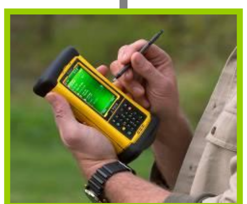




Deriving Quantitative Geological Information From Assay Data

Dave Lawie
Managing Director
ioGlobal

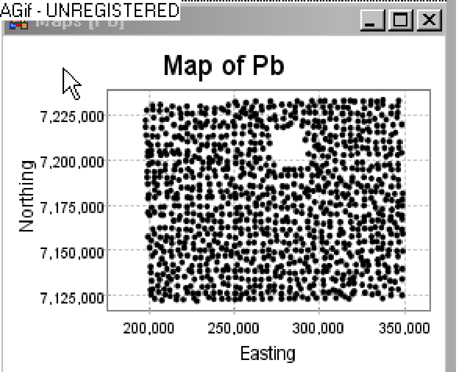
www.ioglobal.net

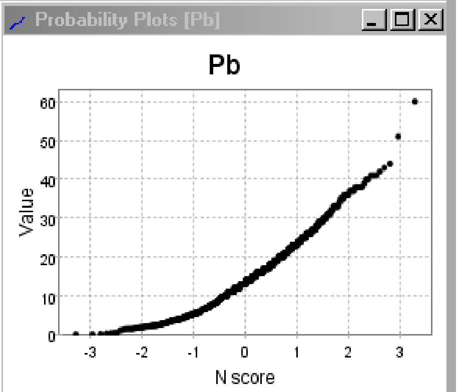
Introduction

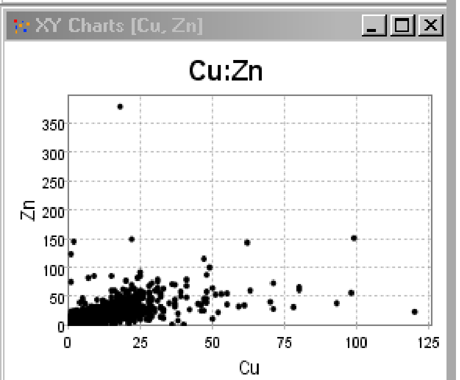
- Multi-element assaying of samples is common in exploration, resource and grade control work

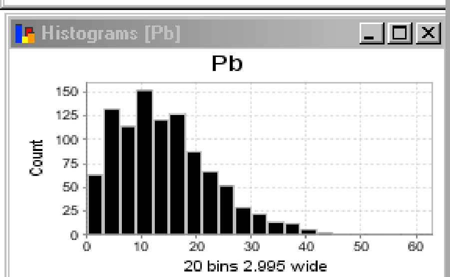
- Other phase-specific data such as ‘extractable’ Cu, sulphide sulphur, silicate Ni and carbonate carbon may also be collected.

- Using relatively simple tools, such data may be used to derive quantitative information for
  - Rocktype identification,
  - Stratigraphic correlation
  - Hydrothermal alteration identification and quantification.
  - Assessment of exploration ‘fertility’
  - Estimates of key metallurgical performance parameters

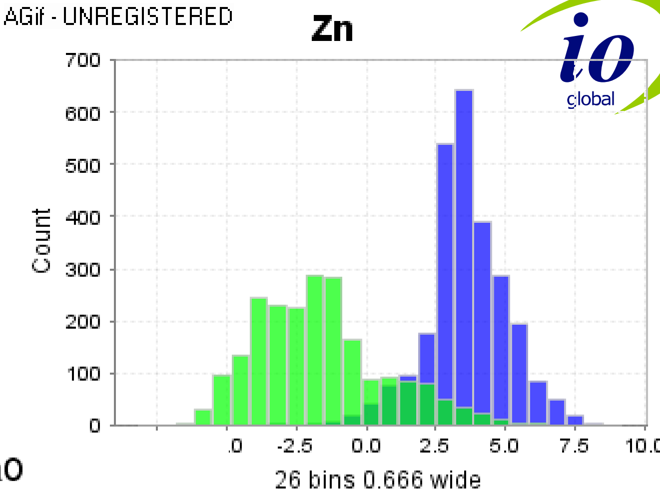


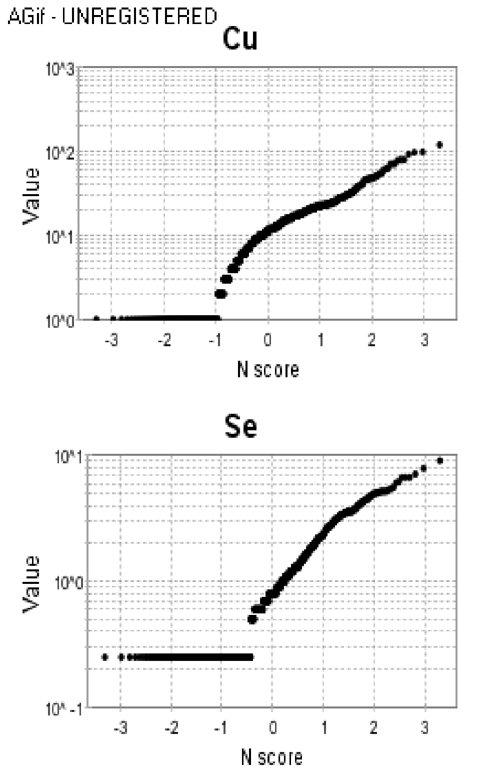


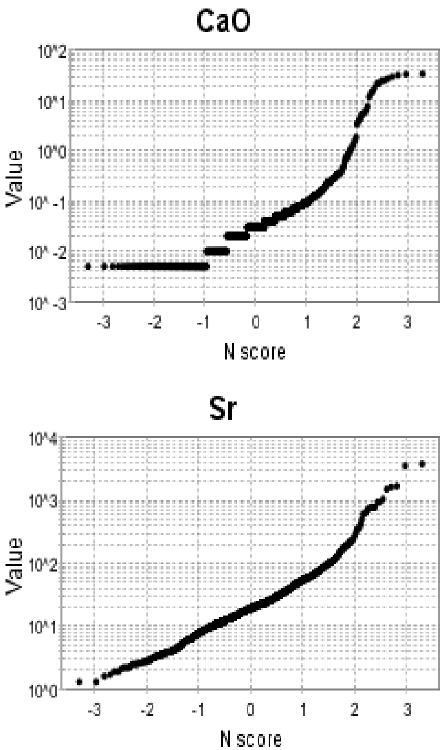




Exploratory Data Analysis





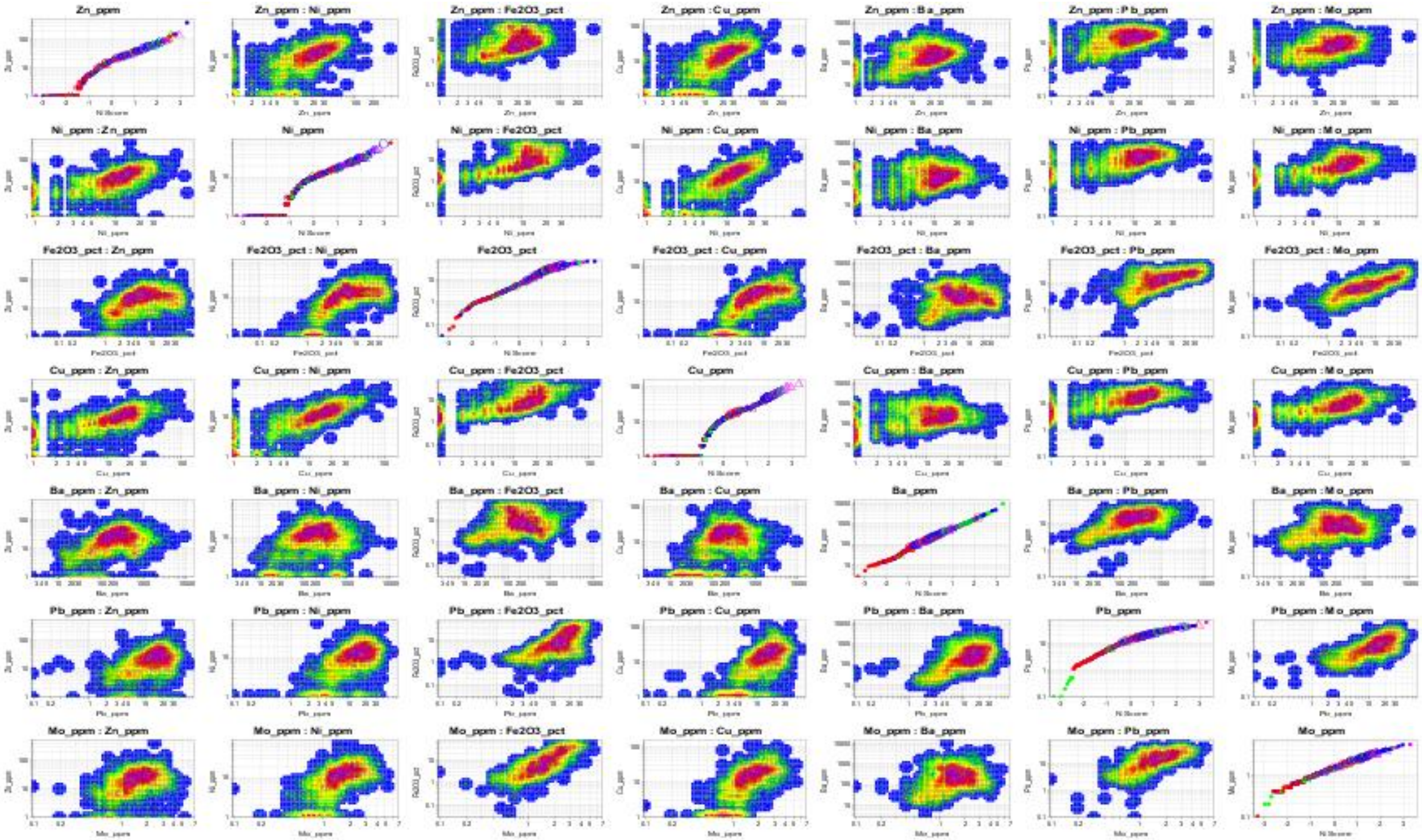


Does not require statistics – or hypothesis testing

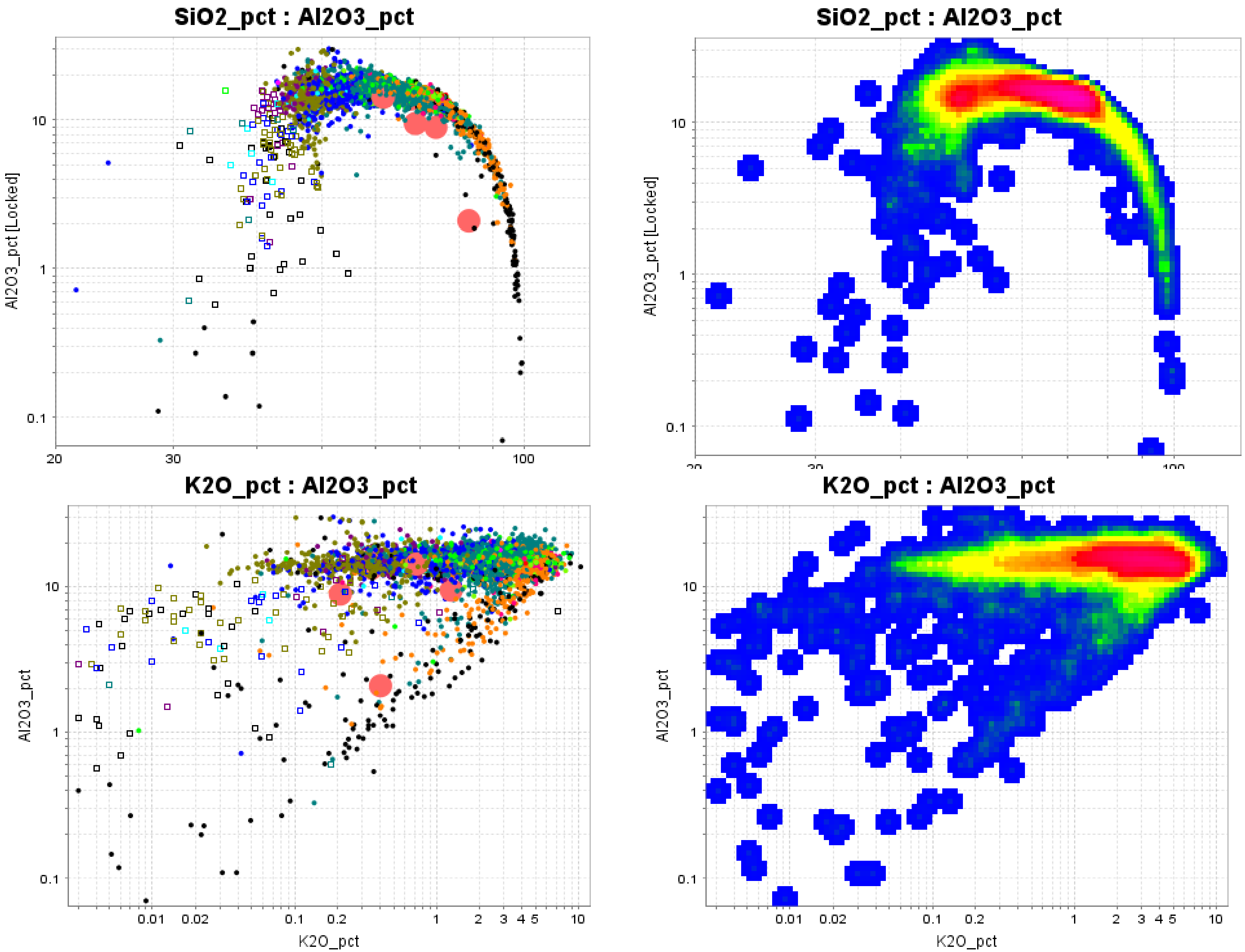
Exploratory Analysis

Point Density

"don't show correlation coefficients without the scatterplots"



Exploratory Analysis

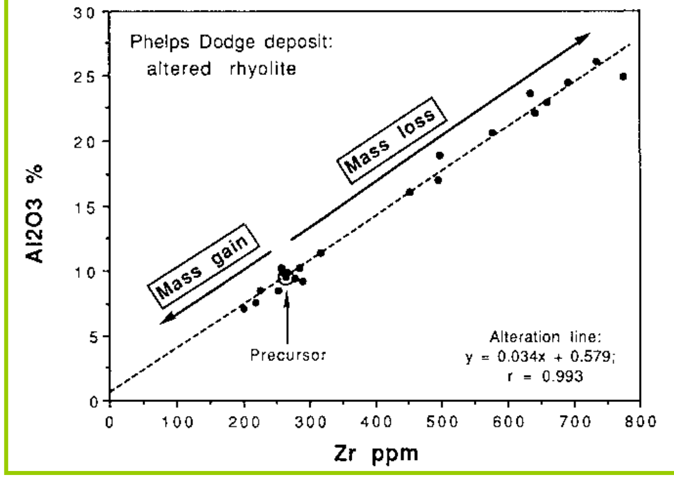


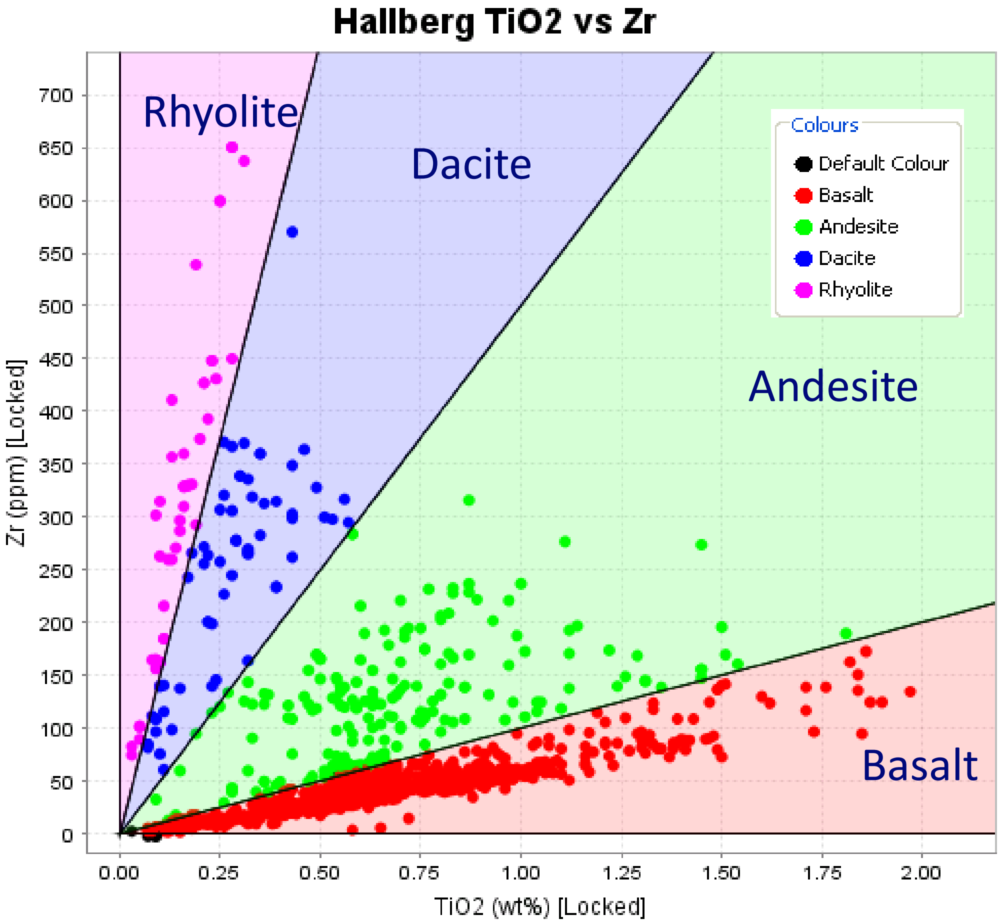
Classification Diagrams

- Can be used to push classification onto data, or verify field relations and geological information
  - For example, some are used to assess tectonic setting, while others are used for rock-type assignment
  - Classification diagrams are commonly applied to igneous rocks, however many other diagrams exist.
- Importantly, you can create your own classification diagram

Classification Diagrams

- Rock type identification in deeply weathered terrain (after Hallberg 1984)





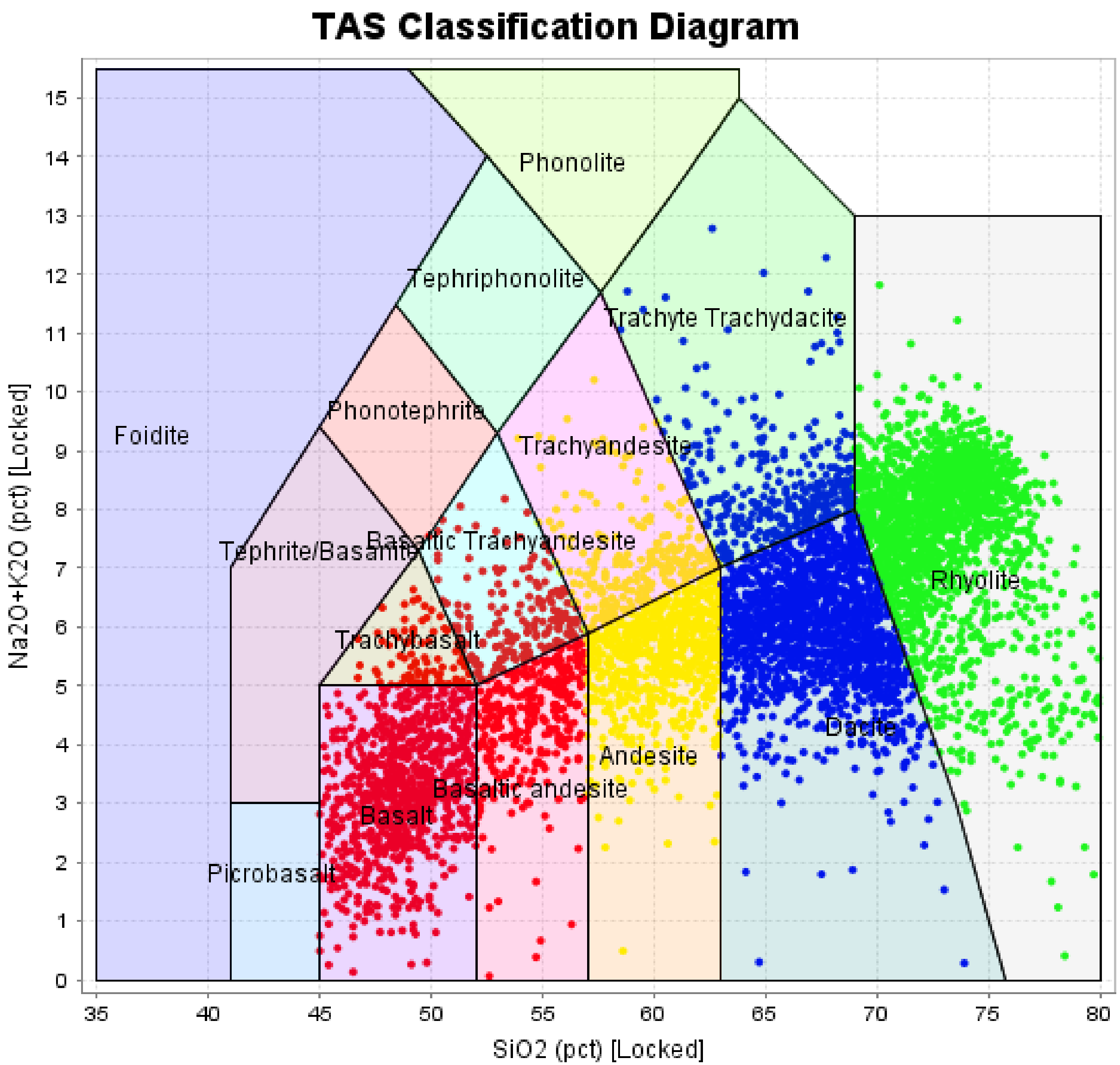
Based on the relatively immobile elements Ti, Zr and Cr, it was possible to discriminate between volcanic rock types in the Yilgarn

The plot works because although mobile constituents are lost from the rock, immobile elements are conserved.

