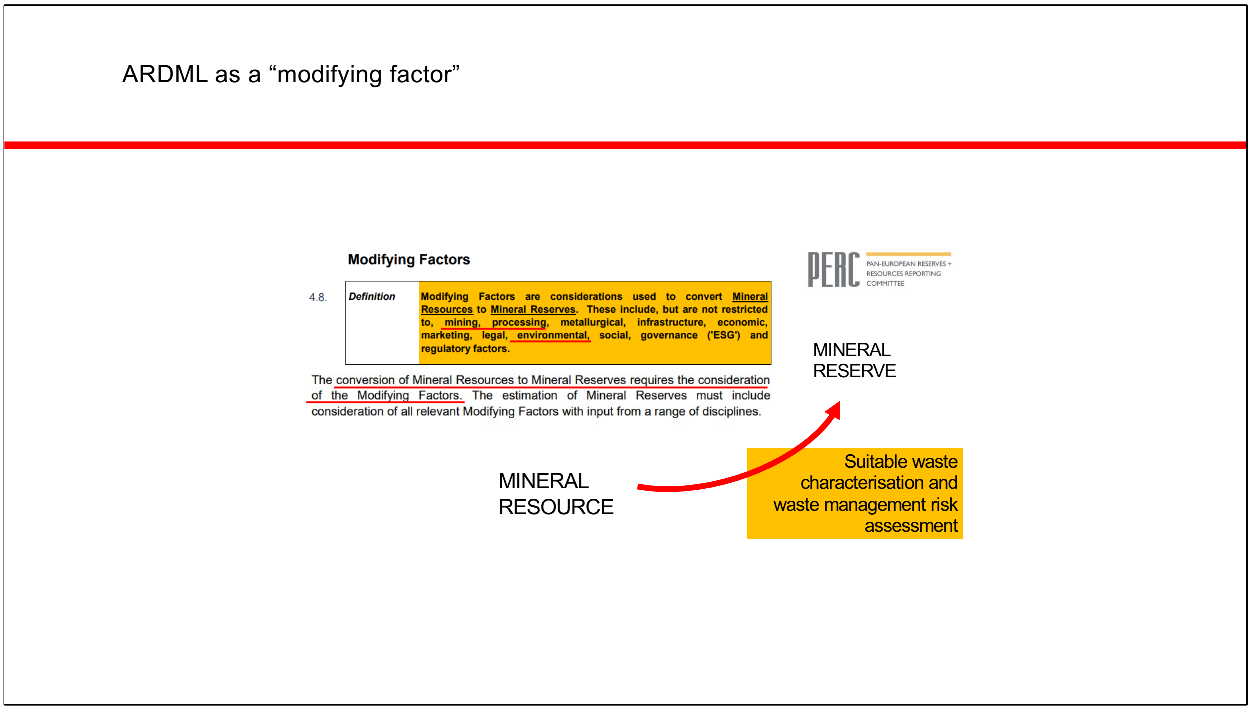
Can we apply the modifying factors (ARD-ML information) in accurately and sufficient detail to support mine planning and evaluation of the economic viability of the deposit?

We can conclude for mine waste:

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

**AND**

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




Notes: 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.

## Requirements for Pre-Feasibility

**A Preliminary Feasibility Study (Pre-Feasibility Study) is a comprehensive study of a range of options for the technical and economic viability of a mineral project that has advanced to a stage where a preferred mining method, in the case of underground mining, or the pit configuration, in the case of an open pit, is established and an effective method of mineral processing is determined. It includes a financial analysis based on reasonable assumptions on the Modifying Factors and the evaluation of any other relevant factors which are sufficient for a Competent Person, acting reasonably, to determine if all or part of the Mineral Resources may be converted to an Ore Reserve at the time of reporting. A Pre-Feasibility Study is at a lower confidence level than a Feasibility Study.**

*The Pre-Feasibility Study will identify the preferred mining, processing, and infrastructure requirements and capacities, but will not yet have finalised these matters. Detailed assessments of environmental and socio-economic impacts and requirements will also be well advanced. The Pre-Feasibility Study will highlight areas that require further refinement within the final study stage.*

