Lead Isotope Geochemistry: A Brave New World?

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Outline

- Traditional Use of Pb Isotopes in Metallogenic Studies
- Exploration Geochemistry –
  - General Principles
  - Gossans and Residual Soils
  - Groundwaters
  - Partial Extractions of soils
  - Vegetation
  - U exploration
- The brave new world -
  - The cost factor – can the commercial labs do better?
  - The confidence factor – will companies use isotopes?

Pb Isotopes in Metallogenic Studies (Plumbotectonics)

- History of the Earth According to my favorite element – Pb.
- Really a history of the fractionation of Pb, Th and U in the mantle and crust through geological time.
- The key information that Pb isotopes provide are:
  - Relative contributions of mantle-derived and crustal-derived Pb in rocks and ores
  - Any evidence of U/Th fractionation as a result of high grade metamorphism or the formation U enriched hydrothermal fluids.
  - Model age

Pb Isotopes

Thesis:

- **In any geological terrain, mineralisation associated with a major hydrothermal event will have distinctive Pb isotope ratios that can be discriminated from minor mineralisation and from Pb derived from background rocks.**
- ***The General Exploration problem is* – can we measure and interpret these fingerprints in common regolith geochemical samples – rocks, soils, vegetation, groundwater?**

Pb Isotope Variables

- Basic Equation:

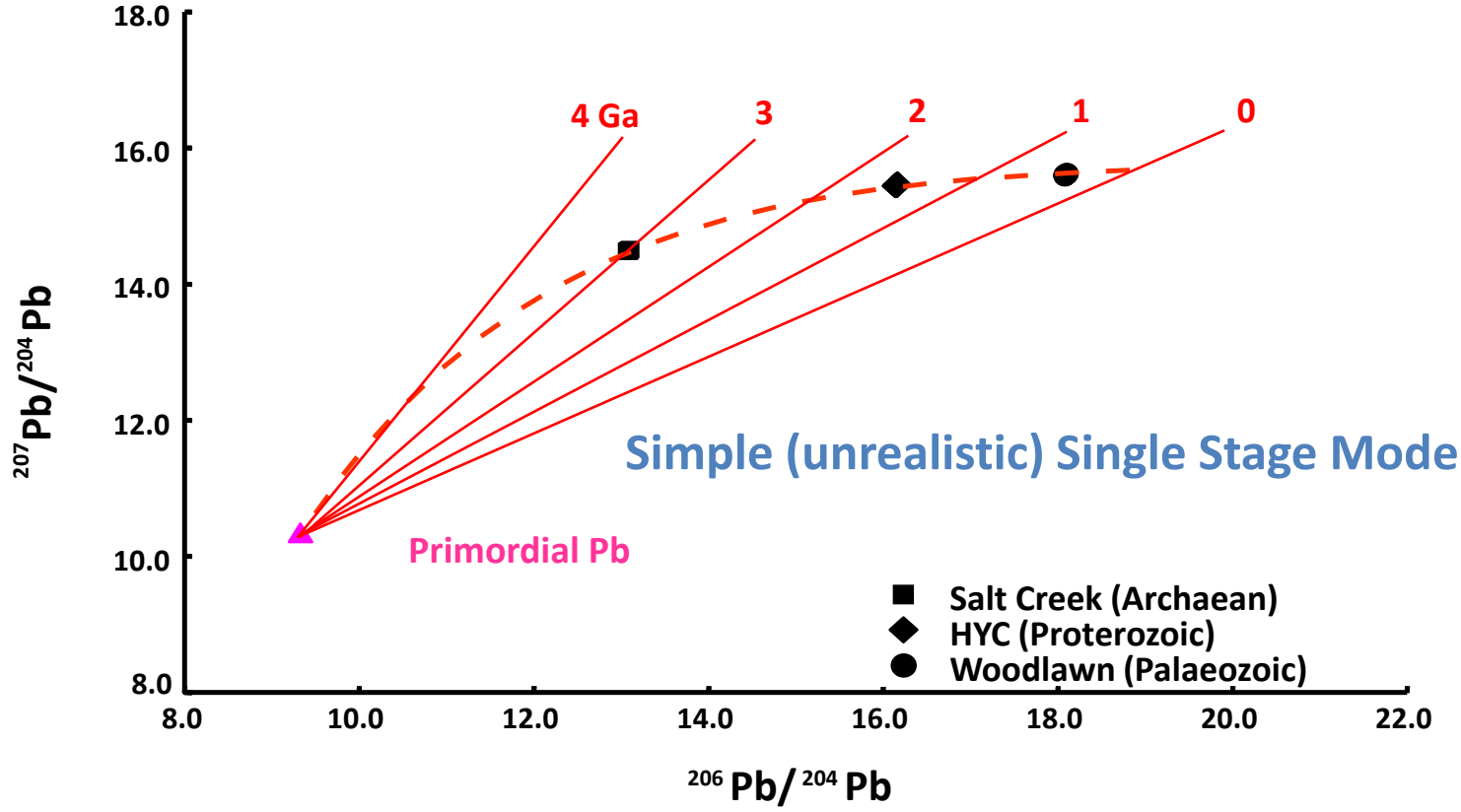
$$^{206}Pb/^{204}Pb = ^{206}Pb/^{204}Pb_i + ^{238}U/^{204}Pb(e^{\lambda t} - 1)$$

Source Rock Chemistry

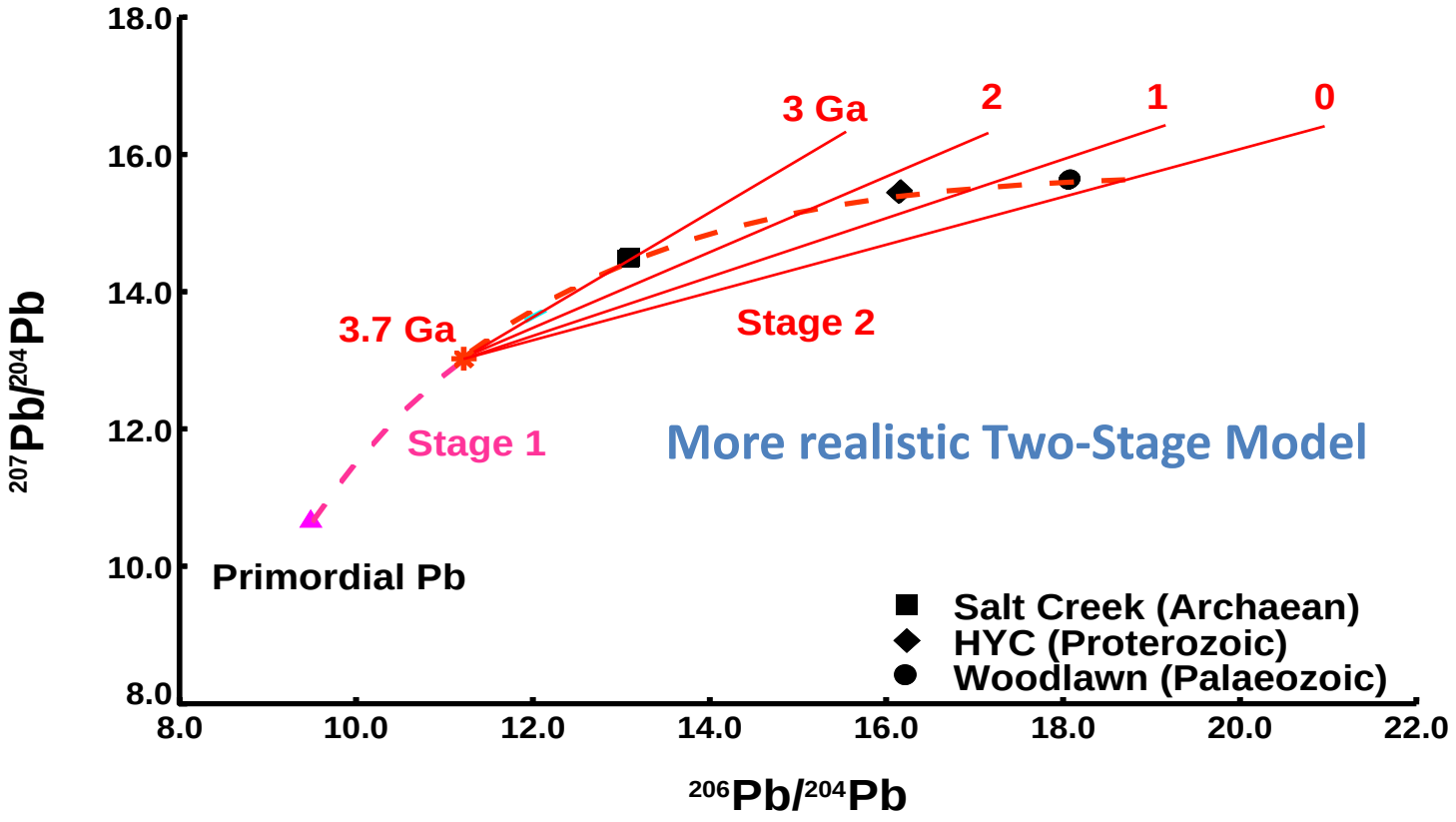
Time

The Growth Curve Concept

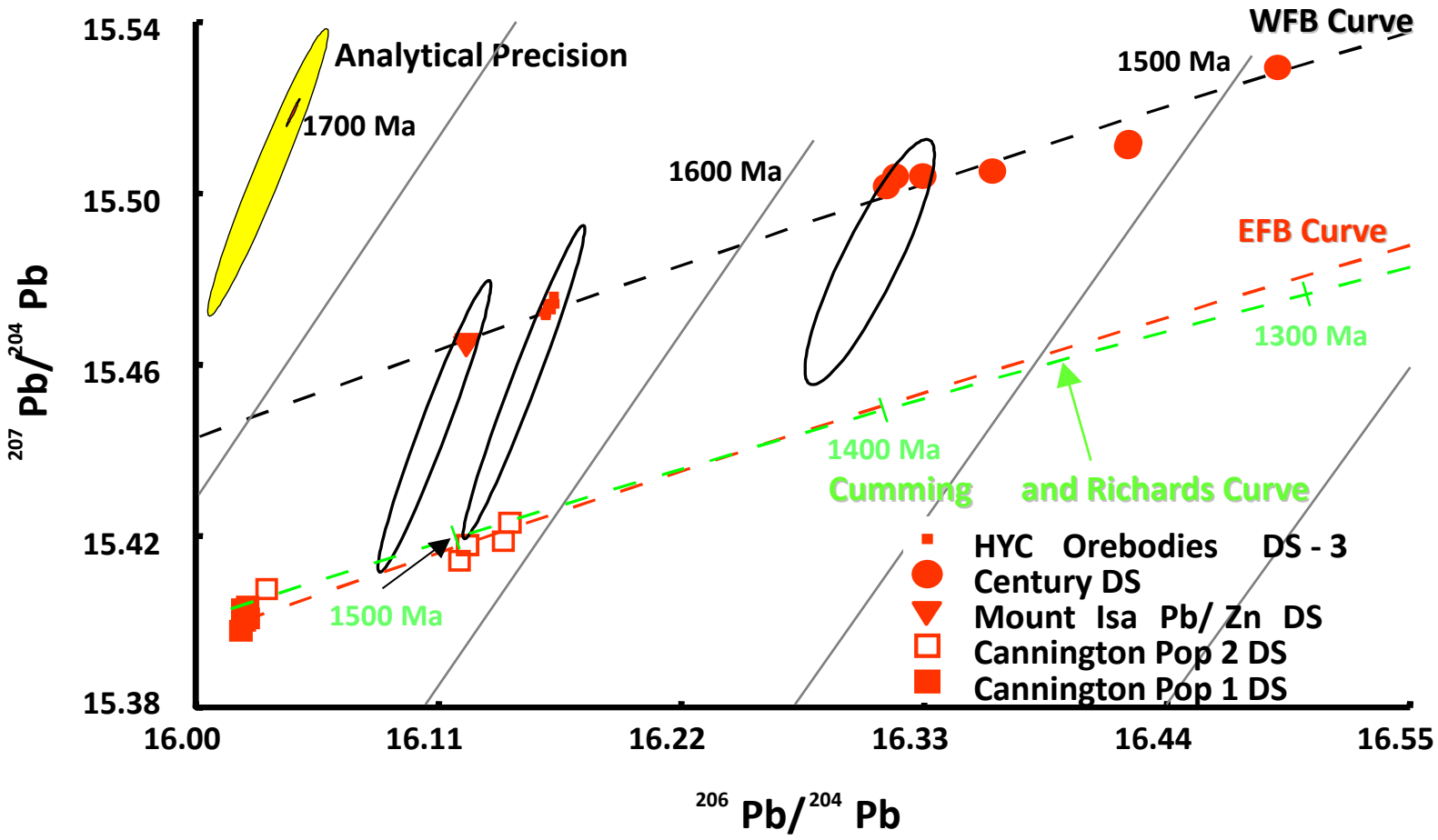
- *Growth Curve*: Co-variation through geological time of a pair of Pb isotope ratios assuming a common, U/Pb (μ)



