LULEÅ UNIVERSITY OF TECHNOLOGY

Geometallurgy – what, why and how?

Pertti Lamberg

Professor in Geometallurgy

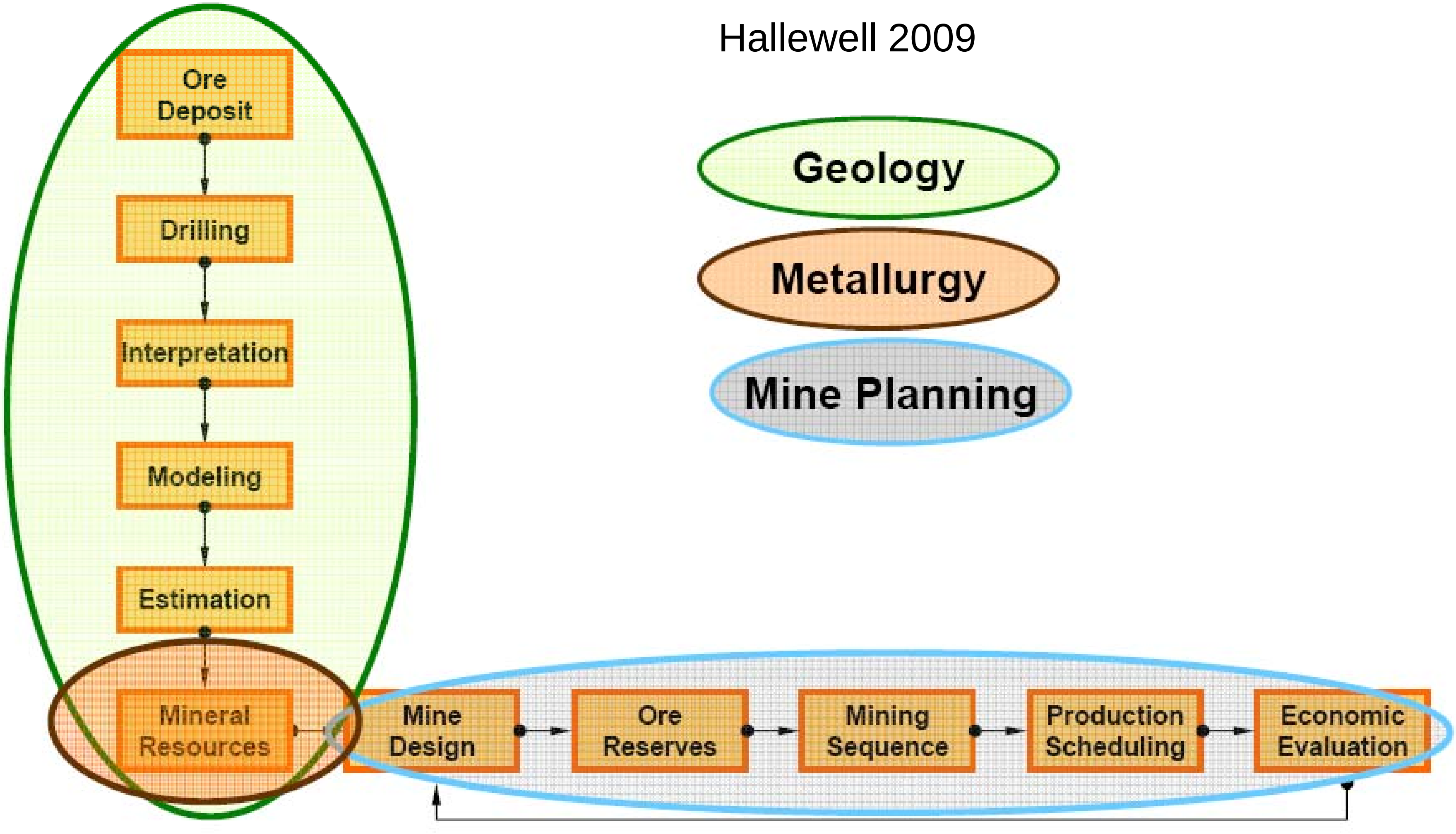
8th Fennoscandian Exploration and Mining – FEM 2011
1-3 November 2011, Levi, Finland

The northernmost University of Technology in Scandinavia
World-class research and education

Pentti Sotka 1950-2011

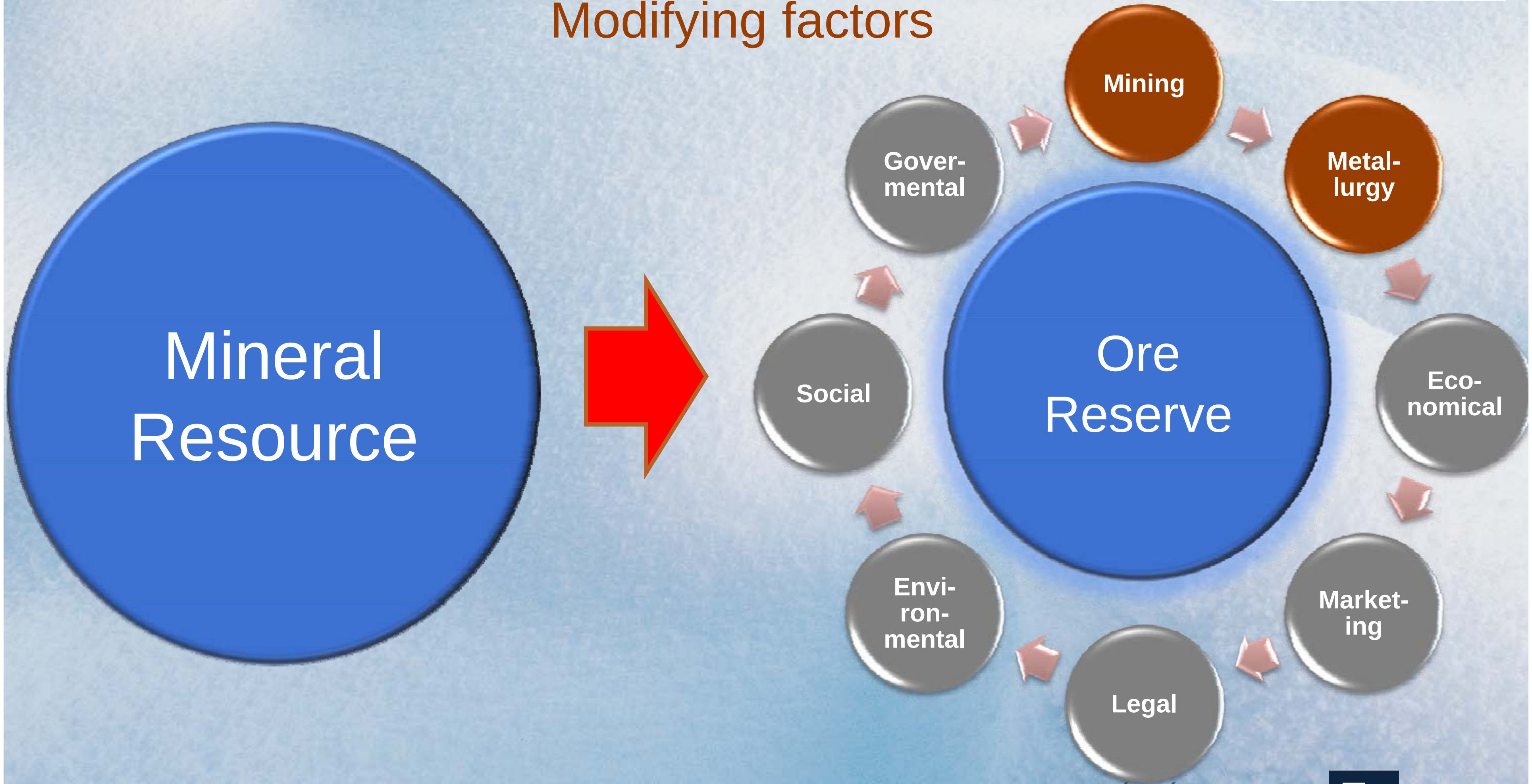
Traditional approach

Hallewell 2009



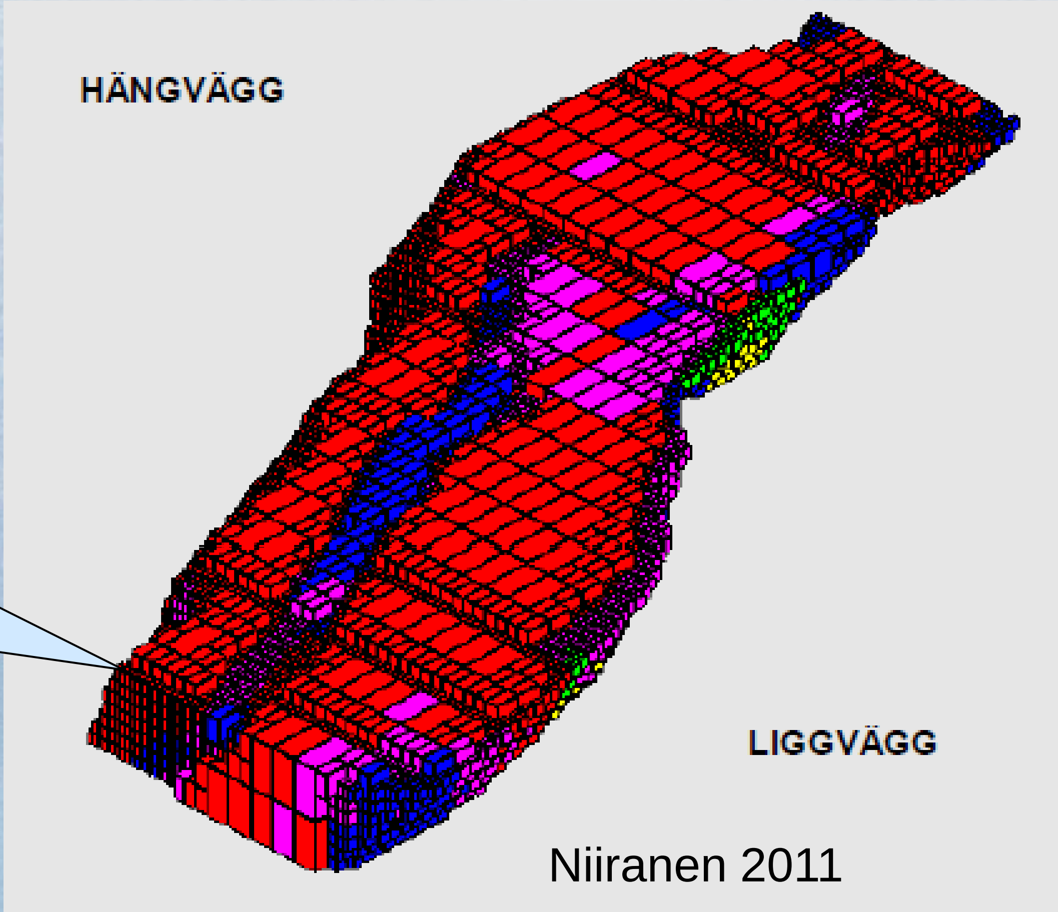
From Mineral Resource to Ore Reserves

Modifying factors



Block model

Resource
- Block ID
- Location
- Grade
- Density (SG)
- Lithology
- Alteration



Technical risks in mining operation

Resource Estimate Risk

- **Grade and tonnage risk**

Mining Risk

- **Risk of wrong mining method**

Technological Risk

- **Risk of wrong technology**

Geotechnical Risk

- **Ground failure risk**

Geometallurgical Risk

- **Metallurgical variation risk**

Glacken 2011; Resource estimation and evaluation in the New Millenium, FEM2011

Problems in traditional approach

- Ore reserve model does not carry information on spatial variation on metallurgical parameters
- Ore boundaries are based on (variation of) grade only

- ➢ Incomplete resource utilisation
- ➢ Unoptimised production
- ➢ Poor risk management
  - ➢ Scenarios studies are difficult to execute

Examples

- Projected metallurgical figures (grade and recovery) are based on few samples
- Testing with high-grade samples only
- Presence of clay minerals in heap leaching operation

Geometallurgy

Geometallurgy combines geological and metallurgical information to create spatially-based predictive model for mineral processing plants.