*In order to achieve the required level of confidence in the Modifying Factors, appropriate Feasibility or Pre-Feasibility level studies will have been carried out prior to determination of the Ore Reserves. The studies will have determined a mine plan and production schedule that is technically achievable and economically viable and from which the Ore Reserves can be derived.*

PFS is:

- Comprehensive
- Detailed assessment
- ***Technically achievable***
- ***Economically viable***

Contains:

- Resource model
- Mine plan (including waste)
- Mine schedule (ore and waste)

## Specific requirements for ARDML

| | |
|---|---|
| *Estimation and modelling techniques* | • *The nature and appropriateness of the estimation technique(s) applied and key assumptions, including treatment of extreme grade values, domaining, interpolation parameters and maximum distance of extrapolation from data points. If a computer assisted estimation method was chosen include a description of computer software and parameters used.*<br>• *The availability of check estimates, previous estimates and/or mine production records and whether the Mineral Resource estimate takes appropriate account of such data.*<br>• *The assumptions made regarding recovery of by-products.*<br>• *Estimation of deleterious elements or other non-grade variables of economic significance (eg sulphur for acid mine drainage characterisation).*<br>• *In the case of block model interpolation, the block size in relation to the average sample spacing and the search employed.*<br>• *Any assumptions behind modelling of selective mining units.* |

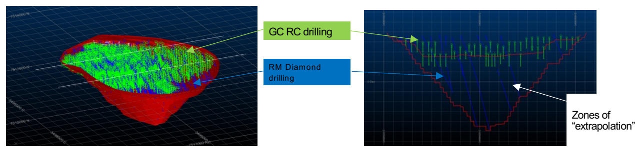
Explicit statement that modelling of parameters relevant for ARDML is required as these have economic significance.

**Therefore we can say that the number of samples required for waste characterisation at PFS stage is:**

**"Equal to that required to construct an ARDML 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"**

**It is not 50 or 100 samples.....Why? Because if a generic sample number is not acceptable for mineral resource estimation then de-facto it is not acceptable for waste characterization for any project proceeding to mining.**

Collecting data for block model construction



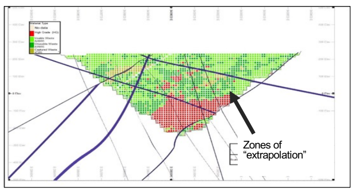

| Parameter | Resource drilling | Grade control drilling |
|---|---|---|
| Drill data | Diamond and RC | RC |
| Distance between boreholes | 100s of m, often no grid | Regular grid, 15x15m (ore) and 30x 30 m waste |
| Depth | Can be hundreds of m | Confined to pit shell, ~25m |
| Assay data | Metals, Sulfide sulfur | Metals/sulfide sulfur/XRD |

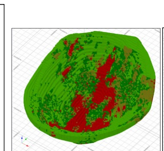
Notes: Block models are based on assay data generated by sampling at set intervals in drillholes that are distributed either in a random or regular pattern. Resource estimation drilling boreholes are often deep, with spacings that allow for the resource to be defined (and therefore would be initially sufficiently-well spaced to construct also a WASTE block model if the data collected allowed this).

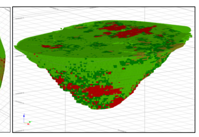
Grade control drilling provides better resolution in the area of operation because of closer spacing of drillholes and is used in conjunction with resource drilling data to refine the block model. It follows that, grade control drilling is needed early on in a project to determine variance and accuracy of waste zone in resource model (similarly to its role in ore definition). This is a very important consideration given the "reliance" on the mine waste schedule for mine planning, specifically in relation to the waste materials that are needed for construction during mine operation.

## Block model construction

| Parameter | Resource block model | Grade control model |
|---|---|---|
| Application | Long term planning | Short term planning / refinement and validation of resource model |
| Block size (m) | 30*40*24 (but drilling at ~100m!) | 10*10*12 (drilling at 15m-30m) |
| Estimation | Indicator Kriging & Ordinary Kriging | Indicator Kriging & Ordinary Kriging |



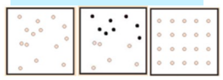


Notes: The block model is created based on the available results, where if the block size is finer than the drilling spacing (as is often the case for resource models), information in the spaces between boreholes is interpolated between available data points on either side to give the block a value. So to construct a sufficiently fine block-sized model, dense data points are required, and for this tool to be useful for planning of operations, it needs to include reliable and sufficiently detailed waste data as well.

