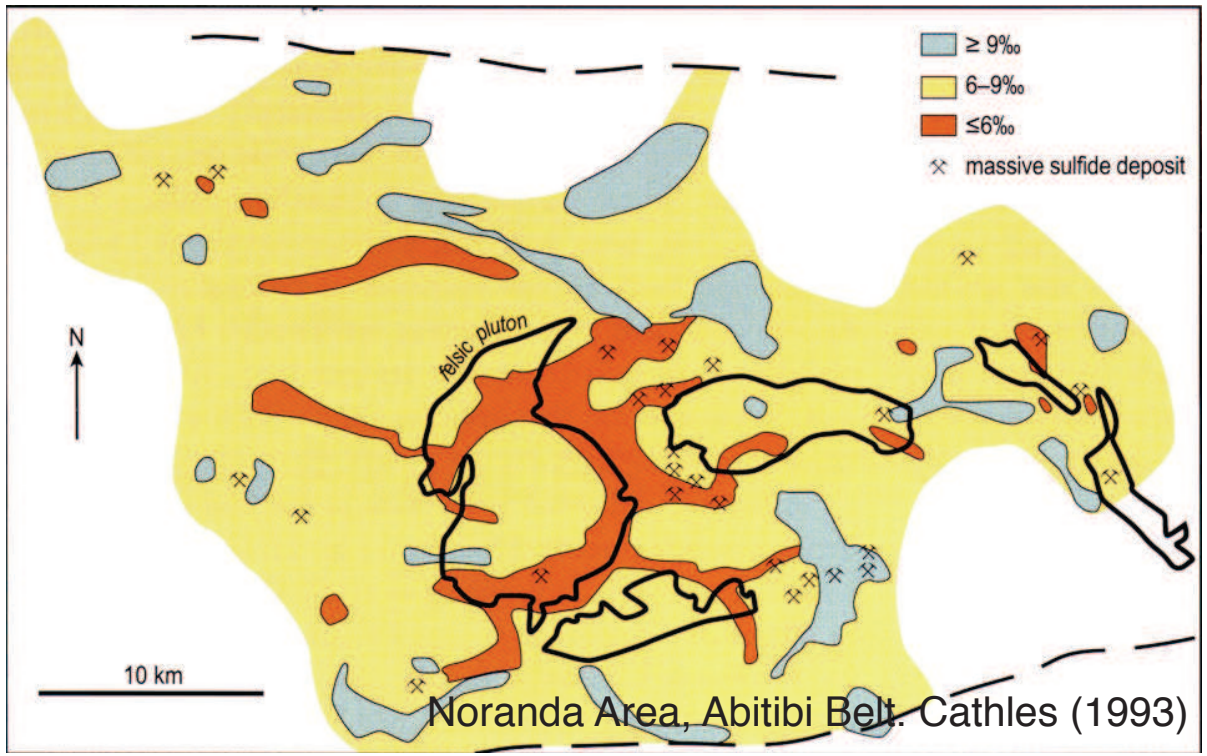
Teaching an old dog new tricks: Stable isotopes in mineral exploration