Expected benefits from geometallurgical consideration

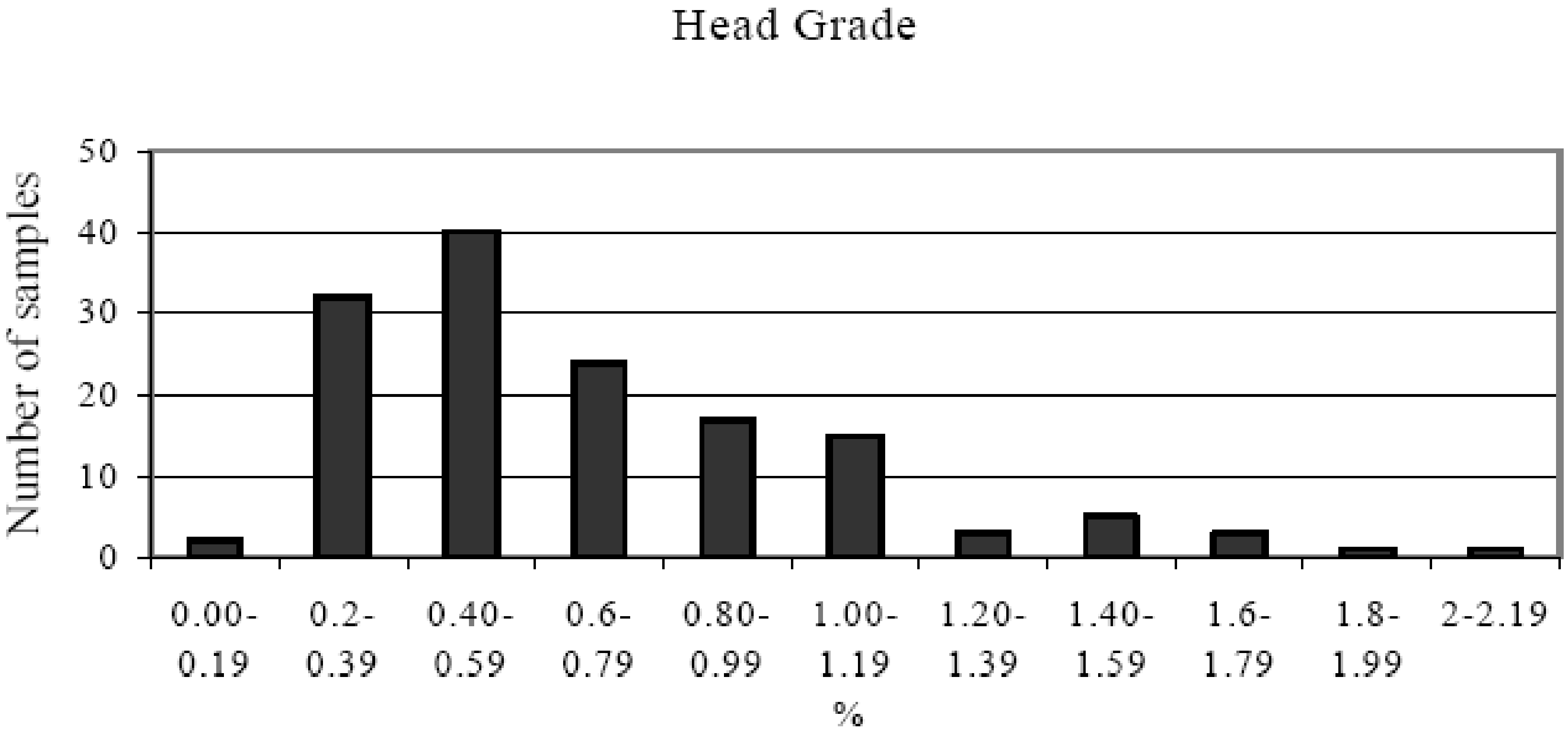
- Better utilisation of the resource
- Better metallurgical performance
- Better changes for new technological solutions
- Better changes in plant optimisation
- Better possibilities for economical optimisation of the full operation
- Lowering risks in the operation

Geometallurgical program

1. Collection of geological data
2. Ore sampling for metallurgical testing
3. Metallurgical laboratory testing
4. Establishing geometallurgical domains
5. Model to derive metallurgical parameters
6. Establishing process model for simulation
7. Plant simulations
8. Model calibration

Bulled & McInnes (2005), David (2007) & Dobby et al. (2004)

Selecting samples for metallurgical testing – Covering the grade range



Williams & Richardson 2004

Number of samples required

Table 7 Possible number of tests needed in a geometallurgical mapping program

Geo-metallur-gical samples

Type of test	Number
Assays	10,000++
Mineralogy	1000+
Grinding	100-300
Metallurgical Tests (e.g. flotation, bottle rolls)	100-300

Metallurgical samples	Minipilot test Pilot test	5-20 2

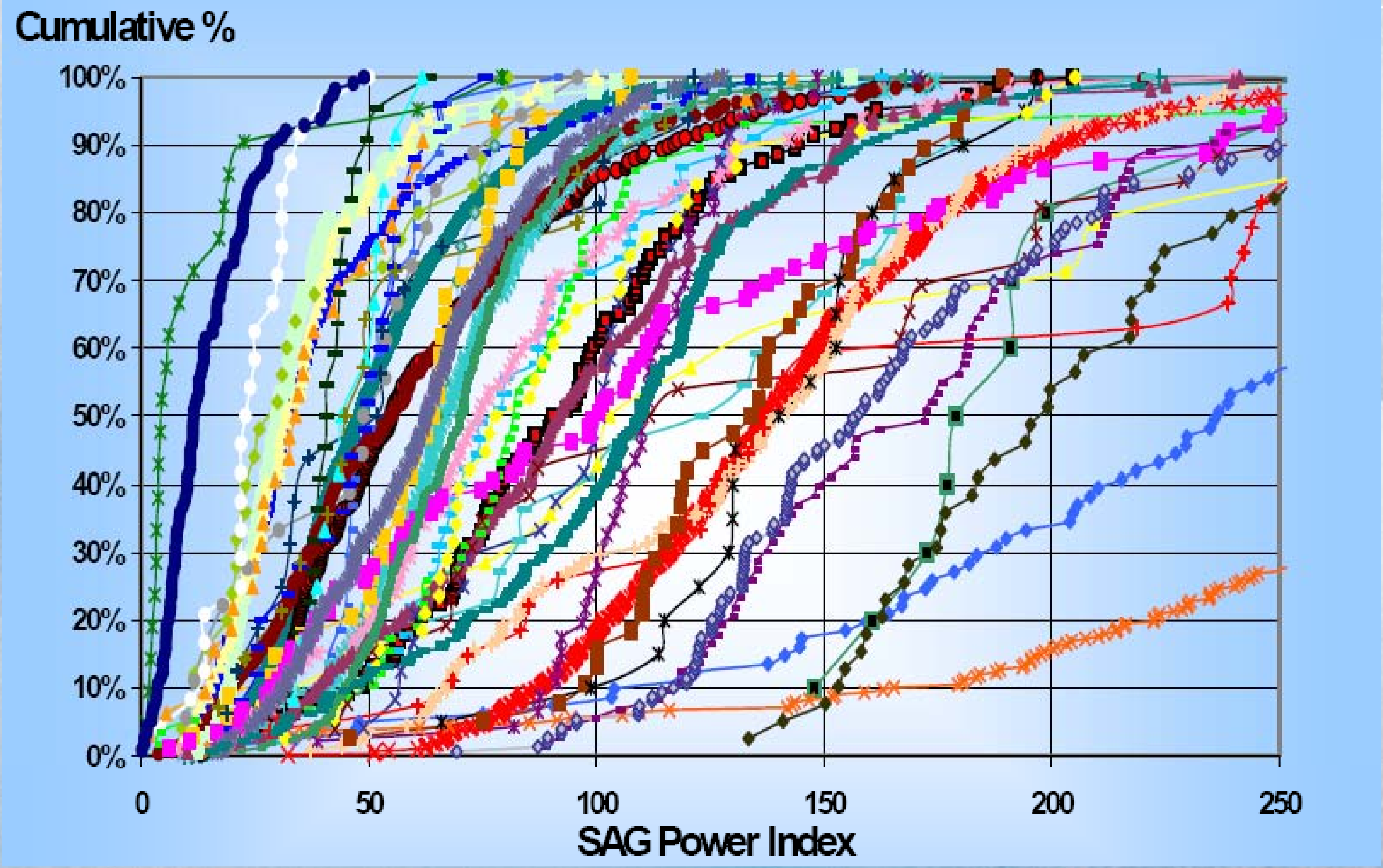
Williams & Richardson 2004

Laboratory bench scale testing

- Require big sample sizes (1-50 kg)
- Tedious
  - Some samples / day
- Examples
  - Bond Work Index test
  - Batch flotation test