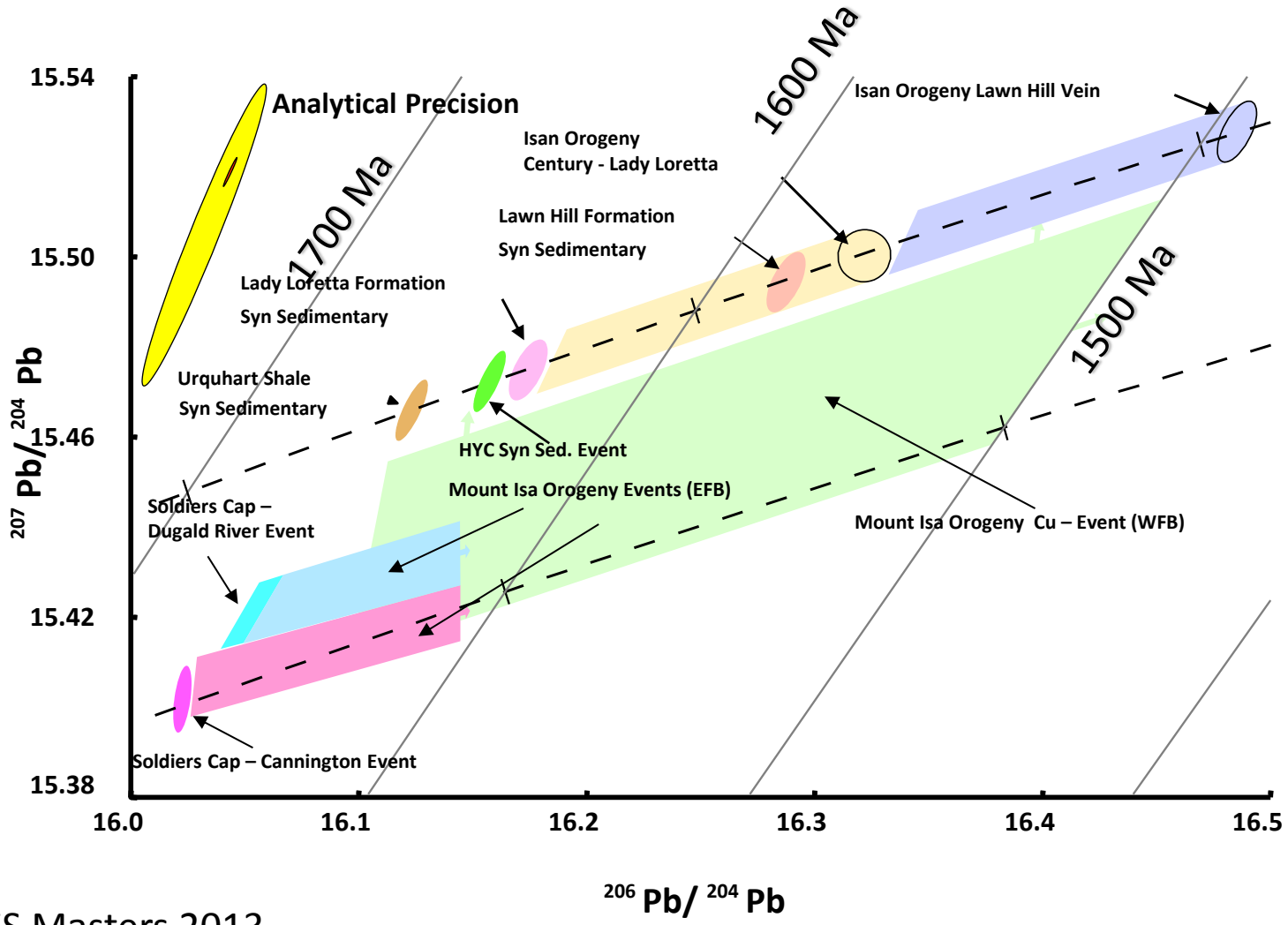
The Growth Curve Concept



The Mount Isa Growth Curves



Mount Isa Template



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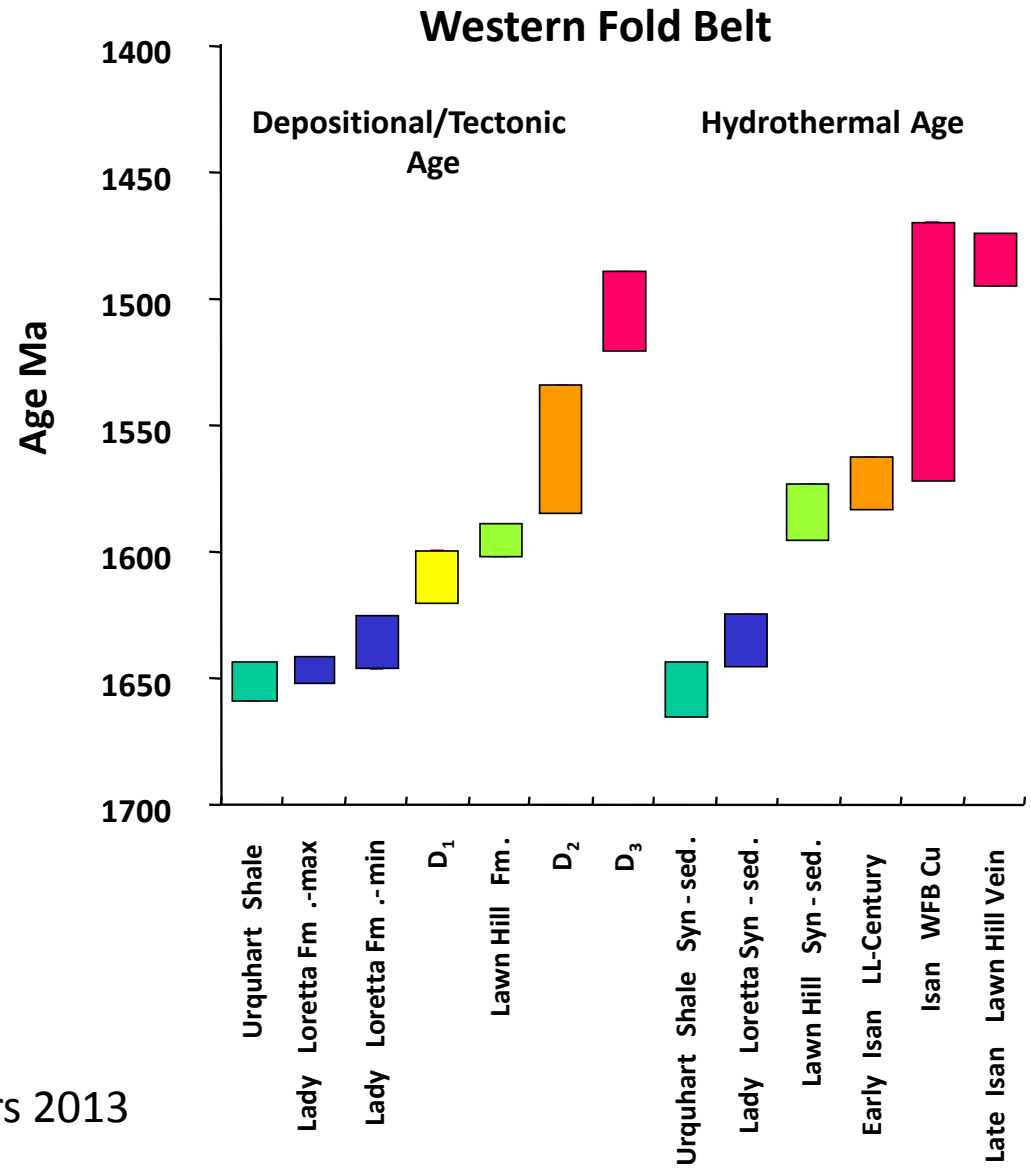
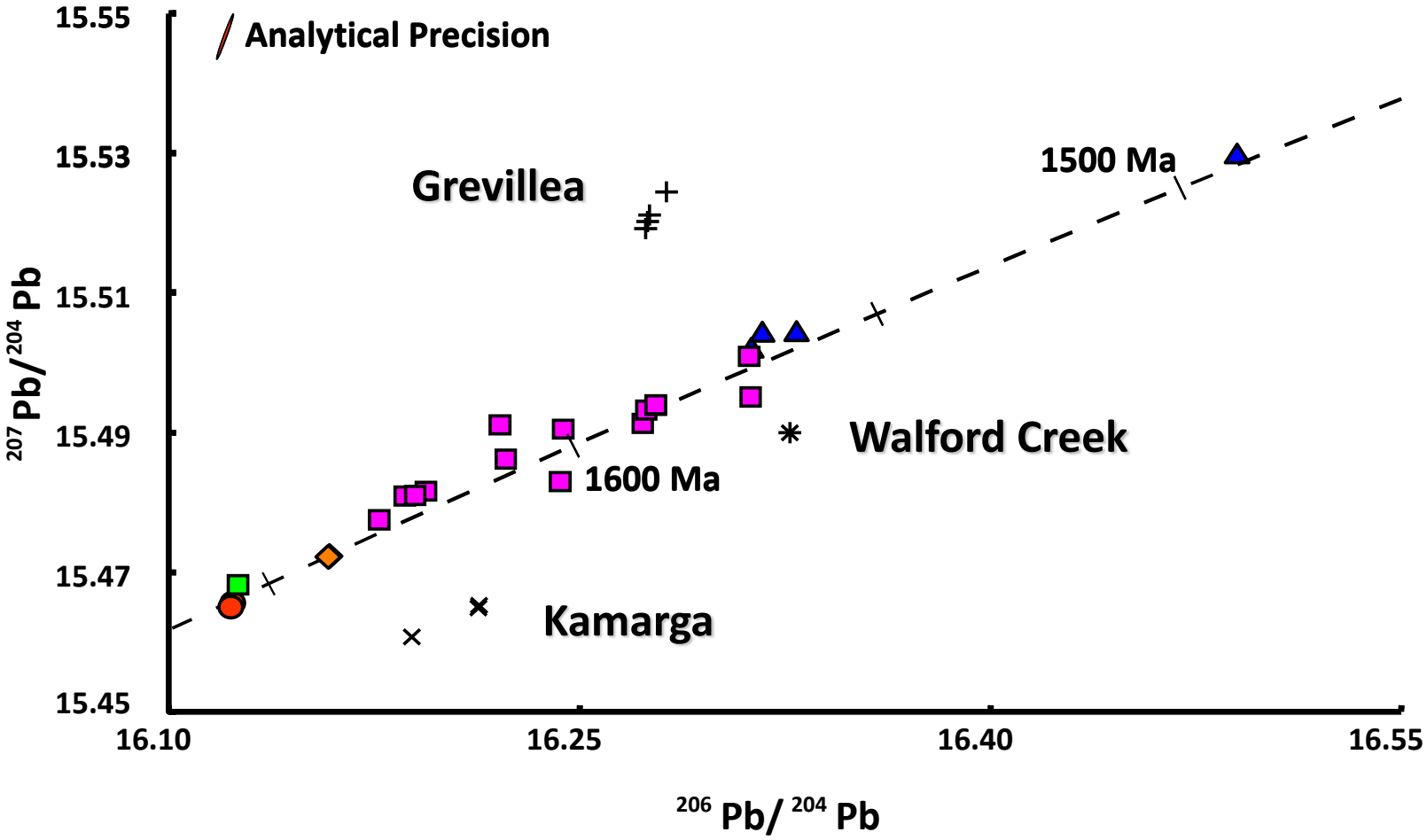
Relating Ores to Tectonics



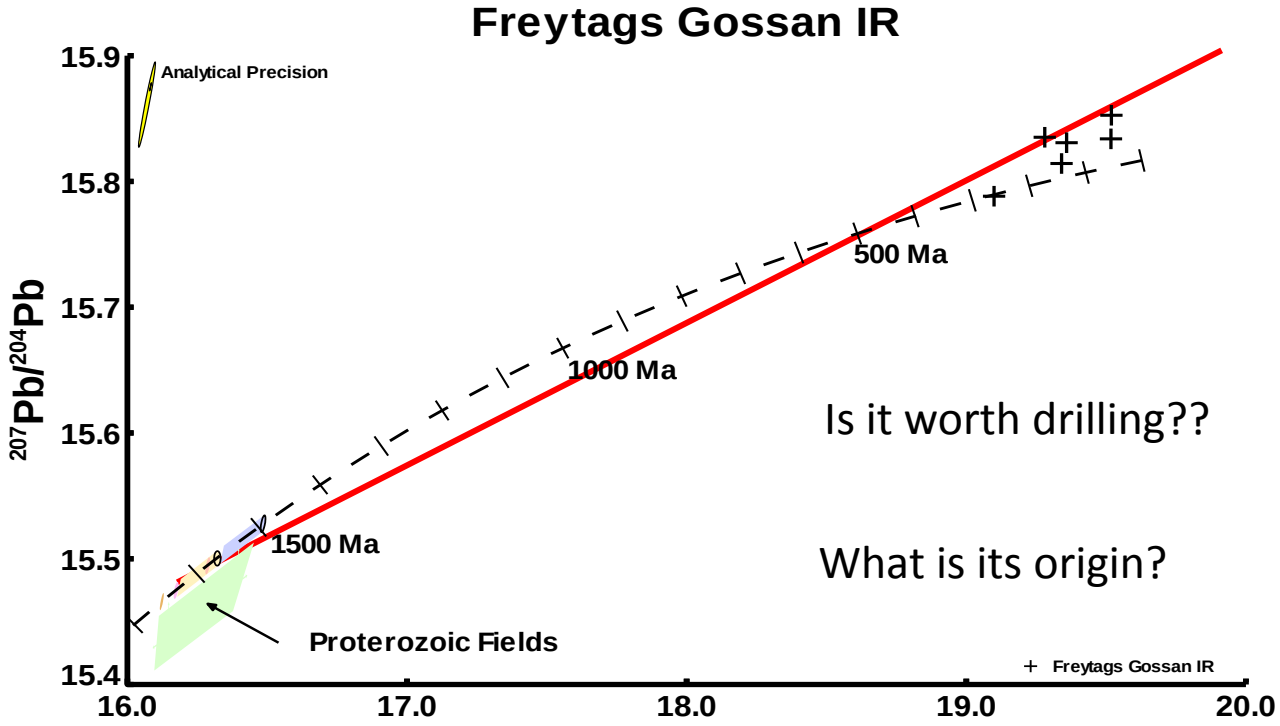
“Other” Deposits



Different fluids and different source rocks, or…..a small subset of the same source rocks.

Exploration Prospect – Mount Isa

- Large, outcropping gossan in Lower Proterozoic rocks of the Mount Isa Western Fold Belt
- Geochemically highly anomalous with % Zn and Pb



Is it worth drilling??

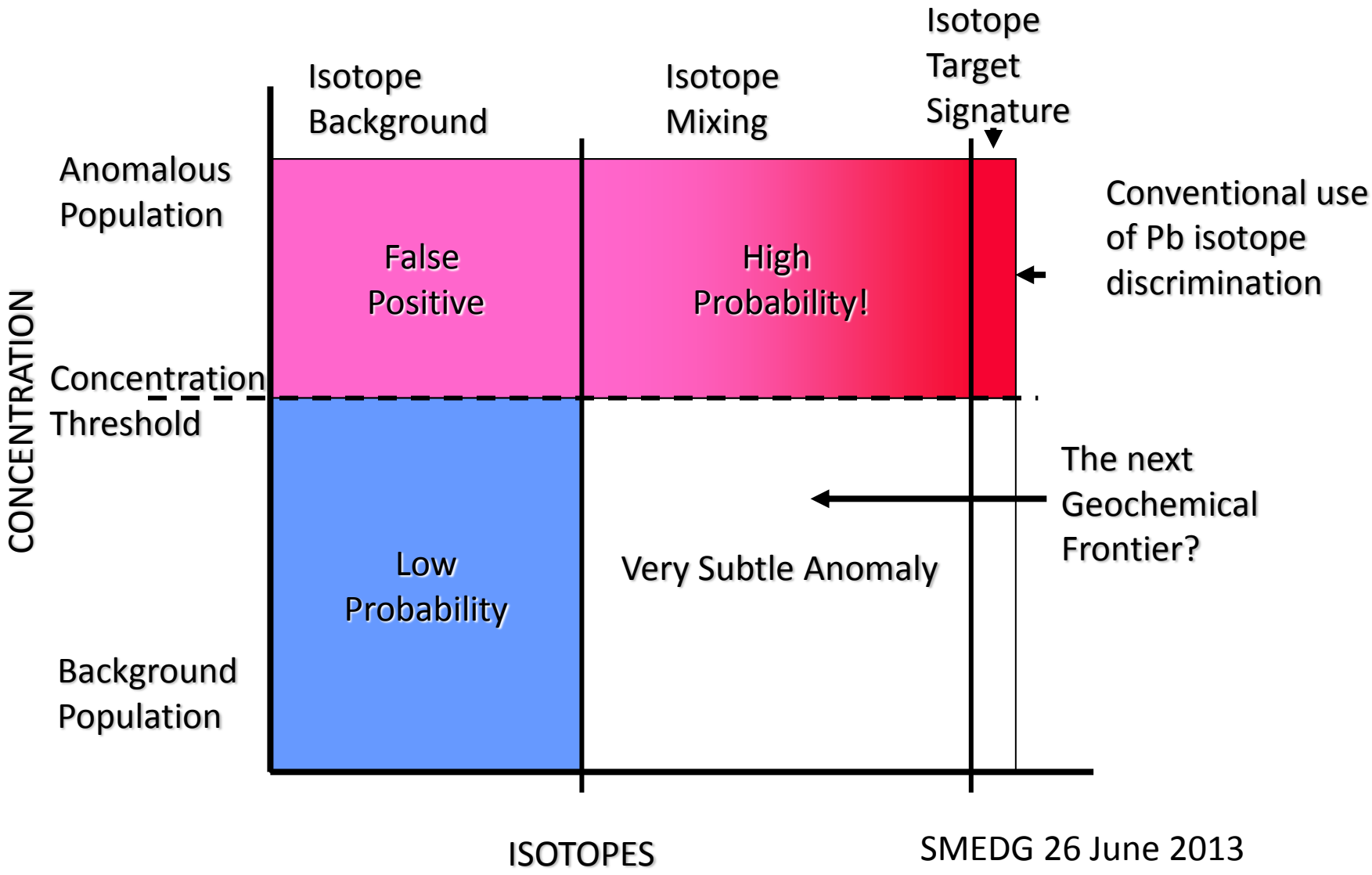
What is its origin?