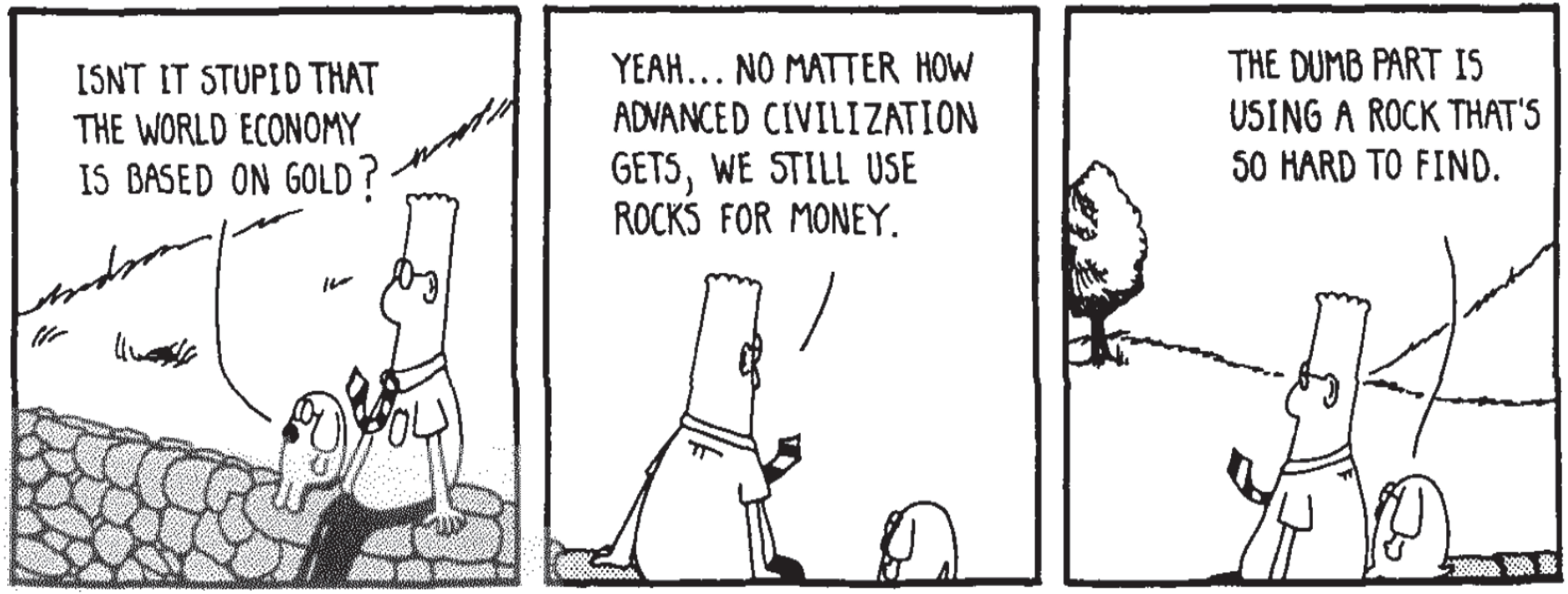
Noranda Area, Abitibi Belt. Cathles (1993)

MDRU
Mineral Deposit Research Unit

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

ALS Minerals

Shaun Barker, Department of Earth and Ocean Sciences, University of Waikato, New Zealand and Mineral Deposit Research Unit, UBC e-mail: sbarker@waikato.ac.nz



Dilbert, Nov 4, 1989

Summary

- Stable isotope alteration haloes are real
- Isotope alteration haloes well outside traditional alteration vectors, providing larger targets and vectors to ore
- Now have a tool for the job - mineral industry relevant and accessible via ALS Minerals - **tick the assay form**!
- Potential exploration impacts:
    - Near miss?
    - Target ranking (e.g. bigger halo = bigger hydrothermal system = more fluid = more ore)?
    - Ground sterilization?
    - Vectoring up fluid pathways towards ore?

Acknowledgements

- With many thanks to many contributors:
  - ★ Greg Dipple, Craig Hart, Ken Hickey - MDRU
  - ★ Will Lepore - MDRU and Pilot Gold
  - ★ Jeremy Vaughan - MDRU and Barrick Gold Corp
  - ★ Paul Dobak - Barrick Gold Corp

