# Partial Leaches, Sulphur Isotopes and Regolith Controls:

# A Case Study from the Osborne Cu-Au Mine far north Queensland

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*David Cohen and Iain Dalrymple, UNSW, for additional collaborative work on soil geochemistry at Osborne.*

*Reference in relation to regolith:*

*Rutherford, N. F., Lawrance, L. M. & Sparks, G. (2005) Osborne copper-gold deposit, Cloncurry Mining District, north west Queensland. In: Regolith Expressions of Australian Ore Systems, CRC LEME, Perth.*

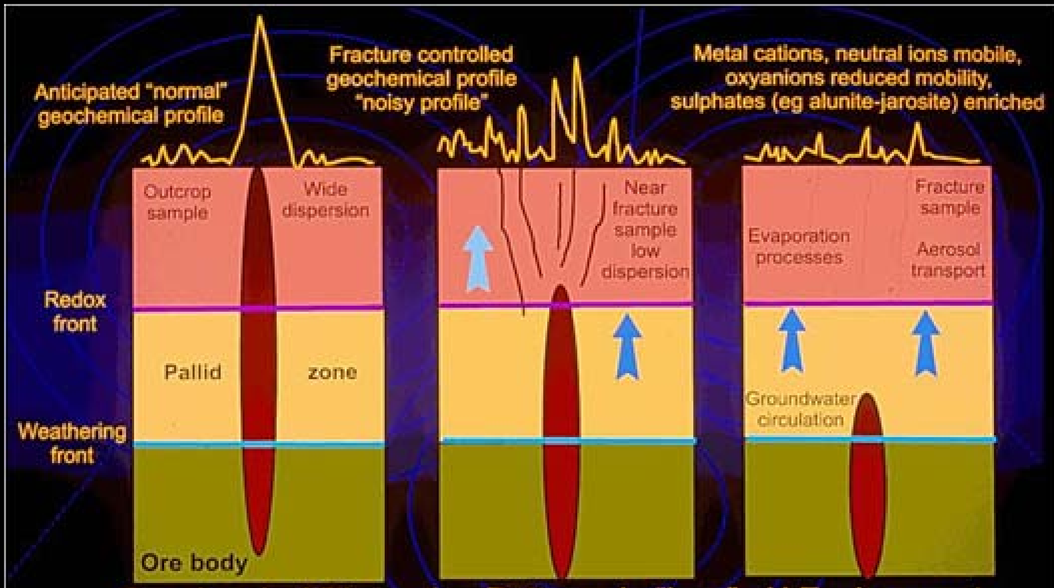
*Contains listing of references on Osborne Cu-Au Deposit.*

*Th extended abstract discusses a number of related issues not discussed here.*

Understanding the nature of geochemical signals and generation of anomalies represents one of the important advances in modern geochemistry.

Issues considered in this presentation include:

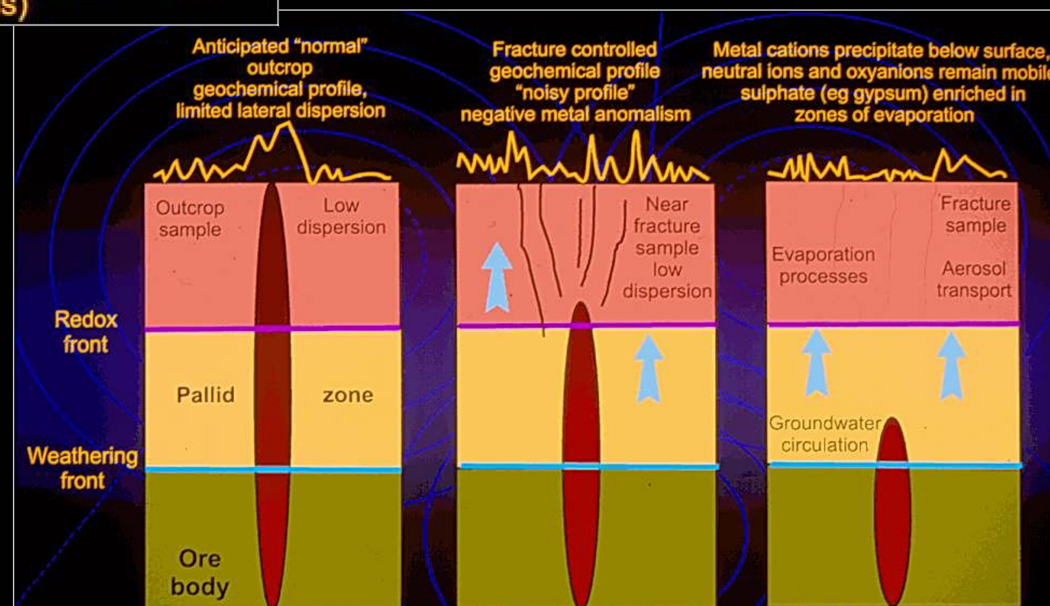
- The impact of the regolith on geochemical redistribution of signal in surface rocks; the need to know your geology and sample site attributes,
- Making use of low levels of detection available from partial leach geochemistry and ICP-MS to resolve the often subtle nature of surface field geochemistry related to deeply buried mineralisation in weathered terrains,
- Resolving anomaly character – what anomalies really look like in detail in terrains with deep cover,
- Alternative methods of defining or resolving anomalies.




Geochemical Dispersion Patterns in "Low" pH Environments (abundant pyrite bearing systems)

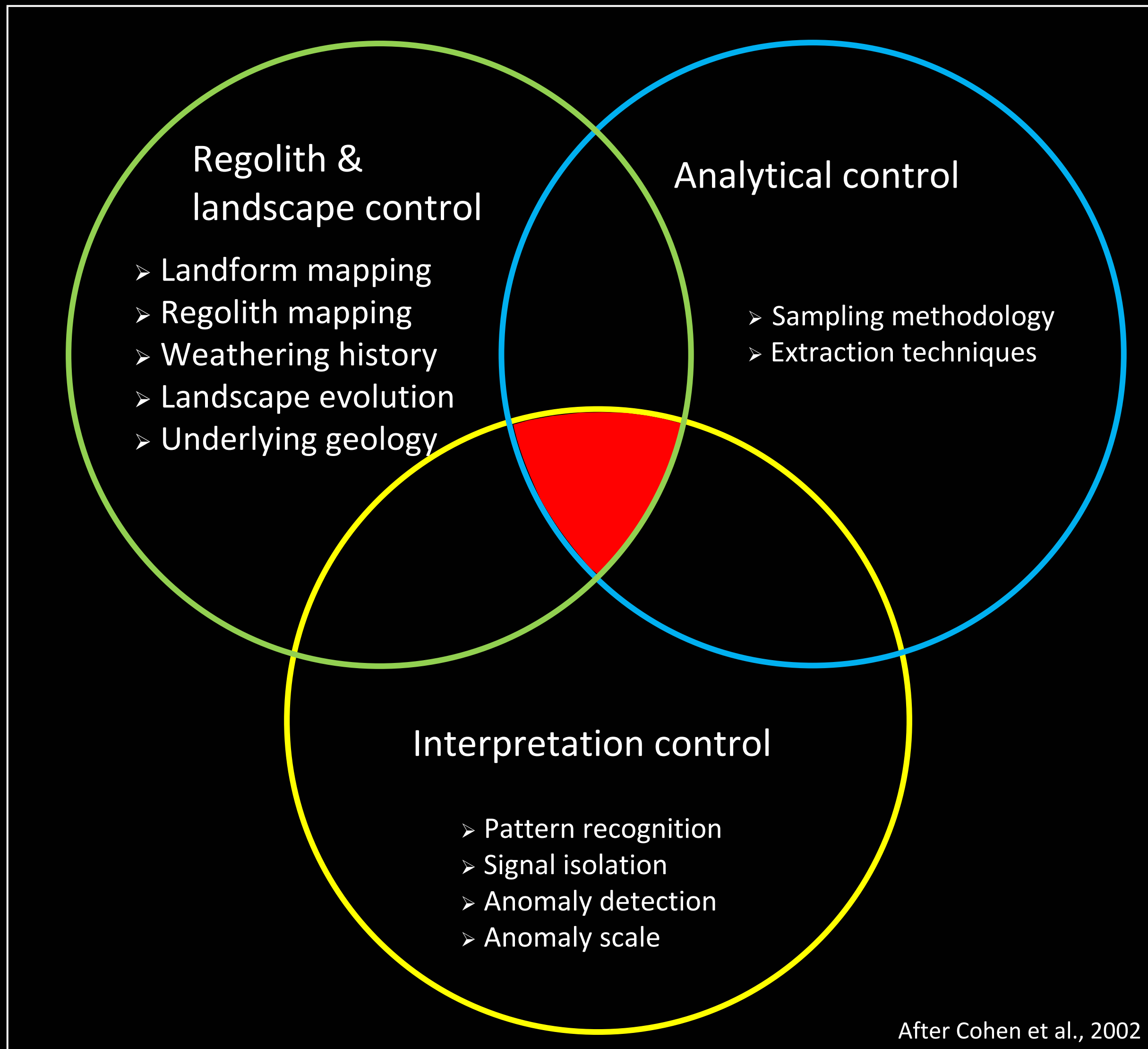
Change in character of geochemical signal with source depth and intensity of weathering.

From a geochemical perspective a "signal" rapidly breaks down to look a bit like a geophysical conundrum ….noise…..
but as geochemists we are not put off by this and we can handle it….like geophysicists somehow manage to do.




Geochemical Dispersion Patterns in "High" pH Environments (carbonate-low pyrite bearing systems)

# The geochemical landscape……..




……strongly influences sampling outcomes.

# The regolith, weathering and erosion and its influence in geochemistry.

# A quick digression

The geochemical problem lies in the often forgotten reality that when we sample in the natural environment we are sampling materials that are formed by inherently chaotic processes. Simply, this means that there is a high rate of natural variability in the landscape at all scales of sampling.

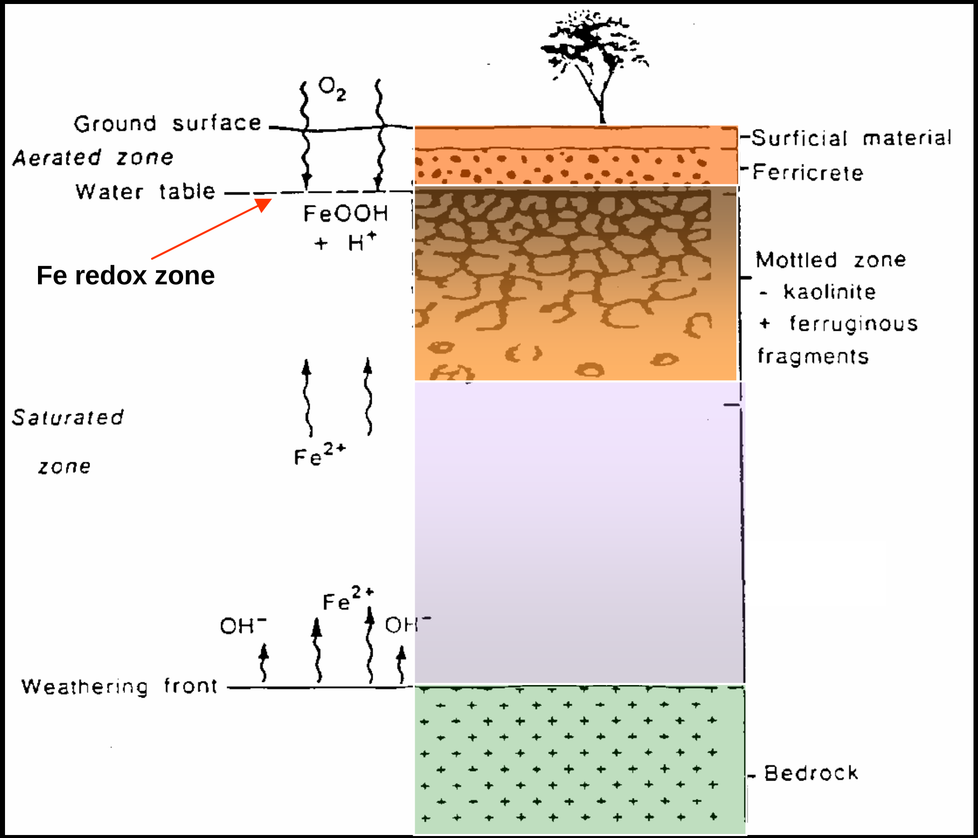
However we need to make sense from this.

# What we are dealing with…………

Fe-oxyhydroxides overprint upper parts of weathered profile
$H^+$ ions break down minerals in rock

Groundwater movement removes soluble salts, Ca, Mg, Na, K, sulphate, chloride etc

Rock weathering ceases where groundwater flow stops




Pisolitic gravel formed from erosion of mottled zone

Upper saprolite dominated by kaolin, degraded illite clays, micas, oxides

Lower saprolite contains mixed kaolin, illite, smectite clays and at its base remnants of primary minerals

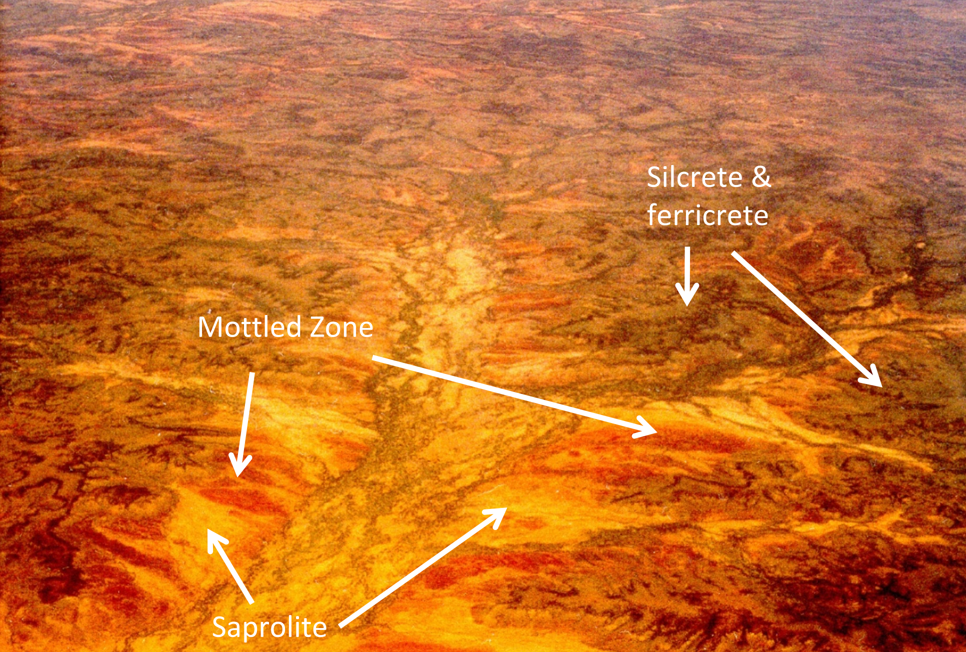
Key features of the "classic" weathered profile.

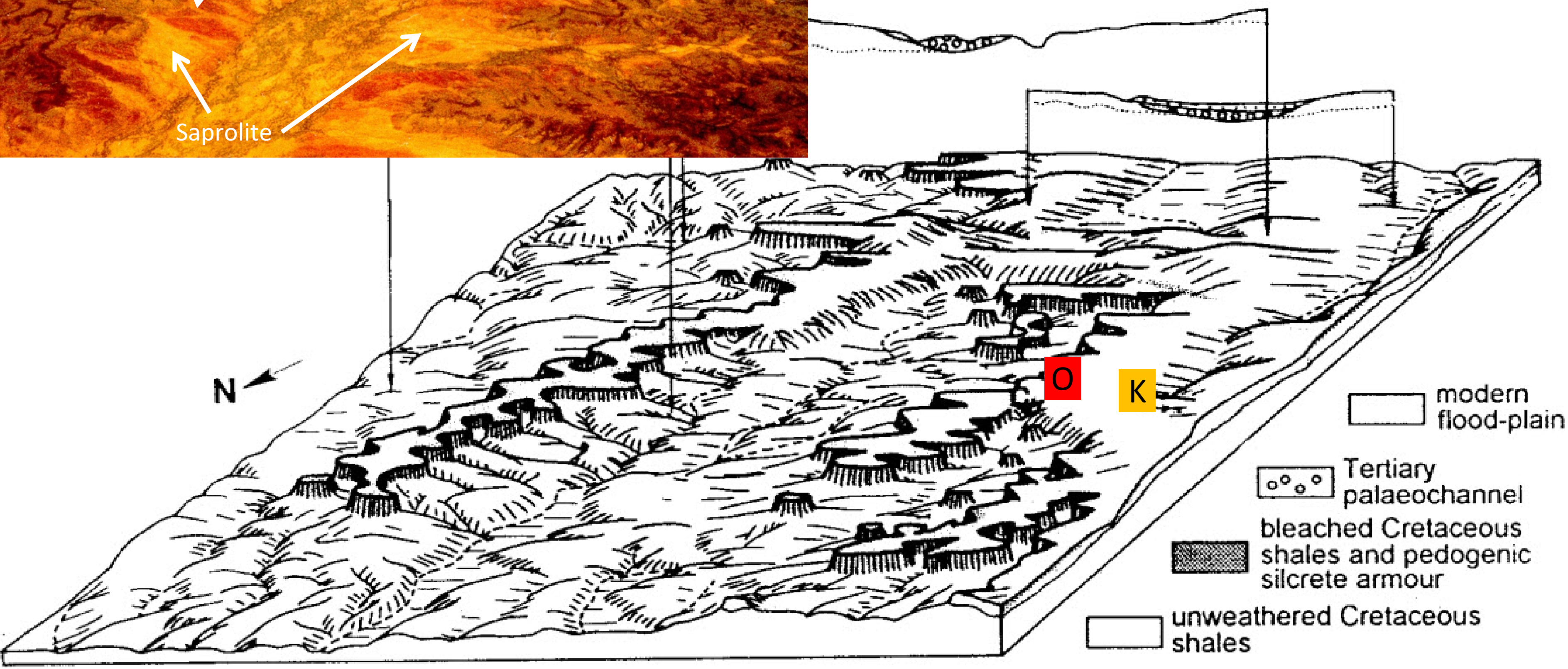
The chemistry is essentially one of hydration, cation exchange driven by $H^+$ ions and oxidation of Fe.

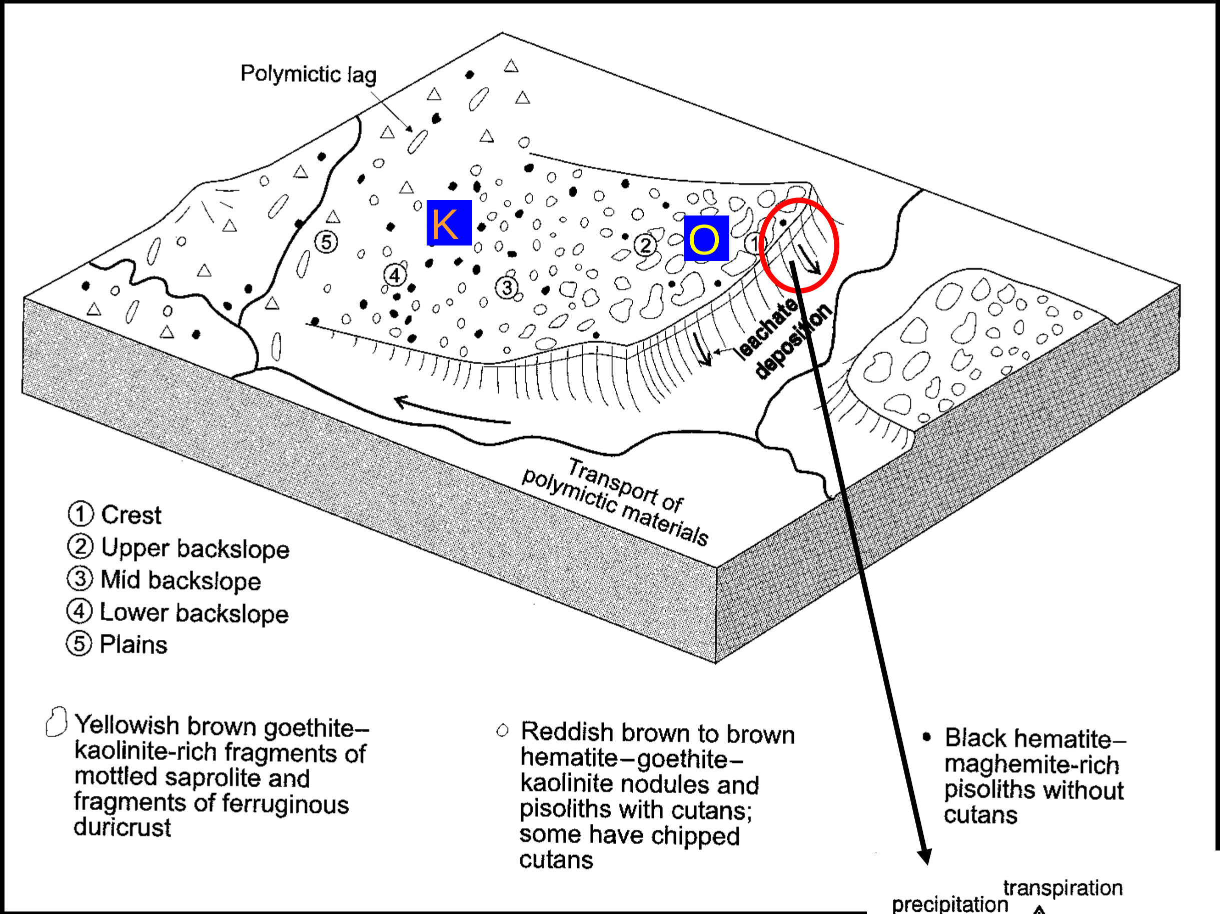
(after Mann, 1991)

Sulphides only modify this process locally.

