Exploration Geochemistry – Basic Principles & Concepts

Soil Geochemistry

Dr. David Lawie
ioGlobal
www.ioglobal.net

Outline

Considerations prior to starting

Scale of sampling

Soils and Soil Development

Sites for Hosting Anomalies Within Soils

Sampling Protocols

Methods of Analysis & Challenges

Anomaly Formation

Some Final Comments

Why/Purpose?

Direct detection of mineralisation via its weathered residues (ore components, alteration products and dispersions thereof)

Geological mapping and identifying areas of endowment

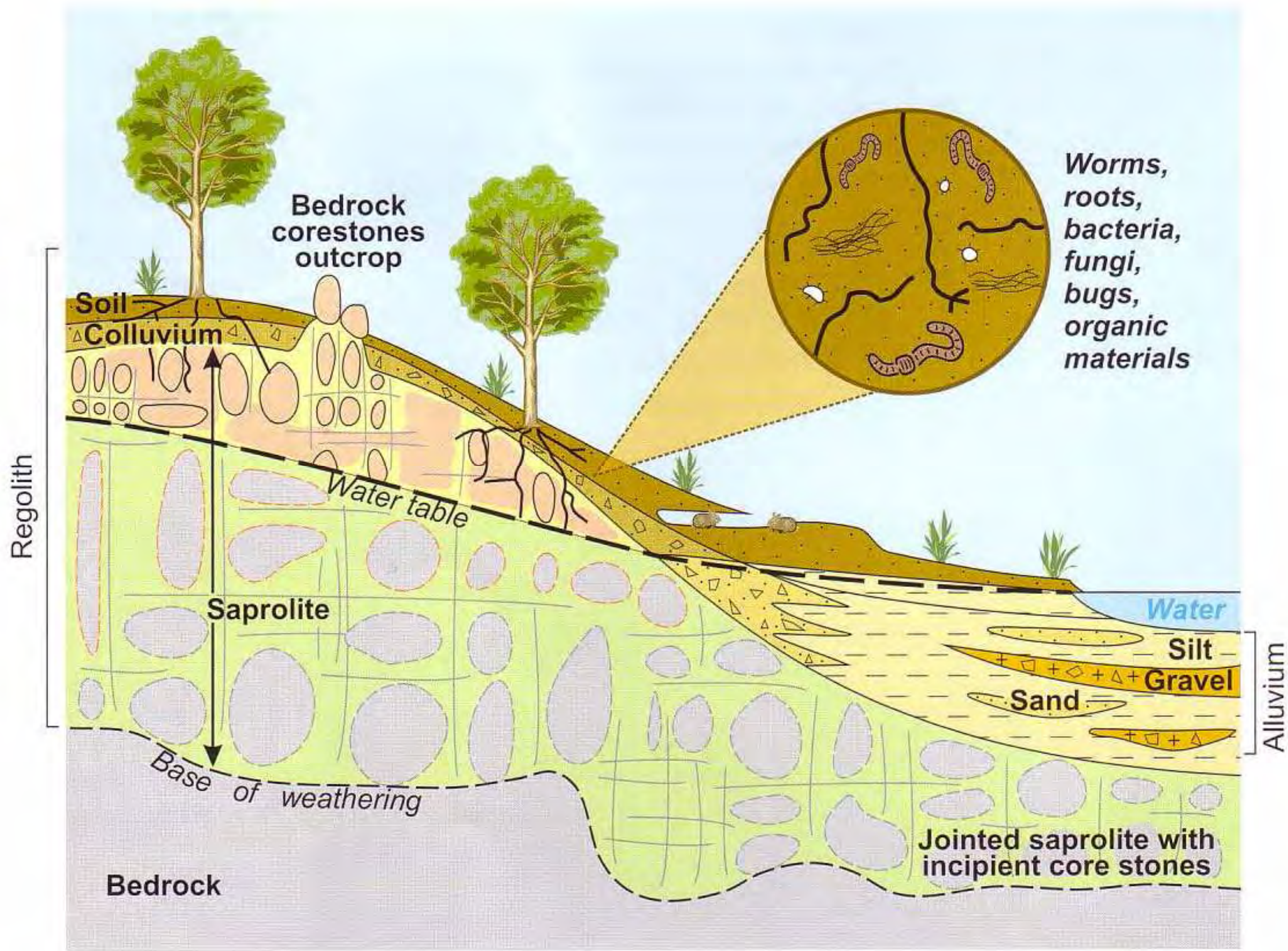
Can be applied at a number of scales especially for the latter purpose

Availability of modern, high quality multi-element data has expanded the scope of the application soil sampling programs

Soil

What is regolith?

Regolith is the blanket of soil, sediment and weathered rock that covers the earth's surface.



From CRC-LEME newsletter

Consideration Prior To Embarking on a Soil Survey

What elements to analyse for (target, pathfinder, regolith control)

Extraction and instrumental finish

Nature of the soil substrate – residual/transported

Soil profile development, what depth or horizon to sample

Local variations due to topography, drainage, parent material

Optimum size of sample and whether to sieve or not

Spatial configuration of the sampling (square or offset grid, tight spacing along widely spaced lines)

QC – Need to monitor the accuracy and representivity of data

Sampling Configuration

Square grids preferred

Offset grid may be better but logistically more difficult

Grid dimensions of 10 x 25 metres may be necessary for small targets, eg shear-hosted gold, VMHS, 200 x 200 for porphyry Cu, and larger spacings in semi-regional and regional surveys

If a square grid is not used, traverse lines should be at right angles to the strike of the target (if known)

Target zones (eg, identified via geophysics) should be intersected by at least 2 lines

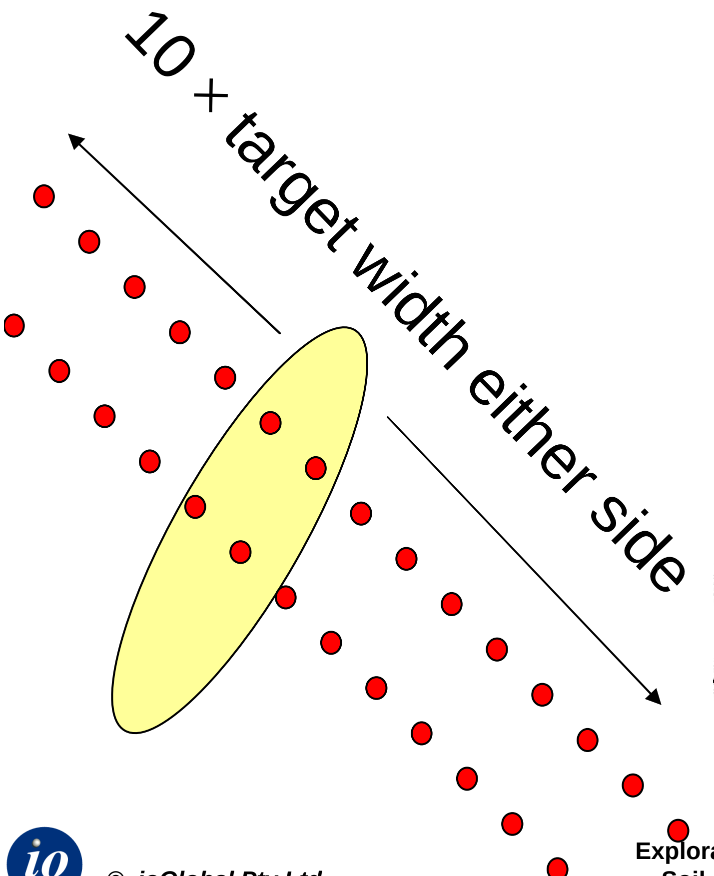
Sample spacing along the line should be such that at least 2 samples fall within the 'zone'.

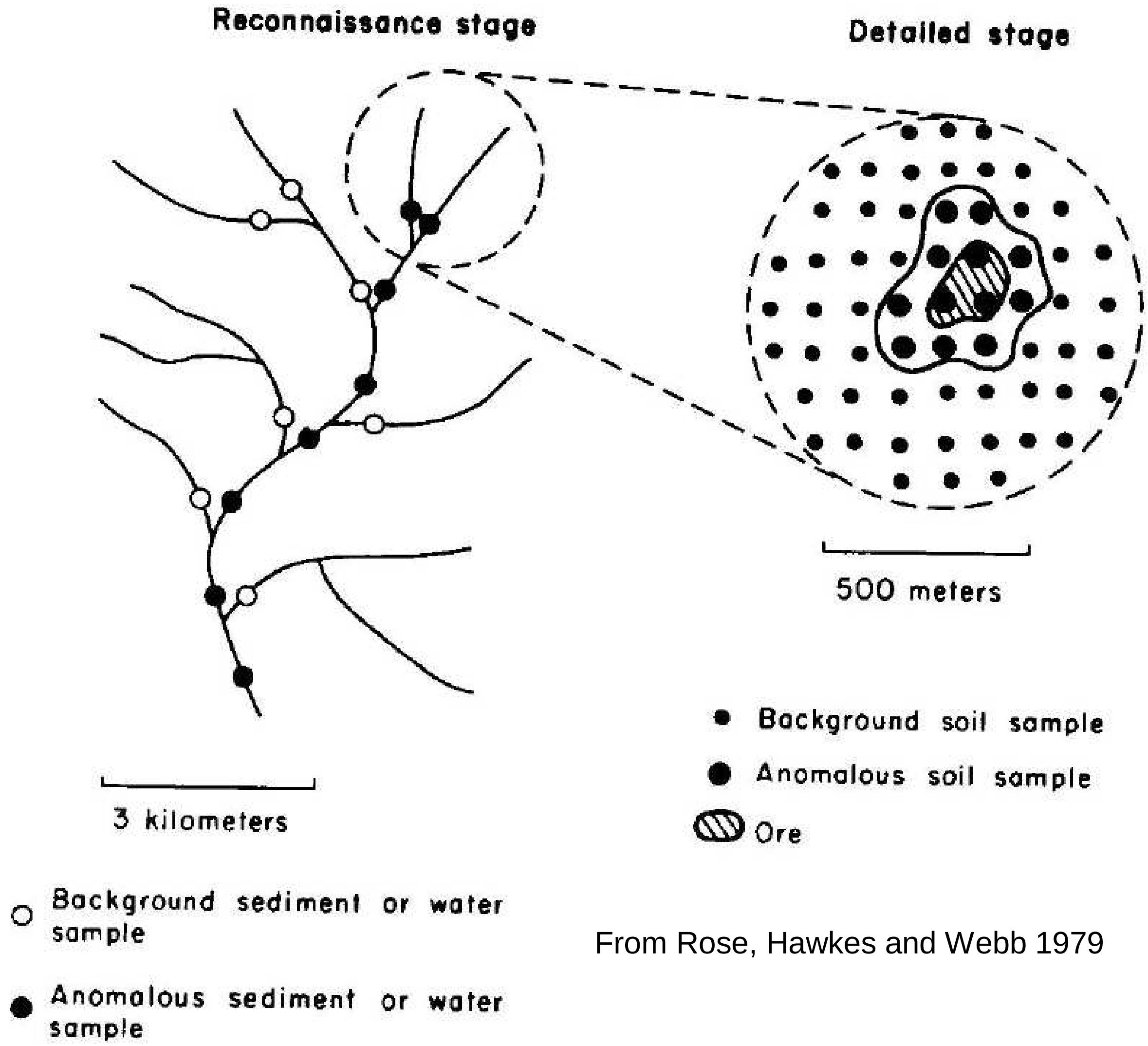
Orientation may be necessary to determine spatial variability.

Topography may require different approach

Prospect Scale - Grid

Prospect scale profile sampling to follow up geophysical anomalies

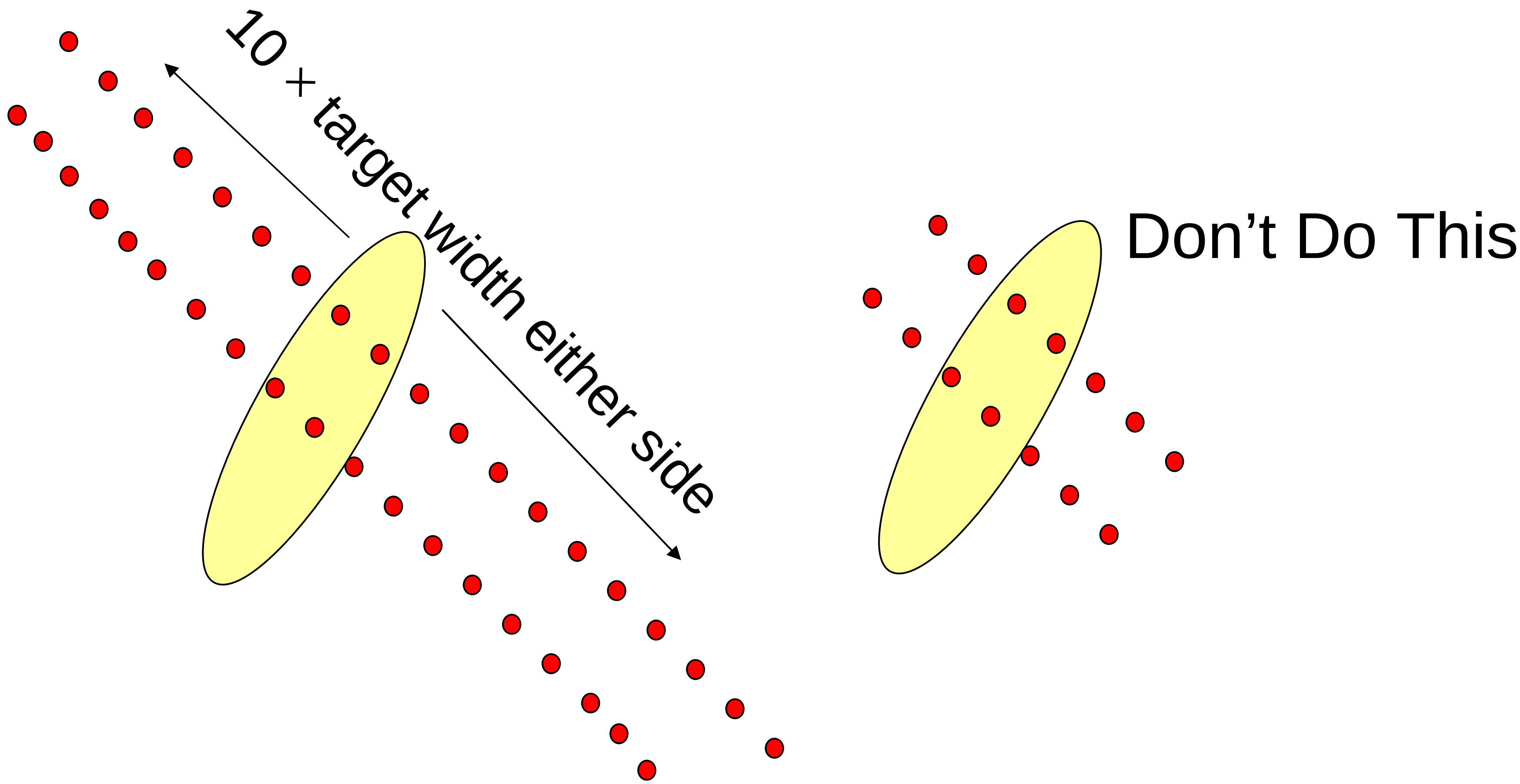




From Rose, Hawkes and Webb 1979

Prospect Scale - Profiles

Prospect scale profile sampling to follow up egg, geophysical anomalies



Prospect Scale – Ridge and Spur

Ridge and Spur Sampling.

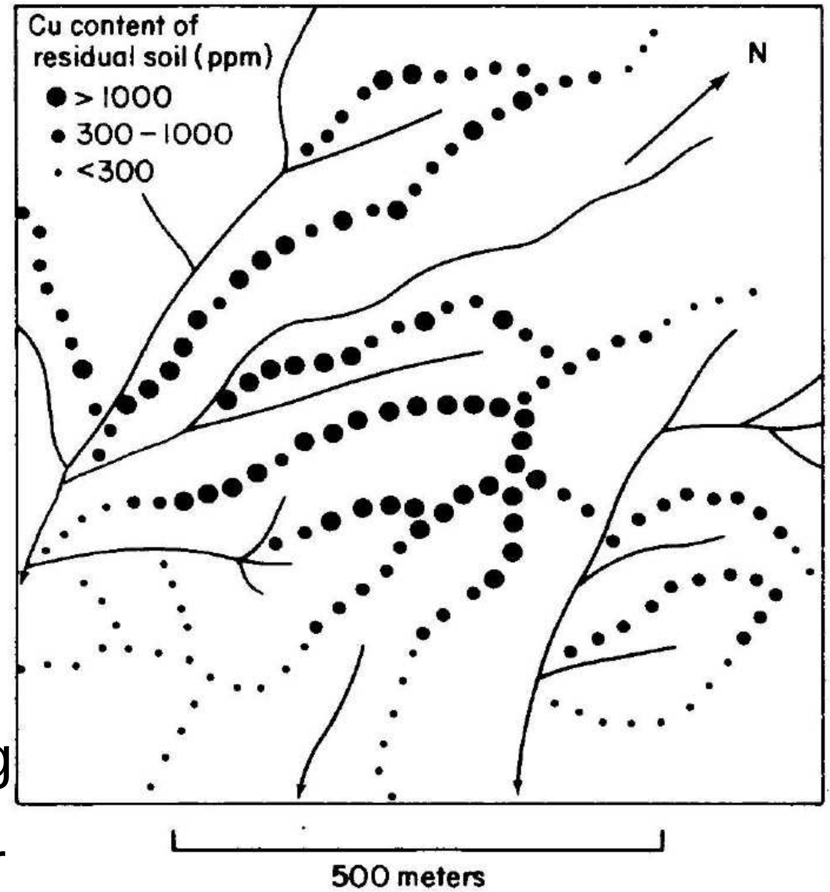
Ridge & Spur generally a logistic choice for ease of access.

Also data is not hydromorphically displaced

Base of Slope

An adjunct of ridge and spur sampling

Sampling maximises hydromorphic or clastic component of dispersion (depending on climate)



From Rose, Hawkes and Webb 1979

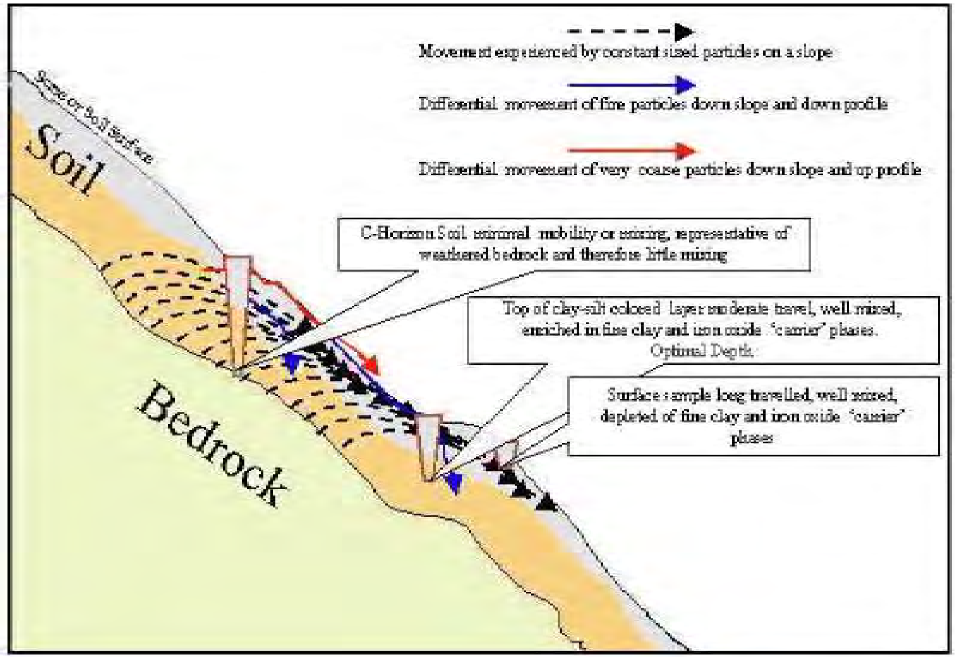
Prospect Scale – Contour Sampling

Good for initial reconnaissance of large area which has not been previously sampled

Relevant where have:

- Strongly and deeply dissected terrain
- Drainage divides have a poor chance of intersecting mineralisation
- Logistical difficulty: poor access into streams and ridges because of terrain.

Speed & Safety: contours often easier to navigate than ridges in extreme topography



Courtesy Simon Gatehouse

Upper most B horizon to maximise dispersion

Compositing rate variable

Semi Regional – Lag Sampling

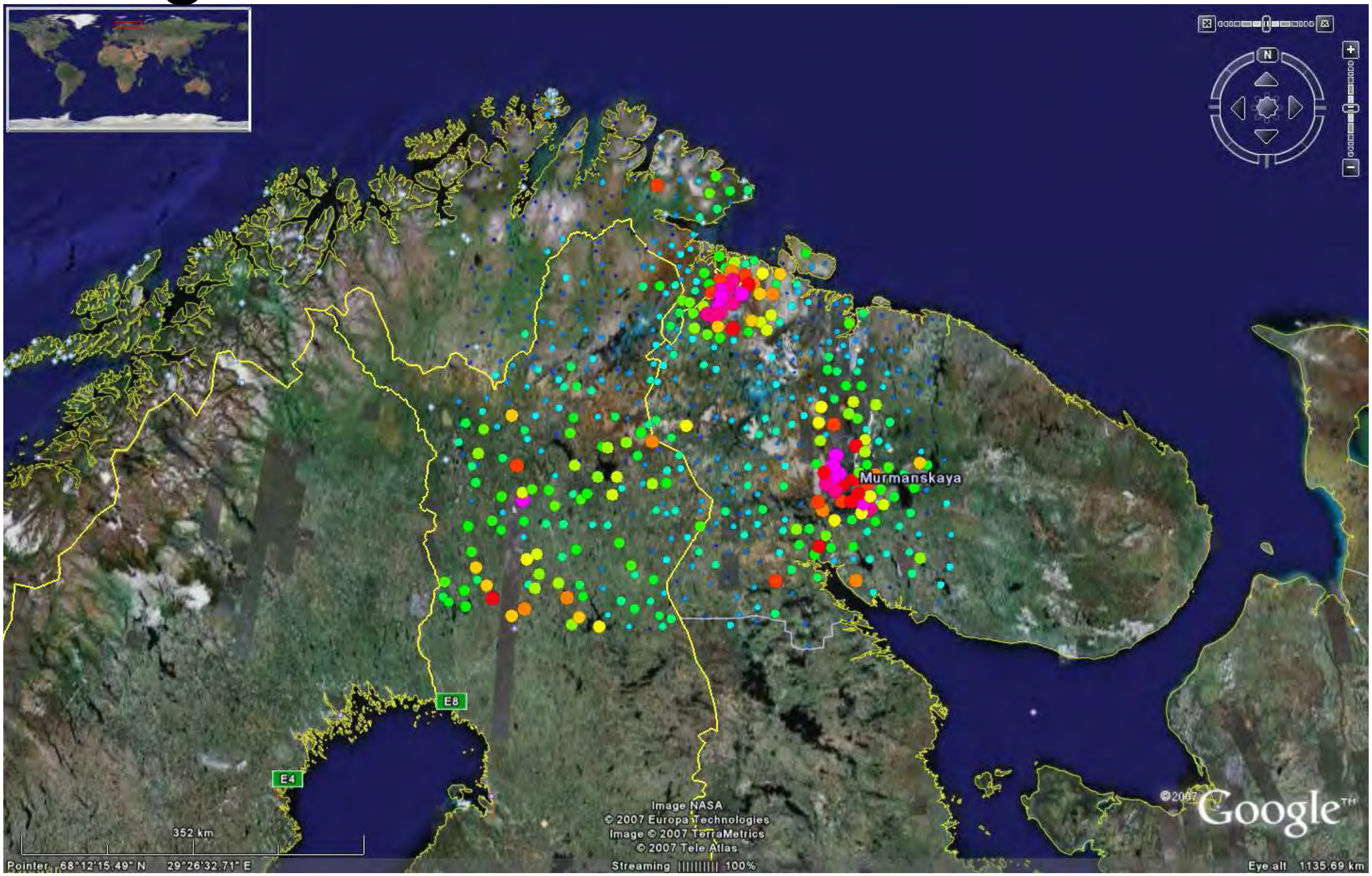
Swept from the surface

Sieved to 2–6 mm

Data may be normalised to Fe content

Sample grids at 500m by 500m have been used

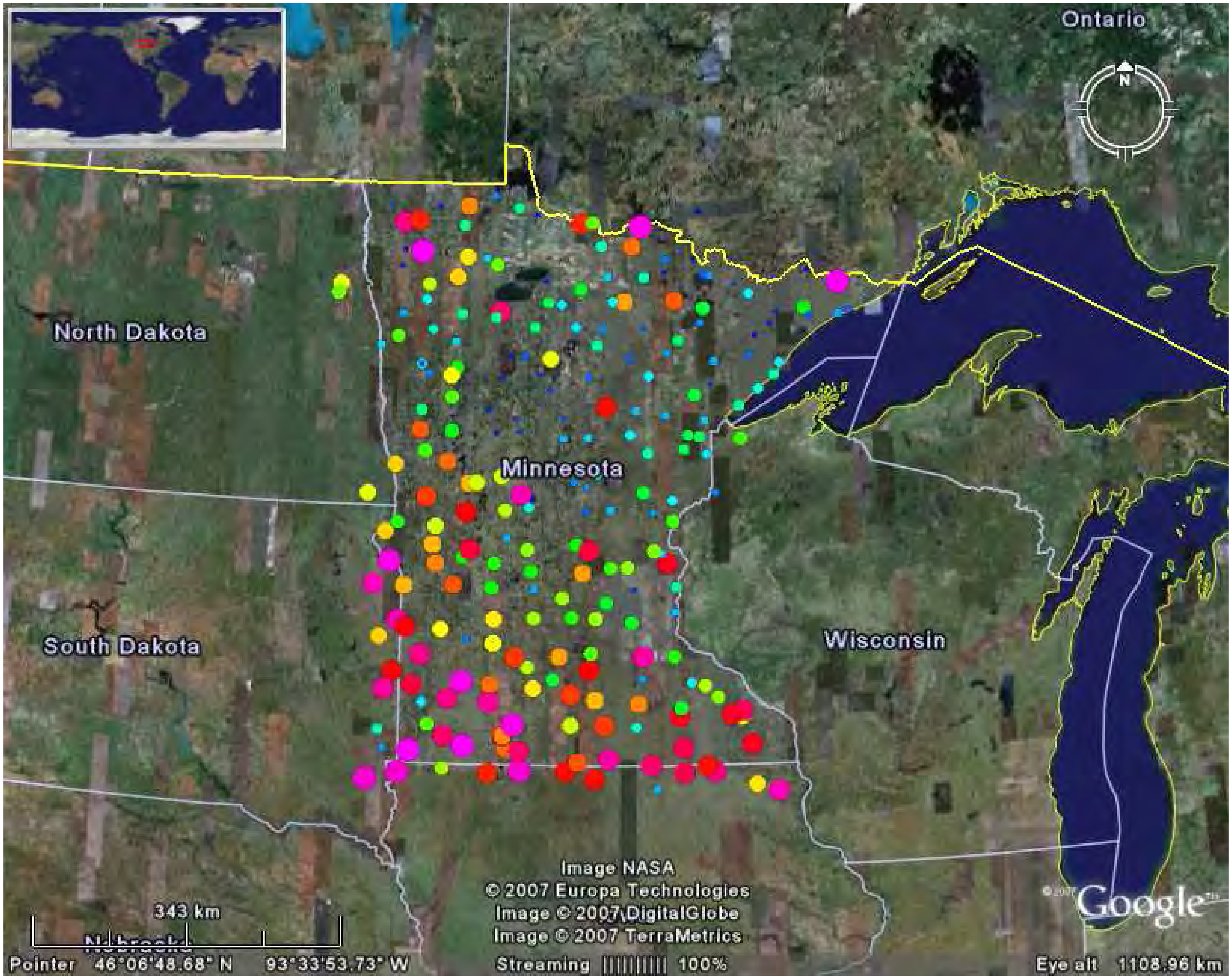
Regional Soil Data - As in humus



Data From: Reimann, Clemens (2000): Kola-Atlas, Humus, *PANGAEA*, doi:10.1594/PANGAEA.56279