Distal Alteration Footprints

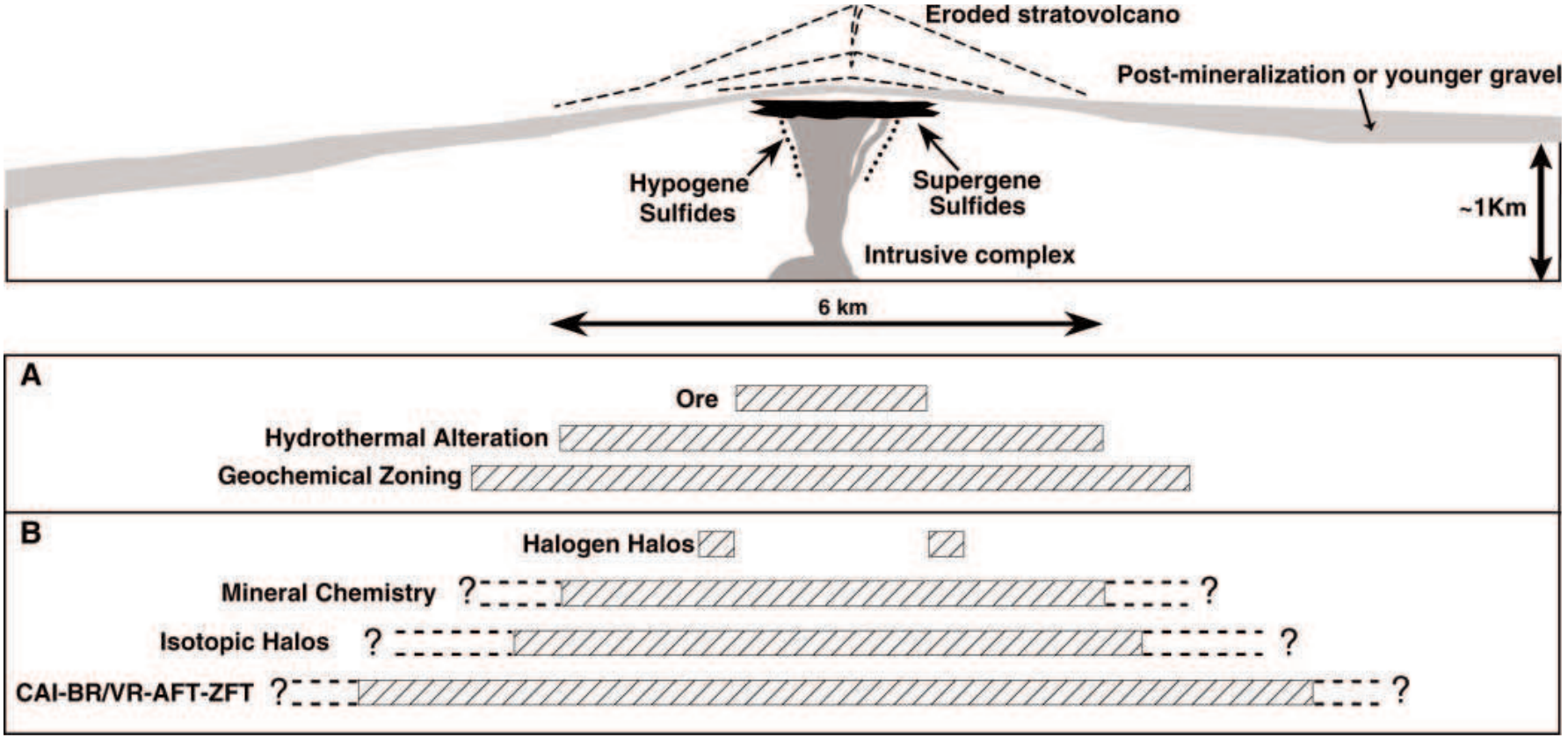


FIG. 1. Schematic cross section through a typical porphyry copper deposit showing (A) common primary features that may be identified within the obvious limits of mineral deposits and (B) primary far field features discussed in the text. Horizontal bars show spatial distributions, which are poorly constrained for far field features. AFT = apatite fission track, BR = bitumen reflectance, CAI = conodont color alteration index, VR = vitrinite reflectance, ZFT = zircon fission track.

Kelley et al, 2006, Econ. Geol.