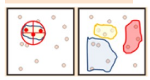
The purpose of the samples

- Difference between sampling to understand the geochemical behaviour of different types of waste and that to construct a block model

Probabilistic sampling



Spot sampling

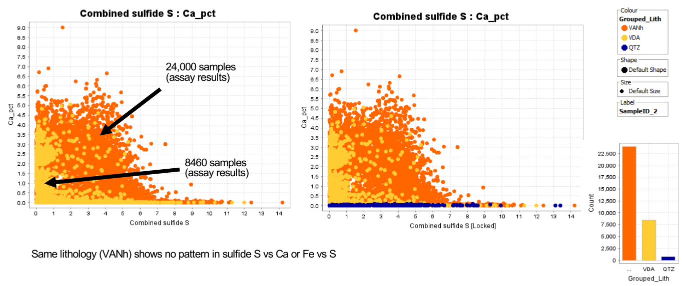


| | Details | Advantages | Application |
|---|---|---|---|
| Probabilistic sampling | Random or regular grid – for example **resource or grade control drilling** | Statistical analysis is possible. Can quantify error | **Construct block model of waste** **Inform spot sampling** |
| Spot sampling | Targeted 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** |

Notes: 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.

The probabilistic samples



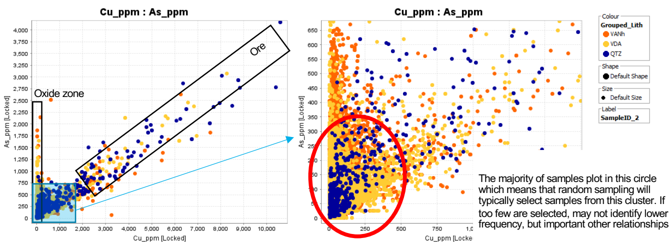

Same lithology (VANh) shows no pattern in sulfide S vs Ca or Fe vs S

Notes: Samples collected on the basis that each has the same chance of being picked as any other (which is the basis of the probabilistic sampling), such as those collected during resource drilling, give an idea of the range of values that could be encountered for each parameter. On this plot are the results for two different lithologies, that clearly show that neither lithology will be diagnostic for ARD-ML risk. The ARD-ML risk will need to be based on Ca/Sulfide S content if those are proven to be reliable for this purpose. On the other hand, lithology QTZ contains no Ca in any of the encountered samples, therefore this level of testing is sufficient to suggest that it can be assumed that Ca content in the QTZ lithology is negligible and no testing for Ca is required for any QTZ lithology sample.

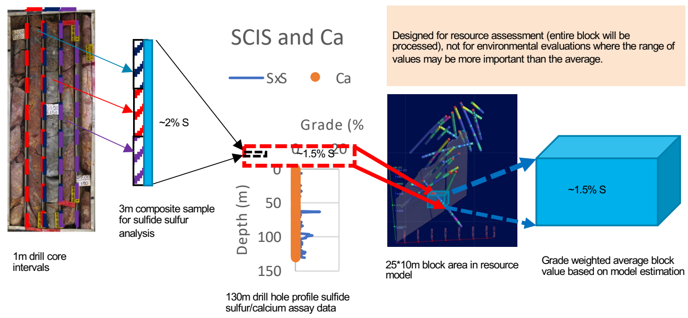
Since it is impractical to test all samples in the assay database for every geochemical property, there is a need to select a subset of samples onto which to perform more detailed testing. The purpose of this testing is to understand the geochemical behaviour that the different materials are likely to display under different conditions (and how to identify those materials (or waste classes). It should follow that once these aspects are known, they are then used to amend the block model to reflect the appropriate waste types based on the identified key parameters that allow delineation of the wastes.

## The spot samples

How many samples would be enough to define the Cu vs As relationship?