Pb Isotopes in Regolith Materials

- **Have greatest value in :**
  - **discriminating and eliminating the "False Positive" geochemical anomaly**
  - **Having greater sensitivity than absolute abundance data in detecting metal derived from a hidden/buried ore source**

- **Greatest inhibitors to use:**
  - **Cost**
  - **Anthropogenic contamination**

The Two Dimensions of Pb



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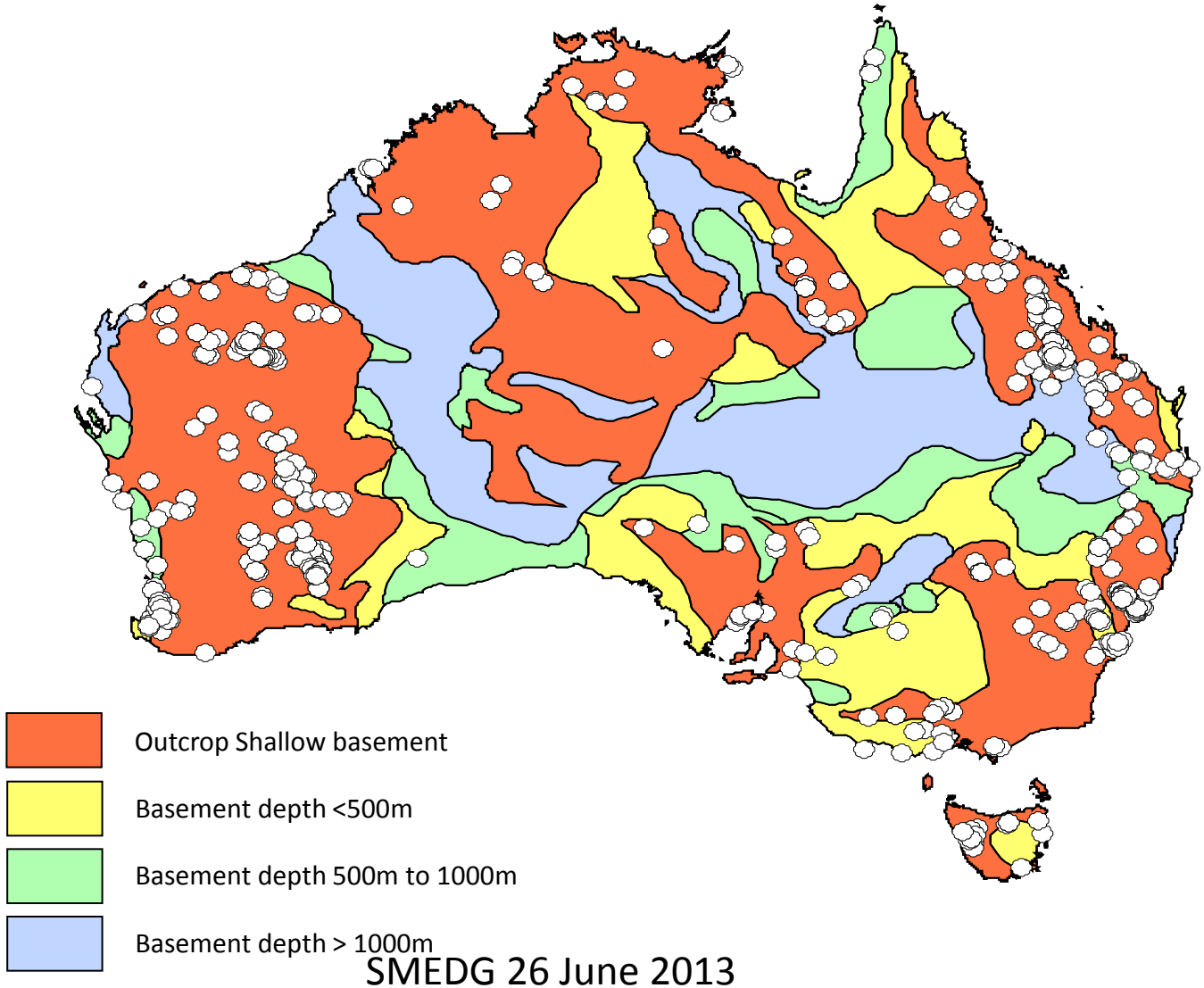
The Problem is Cover



Pb Isotopes in Exploration Through Cover

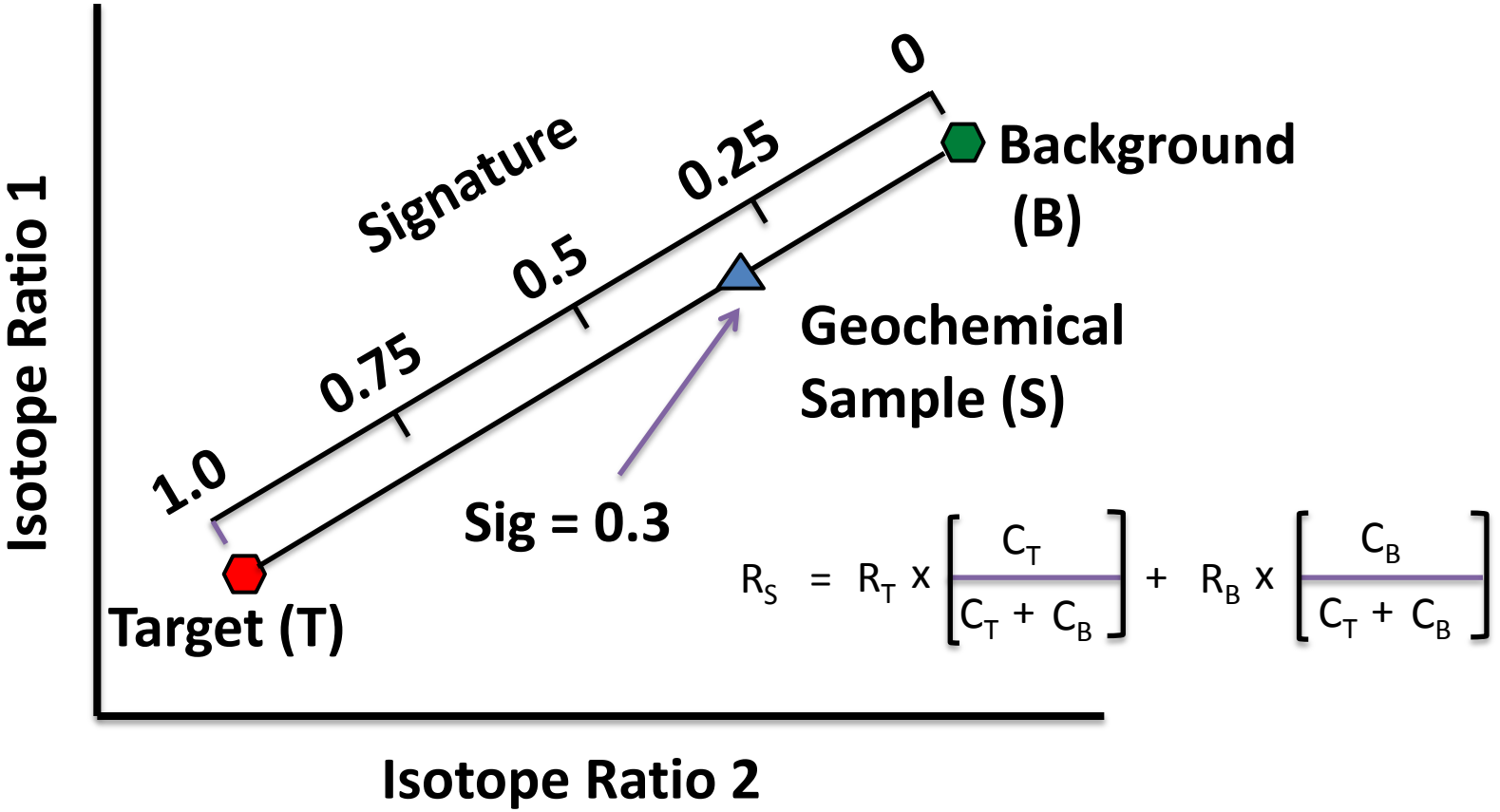
- **Problem – detect and discriminate subtle geochemical signals above buried ore systems**
- **Regolith materials that can be used for geochemistry:**
  - **Soils – partial extraction geochemistry**
  - **Vegetation**
  - **Groundwater**
- **Pb isotopes can be used to discriminate "anomalous" from "background" in each of these media – also detect anthropogenic contamination.**

Pb Isotopes in Exploration Through Cover

- **Partial extraction techniques to determine soil metal concentration are commonly used – but the jury is out on their applicability**
- **Pb isotopes are potentially a valuable discriminator to assess partial extraction anomalies**
- **The technique is based on the ability of isotopes to measure the proportion of end member components with distinctive Pb isotope fingerprints in a mixed system.**

Pb Mixing Model

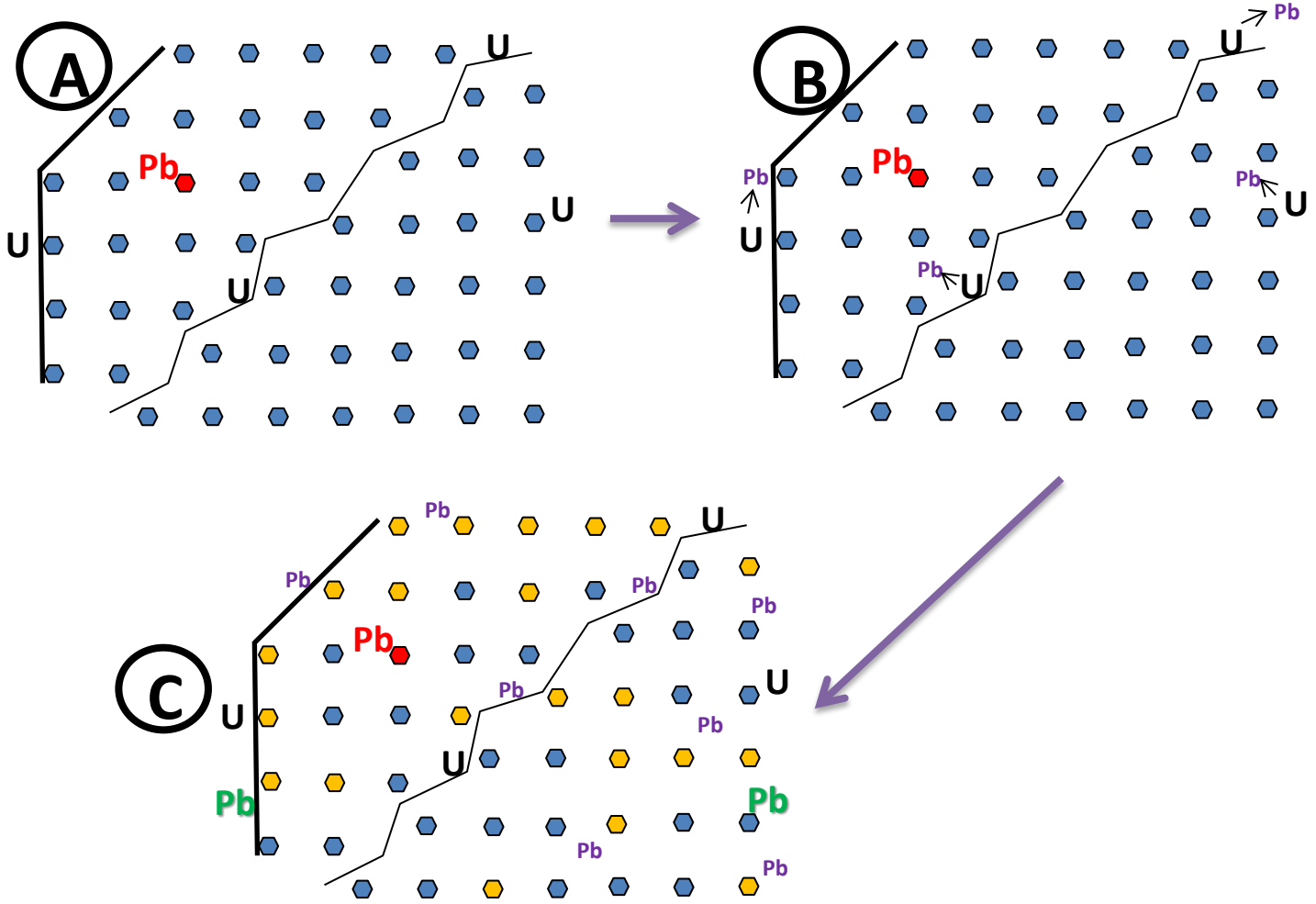
Can be applied to any regolith sample – rock, *soil, groundwater, vegetation*.