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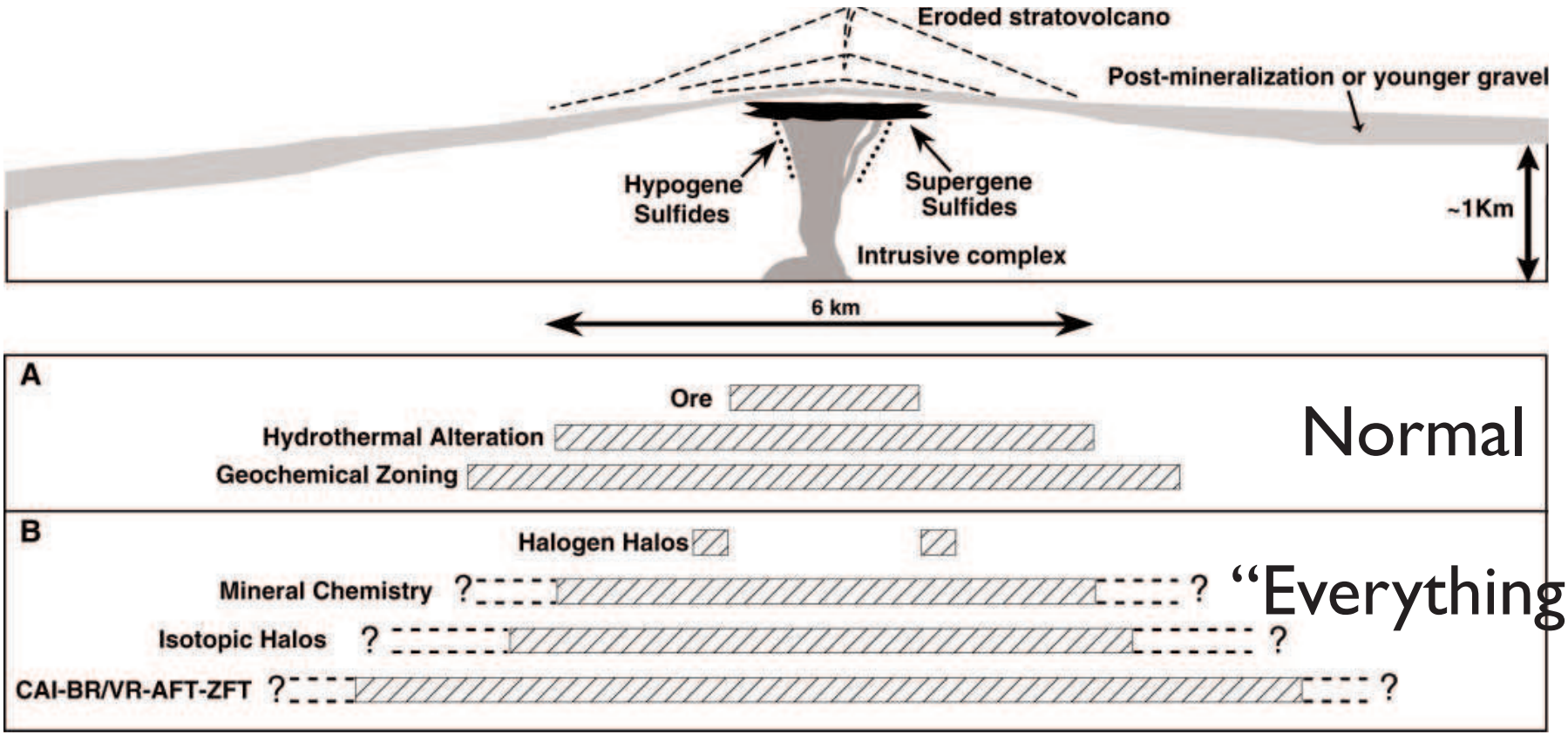
Distal Alteration Footprints



