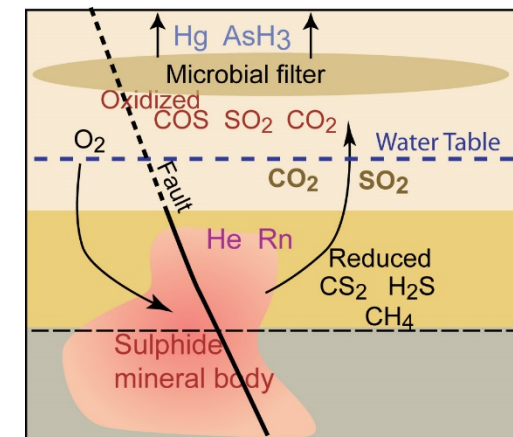
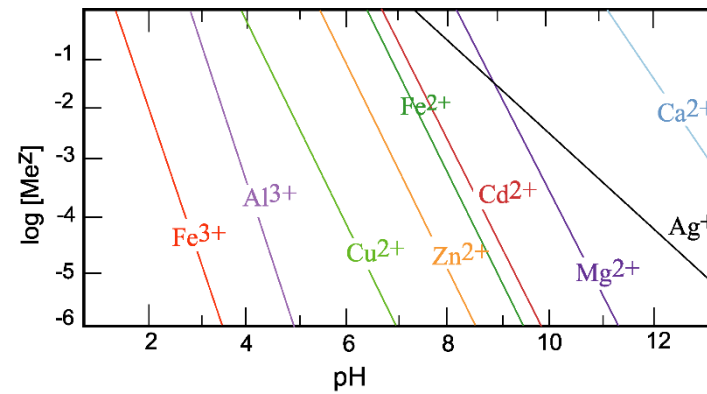
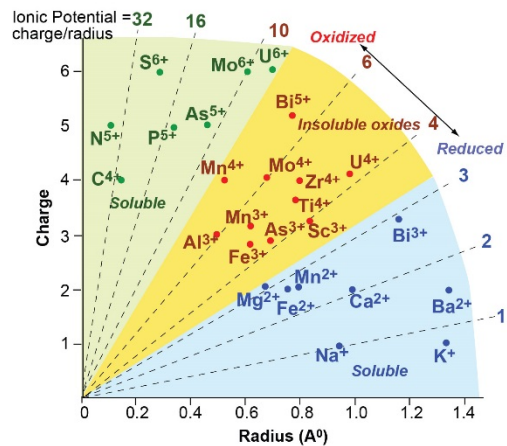


DISPERSION MECHANISMS THROUGH TRANSPORTED COVER

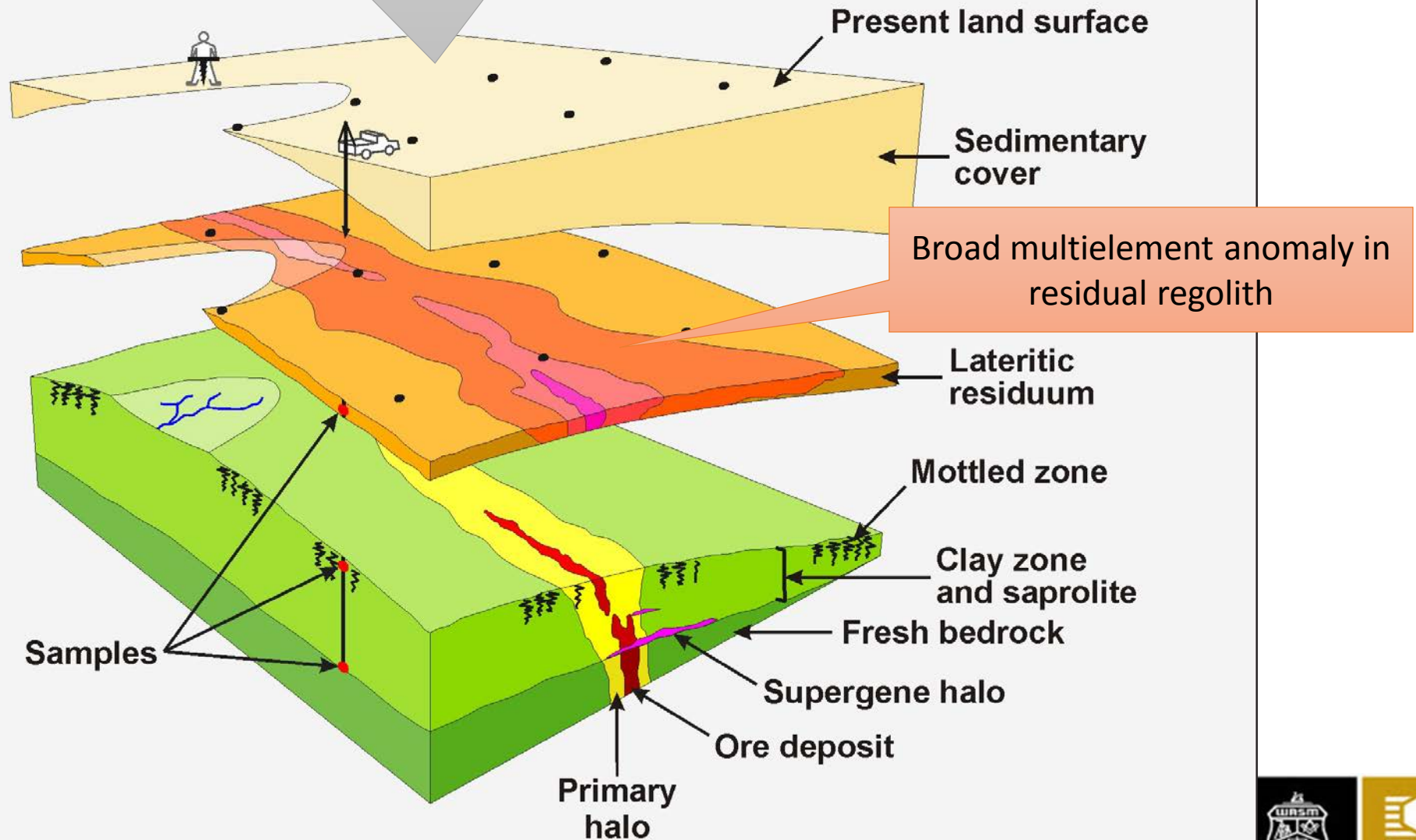
Mehrooz F Aspandiar

Department of Applied Geology

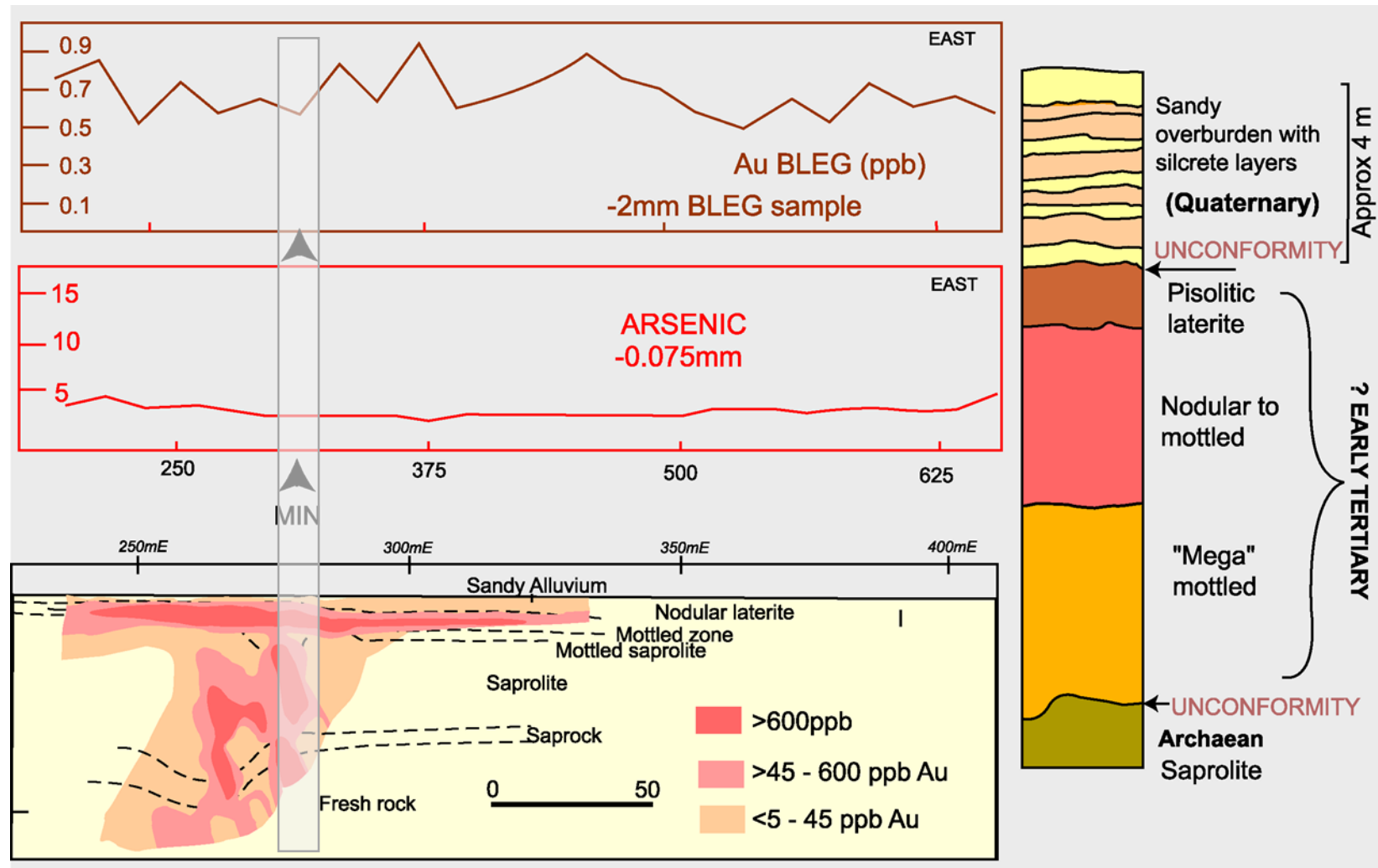
Western Australian School of Mines



Can surface geochemistry in >5m thick transported regolith/overburden cover detect buried mineralisation?



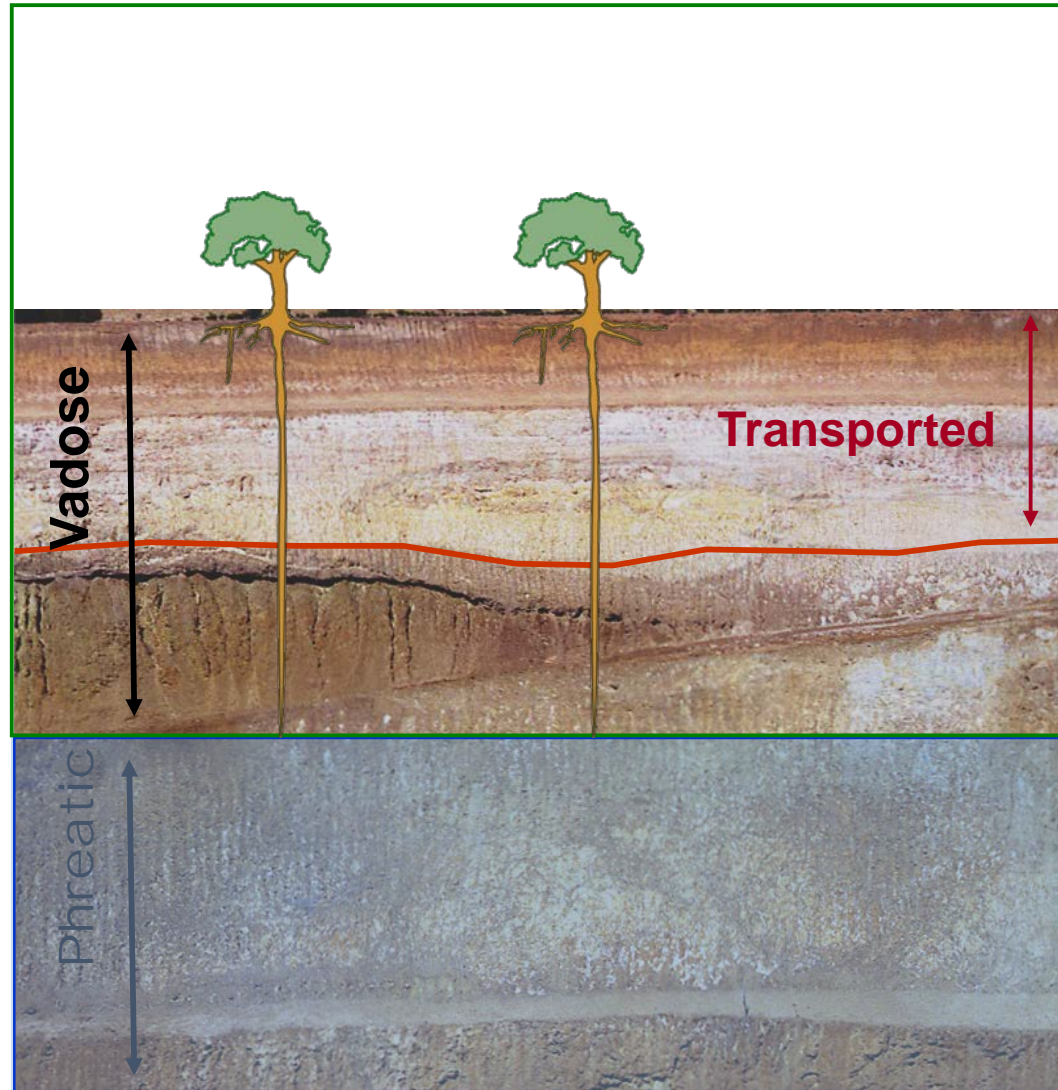
Do metals transfer upwards through transported cover?