# Osborne and Kulthor Regolith Setting

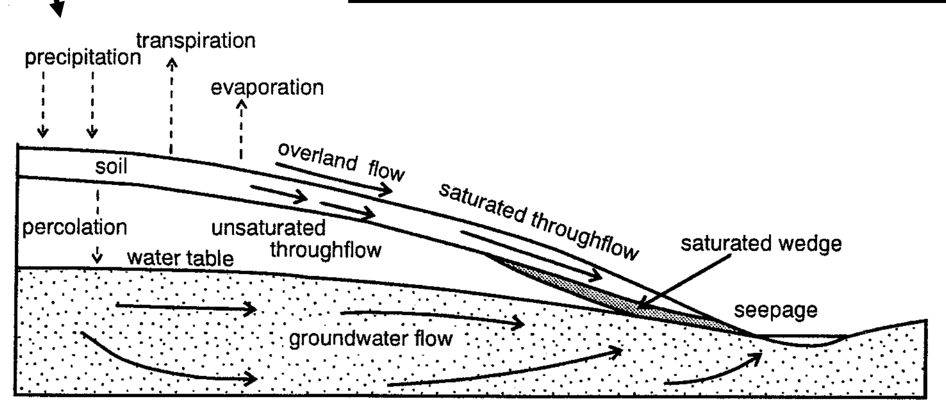


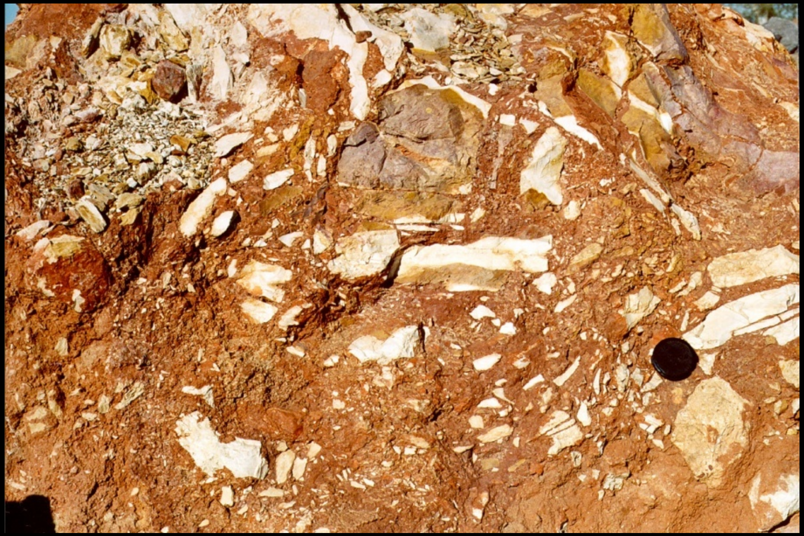



# Osborne Regolith

## Pattern of evolution of the landscape.




Patterns of surface and near surface ground water flow Osborne area. This erodes old and gives rise to new generations of siliceous and ferruginous duricrust which form in the valleys.



At Osborne, as elsewhere, the physical break up of surface rocks can be a rapid and dynamic process…… siltstones and silcretes reduced to rubble and eroded.

Removal of components from the profile and changes in mineralogy reduces volume resulting locally in collapse breccia "pipes" that extend to some 5-10 metres depth at Osborne.

Fe-oxide infill and overprint along vein-filled fracture in mottled zone of weathered sediment.

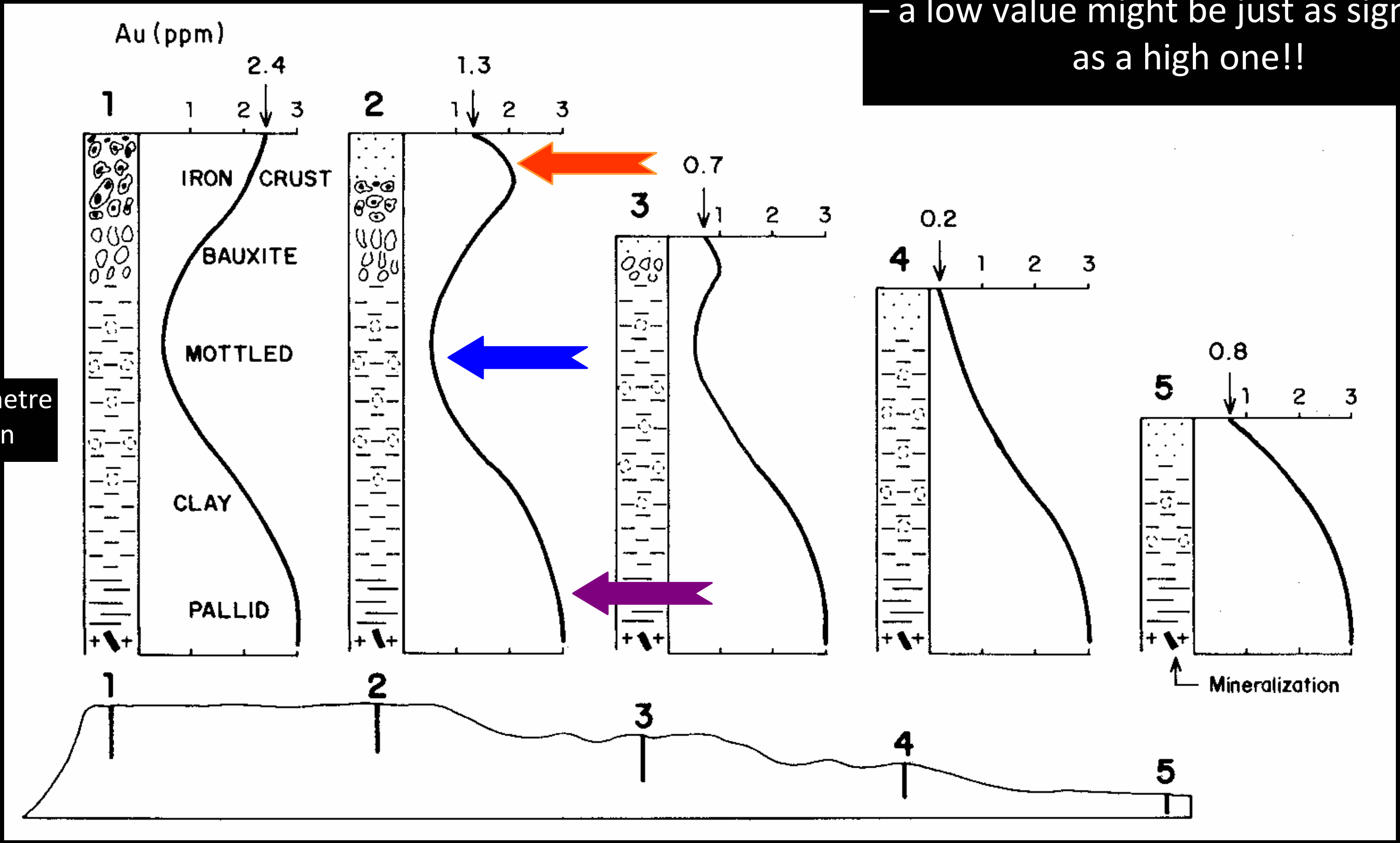
The overprinting illustrates the dynamic and ongoing nature of the chemical weathering process and movement of iron oxides by groundwater.

These features illustrate the "chaotic " nature of material available for sampling in weathered terrains.

*A most important and too often forgotten aspect:*

Surface values vary significantly depending on depth of erosion through a weathered profile
– a low value might be just as significant as a high one!!

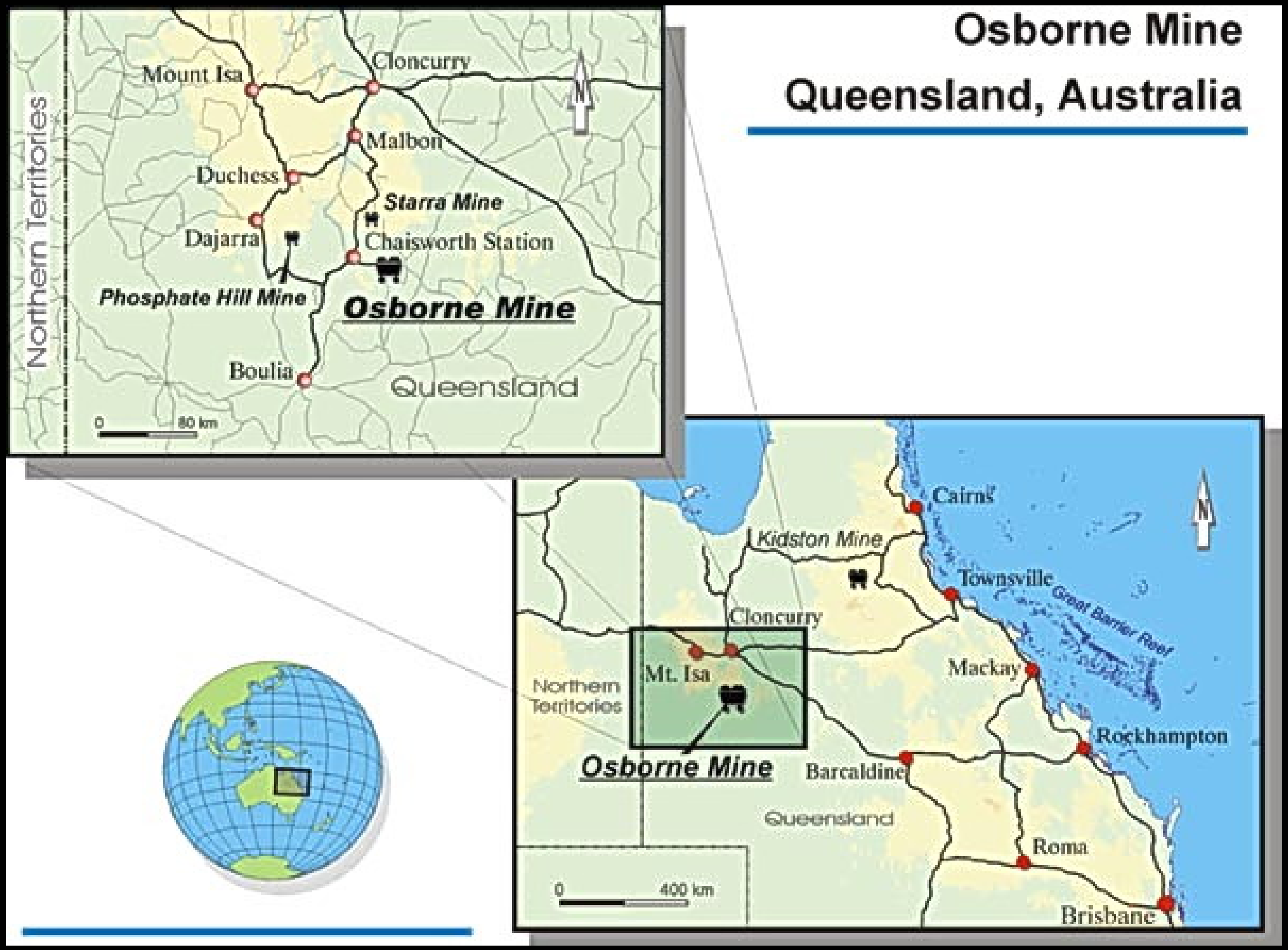
40 - 60 metre section




Geochemistry through weathered profiles
- variation in surface geochemical values with erosional depth -

(after Da Costa, M.L., 1993)

# The setting of the Osborne Cu-Au deposit and the geochemical problem.



# Osborne Cu-Au Mine

~ 39 Mt @ 3% Cu, 1.3 g/t Au
Geochemical and geophysical target.

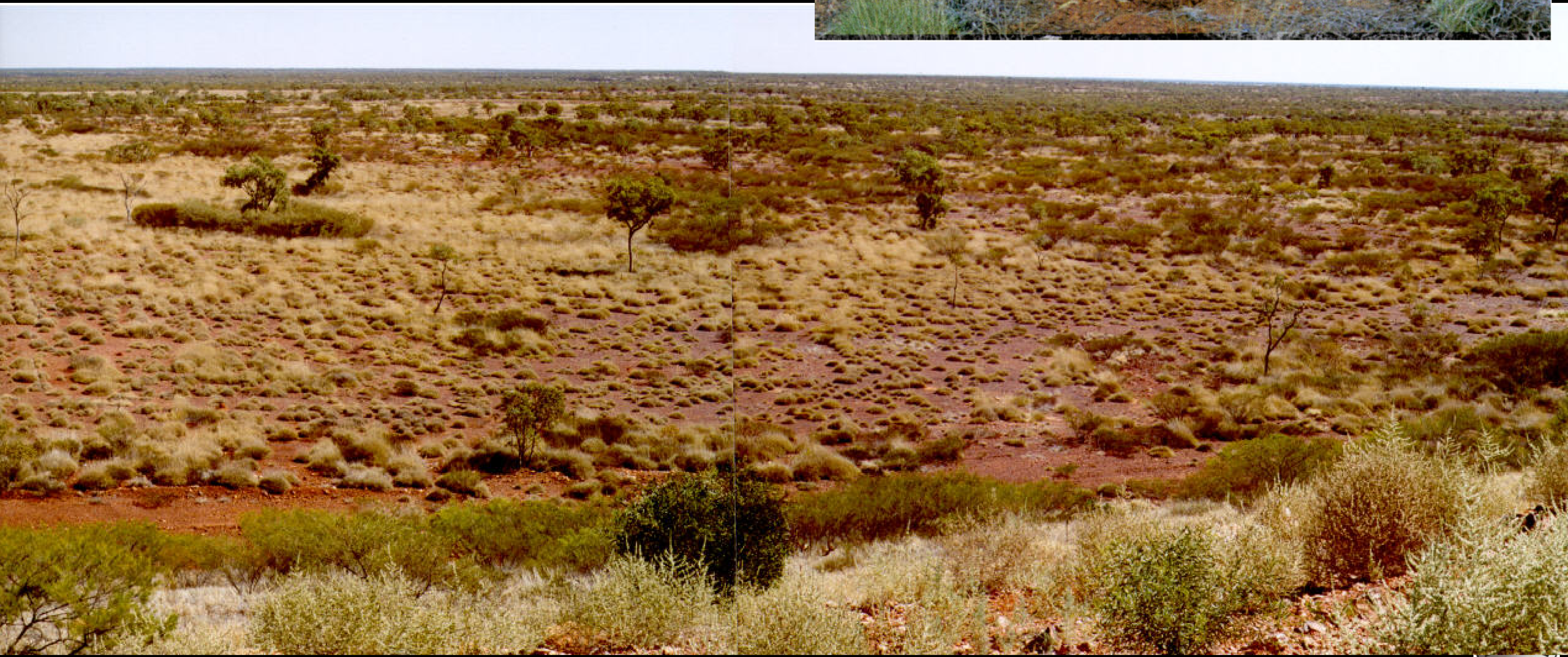
View 2002

View about 1994

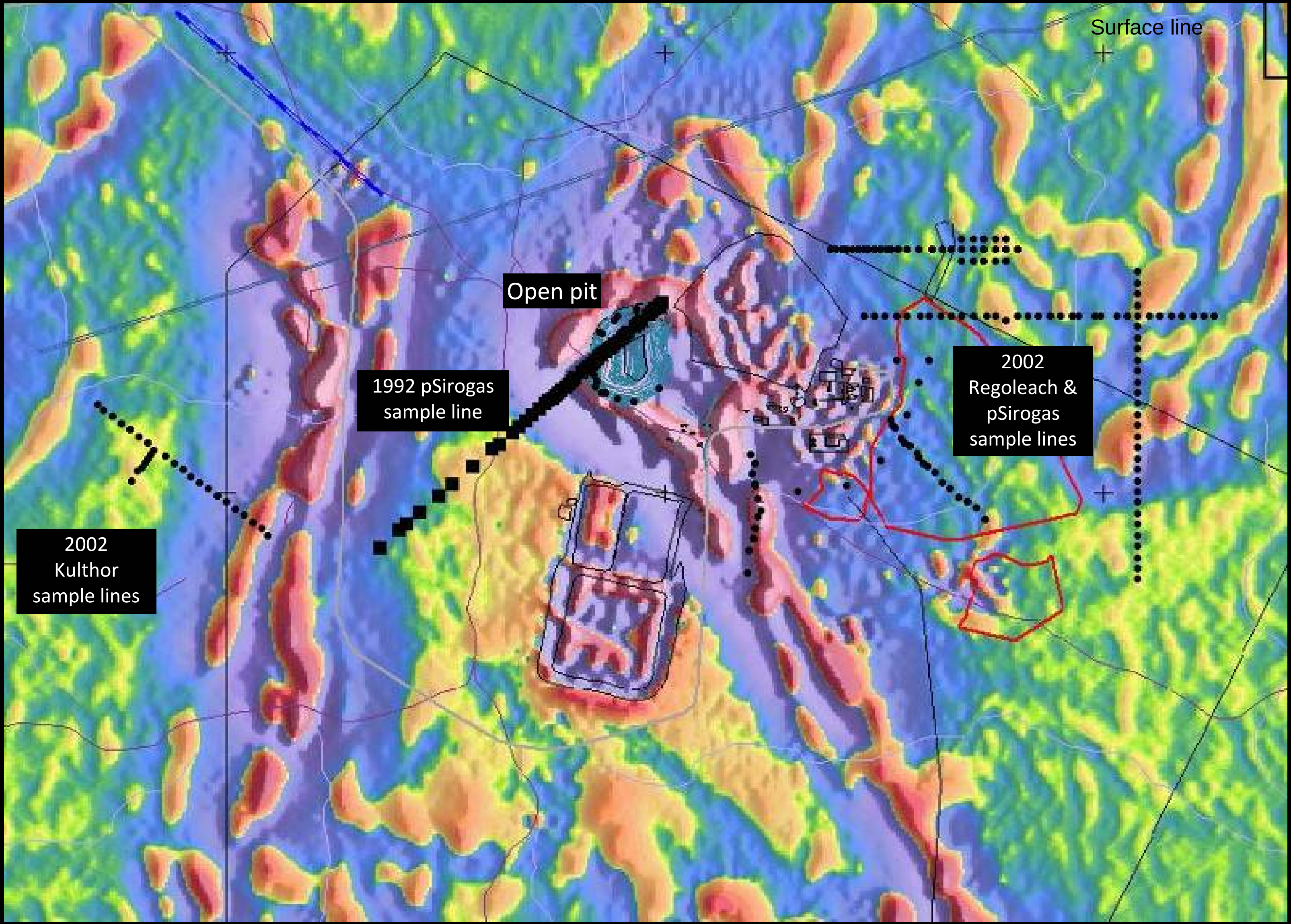
Proterozoic-age epigenetic deposit hosted in multiply deformed amphibolite grade metamorphics and quartz-magnetite ironstone.
Capped by 30 -50 metres of marine Mesozoic sediments.

Original Osborne discovery site with 1992 pSirogas sample holes.