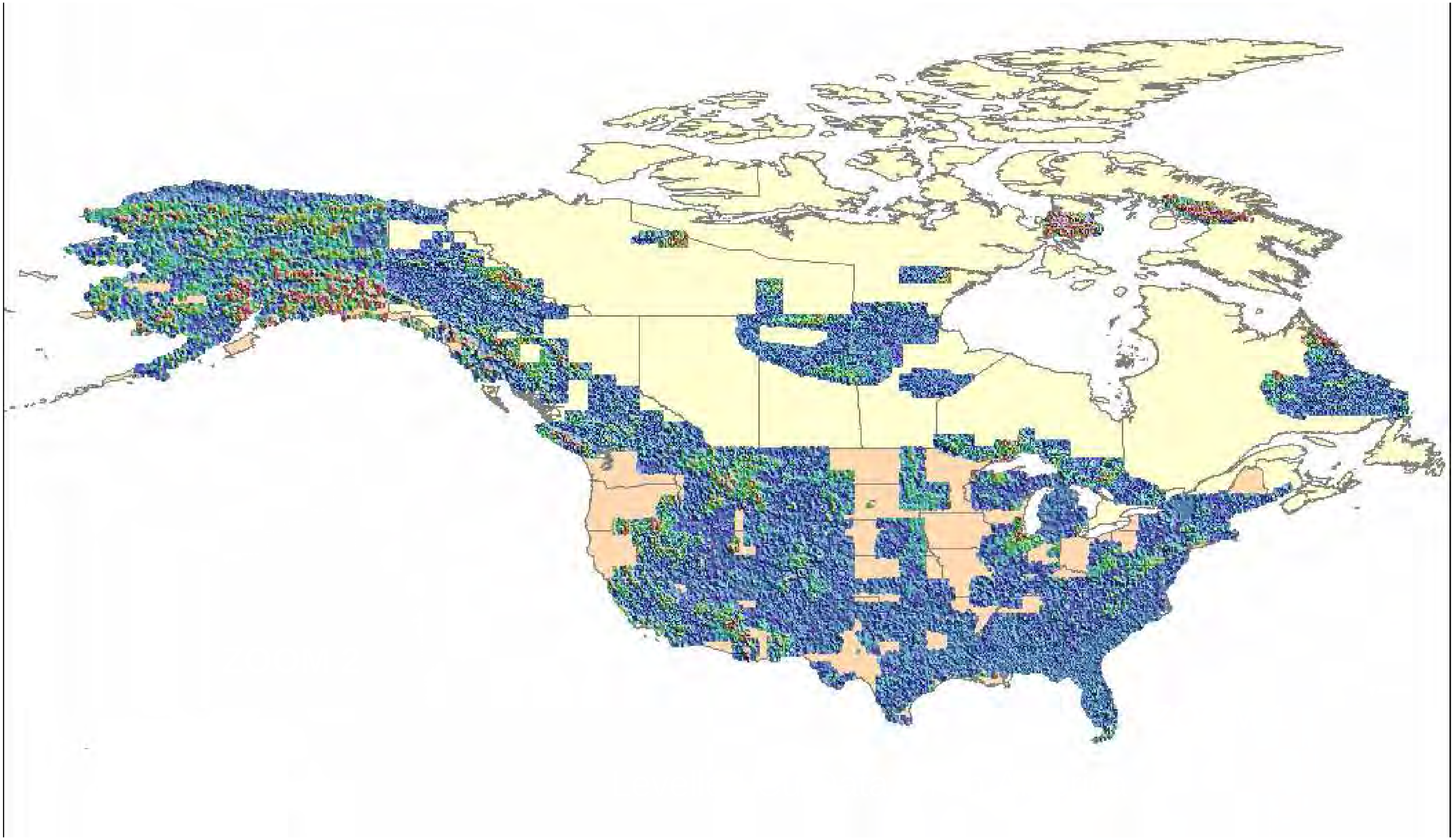
Anthropogenic Control

Regional Soil Data – As in soil



Geological Control

Regional Scale – Soils combined with other surficial data



Soil Formation

Parent Material

Minerals and organic materials present during it's formation. Materials from volcanoes, sediment transported by wind, water or glaciers or minerals left behind by drying lakes are good examples of parent materials.

Climate

Parent material is broken down into smaller pieces by a process called weathering. Cycles of freezing and thawing, wetting and drying, and the frequency of these occurrences coupled with average temperature and moisture levels of region play an important role in soil formation. These smaller pieces are known as (sand, silt and clay), clay being the smallest size.

Living Organisms

Both plants and animals help to create a soil. As they die, organic matter incorporates with the weathered parent material and becomes part of the soil. Living animals such as moles, earthworms, bacteria, fungi and nematodes are all busy moving through or digesting food found in the soil. All of these actions mix and enrich the soil.

Topography

Topography is the hilliness, flatness, or amount of slope of the land. Soils vary with topography primarily because of the influence of moisture and erosion. In many areas, moist, poorly drained soils are located in low areas, and depressions of the land. In contract, soils in sloping areas can be drier and well drained. These soils tend to be moderately and well developed. Erosion can remove all or part of the topsoil and subsoil, leaving weakly developed soil.

Time

It may take hundreds of years to form one inch of soil from parent material. Only the top few inches are productive in the sense of being able to sustain plant growth. This is why soil conservation is so important.

Soil Formation

Always Occur:

Weathering of parent material

Addition and partial decomposition of organic matter

Formation of structural units ***(Profile)***

Depending on Environment

Leaching and acidification

Clay eluviation (washing of clay from upper horizons)

Podzolisation (transport of DOC and Fe & Al from upper h)

Leaching of Si relative to Fe and Al

Reduction (ferric to ferrous)

Salinisation

Erosion

Profile Development

Soil development is initiated by the weathering of the bedrock and the incorporation of organic matter.

<u>These processes produce:</u>

- dissolved matter (bases, silicic acid, Fe, Al etc.);
- dispersed colloidal particles (e.g. silica, etc.):
- hydroxyls (Fe, Al, etc.):
- organic complexes; and,
- fine particulate matter (clay, clay-sized particles, etc.)

Profile Development

Under moist, freely draining conditions pore waters transport these products downward.

The depletion of these components from the upper parts of the soil profile is eluviation.

The accumulation of these components in the lower parts of the soil profile is illuviation.

Illuviated soil horizons often contain the highest abundance of element of interest

The amount of humic material accumulated is a f(climate)

Most well developed soil profiles display four principal horizons: A, B, C and R.

Idealised Soil Profile

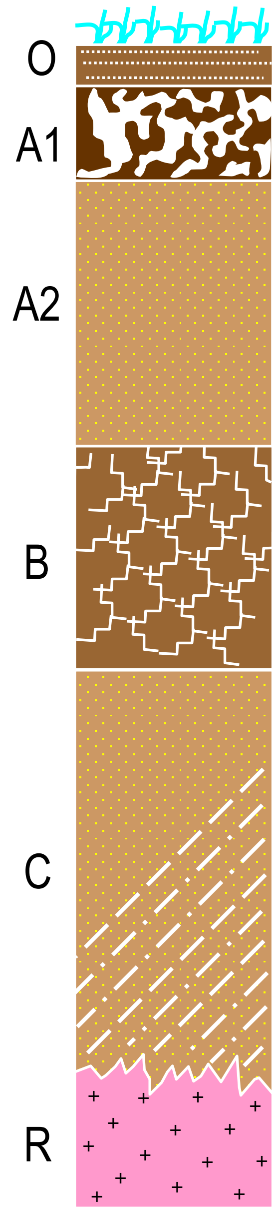
The Solum
(the generic soil developed by soil-forming processes)

Horizons of maximum biological activity, of eluviation (removal of materials suspended or dissolved in water), or both.

Horizons of illuviation (accumulation of material by deposition or precipitation from percolating water).

Parent material derived by weathering

Bedrock



O: Organic debris only partially decomposed

A1: Dark-colored horizon, organic (humus) rich; mixed with mineral matter.

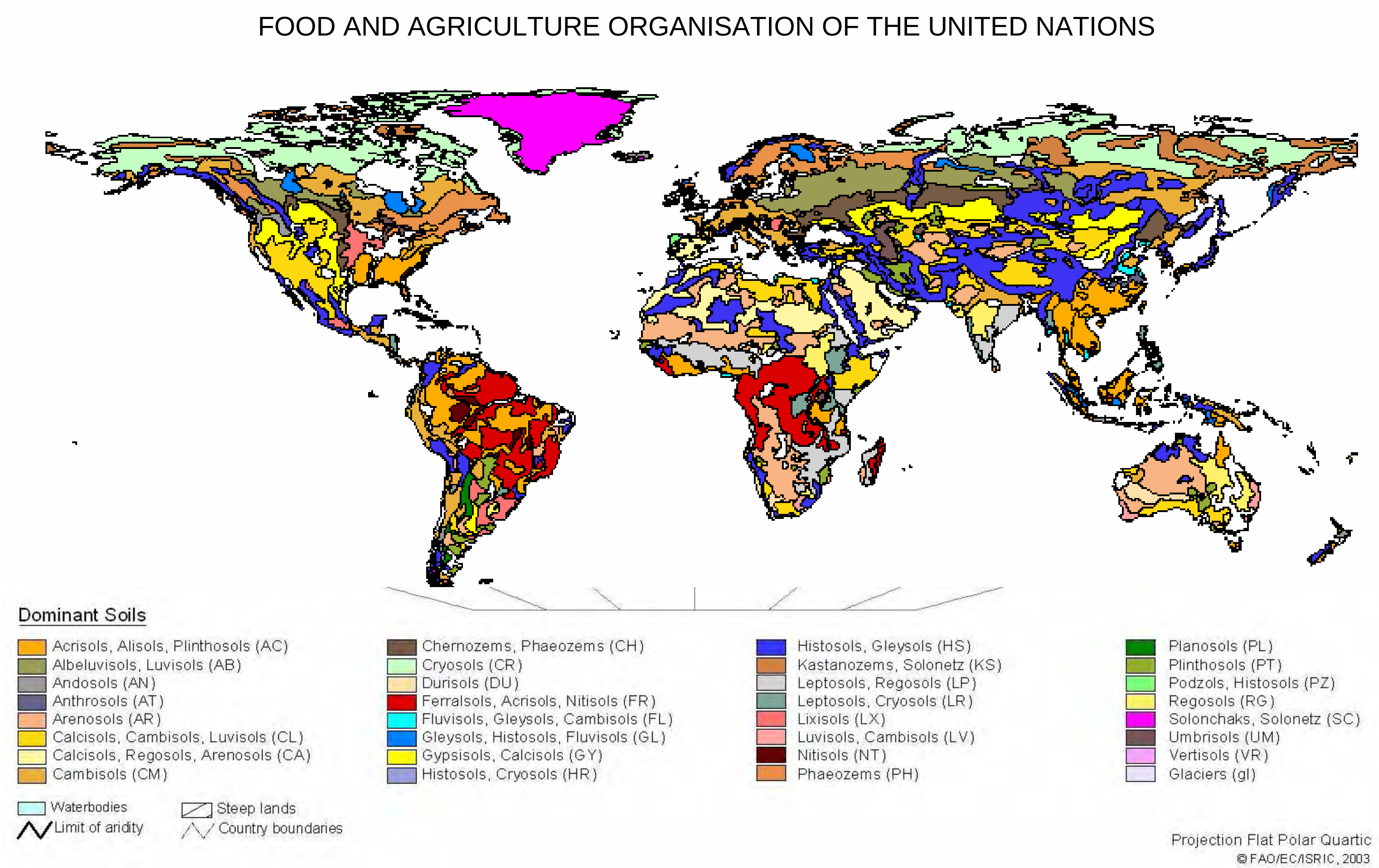
A2: Light-colored horizon of maximum eluviation. Prominent in some soils, faint or absent in others. Generally loose structure.

B: Brown to orange-brown horizons. Accumulation of clay minerals or of iron and organic matter; compact blocky, prismatic structure.

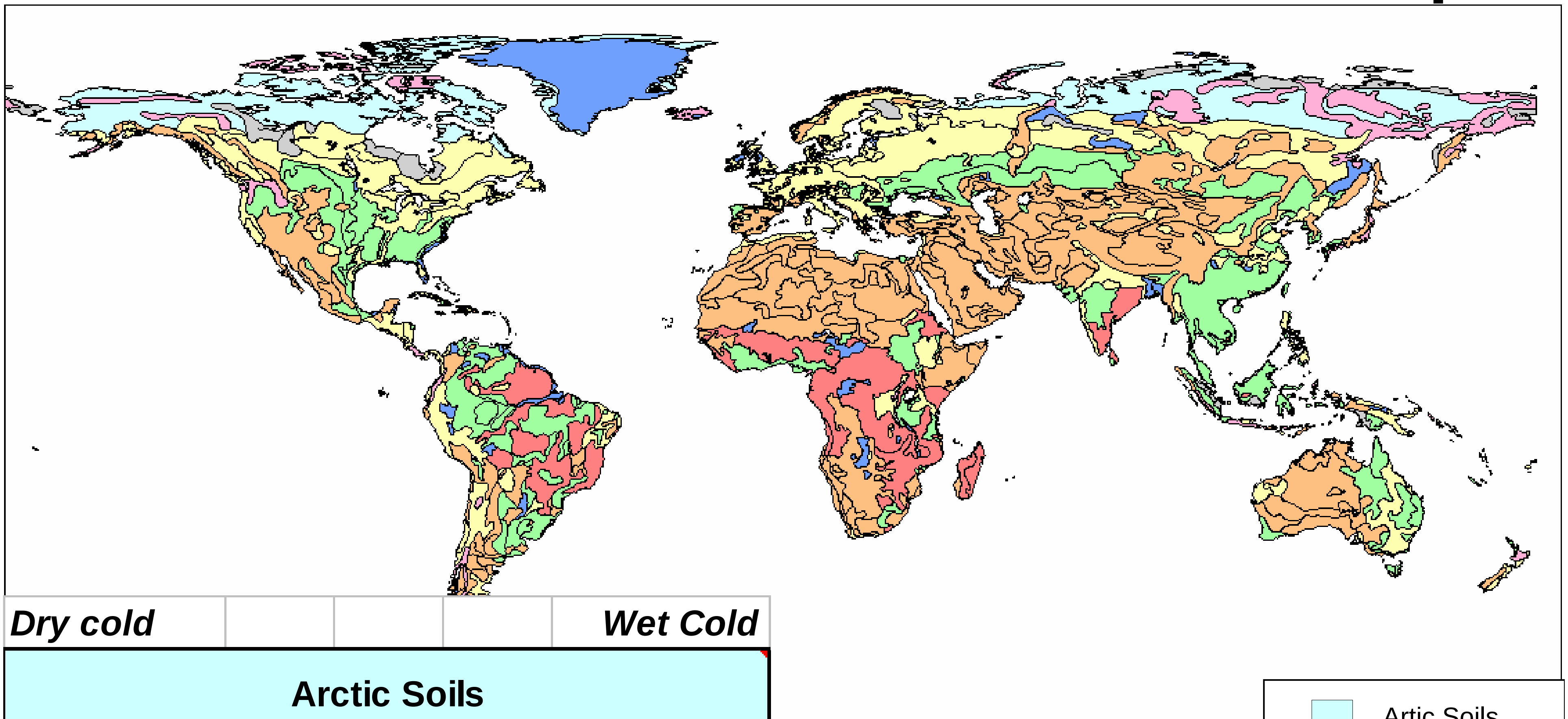
C: Some soils show intensely gleyed layers (Horizon G of hydromorphic soils; G may appear directly beneath A), or layers of calcium carbonate (Horizon C Ca of calcareous soils).

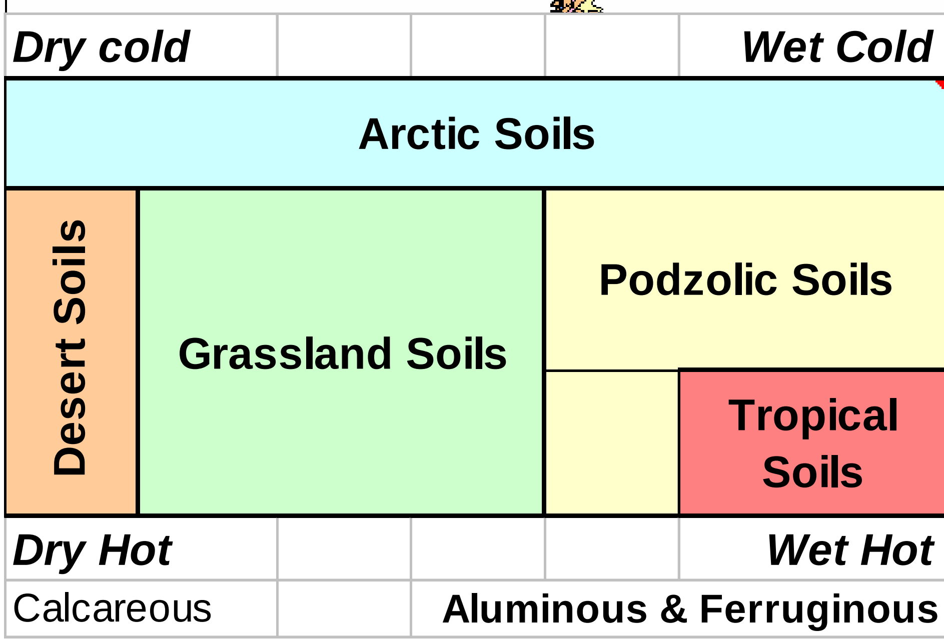
Modified from Rose, Hawkes and Webb 1979

Major Soil Groups of the World



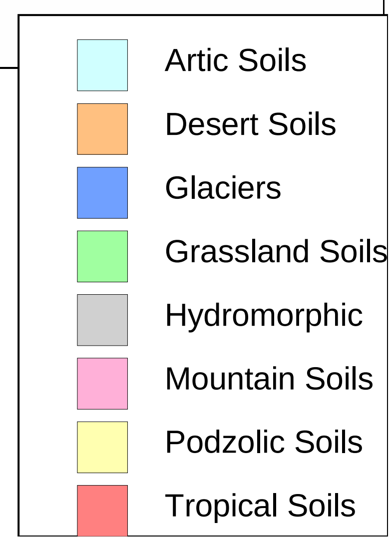
Geochemical Version on the FAO Soil Map*





*Climate based

Modified from Rose, Hawkes and Webb 1979



<table>
<tr><td>Dry cold</td><td></td><td></td><td></td><td>Wet Cold</td></tr>
<tr><td colspan="5">Arctic Soils</td></tr>
<tr><td rowspan="2">Desert Soils</td><td colspan="2" rowspan="2">Grassland Soils</td><td colspan="2">Podzolic Soils</td></tr>
<tr><td></td><td>Tropical Soils</td></tr>
<tr><td>Dry Hot</td><td></td><td></td><td></td><td>Wet Hot</td></tr>
<tr><td>Calcareous</td><td></td><td colspan="3">Aluminous & Ferruginous</td></tr>
</table>

Example Soil Types - Arctic

Characterized by shallow permafrost and limited vegetation (dwarf shrubs and moss).

Limited oxidation, organic matter build-up even though plant growth is slow

Frost heaving

Dry cold				*Wet Cold*
Arctic Soils				
Desert Soils	**Grassland Soils**		**Podzolic Soils**	
				Tropical Soils
Dry Hot				*Wet Hot*
Calcareous		**Aluminous & Ferruginous**		

Example Soil Types - Desert

Lack of rainfall (0-200mm/yr) restricts leaching, chemical weathering and plant growth

Physical weathering (mechanical dissagregation) of parent material is significant

Low organic matter

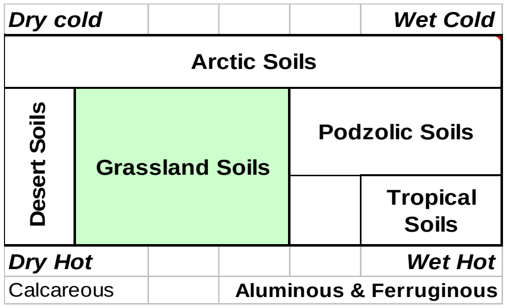
Restricted profile development

In warm semi-arid regions there may be slight accumulation of clay in the B horizon, and development of carbonate crusts and concretions and coatings

In cold semi-arid regions an organic bearing A horizon may sit directly on dark grey clay (transitional to arctic soils)

Dry cold				Wet Cold
Arctic Soils				
Desert Soils	Grassland Soils		Podzolic Soils	
				Tropical Soils
Dry Hot				Wet Hot
Calcareous		Aluminous & Ferruginous		

Example Soil Types - Desert



Example Soil Types – Grassland Soils

Characteristic of tropical and temperate regions with rainfall ranging from approximately 230 – 450mm/yr

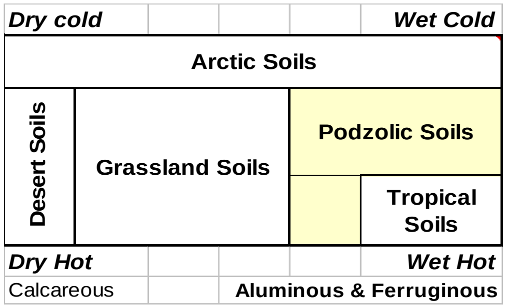
Some soil profile development

Grasslands and sparse forest

Can be organic rich

Includes deeply cracking soils (2:1 clay minerals)

Dominantly alkaline – not conducive to hydromorphic dispersion.