From Radford & Burton (1999) Journal of Geochemical Exploration



Mechanisms - Classification



BIOLOGICAL

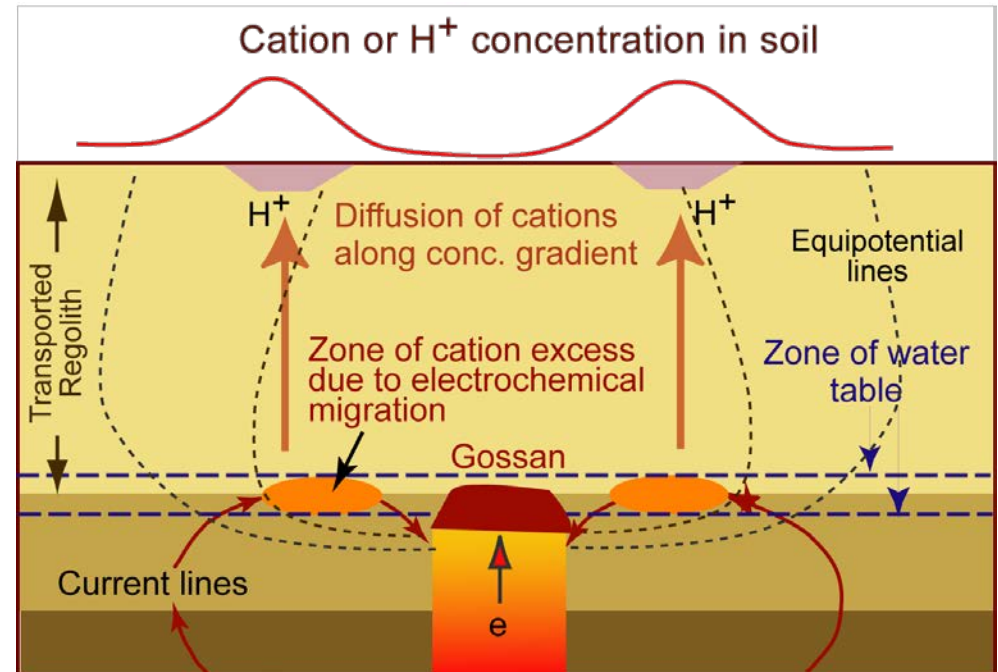
- Plant uptake to Foliage
- Hydraulic Lift – to soil
- Bioturbation

- Dilatancy Pumping
- Capillary
- Convective gas flow
- Barometric Pumping

- Self-Potential
- Redox Gradient
- Bubble Attachment

Self Potential Mechanism – Govett model

- Self potentials develop in response to weathering of sulphide body that gives rise to an Eh differential (current flow)
- Cations migrate along current path and collect at edges of oxidized cap – excess
- Diffusion of cations upwards along concentration gradient?
- Indirect effects – pH changes

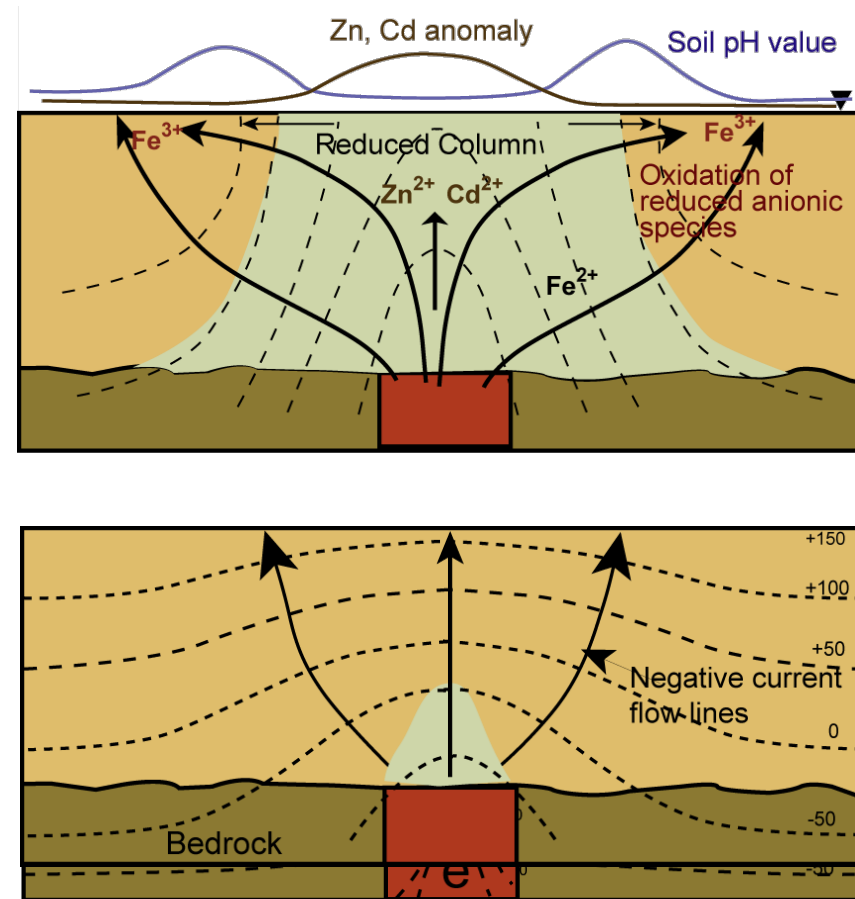


Modified after Govett et al (1984)

- ✘ Sulphide rich mineralization
- ✘ Diffusion of cations in dry media

Redox Gradient Mechanism – Hamilton model

- Development and maintenance of redox anisotropy due to potentials between sulphide and surface
 - “Reduced column” develops over ore and gradually migrates outwards
 - Rapid migration of ions in an electric field
- ✘ High water tables
- ✘ Sulphide rich mineralization

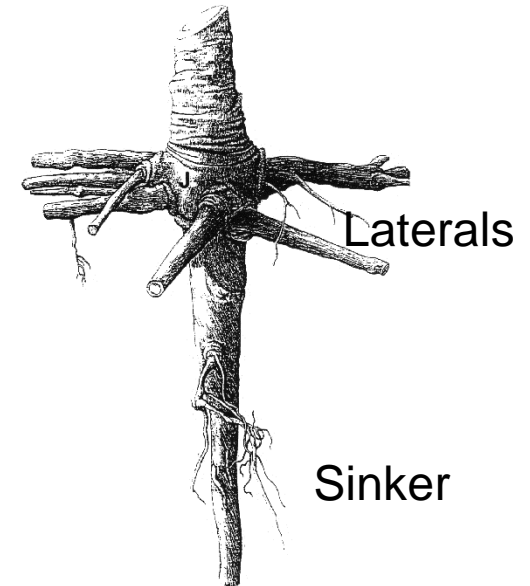


Modified after Hamilton (2000)



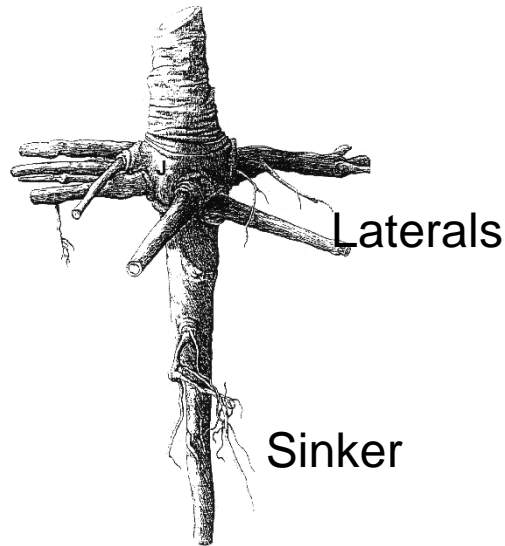
Biological – Vegetation Transfer Above Ground

- Plant uptake via physiological processes and transfer to surface via litter - biogeochemical cycle and “bio-pumps”
- **How deep?** – Need to go to water table or deeper anomalous zone to be effective in transferring ore metals upwards
- **What form?** – Metals transferred upwards and released as what type of species
- Root systems – dimorphic roots
 - Laterals (shallow) roots
 - Sinkers or tap roots
- Hydrogen isotope (Deuterium) data indicates stem relies on water and nutrients acquired from groundwater via sinkers during the summer



Do roots reach groundwater and uptake metals?

Dimorphic Roots System

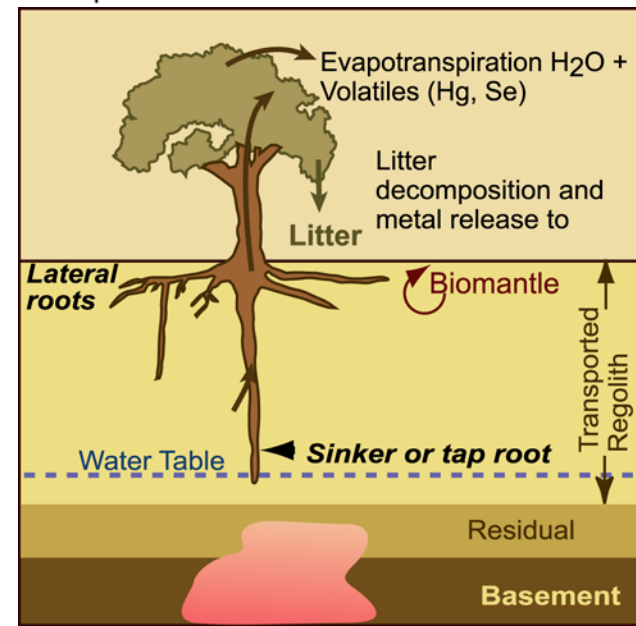
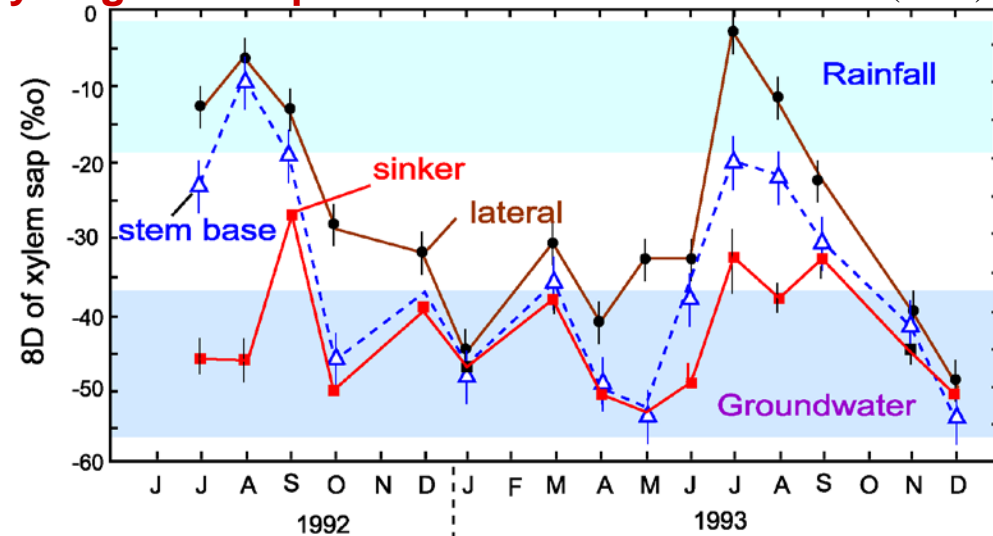


From Pate et al 1999

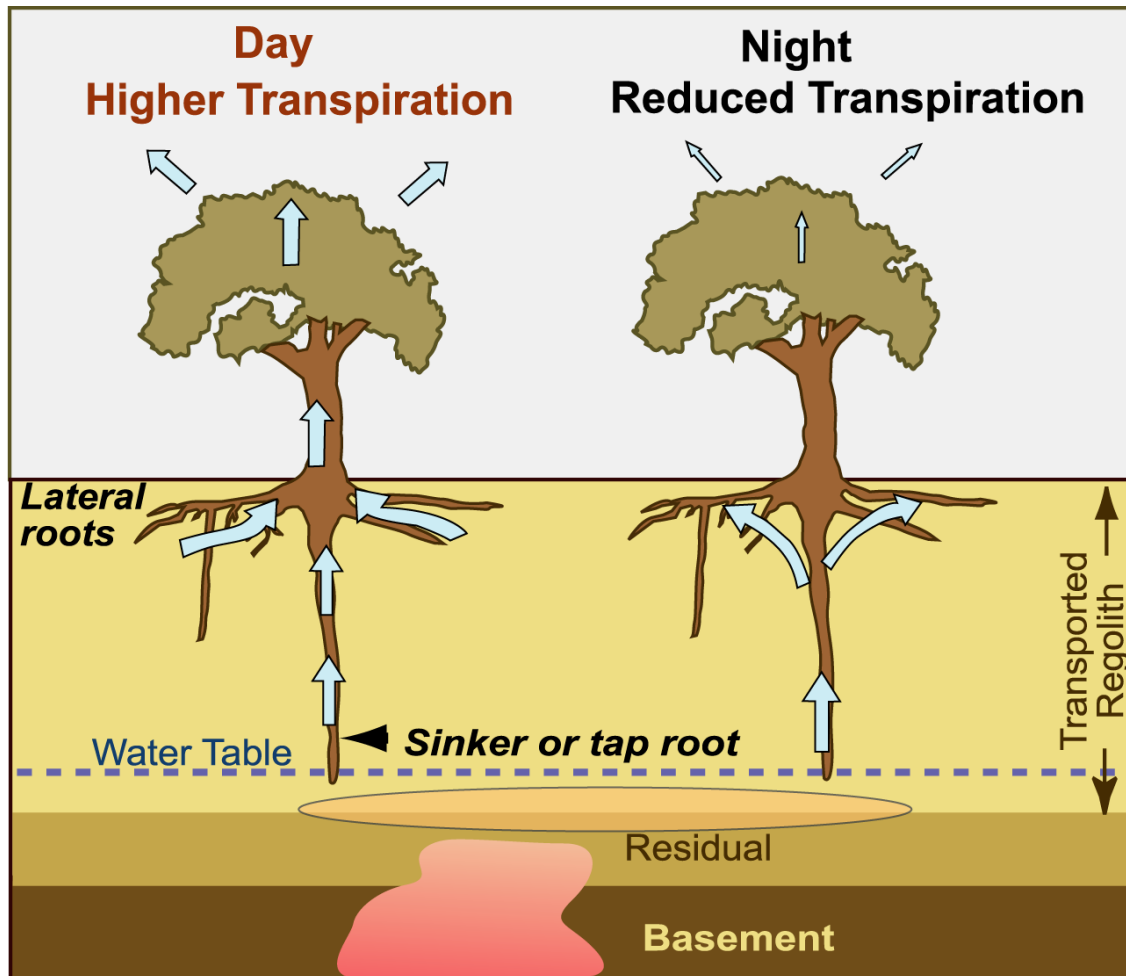
- Commonly access groundwater table at 10 - 15 m SWA
- Macro & micro nutrient uptake by sinkers has been proved

Hydrogen isotope data

From Dawson & Pate (1996)