The concentration of the immobile elements changes, but their ratio does not.

Classification Diagrams - TAS Plot

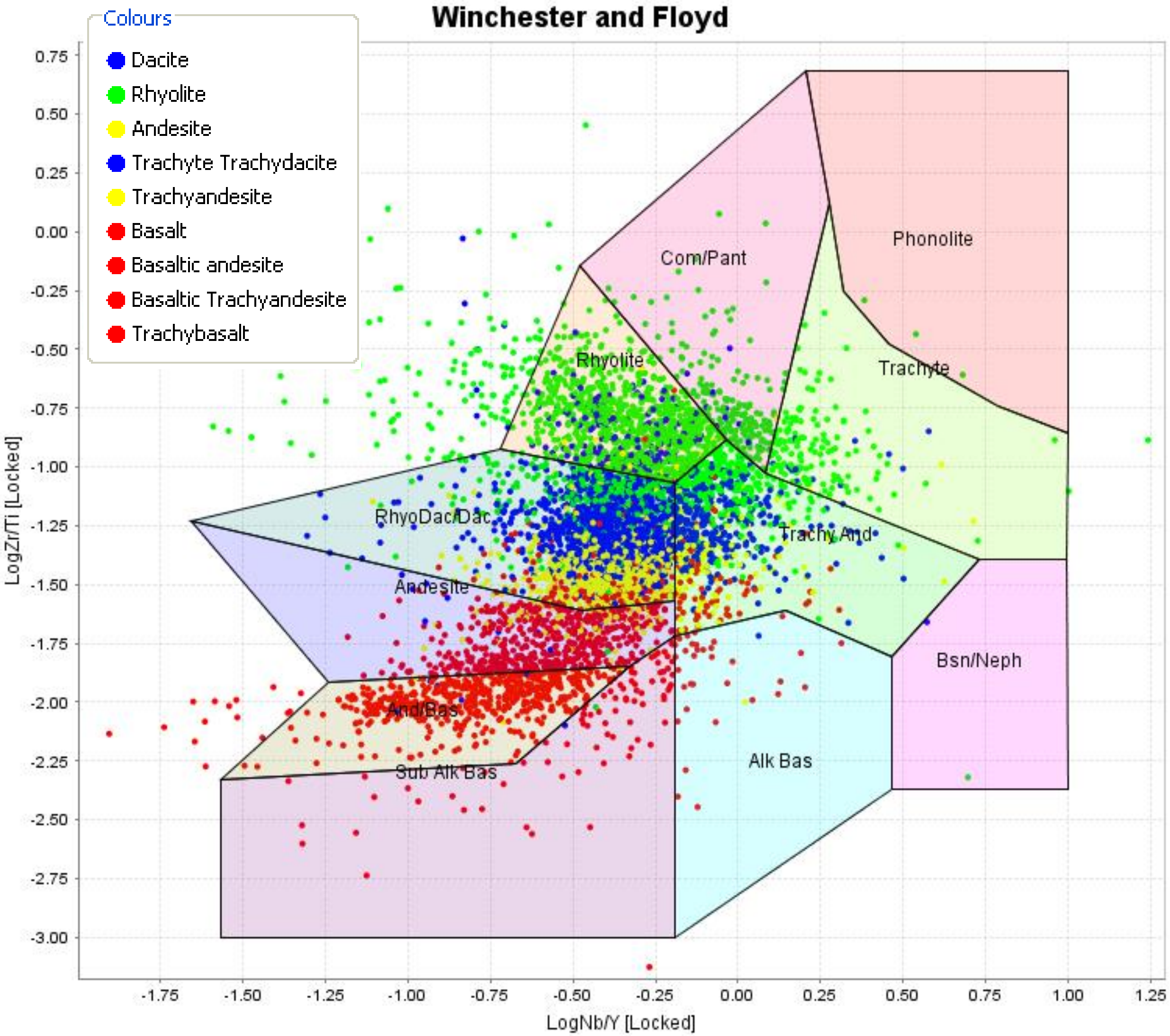
- Provides a classification scheme for volcanic rocks
- Vulnerable to alkali loss, prone to closure effects



Classification Diagrams

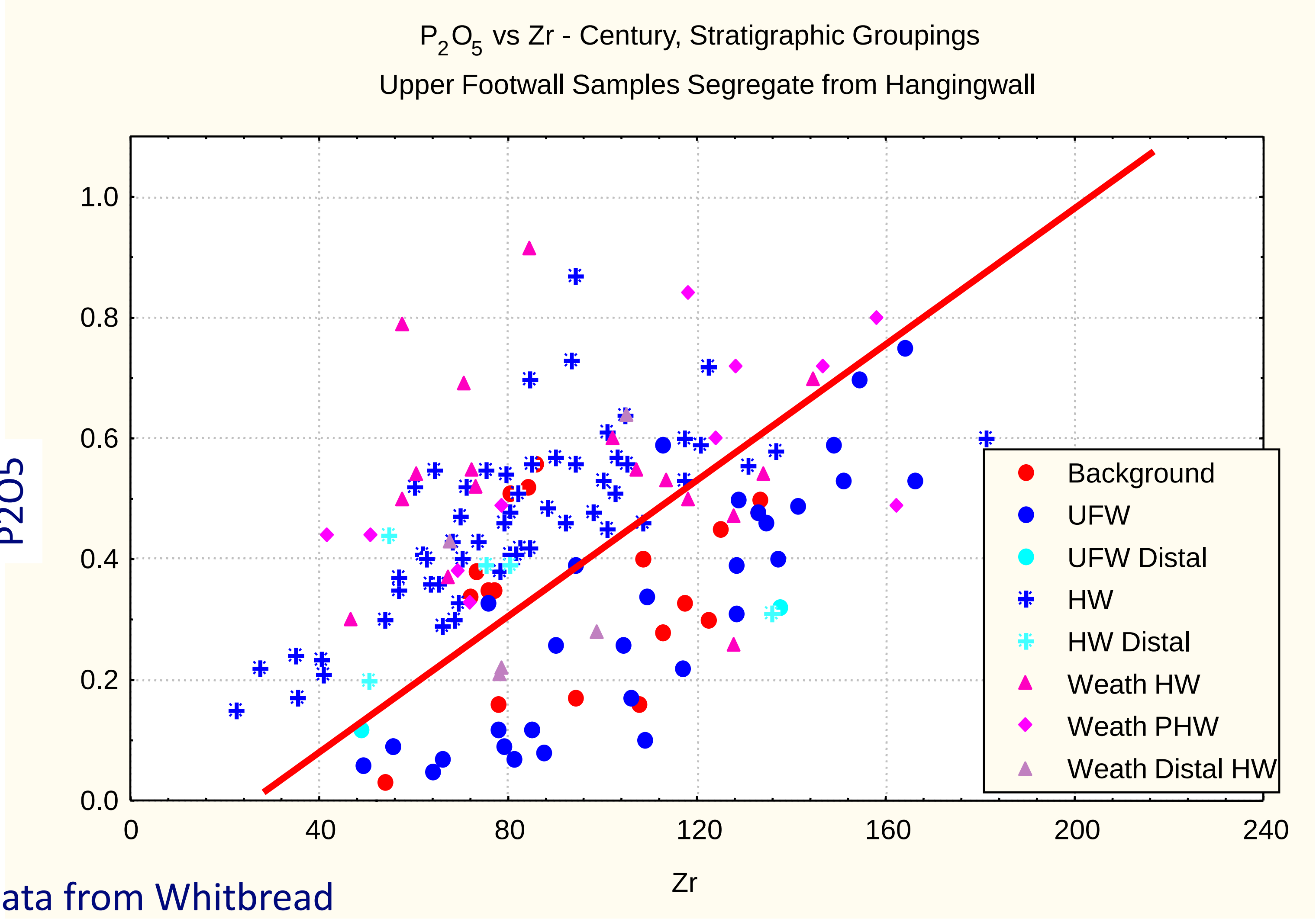
- Rock type identification (Winchester and Floyd 1977)

- 'Immobile' trace element formulation
- Classification scheme for volcanic rocks
- More robust than TAS against mobility of alkalis
- Zr/Ti is a proxy for Si, Nb/Y is a proxy for total alkalis
- Boundary positions debatable



Custom Classification Diagram

Hand Drawn Line



Data from Whitbread

Classification - Caveats

The processes that have led to their derivation should preferable by understood. Different diagrams can give different classification results for the same sample

Things to watch out for: **weathering, alteration, plotting irrelevant rock types on the diagram, closure effects of tri-plots, inappropriate data quality (eg, 4 acid vs fusion for Zr), adequate precision (esp. for divisors) and data too near dl.**

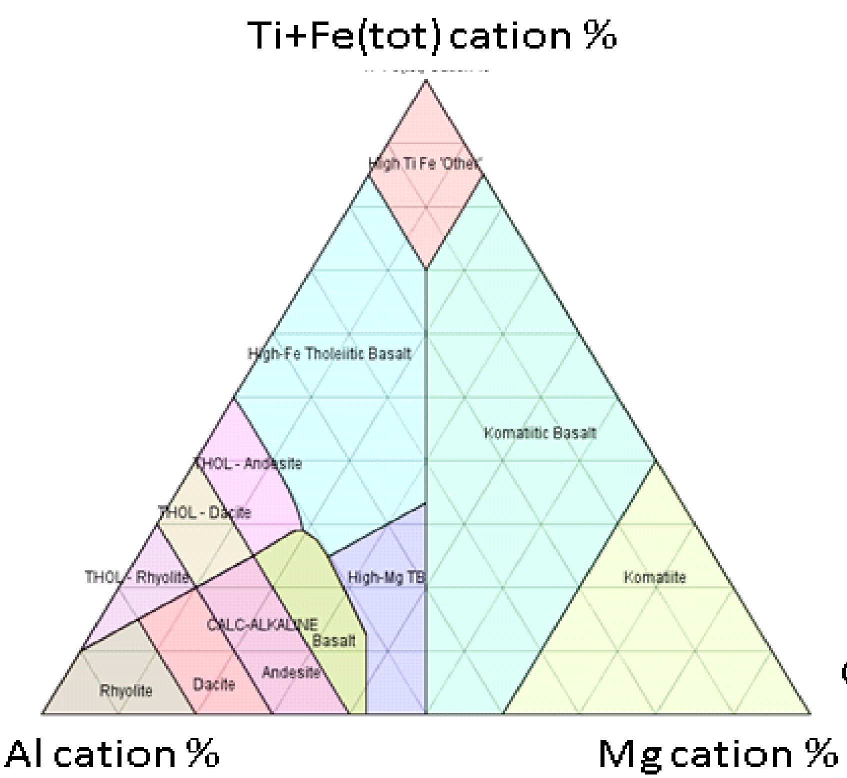
Mineral Chemistry based Classification

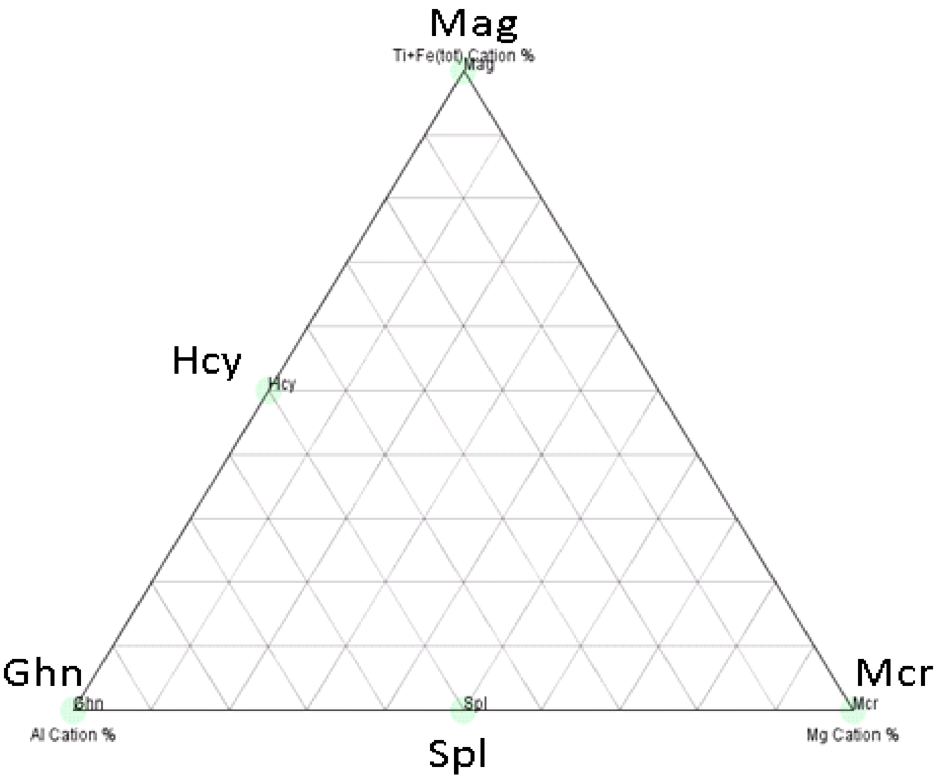
- Data becoming mare available, MLA –type technologies
- Adapt a “whole – rock” chemistry diagram
- Show spinel compositional variation
- Derive an empirical classification scheme for new data

Mineral Chemistry based Classification - Spinels

Jensen cation plot (left) and modified version (right) with spinel nodes shown.

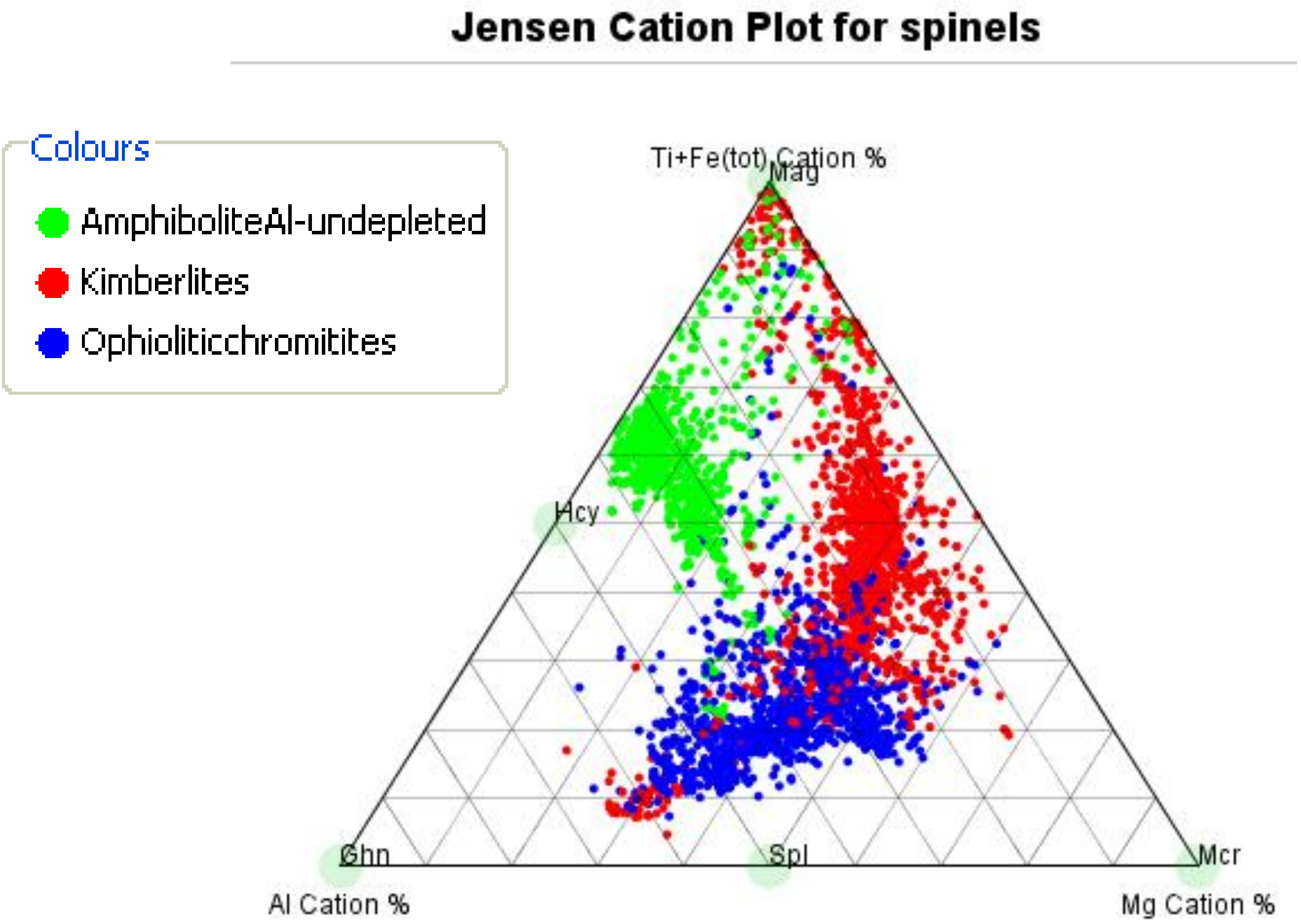
Spinel names abbreviated Mcr=magnesiochromite, Spl=spinel, Hcy=hercynite, Ghn=gahnite, Mag=magnetite.





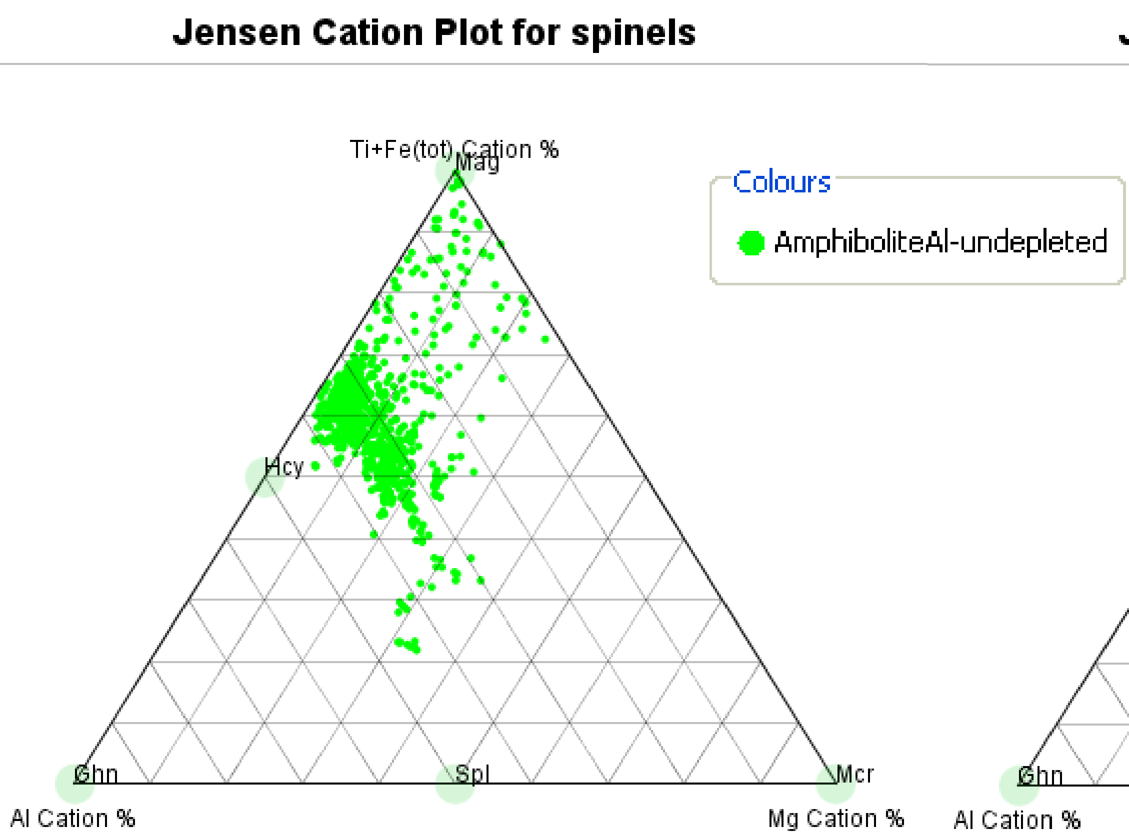
Mineral Chemistry based Classification - Spinels

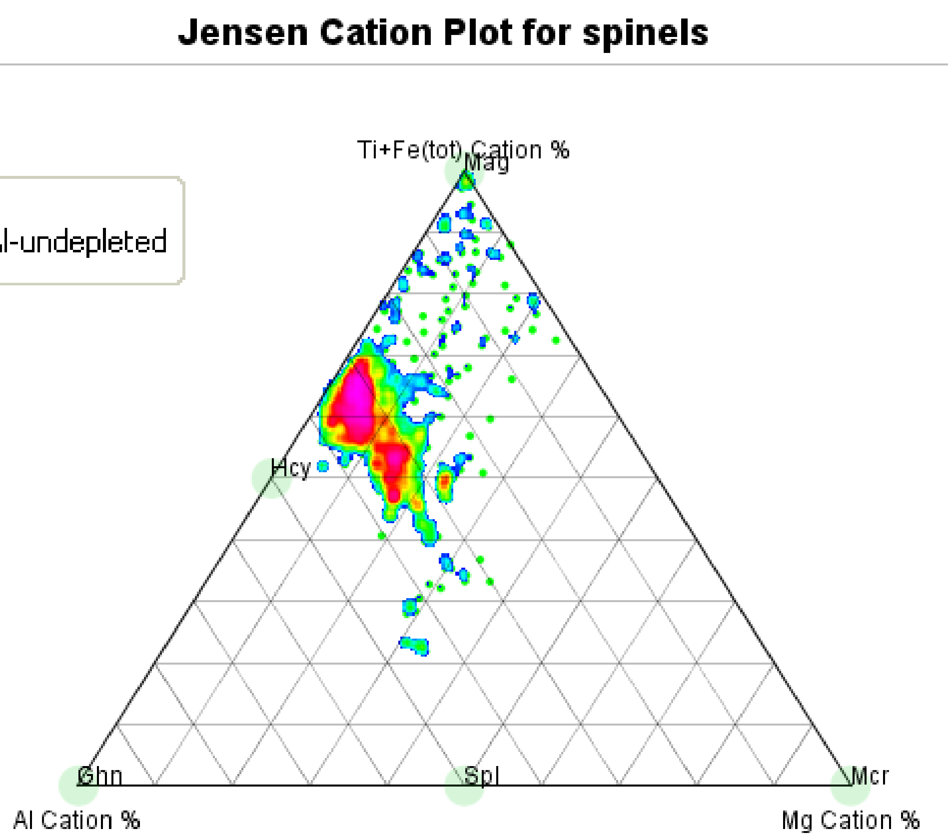
Spinel data from Barnes and Roeder (2001) plotted on the modified Jensen cation plot.