Variability in ore hardness

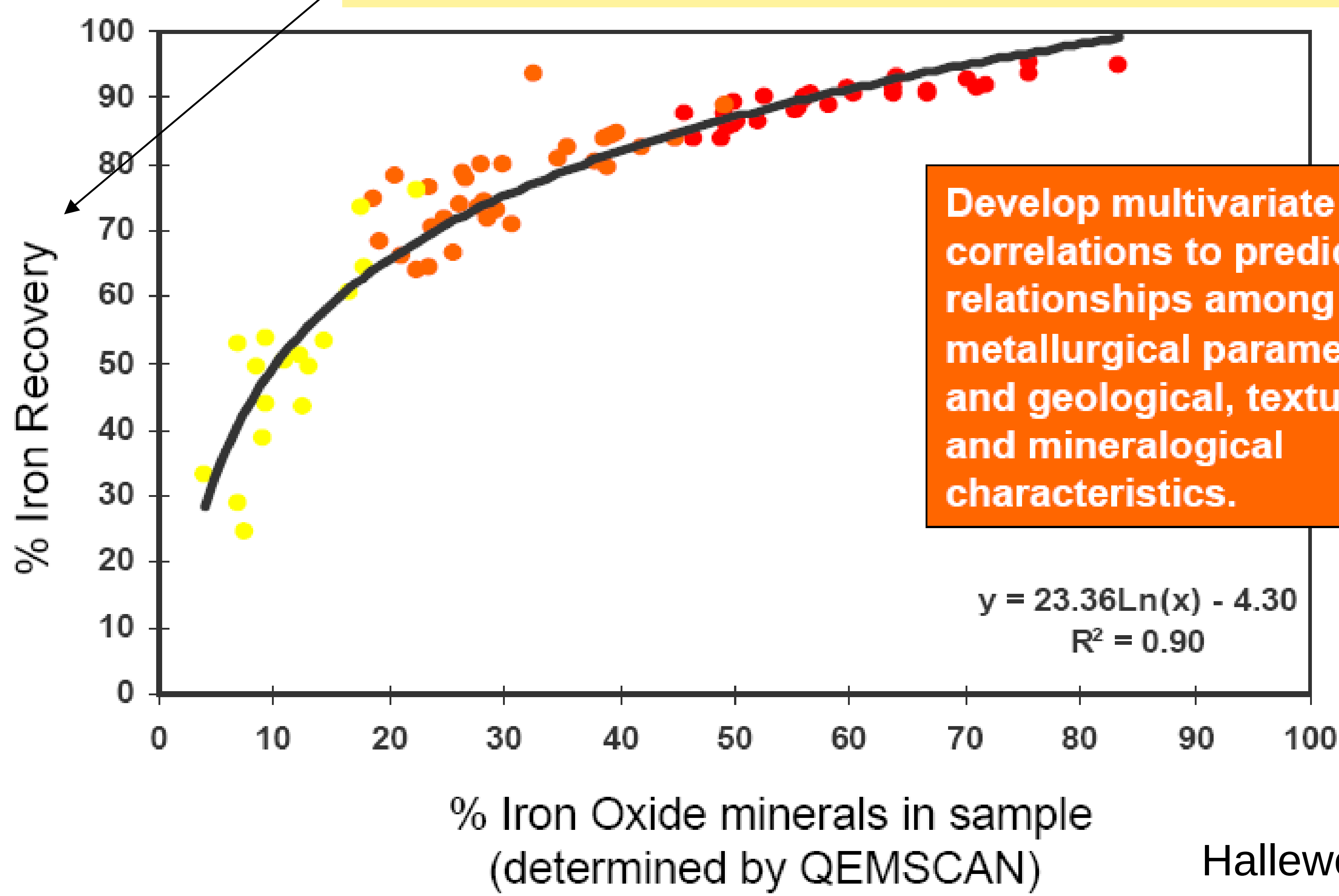
Hallewell 2009



LULEÅ UNIVERSITY OF TECHNOLOGY

Model between ore properties and metallurgical parameters

Model gives directly the recovery -> Black box model!



Develop multivariate correlations to predict relationships among metallurgical parameters and geological, textural and mineralogical characteristics.

Hallewell 2009

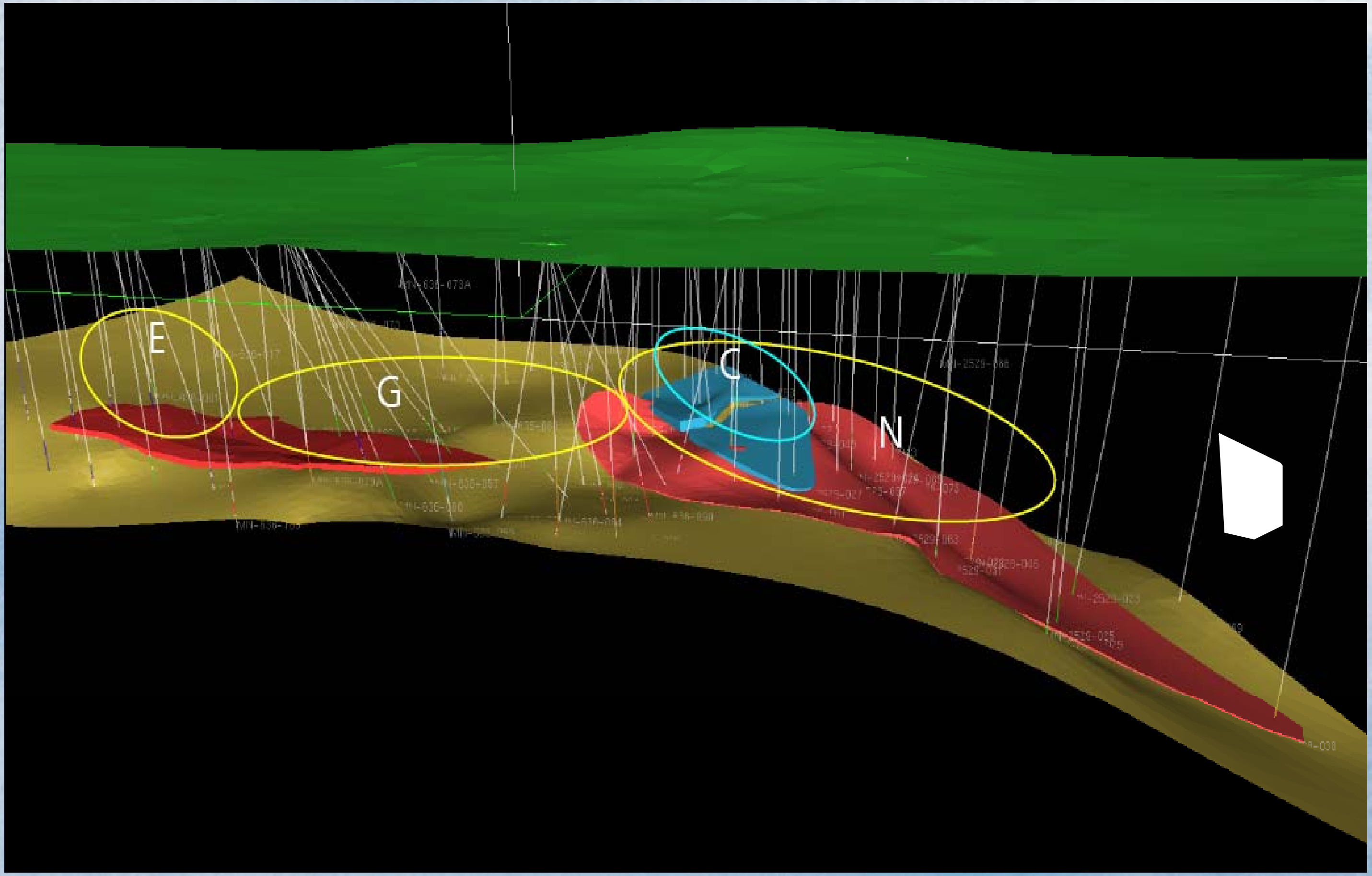
Geometallurgical domains

- Domains defined by homogeneity in terms of
  - Geology
  - Geochemistry
  - Mineralogy
  - Texture
  - Processing technique

- Grinding and metallurgical domains maybe different since they have different drivers.
- This is the platform from which all subsequent stages are derived.

Hallewell 2009

Geometallurgical domains

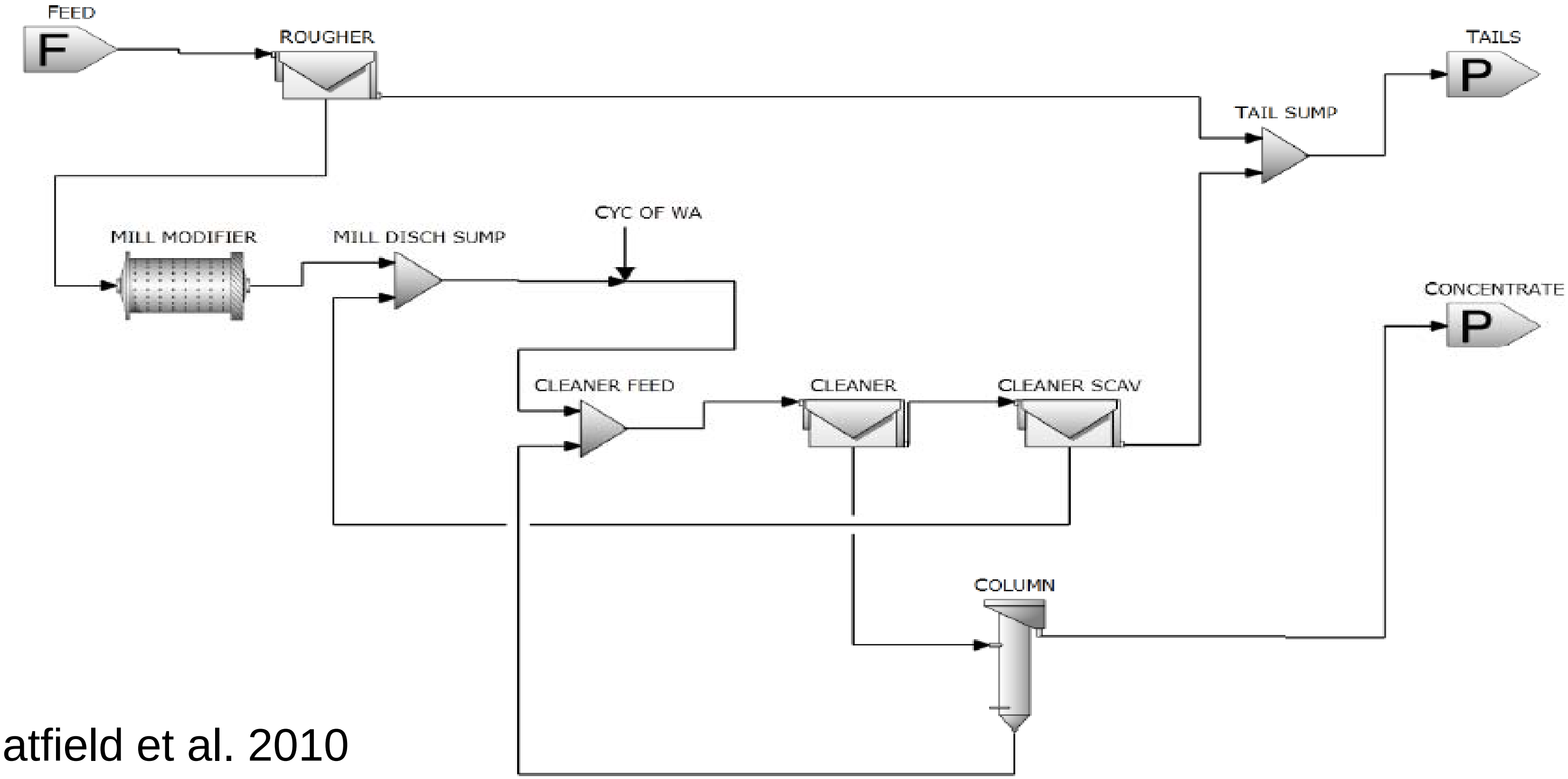


The northernmost University of Technology in Scandinavia
World-class research and education