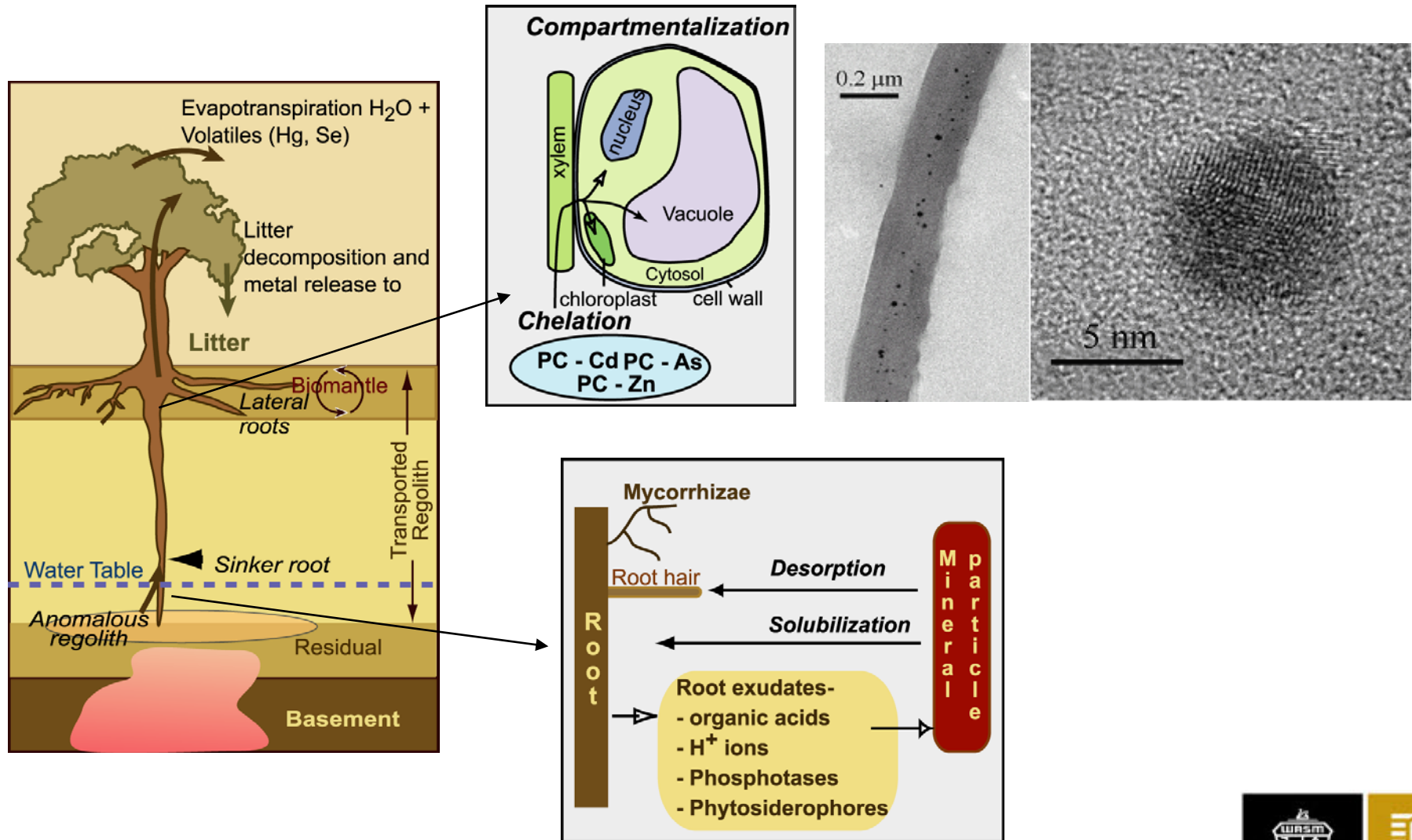


Hydraulic Lift (water redistribution to and from soil)

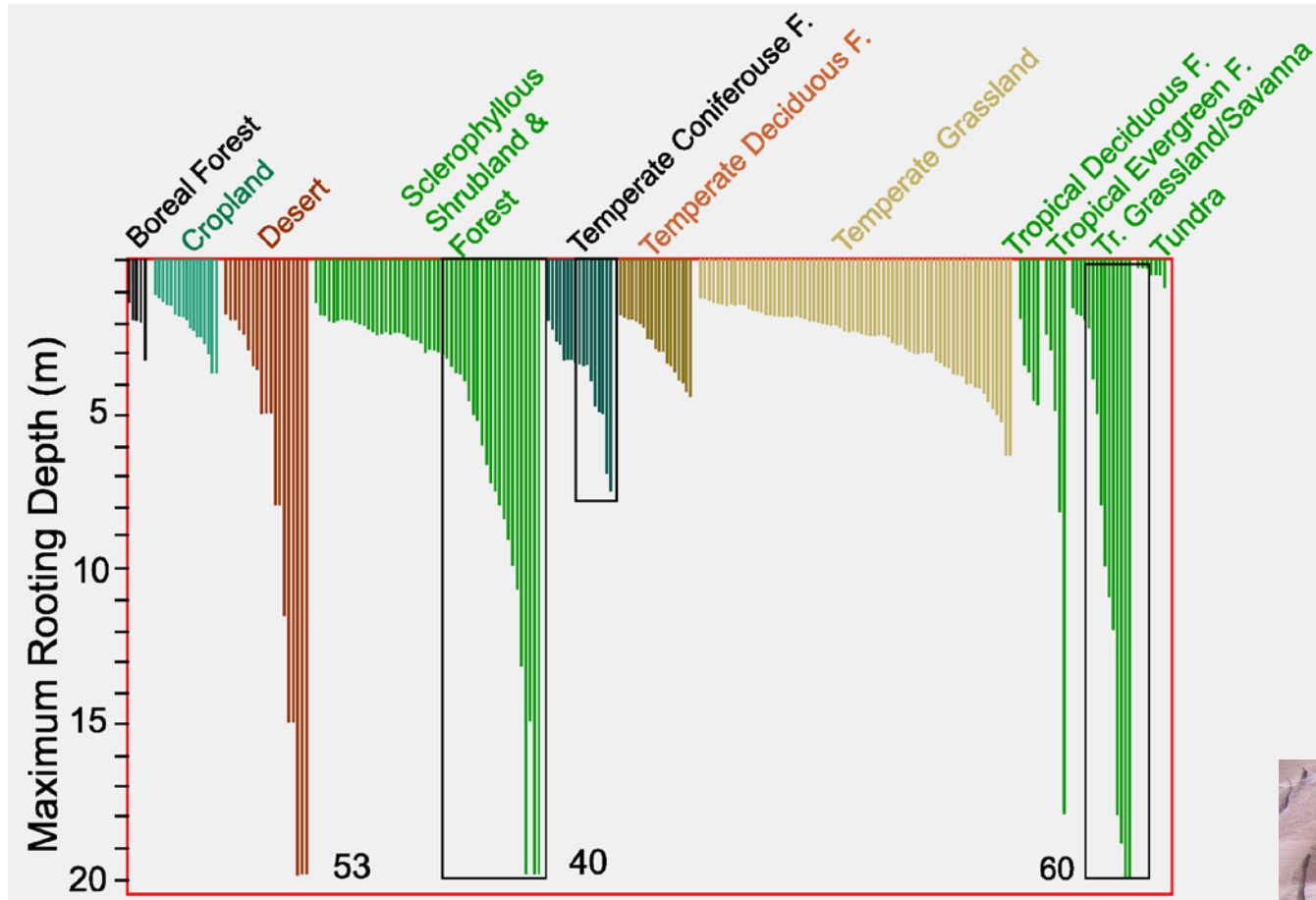


- Reduced transpiration stream at night – water moved from deeper to soil
- Can move large amounts of water (5-100 l/d) into the soil from deeper water source
- 3- 4 m upwards in a day (electrical field diffusion of H^+ would require 1000 years!)
- Recent data shows uplift of major elements during summer

Vegetation Mechanisms - Metal uptake, storage & transformation



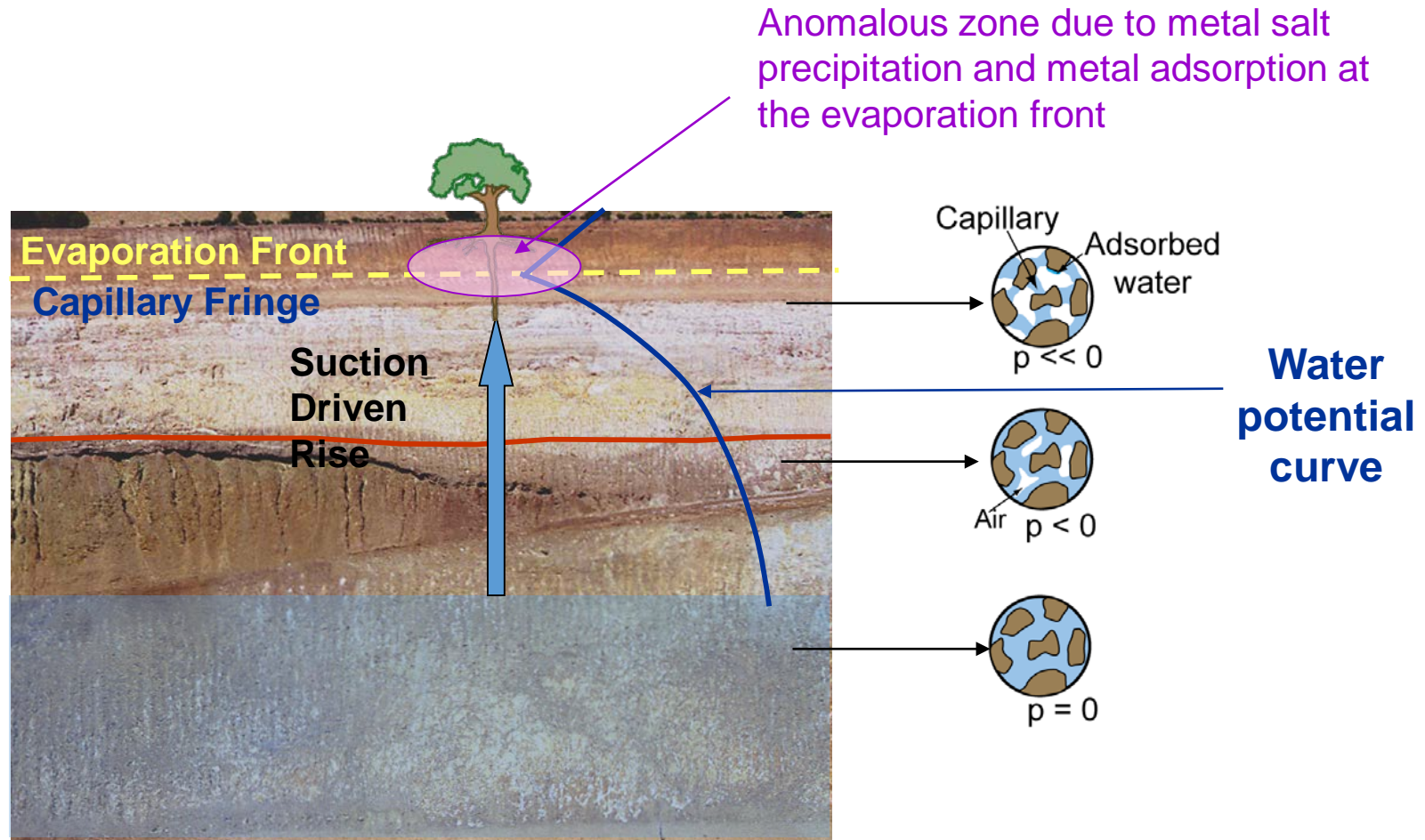
How deep do roots commonly penetrate?



Maximum rooting depth of vegetation types on global scale From Canadell et al (1996)



Capillarity

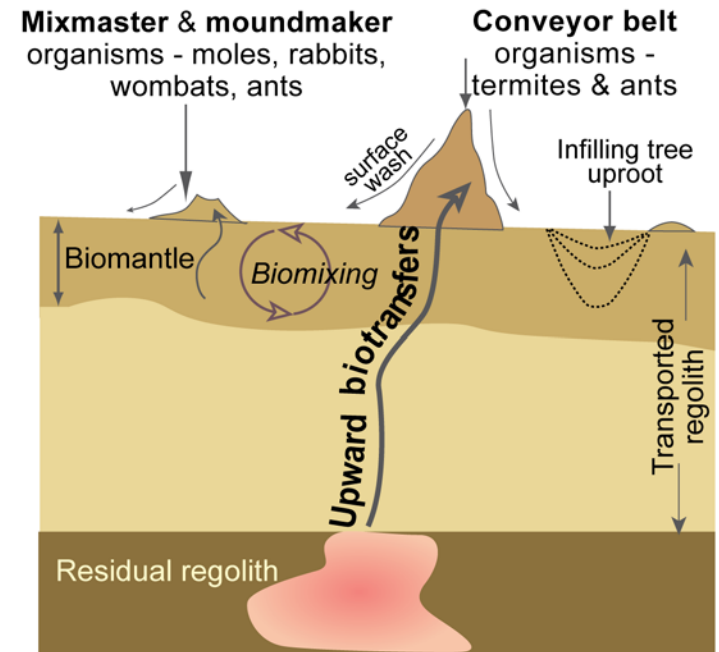


Capillary rise is higher in finer grained materials - ~ 30 m in clays

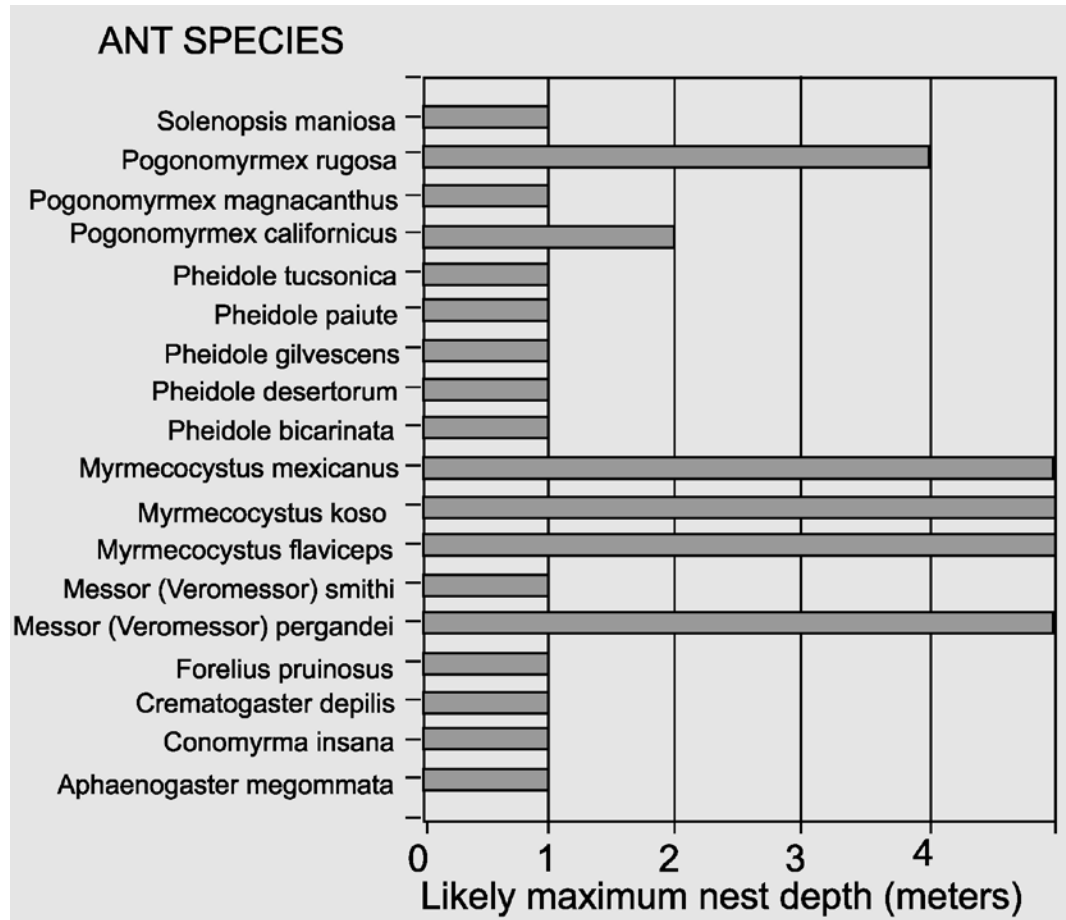
✘ Grain size stratification can limit capillary rise