Mineral Chemistry based Classification - Spinels

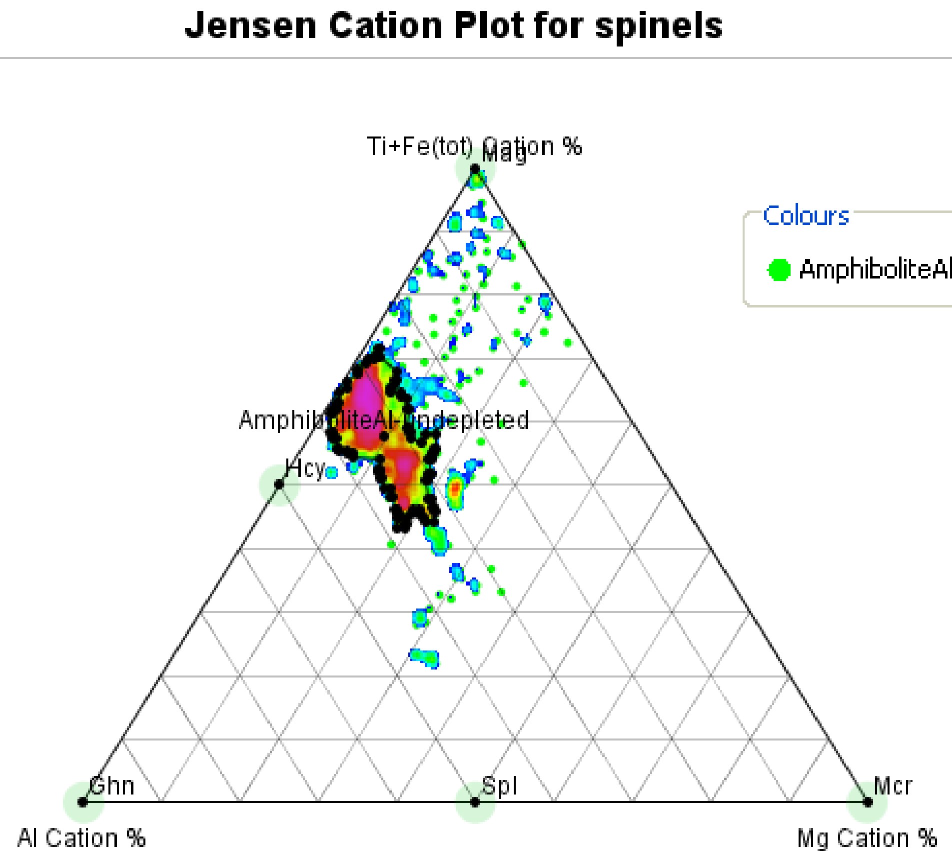
Creating a category from a point density contour

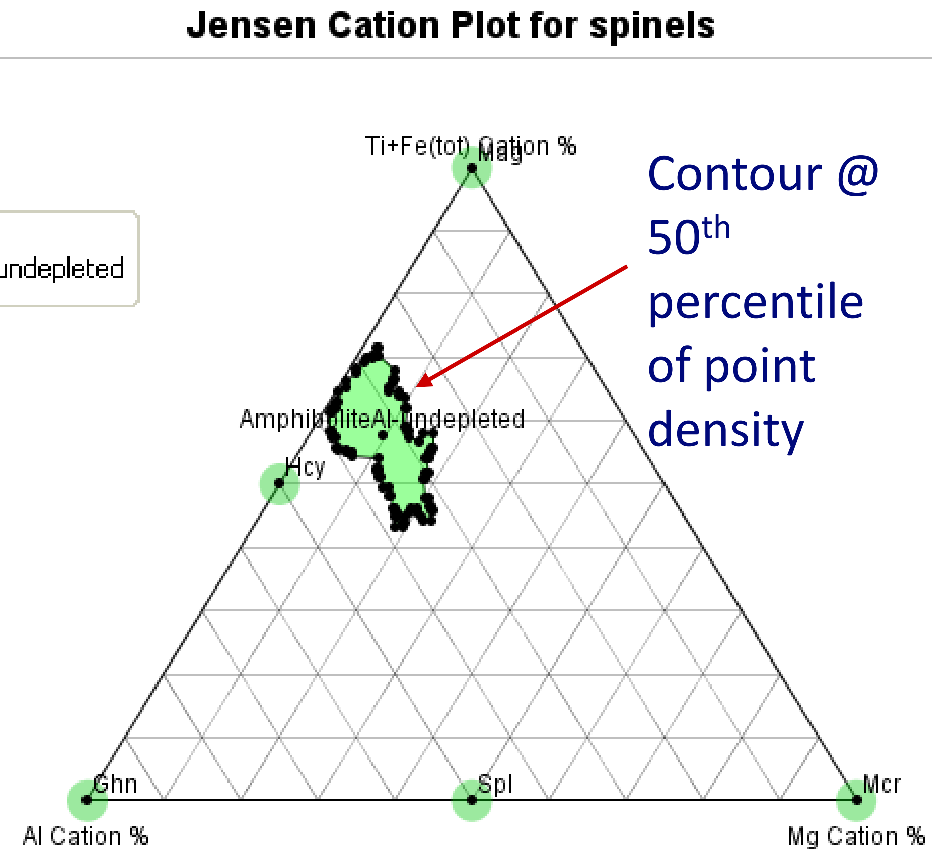




Mineral Chemistry based Classification - Spinels

Creating a category from a point density contour

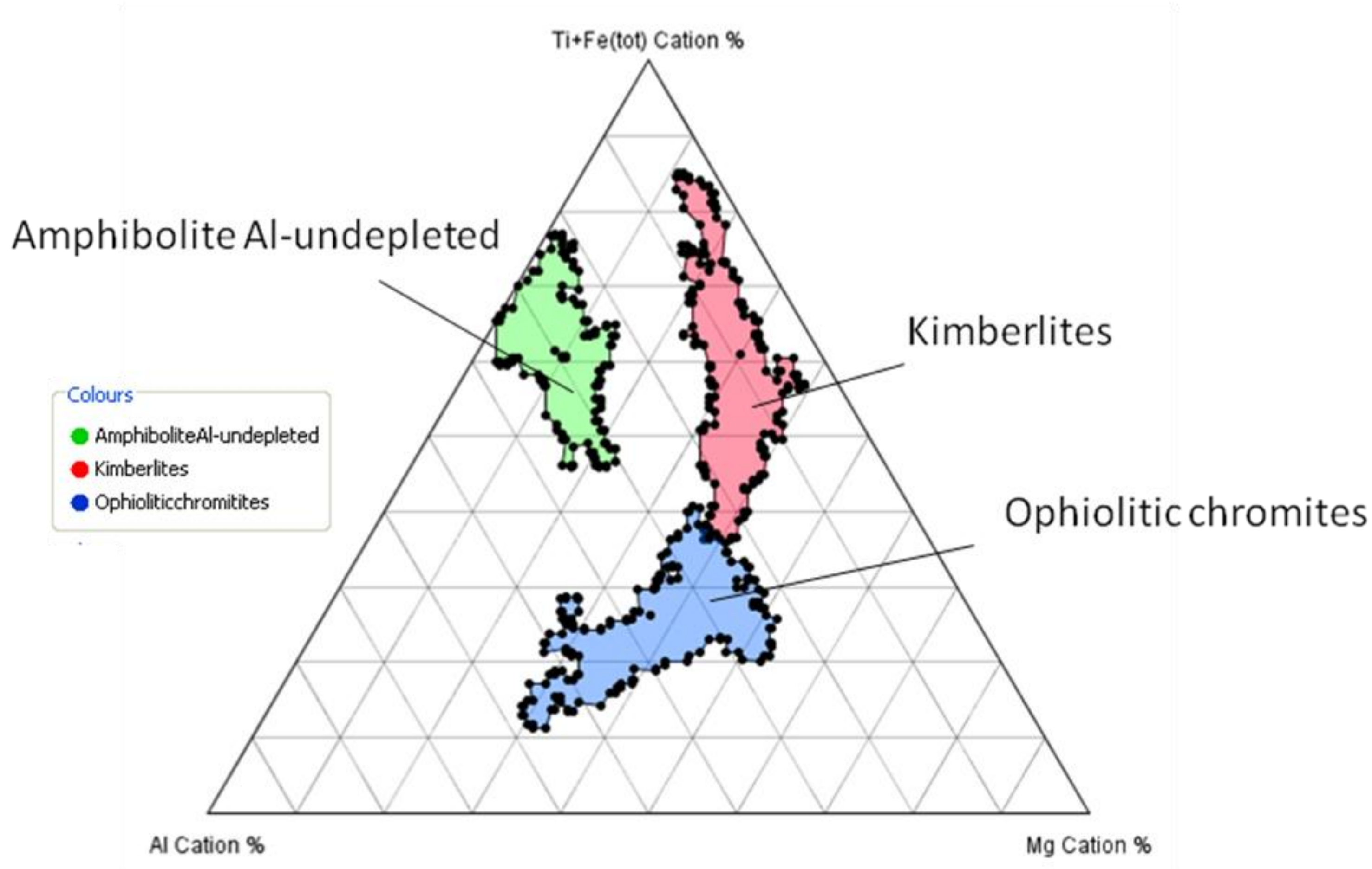




Contour @ 50th percentile of point density

Mineral Chemistry based Classification - Spinels

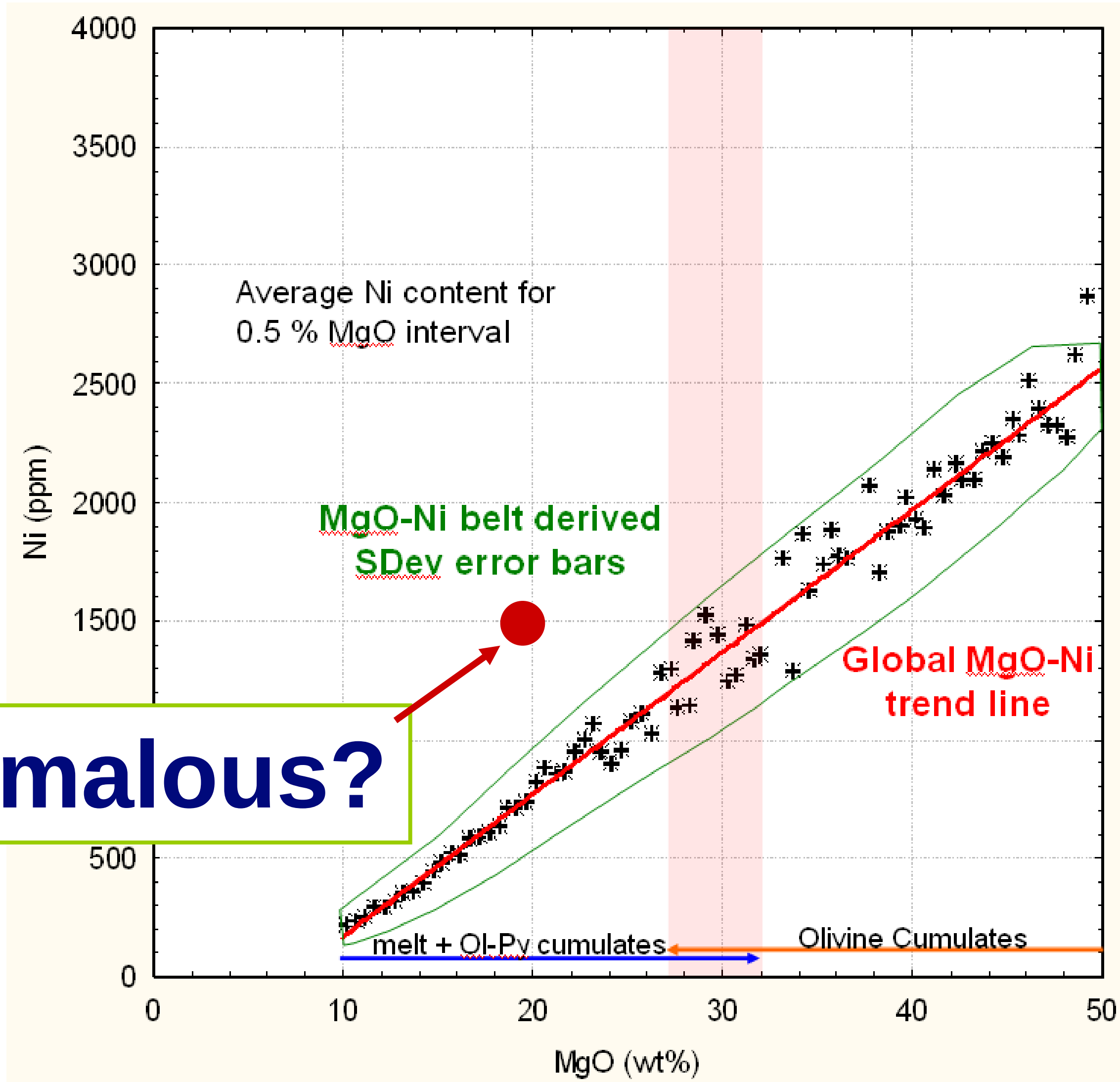
Empirically Derived Classification Fields – Classify New Data



Assessment of Exploration Potential

- Fertility Indicators

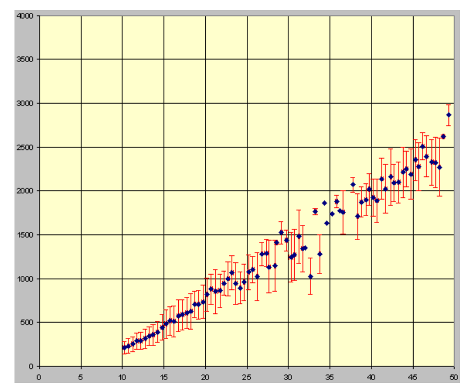
Data Analysis - Lithogeochemistry - Fertility



Anomalous?