Whittaker 2009

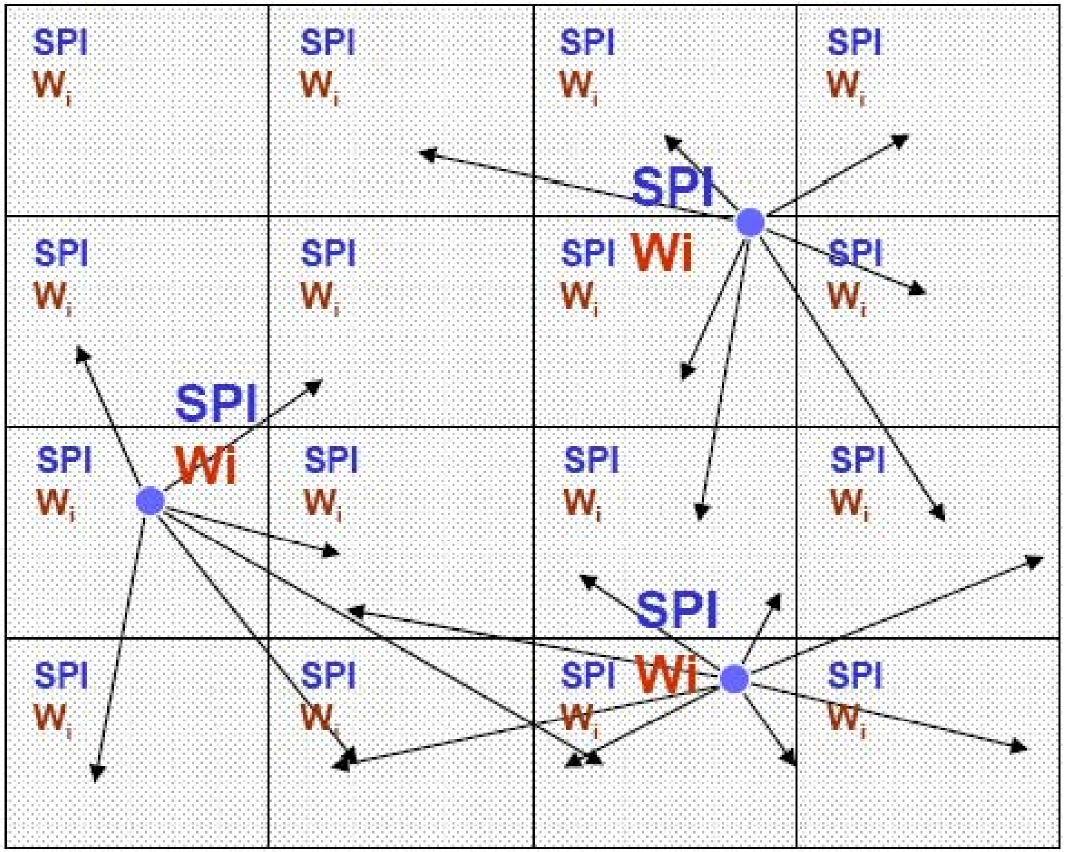
IGS = Integrated Geometallurgical Simulator (SGS)

SGS



Hatfield et al. 2010

Populating block model



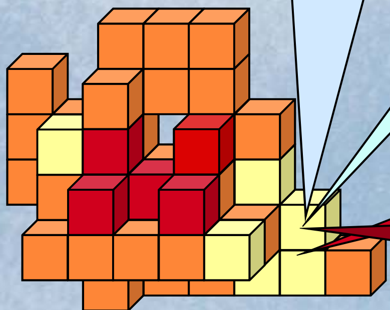
Hallewell 2009

Geometallurgical block model (SGS)

Separate grinding and flotation models and simulations

Resource
- Block ID
- Location
- Lithology
- Alteration
- Grade
- Bulk SG

Metallurgy
- SPI
- BWi
- Ci
- R max
- K average



Grinding model simulation
- Througput (t/h)
- F_{80}, P_{80}
- Operating cost

Flotation model simulation
- Recovery%
- Grade
- Operating cost

Hallewell 2009

LULEÅ UNIVERSITY OF TECHNOLOGY

COLLAHUASI

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

A novel approach to the geometallurgical modelling of the Collahuasi grinding circuit

O.M. Alruiz [a], S. Morrell [b], C.J. Suazo [a,*], A. Naranjo [a]

[a] Compañia Minera Doña Inés de Collahuasi SCM, Av. Andrés Bello 2687, Santiago, Chile
[b] SMCC Pty Ltd., 26 Mermaid Place, Sinnamon Park, Queensland 4073, Australia

Geometallurgical modelling of the Collahuasi flotation circuit

C.J. Suazo [a,*], W. Kracht [b], O.M. Alruiz [a]

[a] Compañía Minera Doña Inés de Collahuasi, Chile
[b] Mining Engineering Department, Universidad de Chile, Chile

- 3000 m drill cores for <u>six combined samples</u>
  - JK Drop weight tests
  - Bond work index tests
  - 10 flotation tests for each to derive flotation parameters

LULEÅ UNIVERSITY OF TECHNOLOGY

Model for throughput

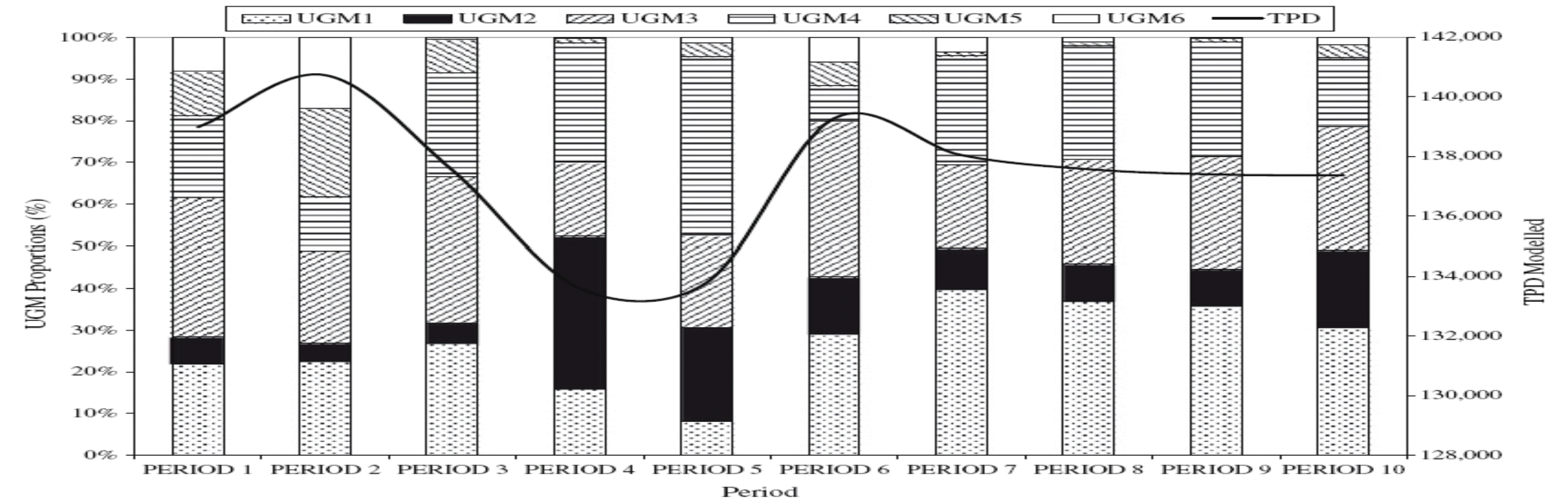
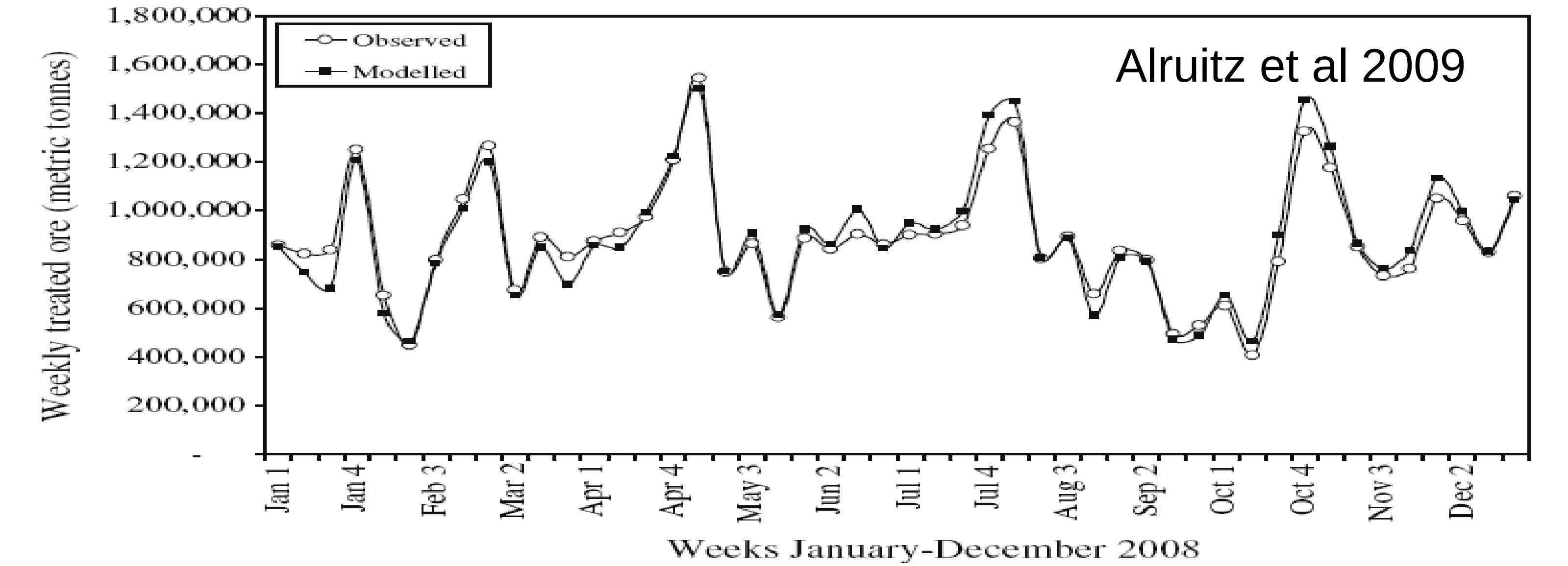