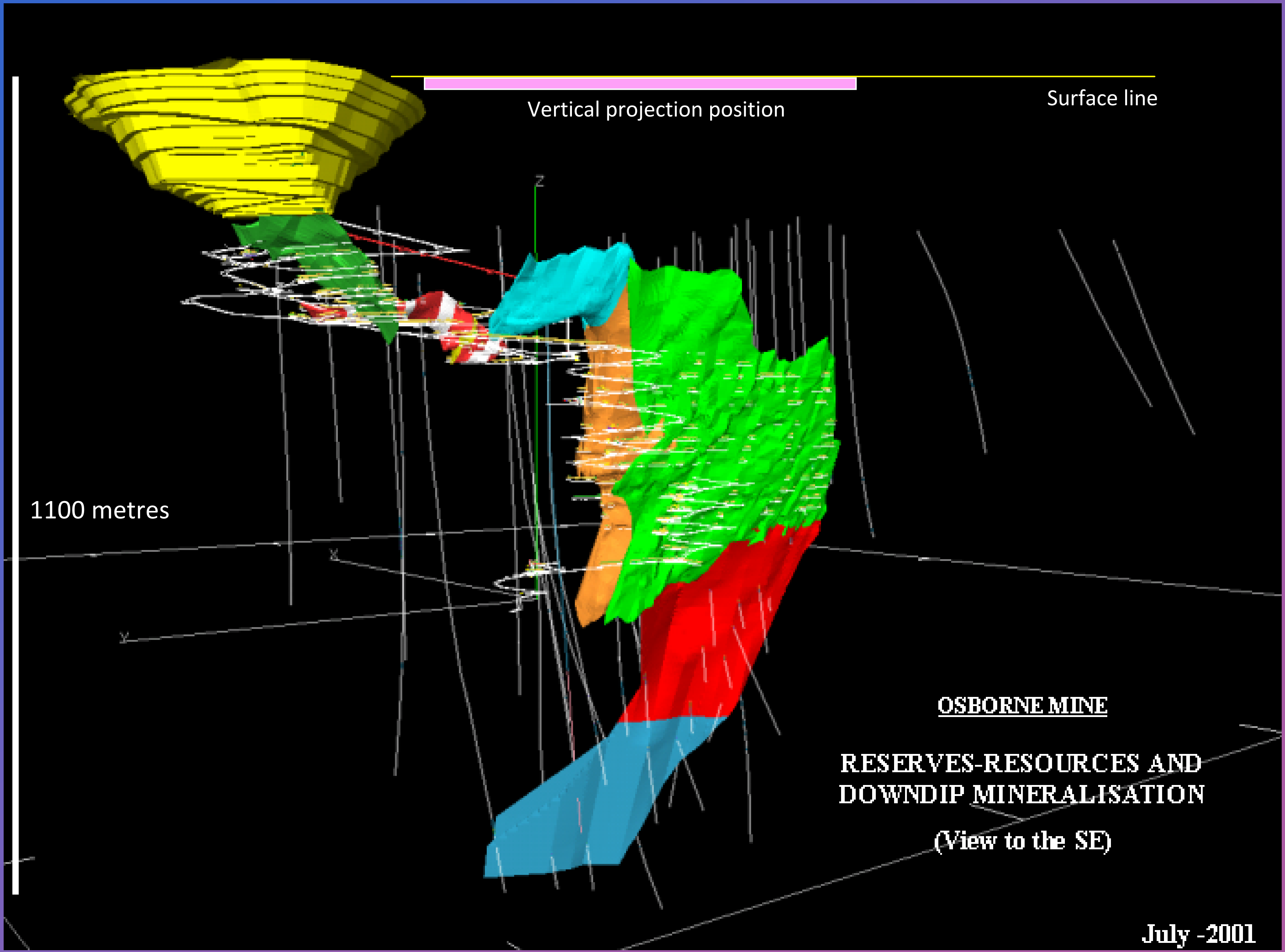
View toward Kulthor area from Osborne waste dump



# Deposit originally discovered in 1989 by drilling magnetic ironstones

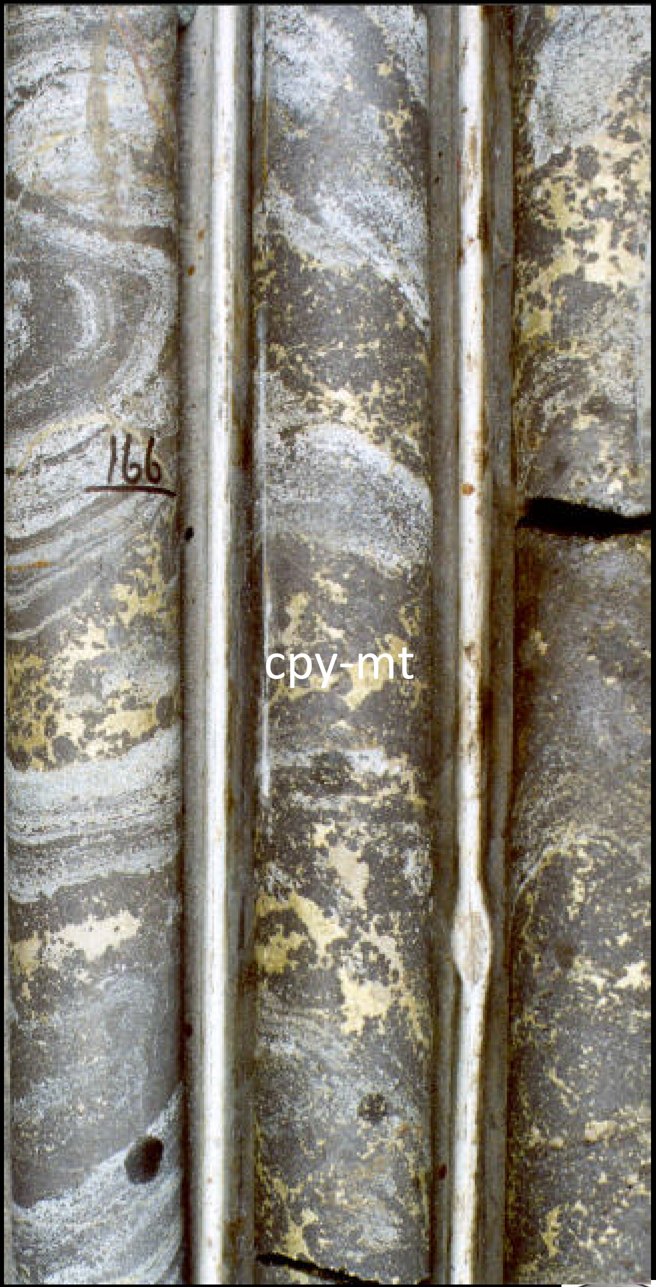



Osborne Mine Area 2nd vertical derivative magnetics



Vertical projection position
Surface line
1100 metres
OSBORNE MINE
RESERVES-RESOURCES AND DOWNDIP MINERALISATION
(View to the SE)
July -2001

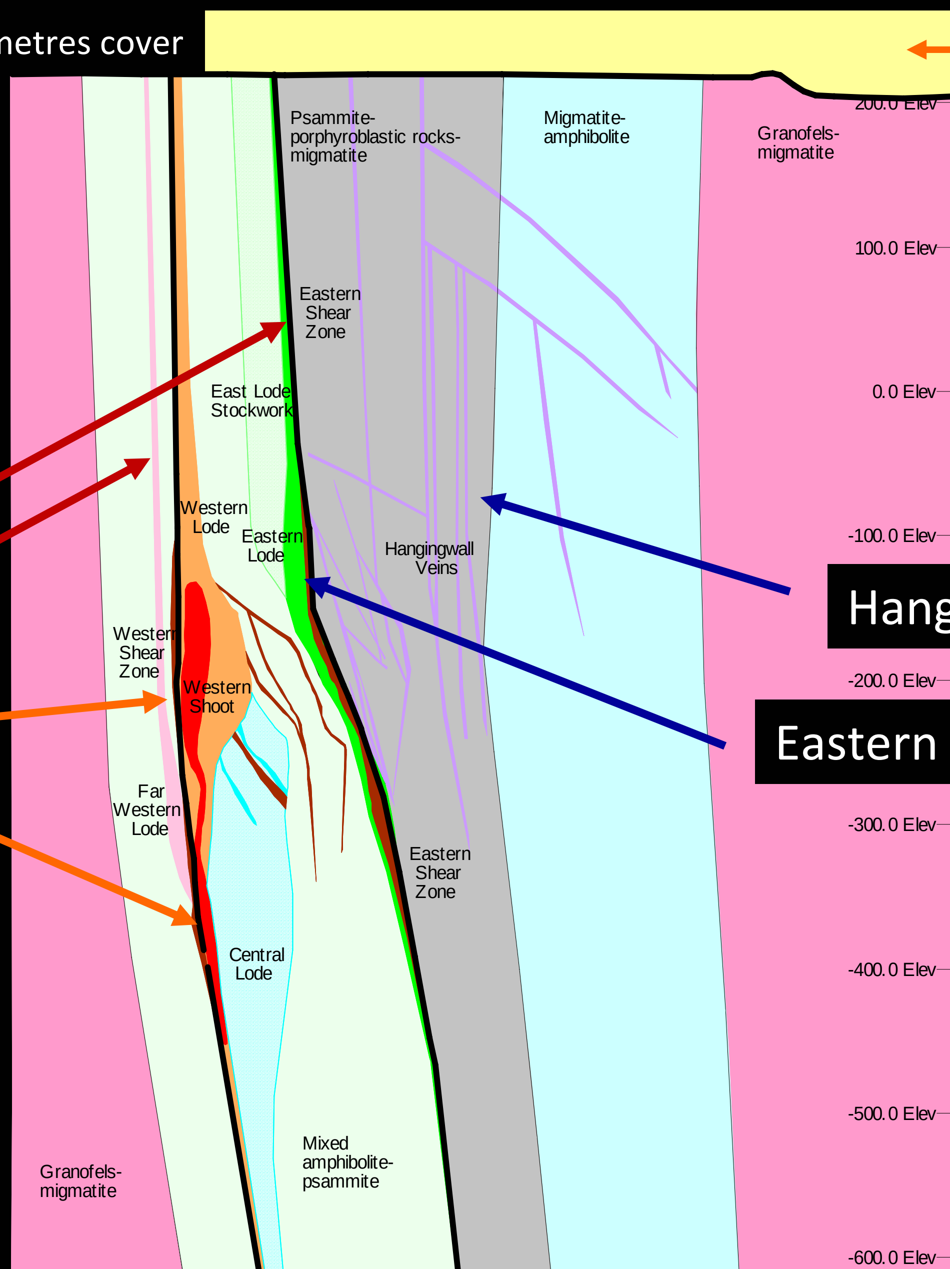

Osborne Ore Structure hosted cpy-mt-silica in folded and faulted BIF units.



# Kulthor Cross-Section

50 - 60 metres cover

Mesozoic cover sequence




350 metres below surface

Bounding faults

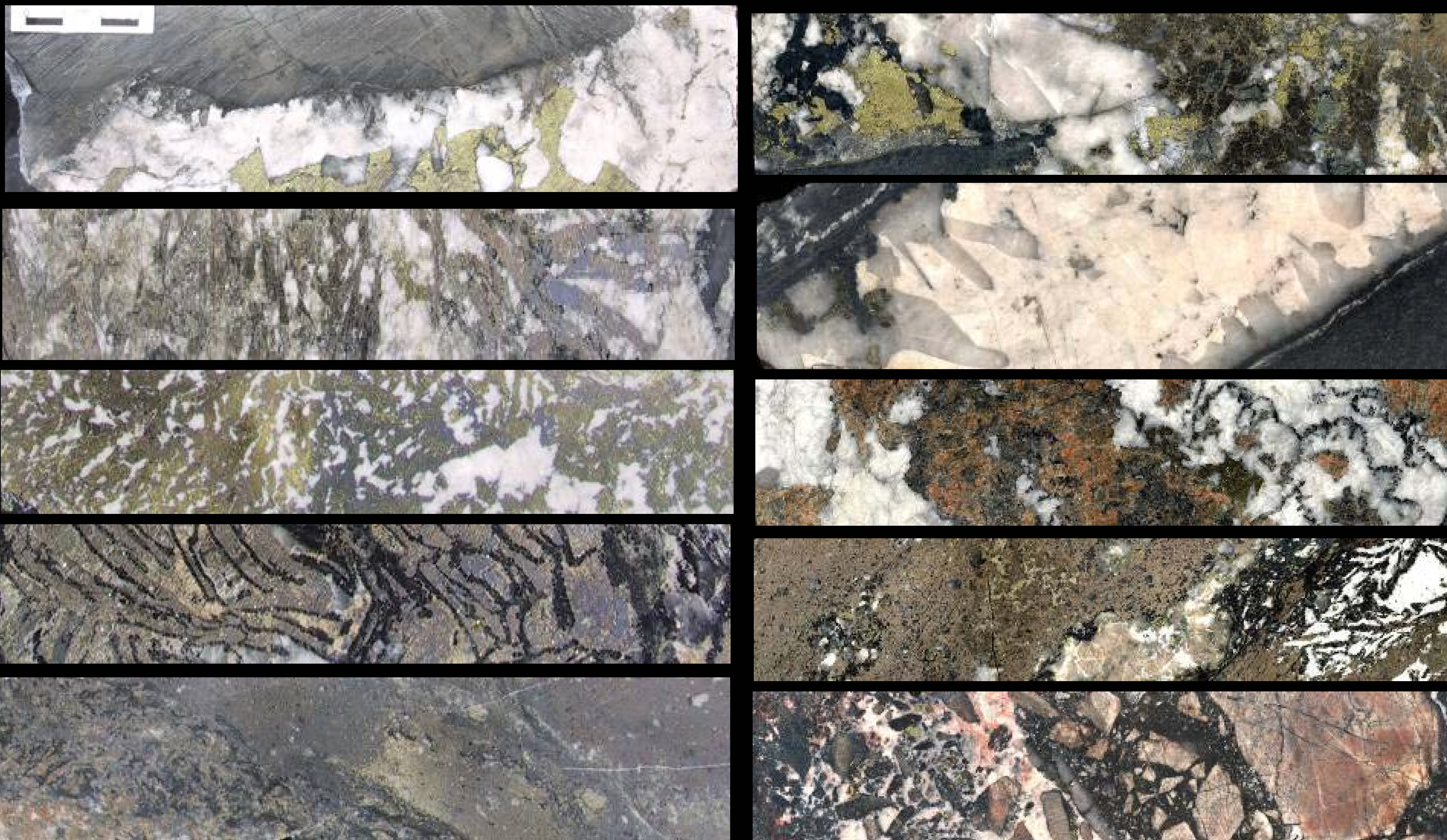
Hanging wall sulphide

Eastern ore lens

Main Cu-Au ore lens

Kulthor is not magnetic nor is it associated with a magnetic banded iron formation.

# Kulthor cpy-py-po-carbonate-quartz-biotite mineralisation



The first ore intercept encountered was 5m @ 3% Cu and 5 g/t Au and the best ore intercept was 9m @ almost 6% Cu and 10 g/t Au.

# A Tale of Two Ore Bodies

# A Dilemma and a Please Explain

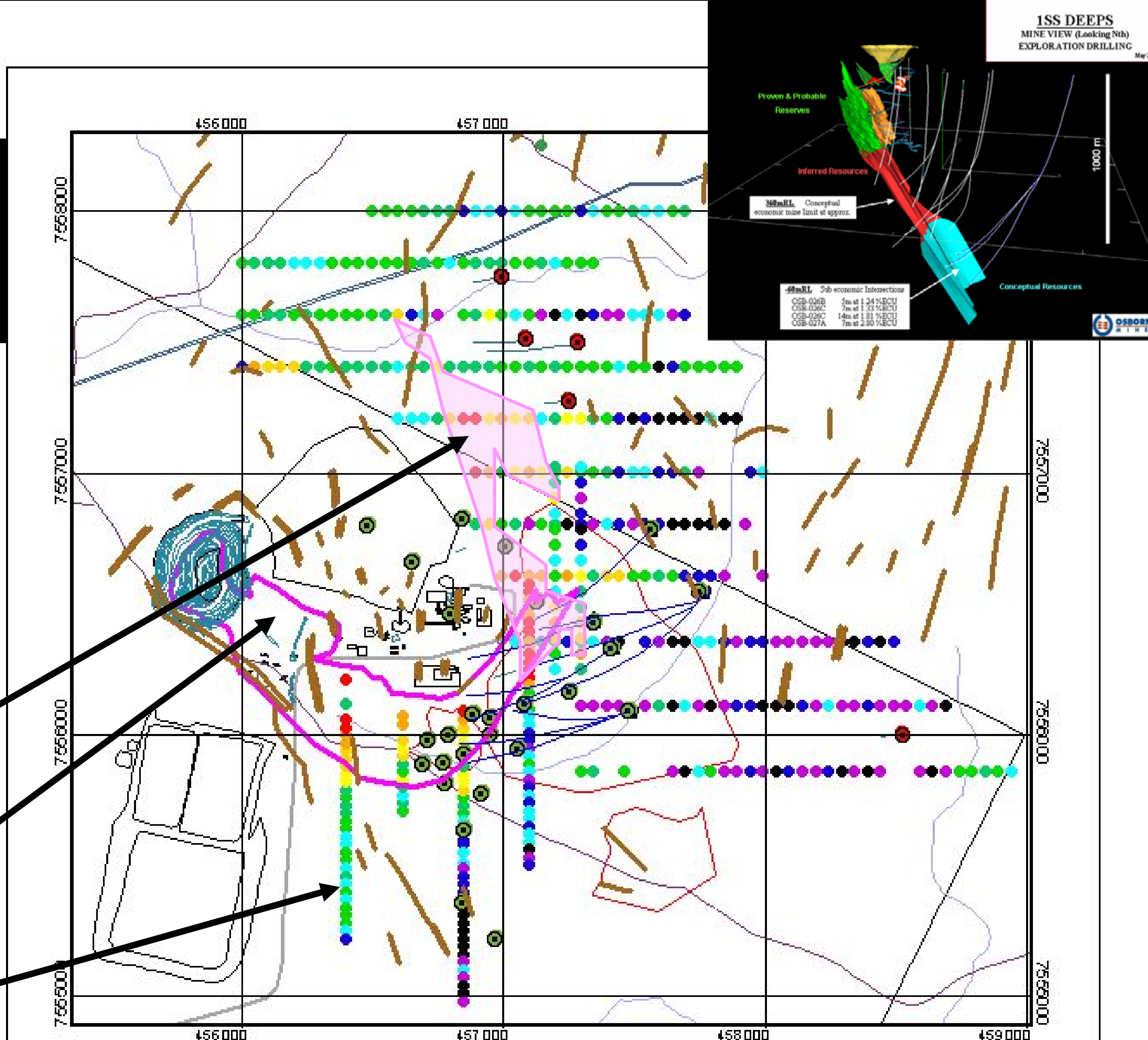
# OSBORNE REGOLEACH PARTIAL LEACH GEOCHEMISTRY

1000 Metres

DRILLED REGOLEACH ANOMALY

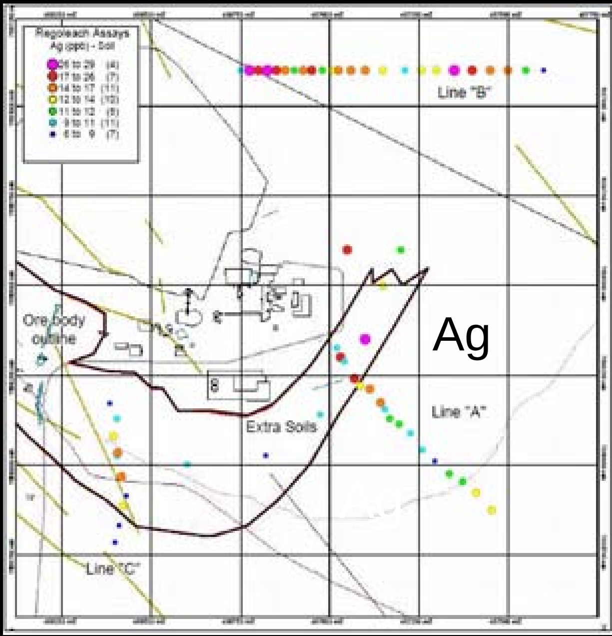
OSBORNE ORE PROJECTED TO SURFACE

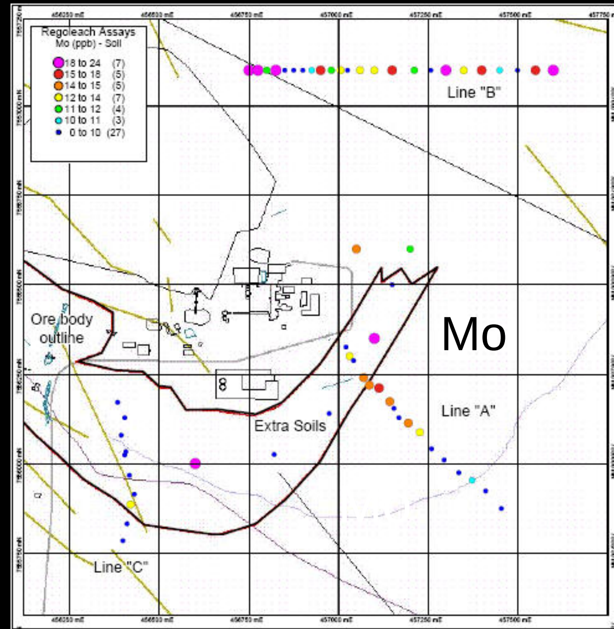
REGOLEACH SOIL SAMPLES

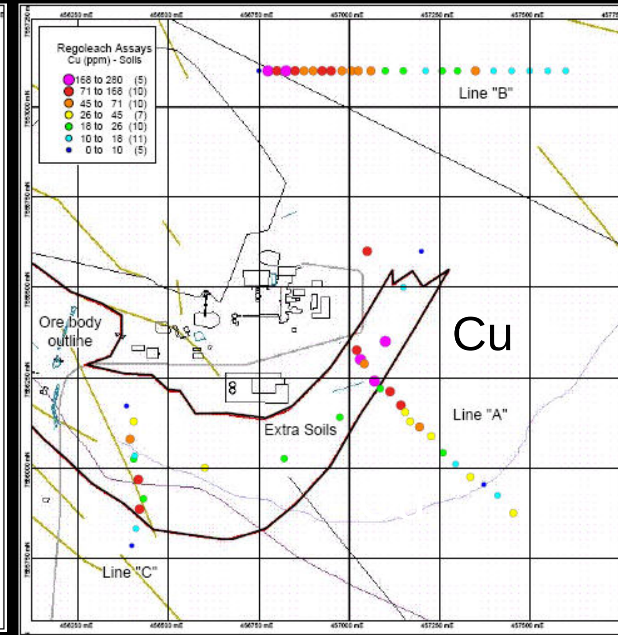


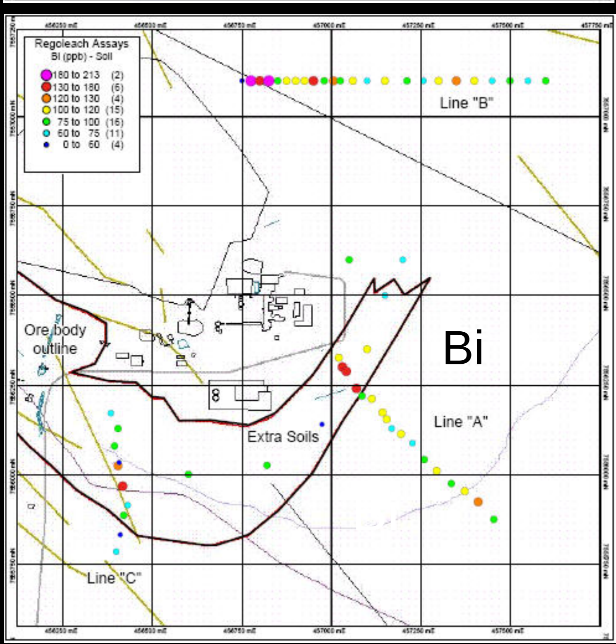

Copper Geochemistry

**The dilemma - How do we explain this anomalism?**



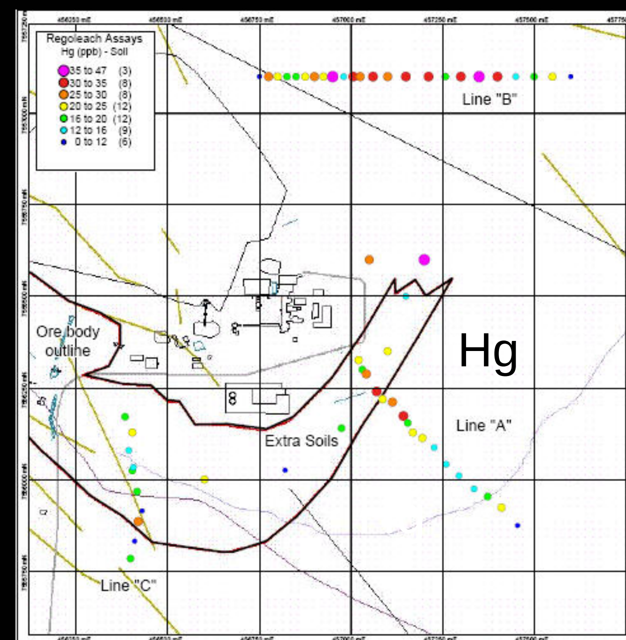




2002 trial lines for pSirogas and partial leach on soils

What is surprising is that with careful sampling the anomalism is reproduced and is multi-element in character