Pb In Soils – The Pb Soil Model - 1

- **The possible sources of Pb in a regolith sample are:**
  - **Crystallization Pb – that is, Pb incorporated in the primary mineral lattice at the time of formation**
  - **Radiogenic Pb – Pb that have derived from the decay of U and Th in the period since crystallisation**
  - **Regolith Pb – labile Pb that has been transported to the sample through regolith processes.**

Sources of Pb in a Regolith Sample



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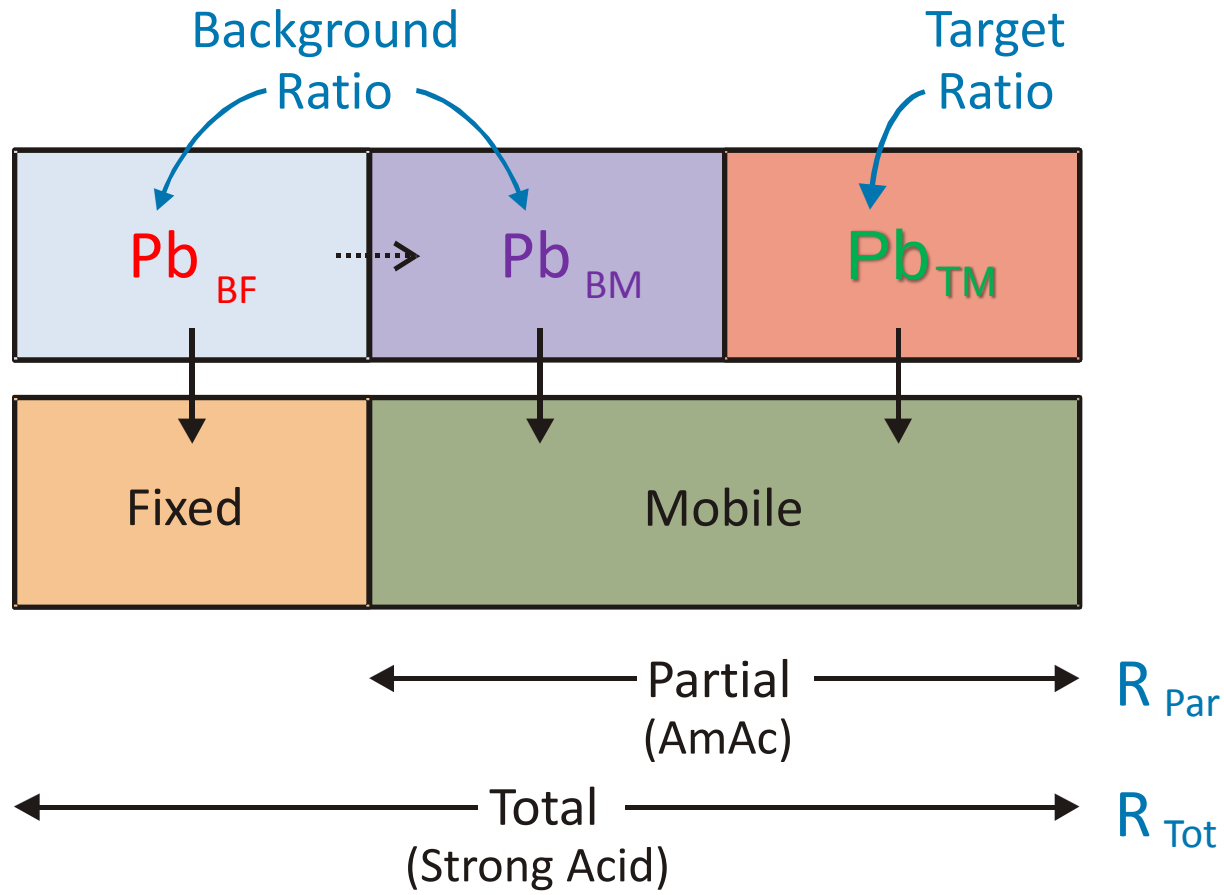
Pb In Soils – The Pb Soil Model - 1



R_{Par} is the measured isotope ratio of the partial extraction
R_{Tot} is the measured isotope ratio of the total extraction

Pb In Soils – The Pb Soil Model - 2

- **The use of Pb isotopes in soil geochemistry requires a knowledge of the target and background isotope populations**
- **In an initial orientation survey both total and partial extractions are required.**
- **Follow up surveys can be based just on partial extractions**

Pb In Soils – The Pb Soil Model - 3

- **Soil contains "Fixed" and "Mobile" components. The boundary between these will vary for different soils and depends on the strengths of the acid leaches used to liberate the metal.**
- **In any one sampling exercise where the media are similar across the terrain and the analytical procedures standardised, the "Background" population will incorporate a proportion of Pb fixed in the sample (Pb_{BF}) and Pb that has been mobilised by weathering from within the sample or from the surrounding background rocks (Pb_{BM}).**
- **It may also contain a component of mobile Pb that has been derived from a Target source buried beneath the cover rocks - or through anthropogenic contamination (Pb_{TM})!**

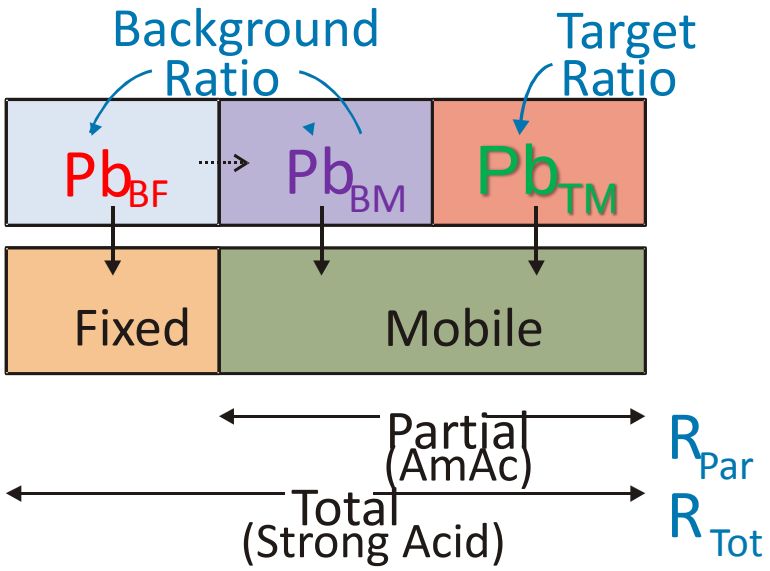
Pb In Soils – The Pb Soil Model - 4

- **From the generalized mixing model we can derive equations to calculate the concentration of each Pb component of the soil sample:**

$$Pb_{TM} = Sig_{Tot} \times Pb_{Tot}$$

$$Pb_{BM} = Pb_{Par} - Pb_{TM}$$

$$Pb_{BF} = Pb_{Tot} - Pb_{Par}$$



- **Where Pb_{Tot} and Pb_{Par} are the measured total and partial Pb concentrations, Sig_{Tot} is the Pb isotope signature of the "total" solution**

Partial Extraction Geochemistry

- **Anomalies *appear* to form in soils over covered mineralisation via processes that transport target and indicator elements through the covered sequence to the near surface.**
- **Possible mechanisms for this transport include:**
  - **Geogas carrier**
  - **Electro-chemical potential**
  - **Interaction of geogas and soil**
  - **Interaction of soil and groundwater**
  - **Residual effects**
  - **Bioturbation**
  - **Biological migration**

Research Procedure

- **Thesis:**
  - **Pb isotopes in soils potentially retain "a memory" of their source – thus we can determine whether the Pb has derived from hidden mineralisation or from a non-mineralisation source.**
  - **We can extract the most mobile Pb from most samples at very low concentrations and differentiate this potentially transported Pb from Pb that is residual in the soil minerals.**
- **Procedure:**
  - **Undertake case histories at sites where there is known covered mineralisation and where there is no anthropogenic contamination**
  - **Study a range of deposits from shallow to deep burial.**

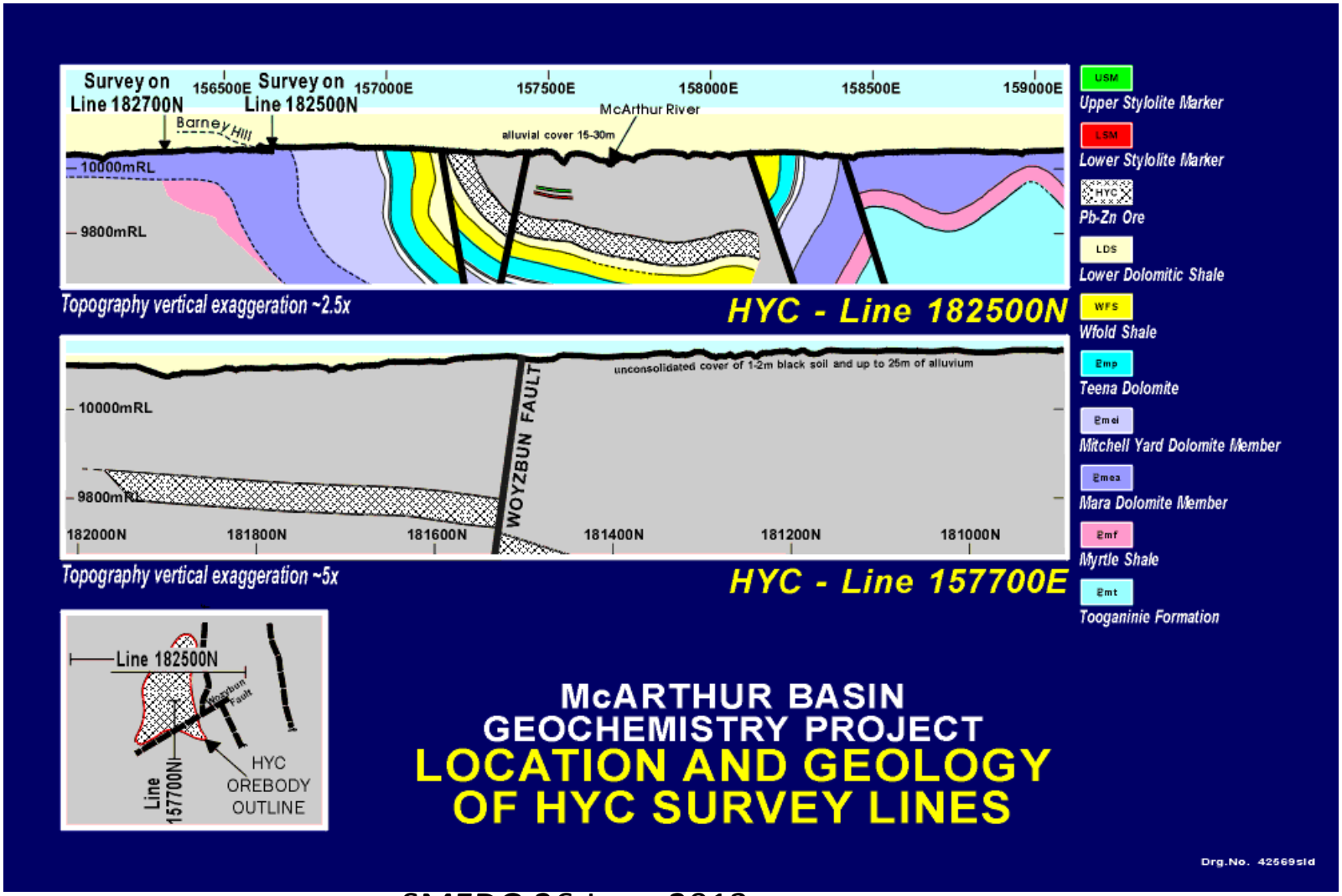
Conclusions of Study

1. **We *have not* seen isotopic or trace element anomalies through thick (> 50m) cover.**
2. **We *have* seen clear, very sensitive isotopic anomalies through shallow cover over mineralisation with very subtle or no trace element anomalies.**
3. **We have seen *anthropogenic contamination* in a variety of situations where it was not expected and which place in doubt the conclusions of many previous studies.**
4. **We *can recognise* anomalies associated with anthropogenic contamination.**
5. **We have *not seen* anomalies that can be ascribed to vapour transport**

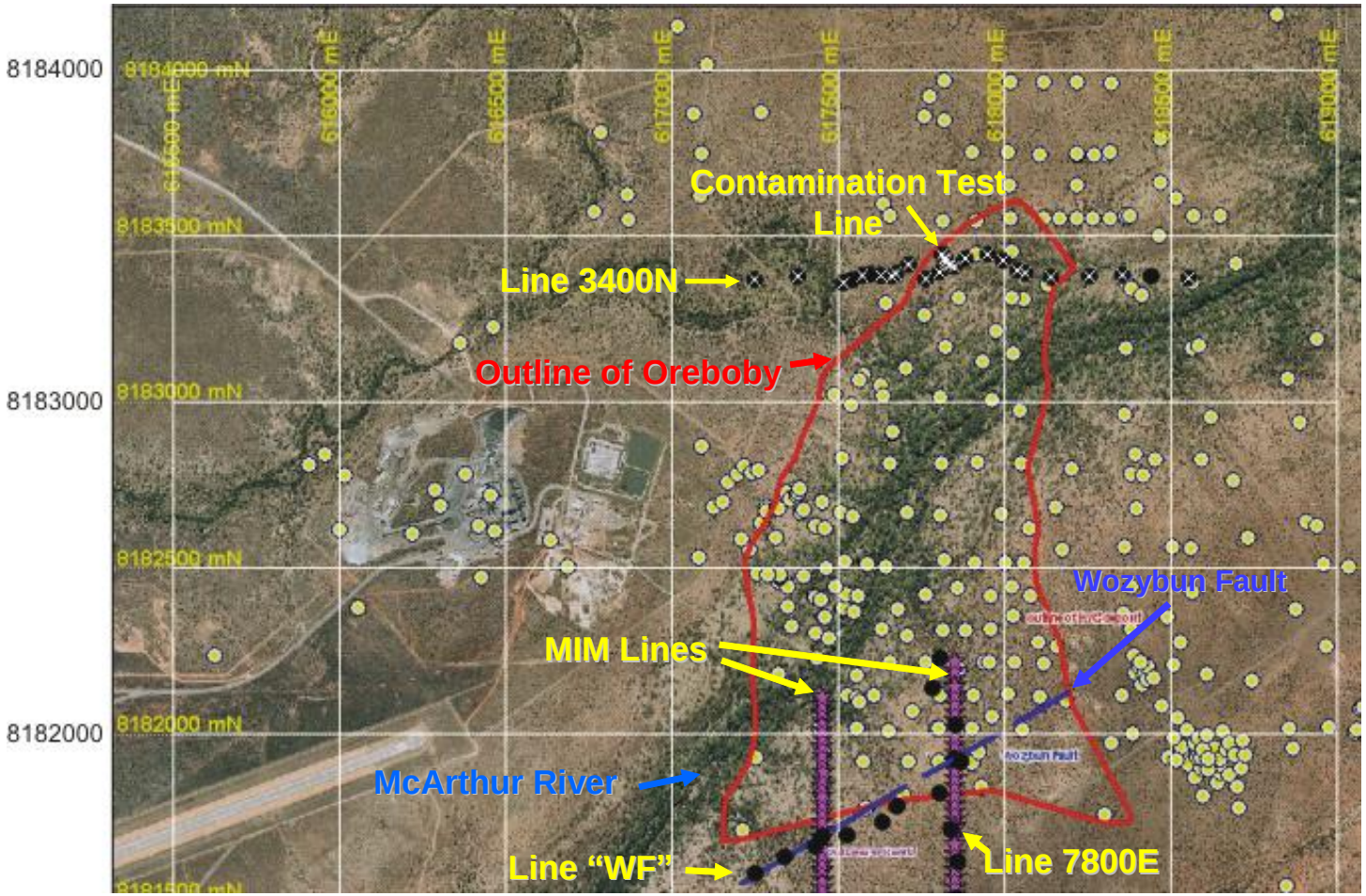
The Pb Soil Model – CASE HISTORY HYC

- **HYC is a sediment –hosted massive sulfide deposit of approximately 400 Mt in the Proterozoic of the Northern Territory.**
- **The host unit sub-crops beneath alluvial sediments but the ore is deep within the stratigraphy.**
- **Numerous attempts have been made to detect the mineralization in the overlying regolith.**