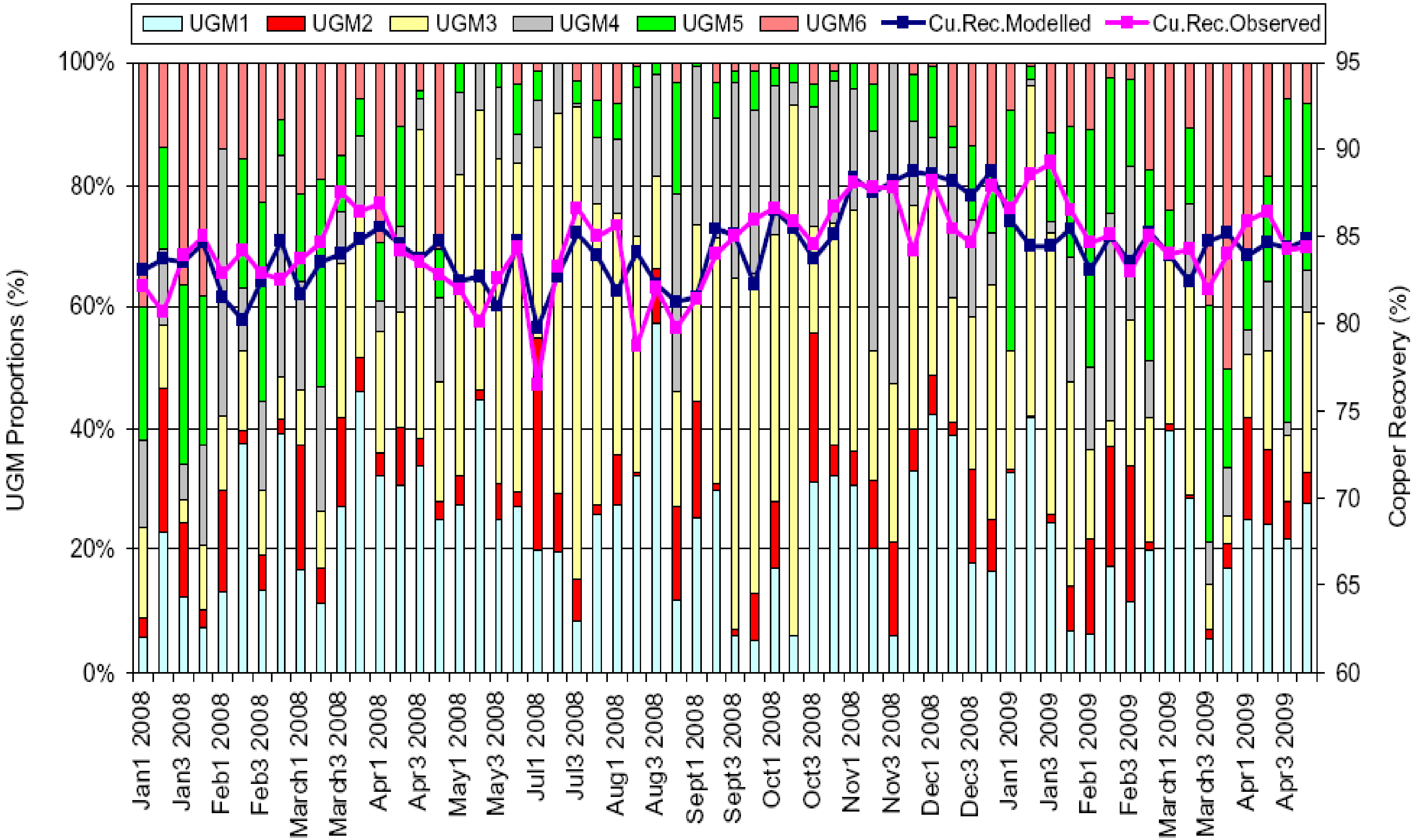
Fig. 6. UGM proportions and estimated tonnes per day (TPD) at a certain P_{80}.



LULEÅ UNIVERSITY OF TECHNOLOGY

Suazo et al. 2010

Copper recovery model (Collahuasi)



Challenges

- How to ensure that geometallurgical domains are defined right?
- How to get the geological model to discuss with the metallurgical model?
- How to reach required reliability without increasing the costs (drastically)?
  - Number of samples tested

Geometallurgical tests

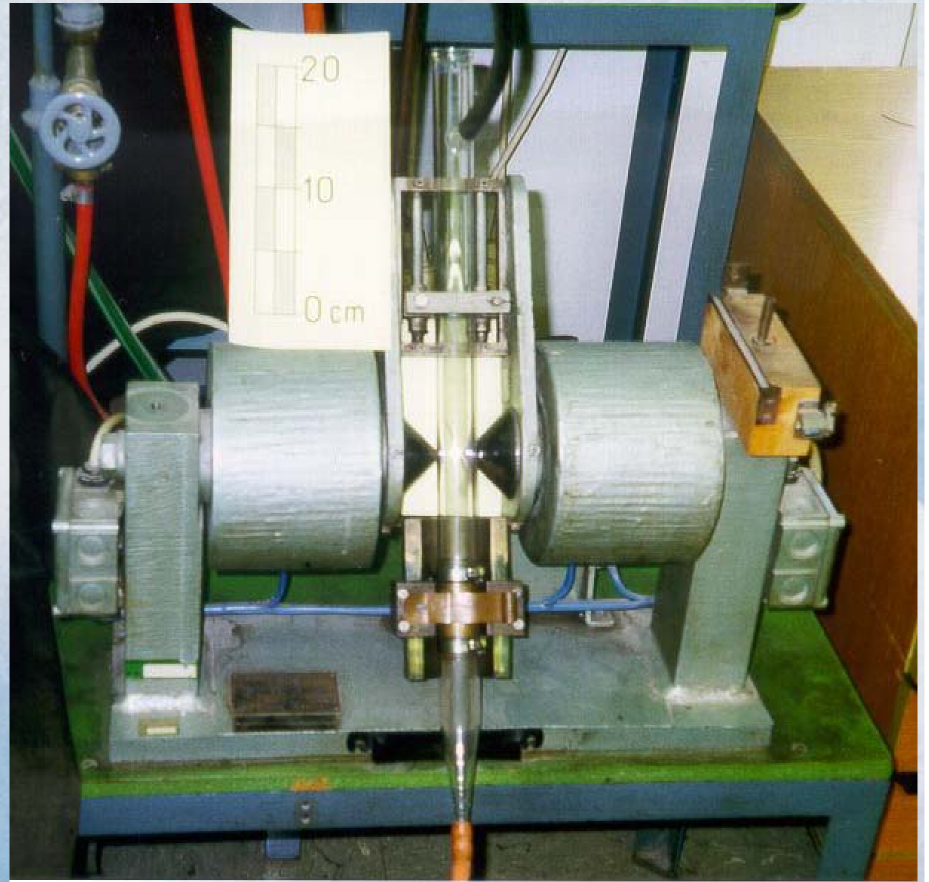
- Short-cut methods which measure metallurgical properties of rocks
  - With smaller samples than metallurgical tests
  - Easier and faster than metallurgical tests

Comminution

- Point-load testing
- RBT Lite

Concentration

- **Flotation**
  - **JK Mineral Separability Index (”Coctail Shaker test”; Bradshaw 2010)**
- **Magnetic separation**
  - **Davis tube (Niiranen 2011)**
- **Gravity separation**
  - **Super pan**



Samples are the link between geological model and metallurgical model

- Geological data

Samples for metallurgical testing

Process model parameters

- Metallurgical testing

- Model to derive metallurgical parameters from geological data

Metallurgical parameters into block model

Production forecast

- Plant model and simulations

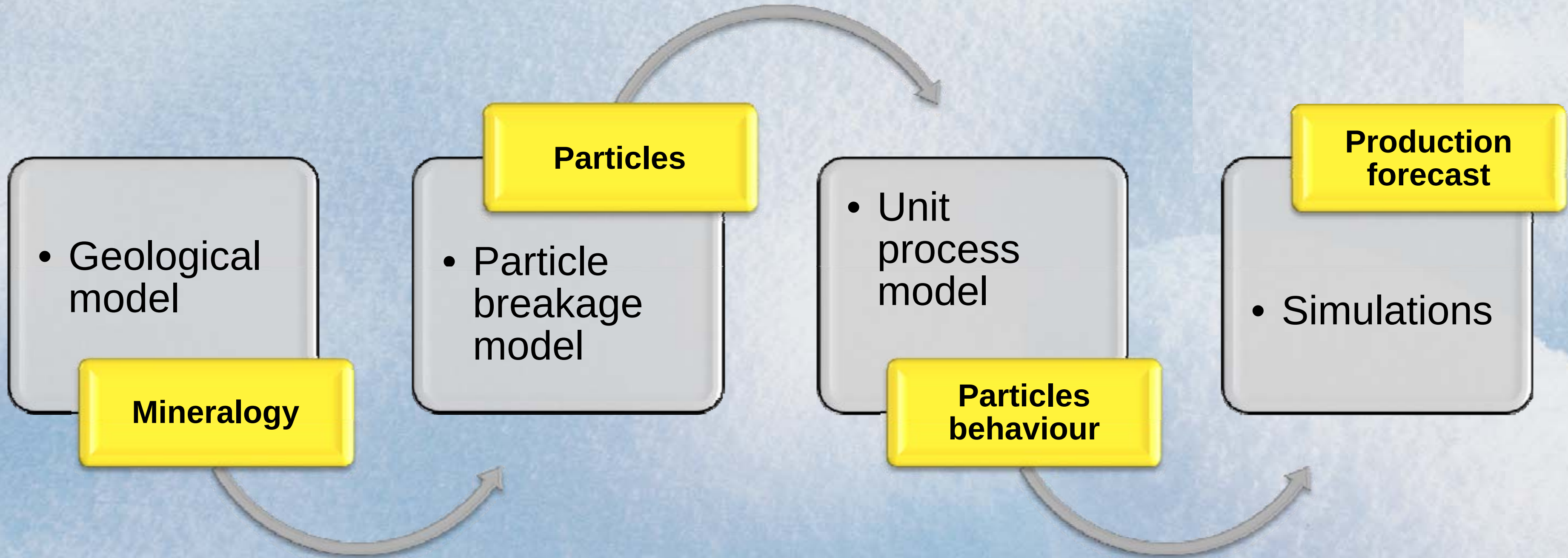
How to link geology and metallurgy?

Table 3 Linkage between geological and metallurgical factors.

Geological/mineralogical Factor	Area of Linkage	Metallurgical unit Operation
Primary rock types and distribution	Hardness	Grinding
Ore assemblage and ore formation processes	Solubility, presence of talc, hardness	Grinding, flotation, leachability,
Alteration • Down temperature (hypogene) • Weathering (supergene)	 Clays, hardness Solubility	Grinding, S/L separation Leachbility, purification
Faulting	Clays, oxidation	S/L separation, flotation
Metamorphism	Clays, presence of talc, hardness	Grinding, S/L separation, flotation