Example Soil Types – Podzolic Soils

Low mean temperatures, natural cover well developed, conifers dominant

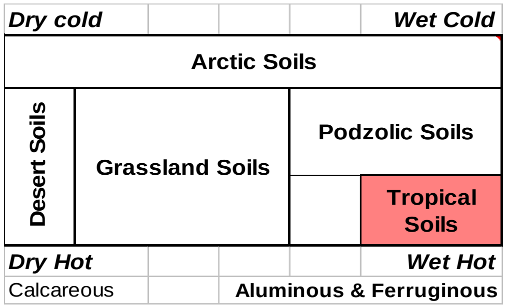
Slow decomposition of forest litter leads to variable development of organic litter and humus (A1) horizons;

This results in acid conditions and produces active water-soluble organic compounds which are strong complexing agents

Short term water-logging of soils occurs seasonally and promotes metal mobility (low Eh/acid);

In well drained materials, eluviation of the upper part of soil leaves a fine quartz residue (A2 horizon), while illuviation produces a distinct strongly coloured (orange to red brown) Fe-Al-Mn sesquioxide-rich B -horizon

Example Soil Types – Podzolic Soils



Example Soil Types – Tropical Soils

Relatively high temperatures, and moderate to high rainfall (>600mm/yr)

High temperature promotes faster breakdown of alumnosilicates and organic matter, and there is greater ‘flux’ or organic matter. <u>Chemical weathering dominant.</u>

Gradation from soils of moderate thickness (<1 m) that include A, B and C horizons with the B (clay) horizon generally enriched in clay, to ferruginous soils with A horizons highly depleted in clay and iron and he B horizon strongly enriched in iron and strongly red colored.

An extreme case of this class of soils is laterite - formed under prolonged periods of humid tropical weathering. Underlain by weathered C horizon up to 100m+ thick. On drying out may irreversible harden.

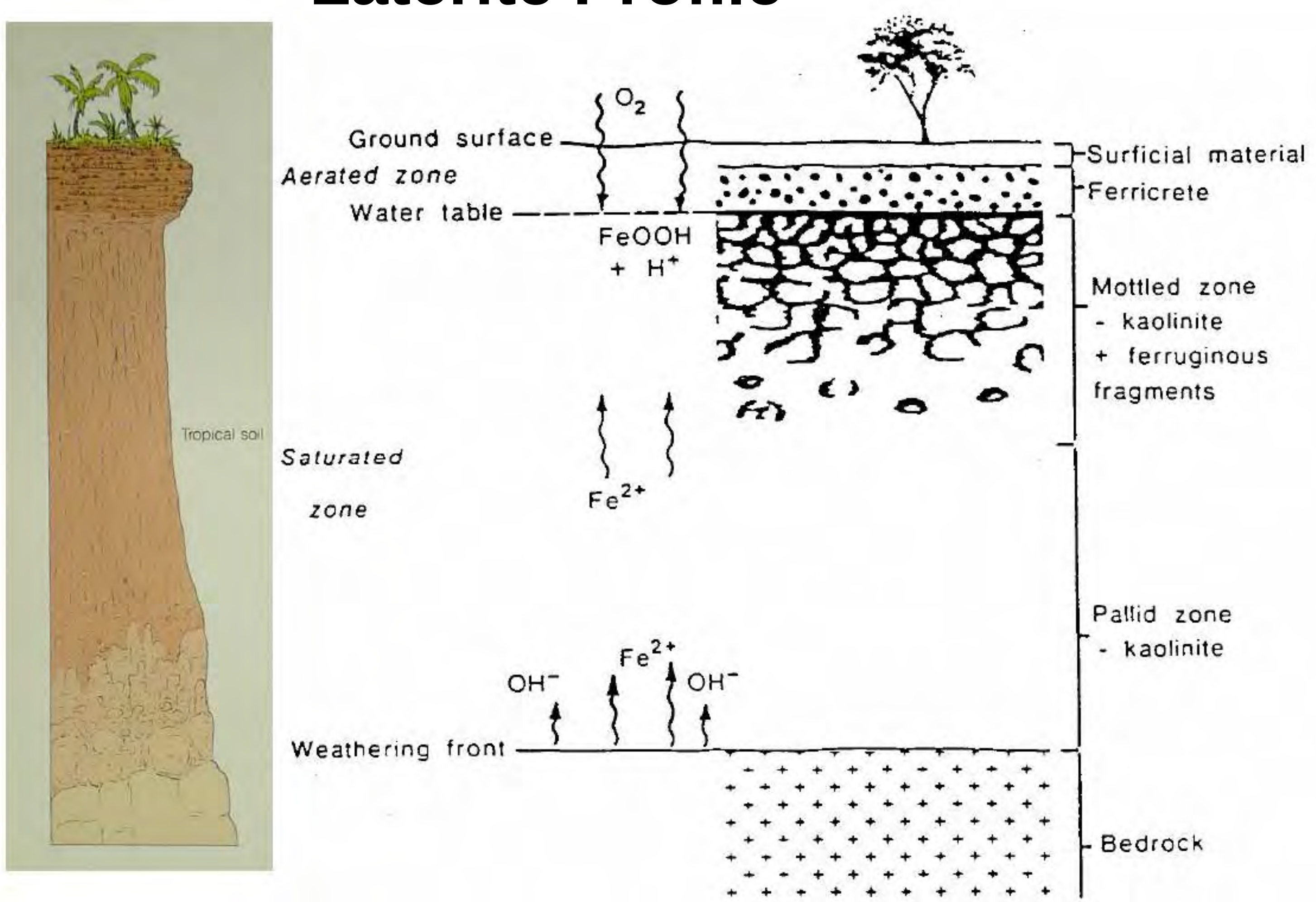
Note: The latter may be associated with a significant component of lateral chemical dispersion. Physical dispersion of lateritic materials provides excellent sample media

Example Soil Types – Tropical Soils

Ferruginous Soil

Laterite

Laterite Profile



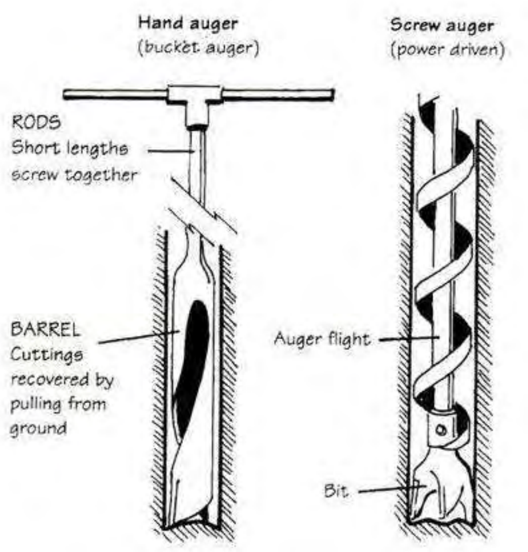
*Importantly, the degraded and eroded products of 'laterites' form important sample media

Intrazonal Soils - Peat/Histosols

Peat deposits can develop through a build up of organic debris in a water saturated topographic low or in old lake basins as they dry up and fill in with organic debris.

As the peat becomes more decayed and compact it goes from exposed green to orange fibrosol, through a more decayed and compact orange to dark brown mesisol, into the dark black greasy and earthy humisol.

Sampling Protocols



Sample depth/horizon

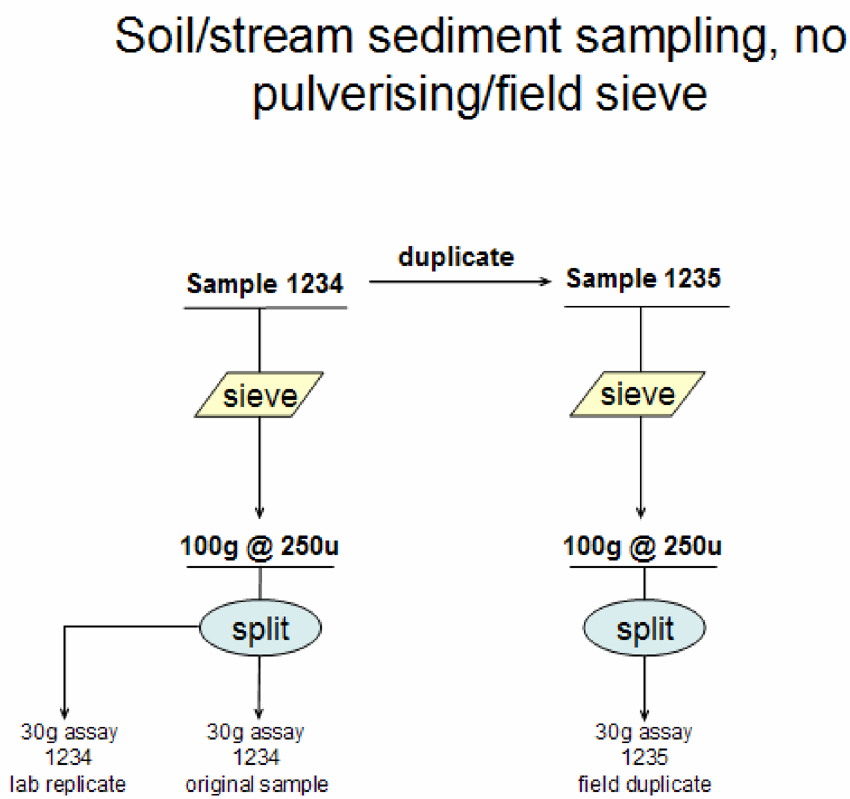
Type of sample bags

Sample weight

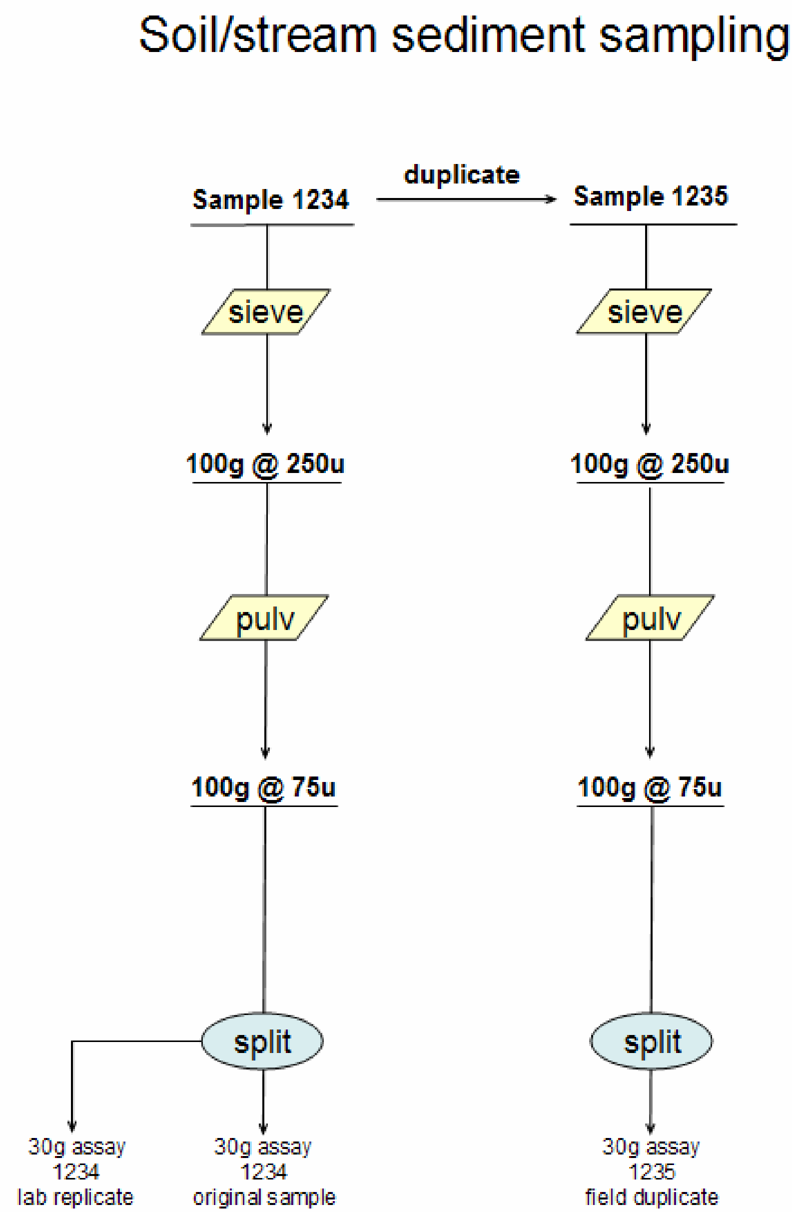
Sieving (or not) & sieve size

No Jewelry

Coords and observations



Pulverise or not (clay-rich samples)
Field dups rate?
Standards insertion rate? eg, 1 in 25



Particular Case of Gold Grains

250um diameter

63um diameter

Consider spherical gold grains with the above diameters.

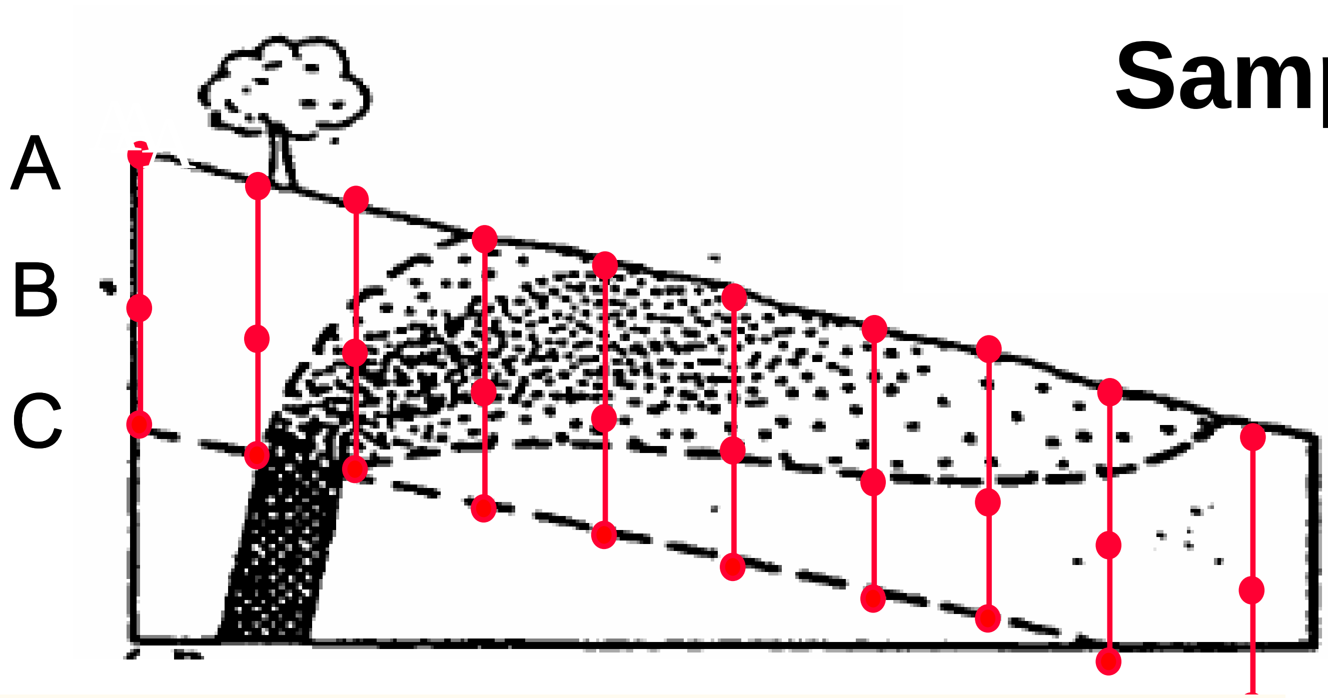
These are the largest grains that would pass through a 250um (60#) and 63um (240#) sieve

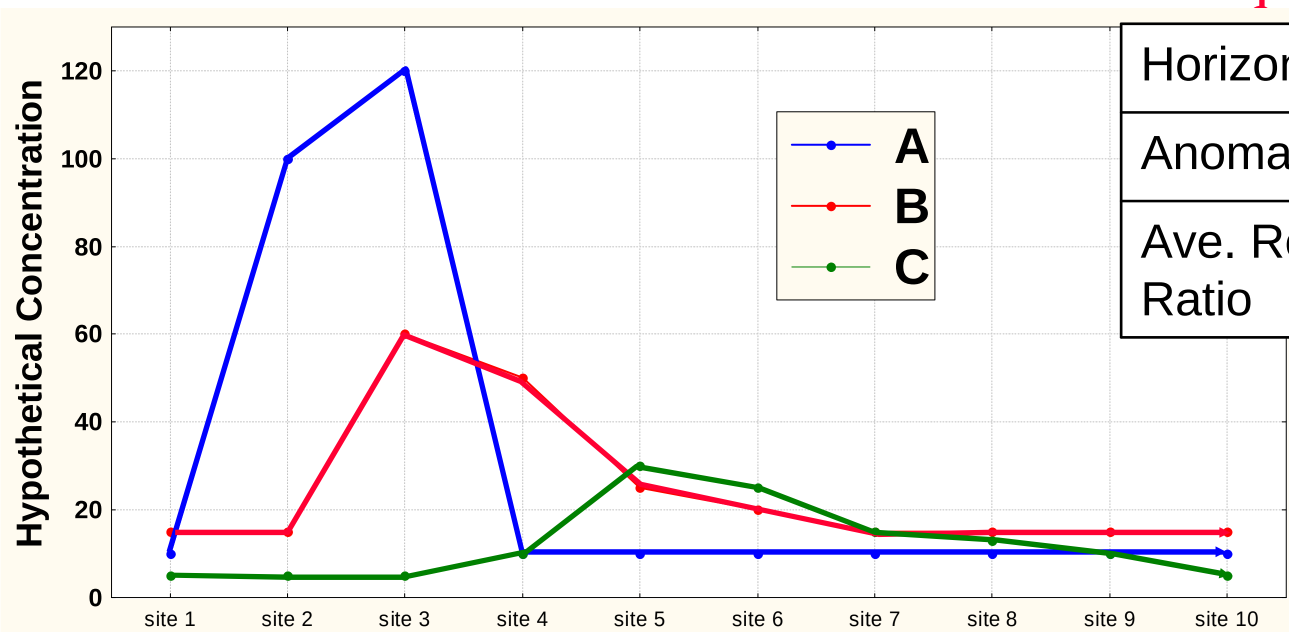
1, 250um diameter Au grain in a 30g sample = 5.260 g/t Au

1, 63um diameter Au grain in a 30g sample = 0.084 g.t Au

Comment: @ 250um – Au= sampling prob, BM diff problem, could have variable dilution

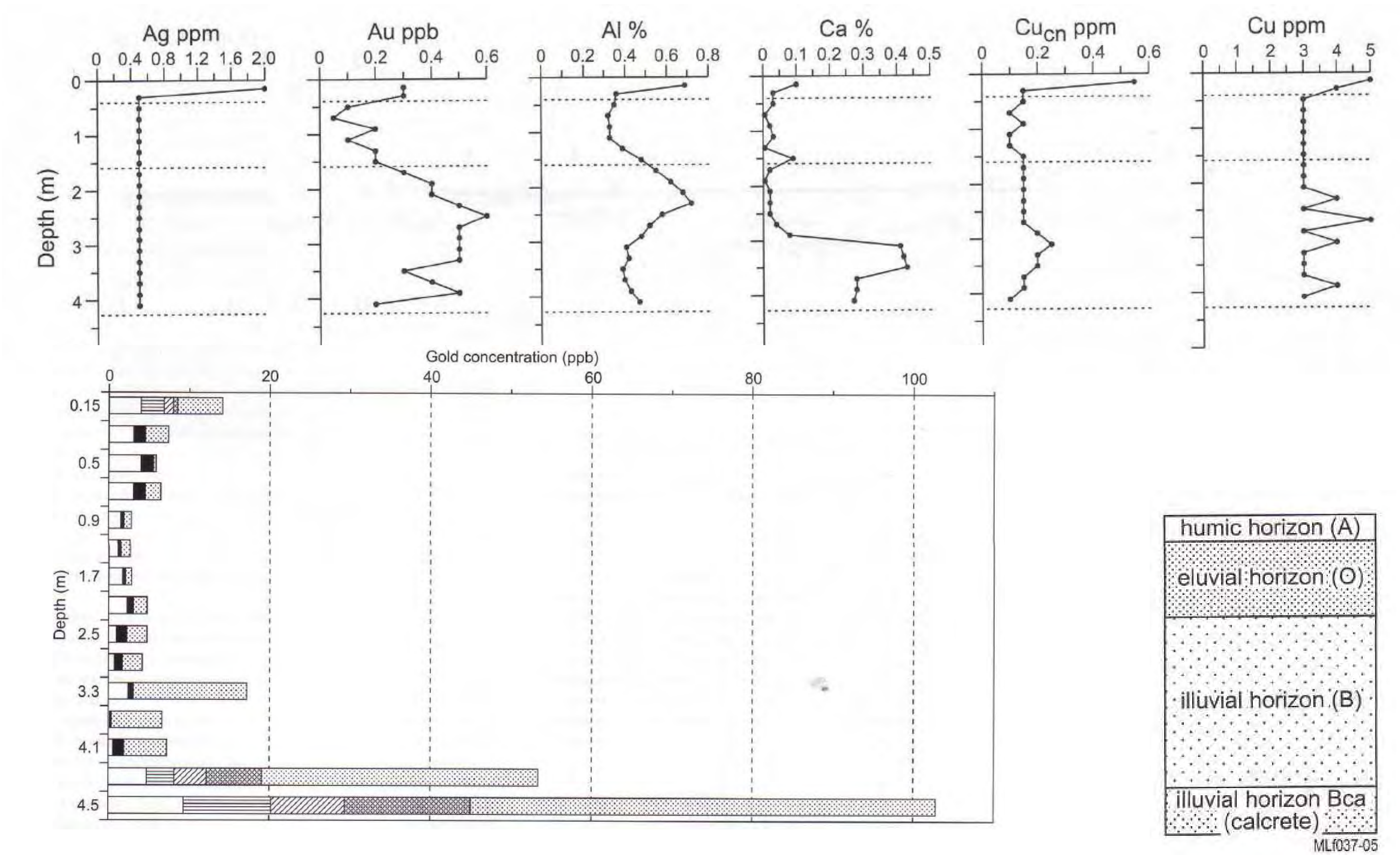
Sample Depth





Horizon	A	B	C
Anomalous Sites	6	4	2
Ave. Response Ratio	2.9	2.6	11

Sample Depth



From: M. J. Lintern (2007) Vegetation controls on the formation of gold anomalies in calcrete and other materials at the Barns Gold Prospect, Eyre Peninsula, South Australia, GEEA, Vol 7, Num 3

Examples from Arid and Hyper-Arid Climates – Spence, Chile

Depth is Still Important!