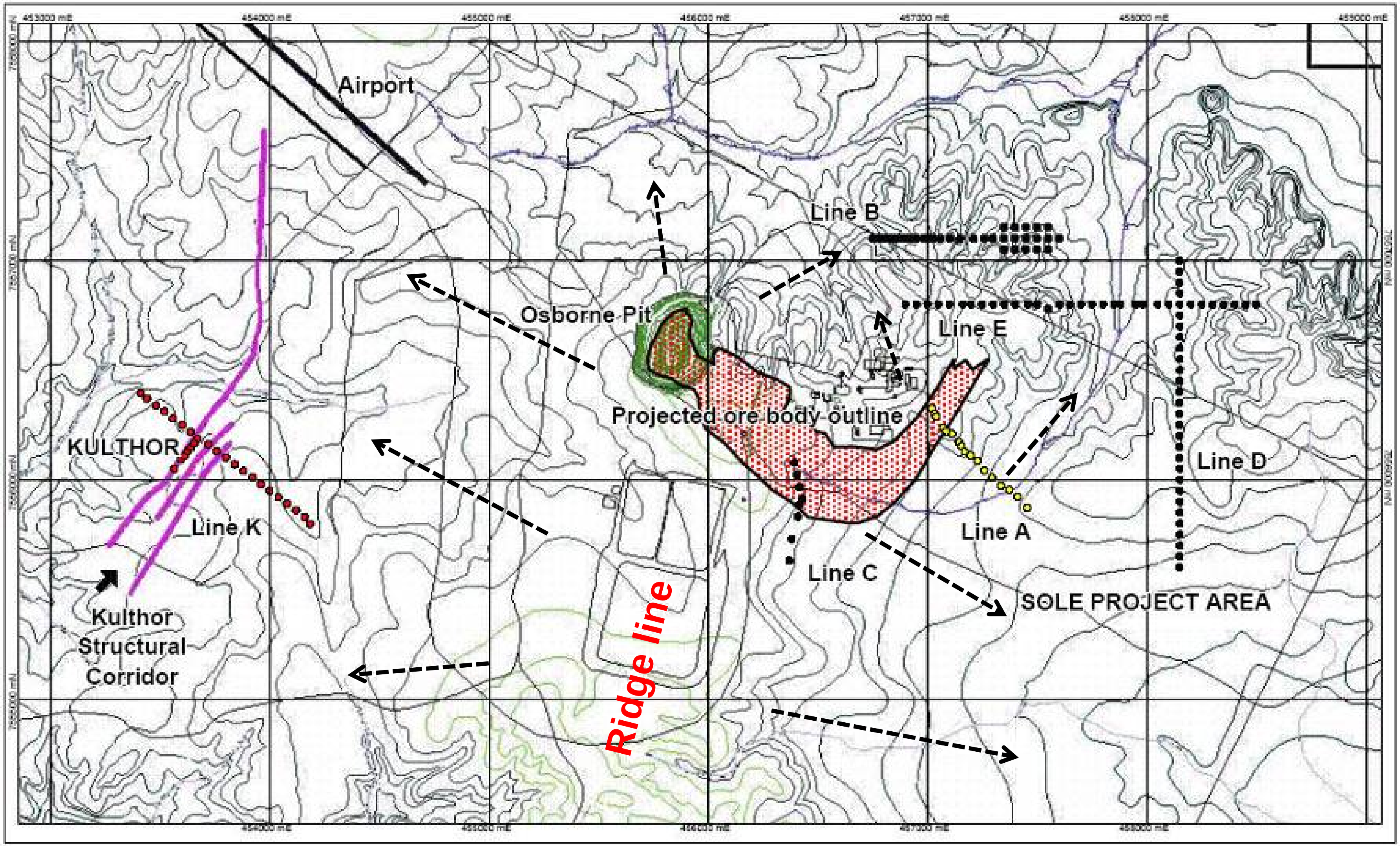
Following the "success" of Regoleach over the Osborne "deeps" mineralisation Osborne Mines undertook a similar soil survey over their new discovery, named Kulthor, located some 1.8 km to the west.

……….no anomaly was detected at all……and drilling at Osborne "deeps" got nothing.

So what is going on?…….

Lets look at some facts.

Soil sampling - 50 metre spaced sample sites, 25-30 cm deep samples -1.8mm (-10#, 1.68mm) fraction.




Osborne-Kulthor Region
Topography, Project Areas and Infrastructure
Location of Sample Traverses

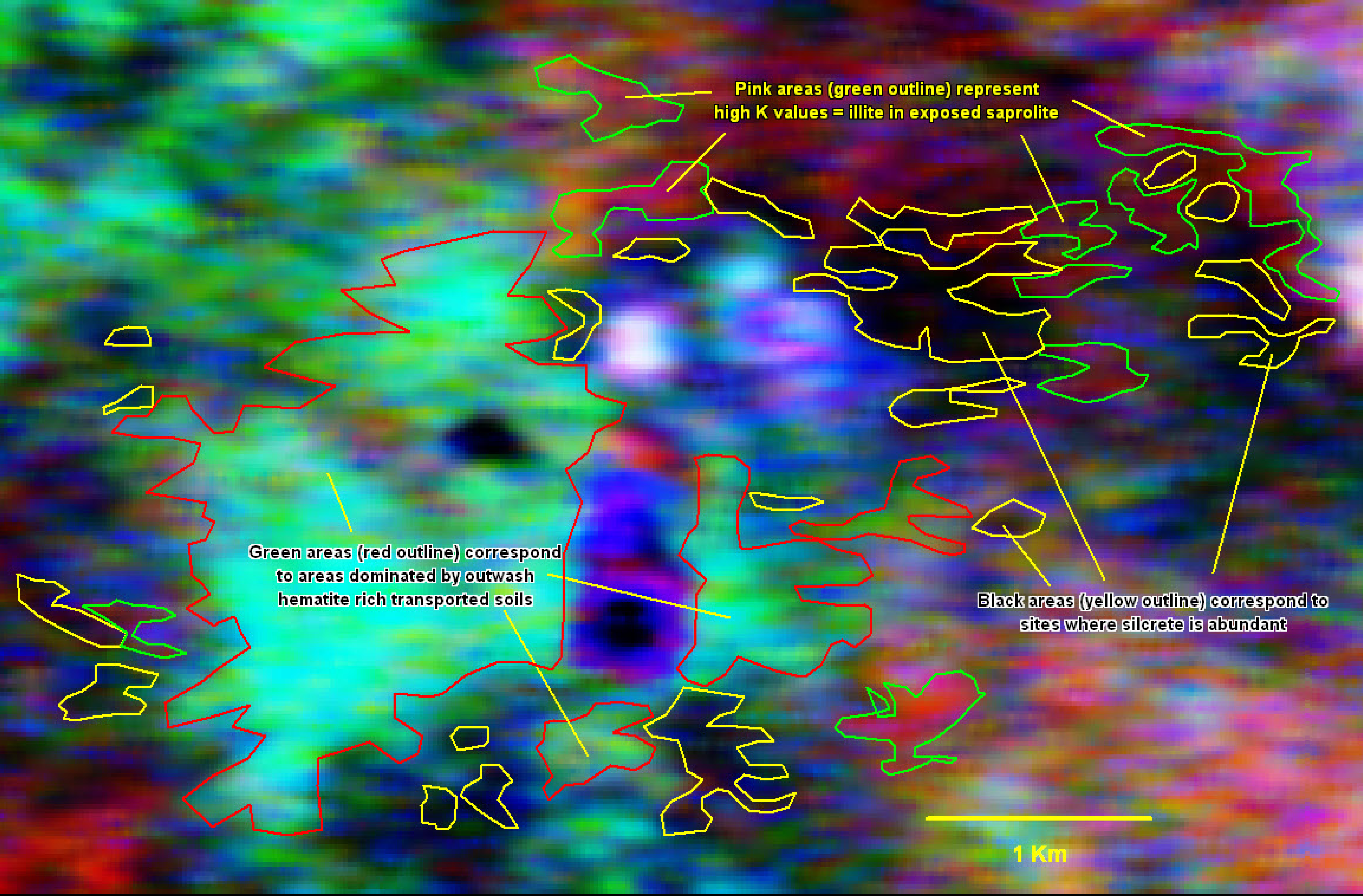
Ridge line and erosional dispersion directions indicated.

As a geochemical method radiometrics can be used to model the regolith and erosion in the terrain.

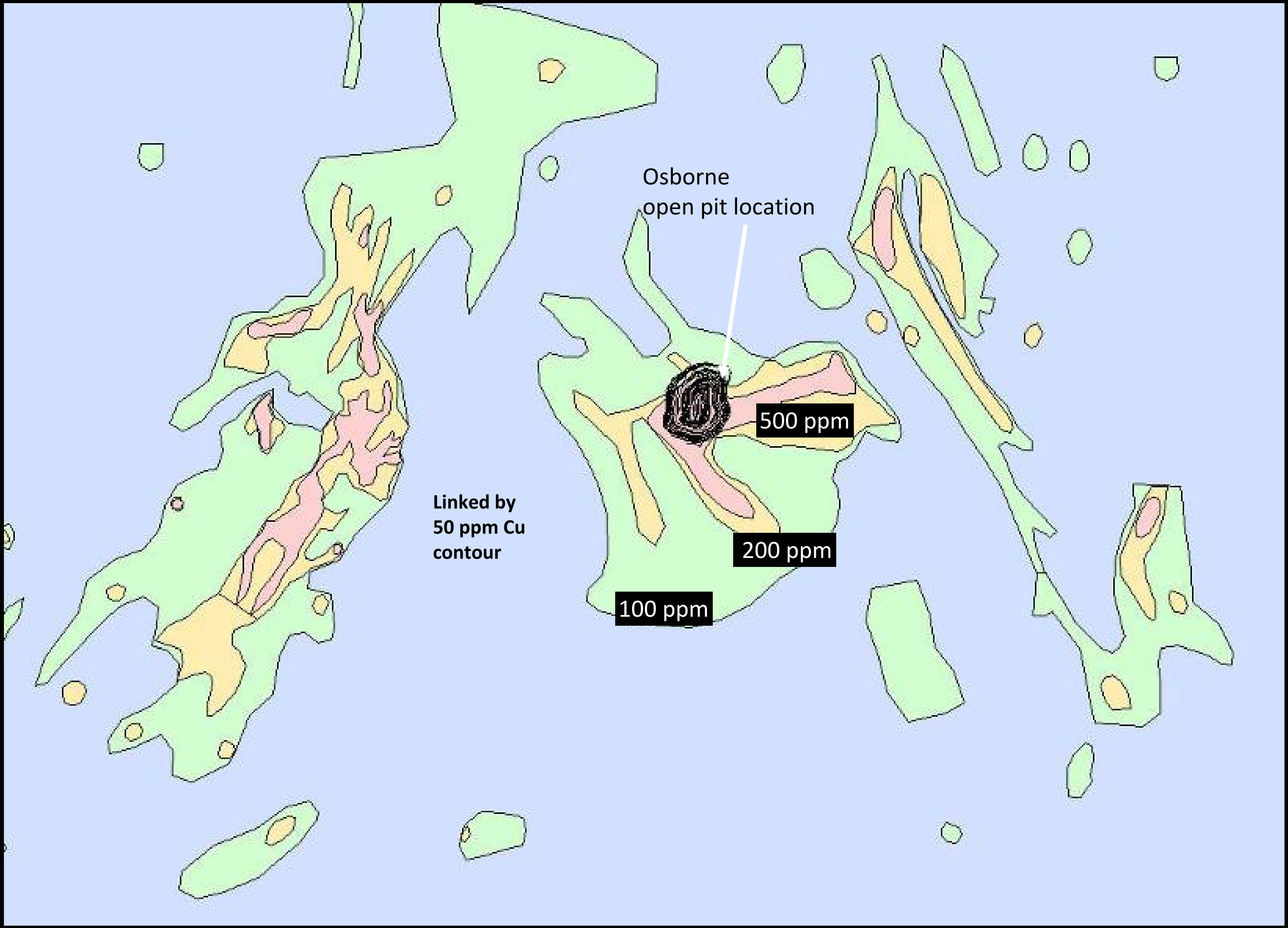
Thorium accumulates in secondary minerals with Fe-oxides in the mottled zone of weathering so the thorium channel can indicate where the mottle zone and ferruginous duricrust are present and exposed at the surface.

Similarly, the potassium channel can highlight areas where bedrock or K-bearing clay persists at the base of the saprolite zone.

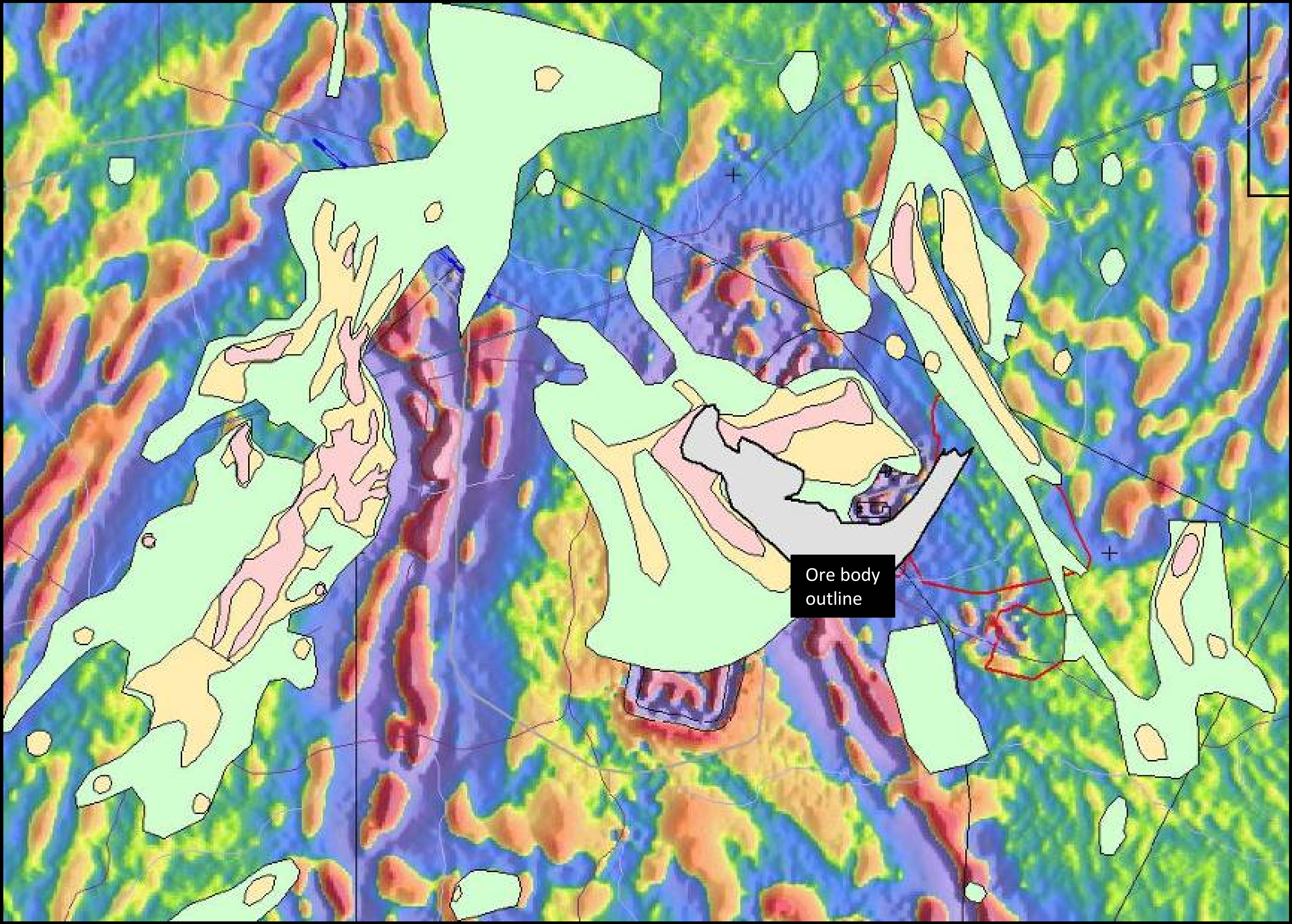
Uranium channel has less value in this exercise, but black areas (effectively lacking any radiometric response) are frequently indicative of areas with silcrete.




Radiometric response over Osborne and Kulthor area




Cu distribution at Mesozoic-Proterozoic unconformity at 30-70 metres depth from RC drilling.




# Cu geochemistry over 2nd vertical derivative magnetics

*pSirogas the ultimate sampling method…..*

*……no leach*

*…………..no soil or rock samples*

*………………. but measurable signal*

*measuring temporal data – and rates of signal transmission*

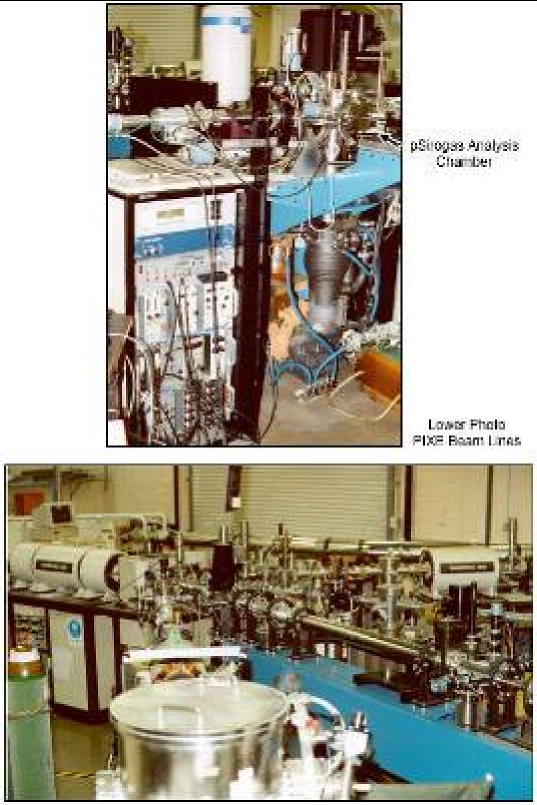
In 1992 an AMIRA-CSIRO project was undertaken to assess the potential application of the Swedish GEOGAS technique in Australia. The method is able to detect very low levels of an analyte ($ng/cm^2$).

The project, named pSirogas, was initiated by Chris Johnston who developed the field program and the methodology and undertook the original surveys.

I subsequently re-activated the procedure in 2002 to help resolve the Kulthor conundrum. By this time ICP-MS had to a large extent filled the niche for very low level analyses.

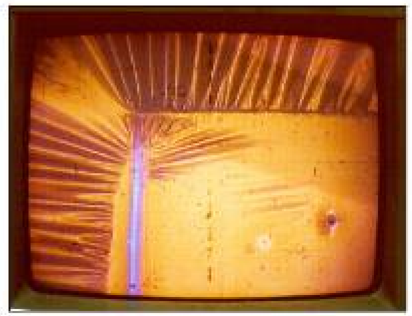
The method was essentially experimental and because of practical difficulties with its execution is probably not viable for general use.

It did however give some very unique information, particularly temporal data that hints at the character and rate of anomaly formation and variations in geochemical signal with the seasons and other things.

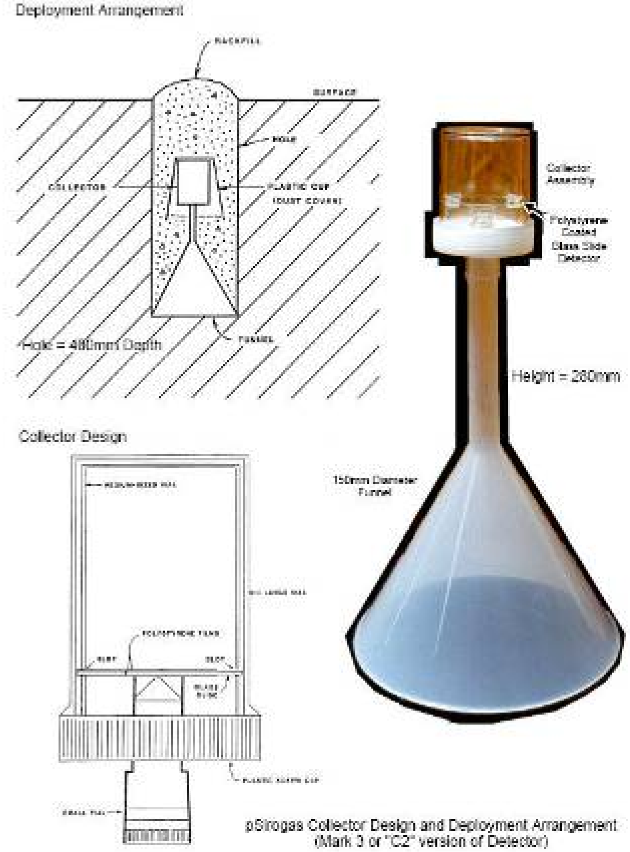



HIAF PIXE Probe Analytical Facility

Left shows scanned area of film - right shows spectra accumulated.
Beam stretches film flat. No dust apparent on film.