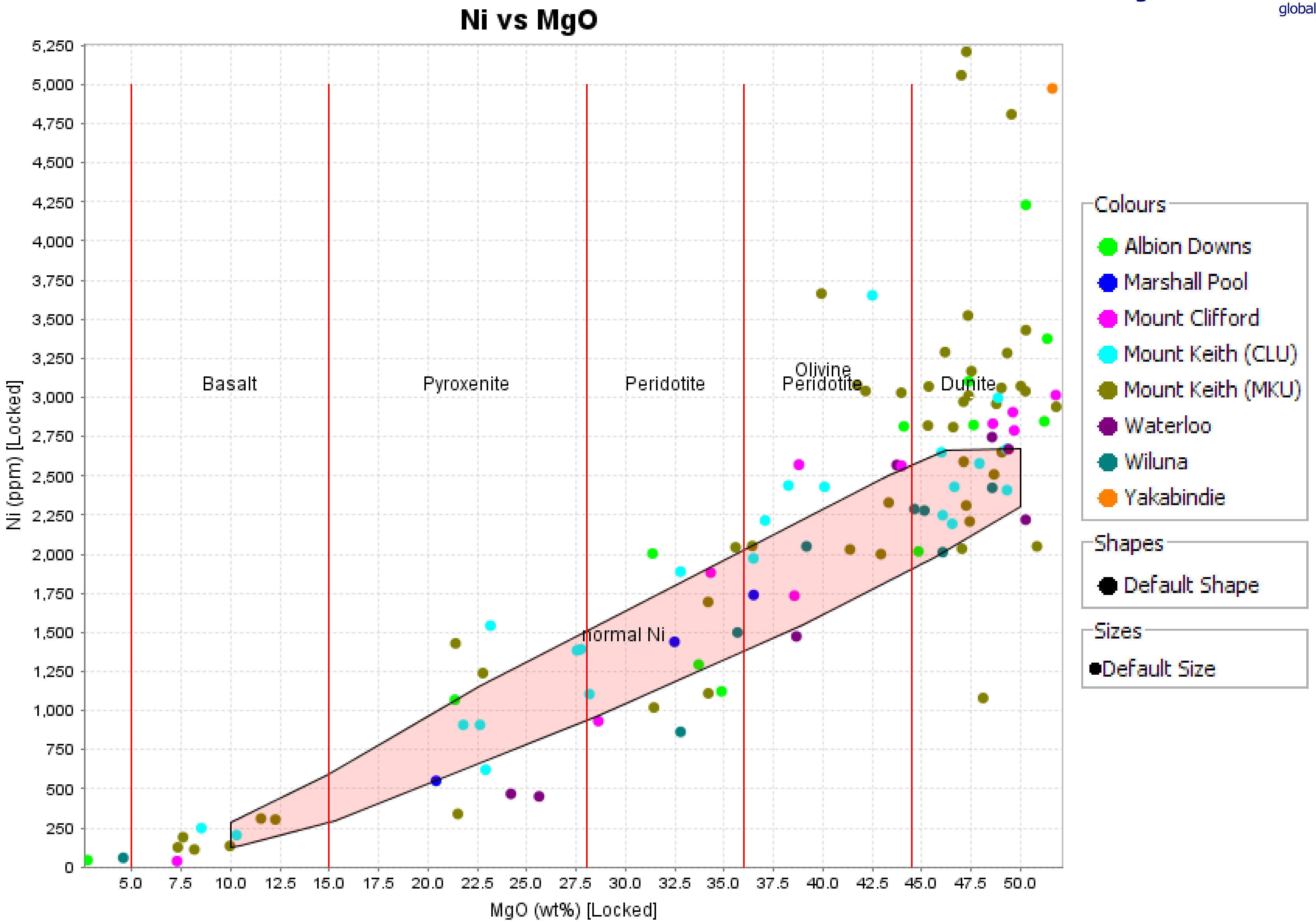
Global Ni-MgO Background

Average Ni content for
0.5 % MgO interval

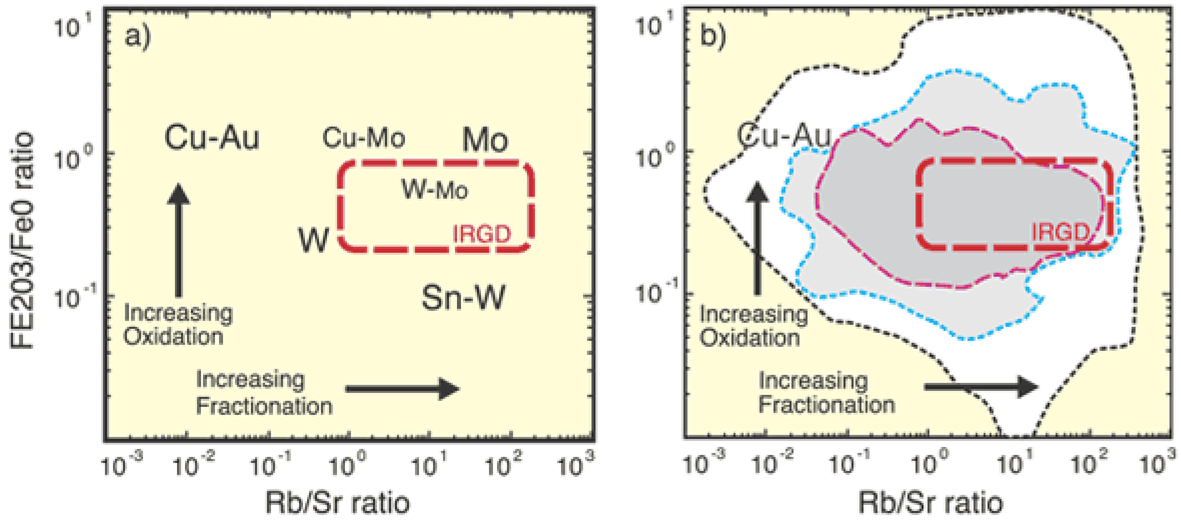


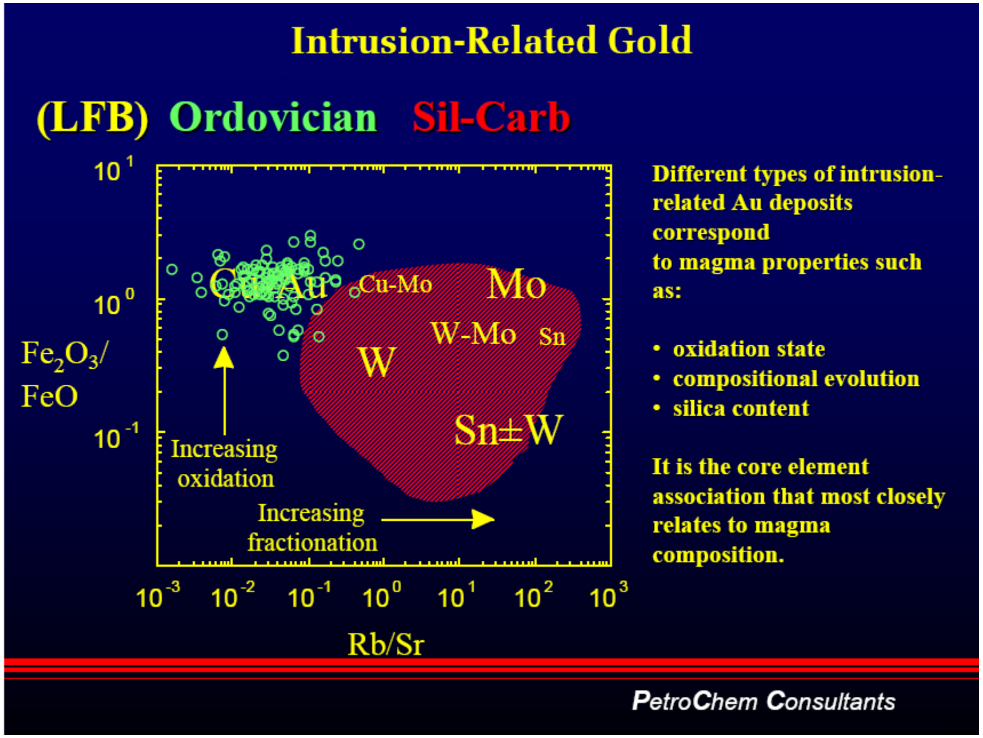
Data: literature and internet

Data Analysis - Lithogeochemistry - Fertility



Fertility Assessment - Model/Process Driven





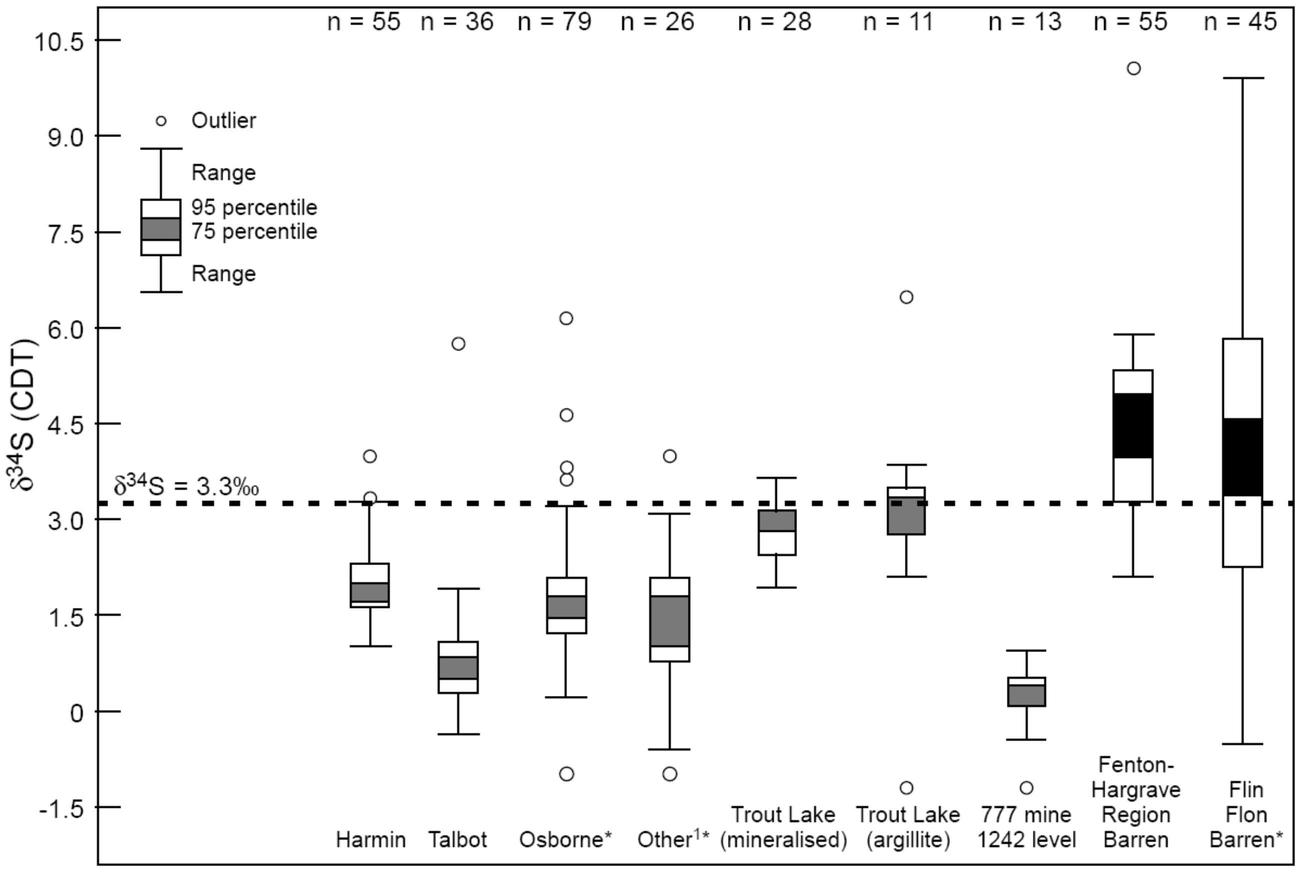
http://www.ga.gov.au/ausgeonews/ausgeonews200509/gold.jsp

Such diagrams are useful for rapidly assessing fertility of large areas, but ‘zones’ on such diagrams commonly vary greatly for different terrains

Source: The Ishihara Symposium: Granites and Associated Metallogenesis

Palaeozoic Granite Metallogenesis of Easter Australia – Phil Blevin (@ Geoscience Australia, 2004)

Isotopes – Fertility Assessment



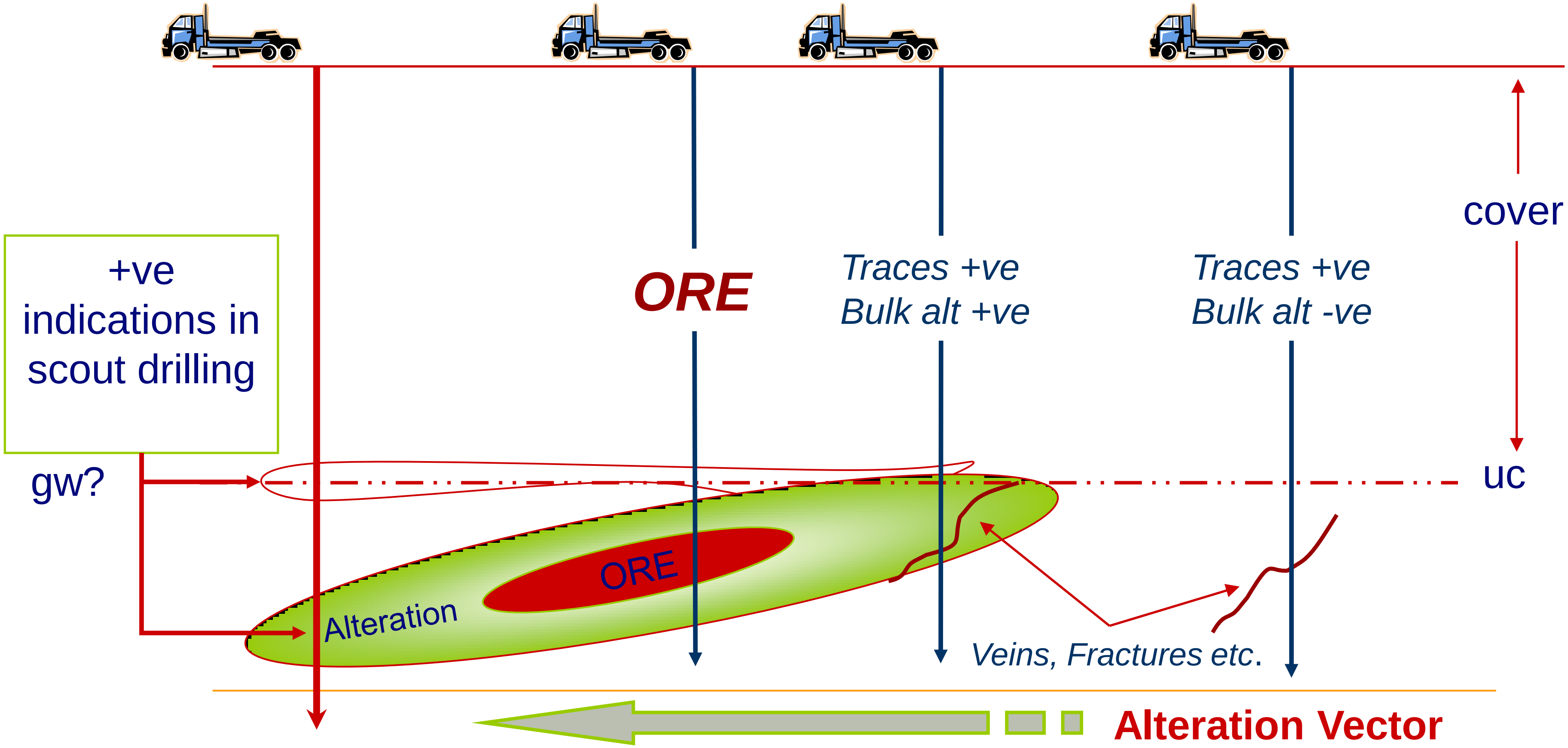
- Application of Sulphur Isotopes to assessing Fertility of ‘Sulphide’ Discoveries
- Simple to apply, robust IF adequate orientation carried out

Poster: IGES 2005 - “Application of sulphur isotopes to discriminate Cu-Zn VHMS mineralization from barren Fe sulphide mineralization in the greenschist to granulite facies Flin Flon – Snow Lake – Hargrave River region, Manitoba, Canada.” by *Paul Polito1,2, Kurt Kyser1, David Lawie3, Steven Cook4, Chris Oates5*

Modelling Alteration

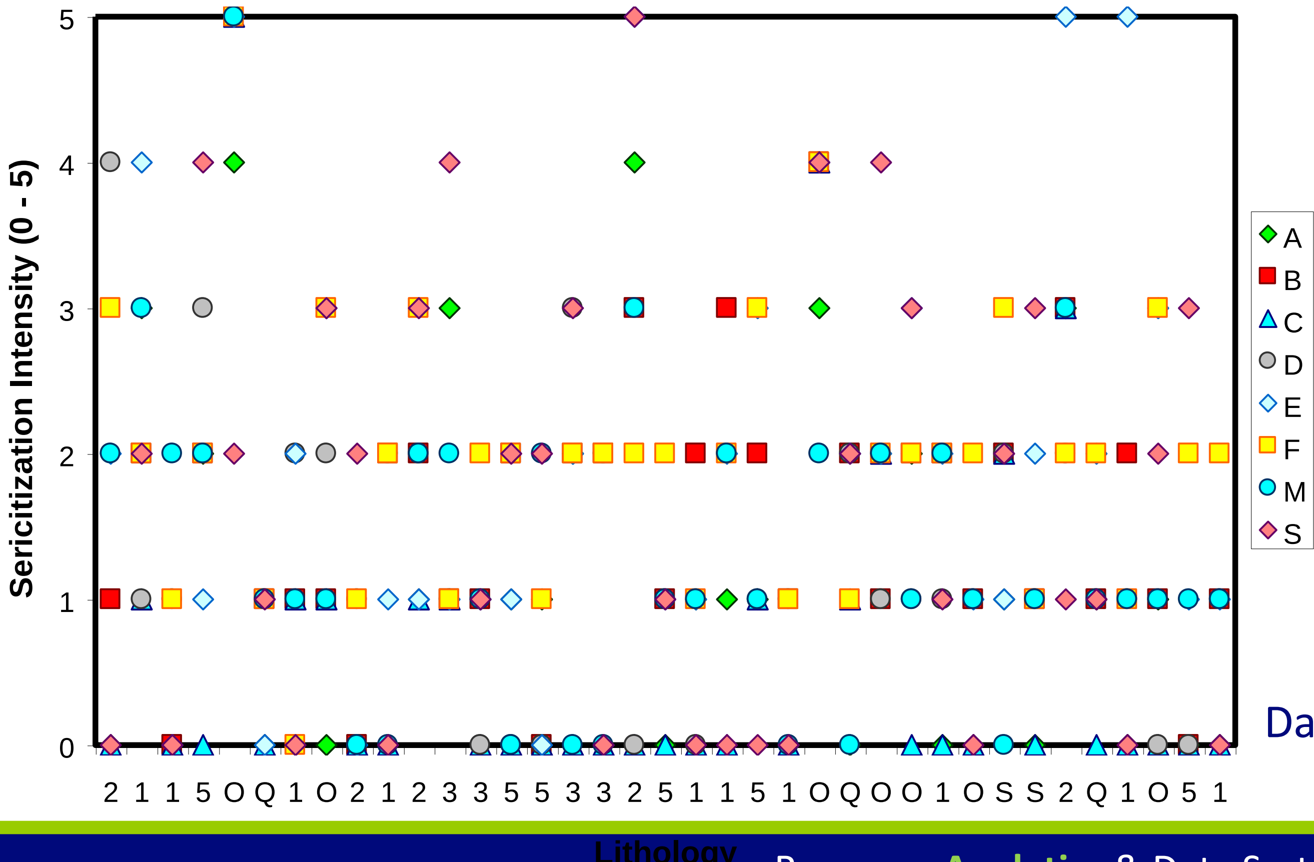
Geochemistry at the End of a Drill Rig

- Enlarging the size of the target by **quantitatively** measuring alteration and/or searching for palaeo-dispersion at the cover - host-rock uc, ie interface sampling
- With sensible use of the above, drill spacing can be enlarged to the extent that many undercover areas can be prospected with a ***sufficient degree of reliability***



Identifying and Quantifying Alteration

completely *partly* *entirely* *mostly* *pervasive* *fully* *speckled*
relatively *wholly* *partially* *kind of* *totally* *absolutely* *spotted*
extreme *none* *sort of* *severe* *dappled* *flooded* *unaltered*
intense *reminiscent of* *feeble* *strong* *incipient* *absent* *fresh*
somewhat *patchy* *moderate* *persistent* *utterly* *mottled* *weak*



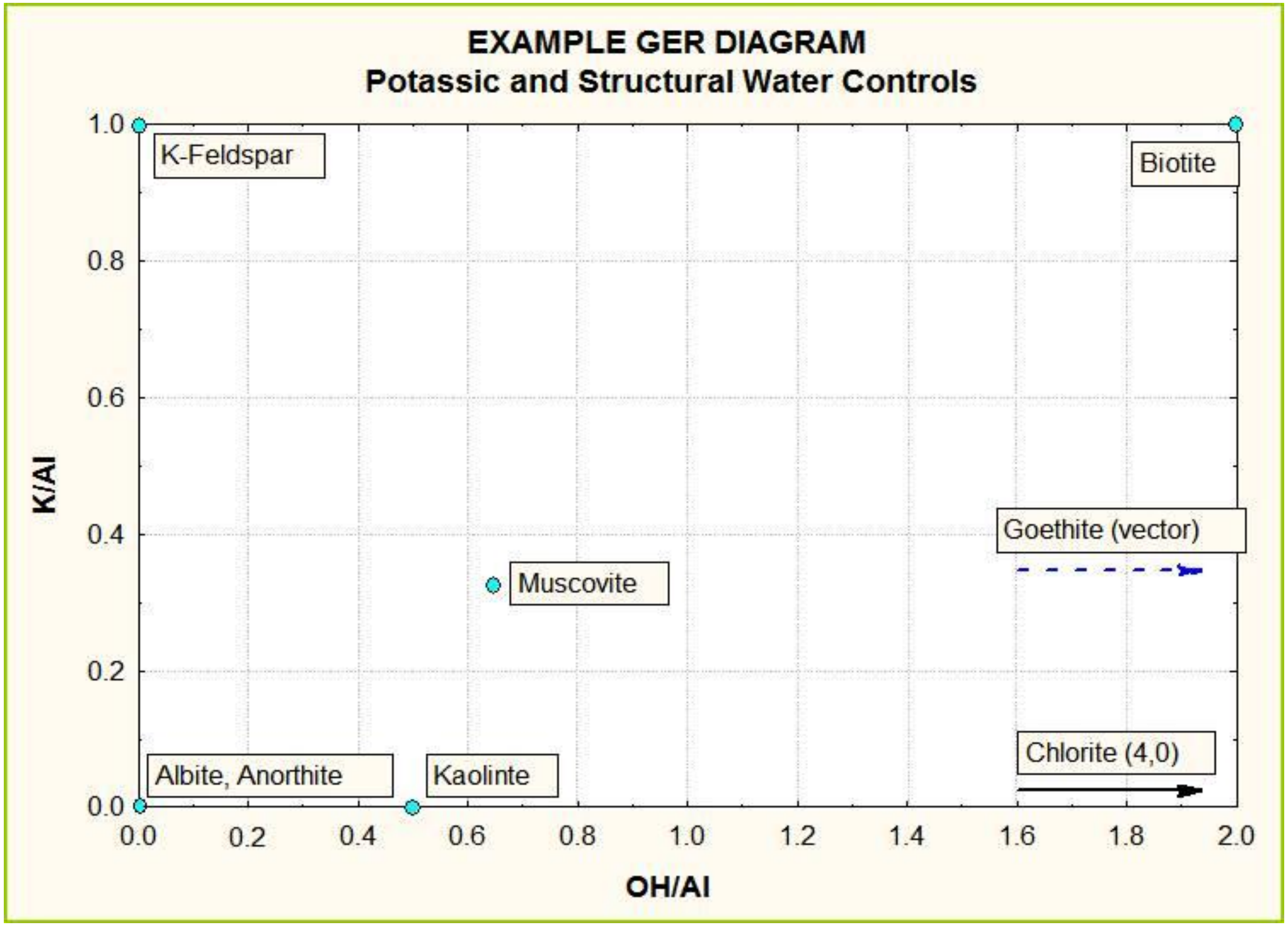
Data: Cliff Stanley

Quantifying Alteration – 2 Diagram Types

- **General Element Ratio (GER)** diagrams Do **Not** use a Conserved Element, but the denominator is chosen based on mineral stoichiometry e.g. K/Al vs. Na/Al
  - Use the position of points relative to mineral nodes on a GER diagram
  - design your plots to put minerals found in background rocks in different areas to the minerals found only in altered rocks

- **Pearce Element Ratio (PER) diagrams** use a Conserved Element as the denominator e.g. K/Ti vs Al/Ti
  - Use the slope on a PER diagram to represent minerals
  - Distance from the origin is proportional to loss/gain