HYC Deposit


Survey on Line 182700N
Survey on Line 182500N
156500E
157000E
157500E
158000E
158500E
159000E
Barney Hill
McArthur River
alluvial cover 15-30m
10000mRL
9800mRL
Topography vertical exaggeration ~2.5x
HYC - Line 182500N
unconsolidated cover of 1-2m black soil and up to 25m of alluvium
WOYZBUN FAULT
10000mRL
9800mRL
182000N
181800N
181600N
181400N
181200N
181000N
Topography vertical exaggeration ~5x
HYC - Line 157700E
USM
Upper Stylolite Marker
LSM
Lower Stylolite Marker
HYC
Pb-Zn Ore
LDS
Lower Dolomitic Shale
WFS
Wfold Shale
Emp
Teena Dolomite
Emci
Mitchell Yard Dolomite Member
Emea
Mara Dolomite Member
Emf
Myrtle Shale
Emt
Tooganinie Formation
Line 182500N
Woyzbun Fault
Line 157700N
HYC OREBODY OUTLINE
McARTHUR BASIN
GEOCHEMISTRY PROJECT
LOCATION AND GEOLOGY
OF HYC SURVEY LINES
Drg.No. 42569sld

HYC Deposit



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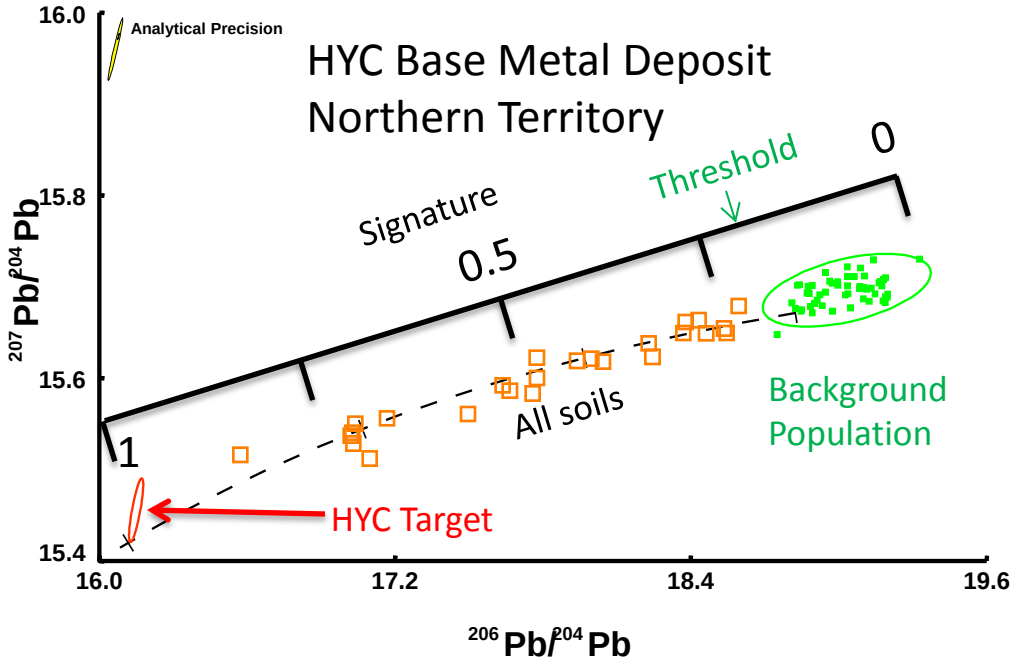
HYC – Pb Isotope Data



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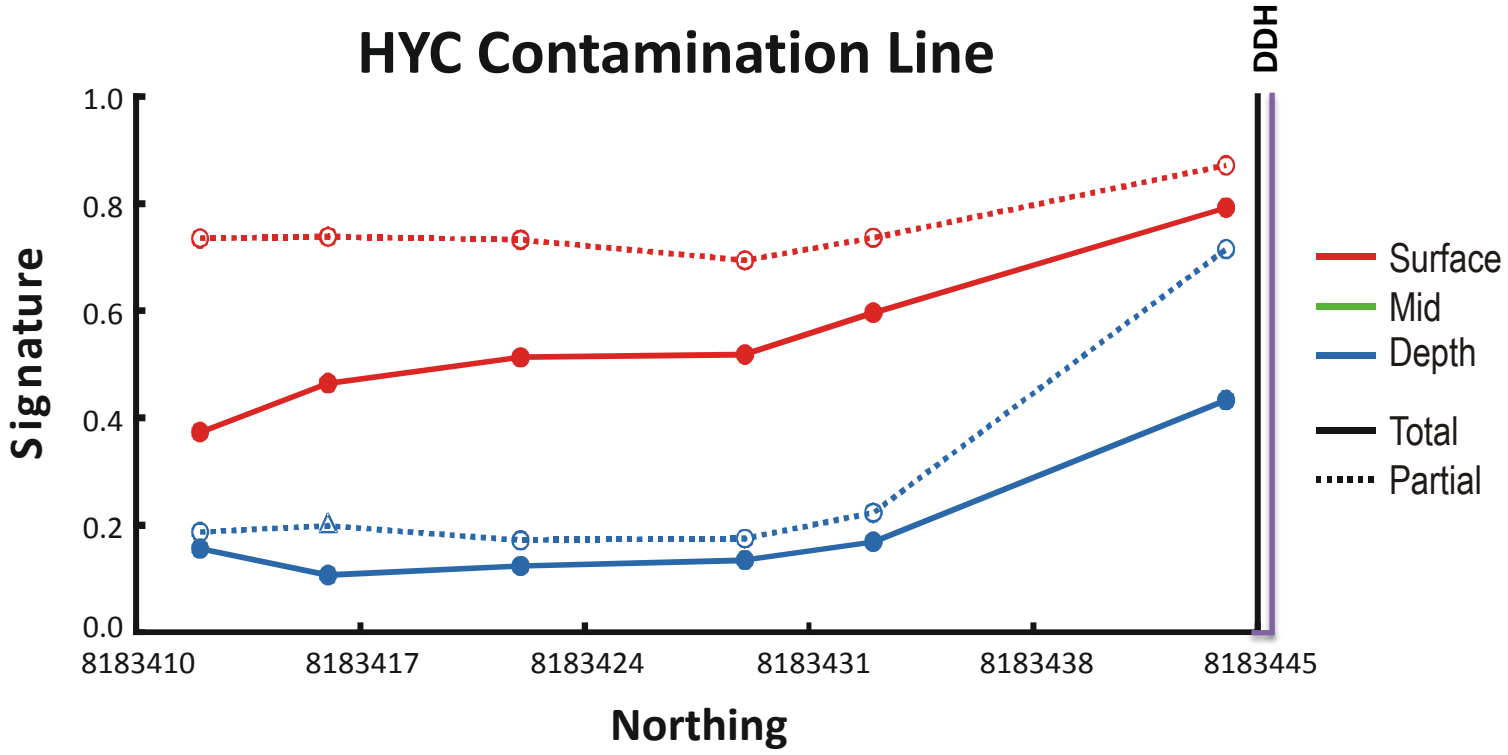
HYC – Test line downslope from a 60 year old drill hole



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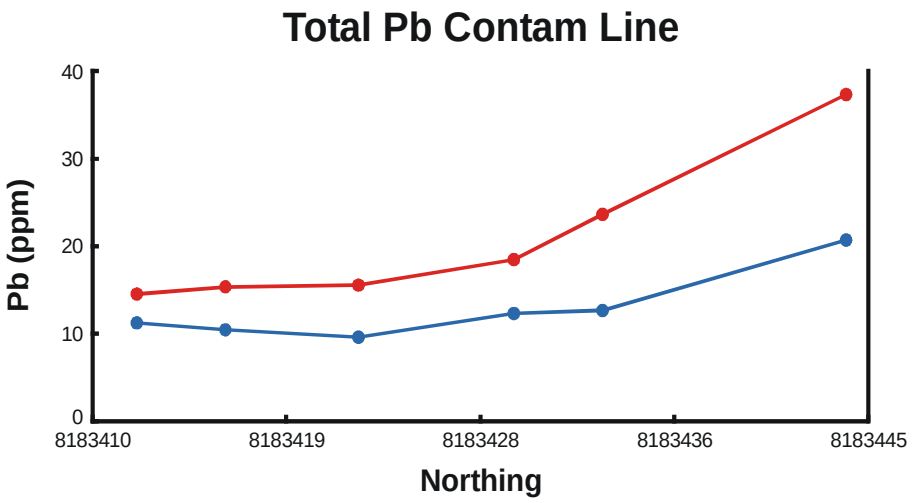

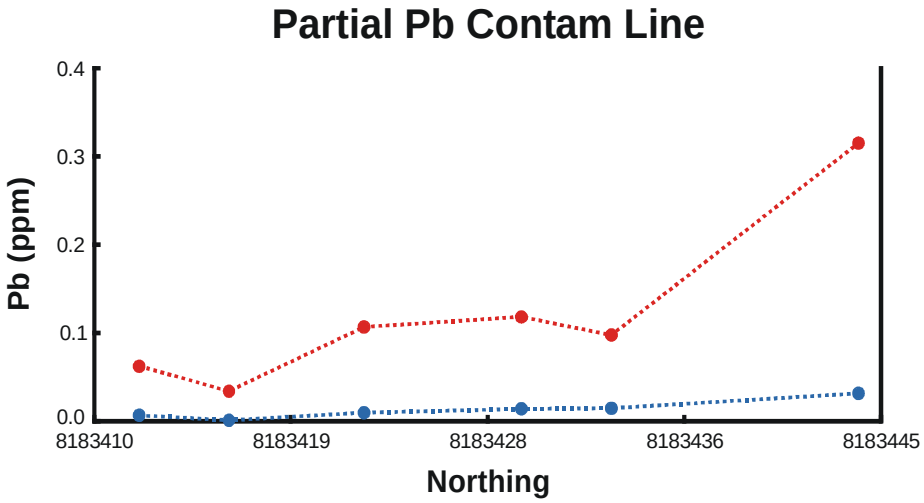

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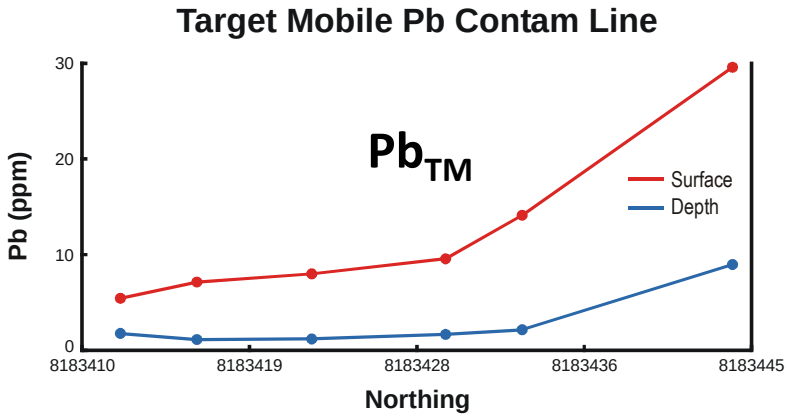
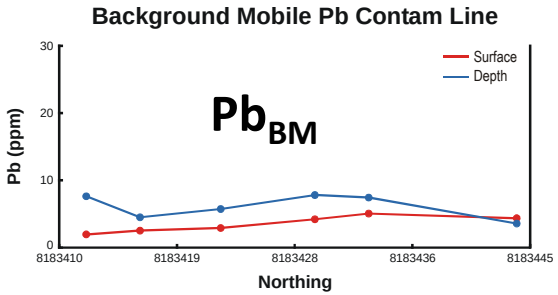
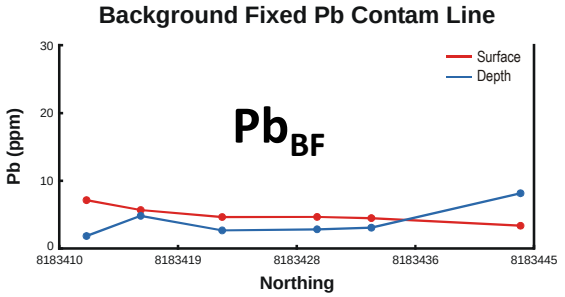
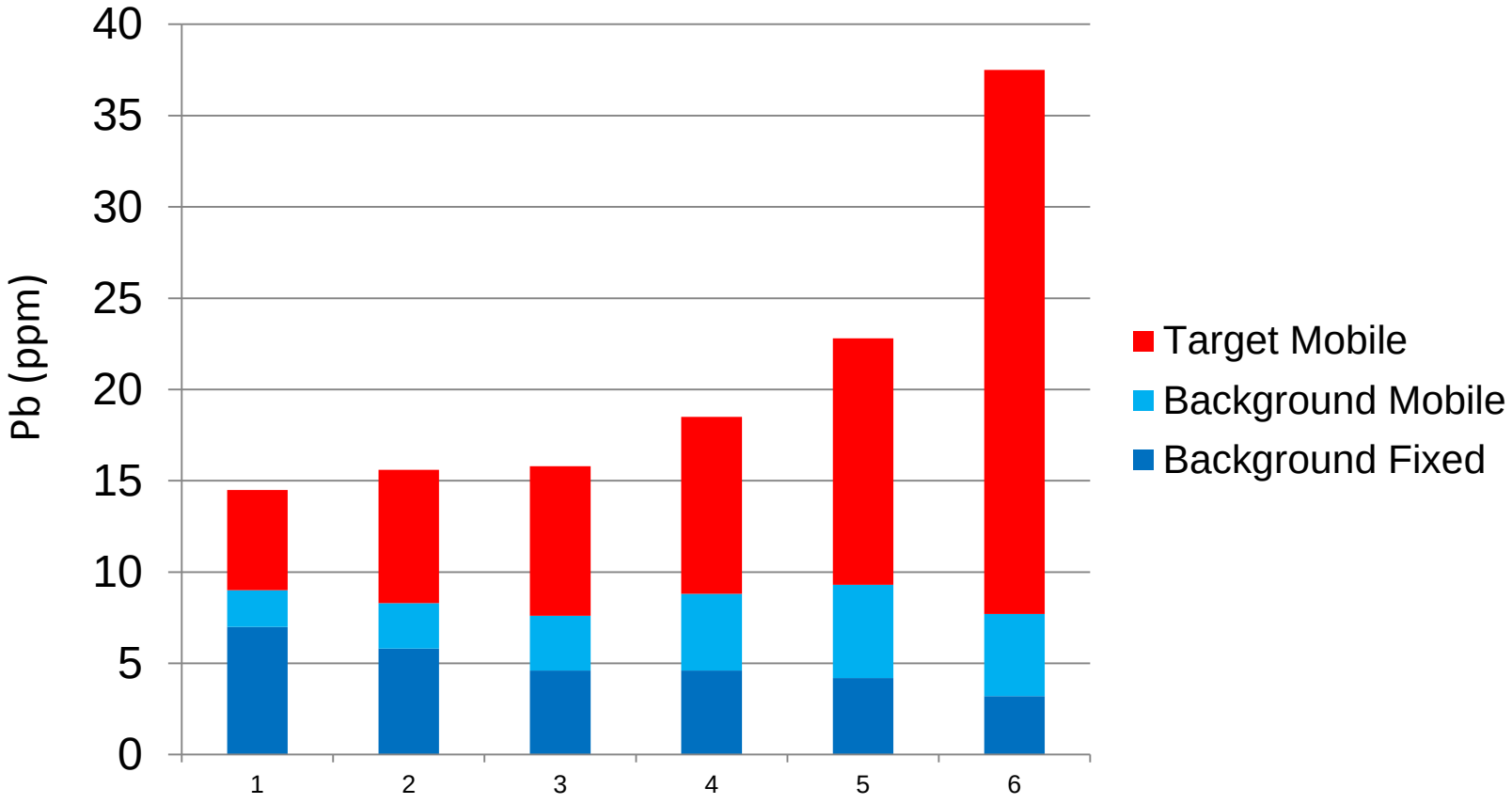