Biological - Bioturbation

- Bioturbation (burrowing activities of ants, termites etc) brings up material from depth and **homogenizes** soil – the biomantle
- Physical movement of huge quantities of soil material – independent of metal state (dominantly mechanical process)
- **Conveyor belt organisms – termites and ants** – main species that burrow below biomantle
- How deep?
- Restricted vertical depth for most environments ~ 2-3 m, but semi-arid/arid & sandy locations can have >10m depths



Potential Ant & Termite Burrowing Depths



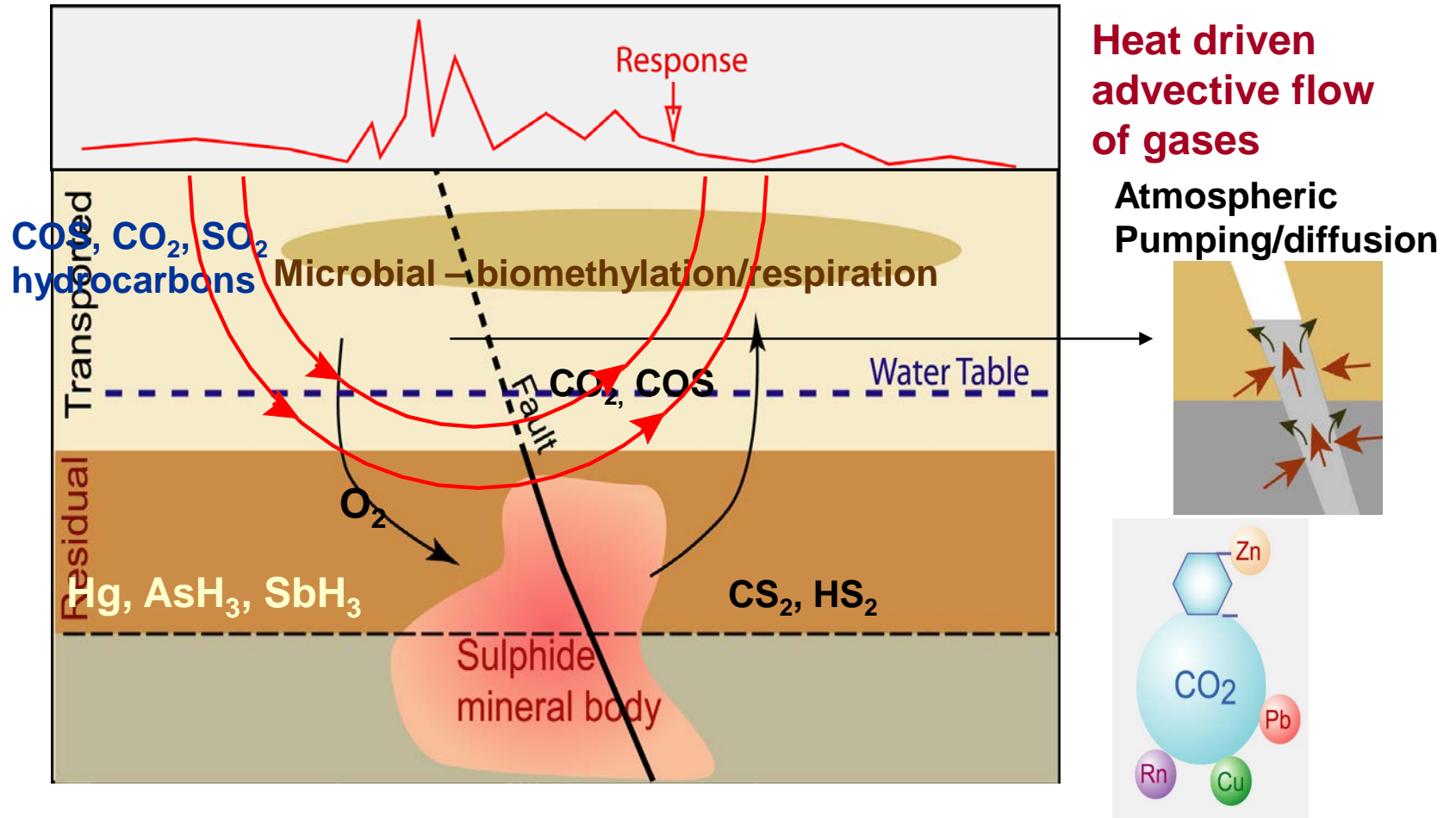
Potential Termite Depths

Depth m	Proportion
0.5	75 %
1.0	10 %
2.0	8%
4.0	3%
6.0	2%
8.0	1%
10	1%

From Jensen & Hooten (2000)



Gas –Volatile Transfer



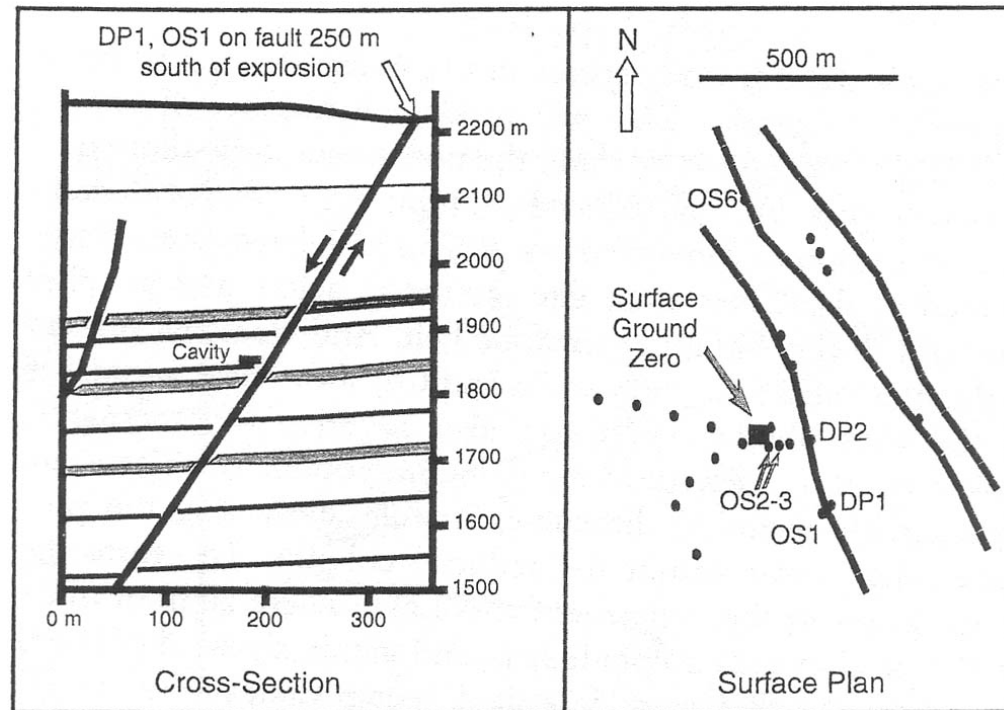
Fast diffusion/advection via faults & fractures

Species stability & microbial

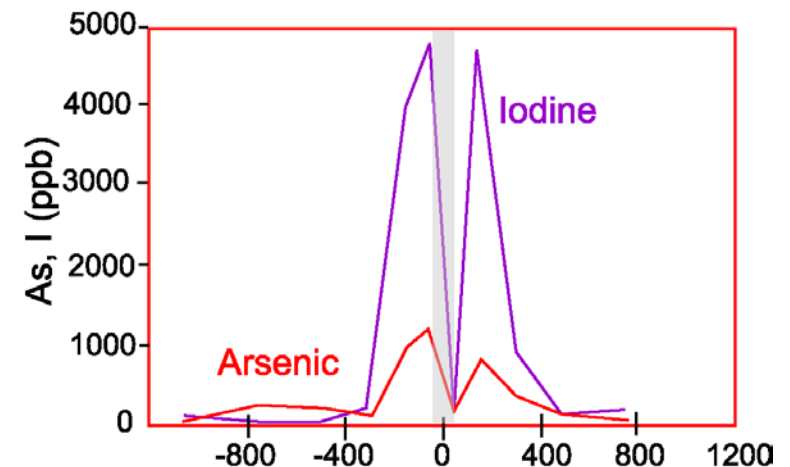
Metal-bubble transport in vadose - unclear

Indirect effects – pH/Eh changes

Gas – Volatile Transfer – Examples



SF6 and He gas at explosion reached surface within the year



Iodine and As higher over blast sites as extracted by hot hydroxylamine

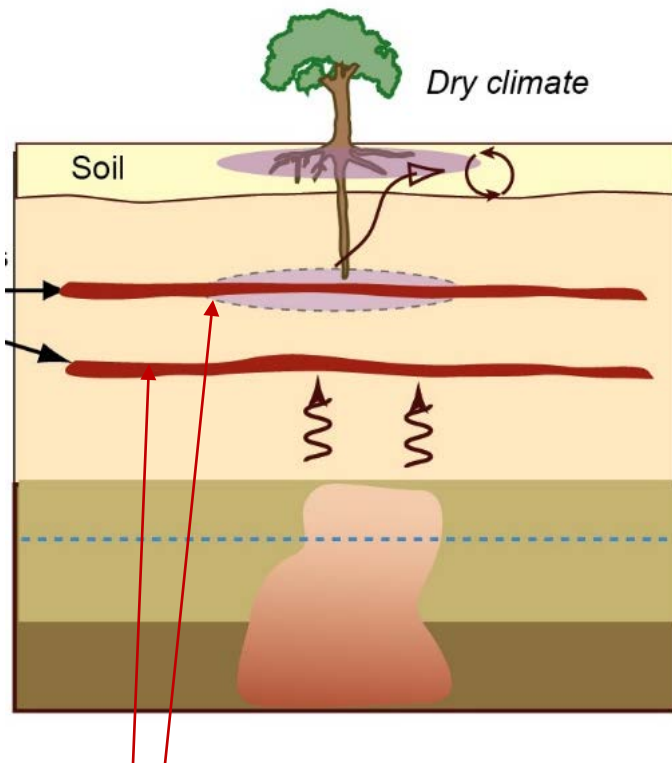
After Hall et al (1997)