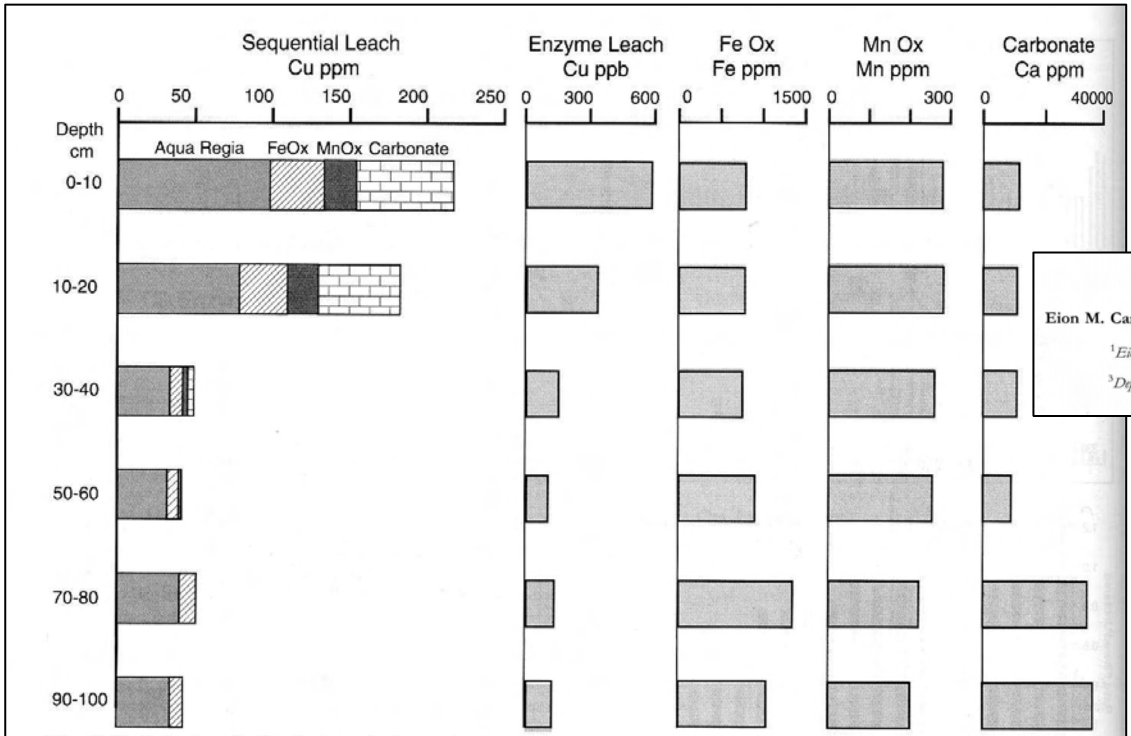
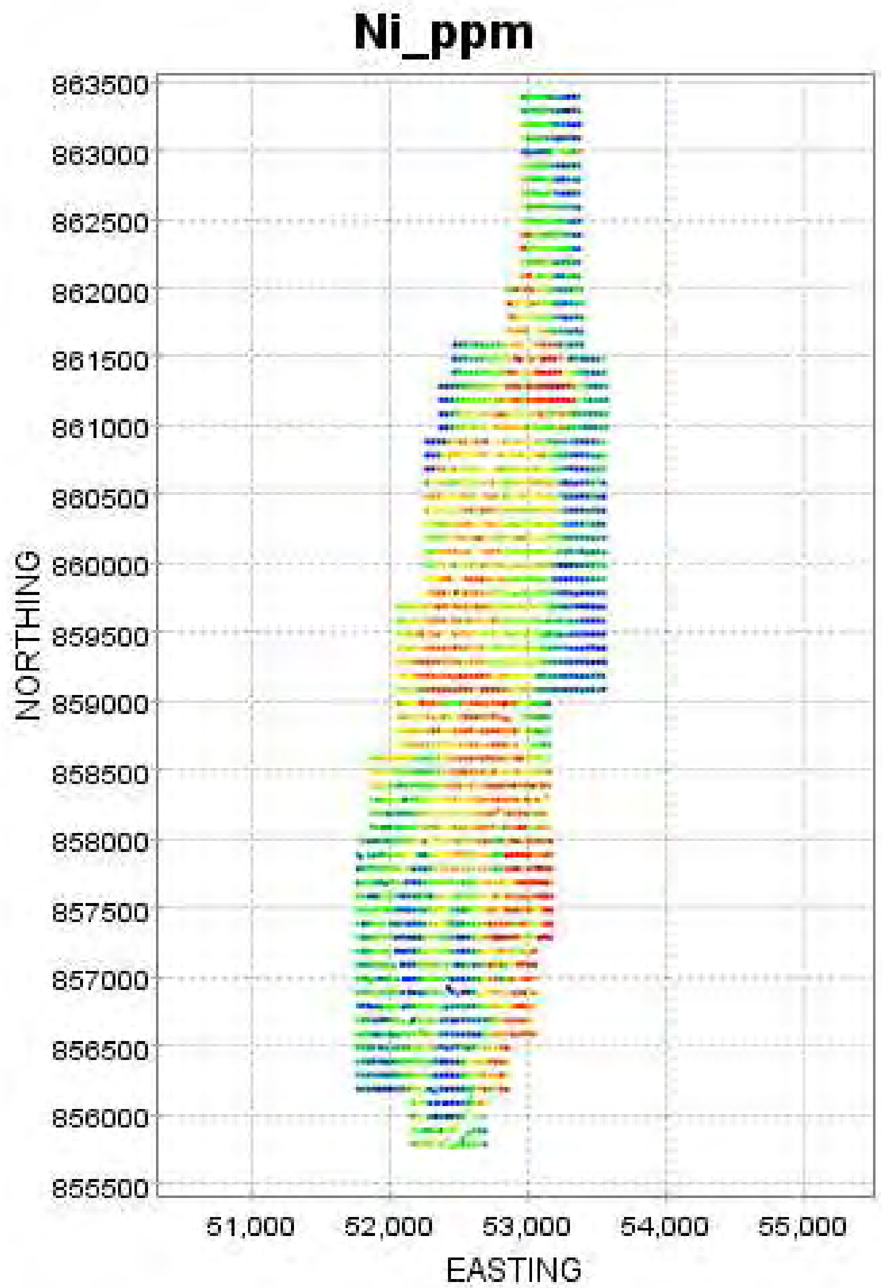


Fig. 20. Vertical soil profile directly above the Spence deposit. On the left are the amounts of Cu in ppm extracted sequentially by: (1) ammonium acetate (AA5) dissolving carbonate, (2) cold hydroxylamine (HX Mn) dissolving manganese oxides, (3) hot hydroxylamine (HX Fe) dissolving Fe oxides, (4) aqua regia. In the centre is Cu in ppb by Enzyme Leach, extracting water-soluble material. On the right is (a) Ca extracted by ammonium acetate (AA5), (b) Mn extracted by cold hydroxylamine (HX Mn), (c) Fe extracted by hot hydroxylamine (HX Fe).

Finding deeply buried deposits using geochemistry

Eion M. Cameron[1], Stewart M. Hamilton[2], Matthew I. Leybourne[3], Gwendy E.M. Hall[4] & M. Beth McClenaghan[4]

[1] *Eion Cameron Geochemical Inc., 865 Spruce Ridge Road, Carp, Ontario, K0A 1L0, Canada*
[2] *Ontario Geological Survey, Sudbury, Ontario, P3E 6B5, Canada*
[3] *Department of Geosciences, University of Texas at Dallas, Richardson, TX 75083-0688, USA*
[4] *Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8, Canada*



Soil Data Example Sampling Error

$S_{total} = S_{geol} + S_{sampling}$

Field Duplicates

$S^2_{Total} = 38$

$S^2_{sampling} = 5.9$

Sampling Error = 17% - FIT FOR PURPOSE

Sites and Mechanisms for Hosting Anomalies

Hosting Anomalies Within Soils

Soil Components

Resistate phases – zircon, cassiterite, qtz

Clay minerals – kaolinites, smectites

Fe and Mn oxides

Organic matter (humic and fulvic acid)

Carbonates

Amorphous material

Via - Mechanisms

Structural presence, Adsorption, Complexation,

Coprecipitation, Chelation

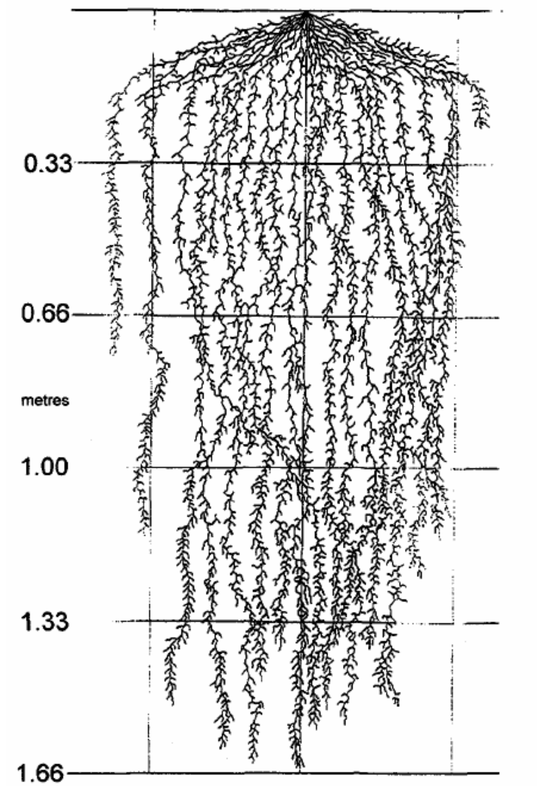
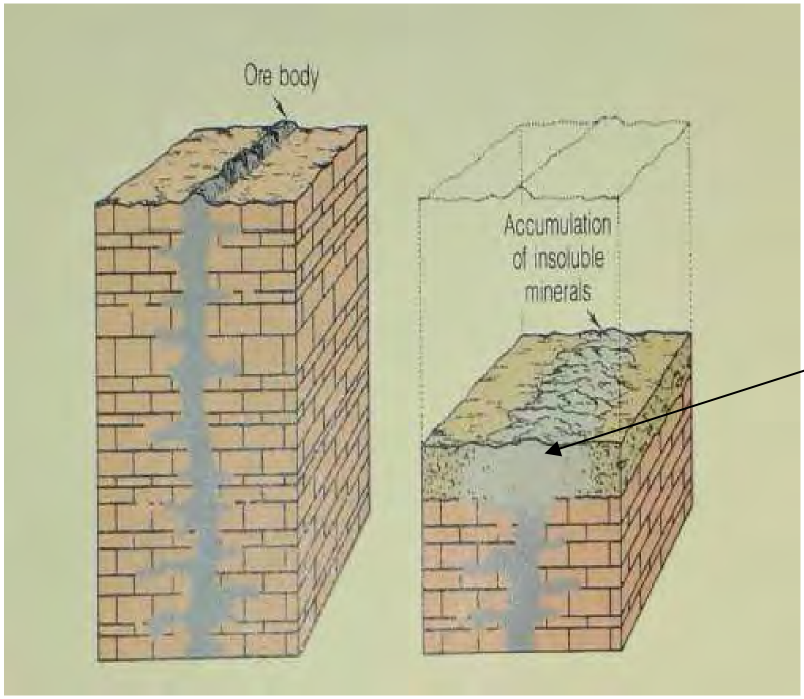


FIGURE 10 The root system of rye (a grass) grown in dry sandy soil showing only primary and secondary roots (based on data of Weaver, 1962).

Image from Gilkes

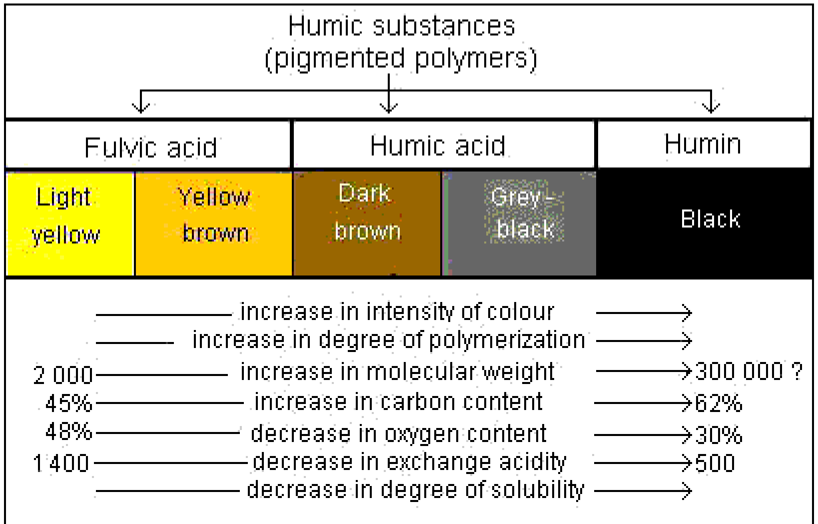
Exploration Geochemistry for the New Millennium, AIG Bulletin 30, 1999, pages 35-55

Hosting Anomalies Within Soils



Residual Component

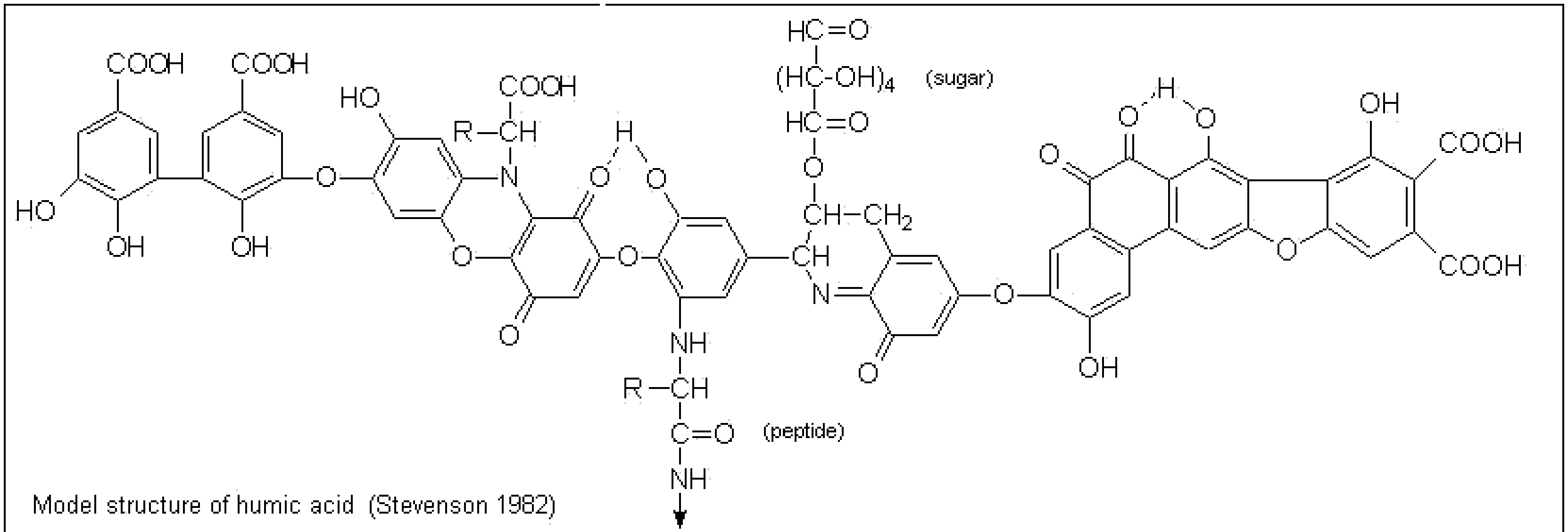
Hosting Anomalies Within Soils



Chemical properties of humic substances. (Stevenson 1982)

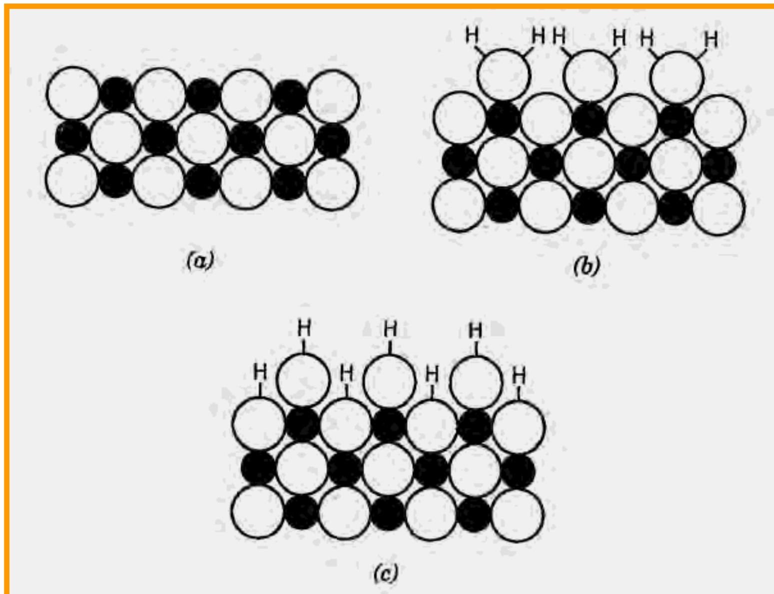
Humic & Fulvic Acids

A substantial fraction of the mass of the humic acids is in carboxylic acid functional groups, which endow these molecules with the ability to chelate (bind) positively charged multivalent ions (Mg++, Ca++, Fe++, Cd++ and Pb++.)

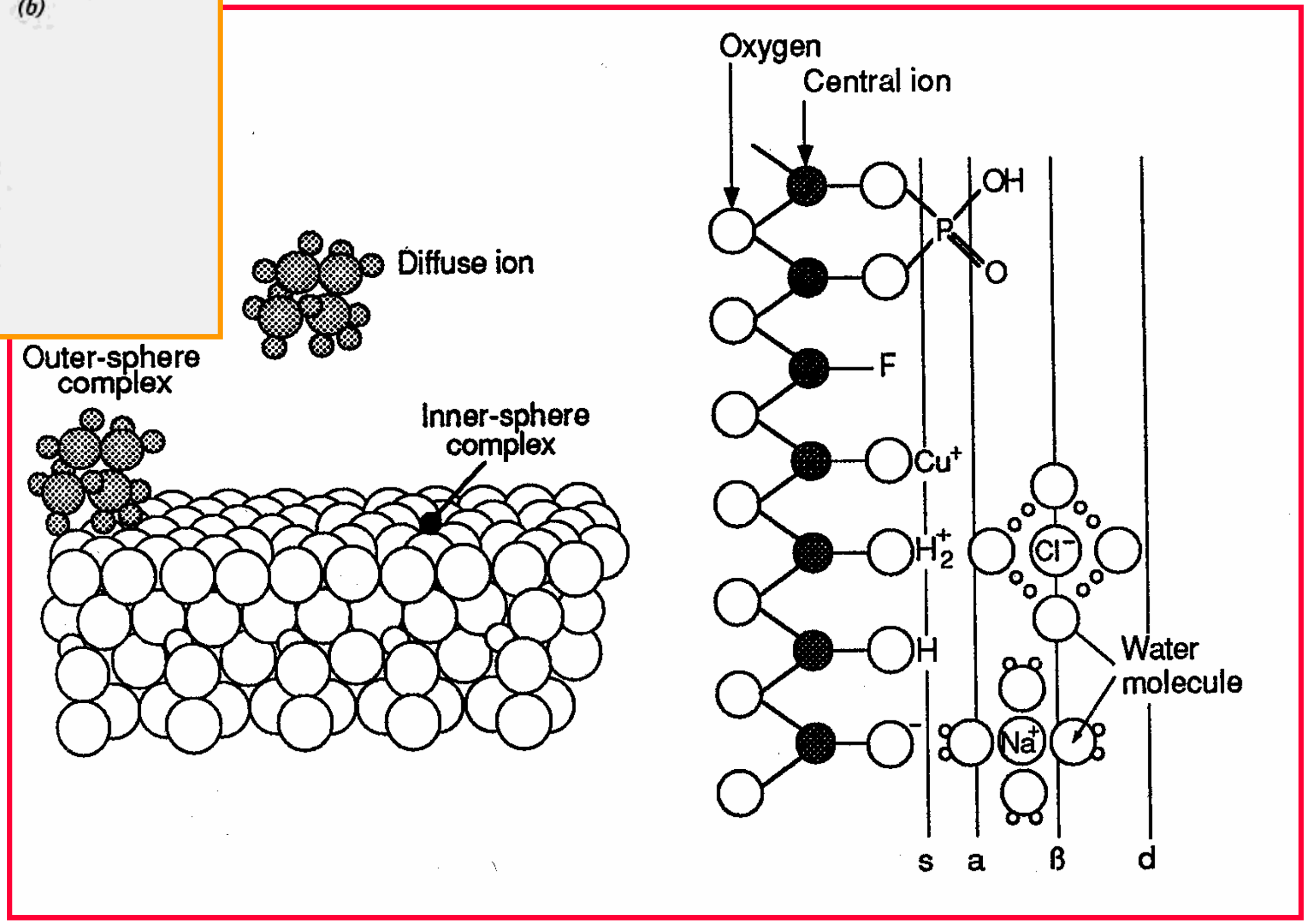


Model structure of humic acid (Stevenson 1982)

Hosting Anomalies Within Soils

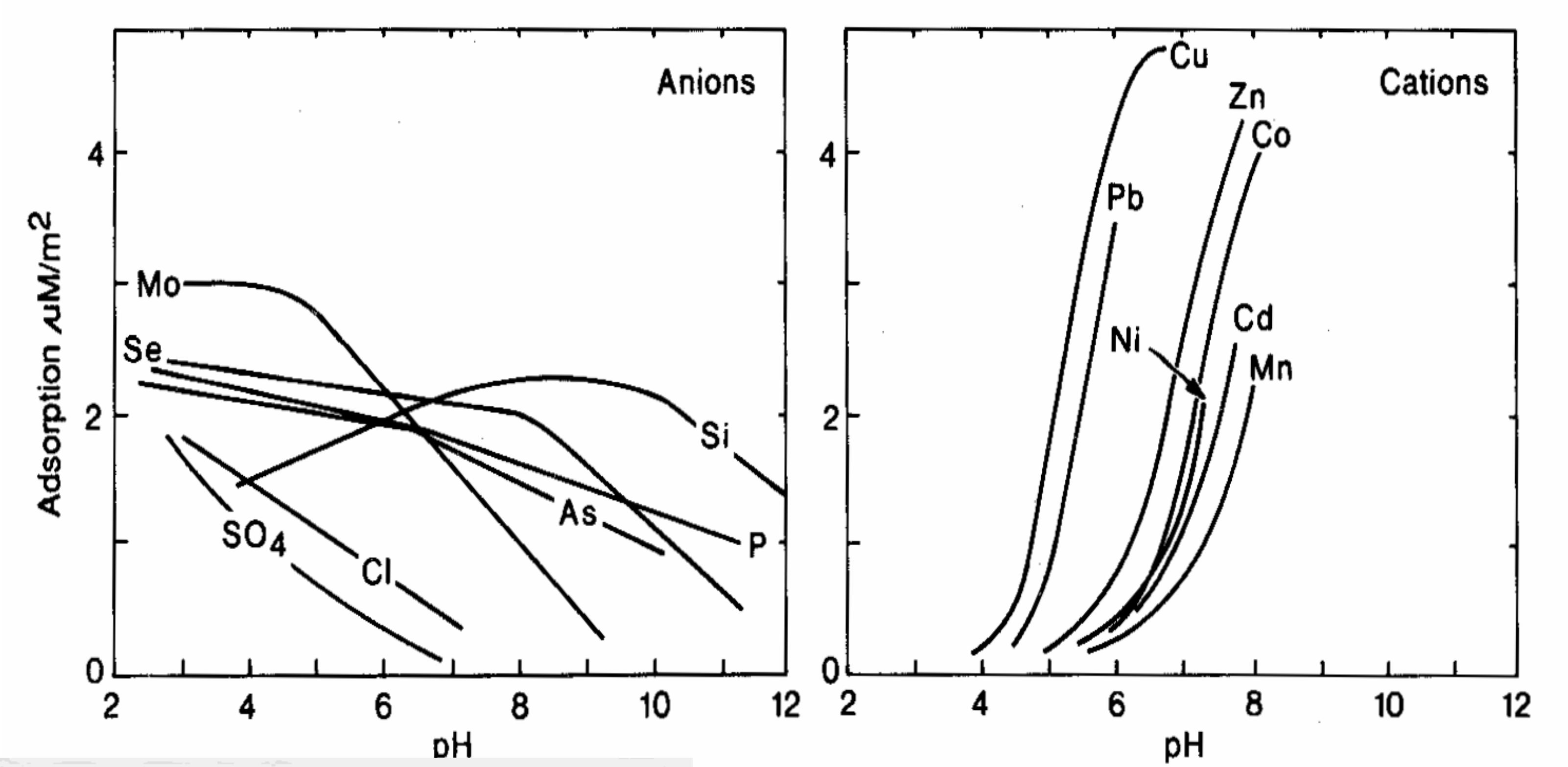


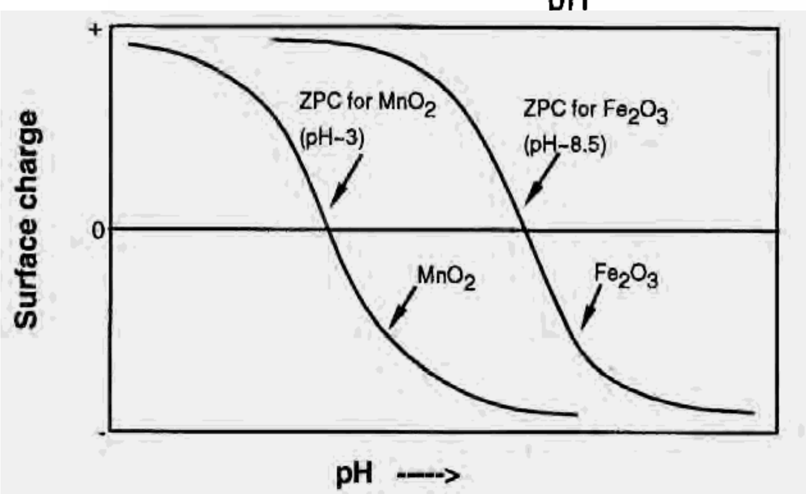
How can a quartz* crystal adsorb ions?



*Note however, low surface area

Adsorption onto Goethite





Note, pH control

Also, co-precipitation is also important (Cu)

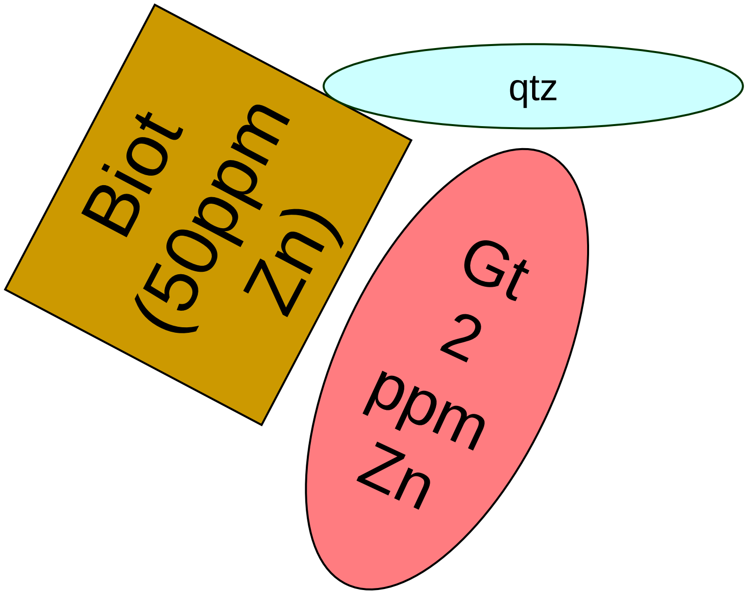
Compilation of adsorption data for anions (SO42-, Cl-, AsO43-, PO43-, SeO32-, SiO44- and MoO42-) and cations on to goethite as a function of pH (Thornber 1985).