Lithogeochemistry – Alteration Modeling



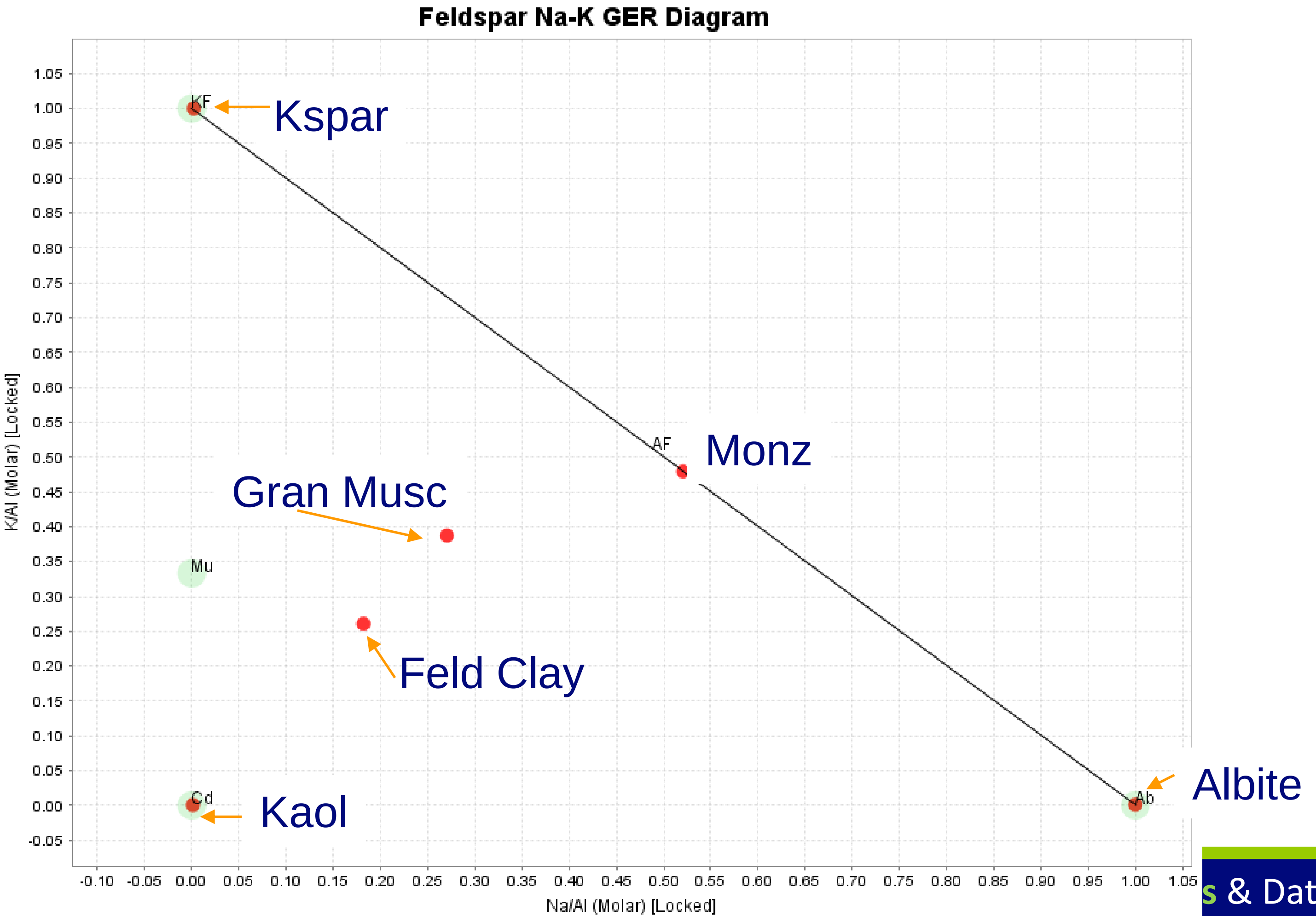
Modal Mineralogy

COMMENT	qtz	kaol	musc	kspar	albite	zircon	Ilmenite
Kspar	50			45		2.5	2.5
Monz	50			22.5	22.5	2.5	2.5
Albite	50				45	2.5	2.5
Granite Musc	35		20	20	20	2.5	2.5
Kaol	50	45				2.5	2.5
Feldspar clay	15	20	20	20	20	2.5	2.5

Chemical Composition

Rock	SiO2_%	TiO2_%	Al2O3_%	Na2O_%	K2O_%	H2O_%	ZrO2_%	Fe2O3_%
Kspar	77.8	2.3	7.8	0.0	7.2	0.0	2.9	2.3
Monz	78.6	2.3	8.1	2.6	3.6	0.0	2.9	2.3
Albite	79.4	2.3	8.4	5.1	0.0	0.0	2.9	2.3
Granite Musc	68.9	2.2	14.6	2.4	5.2	1.8	2.9	2.3
Kaol	66.5	2.2	15.5	0.0	0.0	11.0	2.8	2.2
Feldspar clay	57.4	2.2	21.4	2.4	5.2	6.7	2.8	2.2

COMMENT	qtz	kaol	musc	kspar	albite	zircon	Ilmenite
Kspar	50			45		2.5	2.5
Monz	50			22.5	22.5	2.5	2.5
Albite	50				45	2.5	2.5
Granite Musc	35		20	20	20	2.5	2.5
Kaol	50	45				2.5	2.5
Feldspar clay	15	20	20	20	20	2.5	2.5



Lithogeochemistry – Alteration Modeling

CCPI (chlorite-carbonate-pyrite index) vs AI (alteration index)

Mineral names; ep-epidote, ca-calcite, chl-chlorite, py-pyrite, il-illite, ab-albite, adl-adularia..

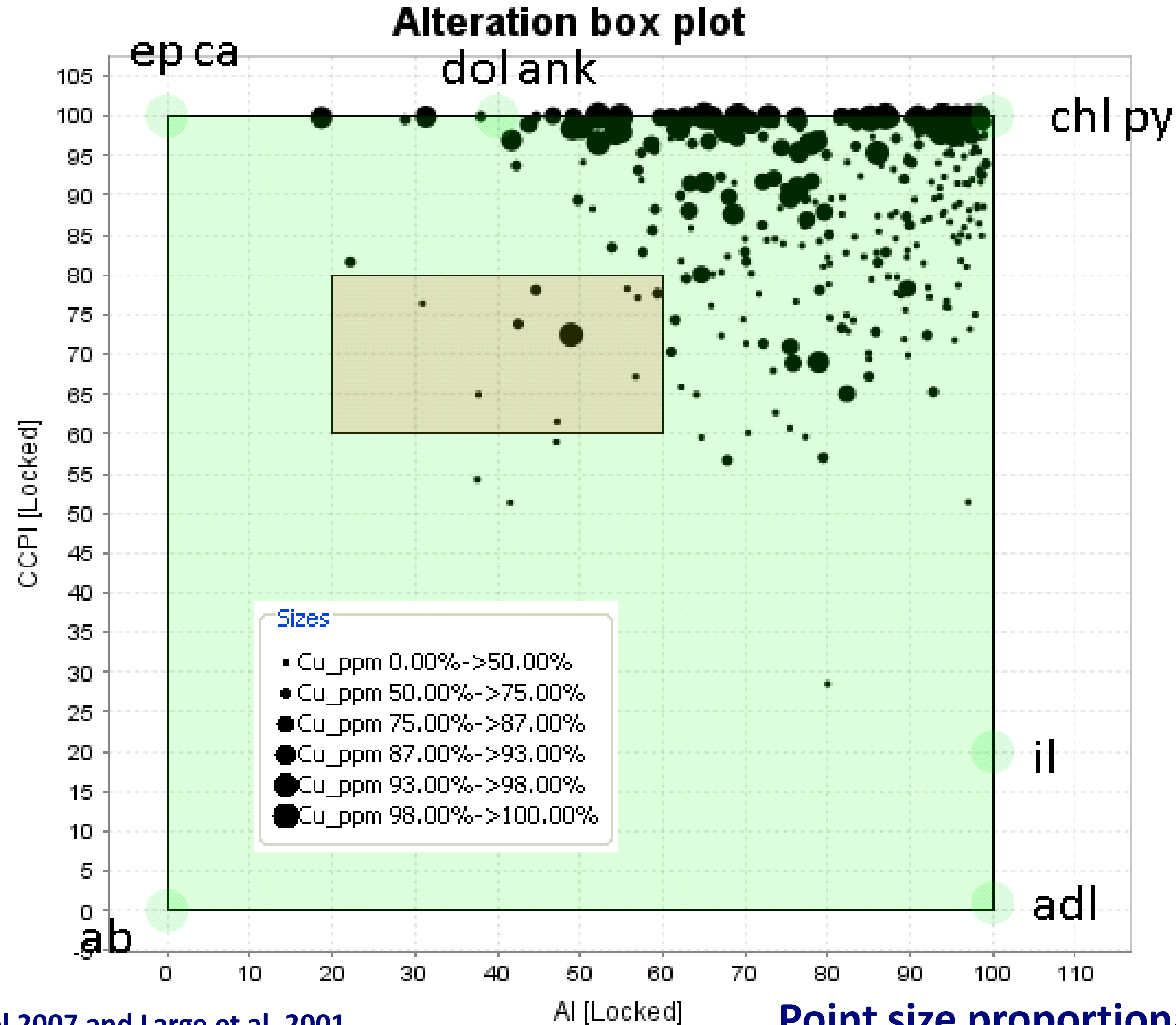
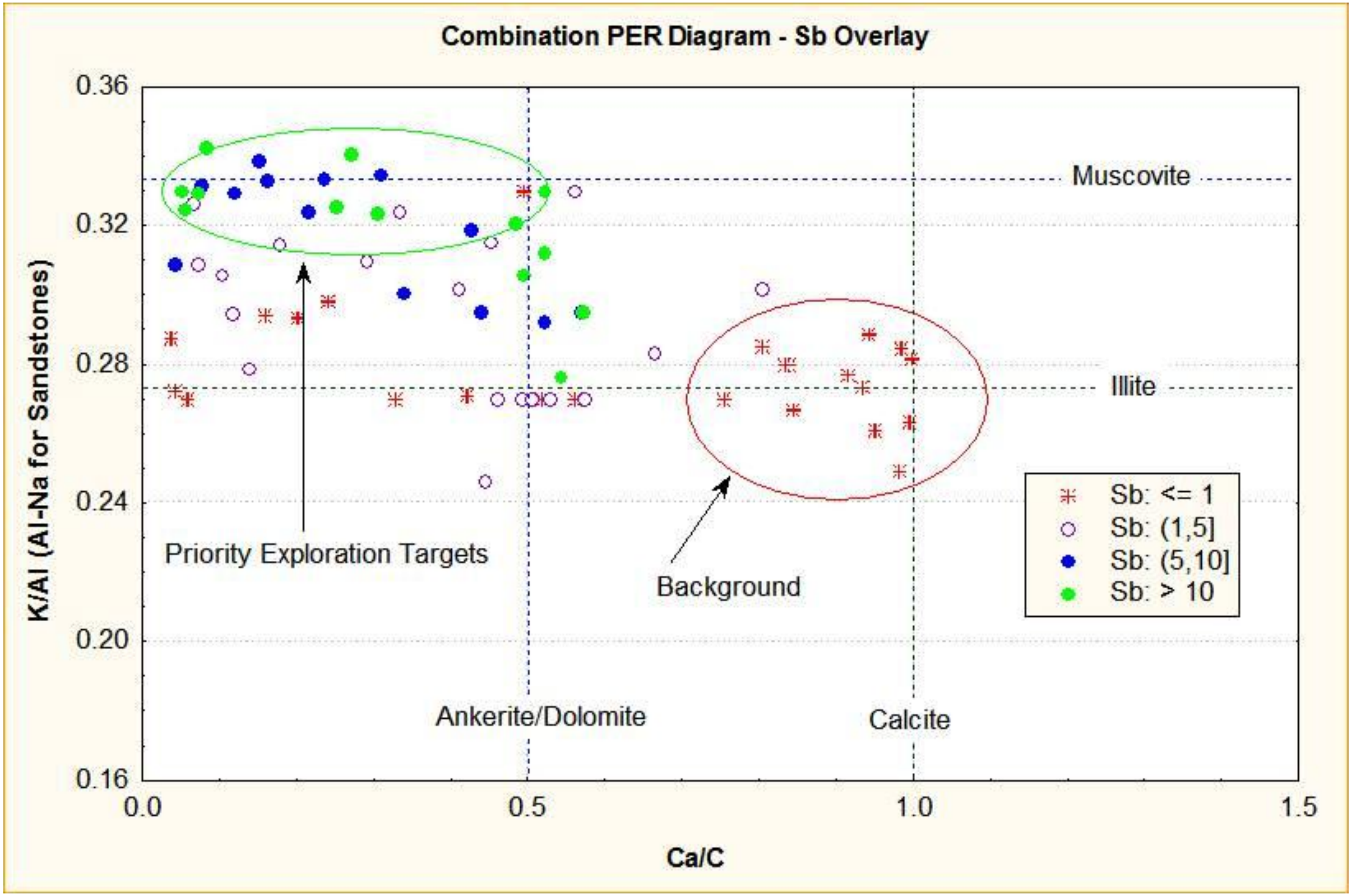


Diagram after Gemmel 2007 and Large et al. 2001

Point size proportional to Cu content.

Lithogeochemistry – Alteration Modeling



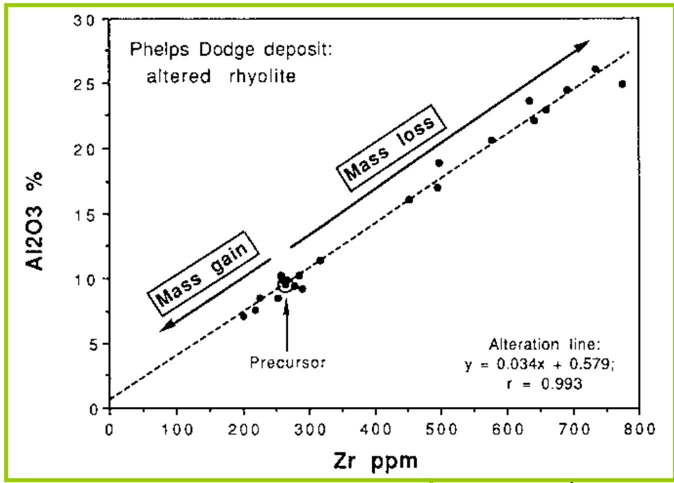
Quantifying Alteration – 2 Diagram Types

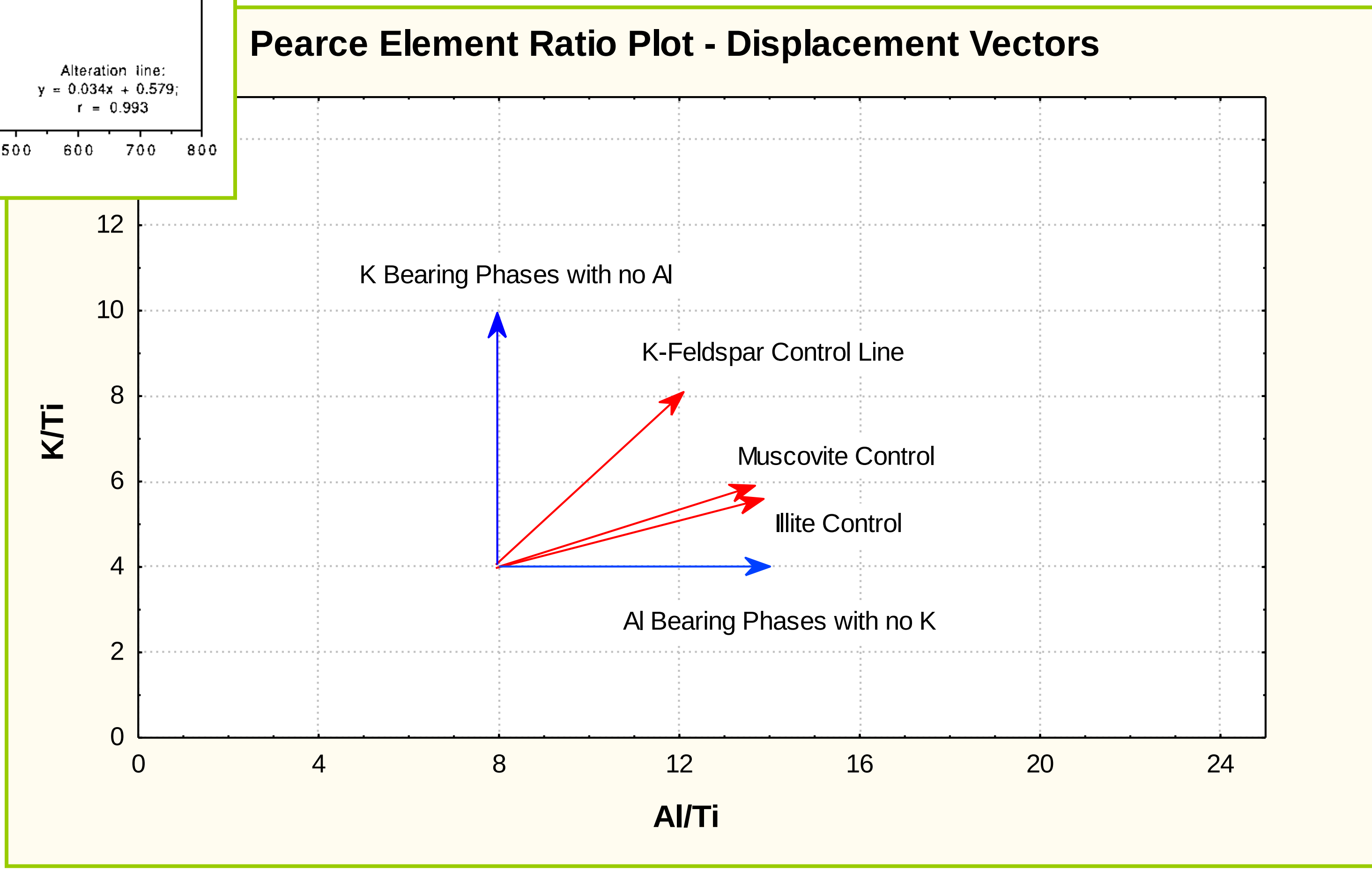
- **General Element Ratio (GER)** diagrams Do **Not** use a Conserved Element, but the denominator is chosen based on mineral stoichiometry e.g. K/Al vs. Na/Al
    - Use the position of points relative to mineral nodes on a GER diagram
    - design your plots to put minerals found in background rocks in different areas to the minerals found only in altered rocks

- **Pearce Element Ratio (PER) diagrams** use a Conserved Element as the denominator e.g. K/Ti vs Al/Ti
    - Use the slope on a PER diagram to represent minerals
    - Distance from the origin is proportional to loss/gain

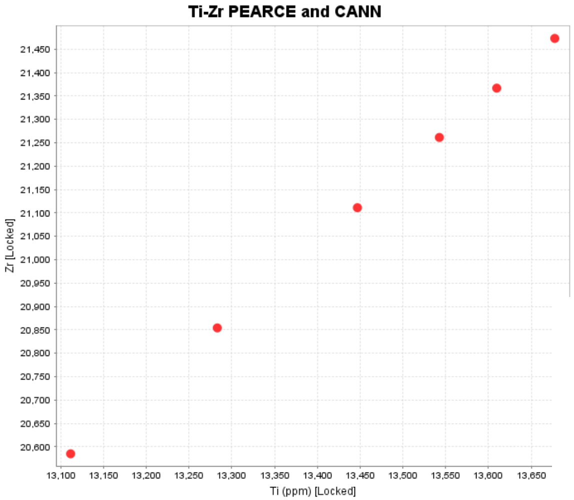
Lithogeochemistry – Alteration Modelling

- Separate chemical variations due to fractionation from those due to alteration
- Avoid closure