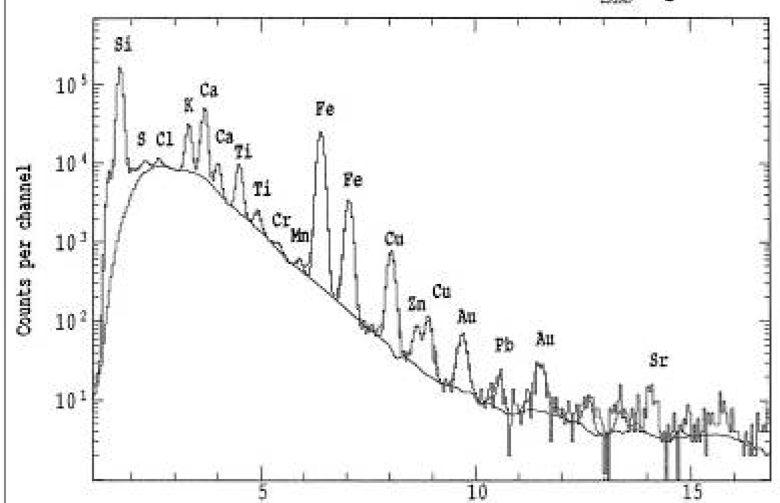


Blue line shows beam width - area scanned is 2mm H x 6mm W




pSirogas Collector Design and Deployment Arrangement
(Mark 3 or "C2" version of Detector)

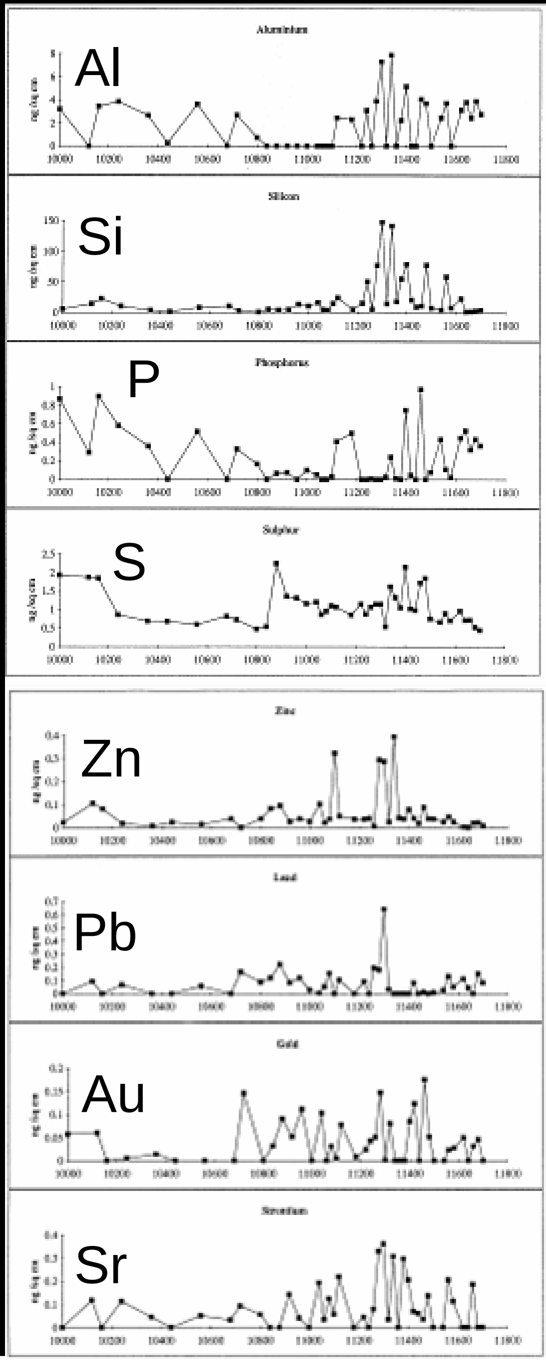
# pSirogas deployment and analysis

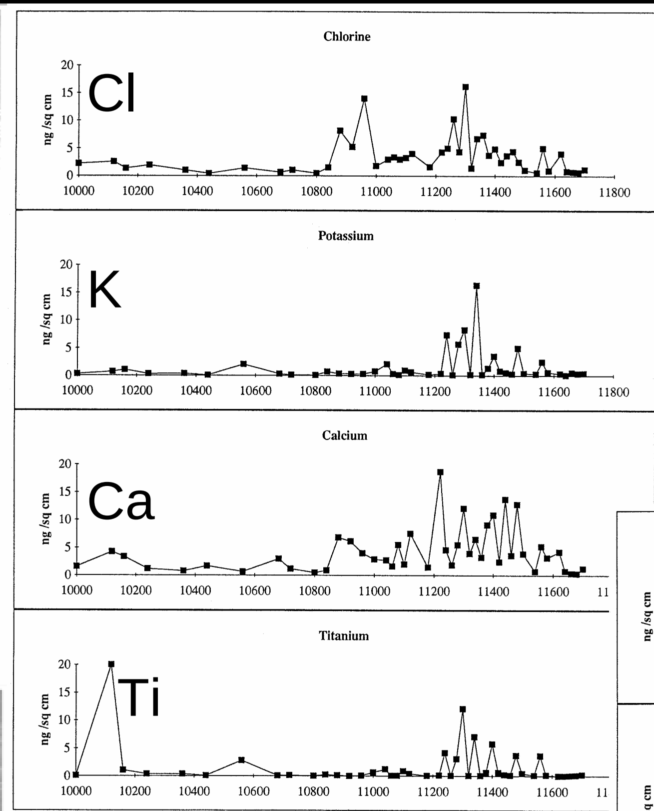



Example of a PIXE Spectra as Generated from a pSirogas Film from Original Survey over Open Pit Area

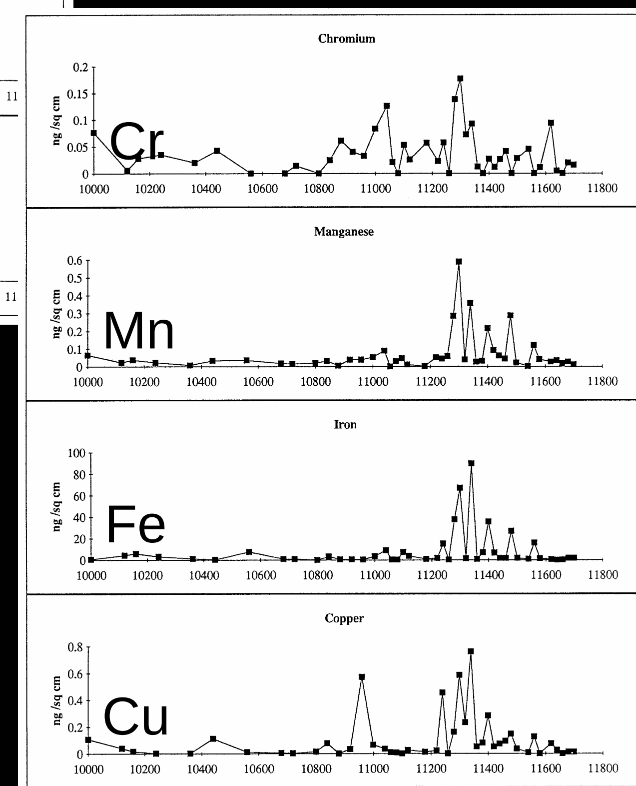
# pSirogas
# 1992 profile over Osborne

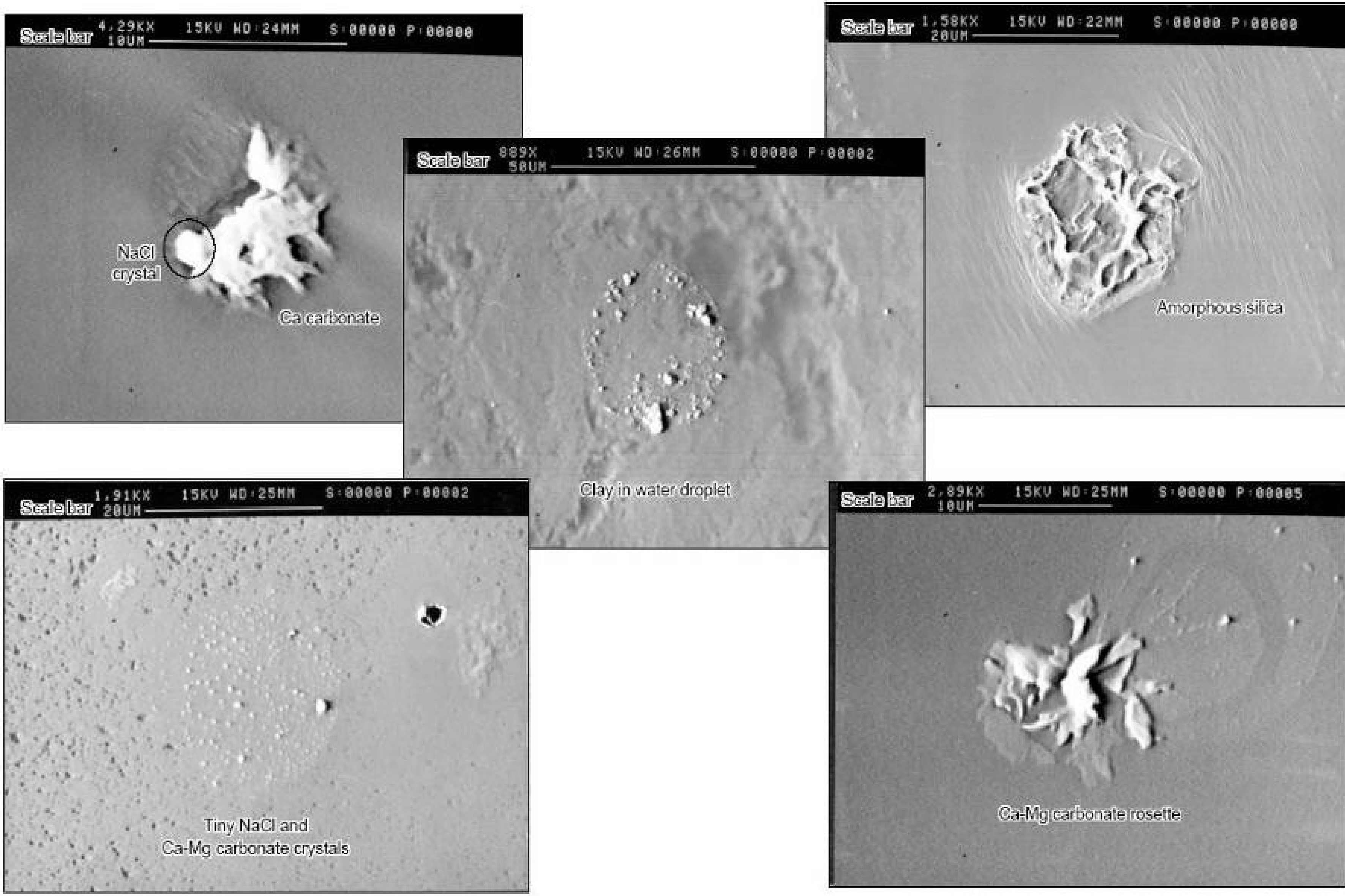
An expected geochemical profile pattern for rocks in deeply weathered terrains




Ore Zone





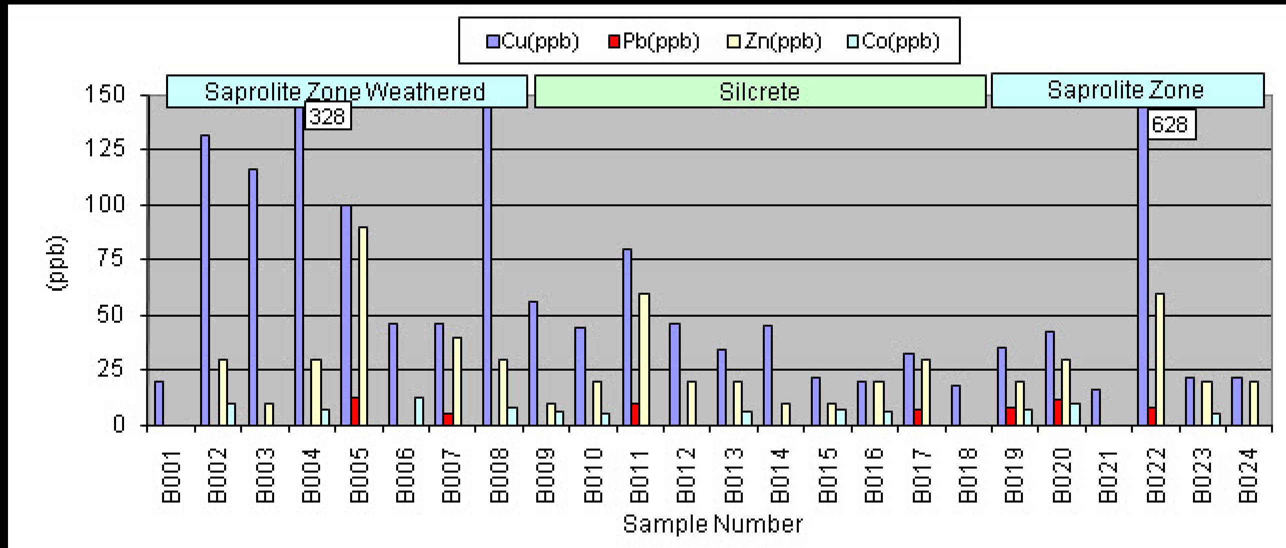

Examples of Salt Precipitates or Clay Particles trapped on pSirogas Films.
Note Water Droplet Outlines.

The pSirogas program suggested:

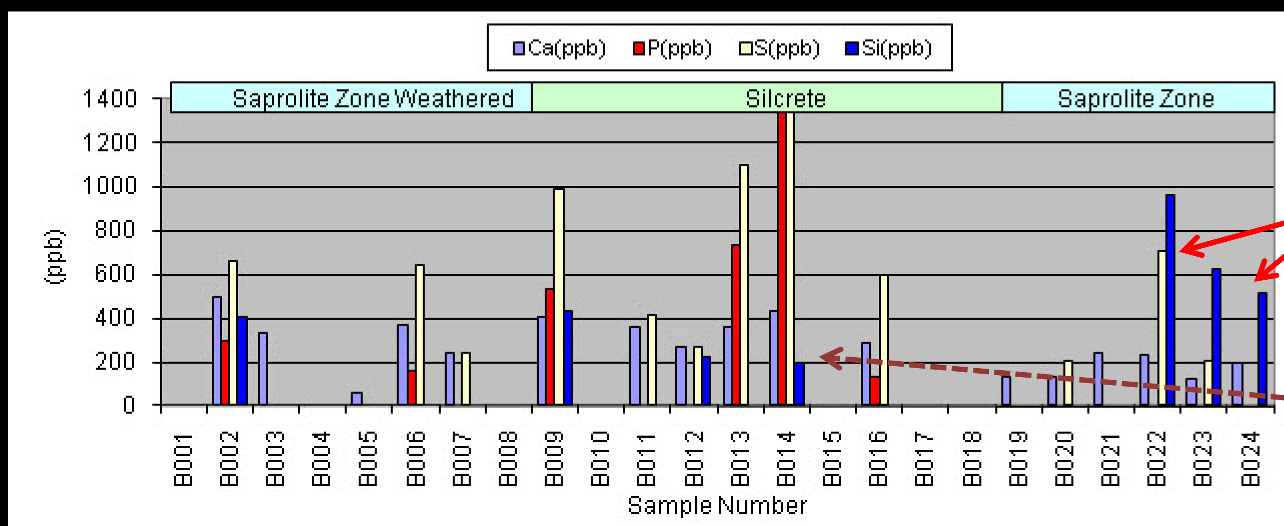
Water aerosols and condensates
…….. as new sample media

and for partial leaches
………control of values by lithotype

…………..and influence of local variations in soil salinity on values measured




Water leach analyses - ICP-MS




Condensate analyses - ICP-AES only

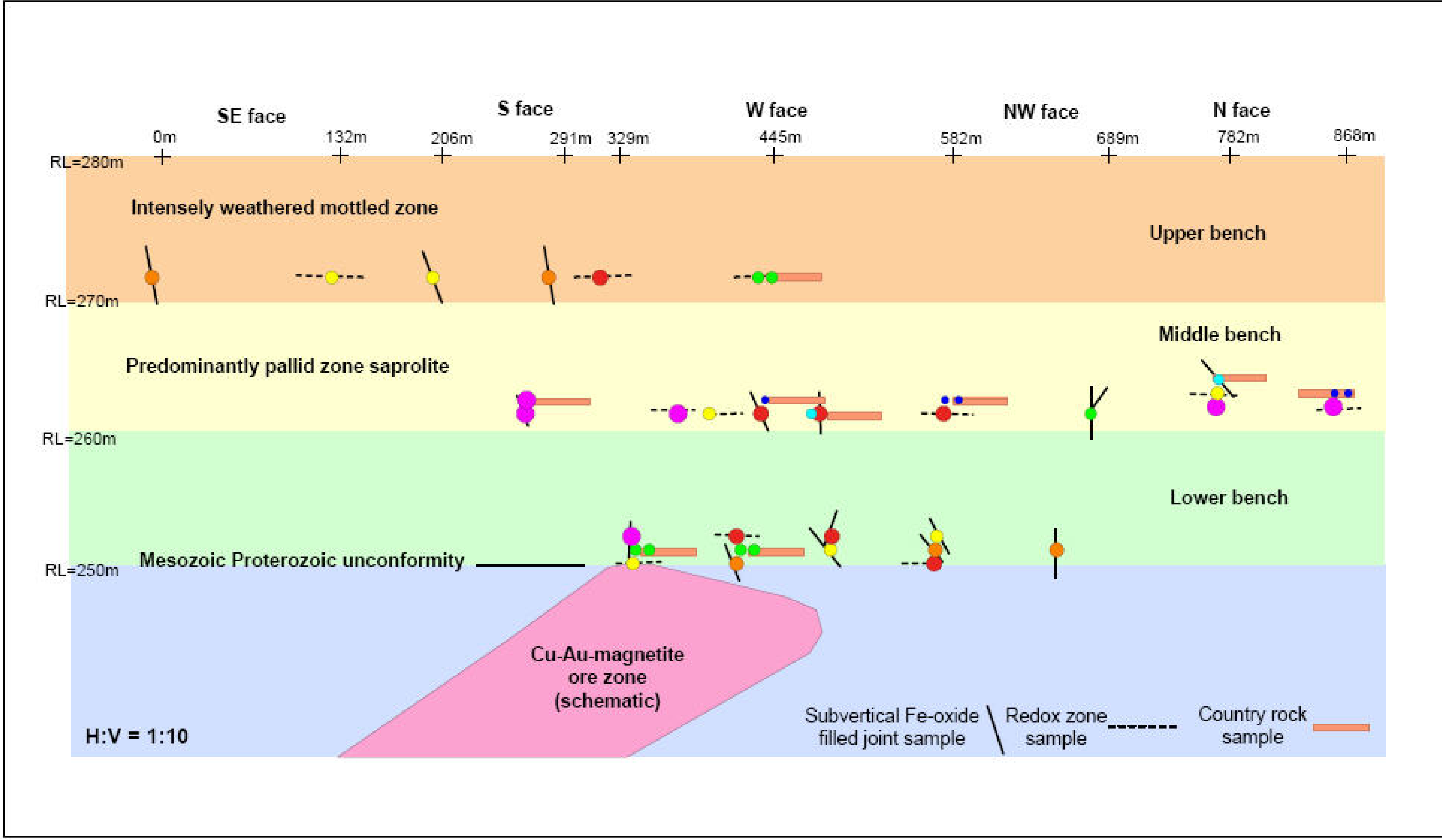
Silica colloids ($H_2SiO_4$) generated in saprolite by destruction of kaolinite precipitated as silcrete.

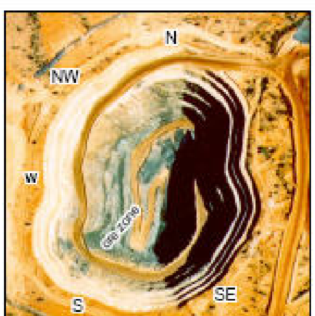
Osborne Pit Wall Studies

Control of Geochemical Signal and Distribution by Fractures

Seismic and barometric pumping, evaporation and capillary movement of water following periodic inundation of fracture systems seem most likely drivers for geochemical signals.

There is a high vertical gradient to signal dispersion.