HYC Soil Pb Model Components Surface Samples



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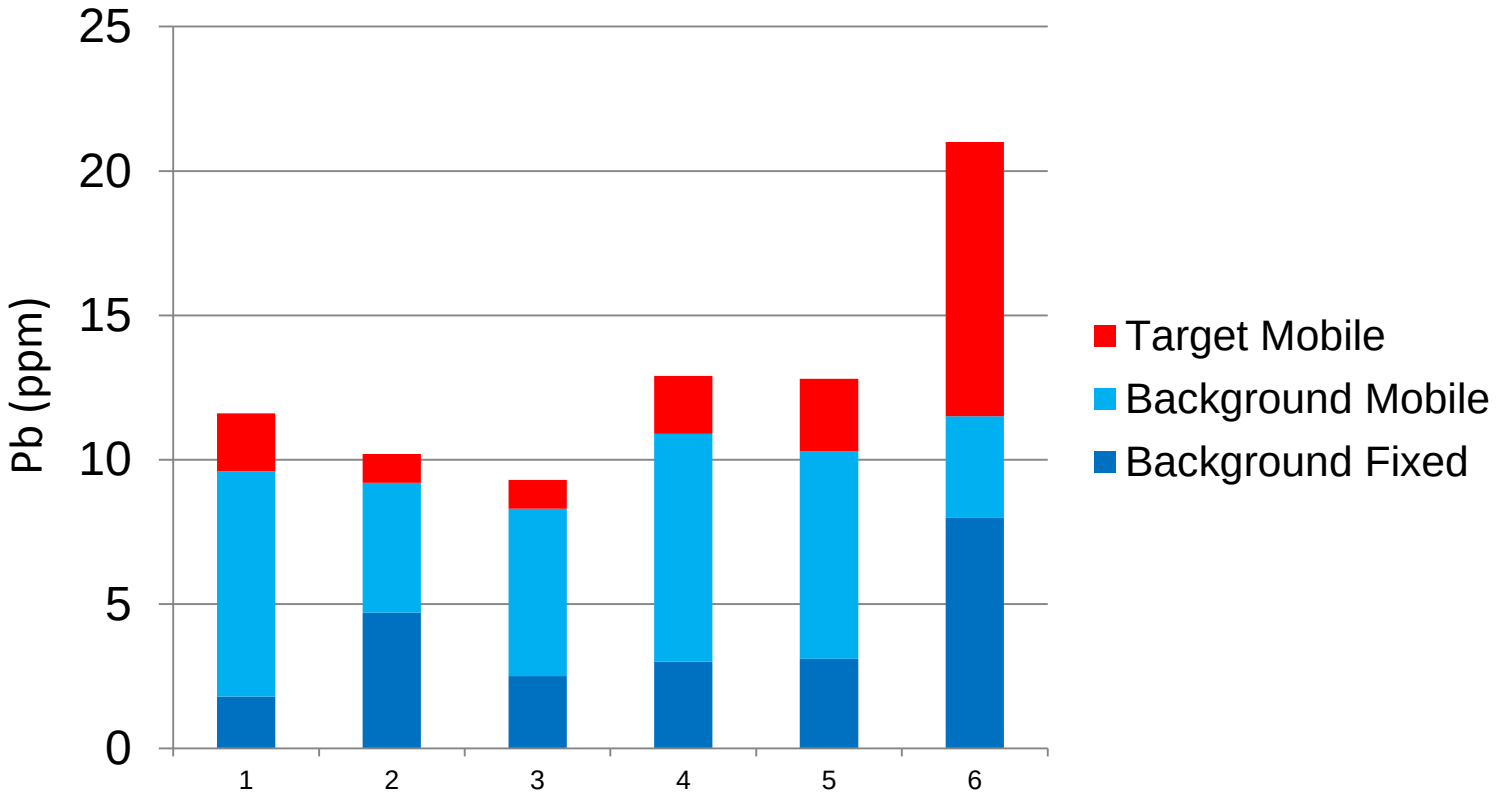
HYC Soil Pb Model Components
30 cm Samples



HYC – The Lesson Learnt

- Pb isotopes are very sensitive to labile, "target" Pb that cannot be discriminated by normal geochemistry
- This will apply also where the source is geological – not anthropogenic
- Case history studies to determine the effectiveness on novel geochemical techniques anywhere near historic mining or exploration is very very problematic!

Pb ISOTOPES – A VEGETATION EXAMPLE

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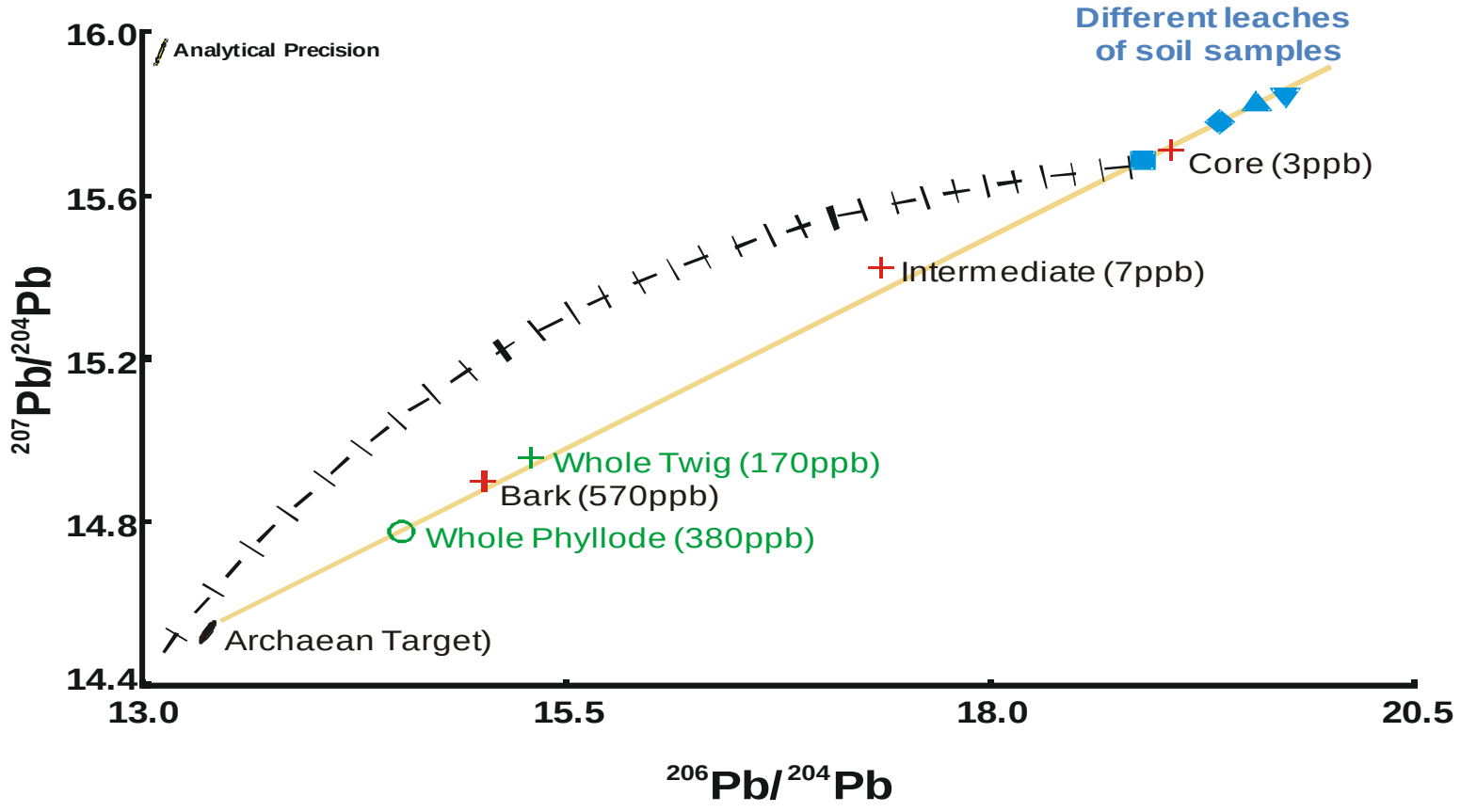
Vegetation 6km from an Archaean VMS Mine



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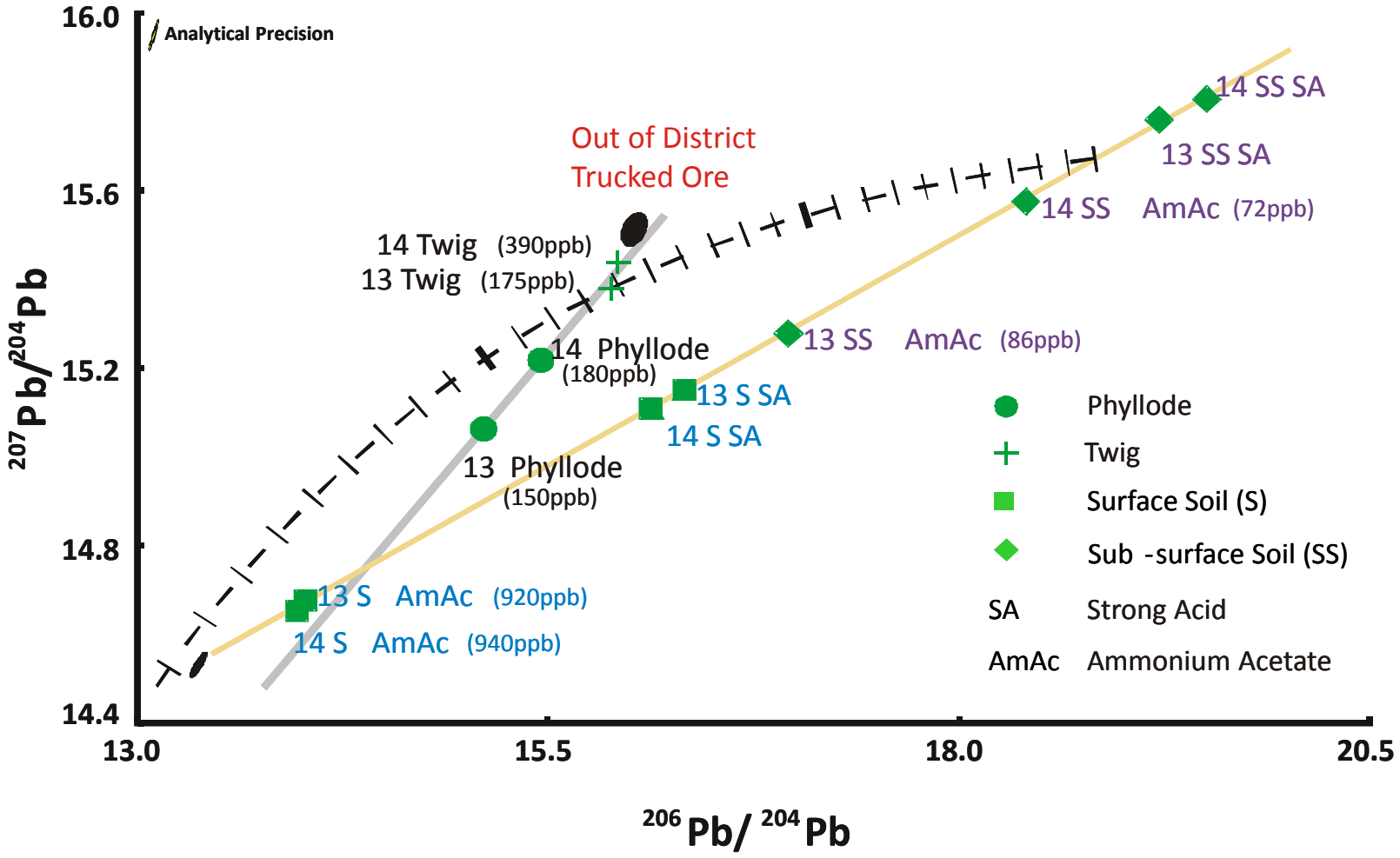
Partial Extraction and Vegetation