A note on grade weight averaging

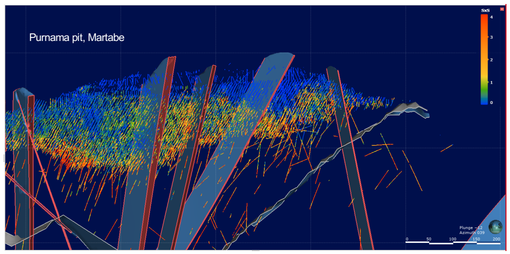



Notes: Grade weight averaging approach has been developed for ore reserve modelling (e.g., JORC) and to inform on processing requirements and economic recovery assessment of ore minerals. It was NOT developed for scale dependant assessments such as AMD and as such it should not be assumed that the approach is valid (although it can be).

With respect to economic assessment of ore extraction changes in material properties, for example, fragmentation effects from mining do not largely matter as the entire block is crushed and processed (i.e., not scale dependant). As such, grade weight averaging is appropriate for ore resource modelling. With respect to AMD assessment, however, changes in the composition of material as a result of mining activities DO matter as AMD risk is driven by the relative concentration of reactive minerals such as sulfides and carbonates AND the particle size distribution of these minerals (i.e., scale dependency).

Most analytical testing is carried out on samples from drilling into solid rock as core or chips that have been homogenised and/or composited. For ore resource assessment this grade weigh approach is likely appropriate, however, for AMD assessments this may not be appropriate.

## Block model ARD-ML definition




Sulfide S value = pyrite content or acid production potential

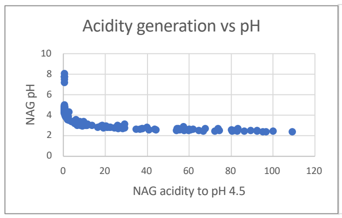
Ca value = calcite content or buffering potential

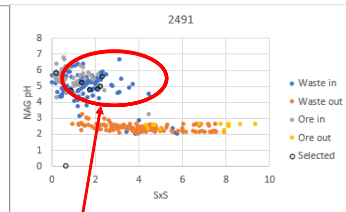
Therefore, NAPP value is sufficient to define ARD-ML risk and distinguish between waste types

**Can we apply the modifying factors accurately and in sufficient detail to support mine planning and evaluation of the economic viability of the deposit? - YES**

Notes: So looking to applying the sampling to the model development: Typically, the AMD block model is based on a parameter such as sulfide sulfur, if it is a reliable proxy of acid generation, for example, where carbonates are low. Or NAPP as a combined parameter where some carbonates are present. This is the case at Purnama and Barani. In this case, detailed testing of subset of samples for different lithologies showed that SxS value reflects pyrite content sufficiently accurately and Ca reflects carbonates, therefore a model based on the NAPP value is sufficiently accurate. Since both SxS and Ca are included in any resource development drilling and grade control, and spacing is the same in ore and waste zones, the AMD model for this pit is of comparable resolution and statistical certainty as the ore.

Parameter selection for ARD-ML model

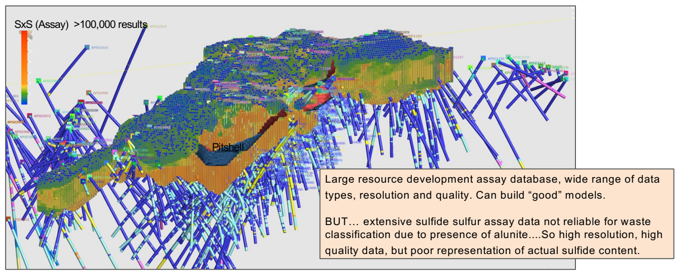



At Ramba Joring and Tor Ulu Ala (TUA) at Martabe, sulfide sulfur value is not a reliable predictor of NAG acidity as alunite present within the deposit contributes to the reported sulfide sulfur value

Notes: However, for Ramba Joring and Tor Ulu Ala, the sulfide sulfur value includes S within alunite, which is a non-acid-producing sulfate. This means that a model based on sulfide S or its derivatives without accounting for alunite will overestimate the amount of acid generation expected, and is therefore not reliable for modelling RJ and TUA. A different approach is therefore required for these pits.