Hosting Anomalies Within Soils

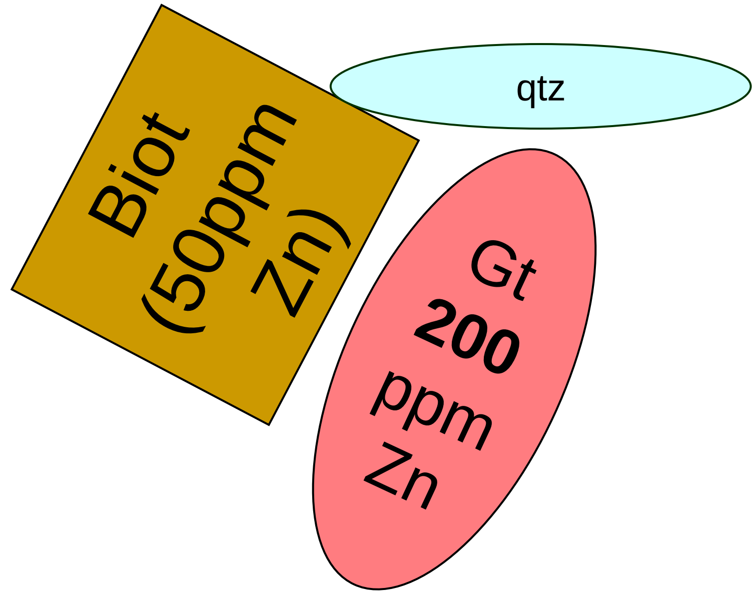
	Mn-oxides	Amorphous Fe-oxides	Goethite	Amorphous Al-oxides	Humic substances[a] (1)	Humic substances[a] (2)
Greatest	Cu^{2+}	Pb^{2+}	Cu^{2+}	Cu^{2+}	Ni^{2+}	Cu^{2+}
	Co^{2+}	Cu^{2+}	Pb^{2+}	Pb^{2+}	Co^{2+}	Ni^{2+}
	Mn^{2+}	Zn^{2+}	Zn^{2+}	Zn^{2+}	Pb^{2+}	Co^{2+}
	Zn^{2+}	Ni^{2+}	Co^{2+}	Ni^{2+}	Cu^{2+}	Pb^{2+}
	Ni^{2+}	Cd^{2+}	Cd^{2+}	Co^{2+}	Zn^{2+}	Ca^{2+}
	Ba^{2+}	Co^{2+}		Cd^{2+}	Mn^{2+}	Zn^{2+}
	Sr^{2+}	Sr^{2+}		Mg^{2+}	Ca^{2+}	Mn^{2+}
	Ca^{2+}	Mg^{2+}		Sr^{2+}	Mg^{2+}	Mg^{2+}
Least	Mg^{2+}					

[a] (1) Schnitzer and Hanson (1970); (2) Gamble and Schnitzer (1973).

“In-situ” Anomaly

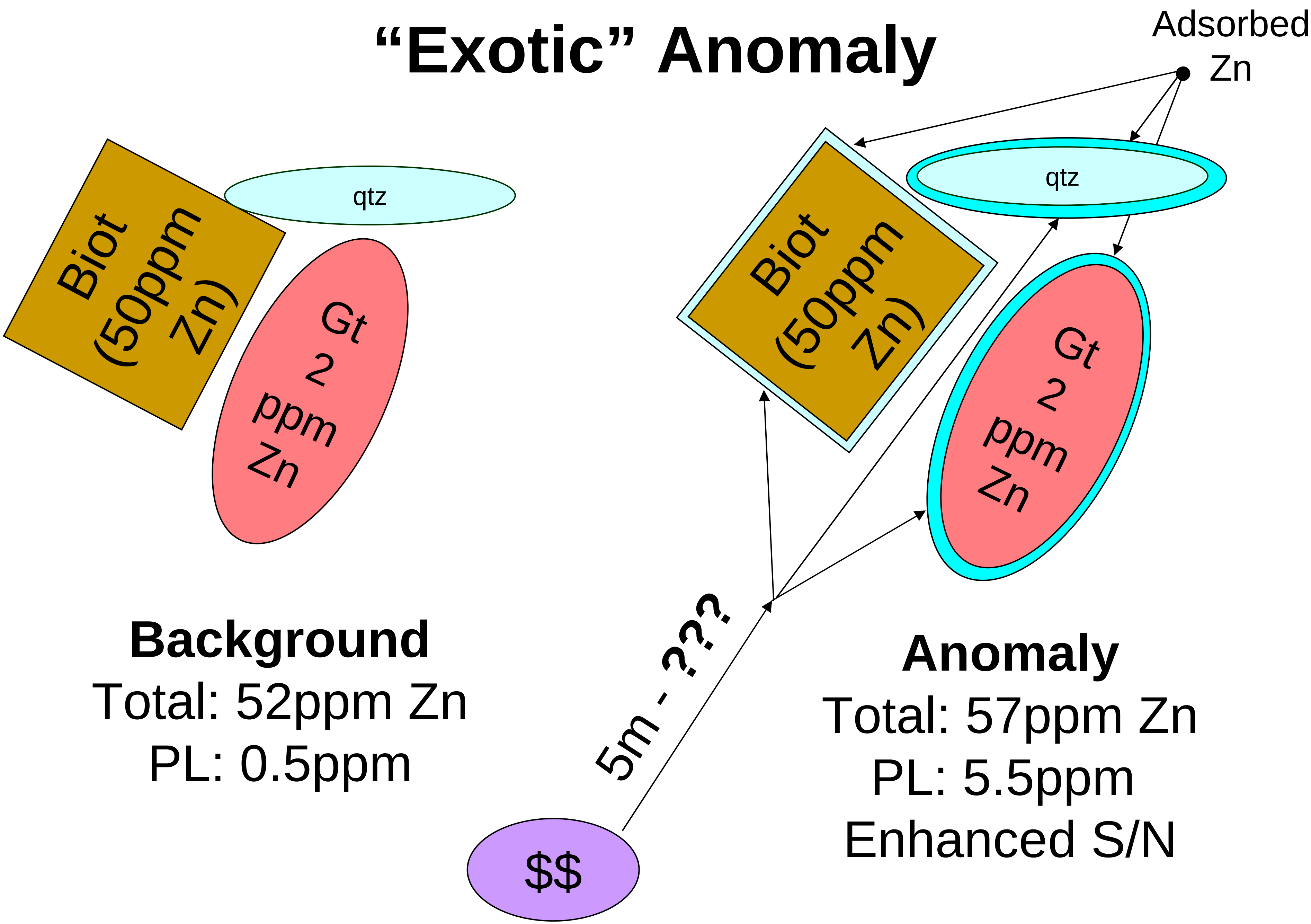


Background
52ppm Zn
Total analysis



Anomaly
250ppm Zn
Total Analysis

“Exotic” Anomaly

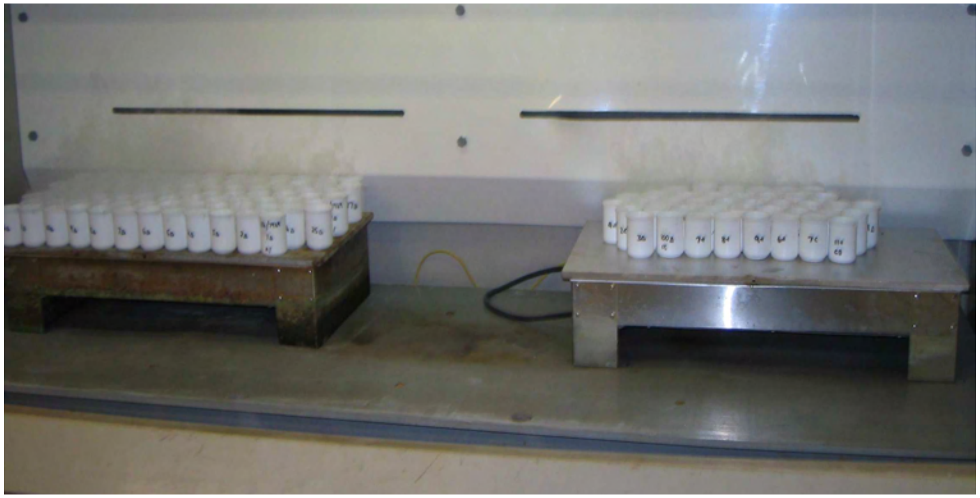


Background
Total: 52ppm Zn
PL: 0.5ppm

Anomaly
Total: 57ppm Zn
PL: 5.5ppm
Enhanced S/N

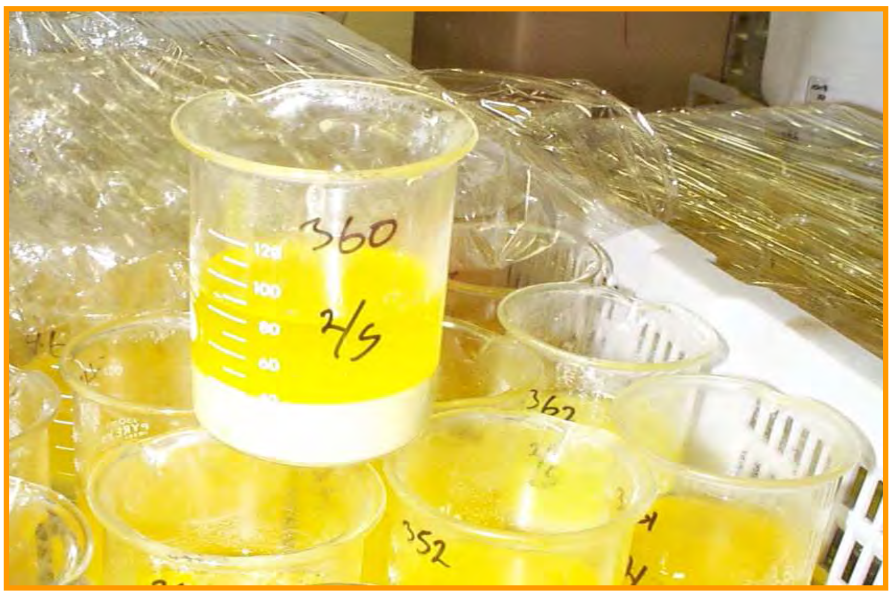
Methods of Analysis

Near Total and Robust Partial



HF – Based Digests

HF reacts with silicates (and is the most effective mineral acid for breaking up Si-O bonds) forming the volatile, unstable silicon tetrafluoride (SiF_4) which is lost on heating.



Aqua Regia– Based Digest

A mixture of concentrated HCl and HNO_3 in the ratio 3:1 is known as aqua regia.

It contains free Cl_2 and NOCl, and is therefore a powerful oxidising agent.

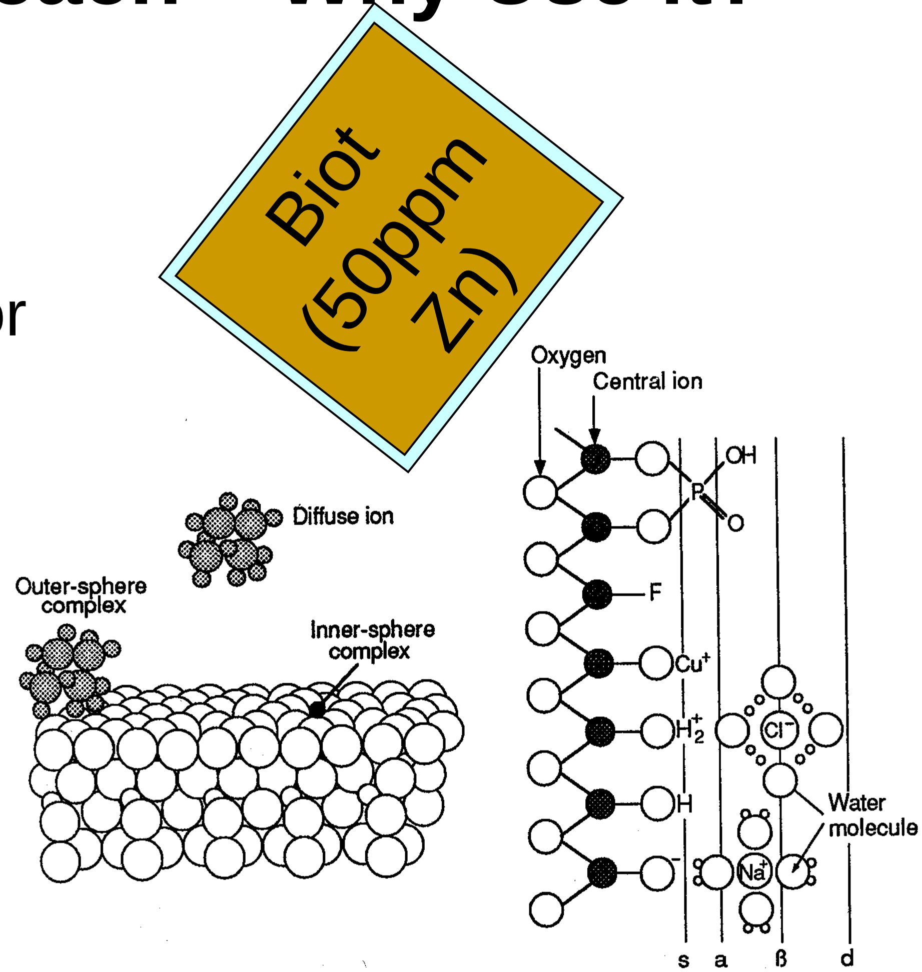
$$3HCl + HNO_3 \rightarrow 2H_2O + NOCl + Cl_2$$

Partial/Selective Leach – Why Use it?

- To specifically map that fraction of an element which has previously been in a free form and has been trapped or immobilised in the surficial environment

- Increased Signal to Noise Ratio

- By achieving points one and two, to attempt to detect mineralisation ***through overburden***



DIGESTION	EXTRACTED	COMMENTS
Deionized Water	Soluble cations, pH, conductivity	
Magnesium Chloride	Soluble and exchangeable cations	Releases only a small fraction of cations. Strongly affected by soil pH and variable re-absorption
EDTA	Exchangeable and weakly bound elements	Dissolves and complexes di- & trivalent cations, some organic complex metal.
Sodium Acetate pH 5	Adsorbed, exchangeable and carbonate	Metals in carbonates and weakly absorbed metals
Buffered Na Acetate	Metal in carbonates	Dissolves carbonate
Hydrogen Peroxide Ascorbic acid	Sulphides	Sulphides, a portion of organic complexes and some absorbed cations. Moderately stable to reabsorption
Ammonium Pyrophosphate	Metal ions from some organics	Acid pH extracts some FeO, alkali does not.
0.1M Hydroxylamine HCl in cold weak acid	Manganese oxides	Also dissolves amorphous FeO. At high pH re-precipitates some metals.

DIGESTION	EXTRACTED	COMMENTS
0.25M Hydroxylamine HCl in 0.25M hot HCl	Manganese and amorphous FeO	FeO extracted very sensitive to temperature.
Acid Ammonium Oxalate (Tamms Reagent)	Amorphous FeO	Also dissolves magnetite
Oxalic Acid	Amorphous & Crystalline FeO	Also some organics and sulphides
Sodium Dithionite	Crystalline & Amorphous FeO	Metal may re-precipitate as sulphide
Cold 4M HCl	Amorphous and some crystalline FeO, MnO, Weakly Bound	Non Specific, but stable
Regoleach (Proprietary)	'Loosely bound on organic matter, clays, as carbonates, sulphates or amorphous hydrated FeO and MnO'	Moderately strong 'acid' reagent, relatively high proportion of FeO extracted in arid environments
MMI A (proprietary)	Cd Cu Pb Zn	Very weakly bound metal, small fraction from exterior of soil particles
MMI B (proprietary)	Ag Au Co Ni Pd	Very Weakly bound, small fraction from exterior of soil particles
Enzyme Leach(proprietary)	Amorphous MnO	Weak mediated hydrogen peroxide attack, very low proportions extracted

Partial Leach, Complications & factors that need to be controlled and that impact on interpretation

Sample Preparation - if the temperature of drying exceeds 40C, adsorbed metals could become incorporated into mineral structures and therefore unavailable to weak leaches. Anaerobic conditions in sample can change element availability.

Results are influenced by the sample matrix. Buffers are often used to maintain a constant pH during the extraction reaction ***It may be difficult to maintain pH across different soil types***

Analytical problems - Extraction varies f(time,temperature). Temperature influences the rate of reaction. In most cases the extraction efficiency will stabilise after a certain time has elapsed but all leaches must be carried out for the same duration. Related to……

Re-adsorption - of metals after dissolution (on glassware, sediment, organics)

Batch to batch variations. Inadequate QAQC

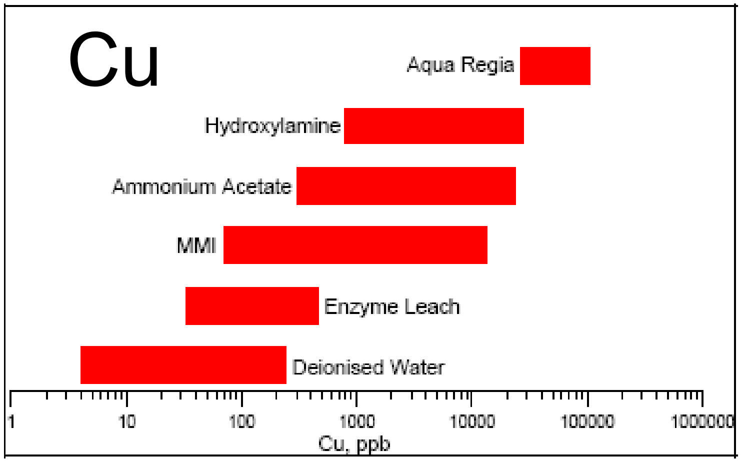
Ratio of sample weight to reagent volume

The more 'gentle' the leach, the more problematic the analysis

….So there are many methods available

&

The variation in metal extracted by different leaches is ***extreme***



Figu
trac
Spe
20 c

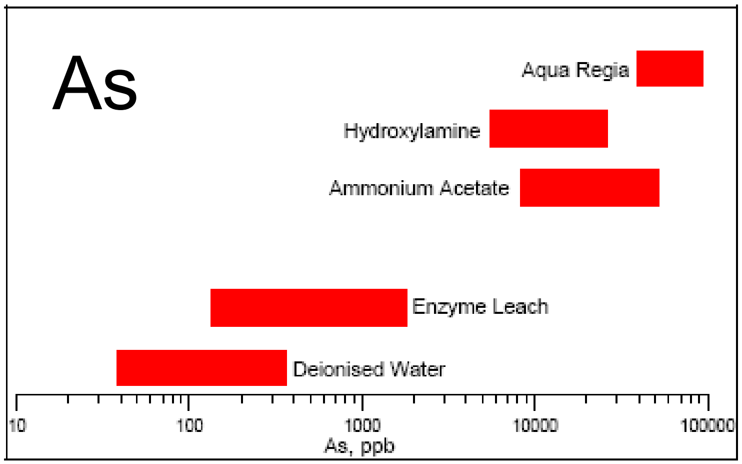


Figure 8. Ranges of As extracted by five leaches for 61 Spence soils collected at 10-20 cm depth.

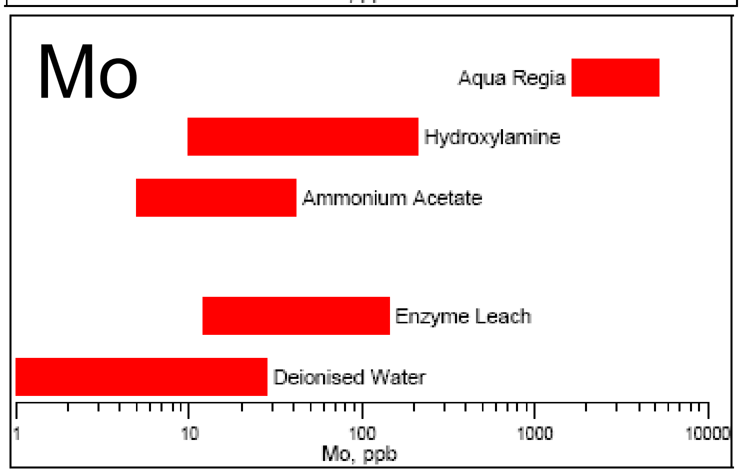


Figure 9. Ranges of Mo extracted by five leaches for 61 Spence soils collected at 10-20 cm depth.

From:

"Deep Penetrating Geochemistry Phase II"

by Eion Cameron and colleagues

OVERVIEW: PRINCIPLES AND COMPARISONS OF LEACHES FOR DEEP EXPLORATION

Eion M. Cameron

Partial Leach, Complications & factors that need to be controlled – batch & lab sampling variance

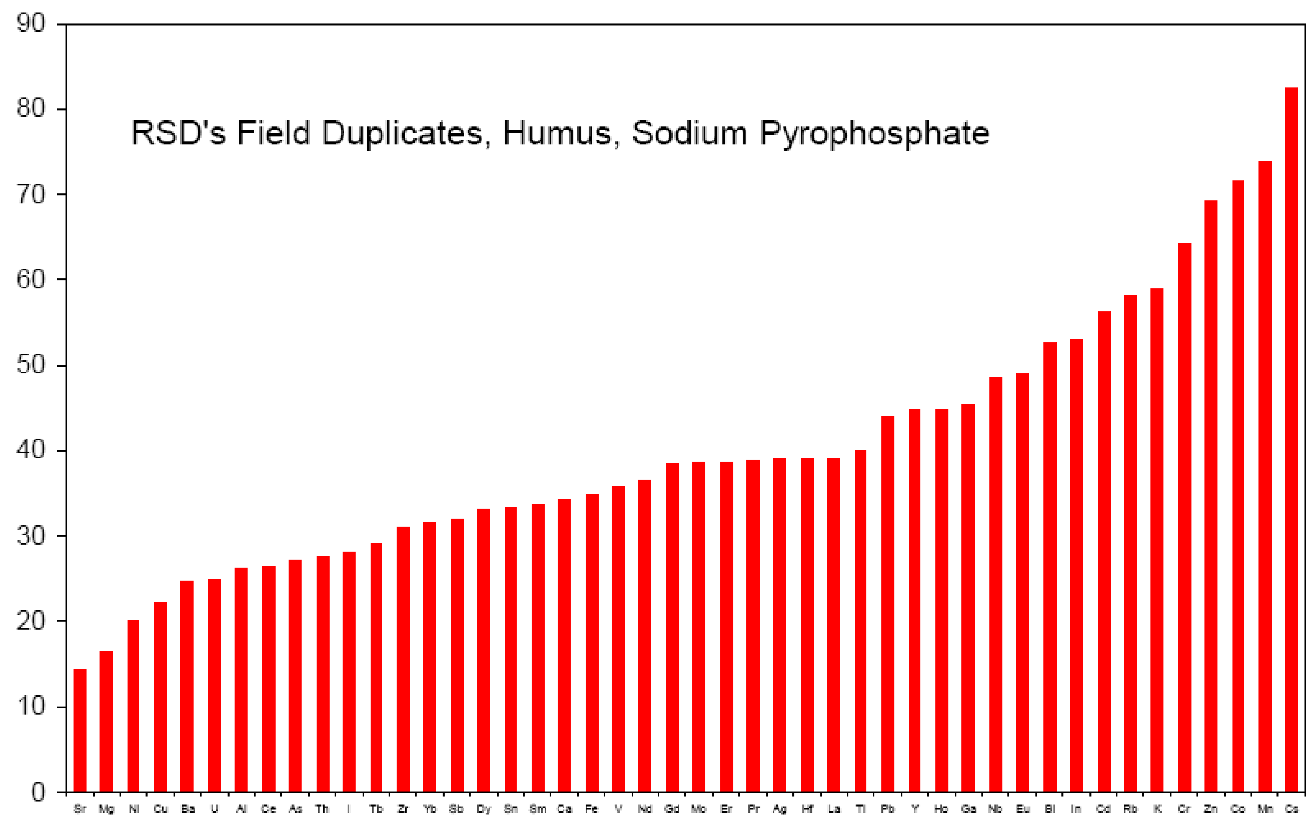


Figure 4. RSD's for field duplicates, humus by sodium pyrophosphate.