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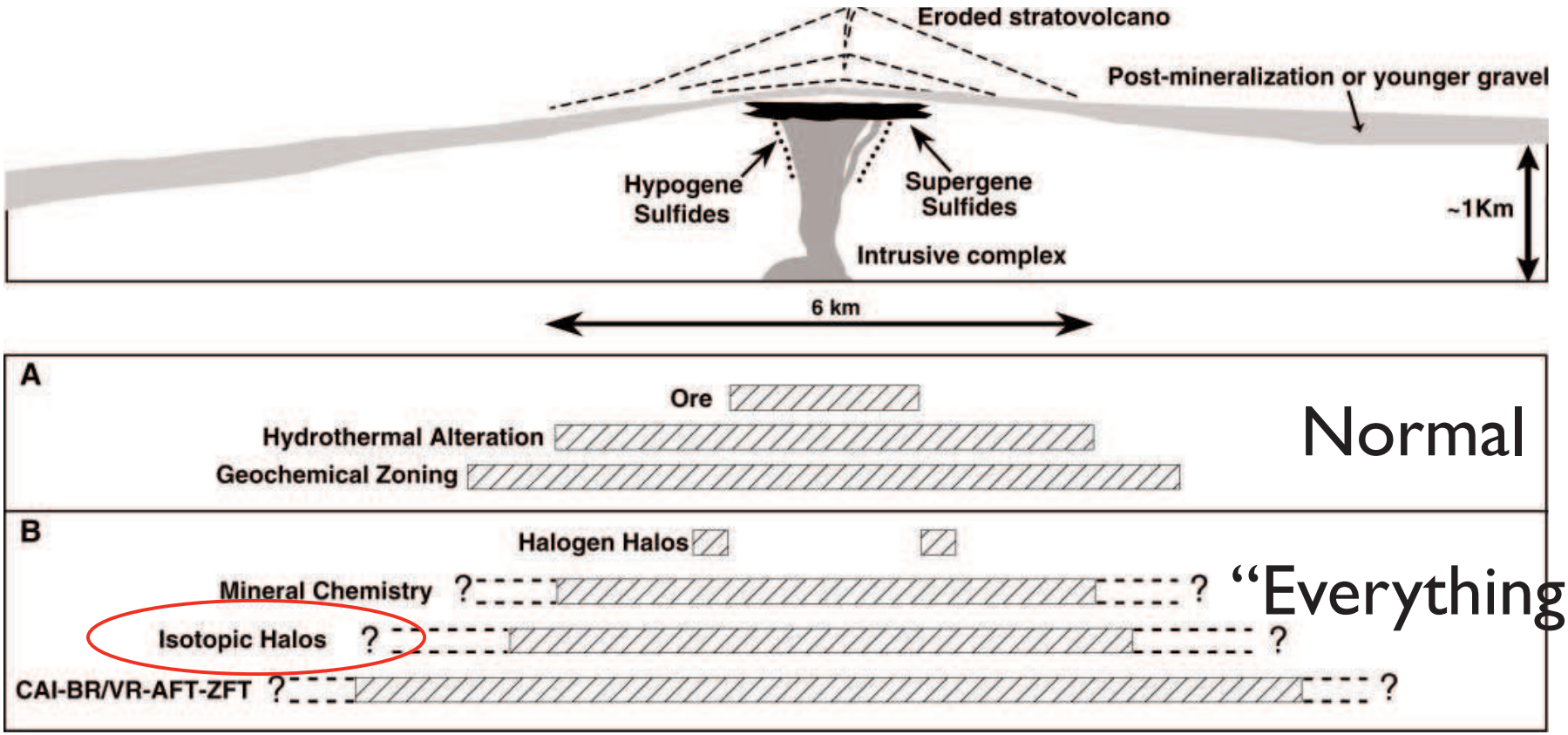
Distal Alteration Footprints