Both examples record surface signature over faults - conduits

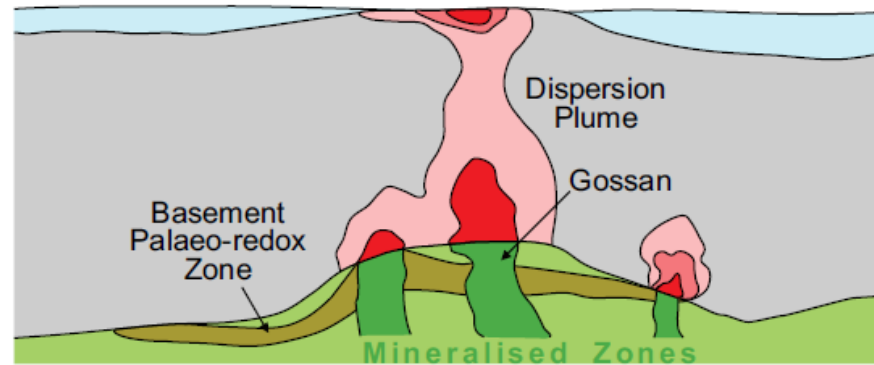


Nature of evolution of the cover

B



a Marine transgression

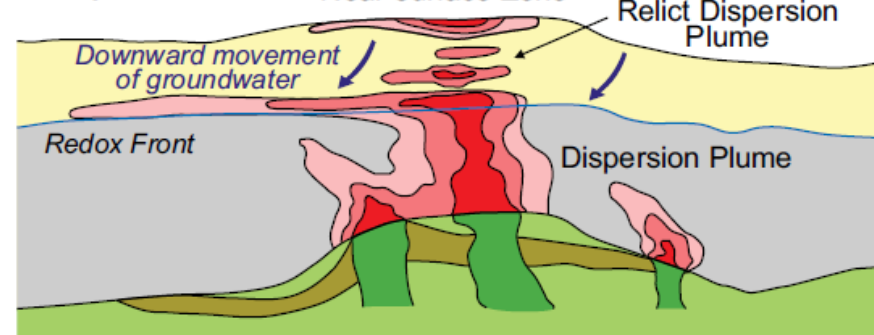


Shallow marine environment

Water-saturated
Reduced Mesozoic
Sediment

Unconformity
Precambrian
Metasediment Basement

b Uplift

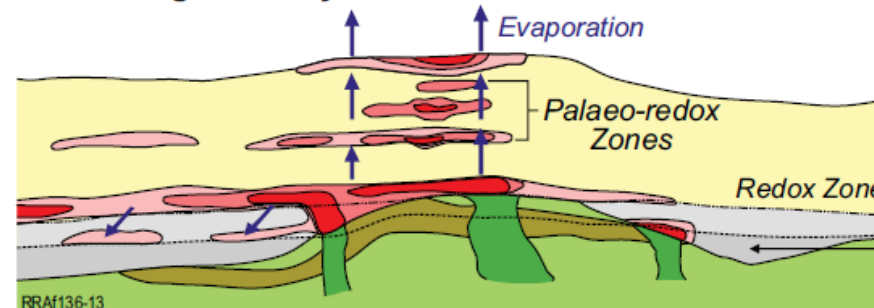


Water-unsaturated Oxidised
Mesozoic Sediment

Water table

Water-saturated Reduced
Mesozoic Sediment

c Prolonged aridity

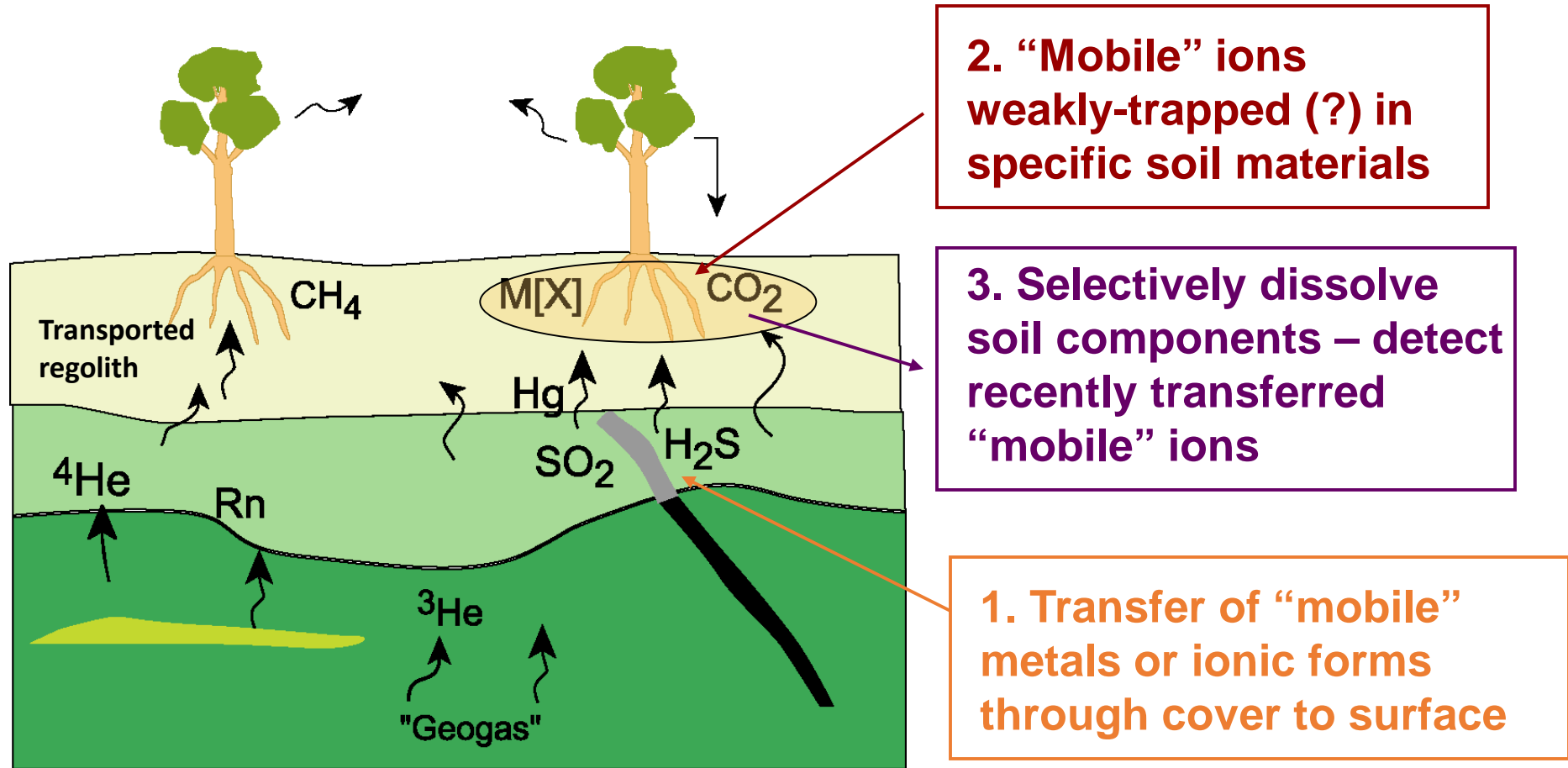


Water-unsaturated Oxidised
Mesozoic Sediment

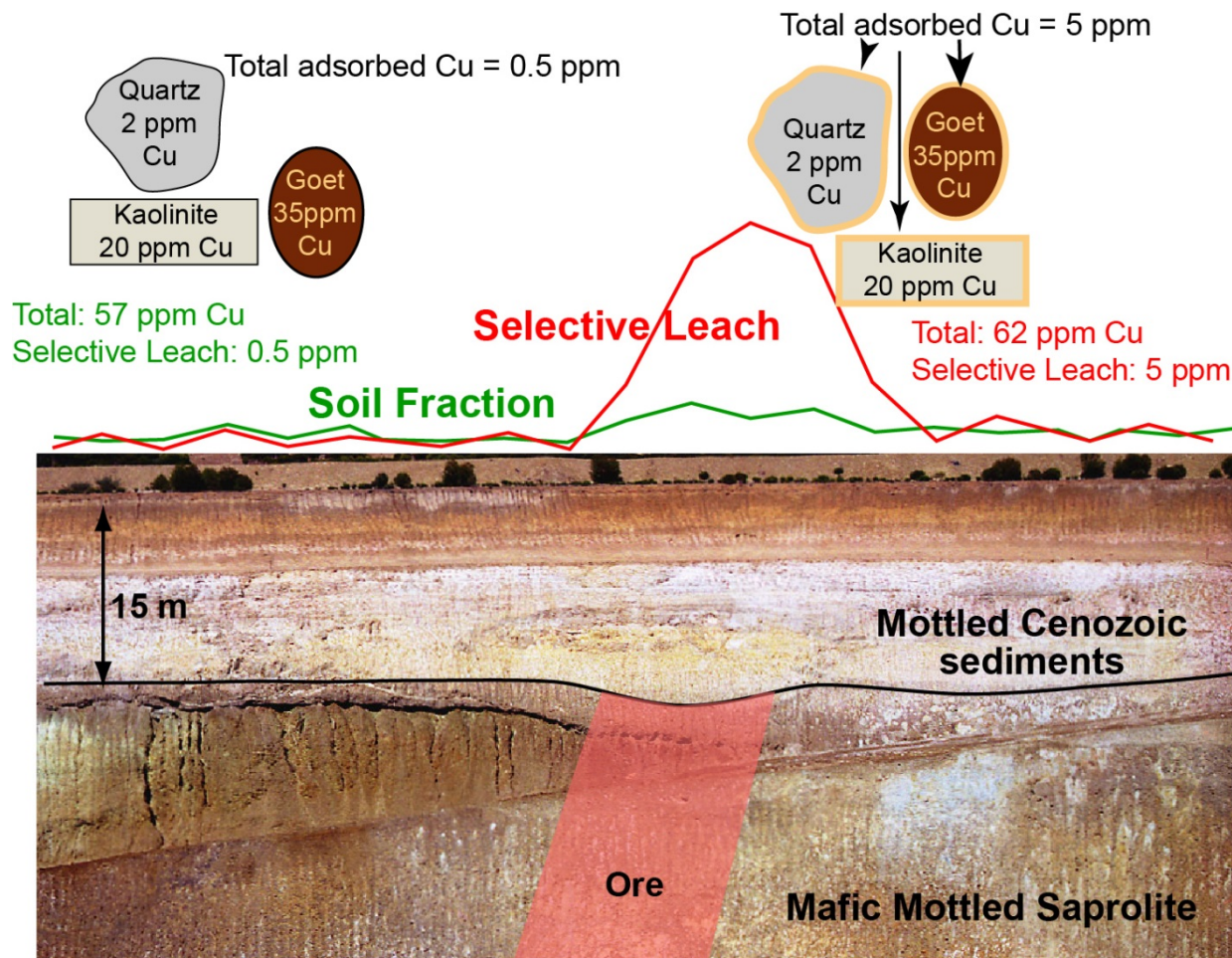
Water-saturated Reduced
Mesozoic Sediment

RRaf136-13

Partial Leach/Extraction Methods -Principle



Selective Leach Principle & Proposed Benefits



Detecting **blind deposits** under 10-100 m of cover

Improved signal to noise ratio

More **accurate identification** of anomaly location

But how do metals transfer to the surface? Suggested, but not proved mechanisms are gases & vapours, capillary, vegetation, bioturbation



The Extraction Methods

All methods subject total soil to selected digest

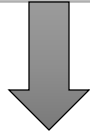
- **Traditional** – used in soil science and geochemistry for over 50 years (cold extractable Cu and Zn)
- **Exchangeable** - easily exchanged from surface sites of minerals
- **Iodide** and **water** extractable Au – surface bound
- **4M HCl** digests
- Three step **sequential**
 - pH 5 acetate (carbonates)
 - 0.1M hydroxylamine (Mn oxides)
 - 0.25M hydroxylamine (amorphous Fe oxides)
- **Enzyme Leach** (Proprietary) – Highly reactive Mn-oxides
- **MMI** (Proprietary) – Exterior soil particles





What Are Selective/Partial Extractions?

Selective Weak Extractions (SWE)



SWE dissolve a specific mineral phase, e.g., organic matter, carbonates, Mn & Fe oxides

Partial Extractions



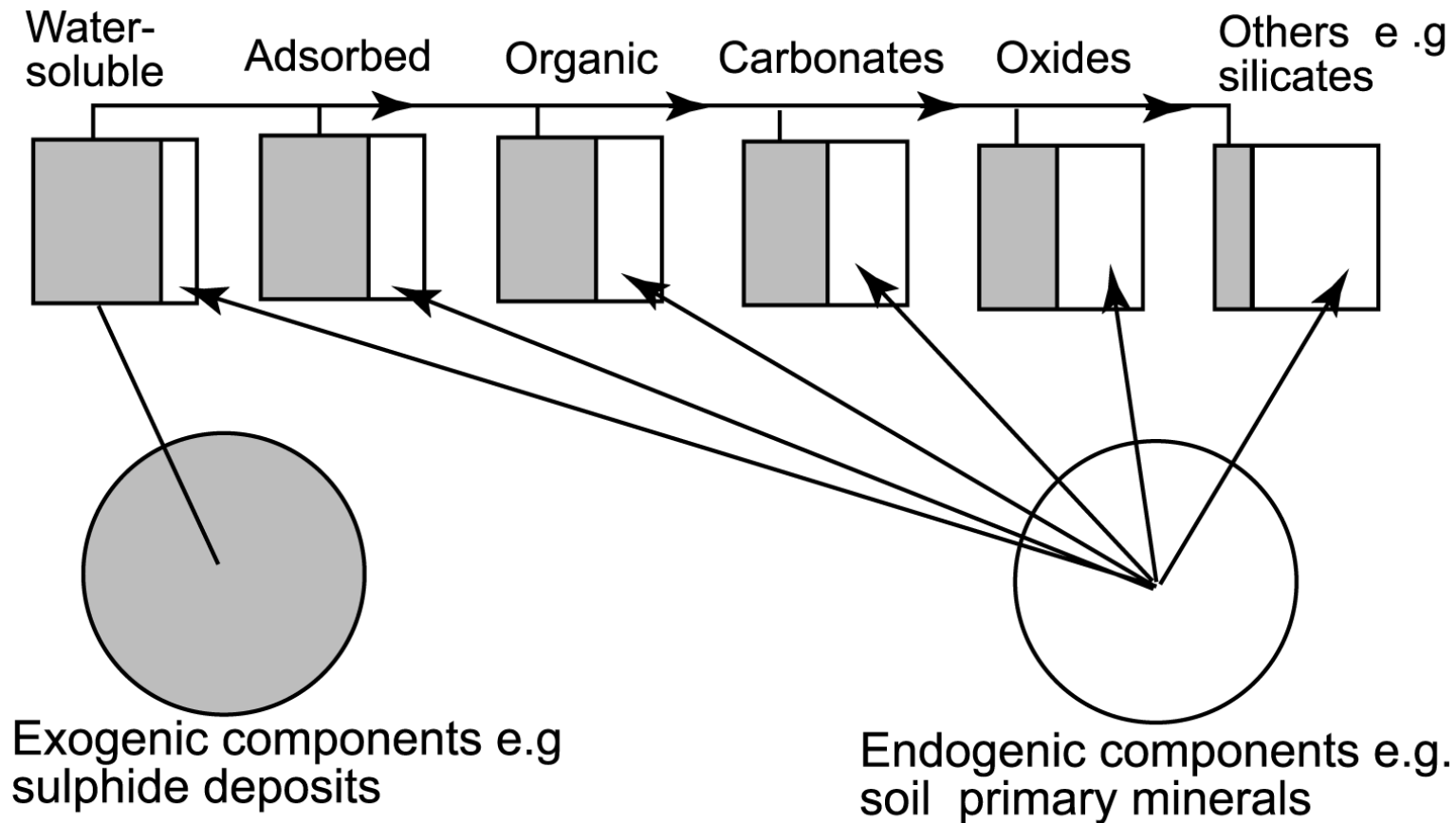
Partial extractions are less specific to phase, e.g., weak acid leach MMI. Not always clear and depends on soil matrix

All vary in **strength of extraction** – 1M HCl vs 5M HCl, acetate etc.

Often shrouded in commercial secrecy – MMI, Enzyme Leach



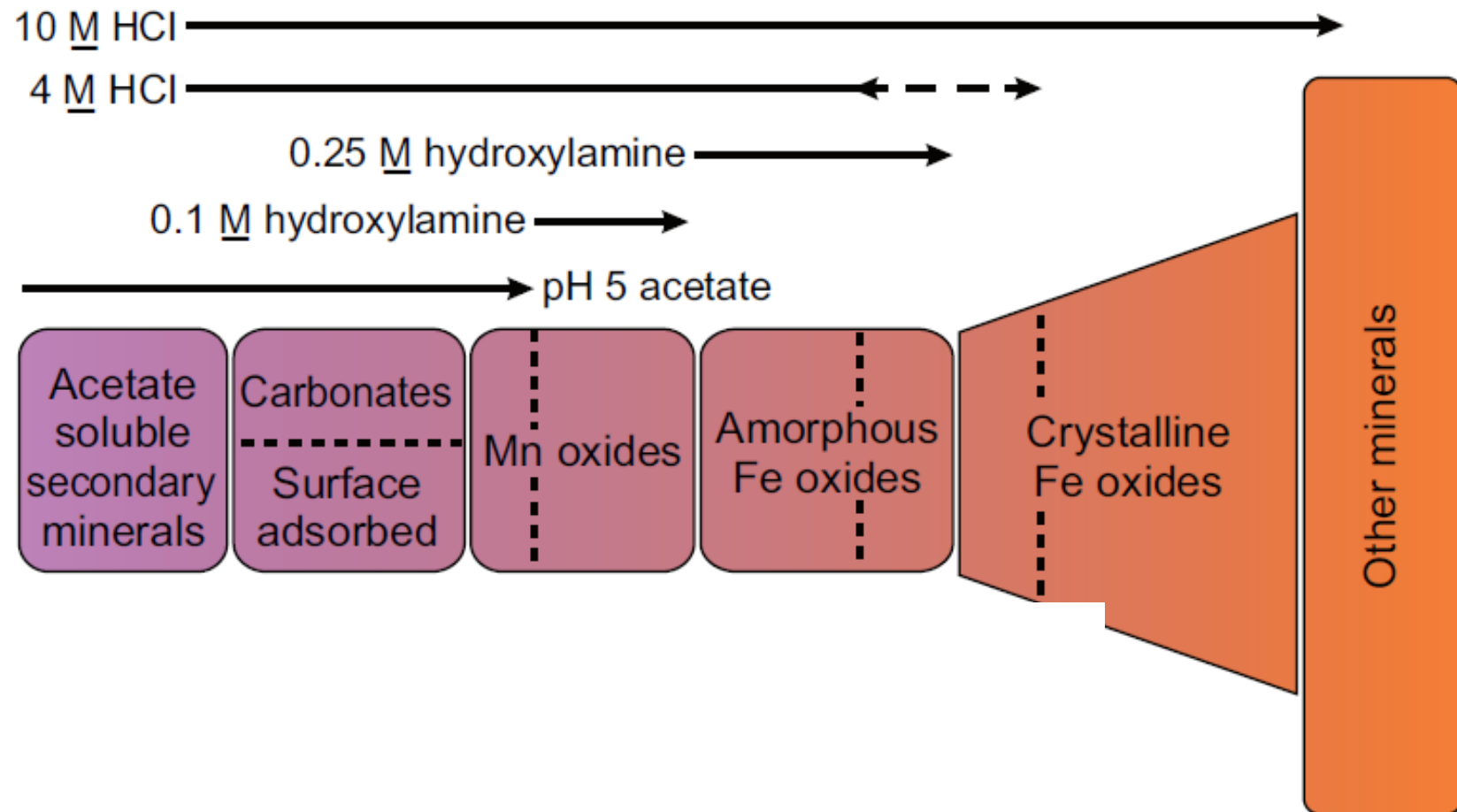
Conceptual model of distribution of exogenic and endogenic phases in soil minerals