ARD-ML Model based on sulfide sulfur (TUA)




**Can we apply the modifying factors accurately and in sufficient detail to support mine planning and evaluation of the economic viability of the deposit? - NO**

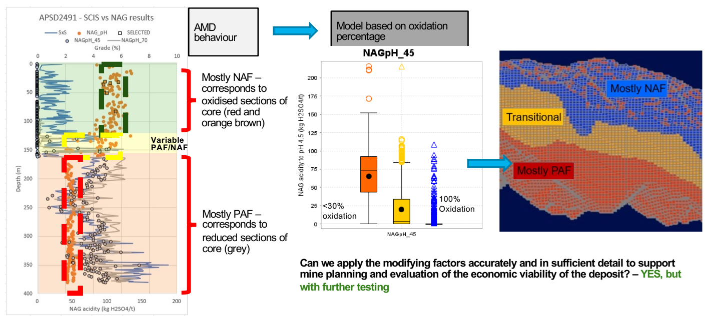
Notes: Here is an example of a model based on over 100,000 assay results of sulfide sulfur, this can create a 'good' model in terms of resolution. However, because the sulfide S value is not representative of the actual acidity production potential, this model does not define the waste classes accurately. This means that more testing is now required to either develop a different set of parameters to use (and validate this approach), or do infill testing of the available drill core with a direct measure of acidity-generating potential (such as NAG).

In search for best modelling parameter

| Parameter | Reliable | Available in assay | Considerations |
| --- | --- | --- | --- |
| Lithology | No | Yes | ARD-ML risk is not directly linked to any one lithology (range of waste types present in each lithology) |
| Alteration | No | Yes | Some correlation with alteration, but not sufficiently clear relationship to construct a reliable model |
| Sulfide sulfur (or NAPP) | No | Yes | Affected by presence of alunite |
| NAG acidity | Yes | Few samples | NAG results too limited to construct a model |
| Oxidation | Partially | Yes | Could be applied in combination with other parameters in oxidised and reduced zone |

Detailed testing of subset of samples over 3-4 programs

Combination of modelling parameters




**Can we apply the modifying factors accurately and in sufficient detail to support mine planning and evaluation of the economic viability of the deposit? – YES, but with further testing**

Notes: We can see on the left a plot of ABA parameters for borehole from TUA. Suflide S is generally lower in the top 120 m, then variable before being generally elevated at depth. However, the NAG pH is 4.5-6 and acidity negligible in the top 120 m, suggesting that most or all of the reported SxS (to 2%) is likely alunite. In this section, the rocks are mostly orange-red in colour and contain oxides and no reduced minerals. This zone is coincident with the oxide zone when 100% oxidation percentage used as modelling parameter.

At depth, NAG acidity is high and pH below 3, confirming presence of pyrite (but not excluding possibility of alunite presence in this section as well). Rocks are grey and can contain visible sulfides. This is generally coincident with the reduced section of the model based on oxidation percentage (<30 % oxidation).

In the middle is a heterogeneous zone where NAG acidity as well as SxS varies on a very fine scale, which is modelled as transition based on oxidation percentage.