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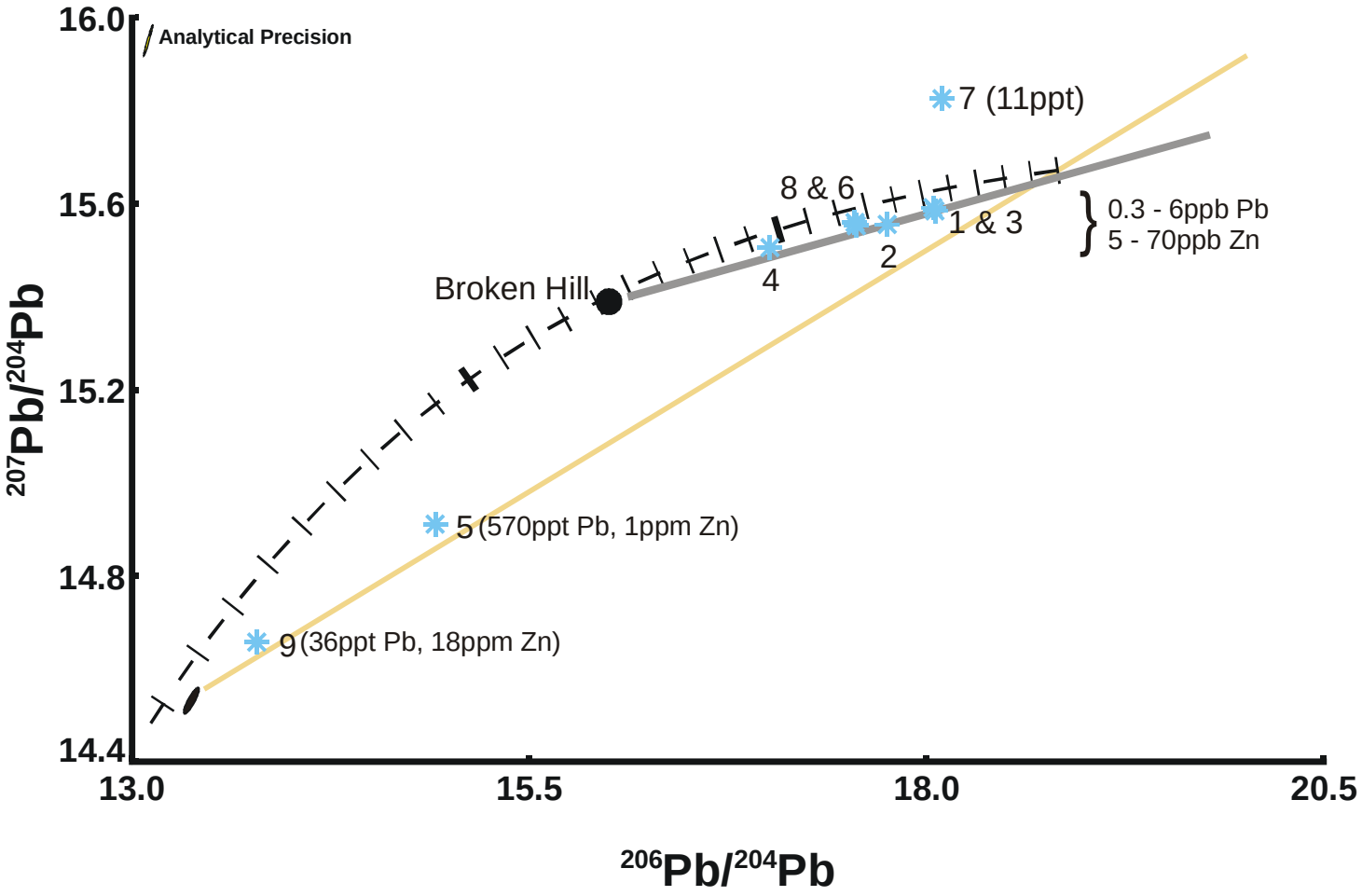
Groundwater in vicinity of Archaean VMS deposit



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MIXING MODEL SENSITIVITY

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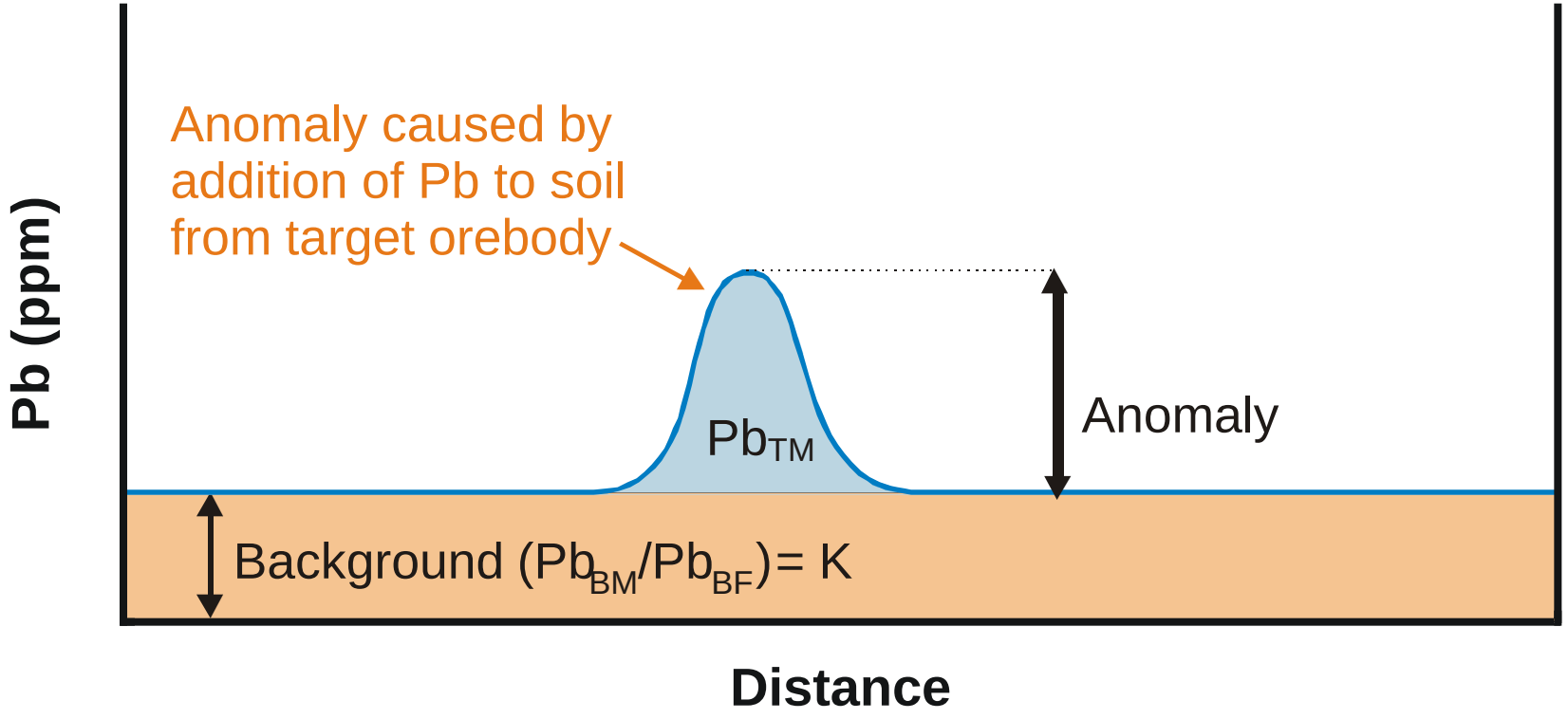
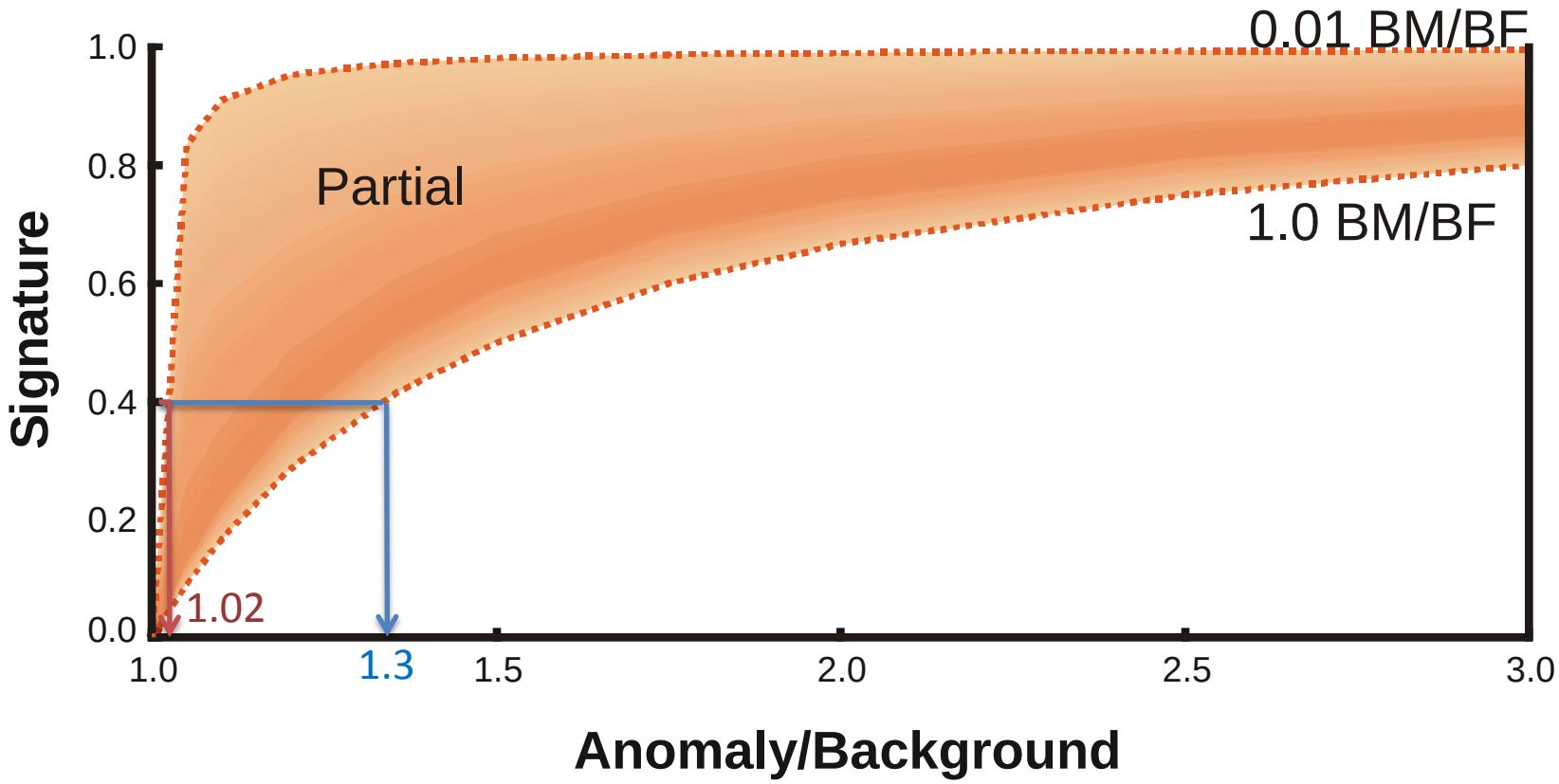
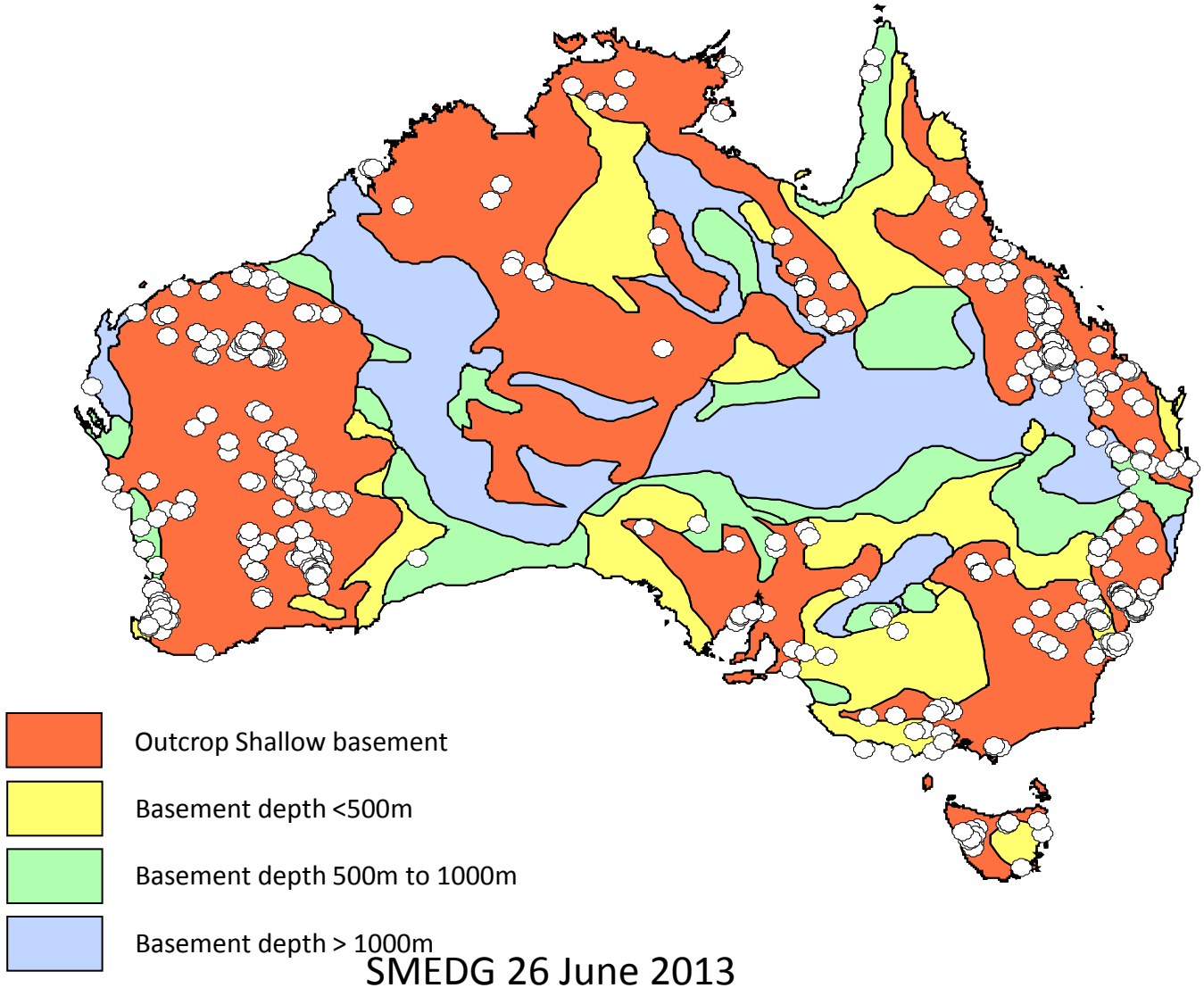
Theoretical Anomaly