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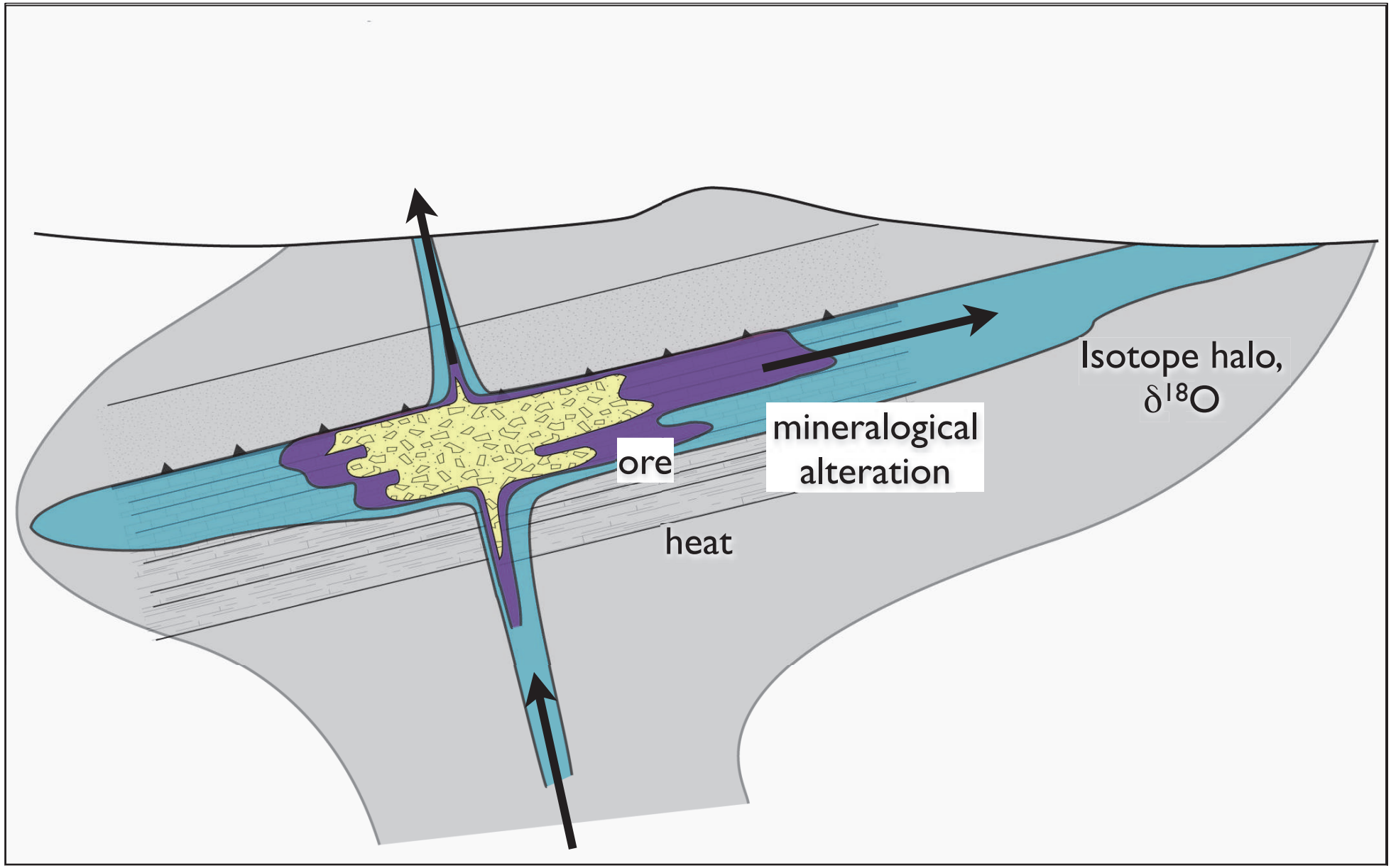