From Cameron et al 200



Phases likely dissolved by selective extractions



Commerical extractions

MOBILE METAL IONS (MMI)

Optimized for elements (ions), not phases

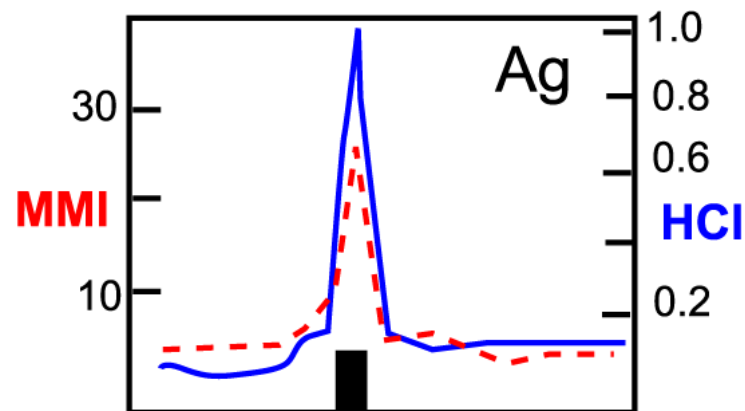
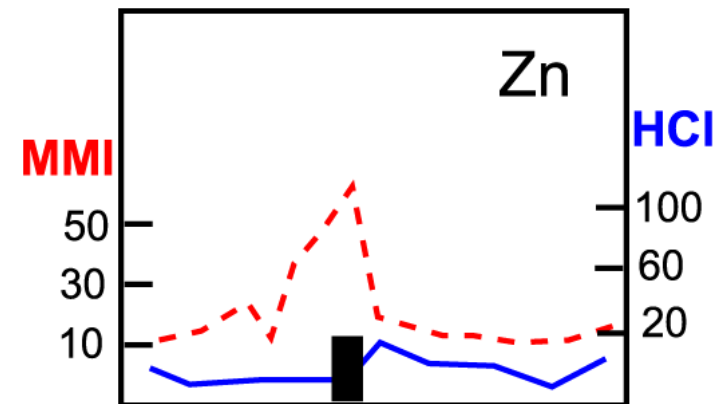
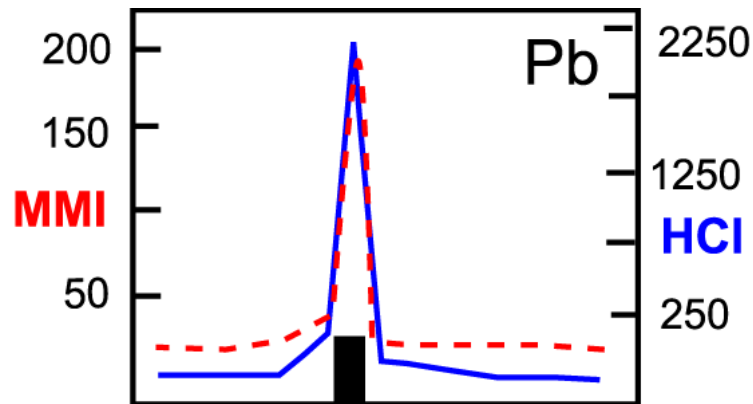
Two different extractions to leach only specific ions considered to be “**unbound**”, not those that are “**bound**”

- **A: Weak acid attack** and analyse for Cu, Zn, Pb, Cd, may attack Mn and Fe oxides
- **B: Alkaline digests**, dissolves most extractable Au and analysed for Au, Ag, Pd, Co, Ni.

Company touts - comparisons with 1M HCl digests indicate MMI gives better contrast (**would depend on soil composition!**)



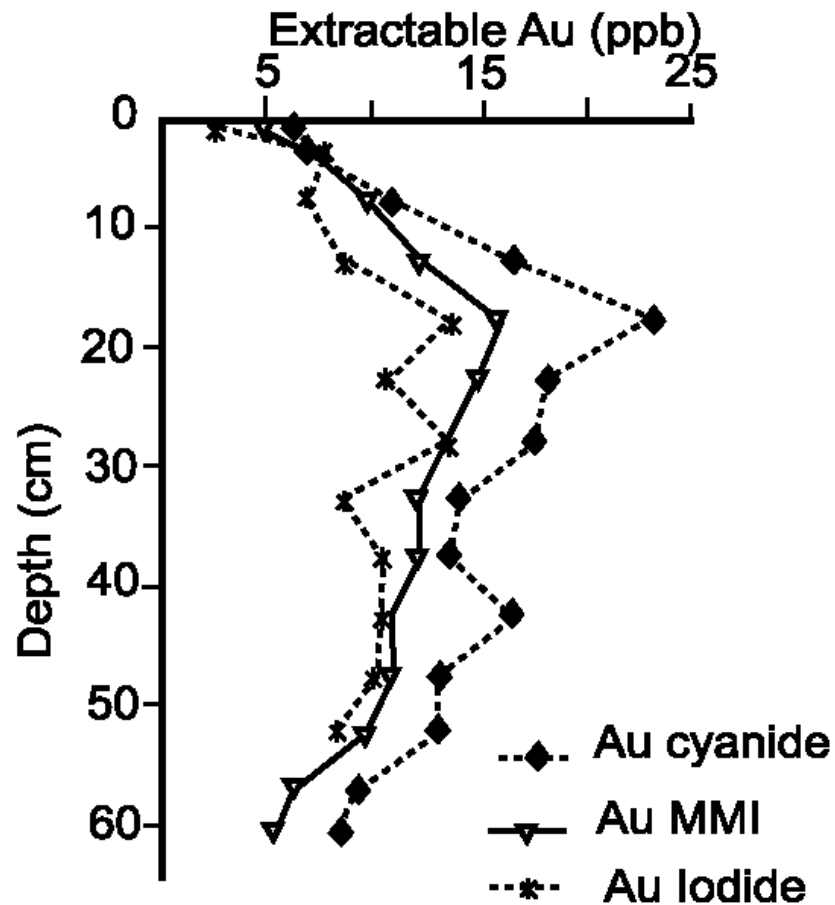
Comparison between MMI and standard HCl Digest



Comparison between
MMI and HCL extraction
After Radford (1996)

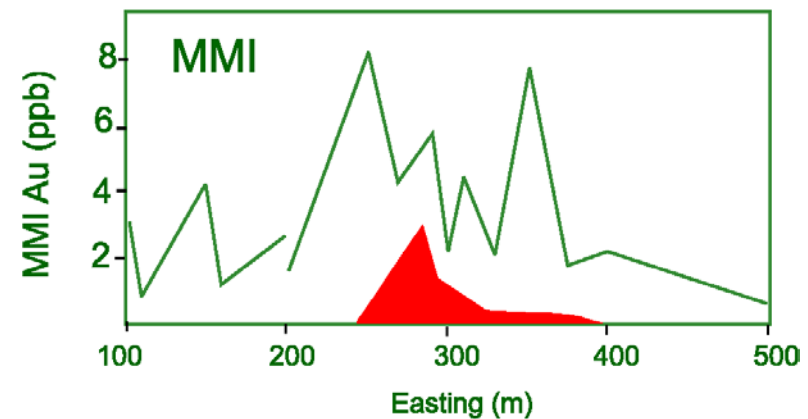
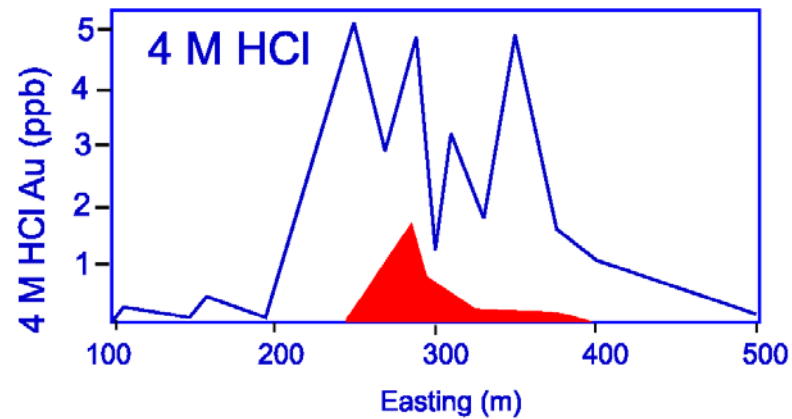
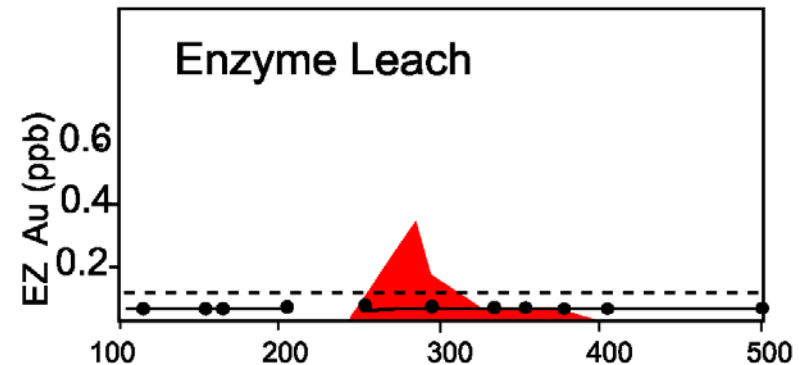
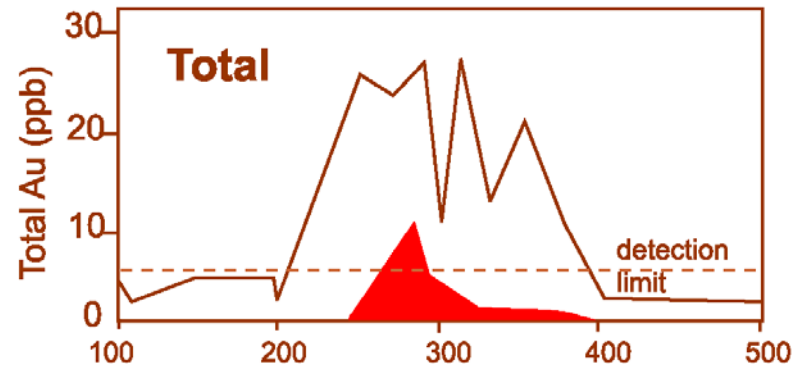
— HCl
- - - MMI

Comparison of Selective Leaches through a Profile



Cyanide leach (similar to BLEG) appears better than MMI to improve contrast

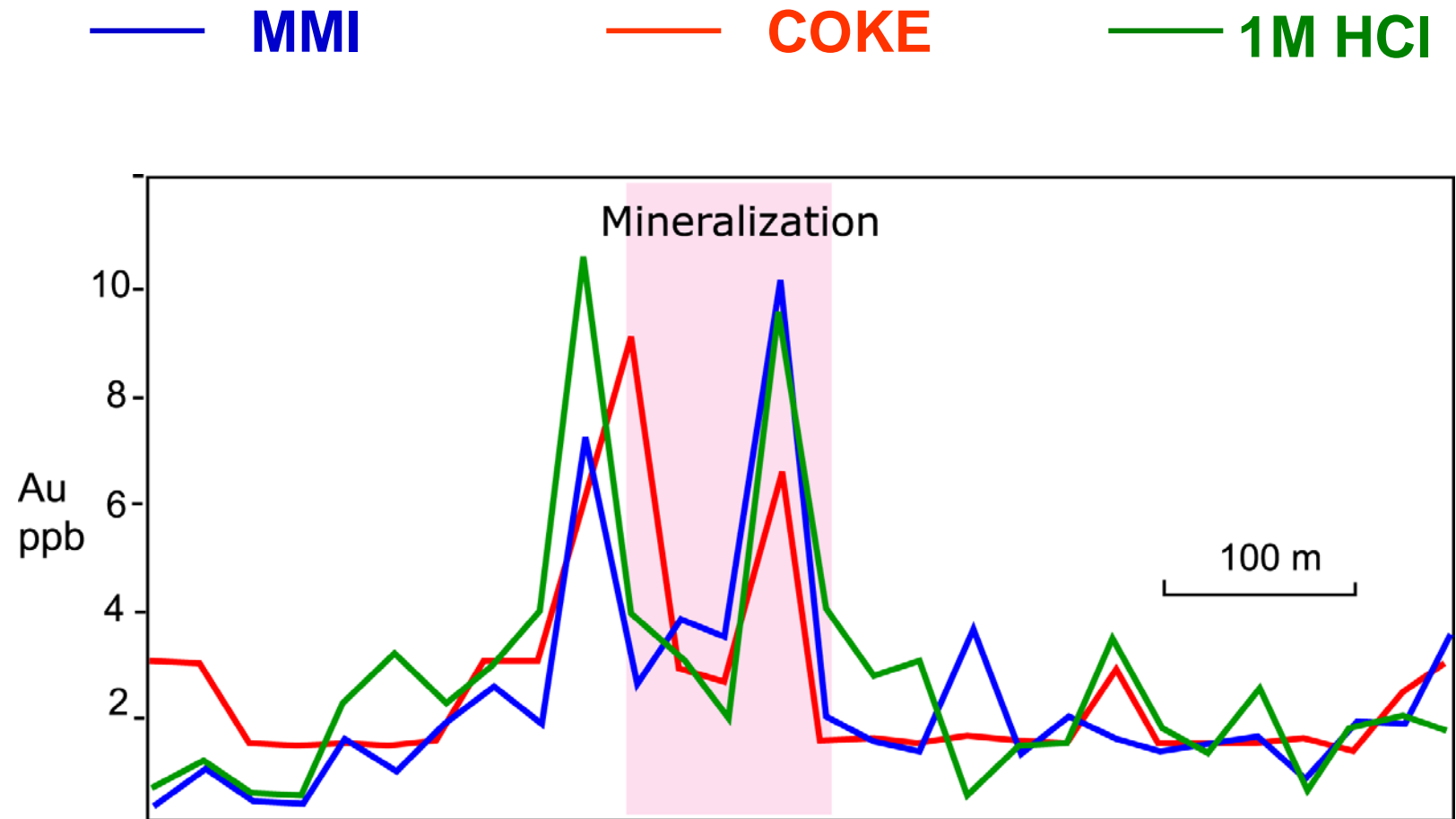
How Do The Different “Leaches” Compare?