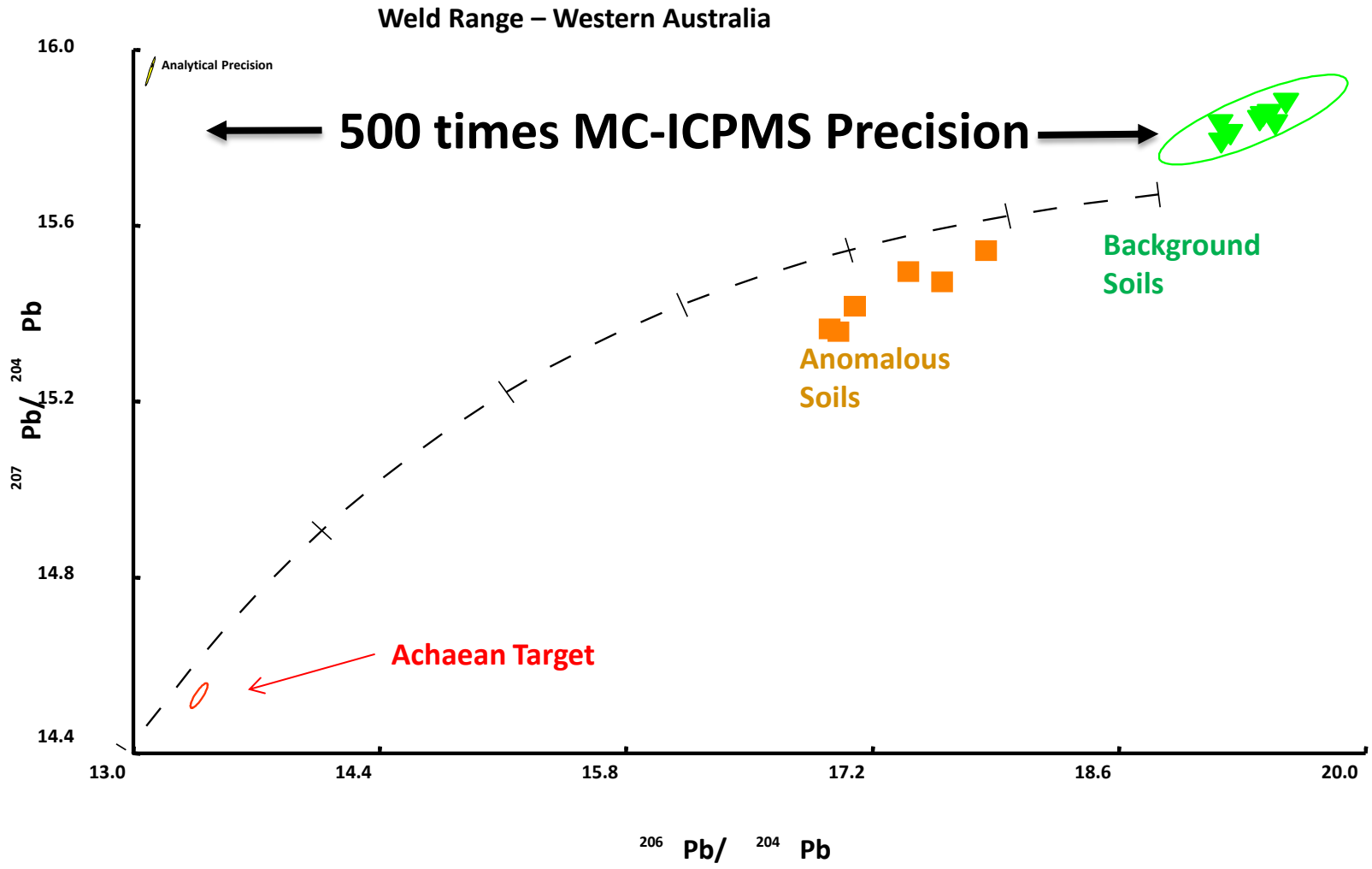
Signature Model Sensitivity



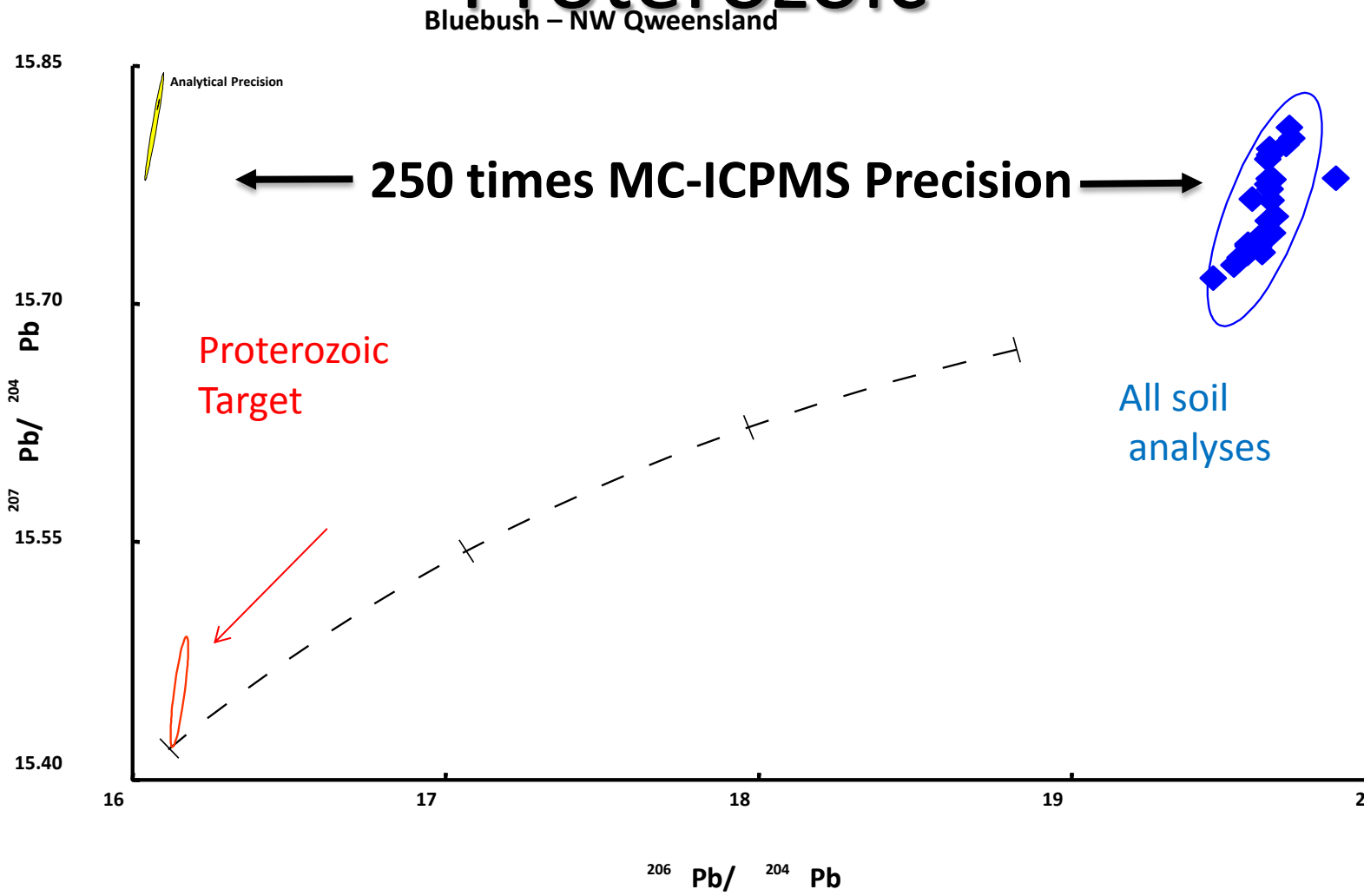
Cover = Homogeneous, background Pb



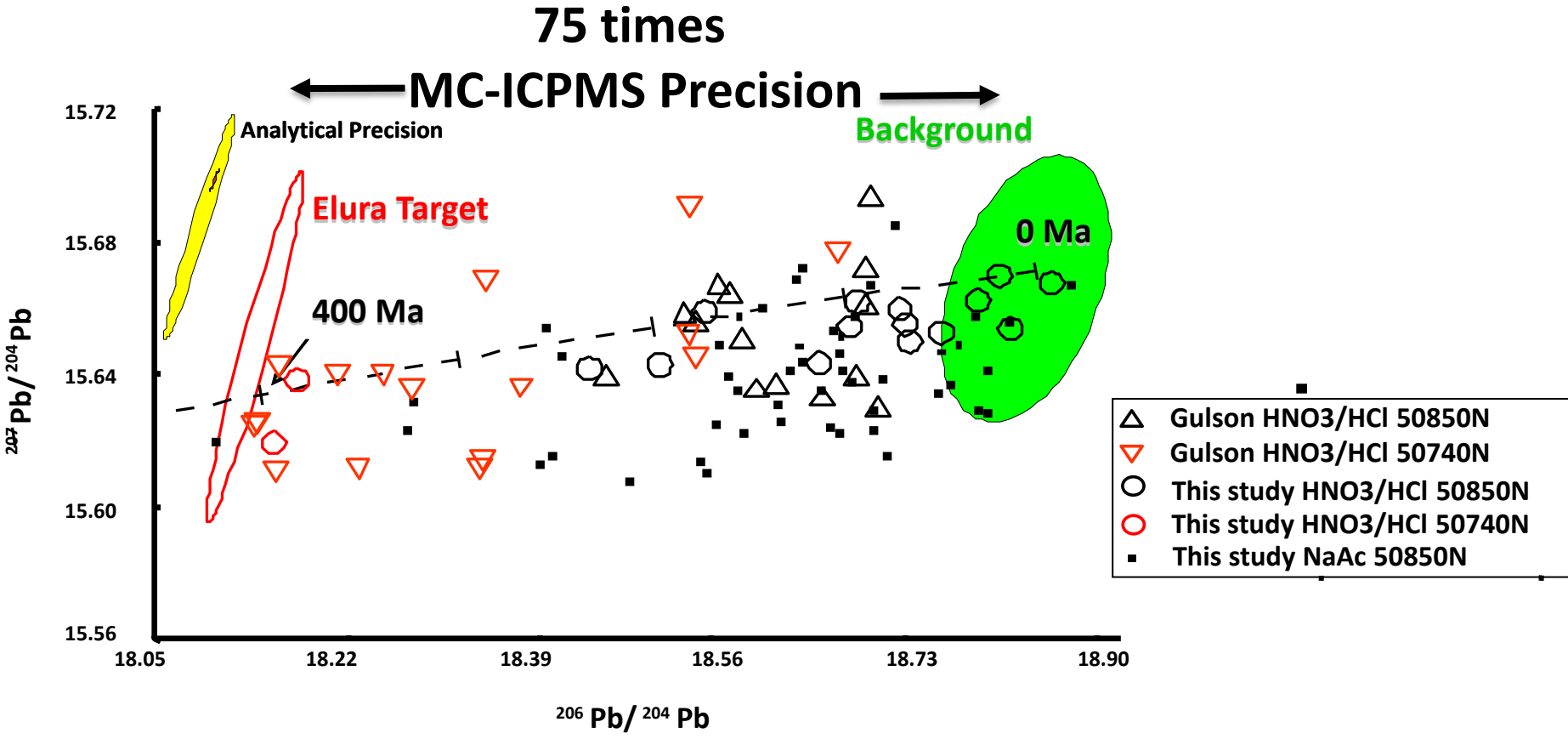
Background Populations Archaean



Background Populations Proterozoic



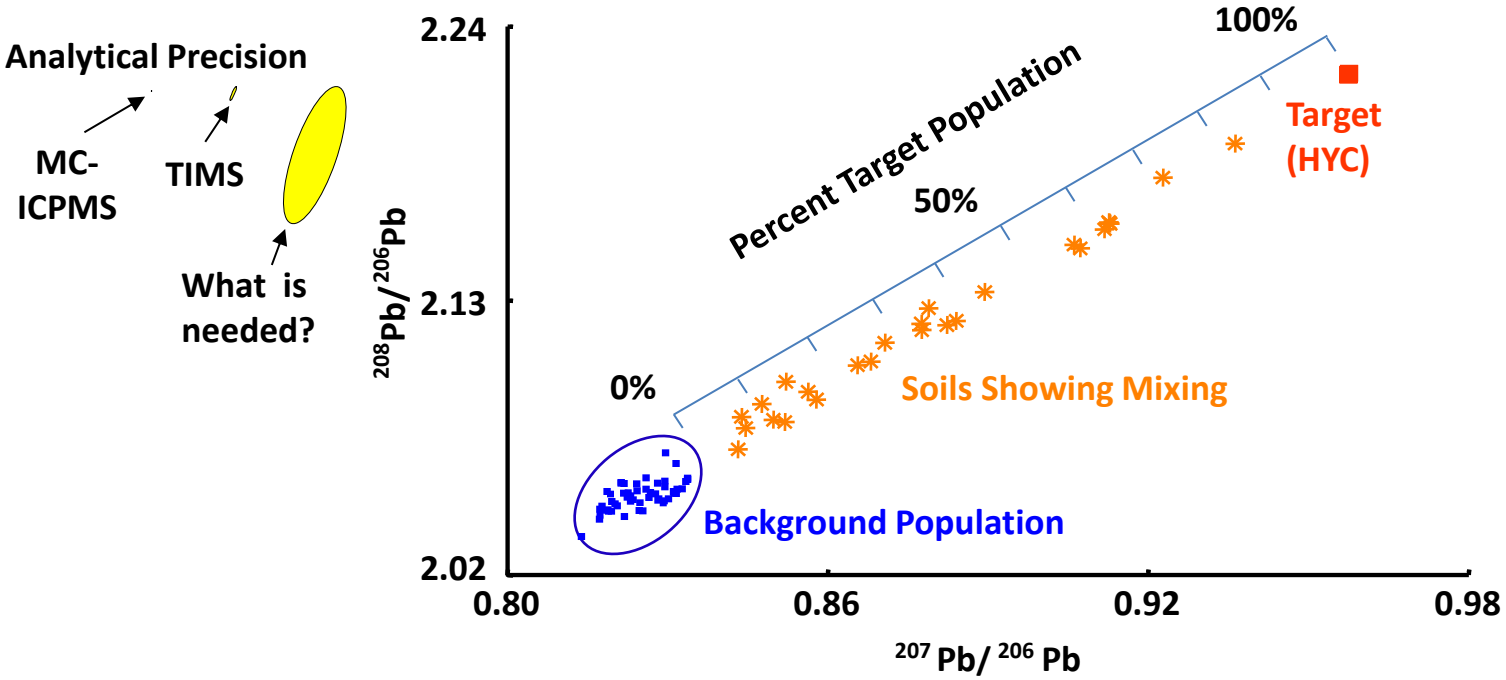
Background Populations Palaeozoic



Analytical Precision

- MC-ICPMS 16.935+/-0.006 (+/- 0.035%)
- Conv. TIMS 16.929+/-0.023 (+/- 0.14%)
- HR-ICPMS 16.806+/-0.044 (+/- 0.26%)
- Quad-ICPMS ?????? (but probably ~ 0.5%)

How Much precision do we need?



Precision of 1% would represent:

- 2.5% of the total expected range of data for Archaean soils,
- 5% of the total expected range for Proterozoic soils,
- 17% of the total expected range for Palaeozoic soils.

Pb Isotopes – What we need to do

- **To develop a robust exploration technology we need to:**
  - **Reduce cost of analyses – very large datasets with lower precision rather than small datasets with high precision , <$50 per sample**
  - **Undertake case histories to validate the technique in greenfields terrains – minimal to no drilling – no mining.**