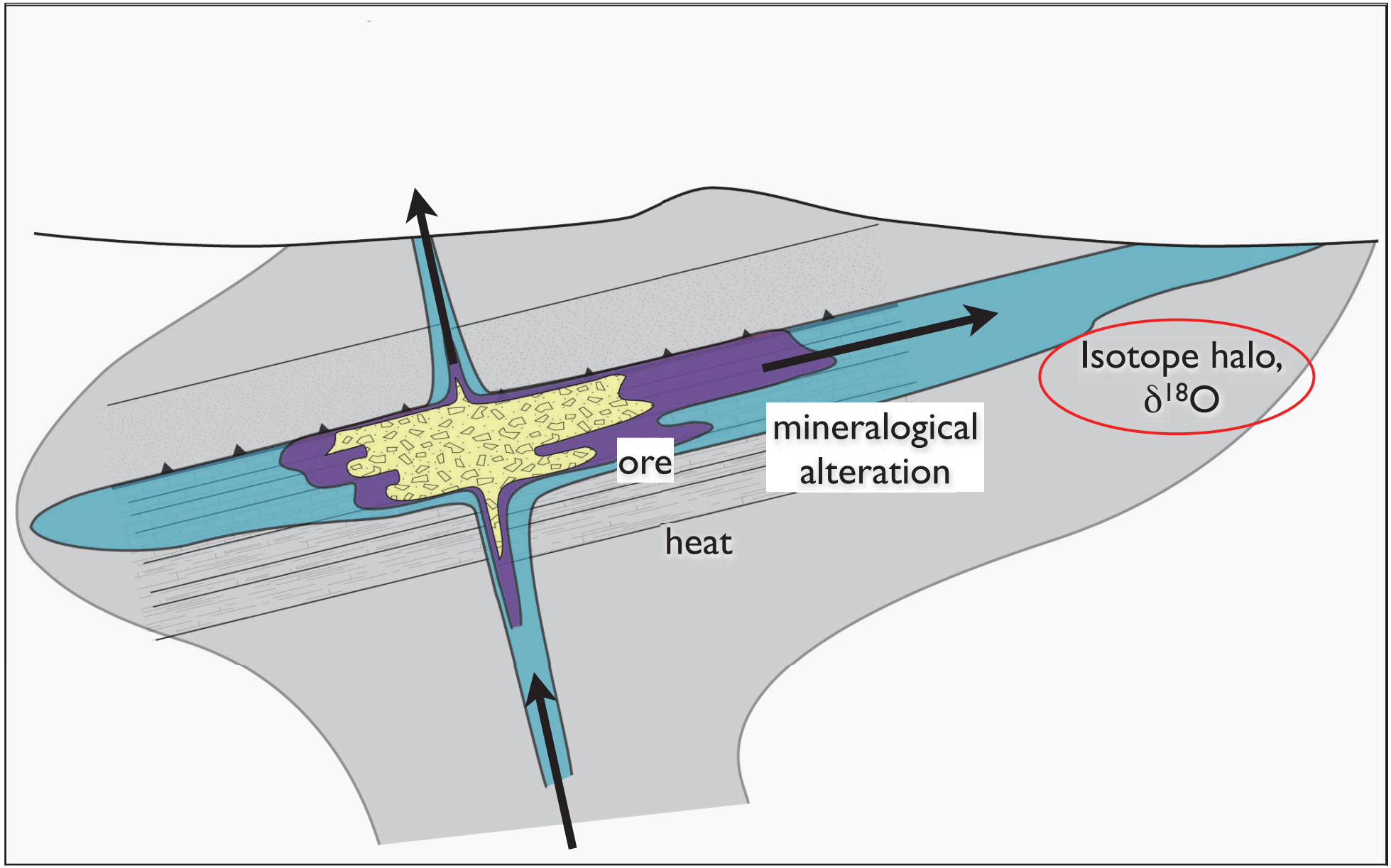
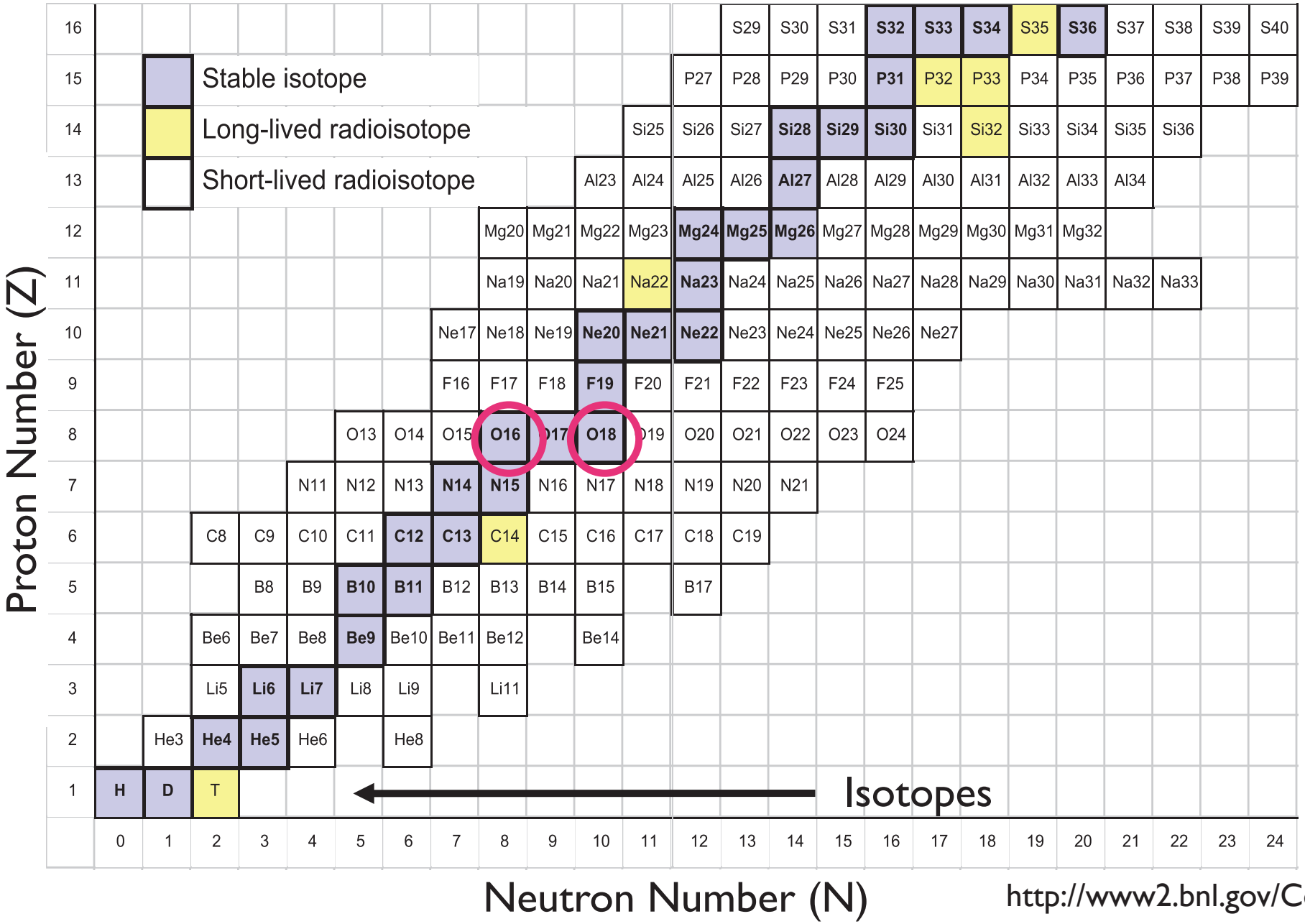
Haloes and vectoring