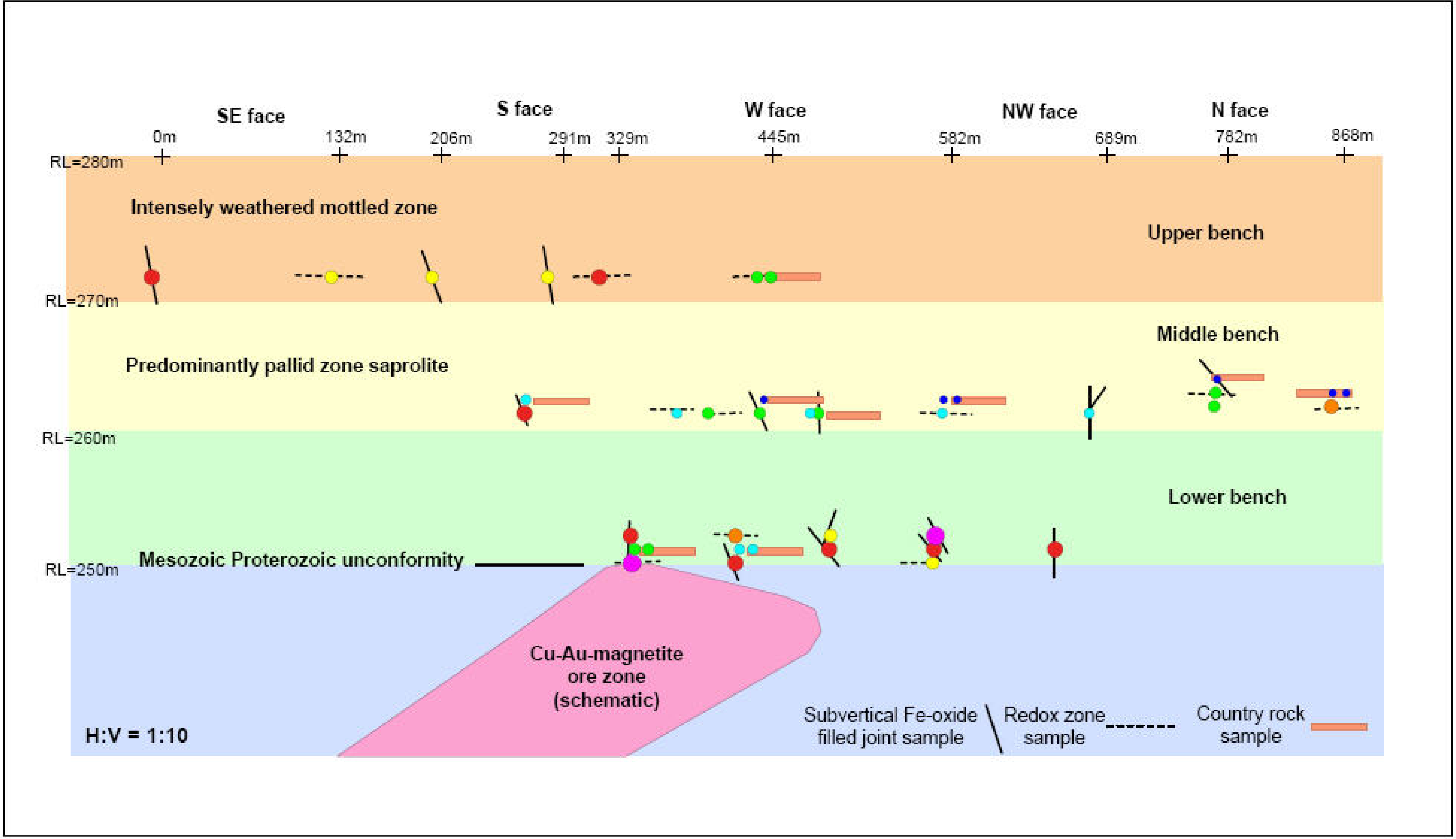



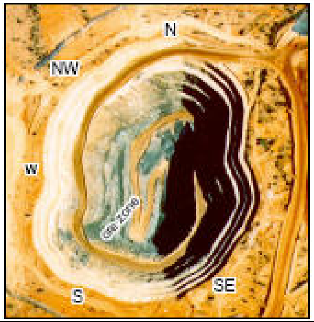

Schematic Plot of Silver Distribution

Redox Horizons and Country Rock.

**Osborne Pit Samples**
Ag (ppb) (Rock Chip - AR)

- 120 to 140 (6)
- 110 to 120 (7)
- 100 to 110 (5)
- 75 to 100 (7)
- 50 to 75 (7)
- 40 to 50 (2)
- 30 to 40 (5)



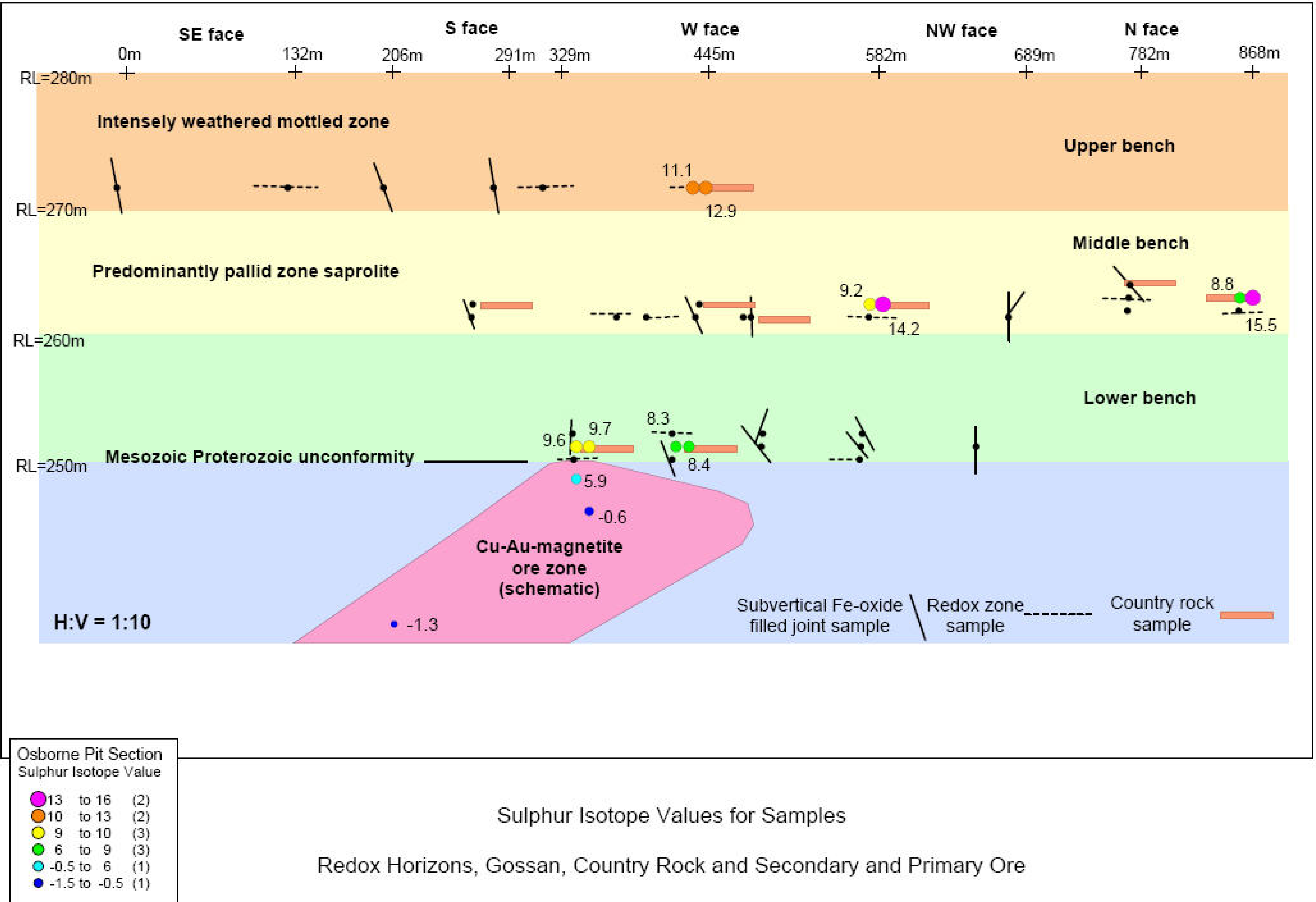




Schematic Plot of Molybdenum Distribution

Redox Horizons and Country Rock.

Osborne Pit Samples
Mo (ppm) - (Rock Chip - AR)

| | |
|---|---|
| 15 to 23.4 | (2) |
| 10 to 15 | (8) |
| 8 to 10 | (2) |
| 4 to 8 | (5) |
| 2 to 4 | (9) |
| 1 to 2 | (7) |
| 0 to 1 | (6) |



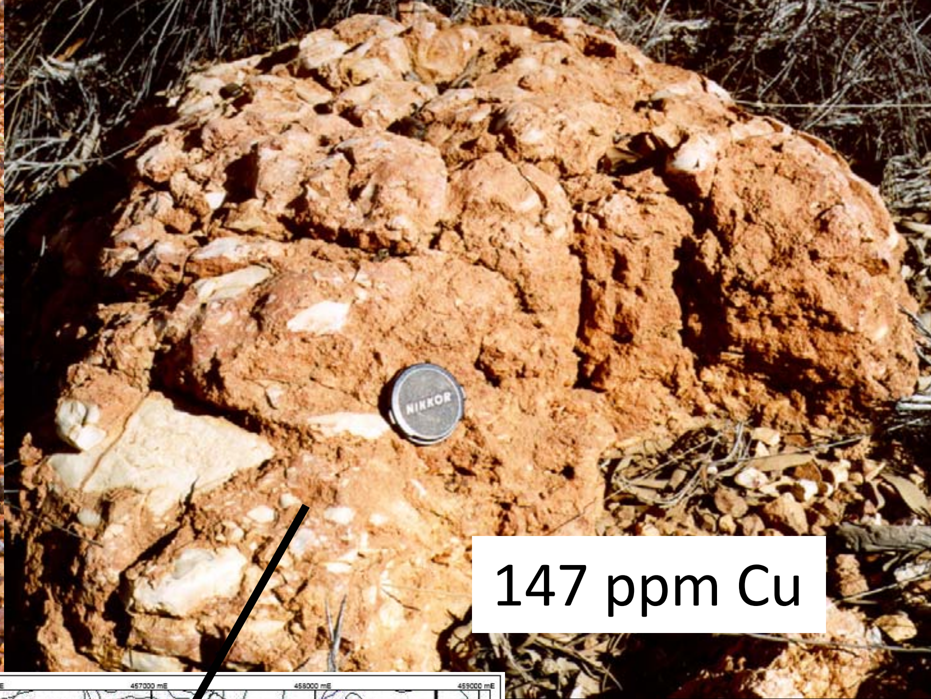

Sulphur Isotope Values for Samples

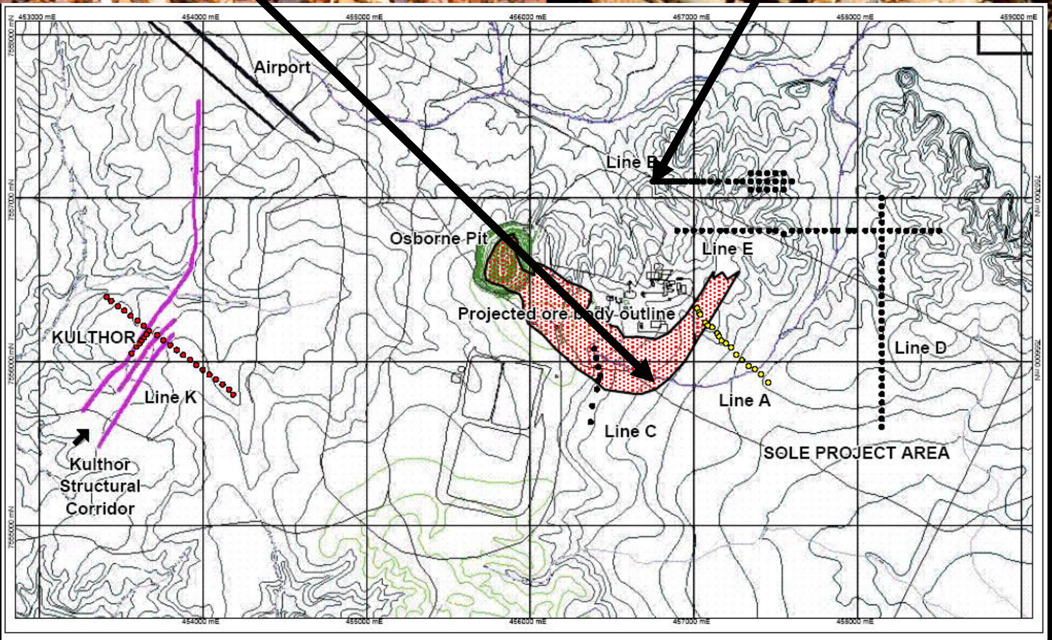
Redox Horizons, Gossan, Country Rock and Secondary and Primary Ore

# So what is controlling the anomaly patterns at Osborne?

Primary control would seem to be hydromorphic barriers in the landscape – notably silcrete with lateral groundwater transport beneath.

Where erosion intersects the edge of these hydromorphic barriers salts are precipitated producing a surface anomaly.




Osborne-Kulthor Region
Topography, Project Areas and Infrastructure
Location of Sample Traverses

# Kulthor Geochemistry

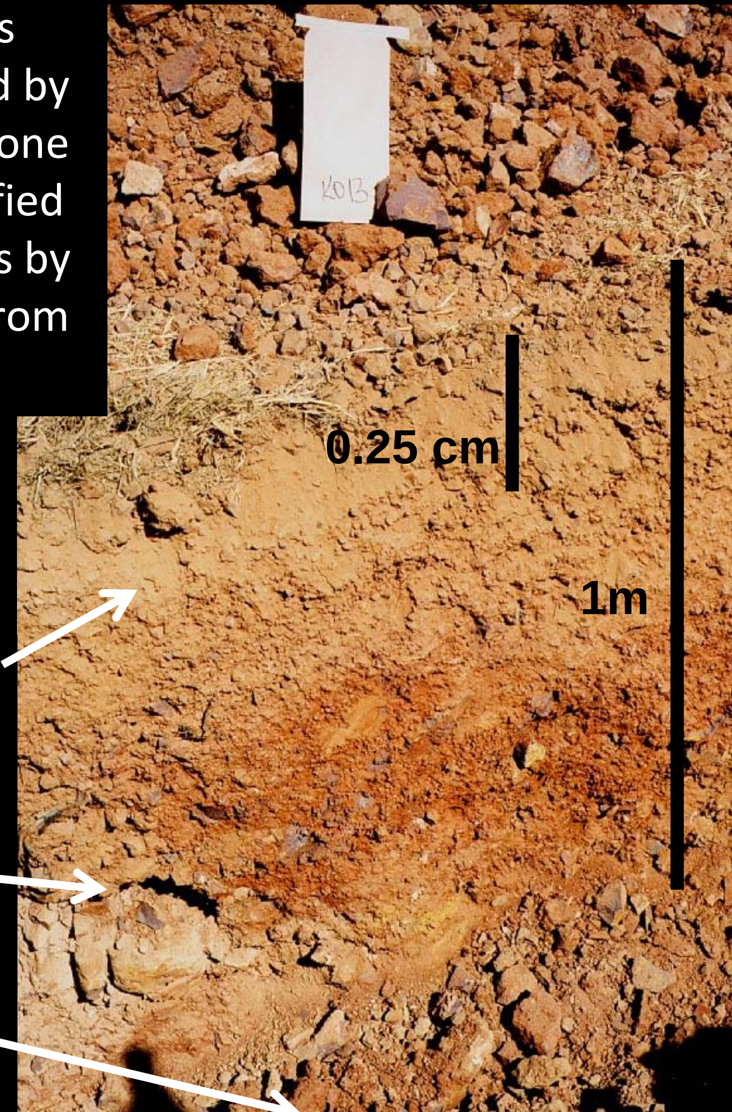
## pSirogas v Regoleach Partial Leach (ICP-MS)

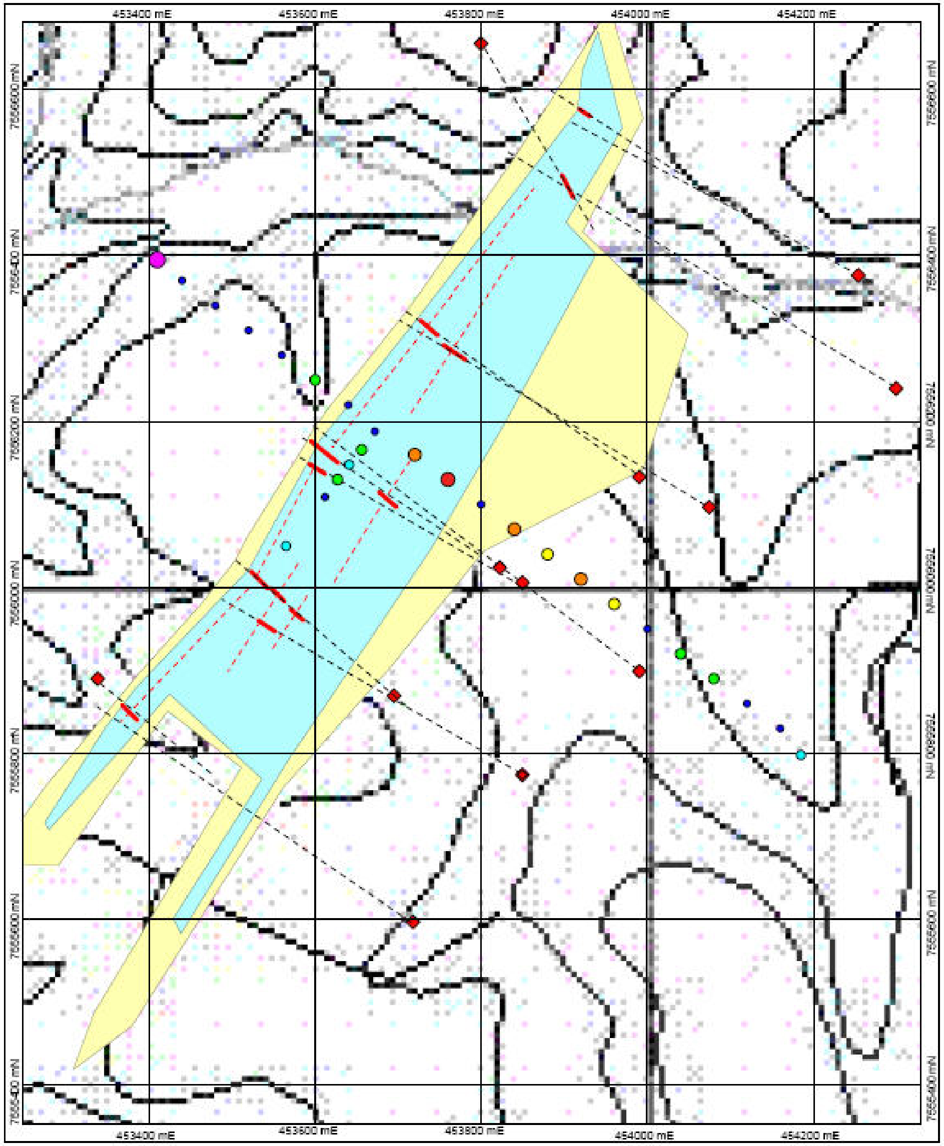
Transported siliceous hematite gravel derived by erosion from mottled zone up slope. Gravels silicified into massive aggregates by opaline silica sourced from saprolite zone

Transported soil

Siliceous hematitic gravel

Gypsiferous saprolite zone (clay).