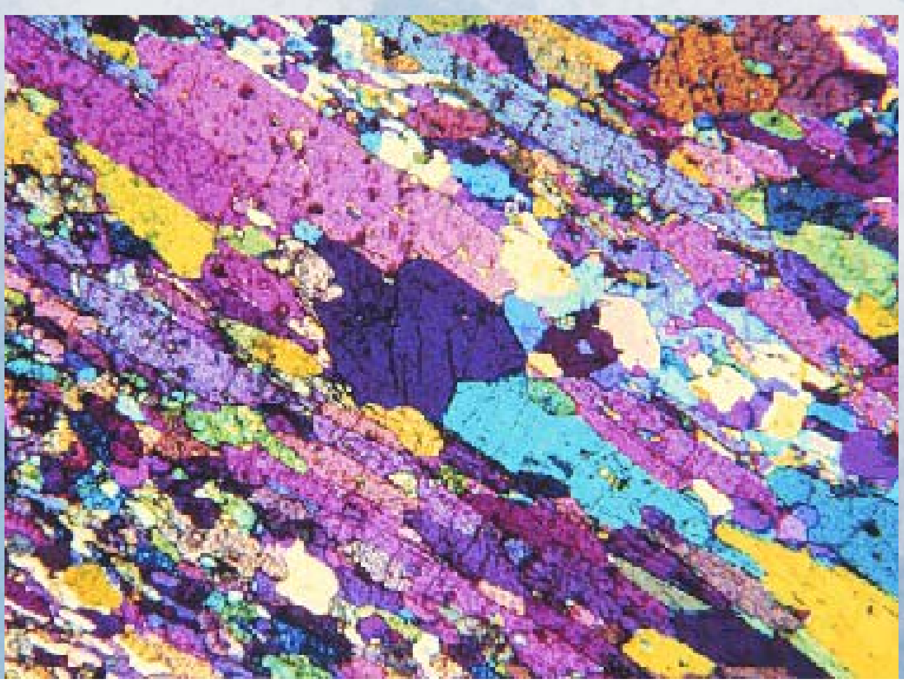
Williams & Richardson 2004

Minerals and particles as links



Requirements for geological model

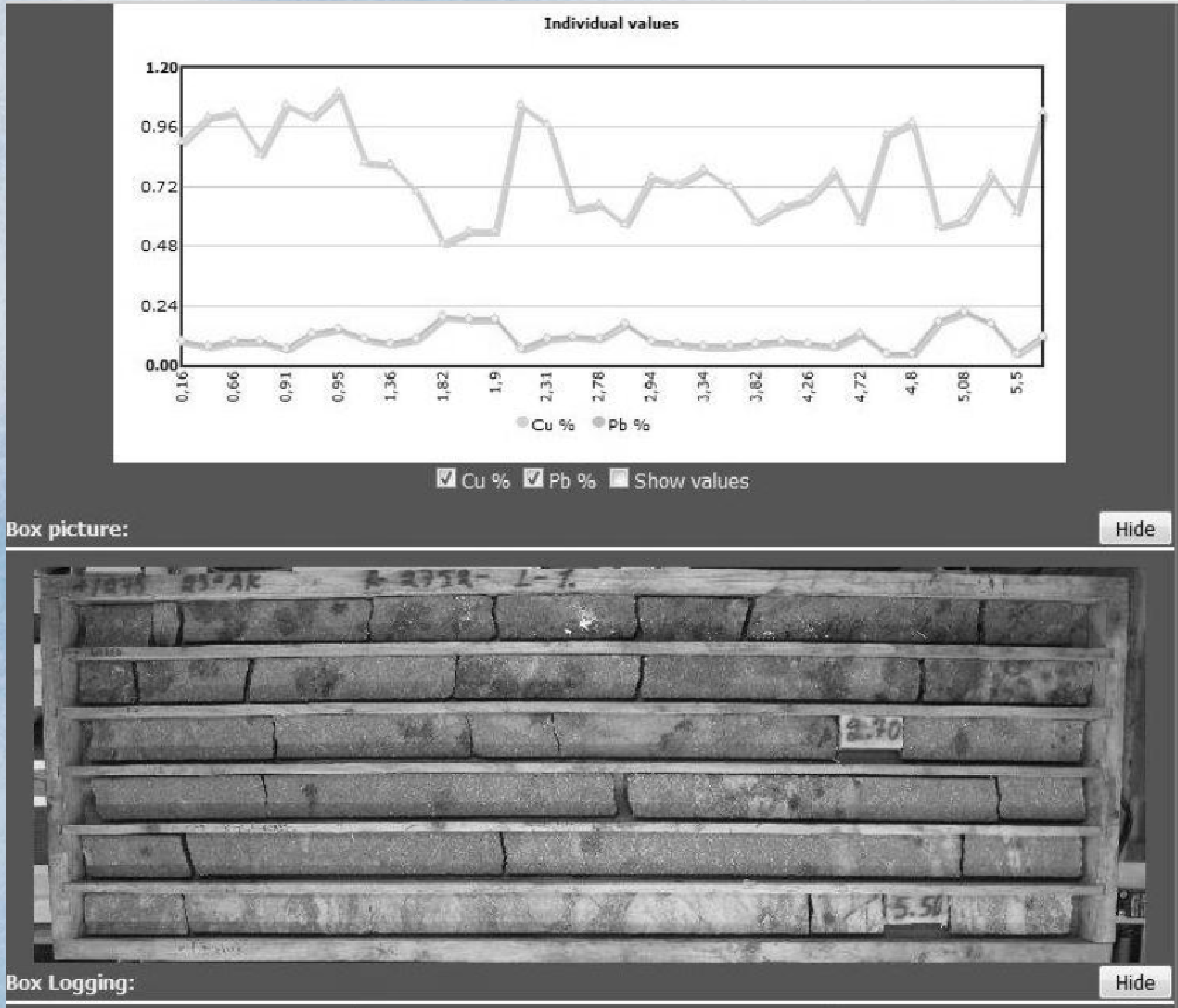
- Mineral grades
- Mineral textures
- (Rock hardness)



Mineral grades - quantification

- SEM Image analysis (MLA, QEMSCAN, ..)
- XRD
- Hyperspectral techniques (HyLogging, SisuRock)
- Element to mineral conversion

Continous XRF analysis



Viitanen 2009

(Mine On-Line Services)

Element to mineral conversion – Malmberget

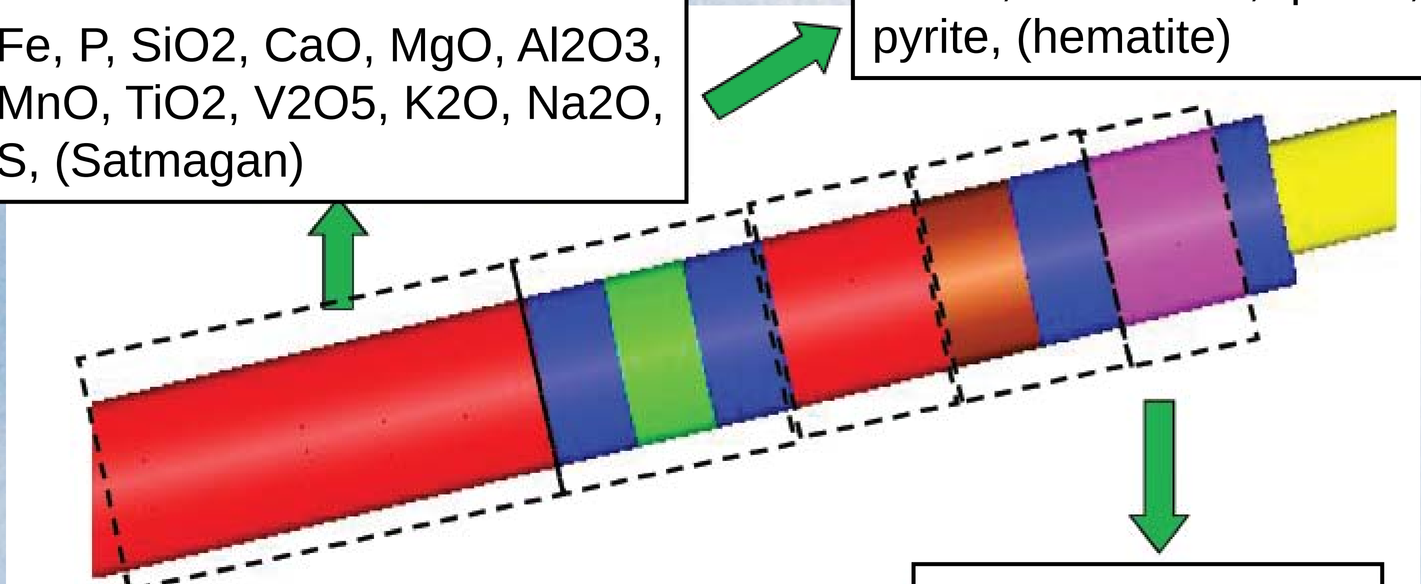
(Cecilia Lund & Pertti Lamberg)

Conversion to minerals (10):

Magnetite, ilmenite, apatite, albite, actinolite, diopside, biotite, orthoclase, quartz, pyrite, (hematite)

Chemical assays (12):

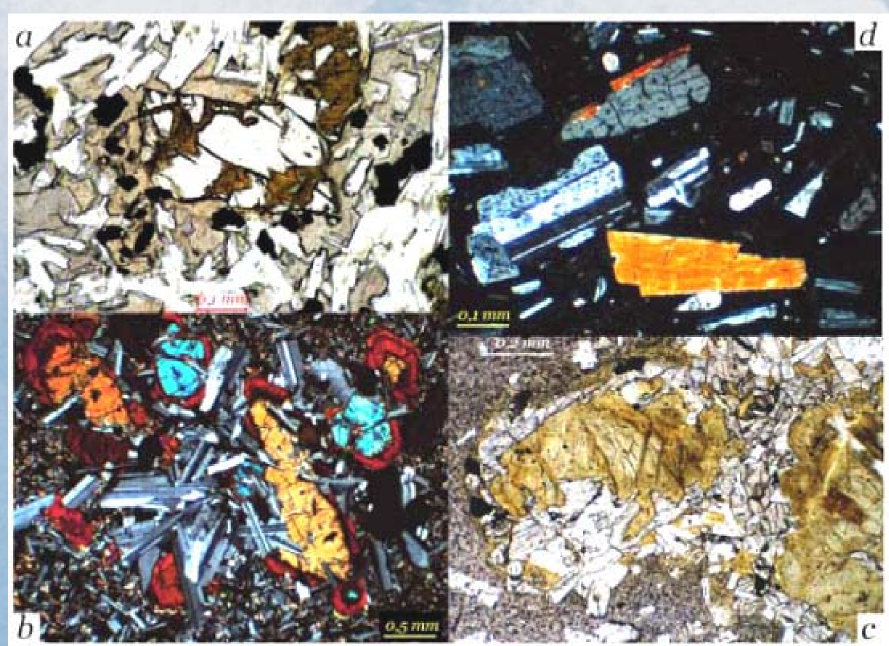
Fe, P, SiO_2, CaO, MgO, Al_2O_3, MnO, TiO_2, V_2O_5, K_2O, Na_2O, S, (Satmagan)