SAMPLING AND ANALYTICAL PRECISION, ABITIBI PROGRAM, 1999

Eion M. Cameron

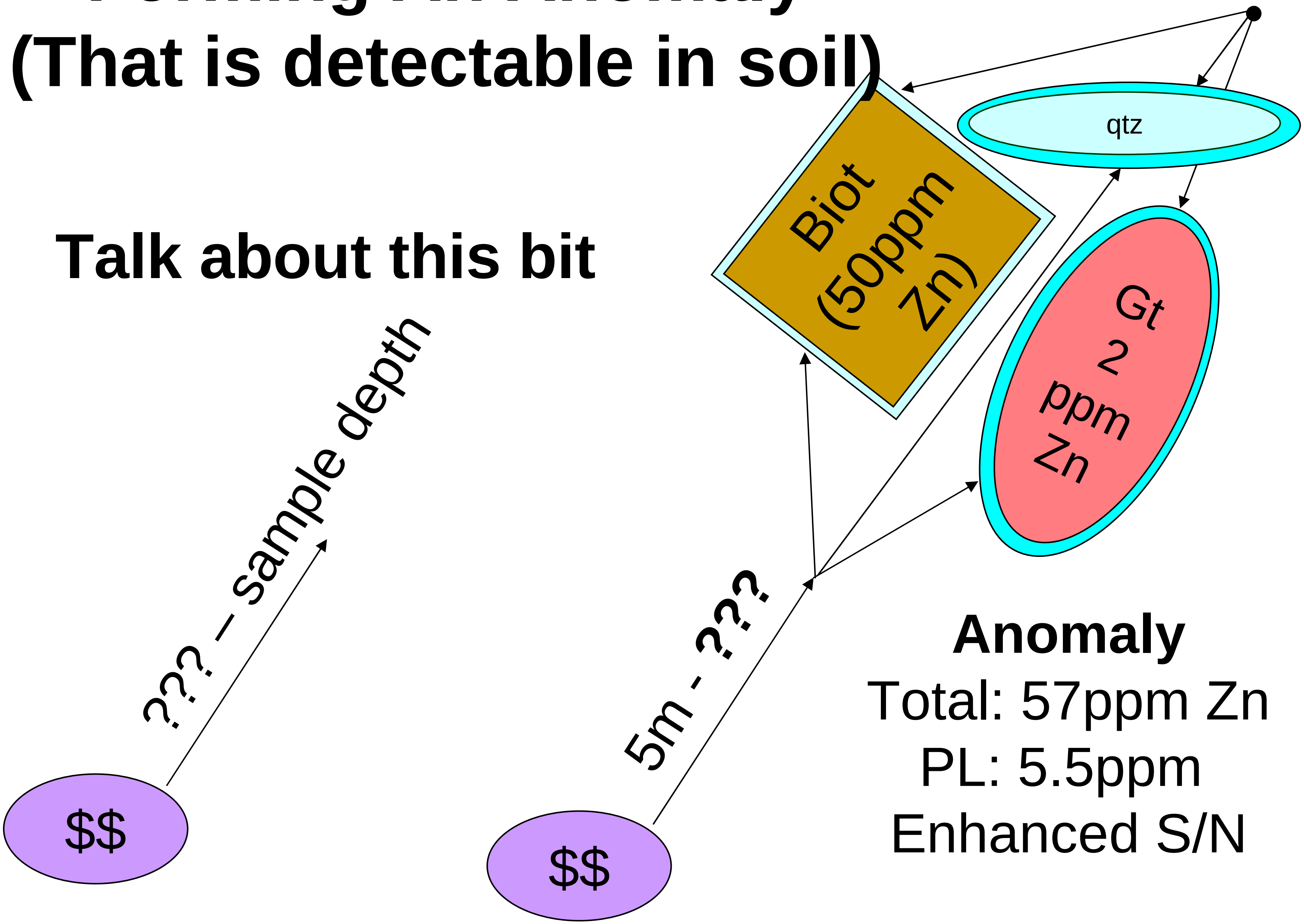
From:

"Deep Penetrating Geochemistry Phase II"

by Eion Cameron and colleagues

Forming An Anomaly (That is detectable in soil)

Talk about this bit



Anomaly
Total: 57ppm Zn
PL: 5.5ppm
Enhanced S/N

Non-Controversial Methods of Anomaly Formation

Clastic dispersion (downslope movement, sheet wash etc.)

Concentration in lateritic materials that become lag pavements

Concentration in soil profiles in response to evaporative processes (A and B horizons)

Recycling via vegetation

Bio-turbation (termites, burrowing animals)

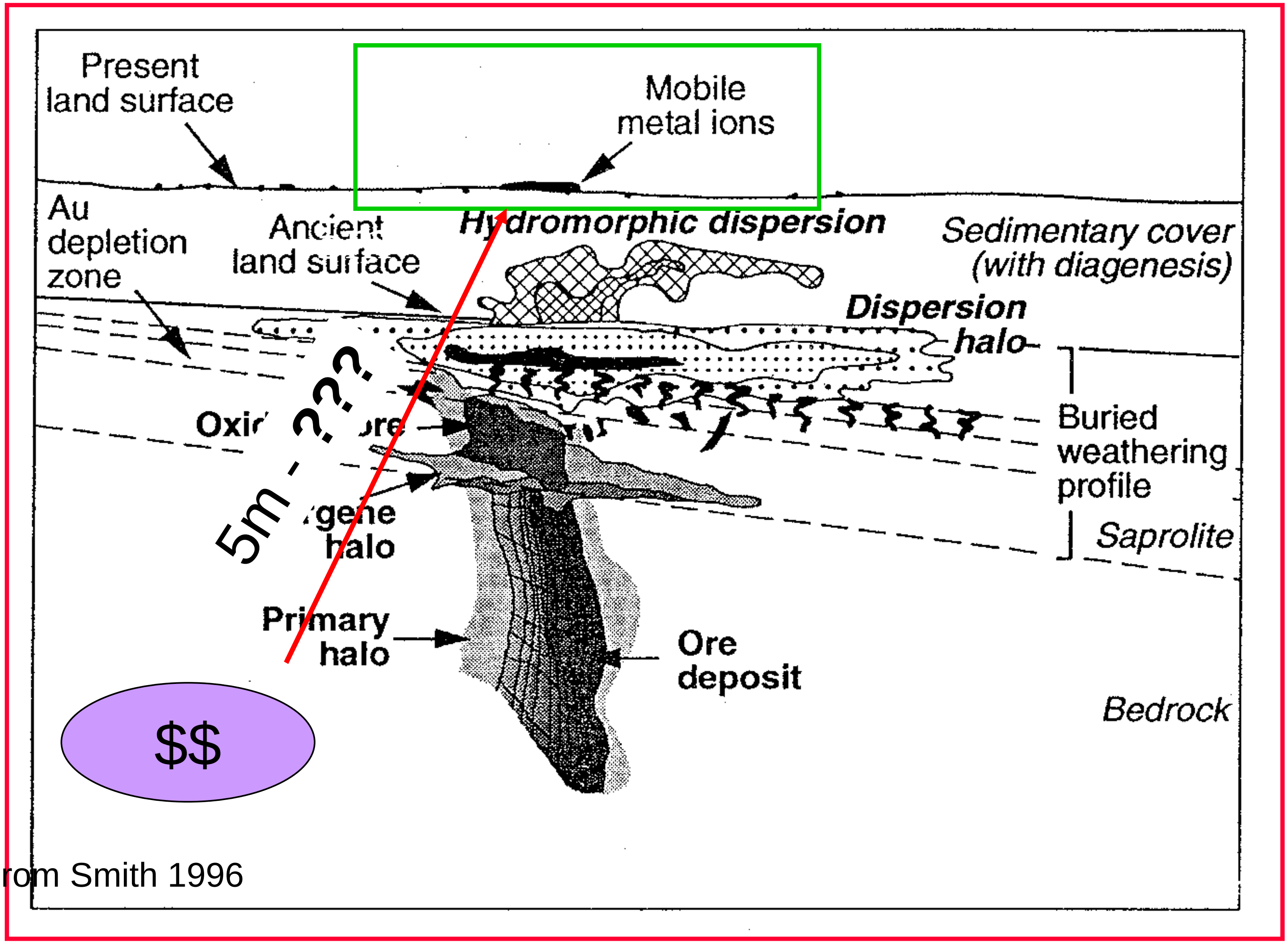
GEOCHEMICAL EXPLORATION IN AREAS AFFECTED BY TROPICAL WEATHERING — AN INDUSTRY PERSPECTIVE

Mazzucchelli, R.H.

Exploration Geochemistry

In "Proceedings of Exploration 97: Fourth Decennial International Co

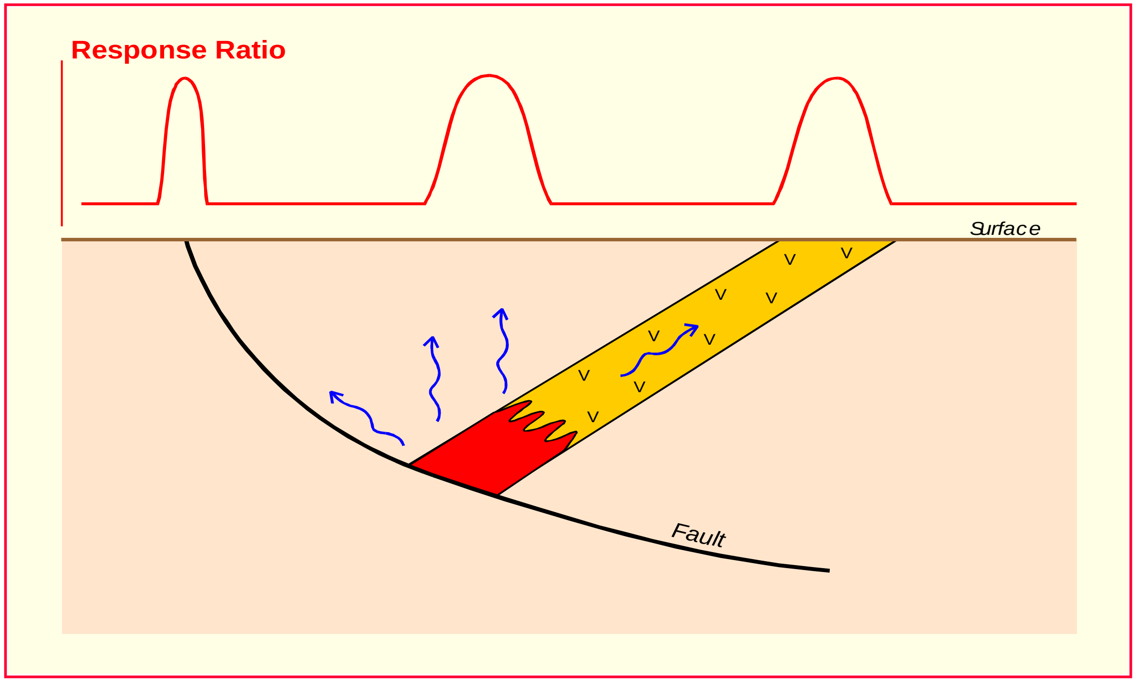
CSIRO Model



From Smith 1996

Anomaly Formation - Mechanism of Transport of Weakly Held Ions

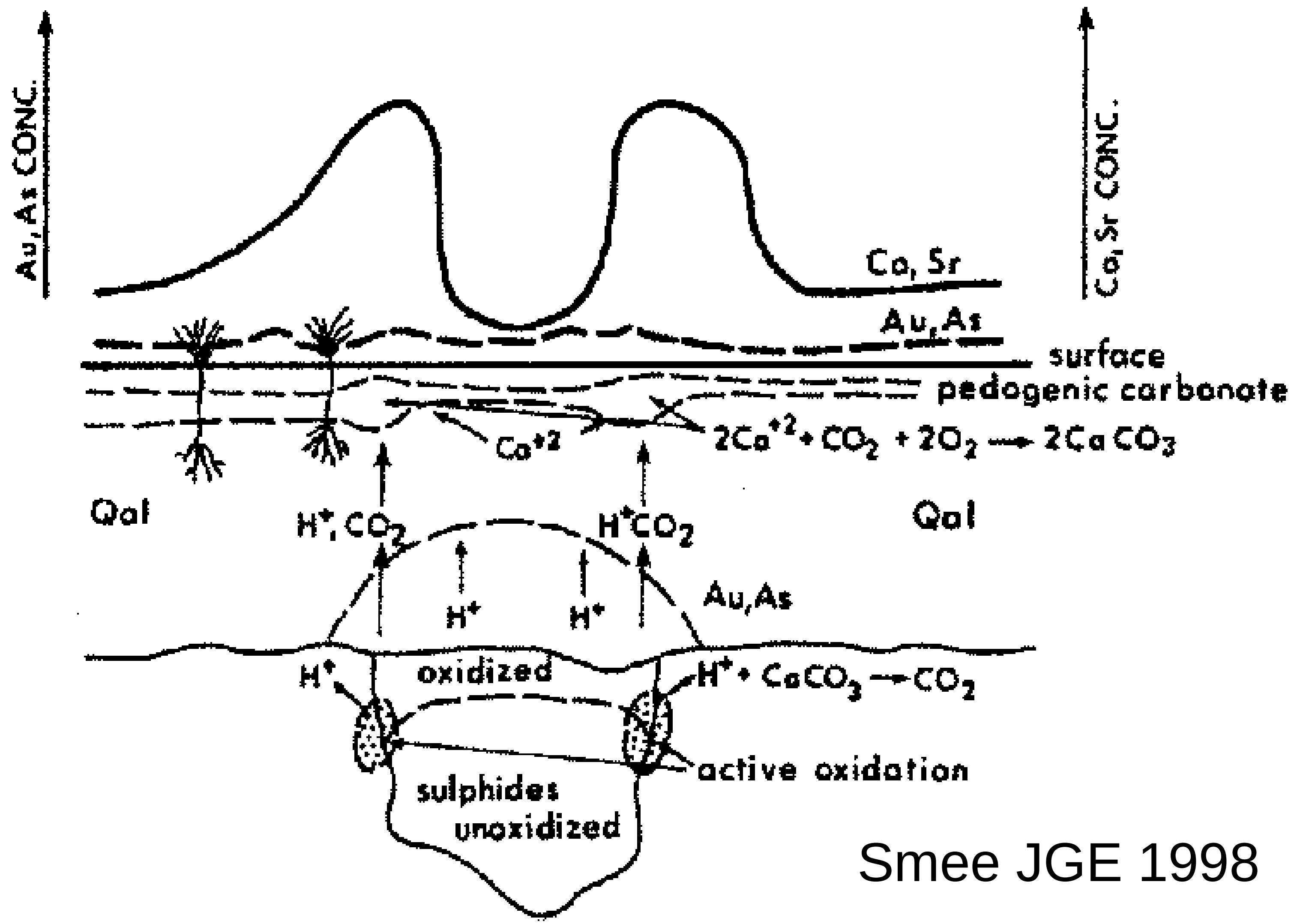
- Gaseous movement
- Fluid movement
- Faults and Fractures
- Electrogeochemical cell/ pH Eh gradient



What Rate?

Groundwater m/year
Diffusion cm/hour
Geogas - supersonic!

Anomaly Formation



Smee JGE 1998

Negative Ni in Soil Anomaly
Semi-arid Zone

eg, courtesy Dr Nigel Brand

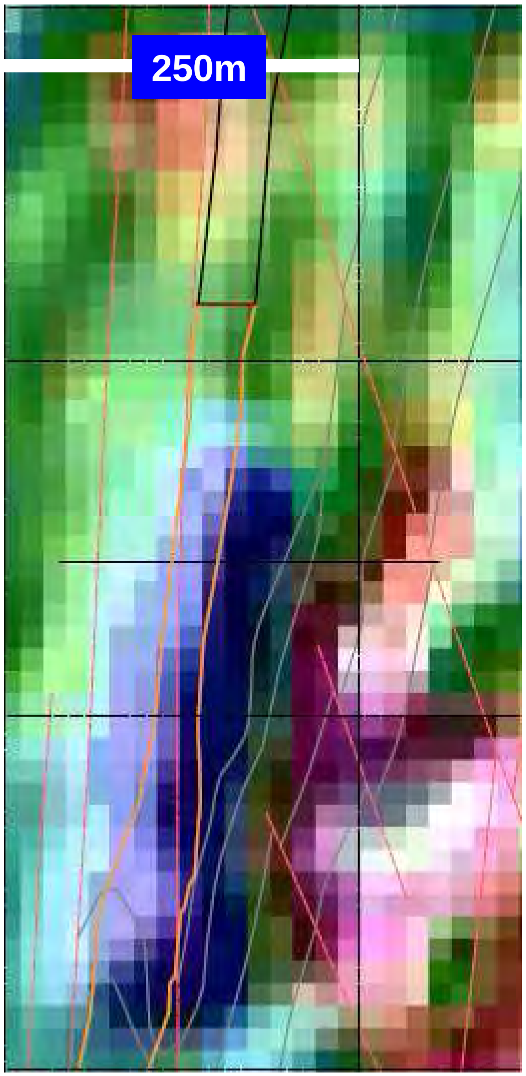


Image of Ni in drill holes

The traverse of the anomalous values depicts the mass sulphide orebody

Image of Ni in soils (-250um, AR)

A negative anomaly in soils directly overlying massive nickel sulphide mineralisation

The oxidised nickel sulphides lie within 6 m of the surface.

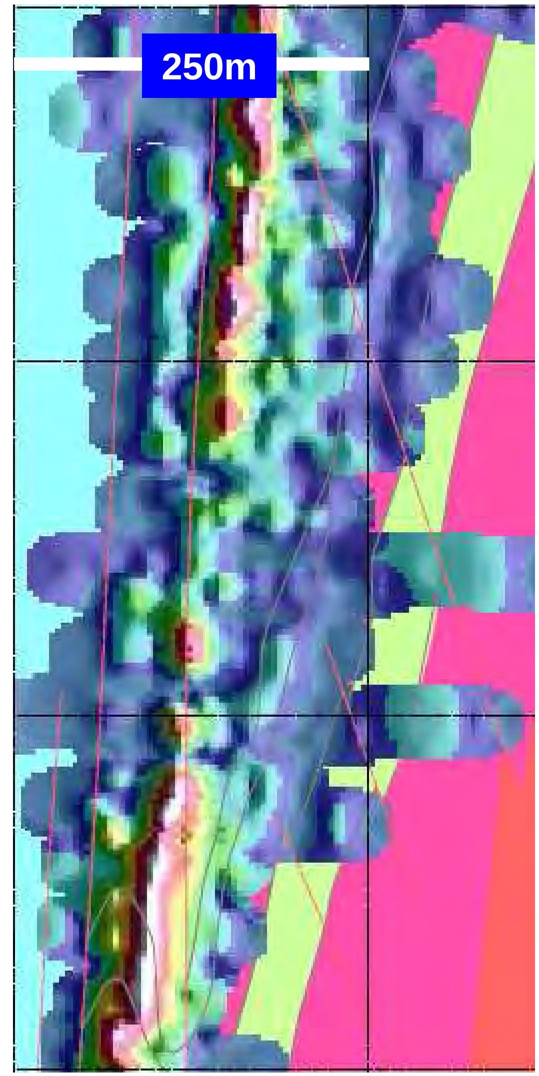


Image of Ni in soils (-250um, AR)

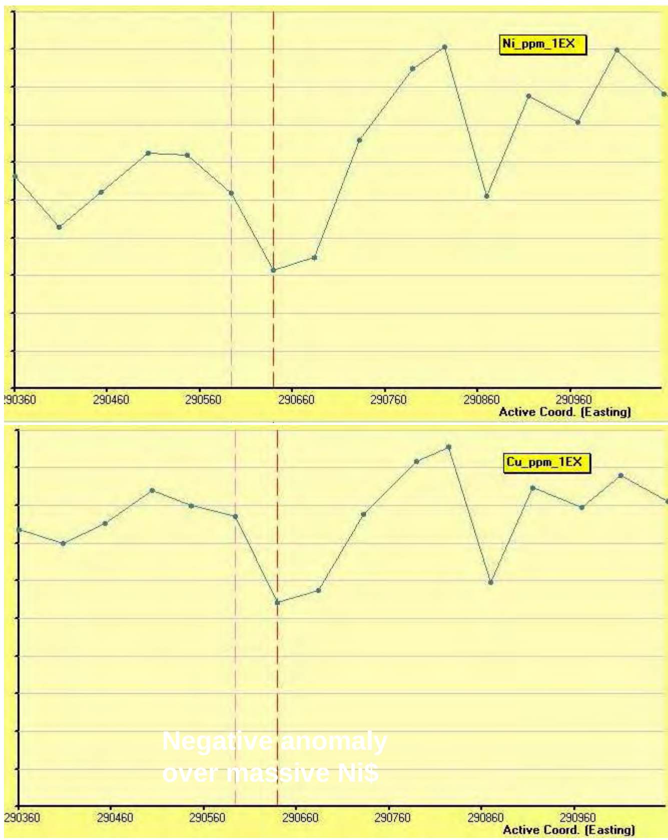
A negative anomaly in soils directly overlying massive nickel sulphide mineralisation

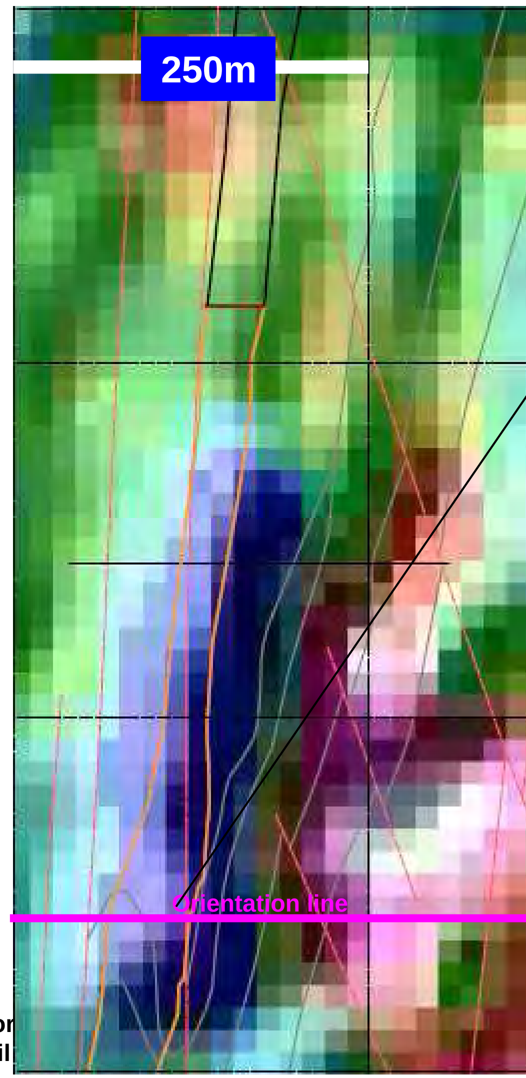
The oxidised nickel sulphides lie within 6 m of the surface.