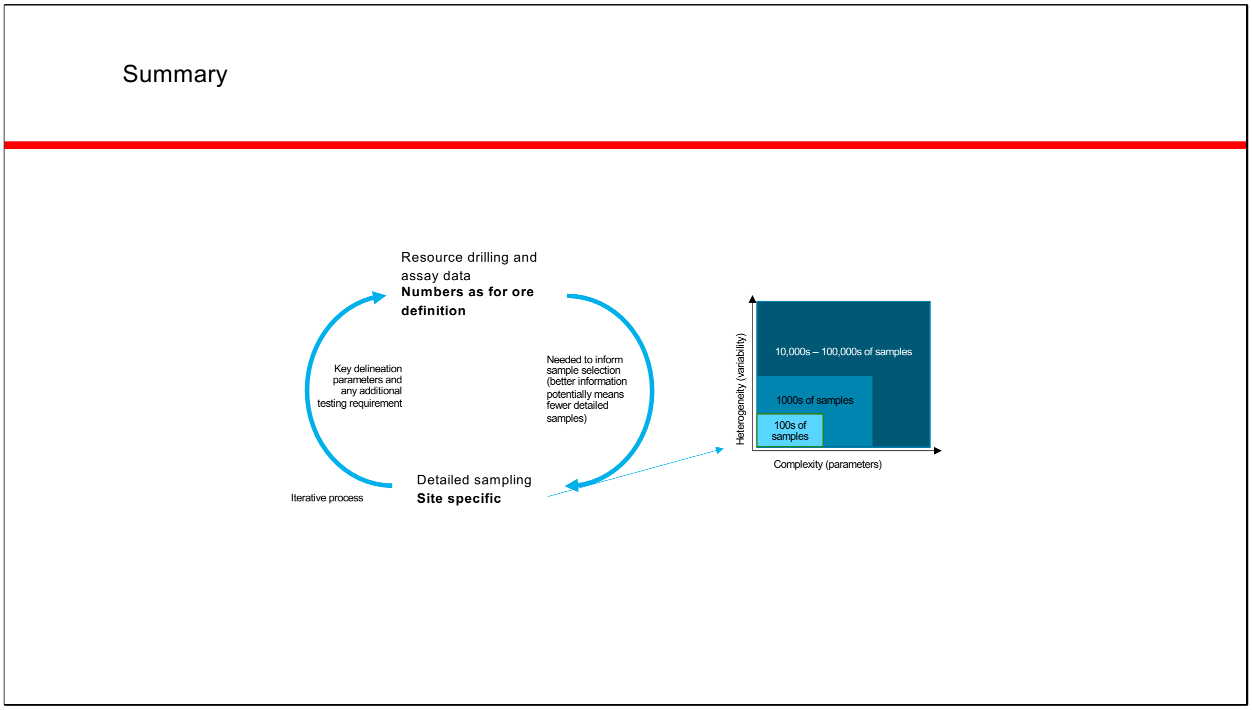
This indicates that a model based on oxidation percentage will be better suited to accurately modelling ARD-ML risk in TUA and RJ, than using the sulfide sulfur value or NAG acidity or pH value, but this is limited to the oxide and sulfide zone (and it does include a margin of error). In the transition zone, materials can range from PAF to NAF within meters. Since no combination of available parameters can be used there, this zone requires NAG testing, either during grade control when this zone is about to be mined, or infill testing of the available samples to populate this part of the model.

## Sampling in grade control stage

- 10,000 -15,000 ARD-ML tests per month
- **By 2030 > 1 million samples**

- Further testing can be done as part of grade control for short term planning
- Reconciliation refines the rolling three-month waste schedules.
- Grade control data can be used to refine and validate the reserve model
- Supplementing long term planning via the resource model requires infill testing to confirm acidity generating potential directly

Notes: Grade control is an additional source of test data, which can be invaluable when used to its full potential.


Summary
Resource drilling and assay data
Numbers as for ore definition
Key delineation parameters and any additional testing requirement
Needed to inform sample selection (better information potentially means fewer detailed samples)
Detailed sampling
Site specific
Iterative process
Heterogeneity (variability)
Complexity (parameters)
10,000s – 100,000s of samples
1000s of samples
100s of samples

## Conclusions

- While methodology can be "borrowed" from well-established practice of modelling ore zones, modelling waste zones requires different approach (often site specific)
- Models are only as good as the data used in them, but also only as representative as the data is of the characteristic of interest
- Modelling is iterative – information obtained in different programs should be combined to maximise the value
- Different parameters can be combined to constrain uncertainty
- Robust validation of waste block models is essential as part of risk management.

- ***Detailed sampling is required at the PFS stage to ensure that accurate modifying factor information is included in sufficient detail to support the mine planning and evaluation of the economic viability of the deposit.***


Thank you
dbrookshaw@memconsultants.co.uk
spearce@memconsultants.co.uk
www.memconsultants.co.uk
Mine Environment Management Ltd
AGINCOURT