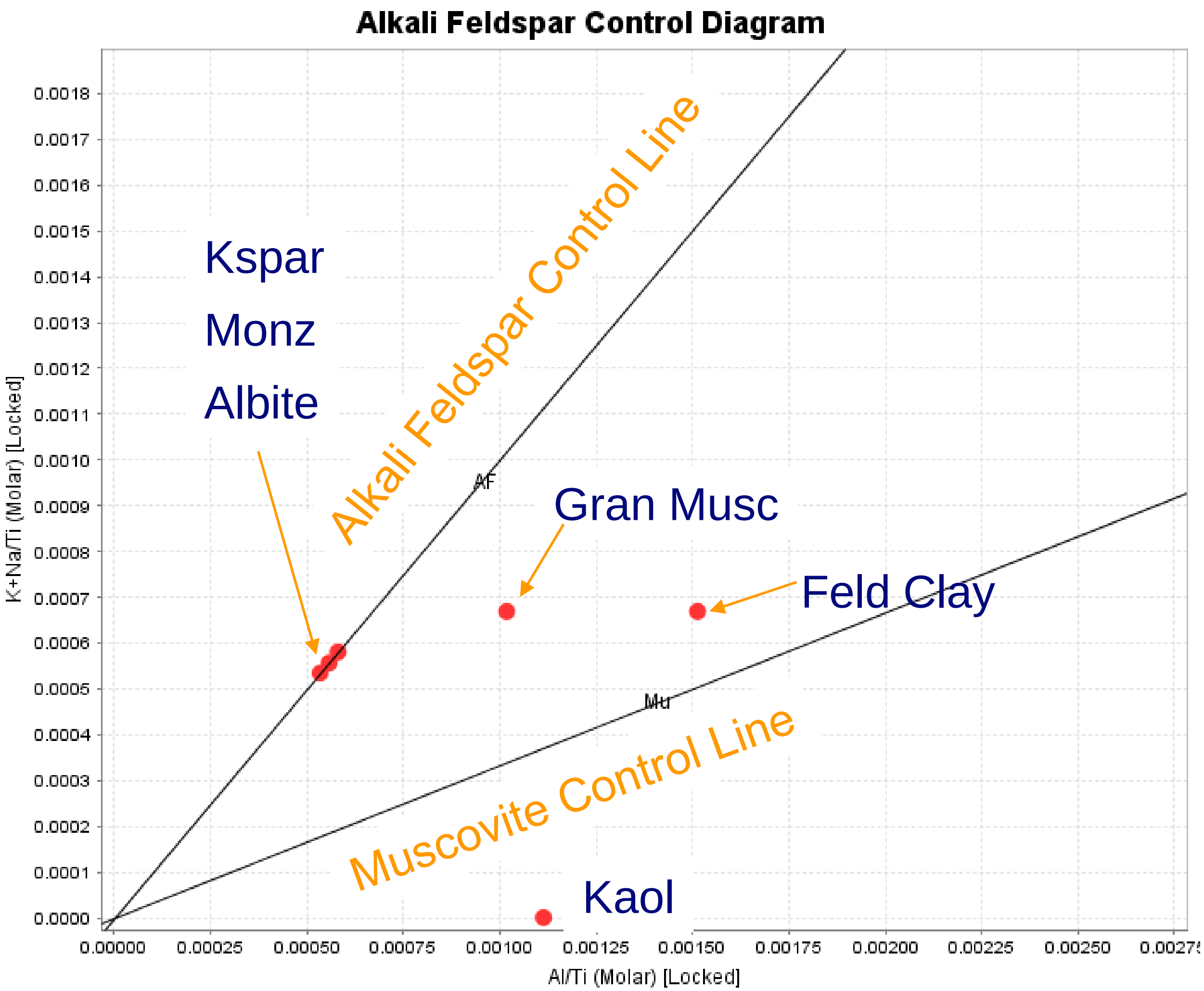




PER Diagram

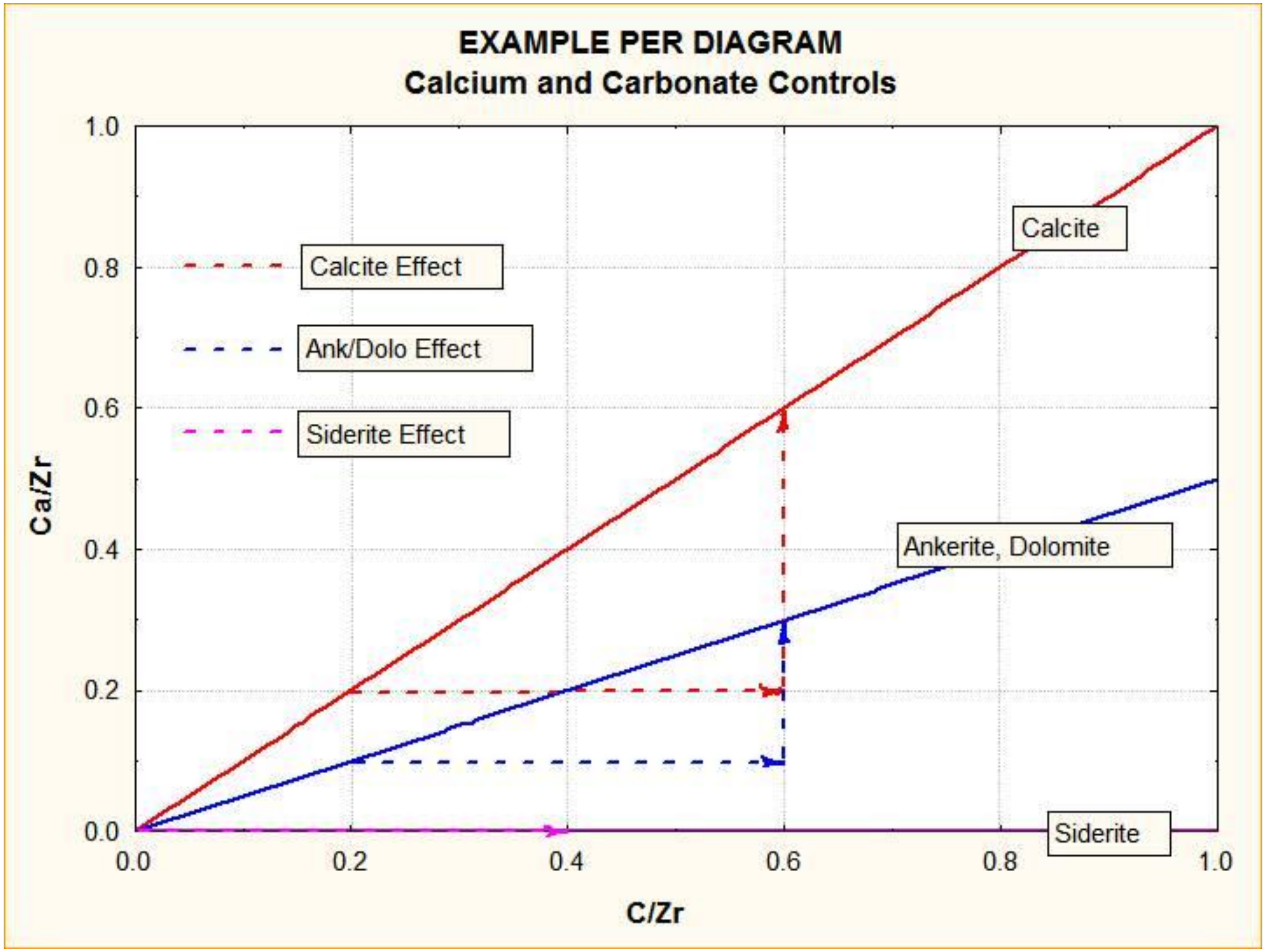


Ti-Zr PEARCE and CANN
Zr [Locked]
Ti (ppm) [Locked]

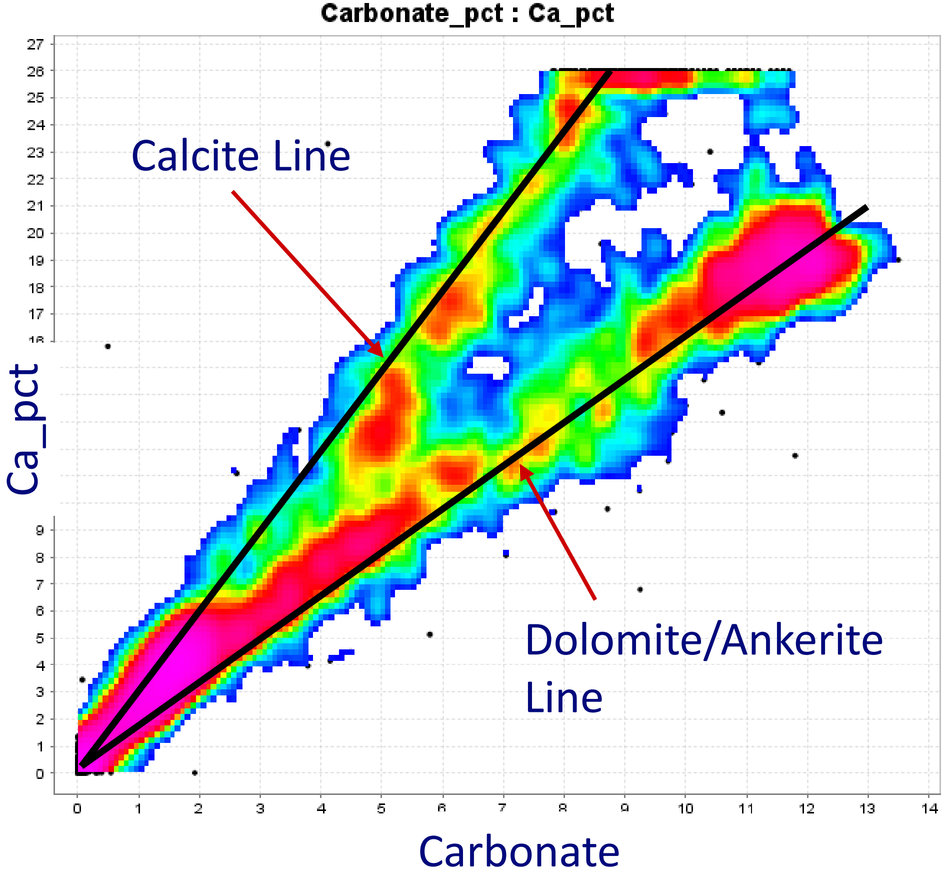


Alkali Feldspar Control Diagram
K+Na/Ti (Molar) [Locked]
Al/Ti (Molar) [Locked]
Kspar
Monz
Albite
Alkali Feldspar Control Line
AF
Gran Musc
Feld Clay
Mu
Muscovite Control Line
Kaol

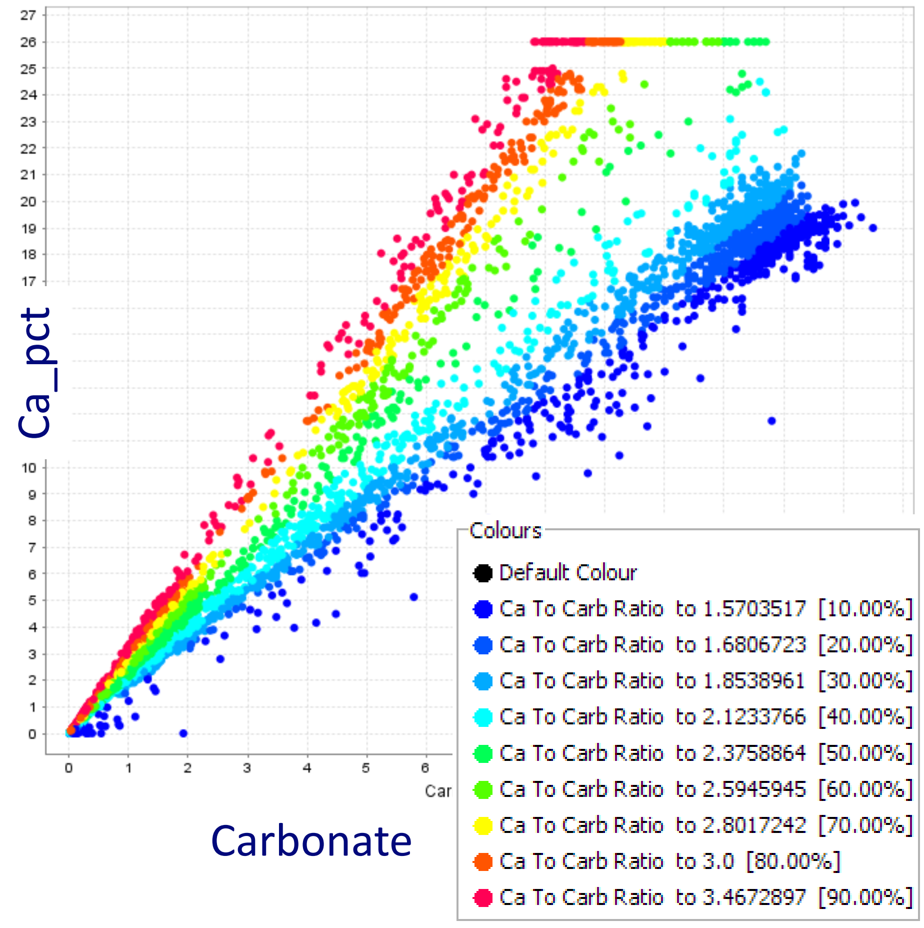
Lithogeochemistry – Carbonate Alteration



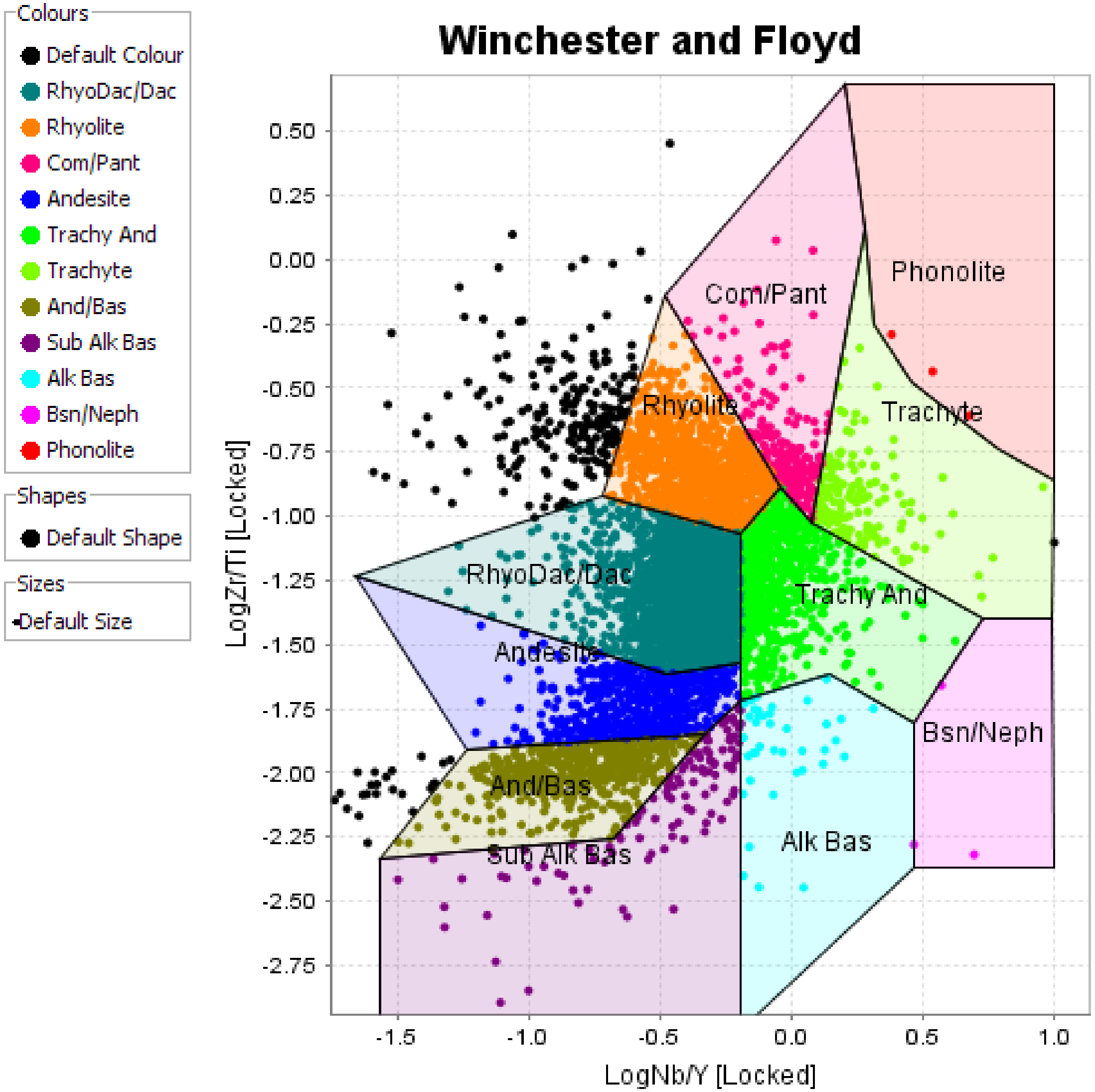
Lithogeochemistry – Carbonate Alteration