eg, courtesy Dr Nigel Brand

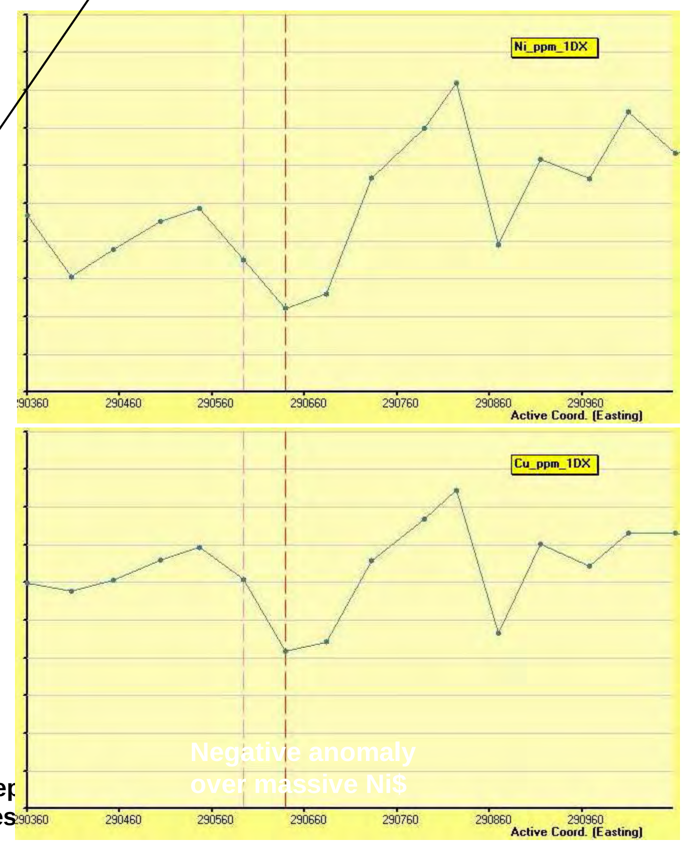
1 pH Unit Low

Four acid digestion





Aqua regia digestion

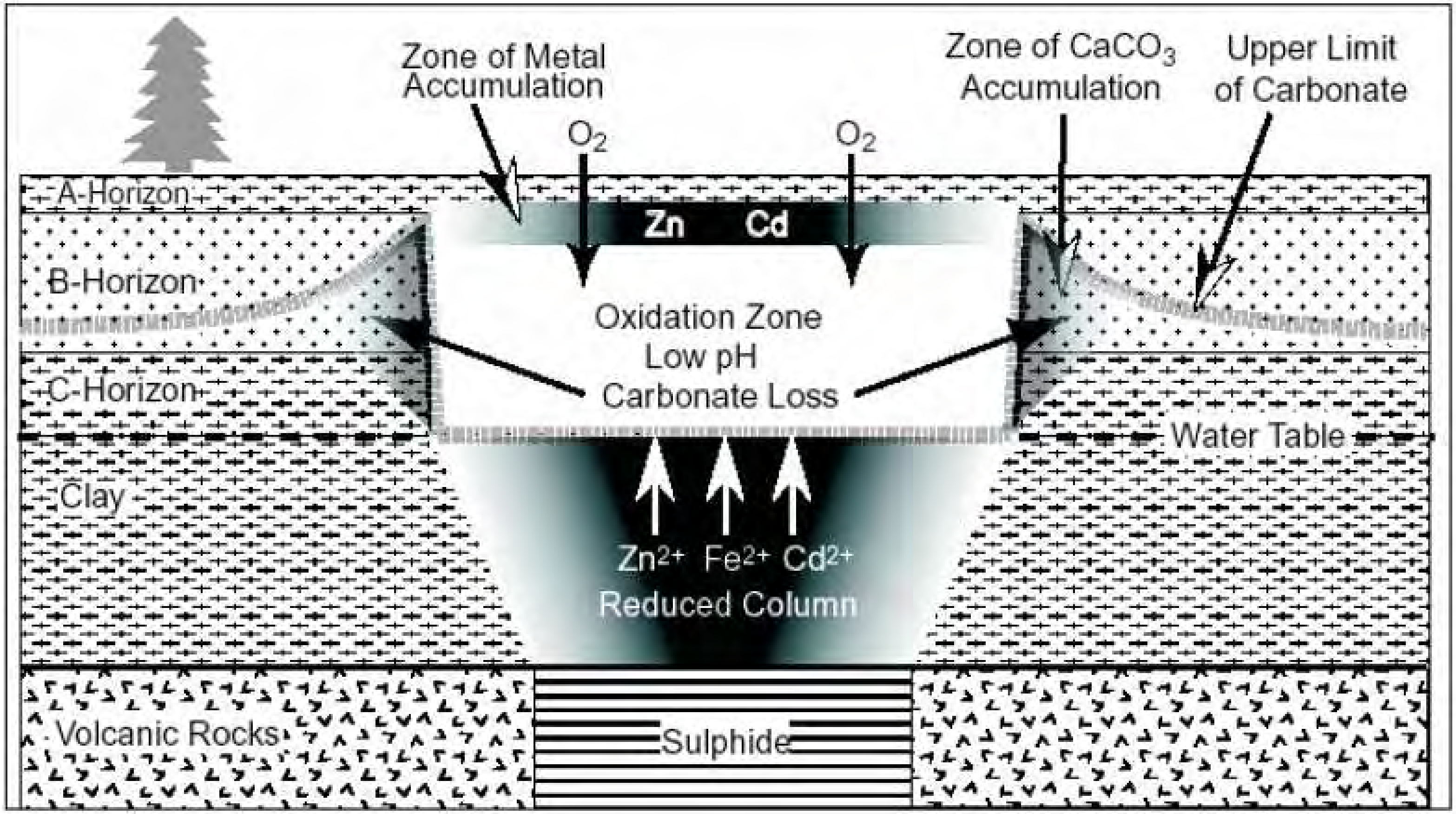


Examples From Wet Glaciated Areas

Secondary geochemical signatures in glaciated terrain

G.E.M. Hall[1], S.M. Hamilton[2], B. McClenaghan[1], E.M. Cameron[3]

[1]*Geological Survey of Canada (GSC), 601 Booth St, Ottawa, Ontario K1A 0E8, Canada*
[2]*Ontario Geological Survey (OGS), 933 Ramsey Lake Road, Sudbury, Ontario, P3E 6B5, Canada*
[3]*Eion Cameron Geochemical Inc., 865 Spruce Ridge Road, Carp, Ontario, Canada K0A 1L0*



Model by Hamilton for development of anomalies through exotic overburden at Cross Lake. A reduced chimney or column is generated above the sulphide body. Reduced metal ions are oxidised at and above the water table by infiltrating oxygen and thereby generate H^+ ions which in turn dissolve carbonate (from C-horizon clay soils) that reprecipitates on the flanks of the zone of low pH. From Cameron et al. (2004).

Examples From Wet Glaciated Areas

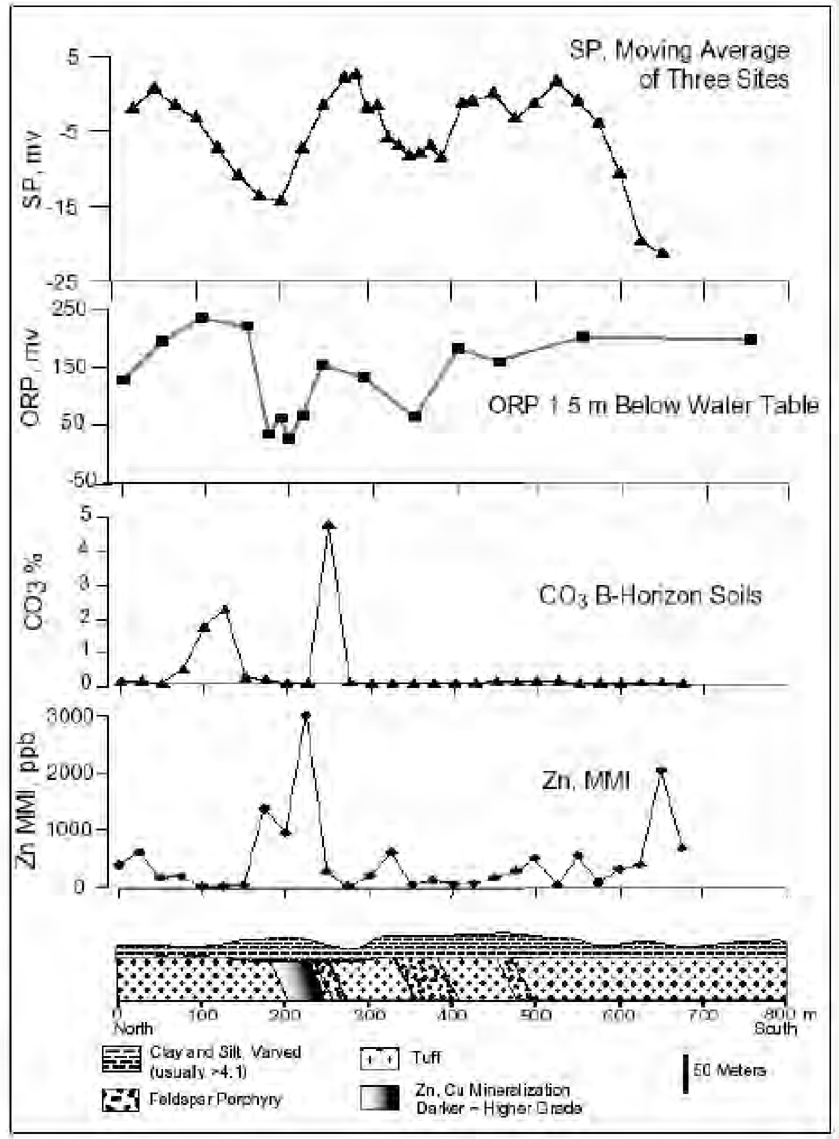
Cross Lake – Canada
OMET & CAMIRO

Secondary geochemical signatures in glaciated terrain

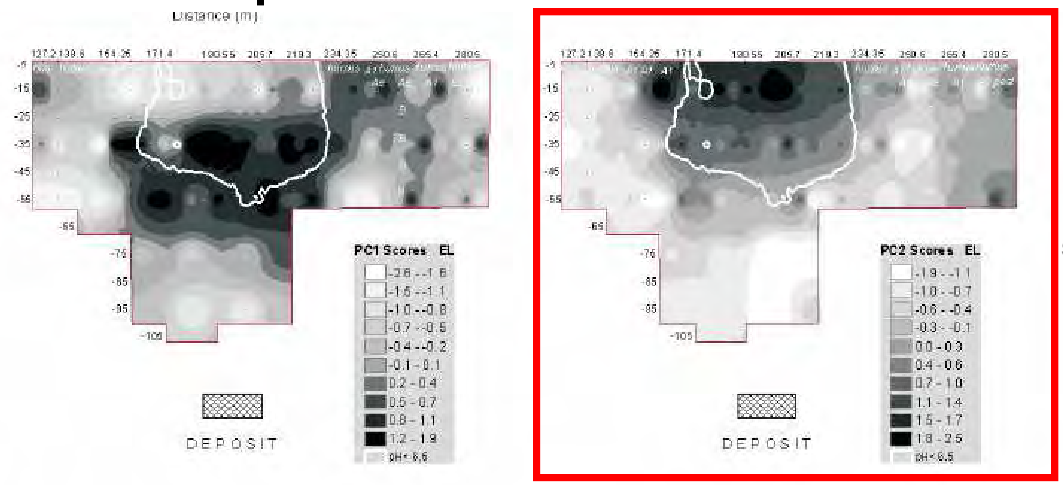
G.E.M. Hall[1], S.M. Hamilton[2], B. McClenaghan[1], E.M. Cameron[3]

[1]Geological Survey of Canada (GSC), 601 Booth St, Ottawa, Ontario K1A 0E8, Canada
[2]Ontario Geological Survey (OGS), 933 Ramsey Lake Road, Sudbury, Ontario, P3E 6B5, Canada
[3]Eion Cameron Geochemical Inc., 865 Spruce Ridge Road, Carp, Ontario, Canada K0A 1L0

Line 6: spontaneous potential (SP), ORP measurements of redox conditions at 1.5 m below water table, carbonate content of B-horizon soils, and zinc by MMI sampled at 10-25 cm below decomposing vegetation; from Cameron et al. (2004).



Examples From Wet Glaciated Areas

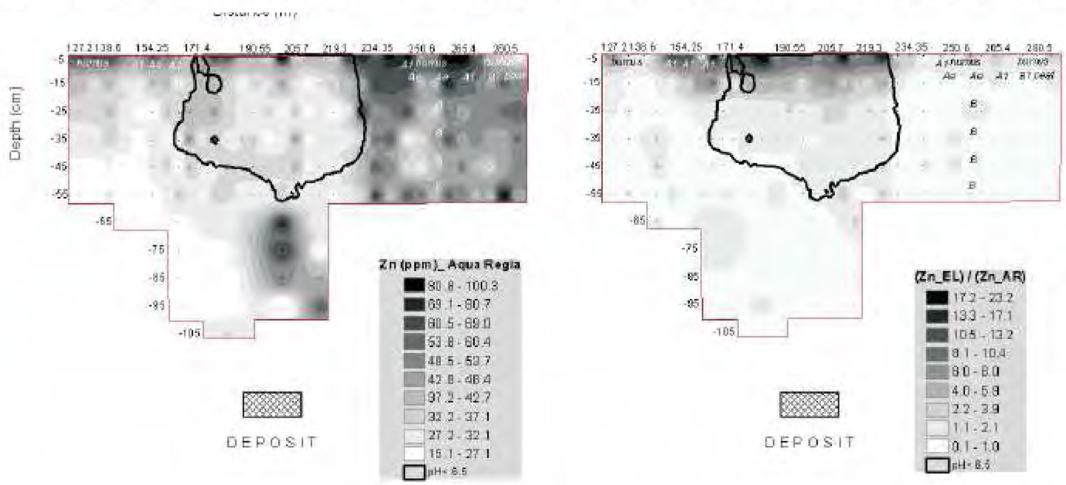


Secondary geochemical signatures in glaciated terrain

G.E.M. Hall[1], S.M. Hamilton[2], B. McClenaghan[1], E.M. Cameron[3]

[1]Geological Survey of Canada (GSC), 601 Booth St, Ottawa, Ontario K1A 0E8, Canada
[2]Ontario Geological Survey (OGS), 933 Ramsey Lake Road, Sudbury, Ontario, P3E 6B5, Canada
[3]Eion Cameron Geochemical Inc., 865 Spruce Ridge Road, Carp, Ontario, Canada K0A 1L0

Figure 6. Distribution of (a) PC1 (REEs, HFSEs) and (b) PC2 (Zn, pH (-), Cu (-), Ba, Tl, Rb) for Enzymeh leach applied to the trench samples on Line 6. PC2 coincident with the pH low near surface above mineralisation.



Remember Smee

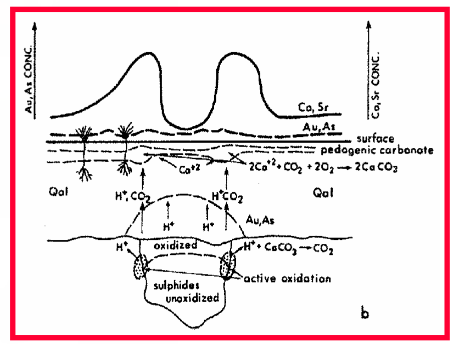
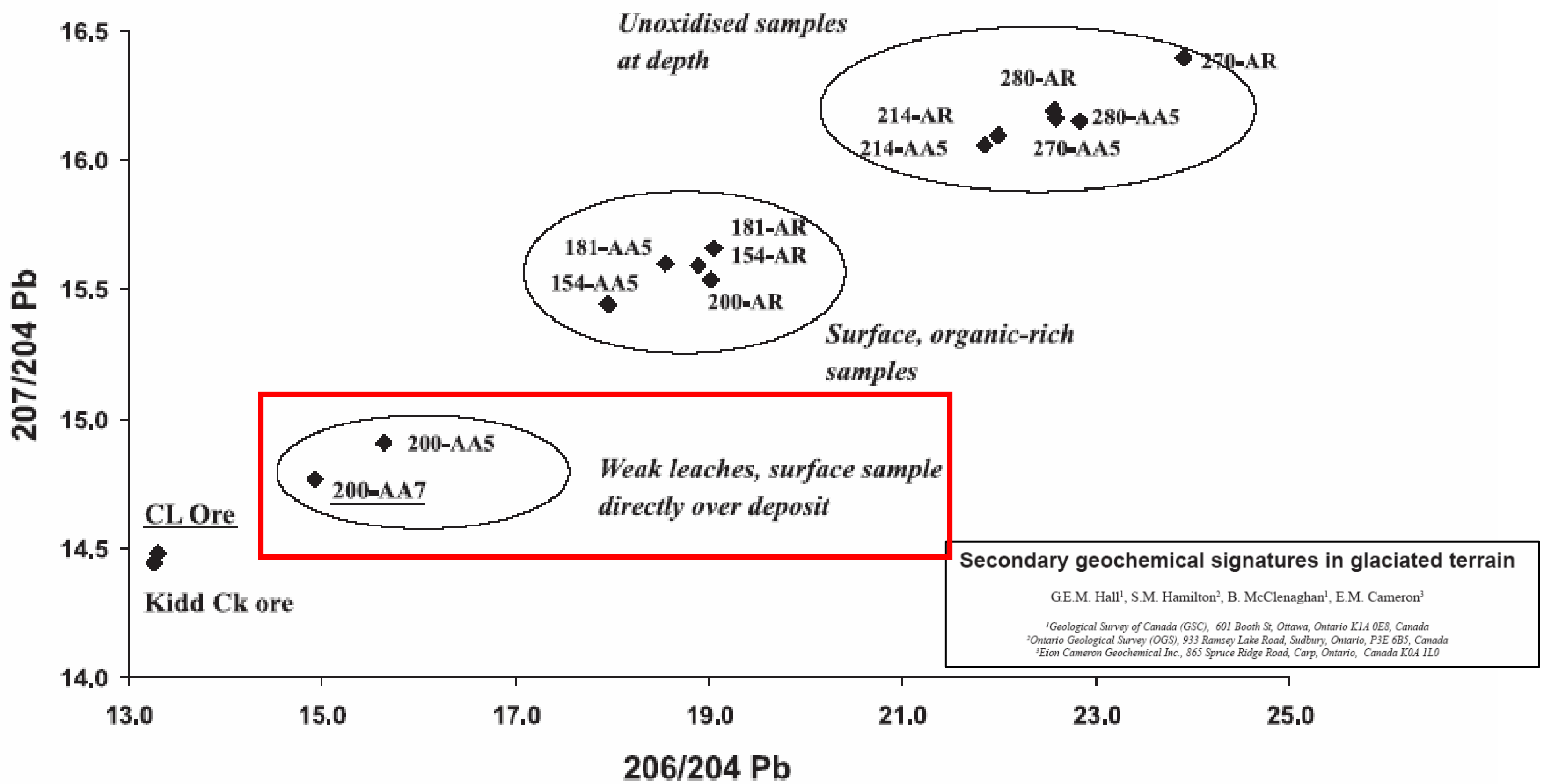


Figure 5. Distribution of (a) zinc by aqua regia and (b) (zinc by Enzymeh leach)/(zinc by aqua regia) x10^{-3} in trench samples on Line 6, showing completely different patterns.

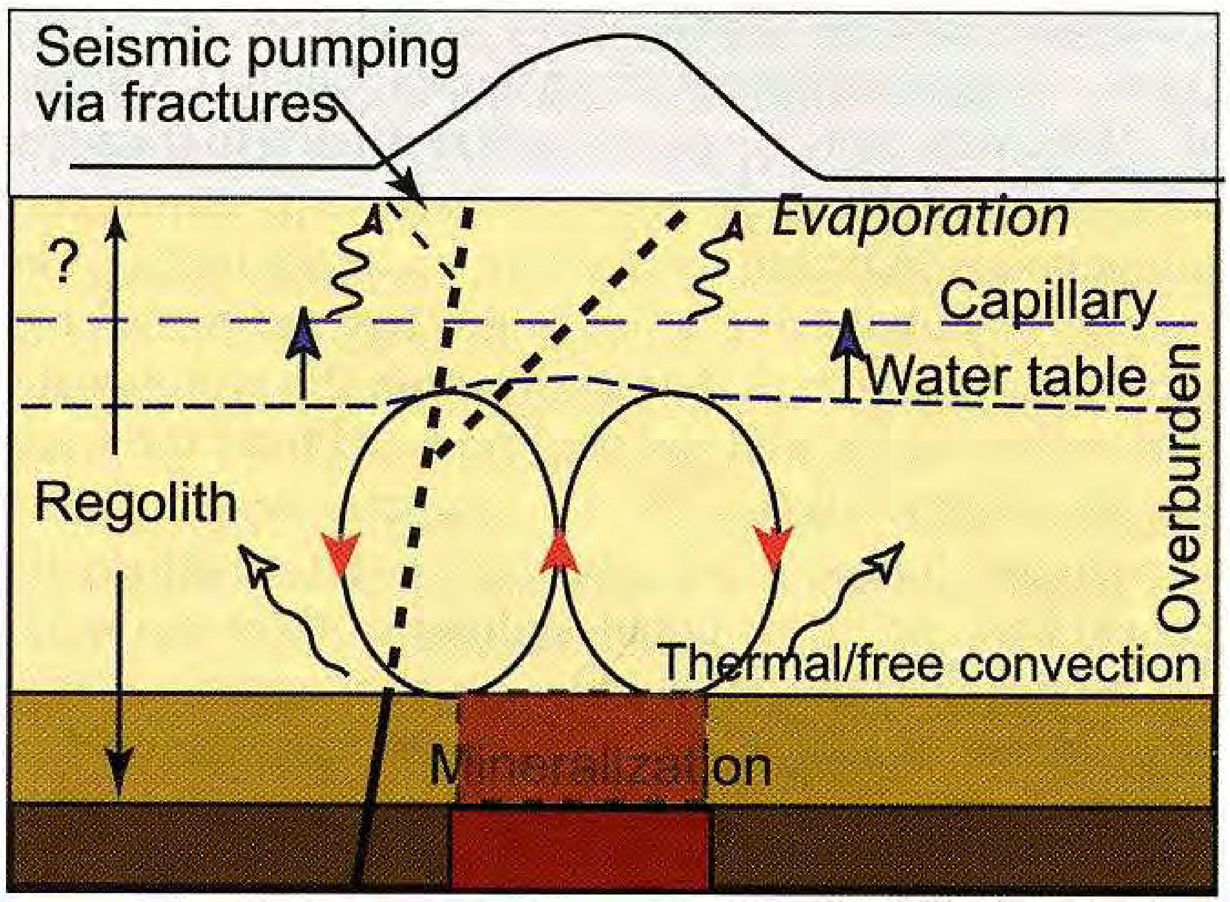
Examples From Wet Glaciated Areas

Pb Isotope Evidence for Movement Through Cover



8. Lead isotopic signatures (by TIMS) of samples at 154, 181, 200, 214, 270 and 280 m south collected from the Line 6 trench, leached in sequence by ammonium acetate pH 7(AA7), ammonium acetate pH 5 (AA5), and aqua regia (AR). The AA7 signature of sample 200 (directly over the VMS mineralisation at depth, in the Ae-horizon) is close to that of the Cross Lake ore.

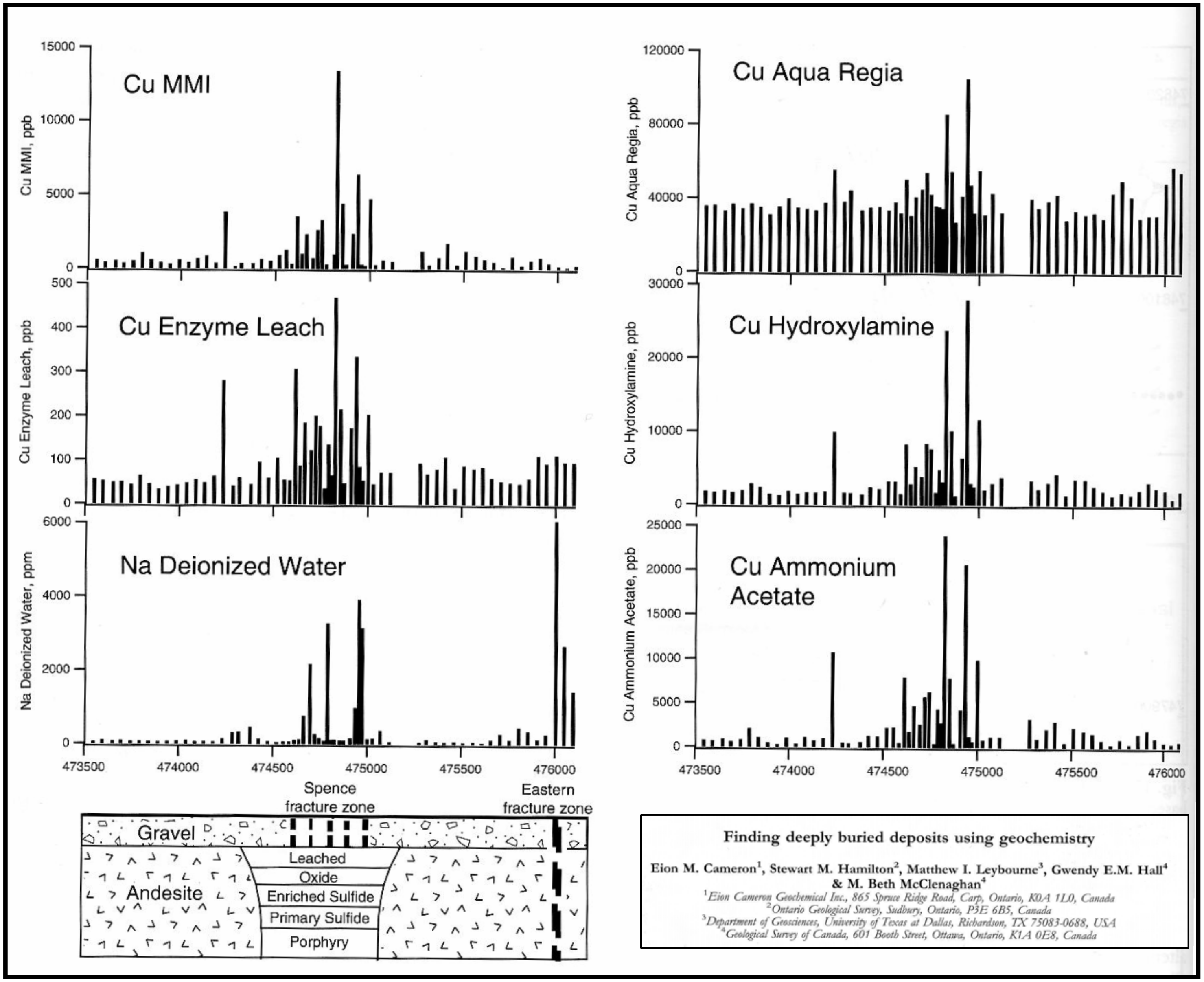
Anomaly Formation – Seismic Pumping



From CRC-LEME Newsletter

Examples from Arid and Hyper-Arid Climates – Spence, Chile

Note, Increased signal/noise in the partial methods



Anomaly Formation – Fracture Control (arid zone)

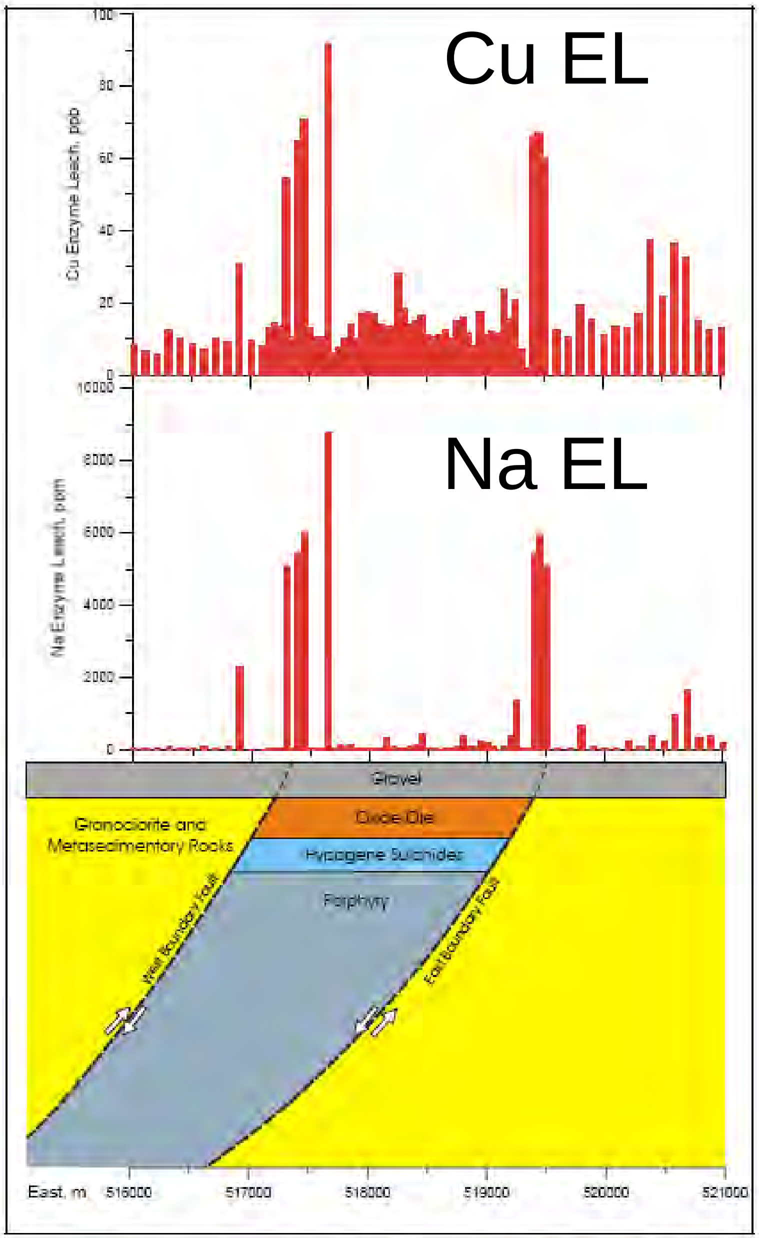


Figure 10. East-west cross section of the Gaby Sur deposit along line 7412500N showing the relationship between anomalies for Na and Cu by Enzyme Leach to the underlying geology.