Block model

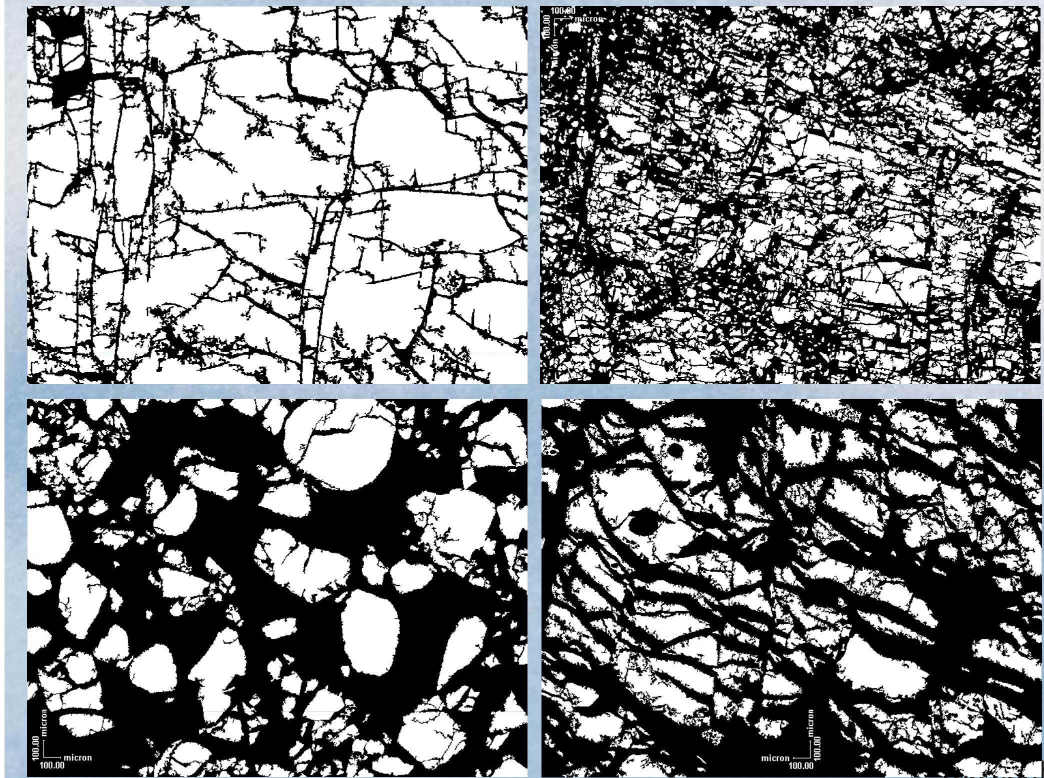
Mineral textures in geological model

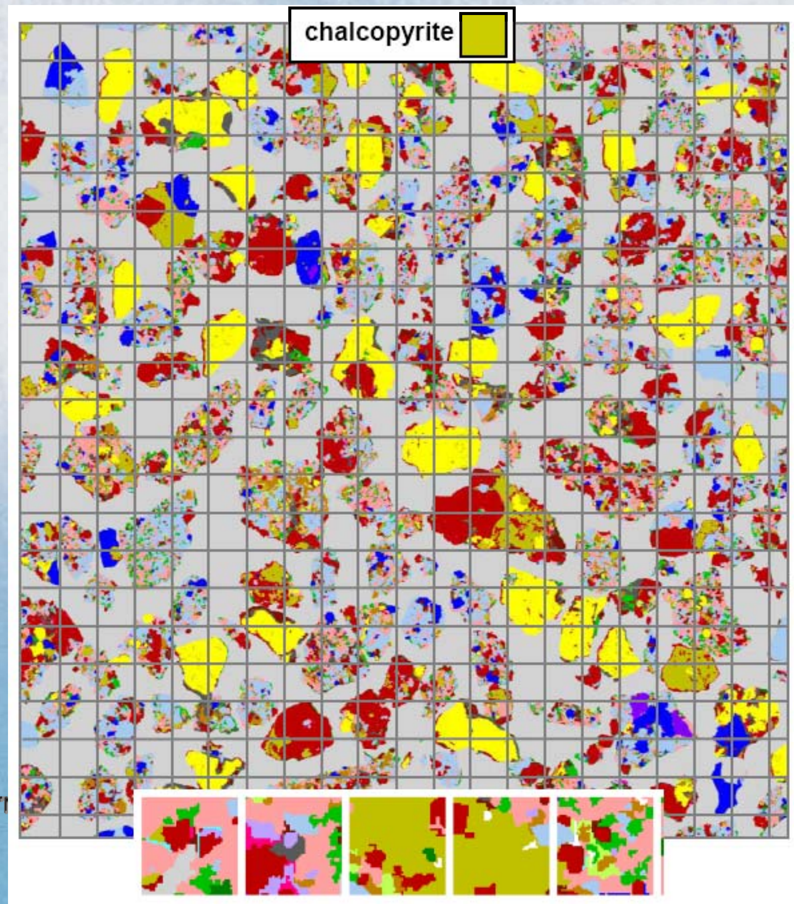
- Descriptive information
  - Difficult to include in the block model (non-additive)



Texture to particles: Optical image analysis

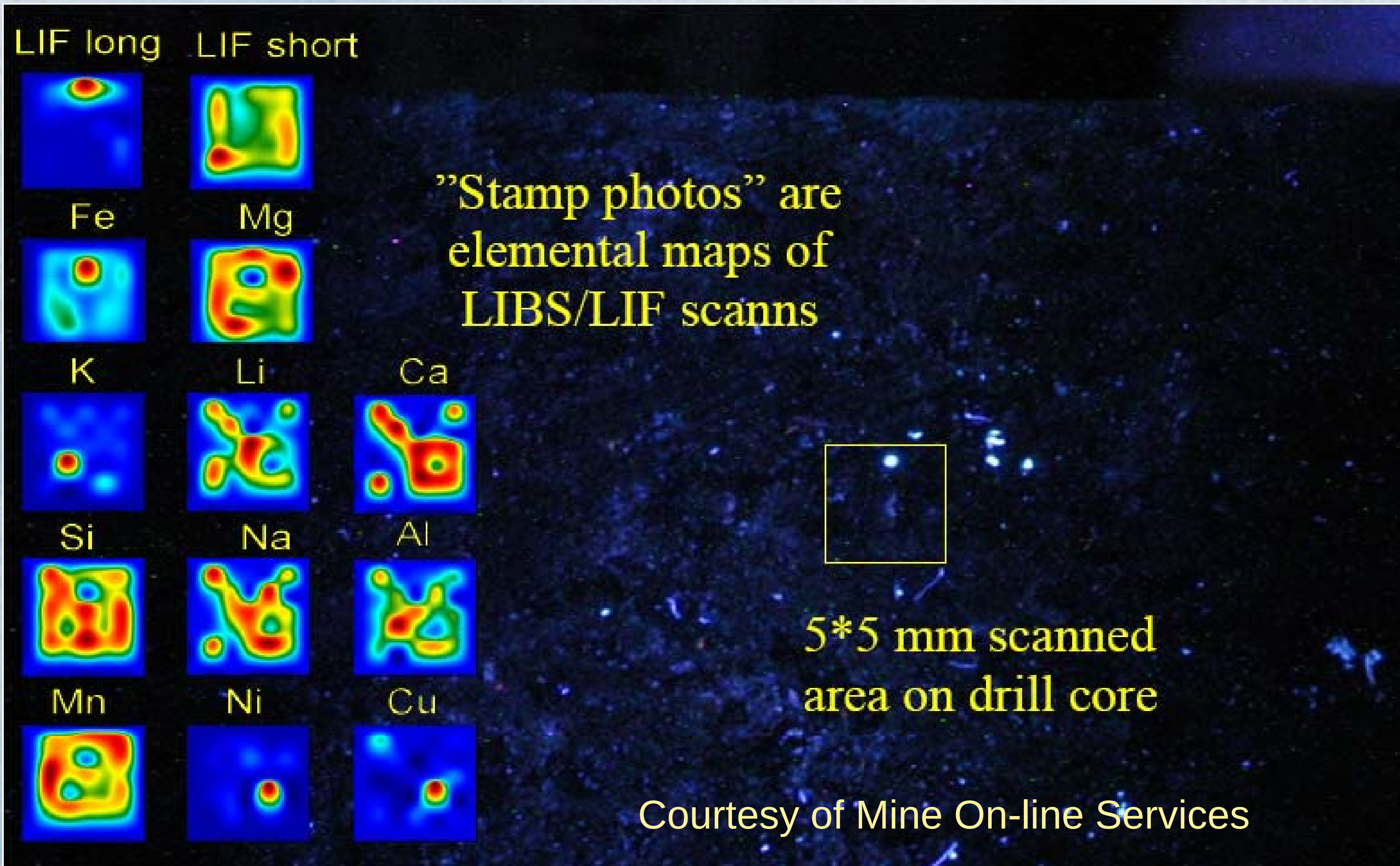
- Breakage of the rock and particles is neither random nor fully preferential (along grain boundaries)





Scanning drill cores

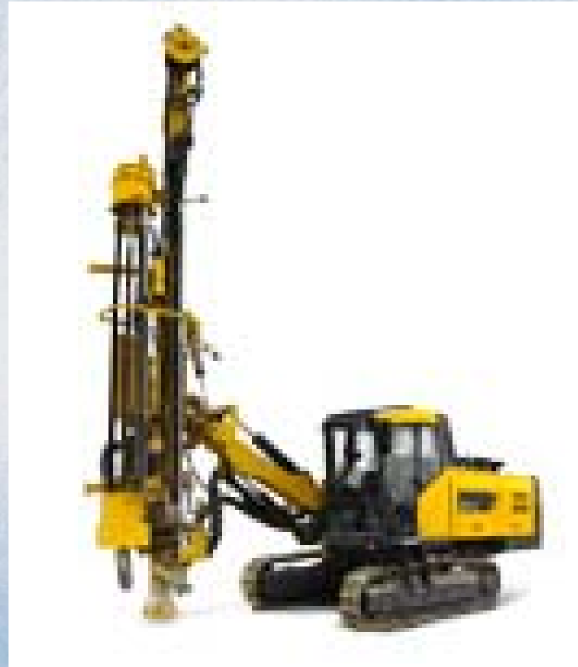
Opitcal / LIBS = Laser Induced Breakdown Spectroscopy



Rock hardness

- Does mineralogy and texture describe it adequately?

- Measurements while drilling (MWD)



Process model

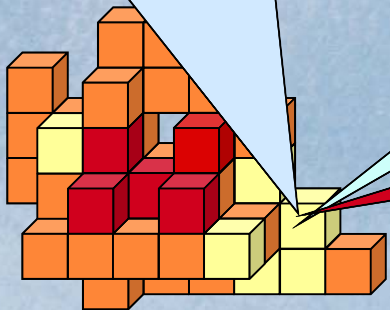
- Based on:
  - Minerals
  - Particles
- Similar particles behave in the process in a similar way
- Properties which define the particle behaviour:
  - Size
  - Composition
  - Density
  - Shape

Particle-based geometallurgical block model

Become global?

Resource
- Block ID
- Location
- Elemental grades
- Chemical composition of minerals
- Mineral grades
- Bulk SG
- Mineral textures
- Hardness

Metallurgy
- Property based parameters
- Breakage model
    - Comminution = size distribution
- Flotation k / mineral / size