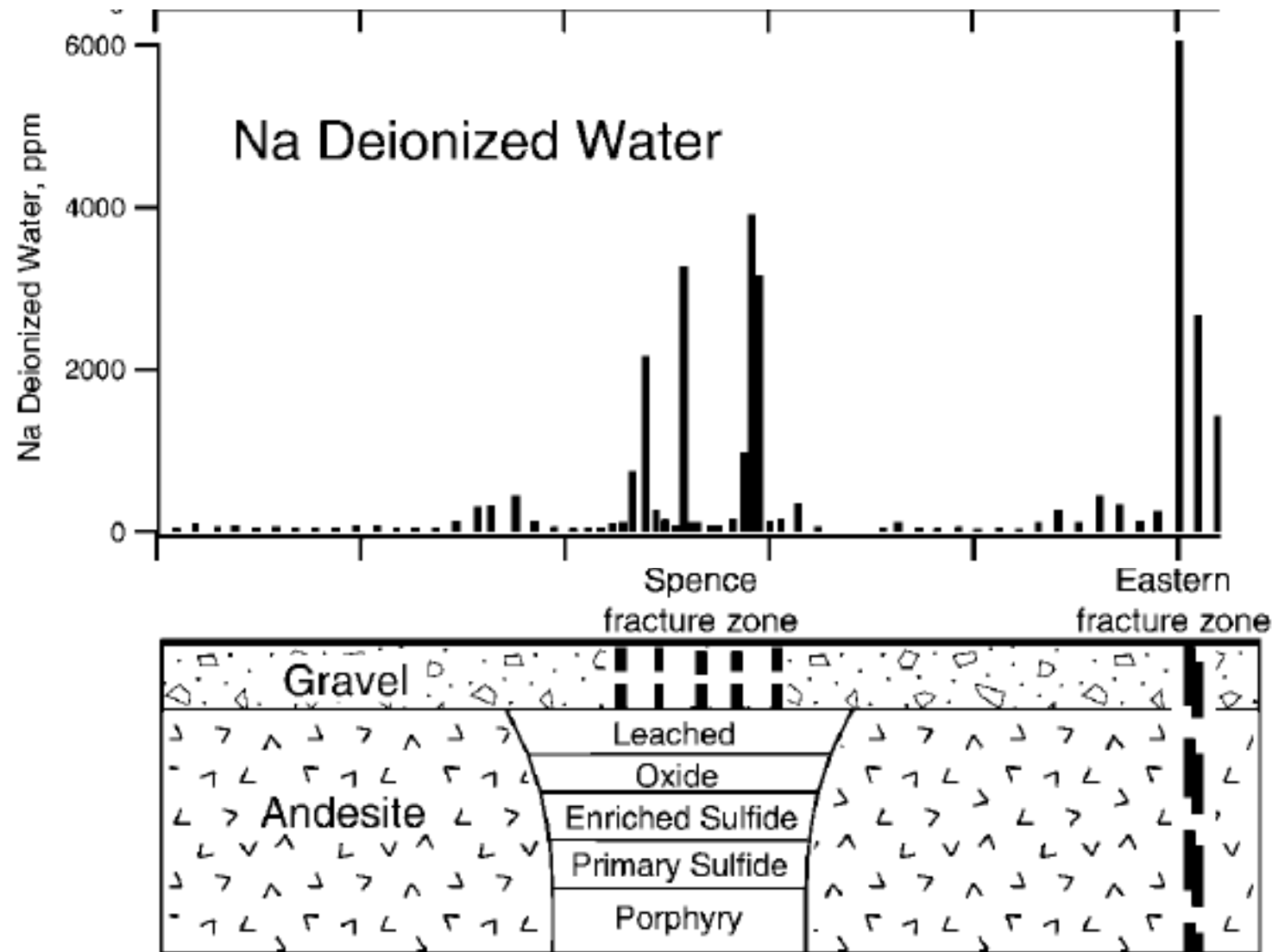
Fender, WA (after Gray et al 1999)



How Do Different Leaches Compare?



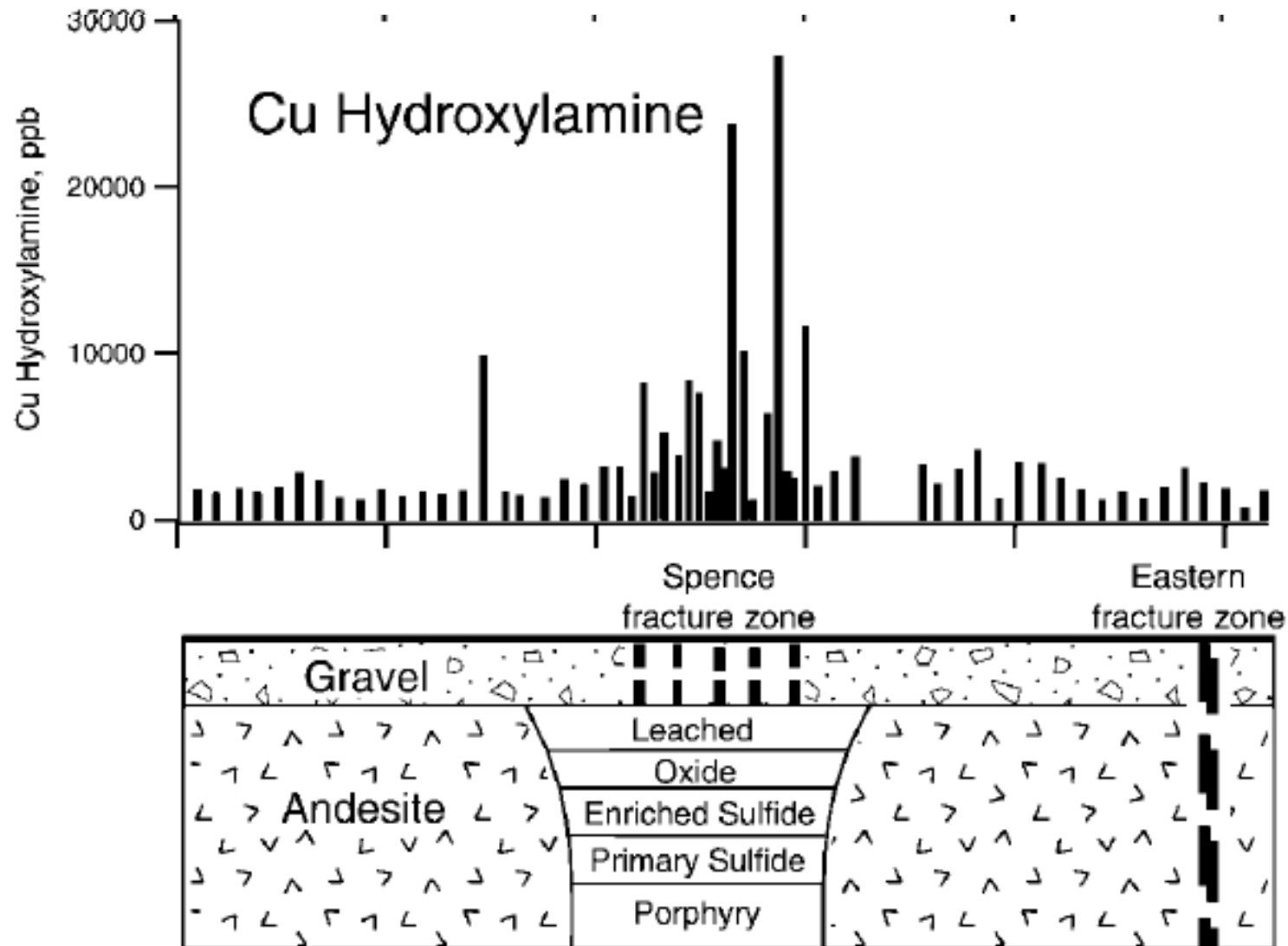
But in other countries, partial leaches appear effective.....



From Cameron et al., 2004



But in other regions, partial leaches appear effective.....



From Cameron et al., 2004

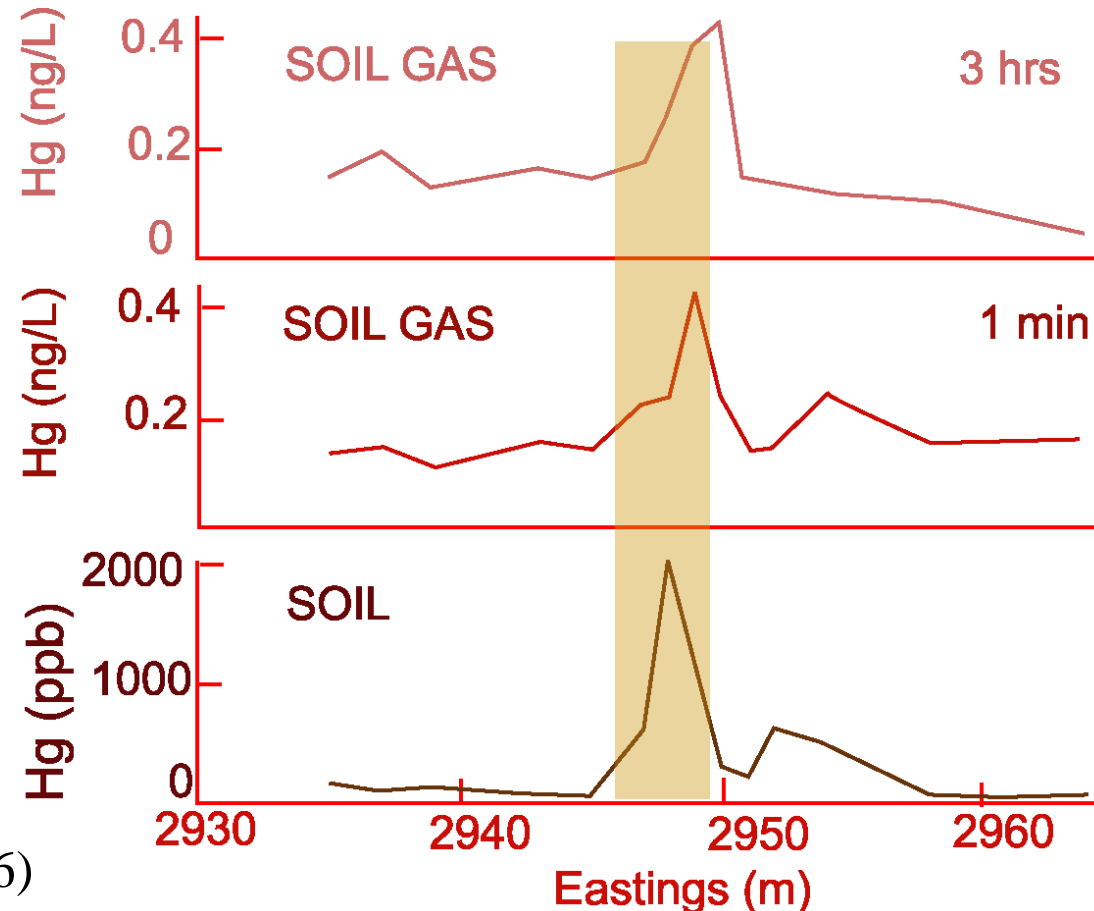


Gas Sampling & Analysis

- Pre-concentrate gas using a collector – pass pumped gas stream over suitable collector
 - Problems arise depending on wet/dry conditions
- Some use alpha-sensitive films (Rn)
- Some gases (He) require specialized storage – minimize loss to atmosphere
- Measurement
 - **mass-spectrometer He**
 - **vapour AAS - Hg**
 - **Scintillators and ionization chambers Rn**
 - **Gas chromatographs**



Case Study - Volatile (Hg) Comparisons

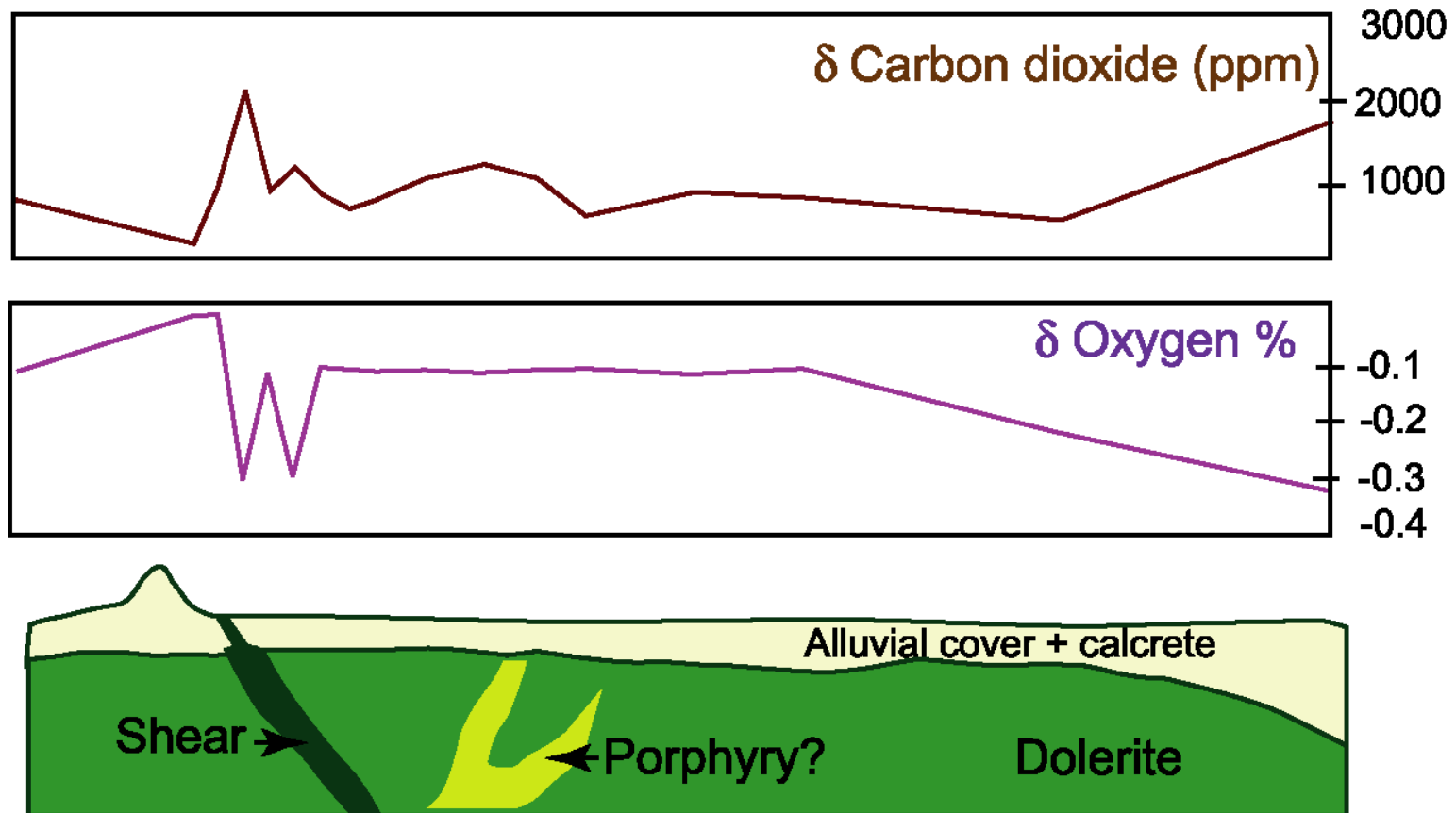


After Carr (1986)

Hg in soil shows better contrast than that in soil air –
So why sample the more problematic and expensive gas?