From:

"Deep Penetrating Geochemistry Phase II"

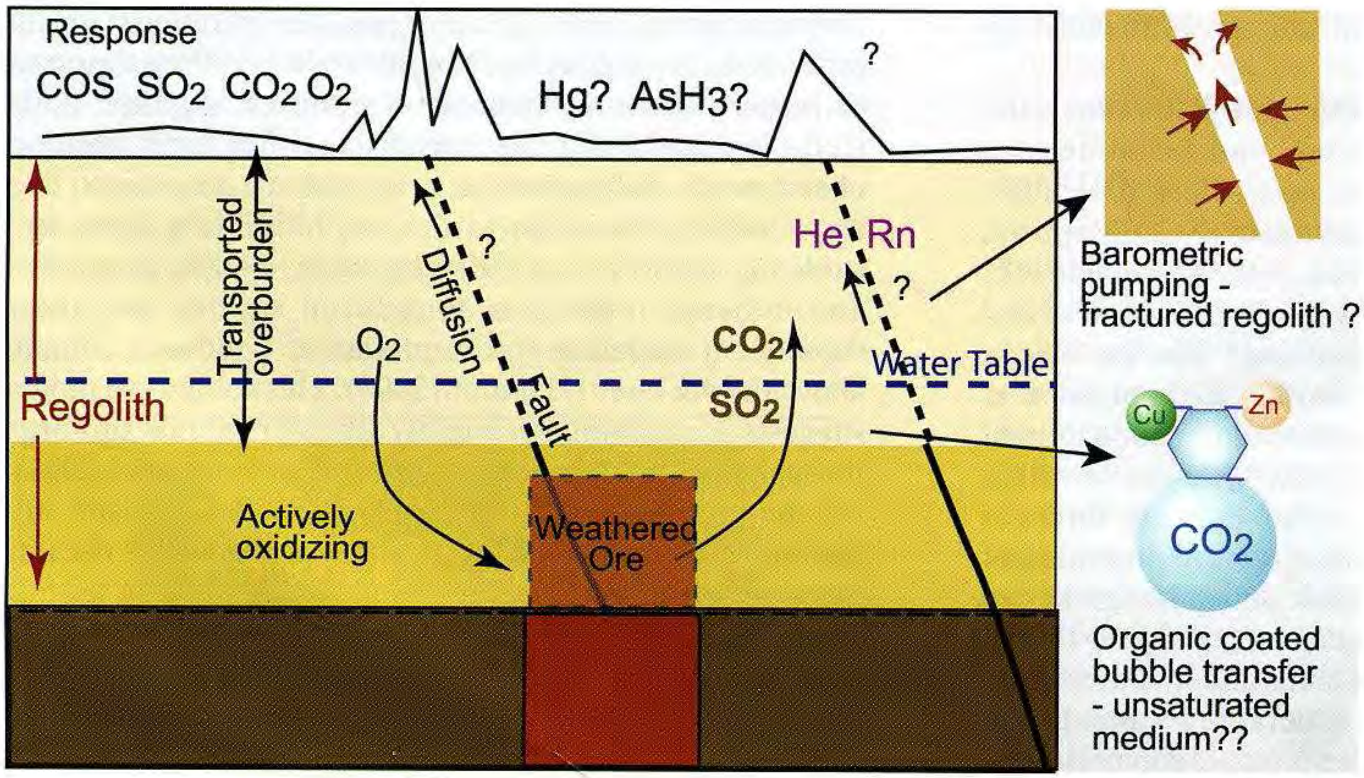
by Eion Cameron and colleagues

OVERVIEW: STRUCTURAL CONTROL ON THE FORMATION OF SURFACE GEOCHEMICAL ANOMALIES

Eion M. Cameron

Gaby Sur

Soil Gas



Figures from a recent issue of Explore drawn by CRC-LEME staff

Soil Gas

Gases associated with ore-forming substances in fault zones, the main routes of ore solution migration (CO_2, H_2, more rarely hydrocarbon gases, occasionally freons and ammonia);

Gases generated in zones of sulphide oxidation (CO_2, H_2S, SO_2, smaller amounts of CS_2 and COS and negligible O_2);

Gases generated by the thermal influence of intrusions and hydrothermal solutions on sediments and organic matter (H_2, heavy hydrocarbon gases, CO_2);

Gases generated by radioactive decay and radiolytic decomposition (Rn, He, Ar, also H_2 and heavy hydrocarbon gases mainly homologues of methane).

Soil Gas

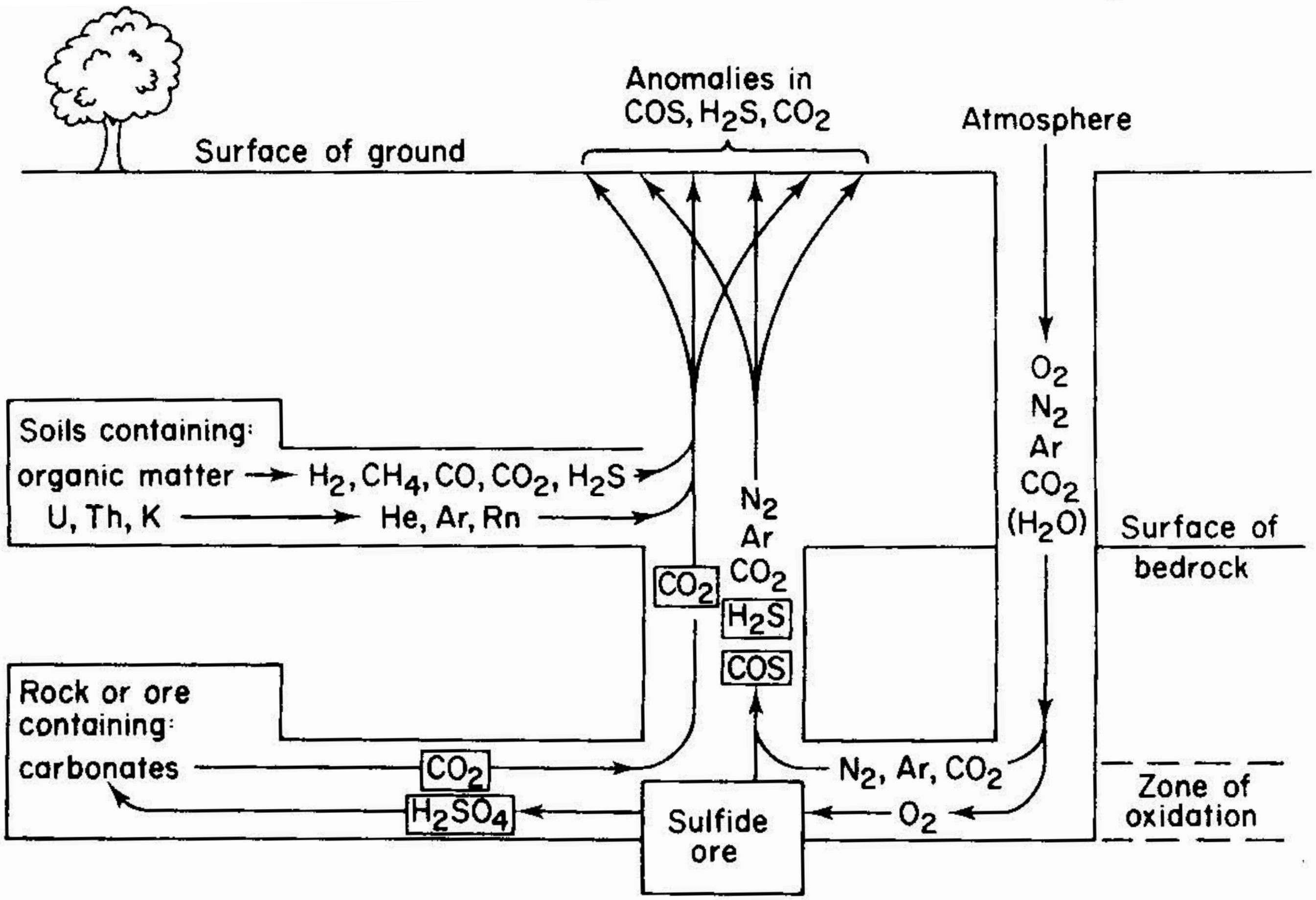


Fig. 18.1b. Diagram of sources and migration of some gases over an oxidizing sulfide deposit.

From Rose, Hawkes and Webb 1979

Soil Gas

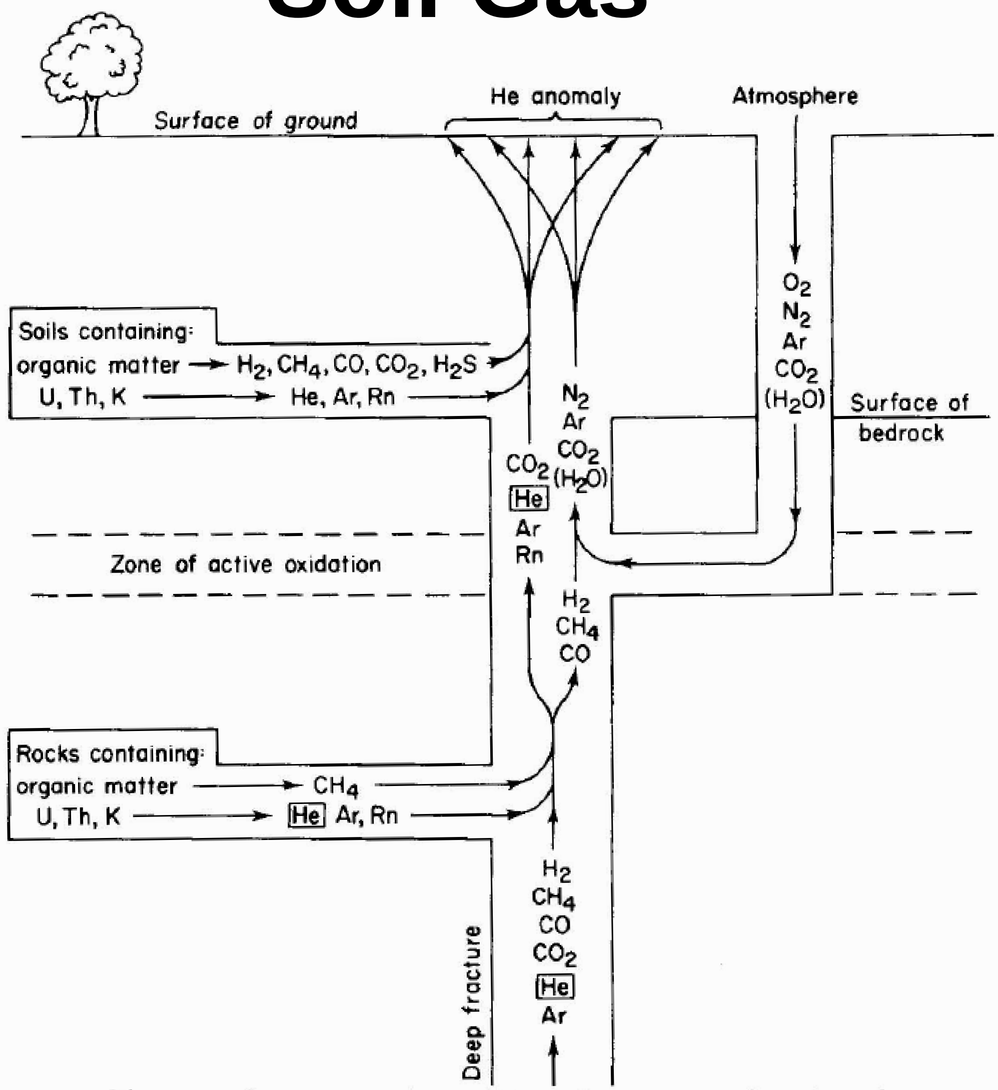


Fig. 18.1a. Diagram of sources and migration of some gases in a deep fracture zone.

From Rose, Hawkes and Webb 1979

Soil Gas

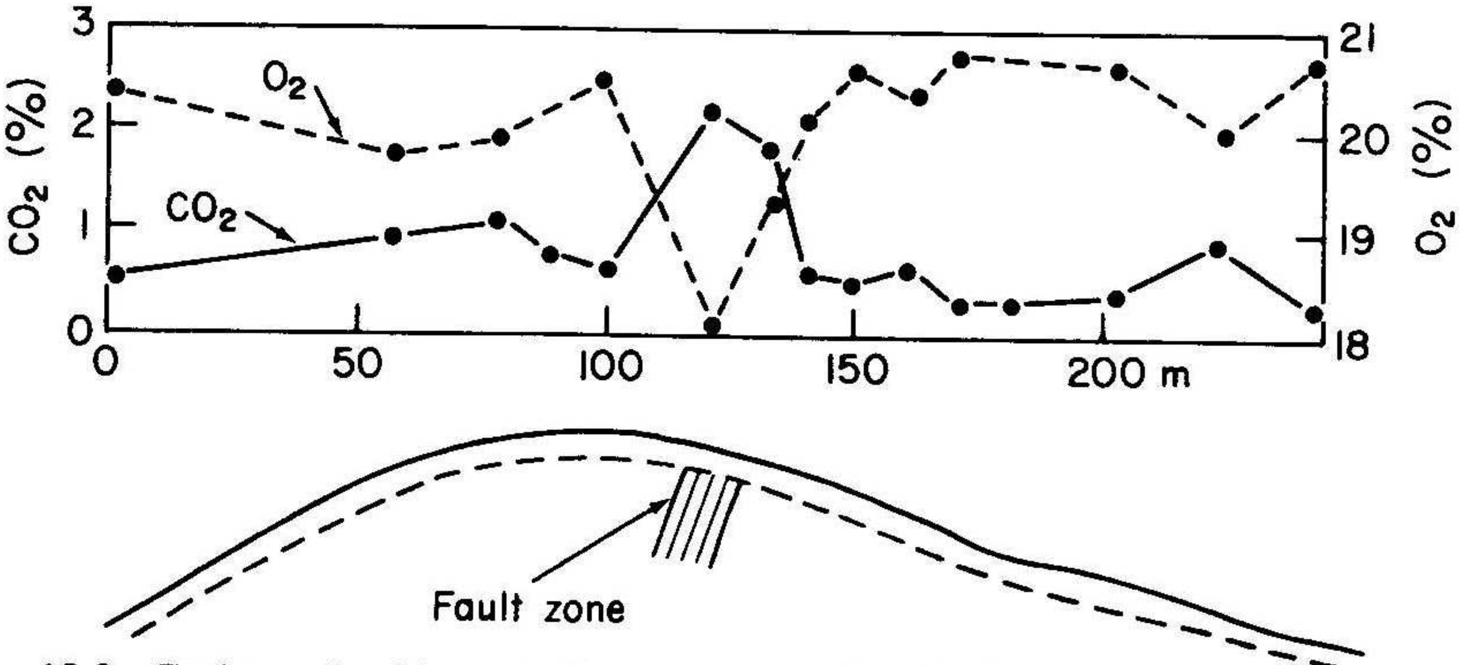


Fig. 18.9. Carbon dioxide and O_2 contents of soil air at 1·5 m depth above a pyritized fault zone. (After Glebovskaya and Glebovskii, 1960, p. 54.)

Soil Gas

Limitations

(a) seasonal variations (Rose, *et. al.*, 1990);

(b) difficulty in interpreting erratic results;

(c) poor reproducibility;

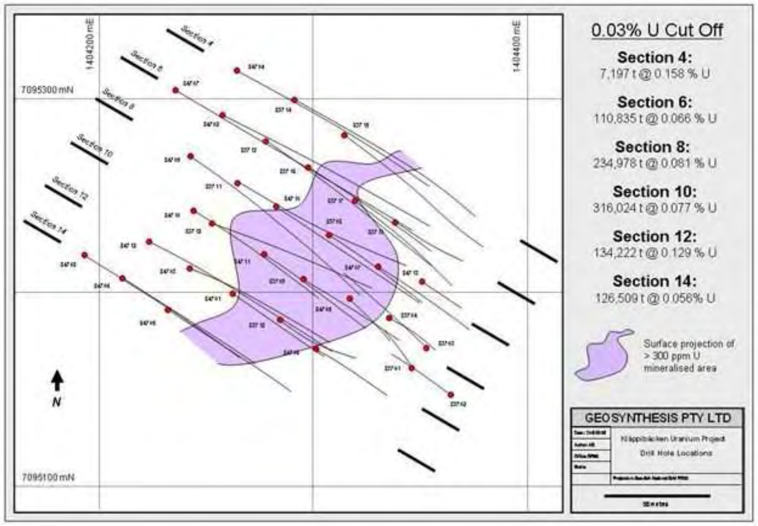
(d) contamination problems

(e) high cost ($A400-500/sample) (some methods)

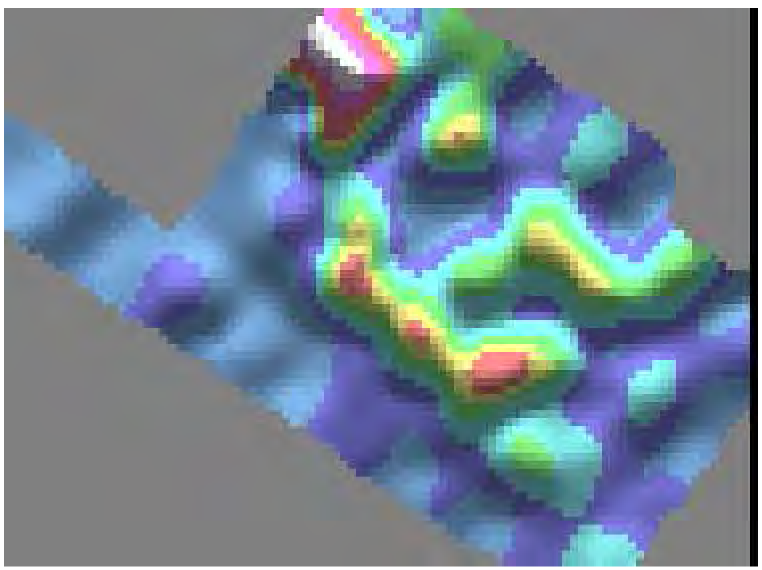
(f) slow turnaround (integration methods) and,

(g) Many methods require expert operators.

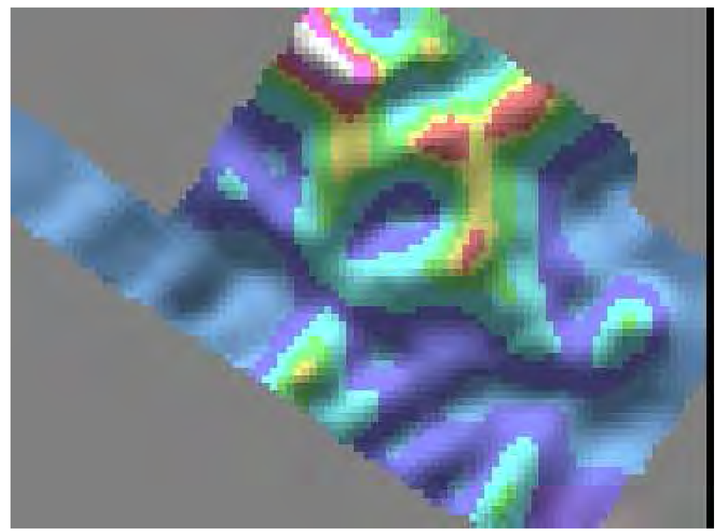
Probably not a topic for "Exploration Geochemistry – Basic Principals and Concepts"!



Radon example



Track-etch / 30 days



Scintillometer

Concluding Remarks

Orientation lines are often too short and don't extend far enough into.background.

More orientation should be grid based (but that costs more)

With many elements, few samples, and poorly represented background, some relationships may be *apparent* with mineralisation in the that would become *'random'* with more extensive sampling

The variety of leaches and variety of elements analysed reveal processes that we don't understand the significance of

Obtaining adequate analytical quality with low extraction partial leach work is very difficult at commercial volumes

Concluding Remarks

Example dl achievable with modern aqua regia ICP-MS

Recording of additional information (eg, soil pH and final pH of leach solution)

Application of the **right** leach in the **right** environment. Know the chemistry of the environment you are working in, and apply a suitable digest.

Don't be disappointed or surprised if the results are ambiguous and difficult to interpret

Use lots of QC samples: You can include standards in PL work to monitor exreaction

Always run a high-quality aqua regia –based ICP-MS survey in parallel, eg

Au	0.2 ppb
Ag	2 ppb
Al*	0.01 %
As	0.1 ppm
B*	1 ppm
Ba*	0.5 ppm
Bi	0.02 ppm
Ca*	0.01 %
Cd	0.01 ppm
Co	0.1 ppm
Cr*	0.5 ppm
Cu	0.01 ppm
Fe*	0.01 %
Ga*	0.1 ppm
Hg	5 ppb
K*	0.01 %
La*	0.5 ppm
Mg*	0.01 %
Mn*	1 ppm
Mo	0.01 ppm
Na*	0.001 %
Ni*	0.1 ppm
P*	0.001 %
Pb	0.01 ppm
S*	0.02 %
Sb	0.02 ppm
Sc*	0.1 ppm
Se	0.1 ppm
Sr*	0.5 ppm
Te	0.02 ppm
Th*	0.1 ppm
Ti*	0.001 %
Tl	0.02 ppm
U*	0.1 ppm
V*	2 ppm
W*	0.1 ppm
Zn	0.1 ppm

Concluding Remarks

Regolith Control Elements	Target and Pathfinder Elements			
	High Abundance	Moderate Abundance	Low Abundance*	Trace Abundance*
Fe Mn Ca Mg (K, Na, Org C, Al)	Ni Co Zn S Ba Cr Sr	Cu Pb Th As U Sn	Sb Bi Mo Se Ag Hg Cd Tl	Au Pt Pd Te

*These elements may now be determined routinely to virtually their crustal abundance

Concluding Remarks

As far as surficial geochemical methods ability to see mineralisation at depth…..

…Biggest concern is the - ***true ability*** to see to depth with a sufficient degree of ***reliability.***

There are plenty of parts of the world that would benefit from the application of high quality 'routine' multi-element geochemistry