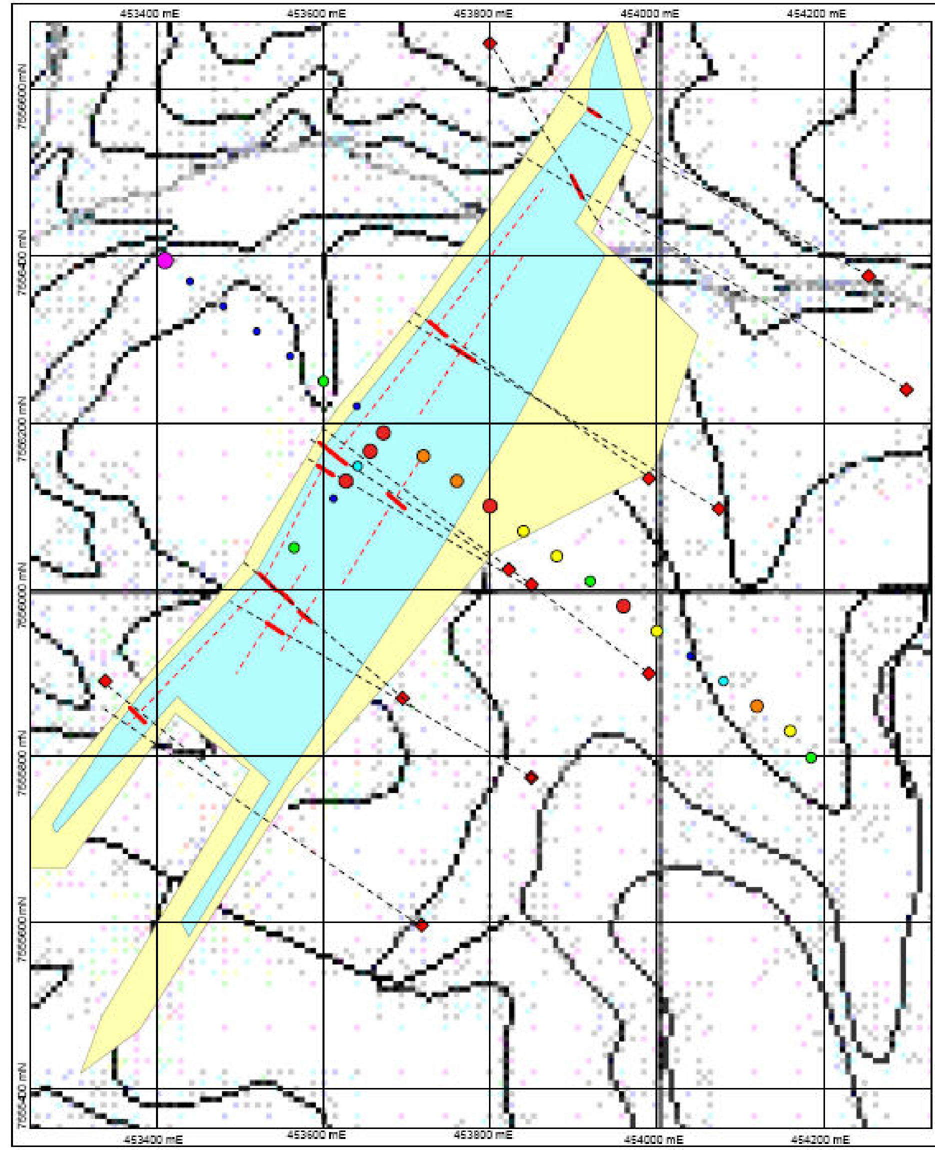

Kulthor pSirogas Geochemistry
Au (ng/cm2)

- 1.5 to 1.5 (1)
- 0.6 to 1.5 (1)
- 0.4 to 0.6 (3)
- 0.3 to 0.4 (2)
- 0.18 to 0.3 (5)
- 0.09 to 0.18 (3)
- 0 to 0.09 (11)

# Au - pSirogas

Kulthor pSirogas Geochemistry
Over Alteration Envelope and Topography
Mineralised Intercepts and Ore Trend Indicated

Gold values (ng/cm2)



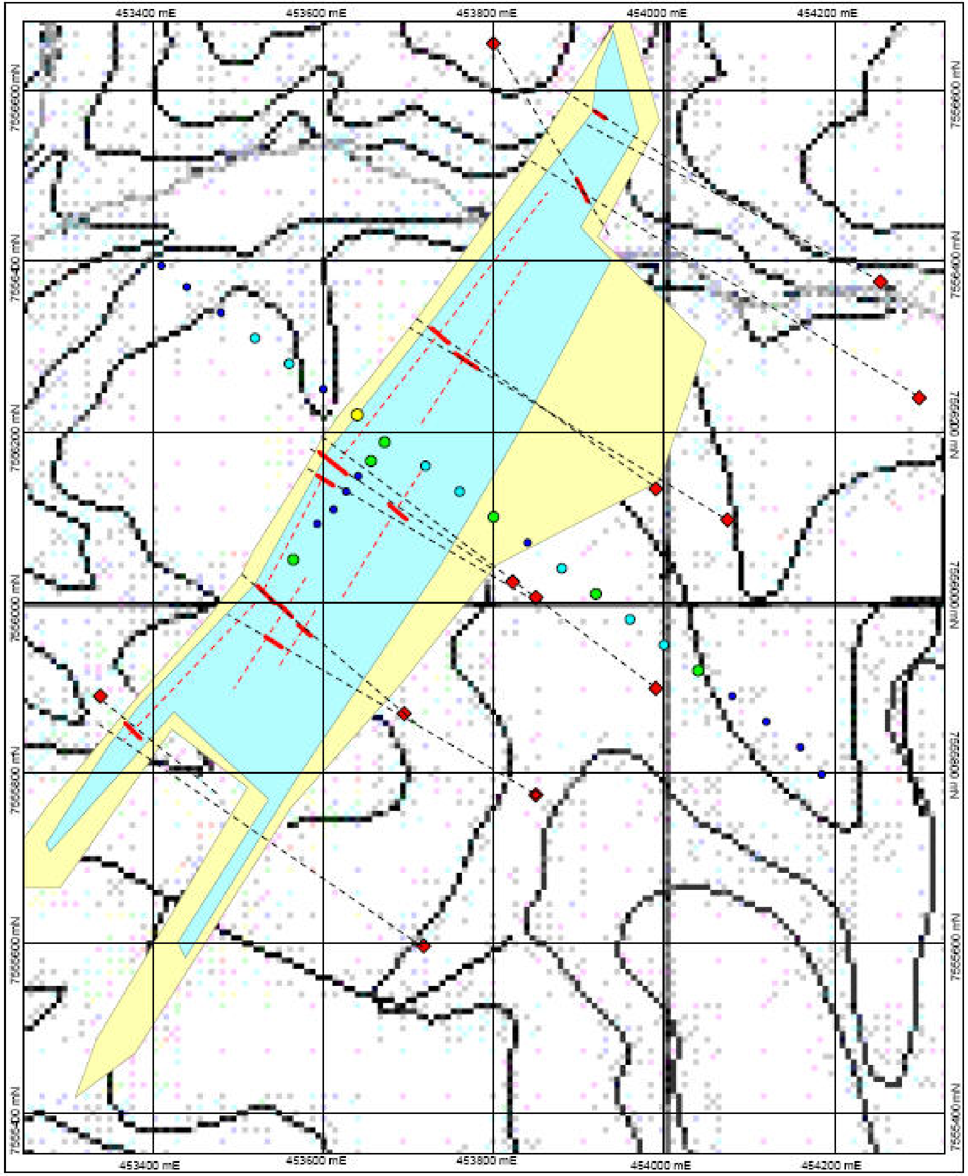

Kulthor pSirogas Geochemistry
Ag (ng/cm2)

- 20 to 24 (1)
- 3.25 to 20 (5)
- 3 to 3.25 (3)
- 2.5 to 3 (4)
- 2 to 2.5 (4)
- 1.5 to 2 (2)
- 0 to 1.5 (7)

# Ag - pSirogas

Kulthor pSirogas Geochemistry
Over Alteration Envelope and Topography
Mineralised Intercepts and Ore Trend Indicated

Silver values (ng/cm2)

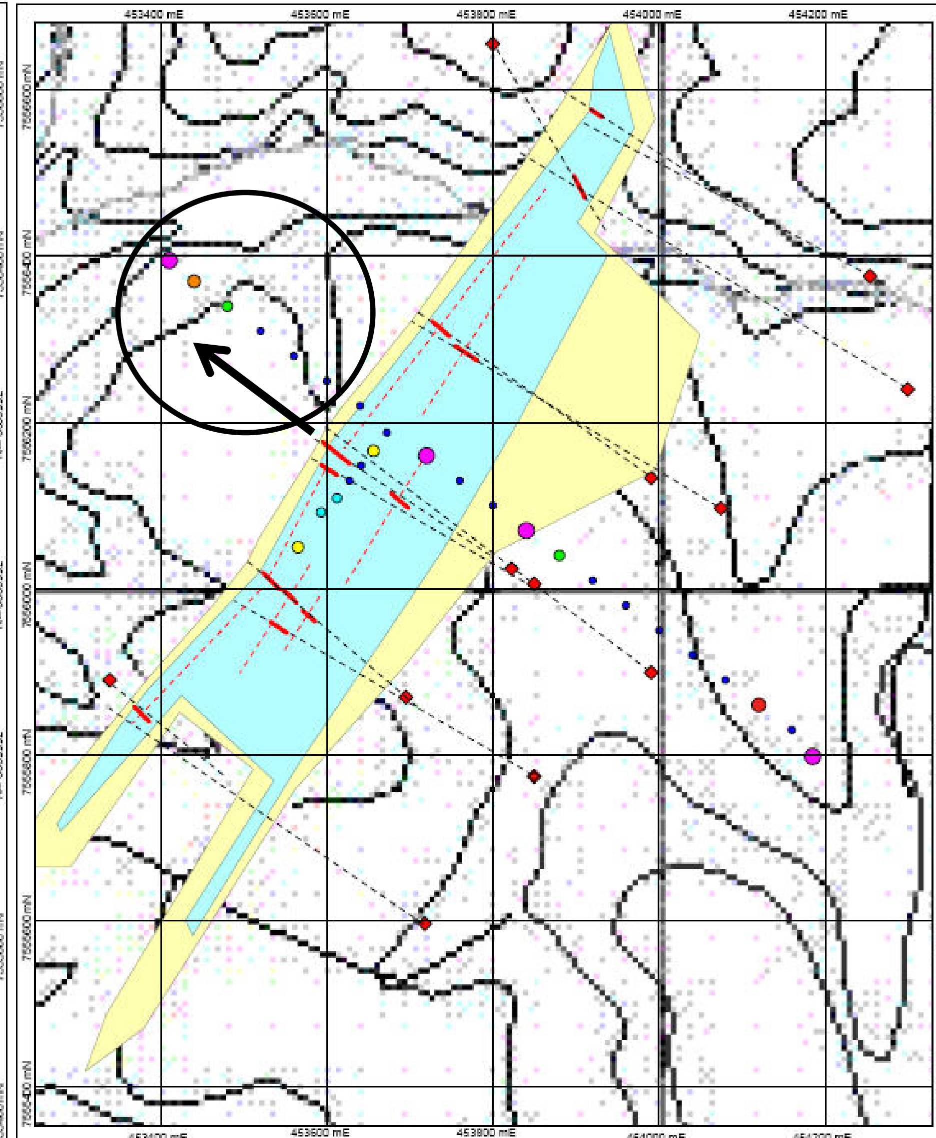



Kulthor Soil Assays
Au (ppb) (Regoleach -0.89mm)

- 3 to 3 (1)
- 2 to 3 (6)
- 1 to 2 (7)
- 0 to 1 (13)

# Au - Regoleach

Kulthor Regoleach Soil Geochemistry
Over Alteration Envelope and Topography
Mineralised Intercepts and Ore Trend Indicated
Gold values (ppb)

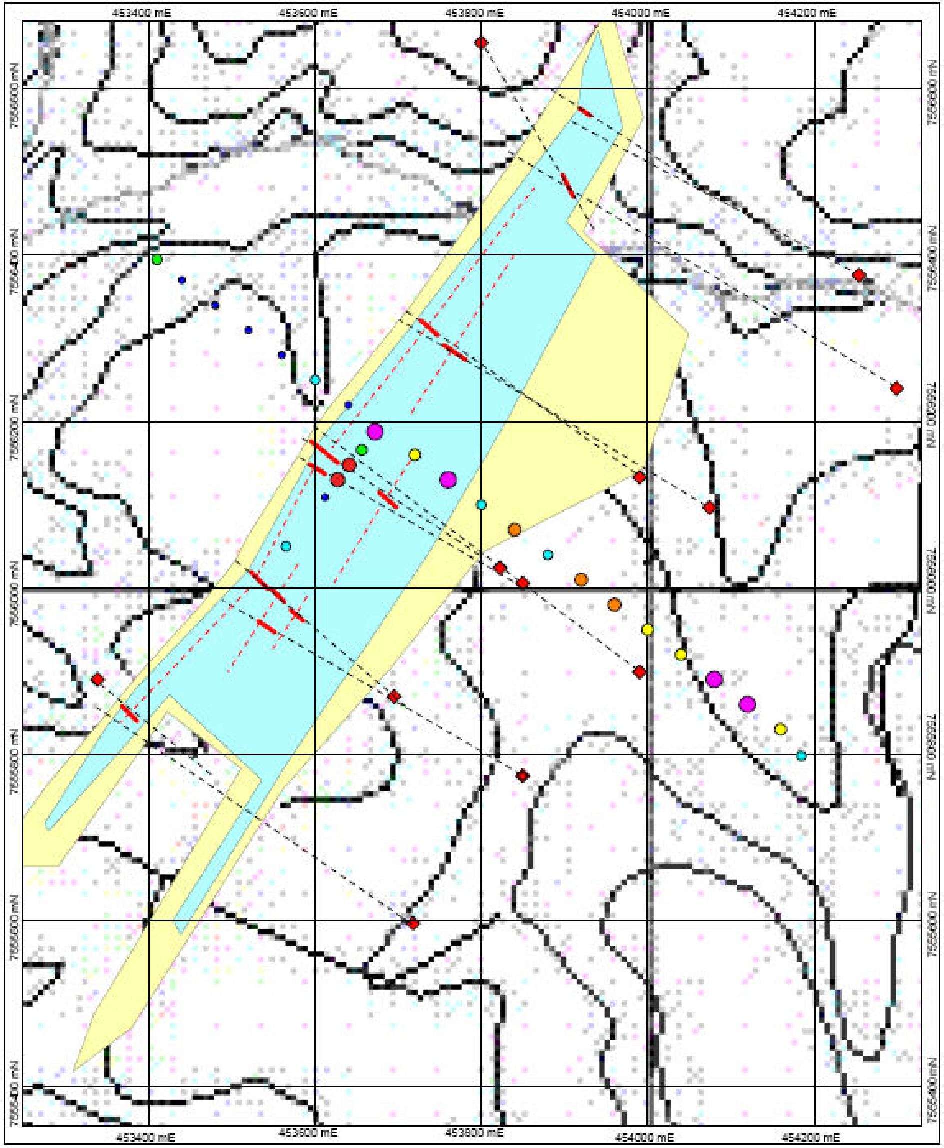



Kulthor Soil Assays
Ag (ppb) (Regoleach -0.89mm)

- 13 to 14 (4)
- 10 to 13 (1)
- 8 to 10 (1)
- 7 to 8 (2)
- 6 to 7 (2)
- 5 to 6 (2)
- 0 to 5 (15)

# Ag - Regoleach

Kulthor Regoleach Soil Geochemistry
Over Alteration Envelope and Topography
Mineralised Intercepts and Ore Trend Indicated
Silver values (ppb)



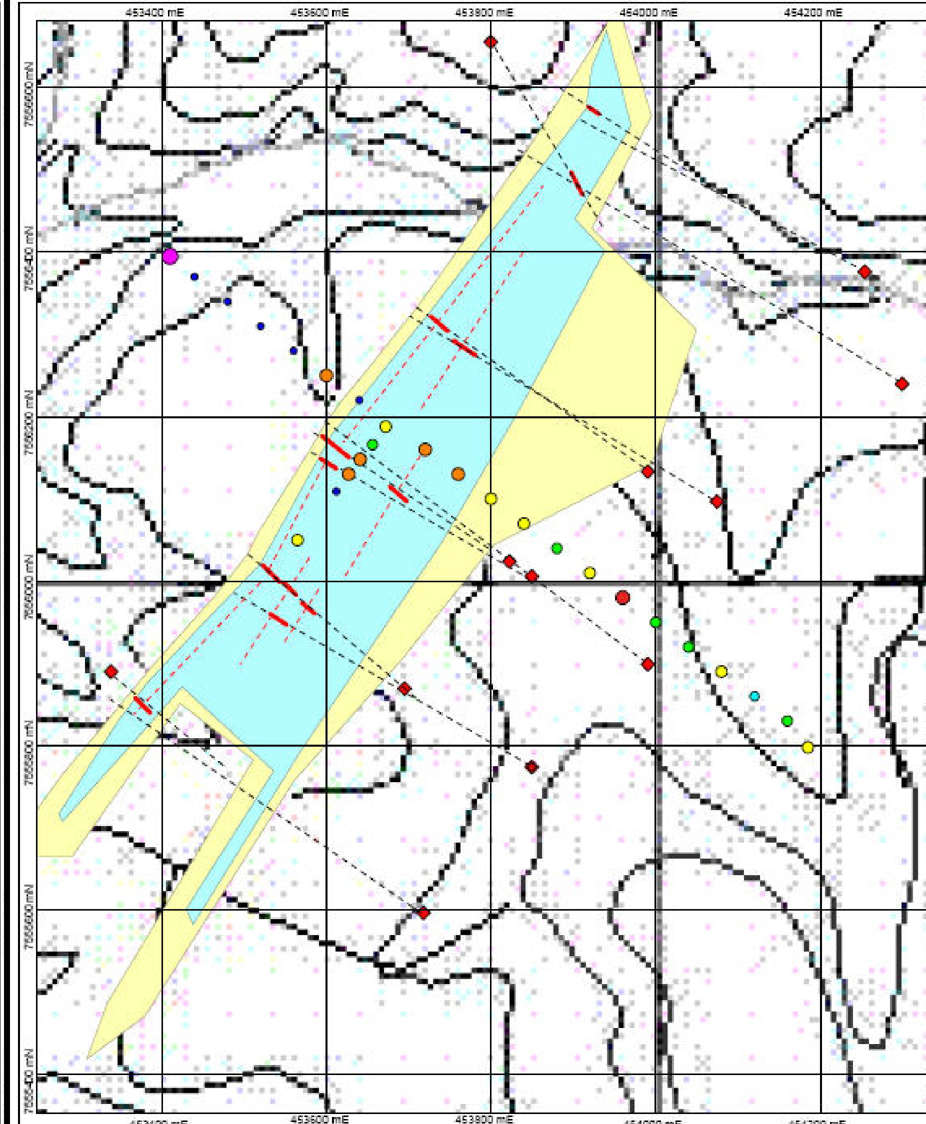

Kulthor pSirogas Geochemistry
Cu (ng/cm2)

- 0.54 to 0.63 (4)
- 0.47 to 0.54 (2)
- 0.41 to 0.47 (3)
- 0.35 to 0.41 (4)
- 0.3 to 0.35 (2)
- 0.23 to 0.3 (5)
- 0 to 0.23 (6)

# Cu -pSirogas

Kulthor pSirogas Geochemistry
Over Alteration Envelope and Topography
Mineralised Intercepts and Ore Trend Indicated

Copper values (ng/cm2)



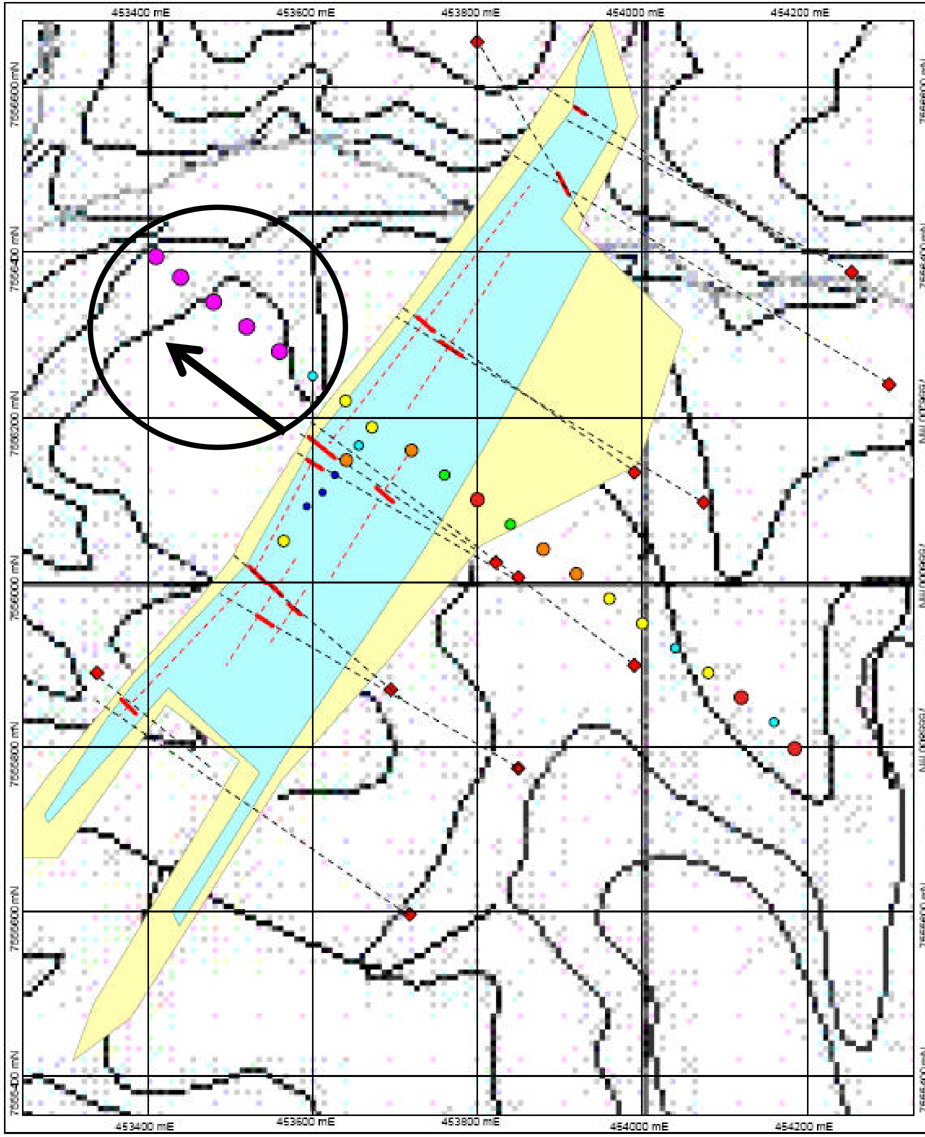

Kulthor pSirogas Geochemistry
Mo (ng/cm2)

- 6 to 6 (1)
- 1 to 6 (1)
- 0.6 to 1 (5)
- 0.5 to 0.6 (7)
- 0.3 to 0.5 (5)
- 0.1 to 0.3 (1)
- 0 to 0.1 (6)

# Mo - pSirogas

Kulthor pSirogas Geochemistry
Over Alteration Envelope and Topography
Mineralised Intercepts and Ore Trend Indicated

Molybdenum values (ng/cm2)