CO₂ Analysis



Is it a reflection of better aeration via a shear or is it related to mineralization?

From Polito et al (2002)



Assessment of use of Gasses in Exploration

All studies show relationship between **gas concentrations in soil** and **conduits** – faults and shears

Suggests **preferential pathways** of gas phase travel

Soil gas concentrations can be affected by **seasonal** and **atmospheric variations**

Sampling and analysis difficulties limited its use, but newer field sampling methods and desorption analysis of clays hold promise

Several unbiased investigations of gas based techniques has shown gases to be of limited value in exploration





Biogeochemical Survey

Determine

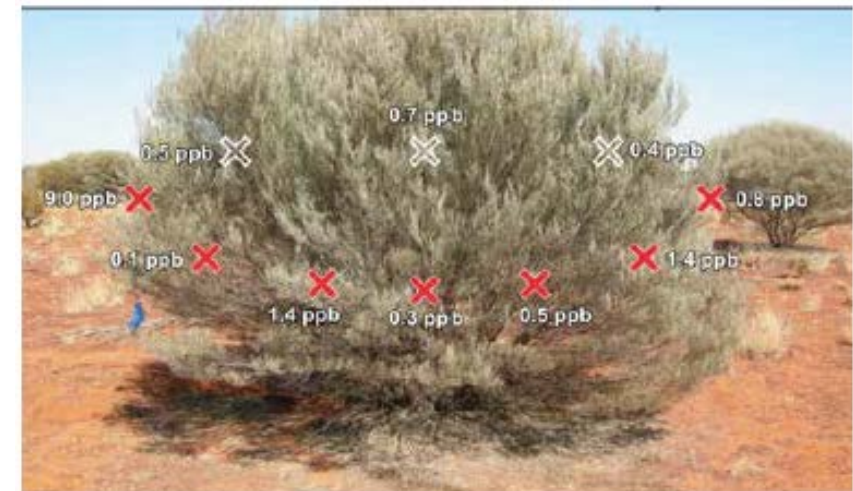
- **Type of plant/species** – eucalypti, red gums, mulgas
 - distribution – ease of recognition
 - ease of sampling
- **Type of organ** – leaves, bark, branch, twigs
- **Size of plant** – under-story, large tree etc
- **Season** – summer, spring or winter
- **Amount of sample** needed to give adequate ground or ashed sample

Considering number of species - variables are large and often difficult to constrain
– needs extensive orientation surveys

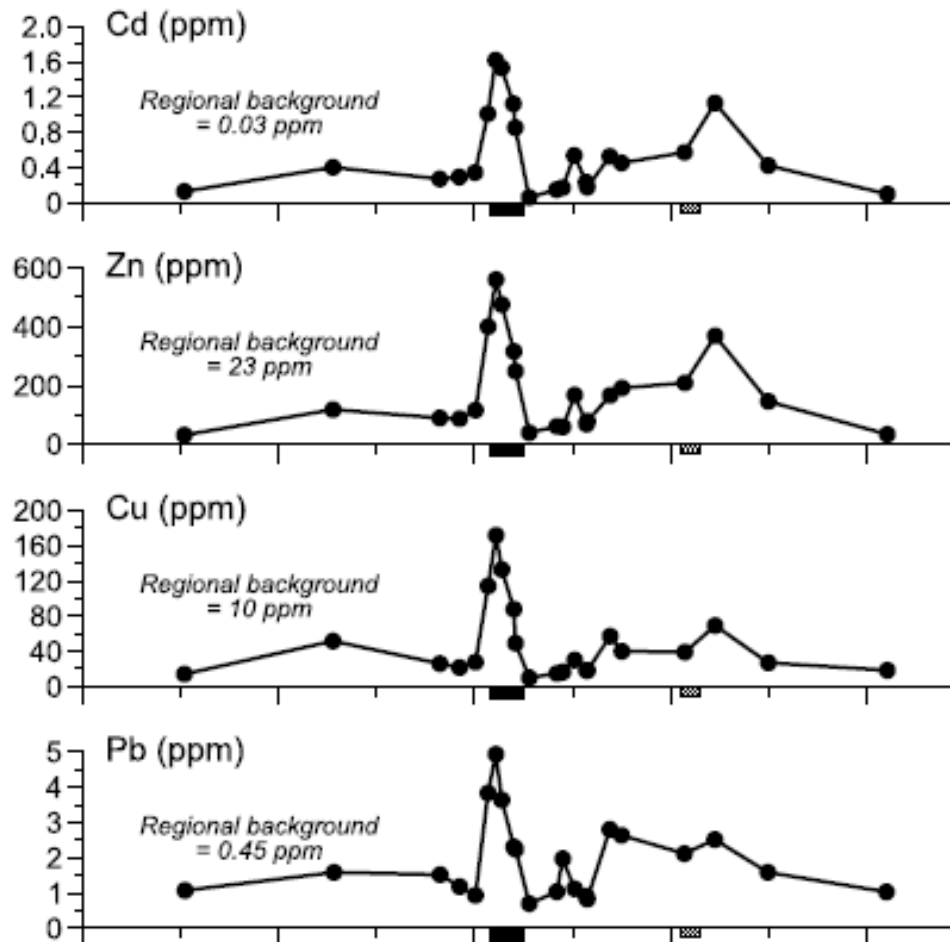


Sampling & Assaying

- Dense areas - geometrical grids
- Scattered - wherever plants are found
- Foliage collection - generally around 300-500g sufficient
- Standard metal secateurs
- Avoid wearing jewellery and sunscreen and avoid sweat touch to plant.
- Placed in calico bags
- Grind ~ 300-400 g sample
- Pre-digested with an oxidising agent e.g. nitric acid or hydrogen peroxide.
- Digested in Aqua Regia
- The digest is analysed by ICP-MS and ICP-OES.



Biogeochemistry works at one location (through 20 m of transported regolith)

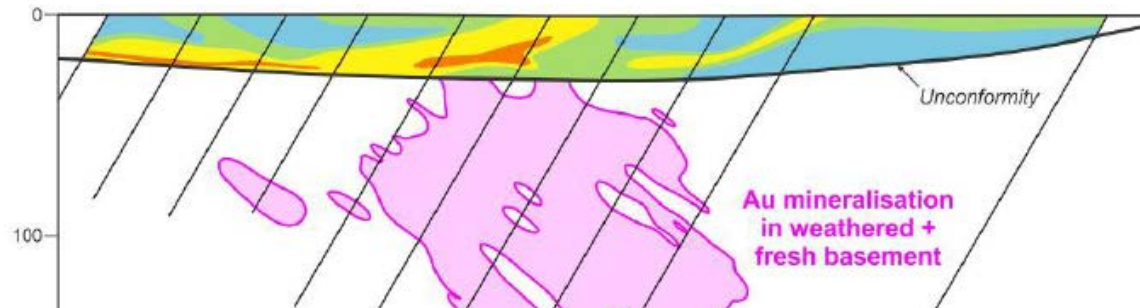
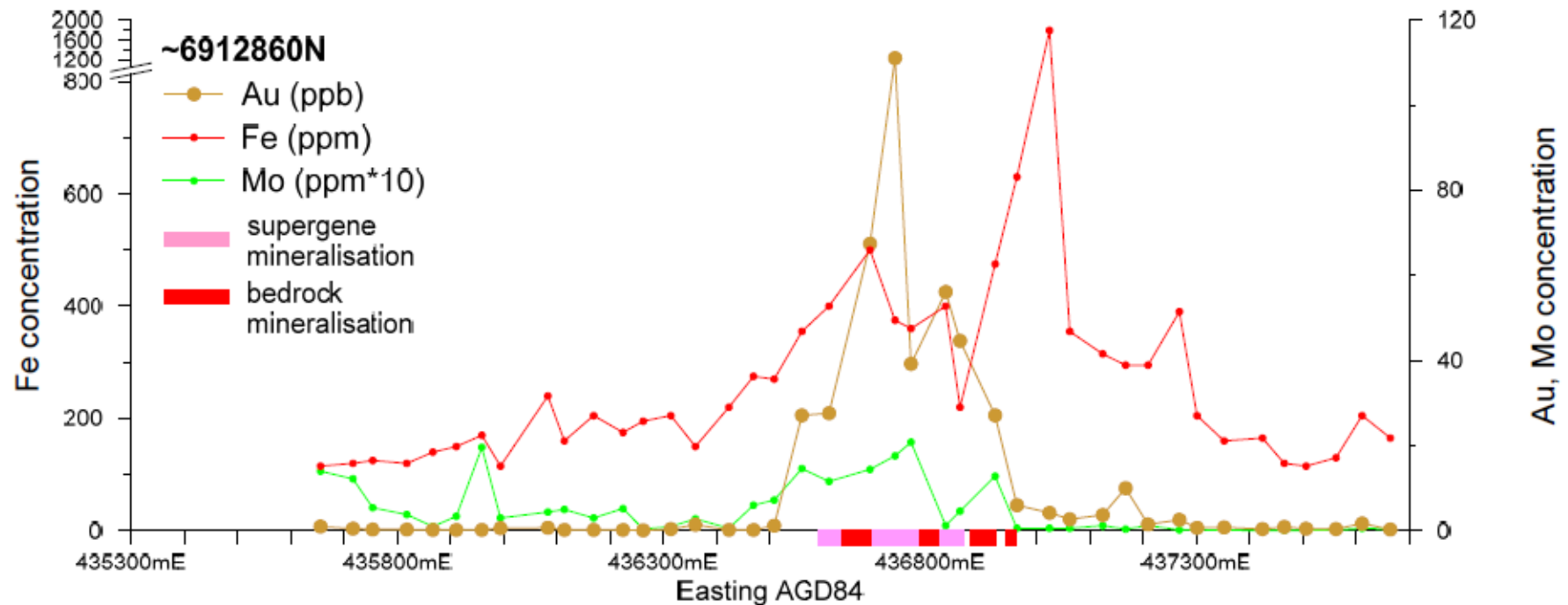


Mulga litter data at Jaguar deposit

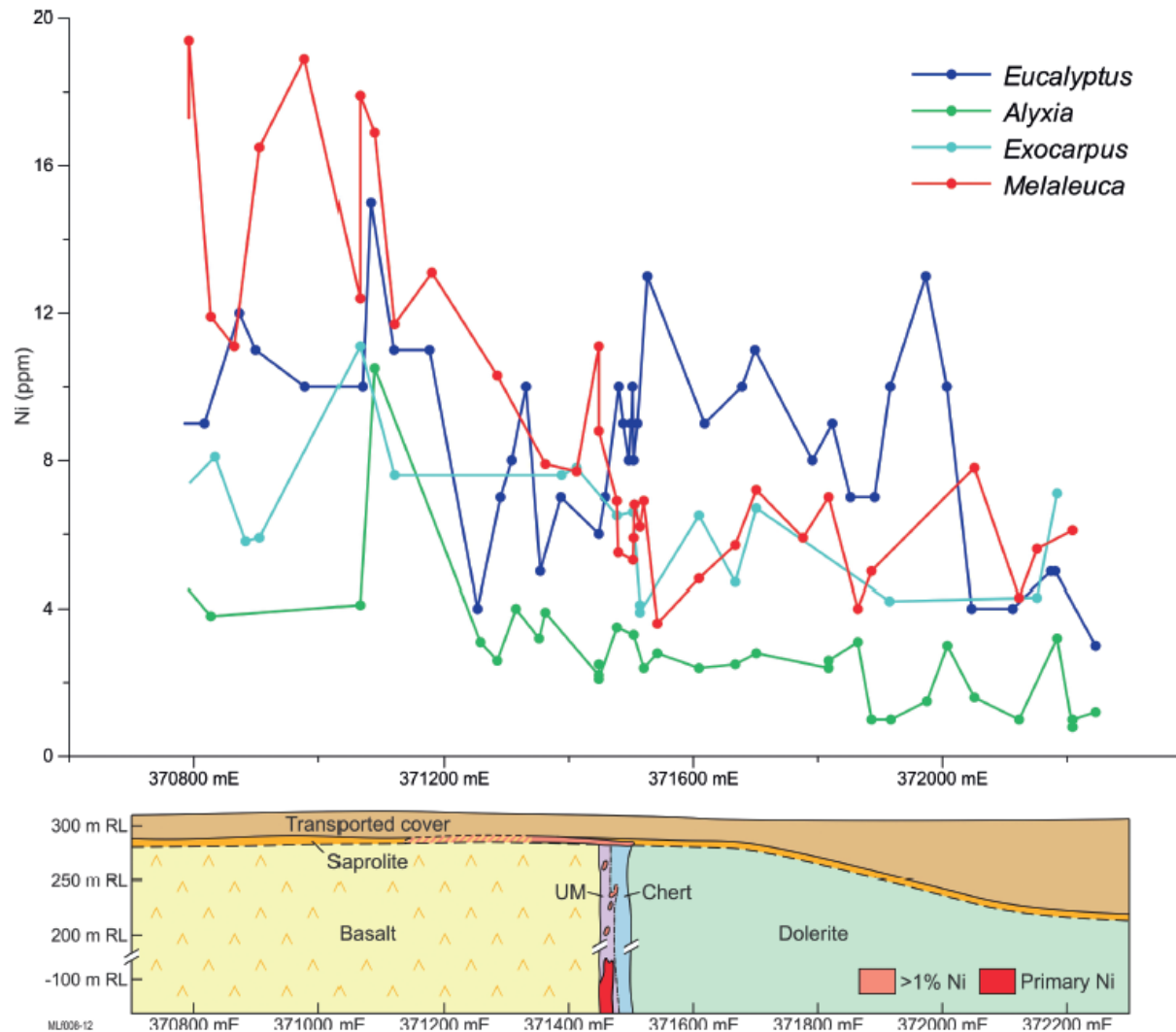
From Anand et al (2007)



Biogeochemical expression through 10 m of transported cover at some locations



Biogeochemistry does not work at another location (through 10 m of transported regolith) – why?



From Lintern et al (2013)