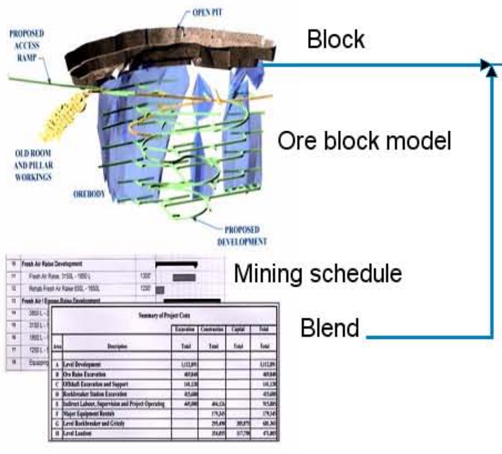


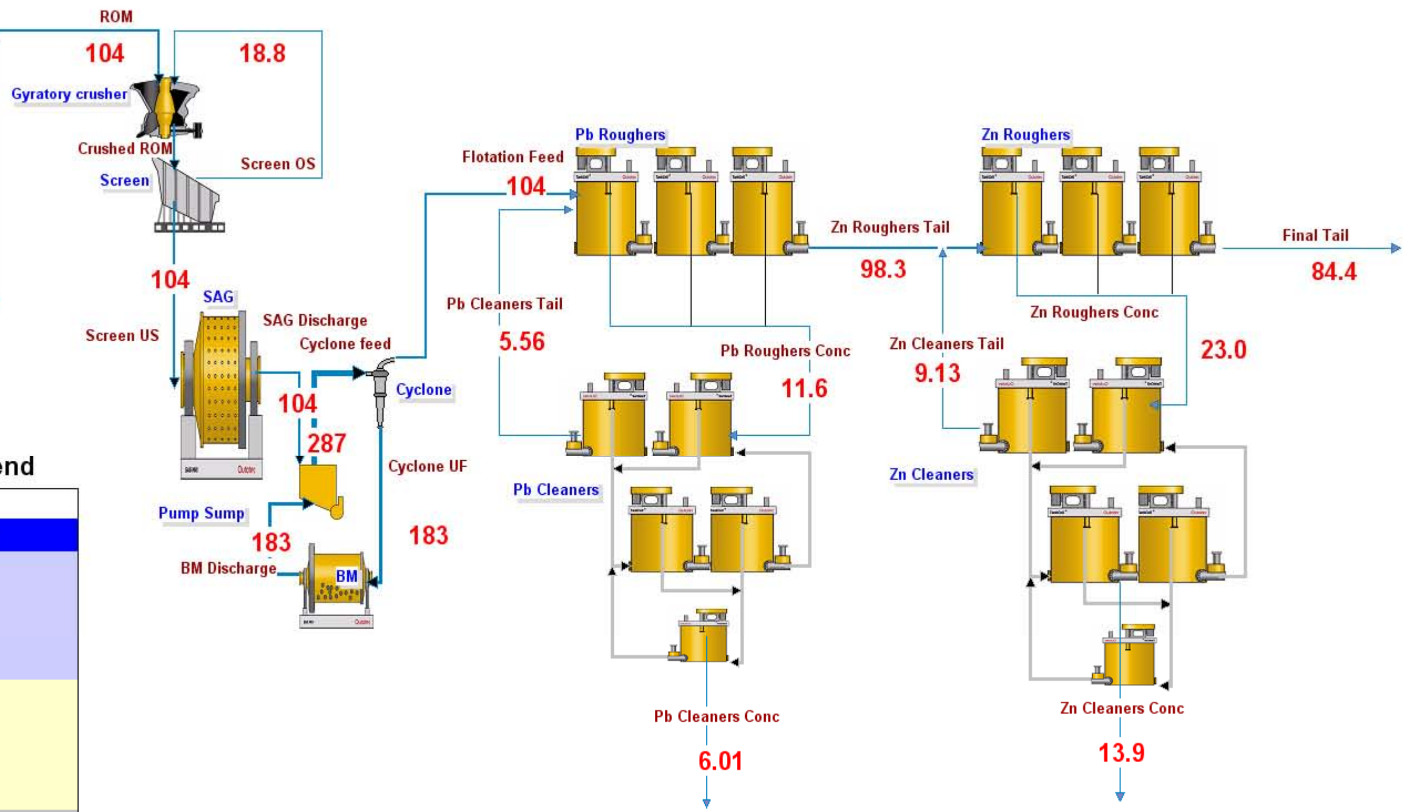
Process model & simulation
- Througput (t/h)
- Grade
- Recovery
- Operating cost

Scenarios
- Production alternative
- Metal prices
- Consumable prices

Geometallurgical simulation

Geometallurgical simulation based on particles **Total solids t/h**





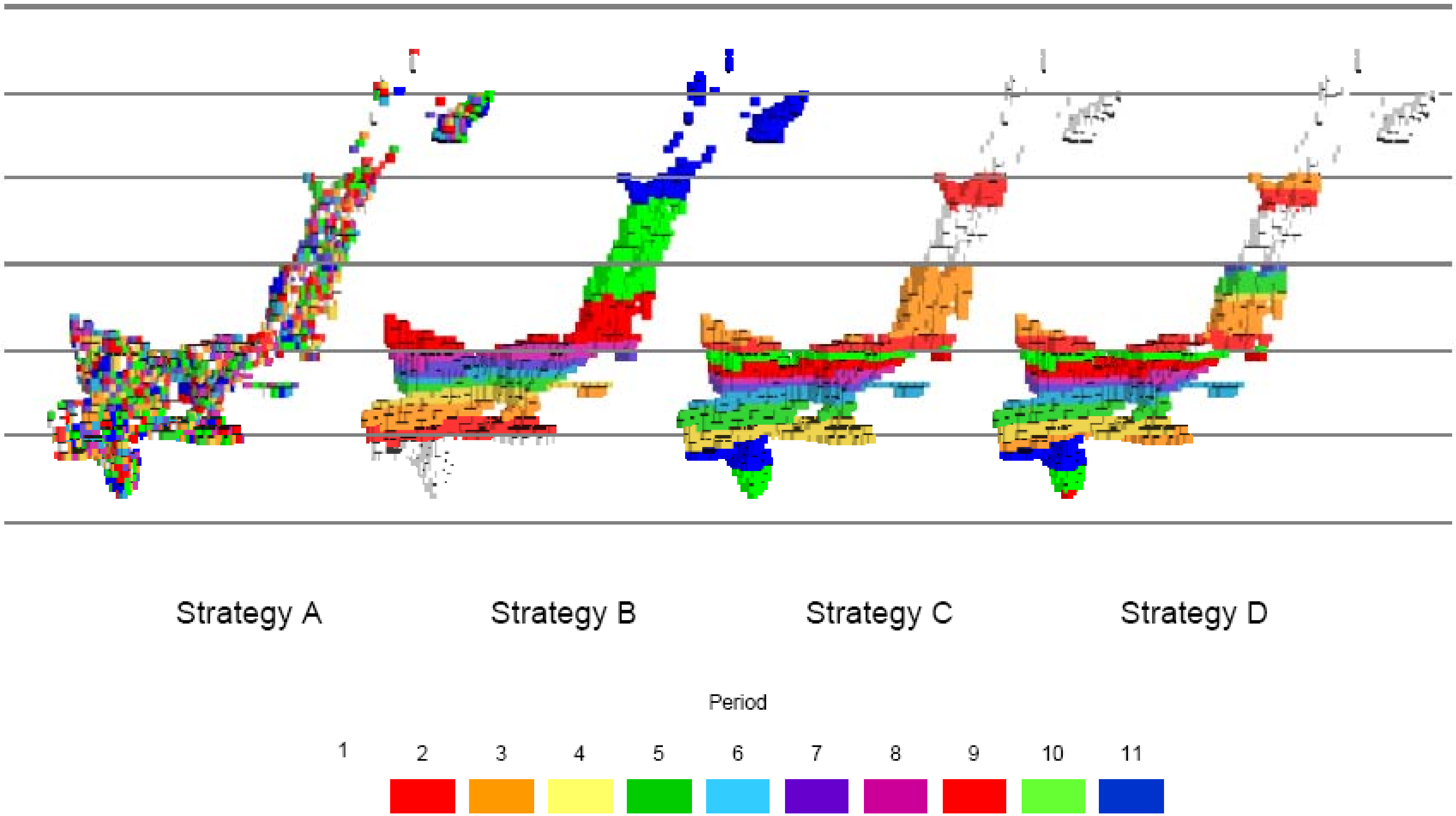
Simulation output for the ore block / blend

Simulation output:

Plant	Throughtput	tph	104.30
Pb Concentrate	Amount	tph	6.01
	Pb Grade	%	73.26
	Pb Recovery	%	55.84
	Zn Grade	%	3.73
Zn Concentrate	Amount	tph	13.88
	Zn Grade	%	49.12
	Zn Recovery	%	62.86
	Pb Grade	%	9.44
Final Tail	Amount	tph	84.41
	Pb Grade	%	2.54
	Zn Grade	%	4.55
	S Grade	%	42.32

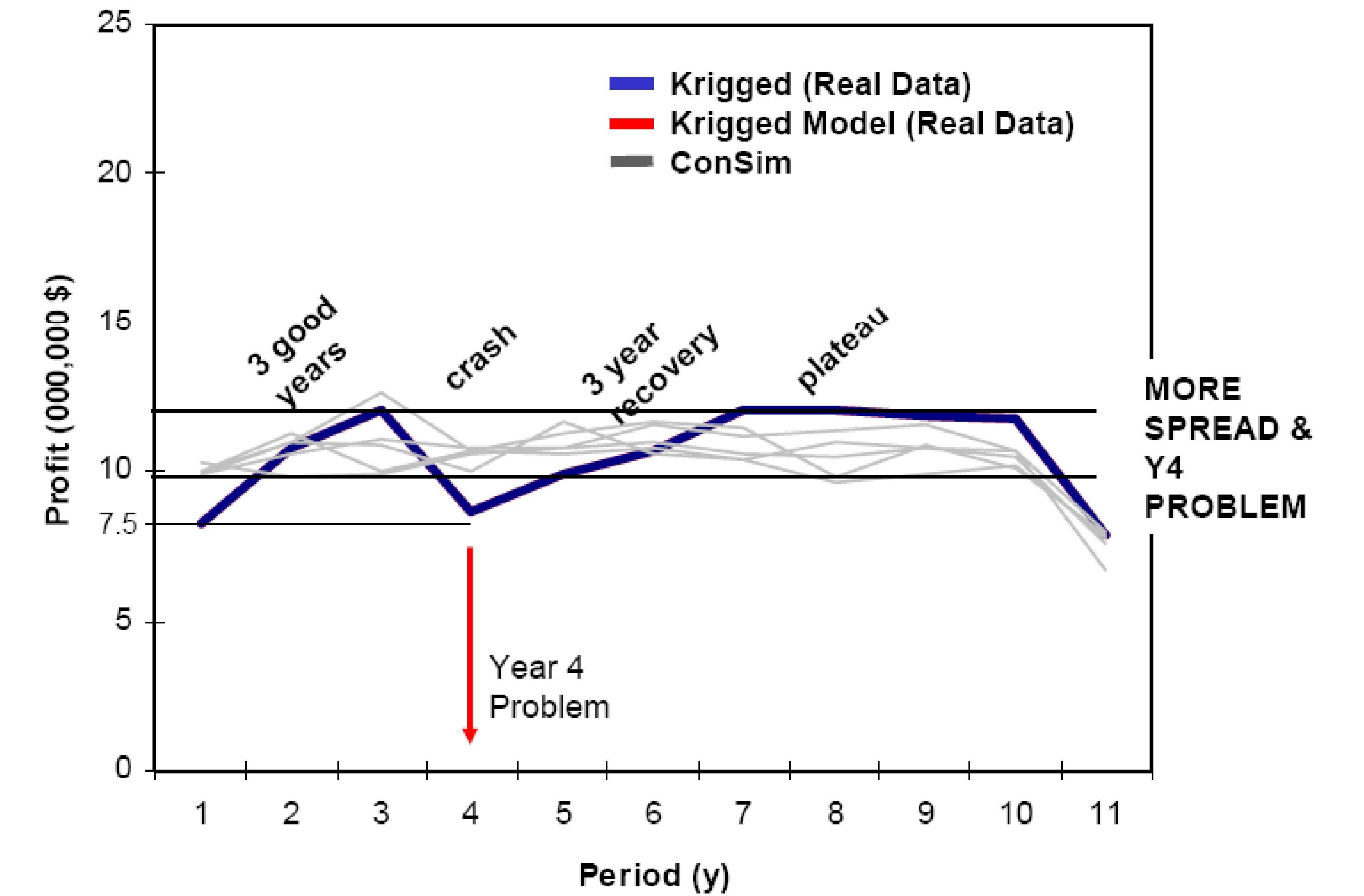
LULEÅ UNIVERSITY OF TECHNOLOGY

Production scenarios



LULEÅ UNIVERSITY OF TECHNOLOGY

Startegy B



Summary

- Geometallurgy
  - combines geological and metallurgical information in a model
  - lowers the technological risk
  - is executed through geometallurgical programs
- Current practices rely on quite small number of samples
- Geometallurgical tests are under development

- You should start geometallurgical program already when exploration project changes to mineral resource stage
- Take your geological and concentration model into mineral level

Acknowlegements

camm

CENTRE OF ADVANCED MINING AND METALLURGY

LKAB

HLRC

HJALMAR LUNDBOHM RESEARCH CENTRE

A research centre sponsored by LKAB at the Luleå University of Technology in Sweden.

norden

NordForsk