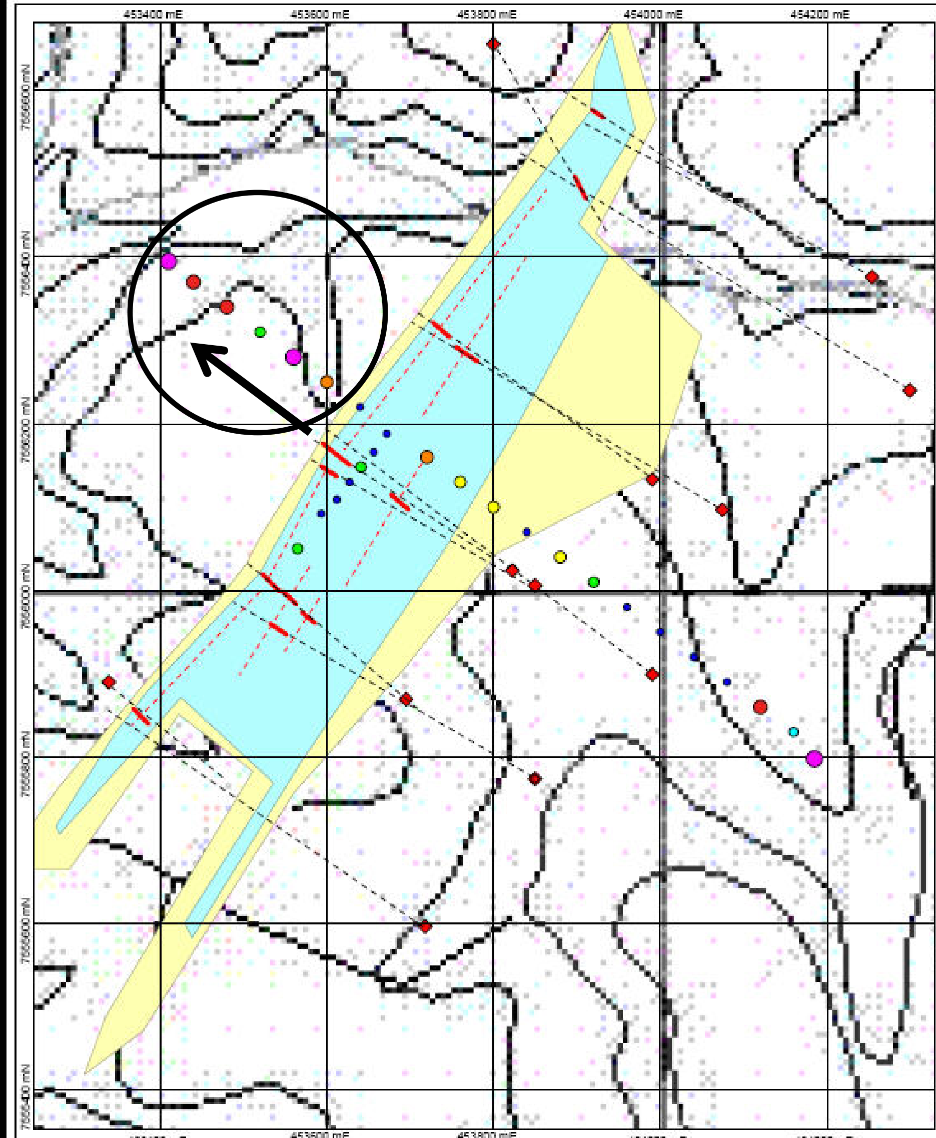



Kulthor Soil Assays
Cu (ppm) (Regoleach -0.89mm)

- 7.09 to 9.15 (5)
- 5.61 to 7.09 (3)
- 4.61 to 5.61 (4)
- 3.86 to 4.61 (6)
- 3.51 to 3.86 (2)
- 3.07 to 3.51 (4)
- 2.02 to 3.07 (3)

# Cu - Regoleach

Kulthor Regoleach Soil Geochemistry
Over Alteration Envelope and Topography
Mineralised Intercepts and Ore Trend Indicated
Copper values (ppm)




Kulthor Soil Assays
Hg (ppb) (Regoleach -0.89mm)

- 19 to 24 (3)
- 12 to 19 (3)
- 10 to 12 (2)
- 8 to 10 (3)
- 7 to 8 (4)
- 6 to 7 (1)
- 0 to 6 (11)

# Hg - Regoleach

Kulthor Regoleach Soil Geochemistry
Over Alteration Envelope and Topography
Mineralised Intercepts and Ore Trend Indicated
Mercury values (ppb)

## There are distinctive, albeit weak, patterns shown by the ore metals – both higher and depleted signals over the ore position at Kulthor.

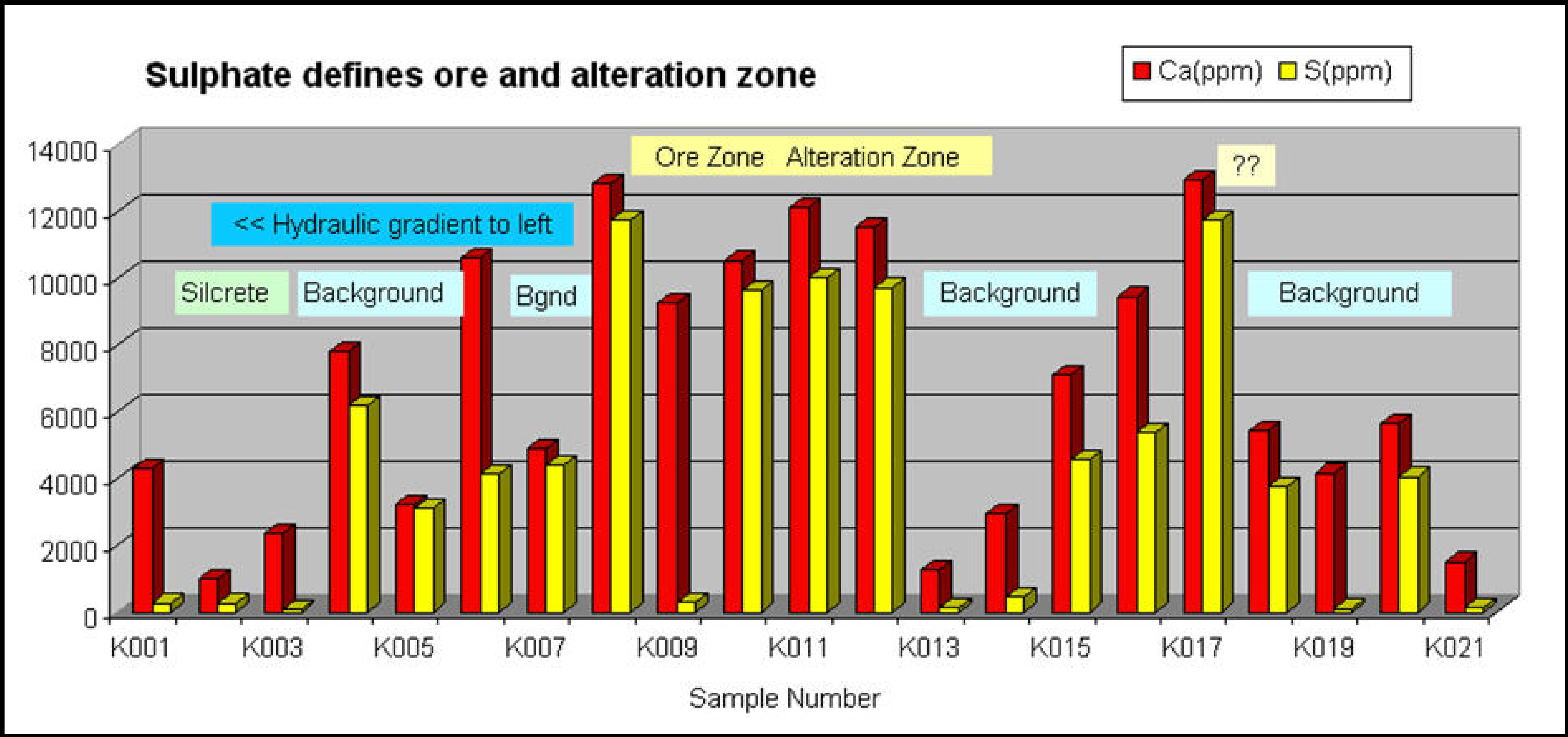
Those in the top sample (25 cm) may derive from Osborne and could have been transported over the Kulthor position in the cover.
Lower is true bedrock saprolite sample.

## What do the "bulk" alteration elements give – namely the Ca from the carbonate and S from the sulphide (pyrite).

| Position | Au | Ba | Ca | Cd | Co |
|---|---|---|---|---|---|
| Upper | 0* | 44-175 | 509-1180* | 7-22 | 2.62-3.92 |
| Middle | 1 | 243-418* | 870-3350 | 0-9 | 4.14-10 |
| Lower | 1-2 | 0-2* | 6690-12900 | 0 | 1.21-3.88 |

| Position | Cu | Fe | Hg | Mg | Mn |
|---|---|---|---|---|---|
| Upper | 3.98-9.63 | 3680-6810 | 10-16 | 463-1040* | 38-126 |
| Middle | 4.27-9.46 | 5950-8180 | 5-19 | 947-3220 | 67-106* |
| Lower | 2.18-7.09 | 3290-7470 | 0-8 | 1240-5820 | 18-61 |

| Position | Na | Ni | S | Se | Te |
|---|---|---|---|---|---|
| Upper | 124-510* | 1.17-3.48 | 41-135* | 92-236 | 7-12 |
| Middle | 1030-4050* | 3.02-4.12 | 272-2530 | 44-268 | 15-39 |
| Lower | 1090-2690* | 1.65-2.33* | 5730-11710* | 84-163* | 20-34 |

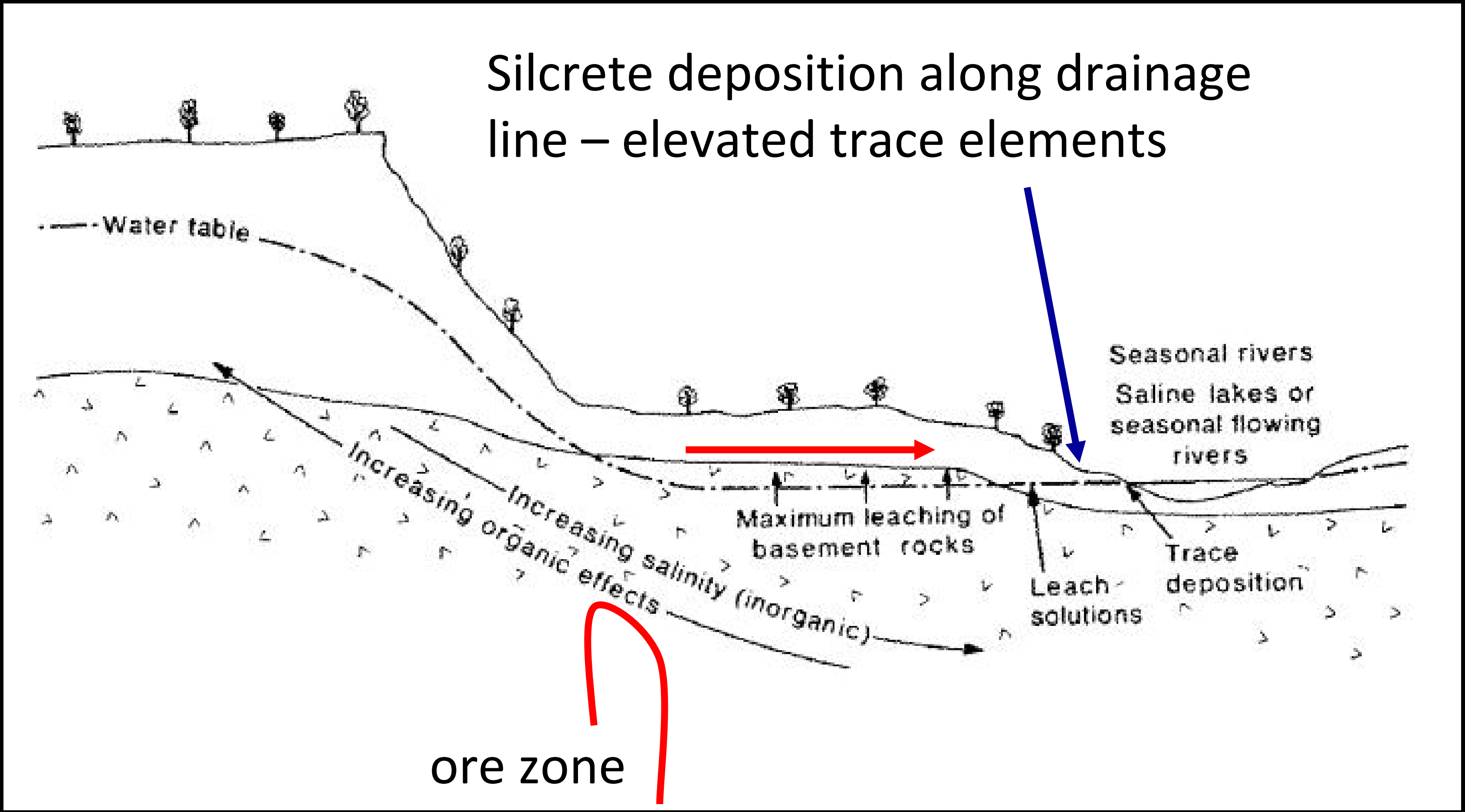

Sulphate defines ore and alteration zone
Ca(ppm)
S(ppm)
14000
12000
10000
8000
6000
4000
2000
0
Ore Zone
Alteration Zone
??
<< Hydraulic gradient to left
Silcrete
Background
Bgnd
Background
Background
K001
K003
K005
K007
K009
K011
K013
K015
K017
K019
K021
Sample Number

At Kulthor we have:

High gypsum levels at about 1 metre depth above ore zone

Lateral dispersion of soluble elements down hydraulic gradient with subsequent concentration at bottom of drainage slope along with amorphous silica probably during the wet season.

Elevated chlorine determined by pSirogas might suggest metal chloride complex transport for some elements (or possibly thiosulphate at depth).



Silcrete deposition along drainage line – elevated trace elements
Water table
Seasonal rivers
Saline lakes or seasonal flowing rivers
Increasing organic effects
Increasing salinity (inorganic)
Maximum leaching of basement rocks
Leach solutions
Trace deposition
ore zone

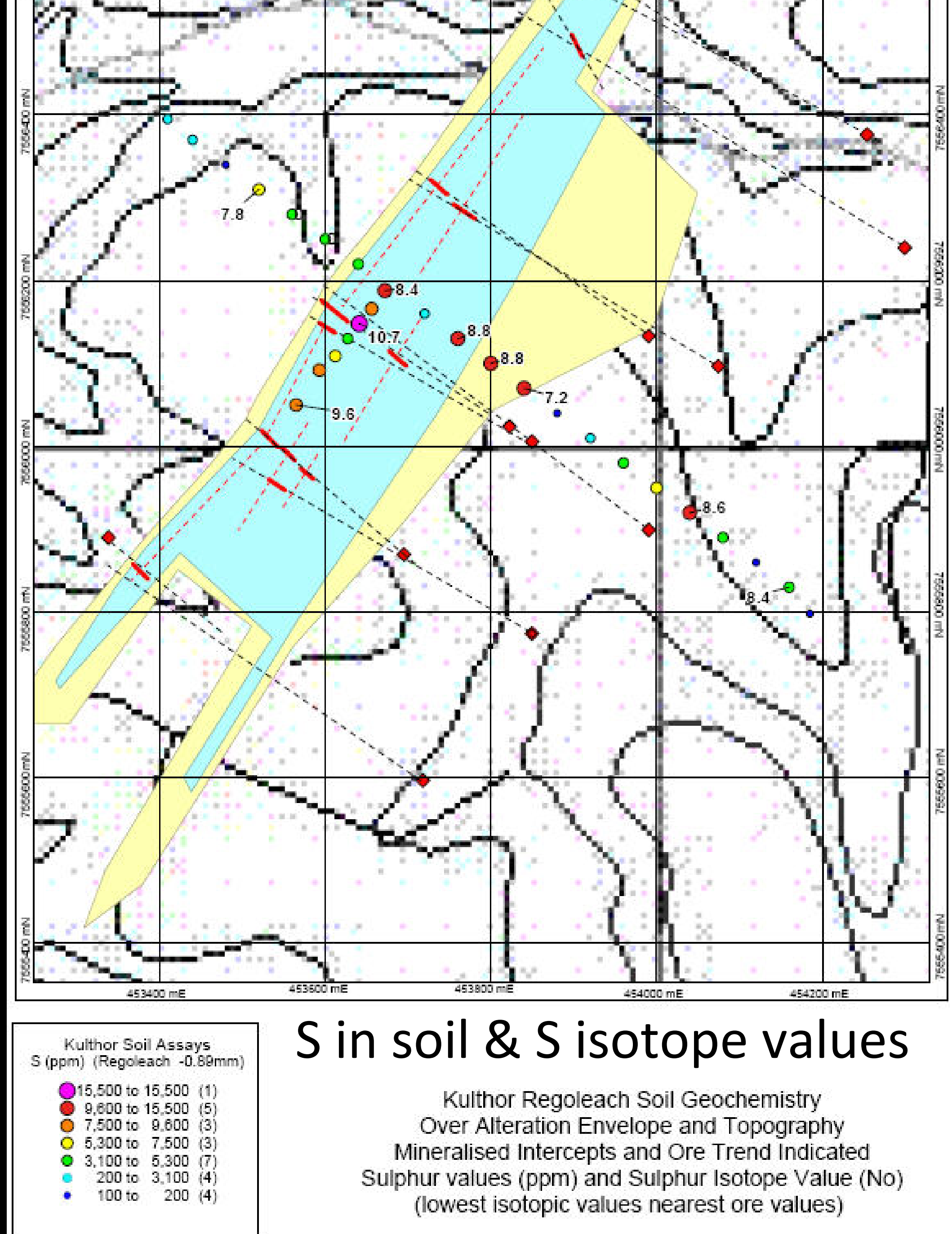
# Kulthor sulphur isotope values in ore and soil

Ore values
cpy = +7.0 to +8.0
po = +6.6
py = +7.8 (main ore)
py = +7.2 (2nd zone)
py = +7.9 (halo zone)

Gypsum in soil
+7.2 to +10.7

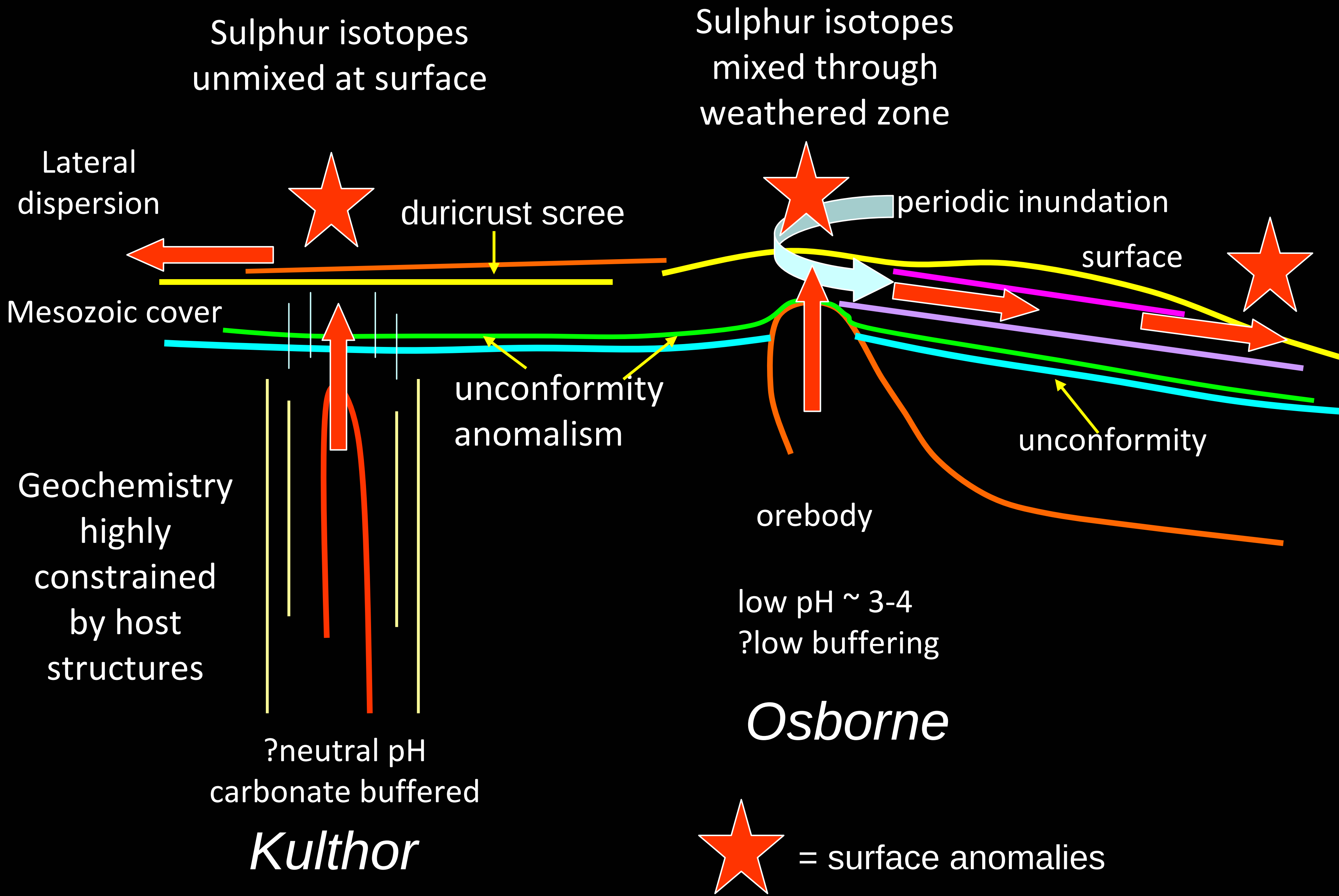
Regional background
+11.1 to +12.3

+10.7 value in soil is in drainage line and is likely mixed with background isotopic values.




## S in soil & S isotope values

Kulthor Regoleach Soil Geochemistry
Over Alteration Envelope and Topography
Mineralised Intercepts and Ore Trend Indicated
Sulphur values (ppm) and Sulphur Isotope Value (No)
(lowest isotopic values nearest ore values)



Sulphur isotopes unmixed at surface
Sulphur isotopes mixed through weathered zone
Lateral dispersion
duricrust scree
periodic inundation
surface
Mesozoic cover
unconformity anomalism
unconformity
Geochemistry highly constrained by host structures
orebody
low pH ~ 3-4
?low buffering
Osborne
?neutral pH
carbonate buffered
Kulthor
= surface anomalies