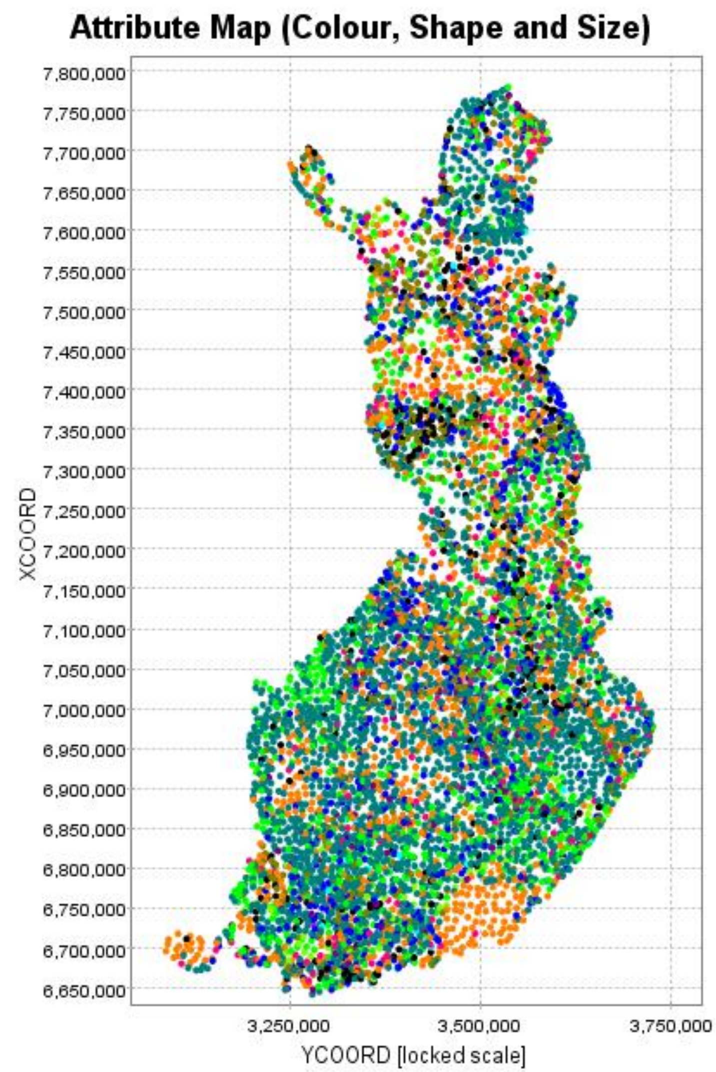


Ca/C Ratio Thematic Colouring

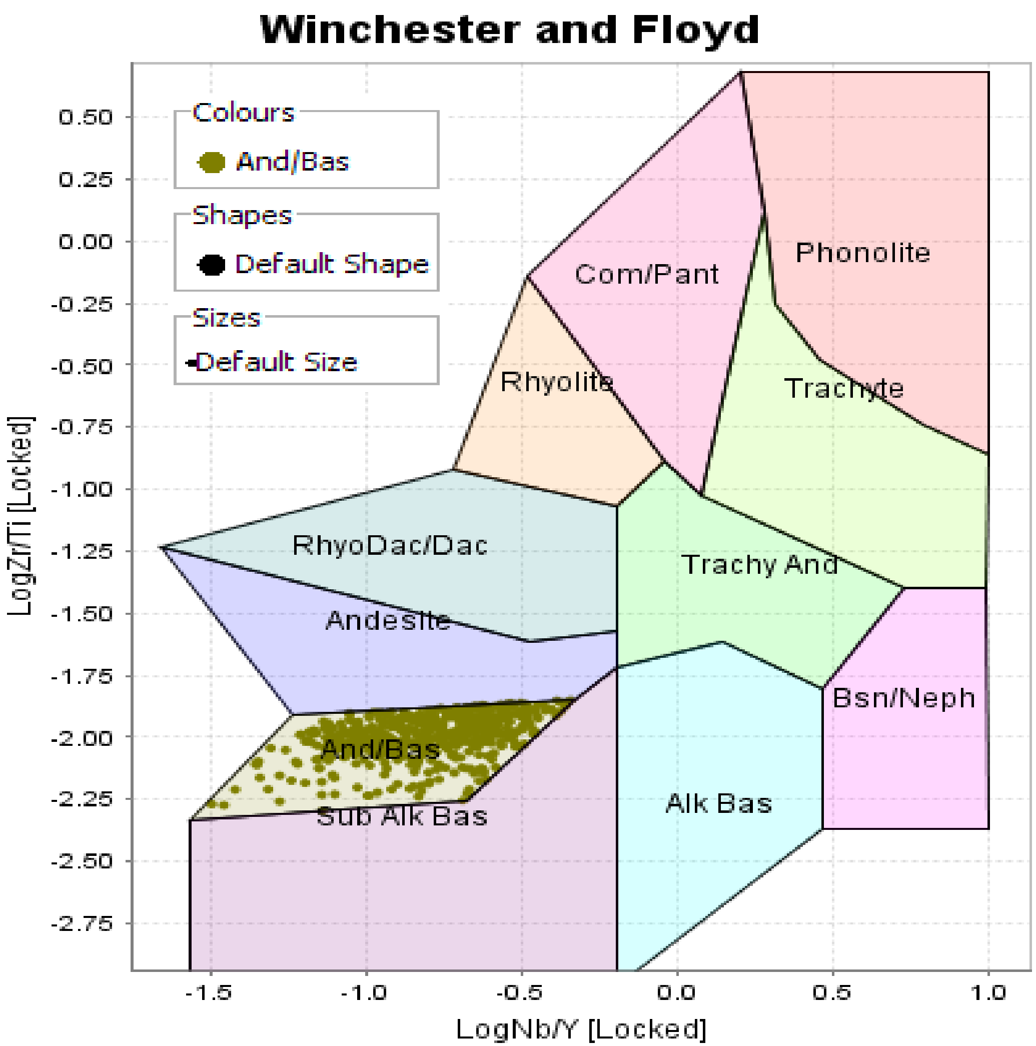


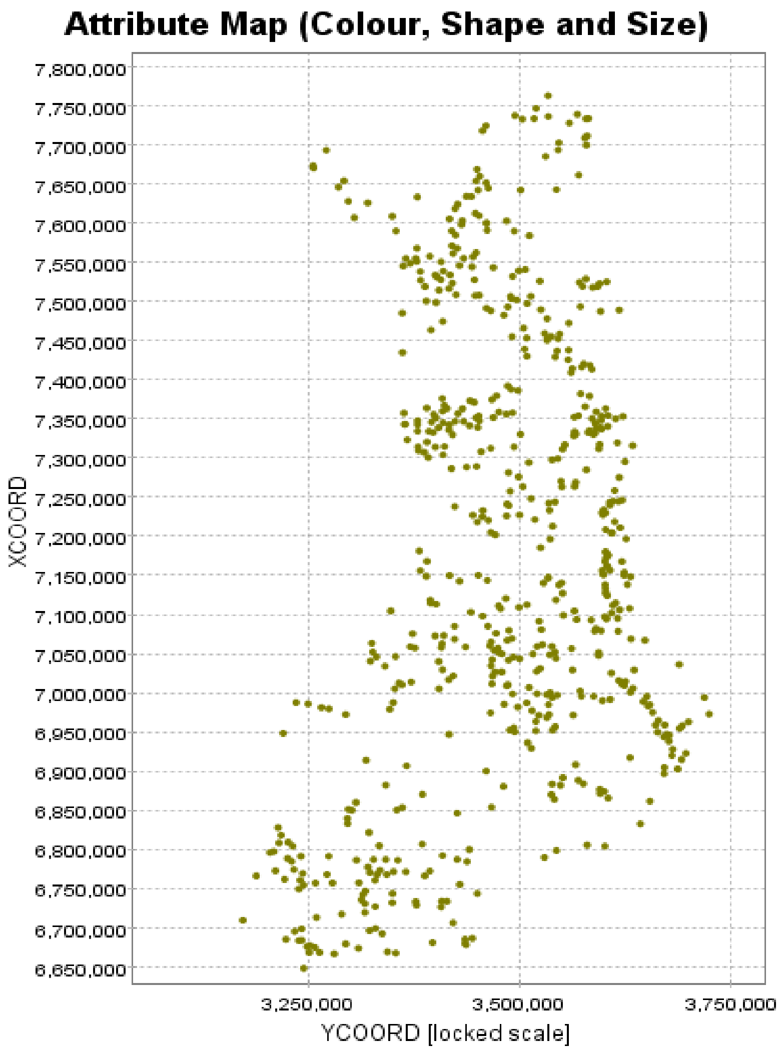
Integrated Workflow Example



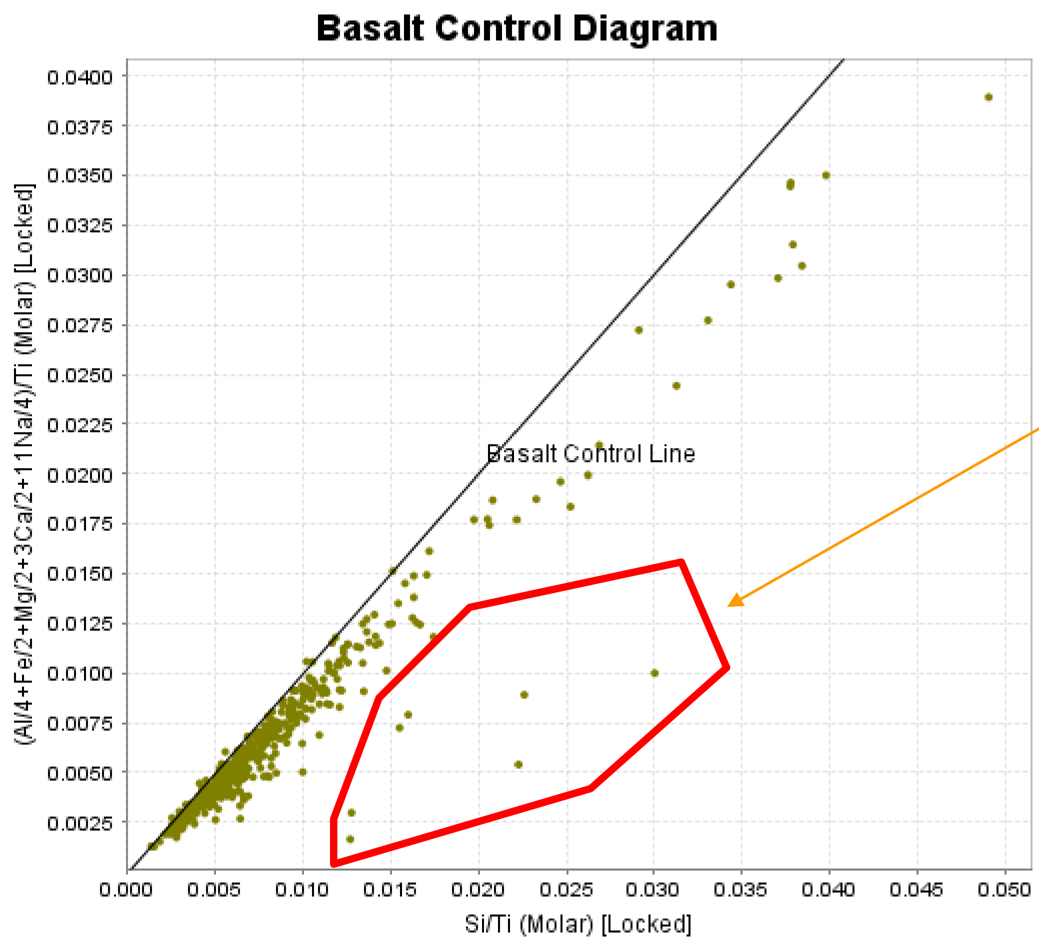


Complex Workflow Enabled Interpretation



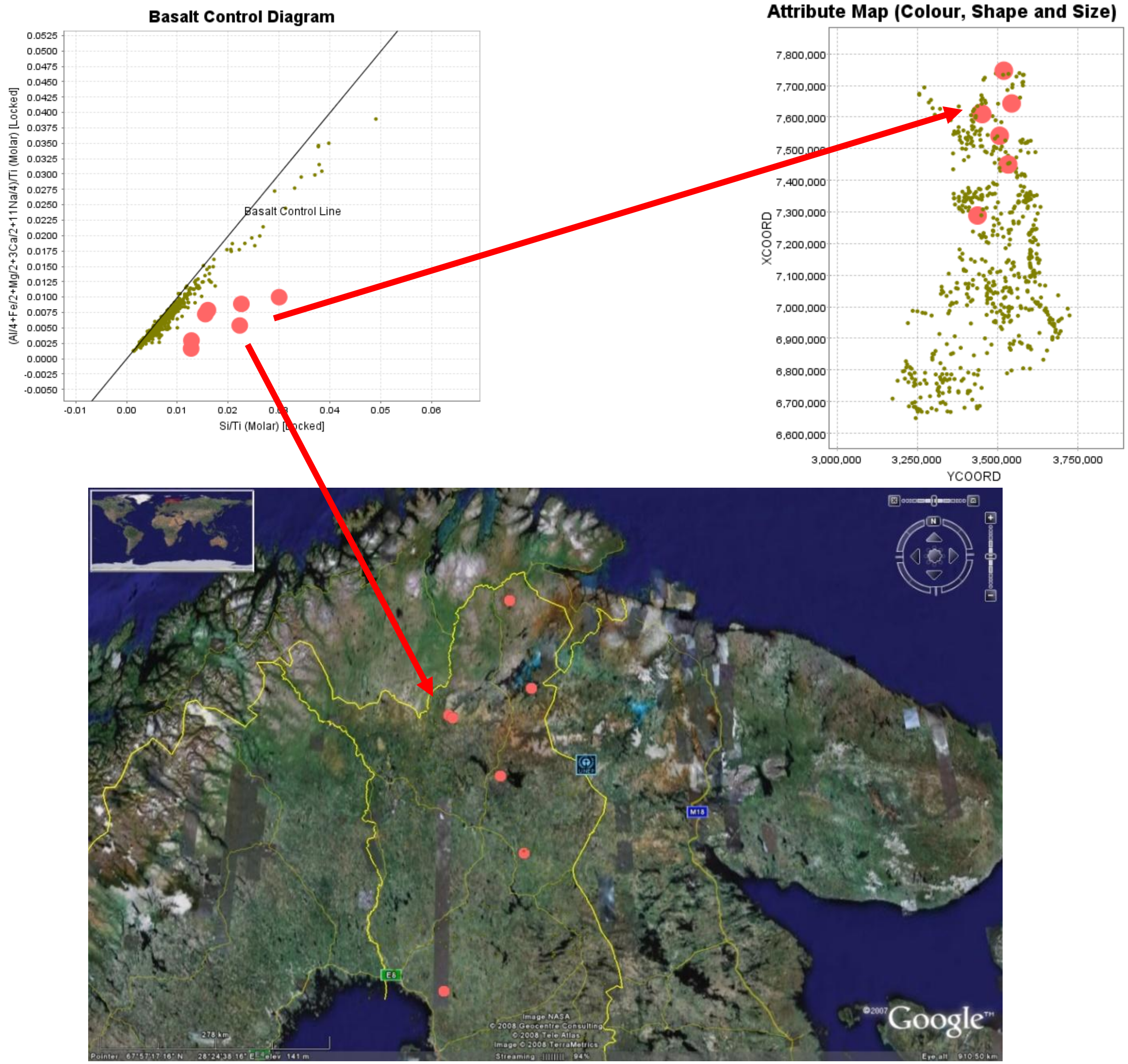


Complex Workflow Enabled Interpretation



Altered basalts

Complex Workflow Enabled Interpretation



Metallurgical Applications

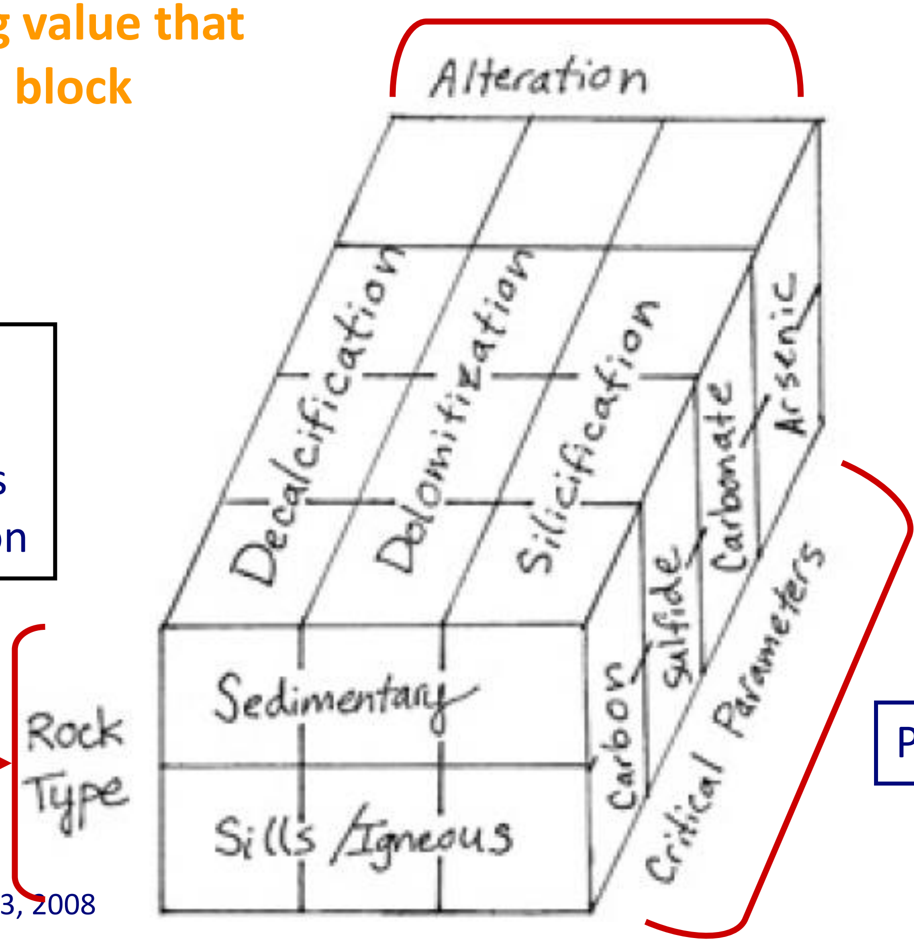
Geochemistry – Geometallurgy

Carlin Style Mineralisation

Quantitative alteration mapping from assay data

Each block is assigned a predictive processing value that can be input into the block model

Whole rock chemistry
Immobile traces
Classification diagrams
Consistent classification



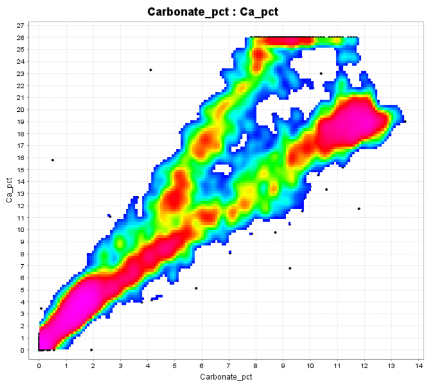
Phase specific assaying

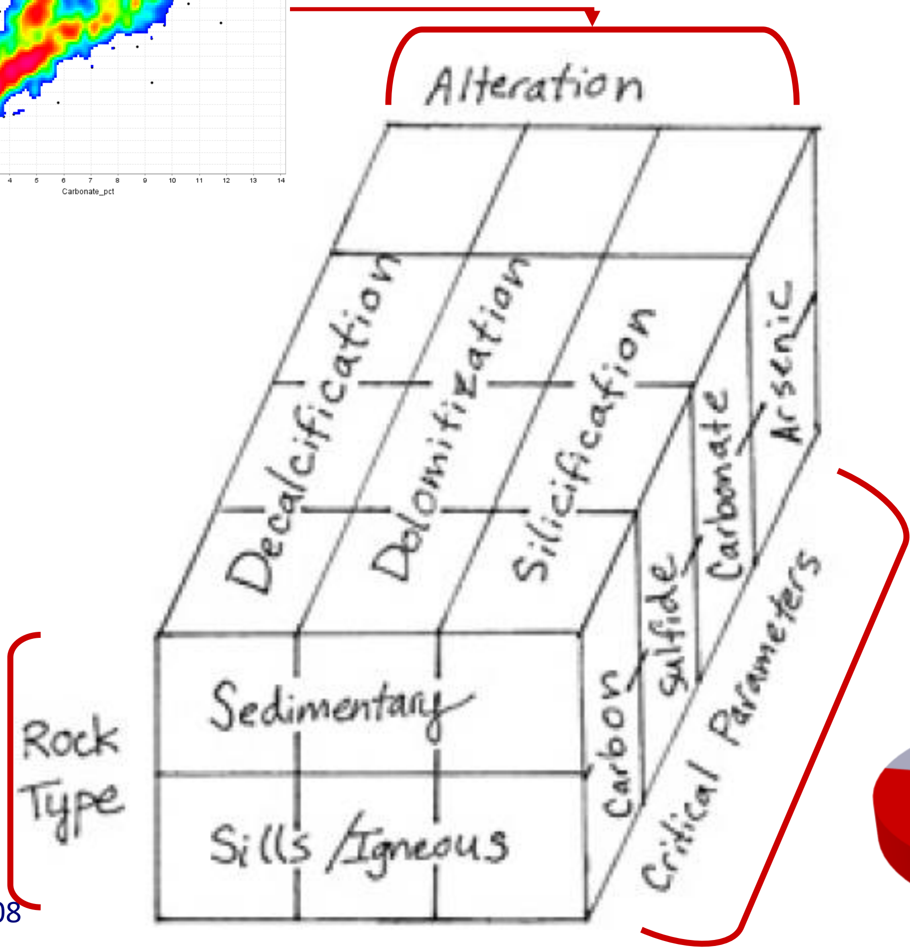
Diagram from: SEG Newsletter, No. 73, 2008

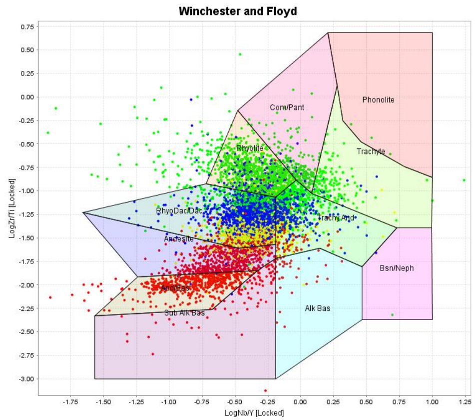
Getting the Geo into Geomet

Karin O. Hoal (SEG 1998 F) Director, Advanced Mineralogy Research Center and Research Professor, Department of Geology and Geological Engineering, Colorado School of Mines, Golden, Colorado USA 80401; e-mail, khoal@mines.edu

Geochemistry - Geometallury







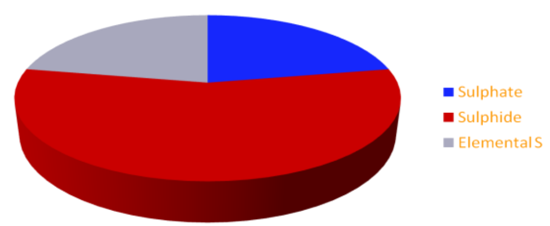
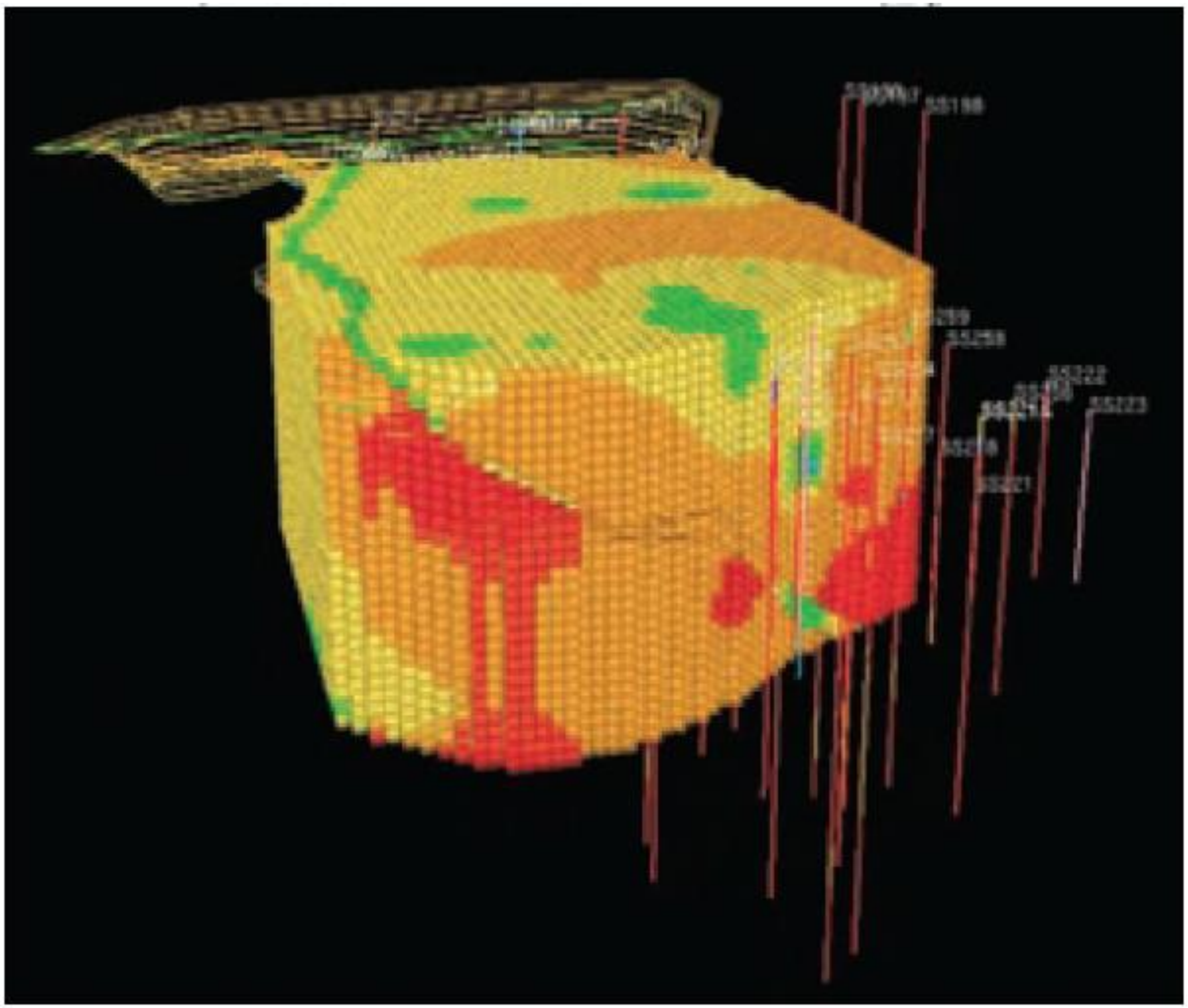


Diagram: SEG Newsletter, No. 73, 2008

Getting the Geo into Geomet

Karin O. Hoal (SEG 1998 F) Director, Advanced Mineralogy Research Center and Research Professor, Department of Geology and Geological Engineering, Colorado School of Mines, Golden, Colorado USA 80401; e-mail, khoal@mines.edu



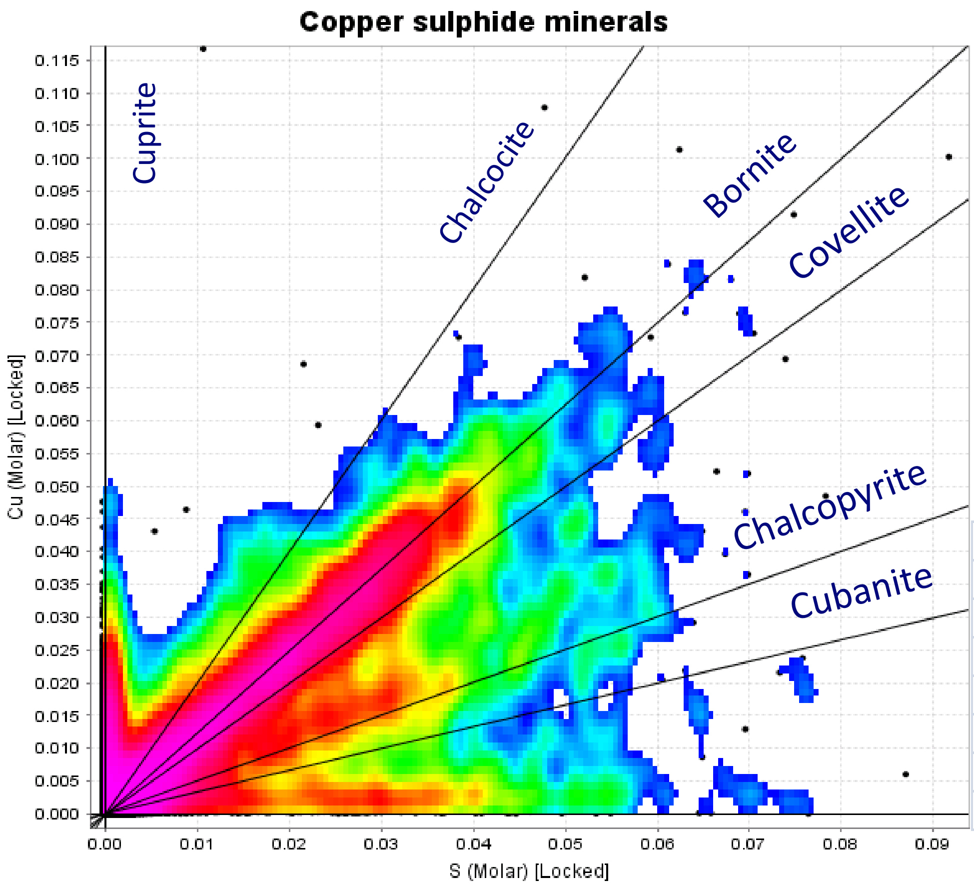
Bye*, A (2007) The application of multi-parametic block models to the mining process. The Journal of The Southern African Institute of Mining and Metallurgy, 107

Some Important Metallurgical Parameters Measurable by Assaying at the Sample Scale

- Refractoriness (e.g. CN- leachable to non-leachable metal)
- Preg robbing (e.g. activated carbon)
- Mineralogical variability (e.g. cassiterite vs. stannite)
- Clay content (affects material handling properties)
- Acid-forming & acid-consuming minerals (e.g. carbonates)
- Cyanicides (e.g. cyanide consumers such as Cu, Fe, Zn, Hg)
- Oxygen consumers (e.g. sulphide phases)
- Deleterious or toxic elements (e.g. P distribution in iron ore)
- Coarse Au distribution (nugget effect)
- Sulphate producers (e.g. oxidation of sulphides)

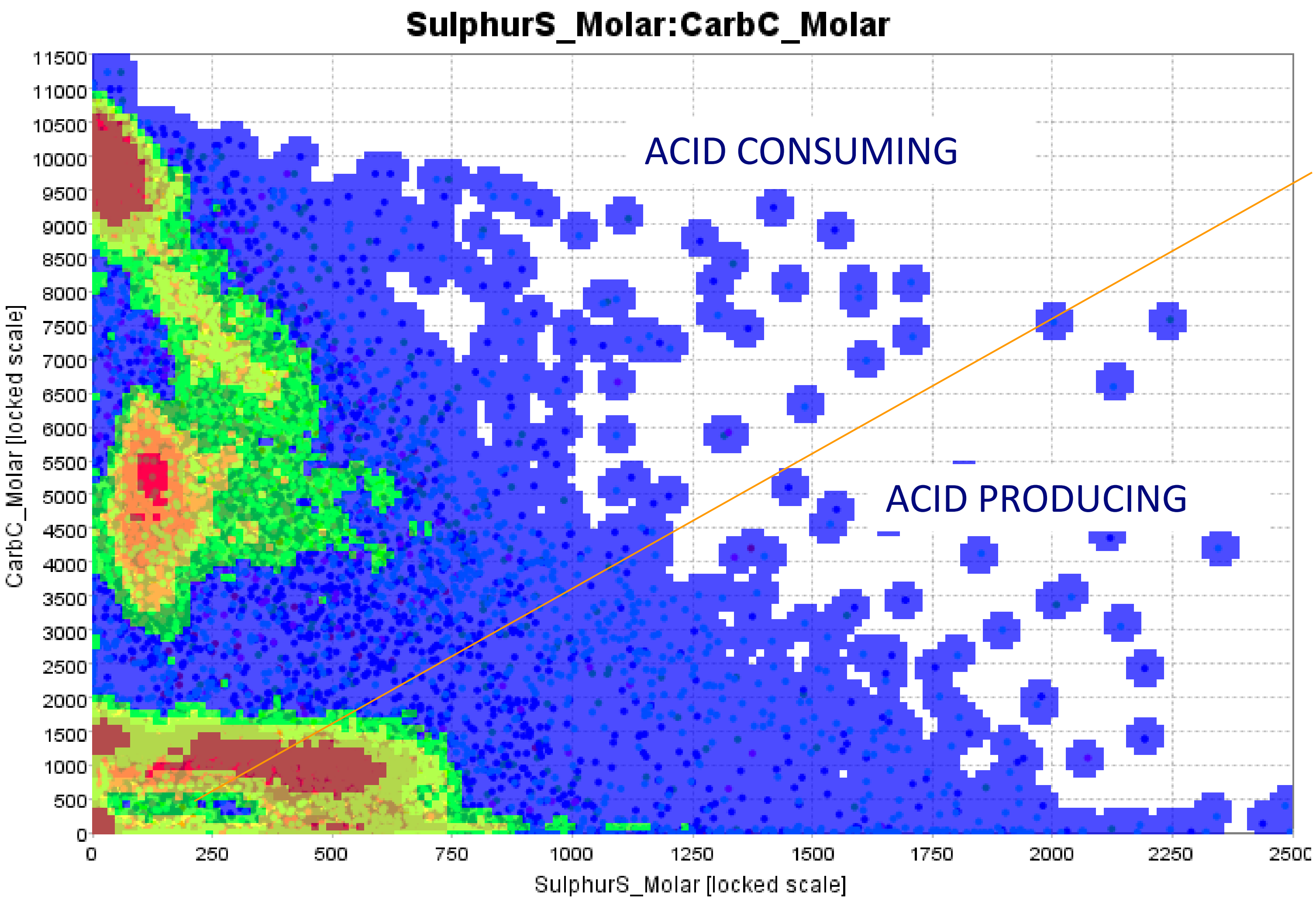
Metallurgical Applications - Molar Ratio Diagrams

- Copper assay data plotted on a molar Cu vs S diagram. Molar ratios of Cu to S and their 'slopes' for the diagram are provided in the table. The plotted data are shown as coloured point density regions.

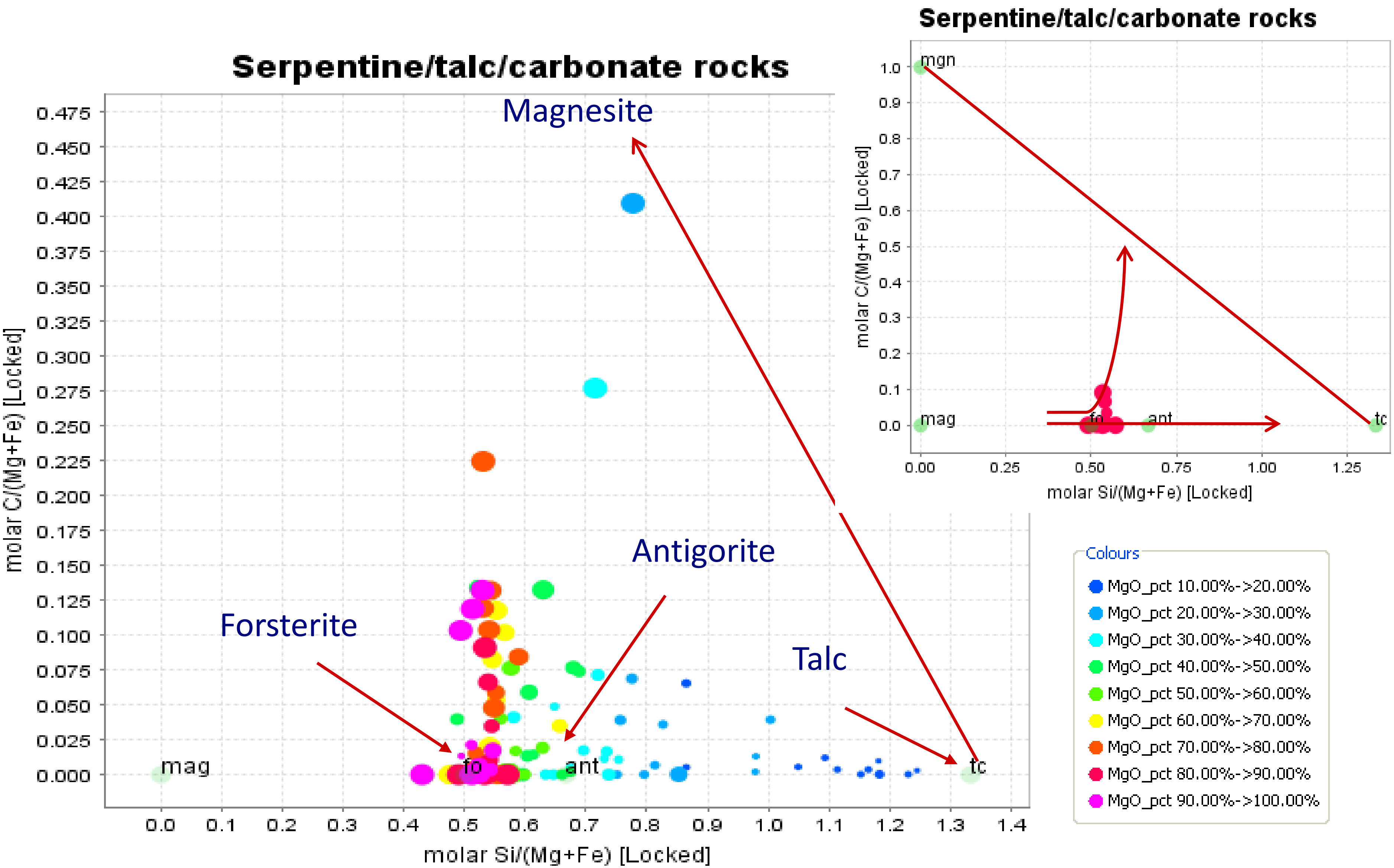


Copper minerals

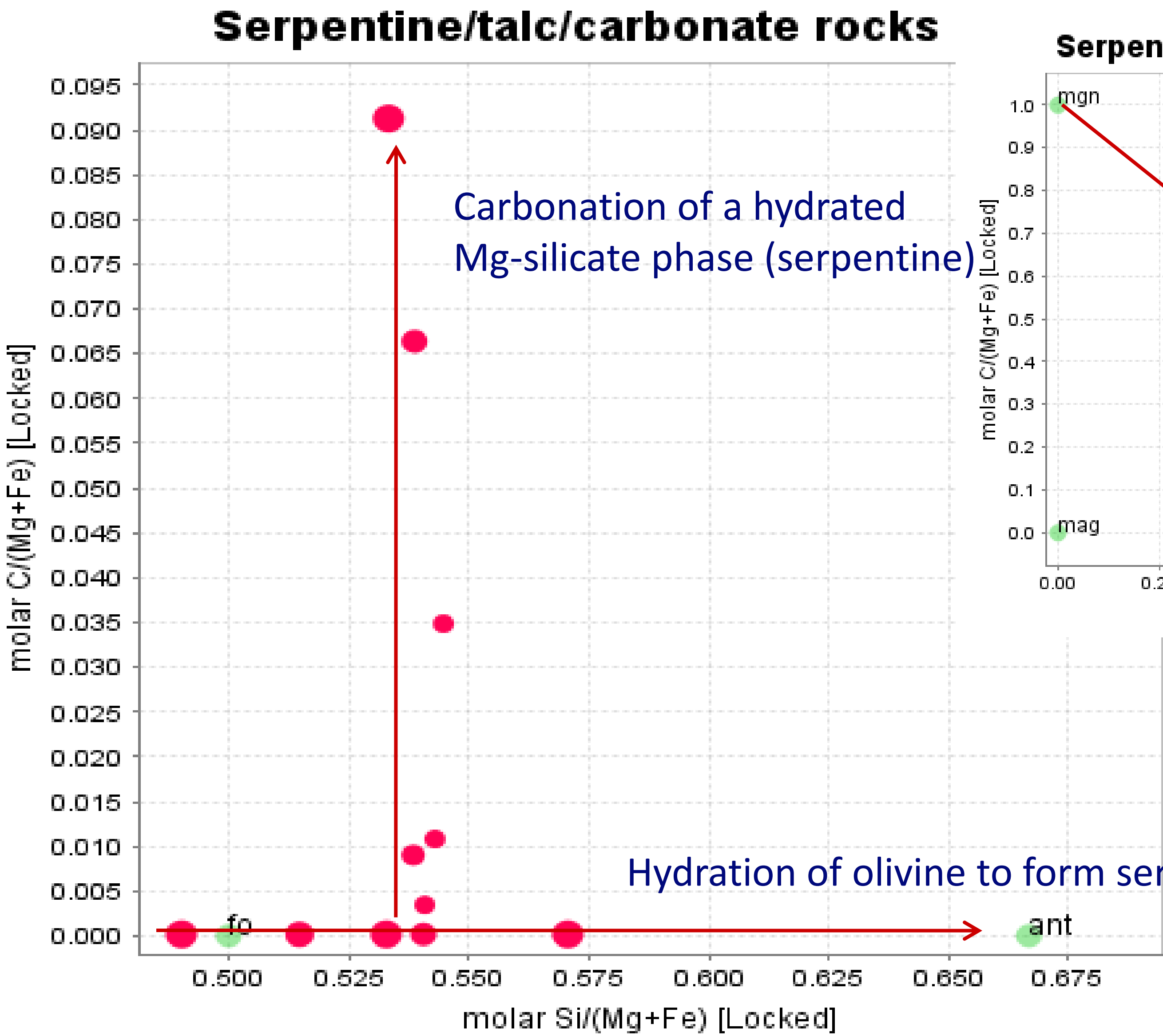
Mineral	Formula	molar Cu:S	Slope
Cuprite	CuO	1:0	inf
Chalcocite	Cu2S	2:1	2
Bornite	Cu5FeS4	5:4	1.25
Covellite	CuS	1:1	1
Chalcopyrite	CuFeS2	1:2	0.5
Cubanite	CuFe2S3	1:3	0.33

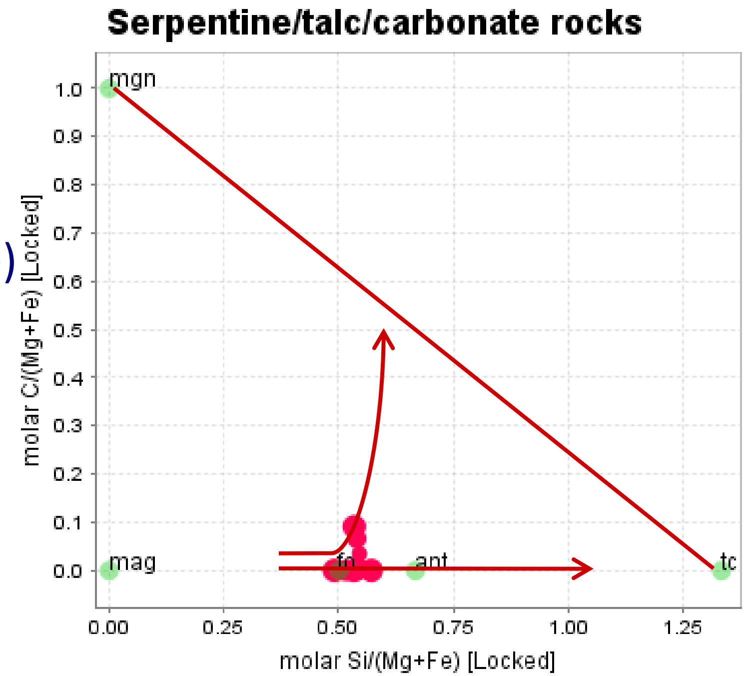

SulphurS_Molar:CarbC_Molar
ACID CONSUMING
ACID PRODUCING
CarbC_Molar [locked scale]
SulphurS_Molar [locked scale]
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
10500
11000
11500
0
250
500
750
1000
1250
1500
1750
2000
2250
2500

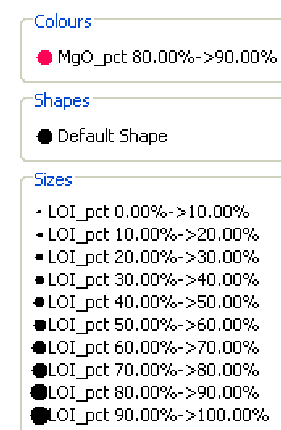
Metallurgical Applications – Alteration of Ultramafic Rocks



Alteration of ultramafic rocks

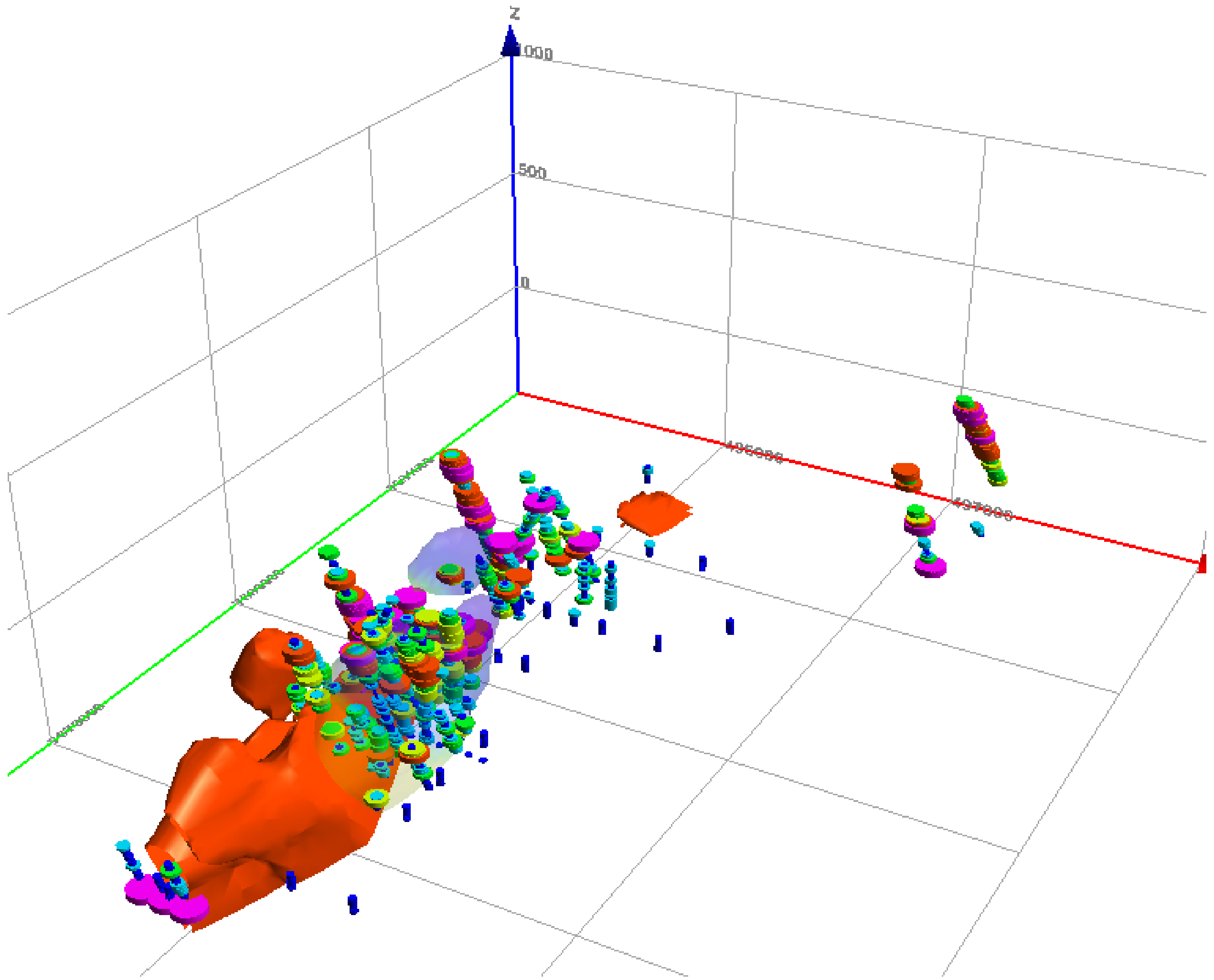






3D Integration

Magnetic model isosurface colour modulated by gravity



CONCLUSIONS

- Quantitative geological information is easily extracted from assay data
- Applying existing methods in new areas yields useful results
- If you have the data – use it
- If you don't have the assay data– it may be worth getting
- Cost is trivial cf that of obtaining the samples