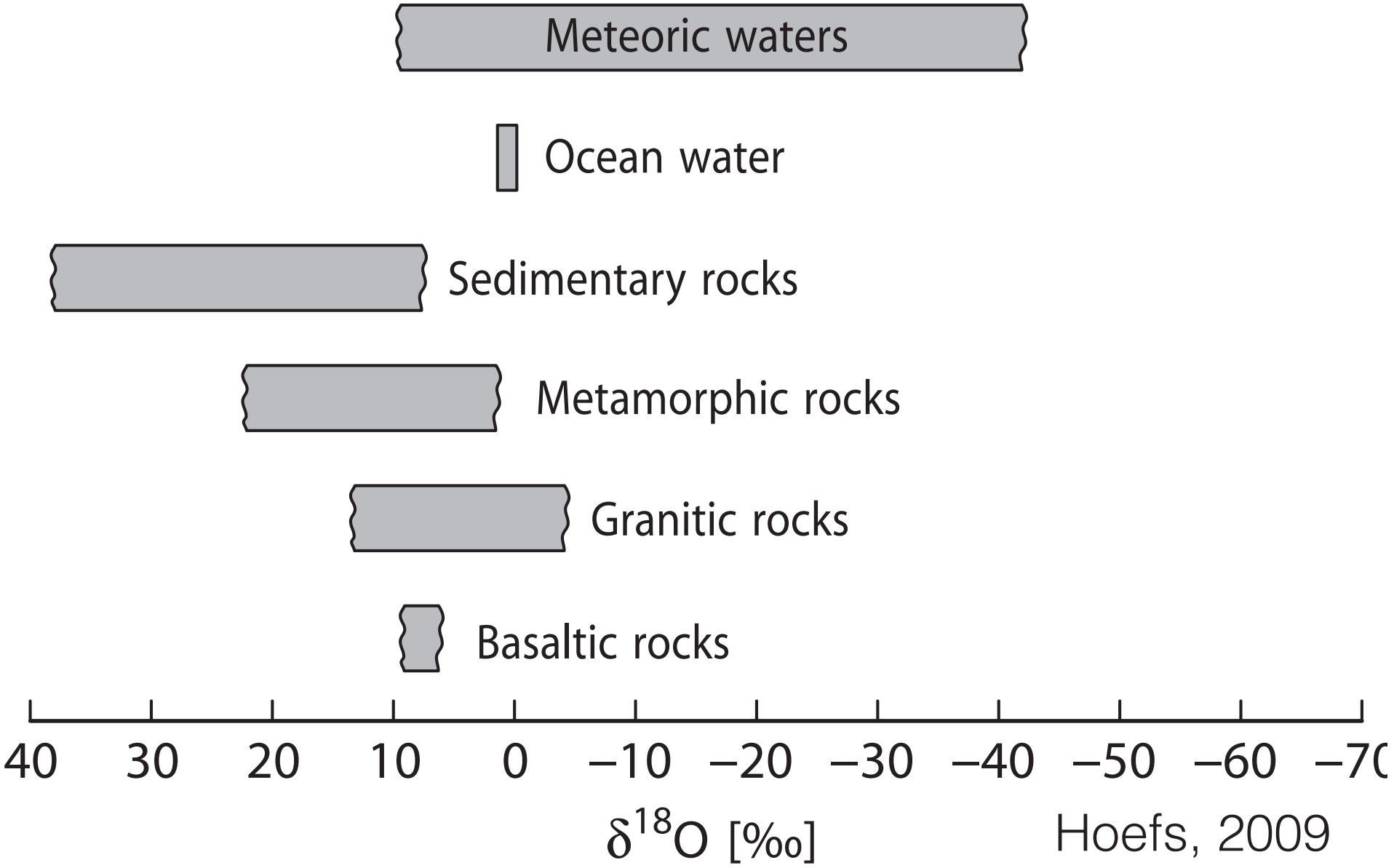
Haloes and vectoring



What are isotopes?



$\delta^{18}O$ for Earth Materials



What isotope systems?

- Most hydrothermal fluids are very water (H_2O) rich, so hydrogen and water should have most significant isotopic alteration
- Carbon and sulfur may capture important redox gradients (Alkalic porphyries - Dave Cooke and coworkers, Orogenic gold - John Walshe)

Epithermal Au-Ag

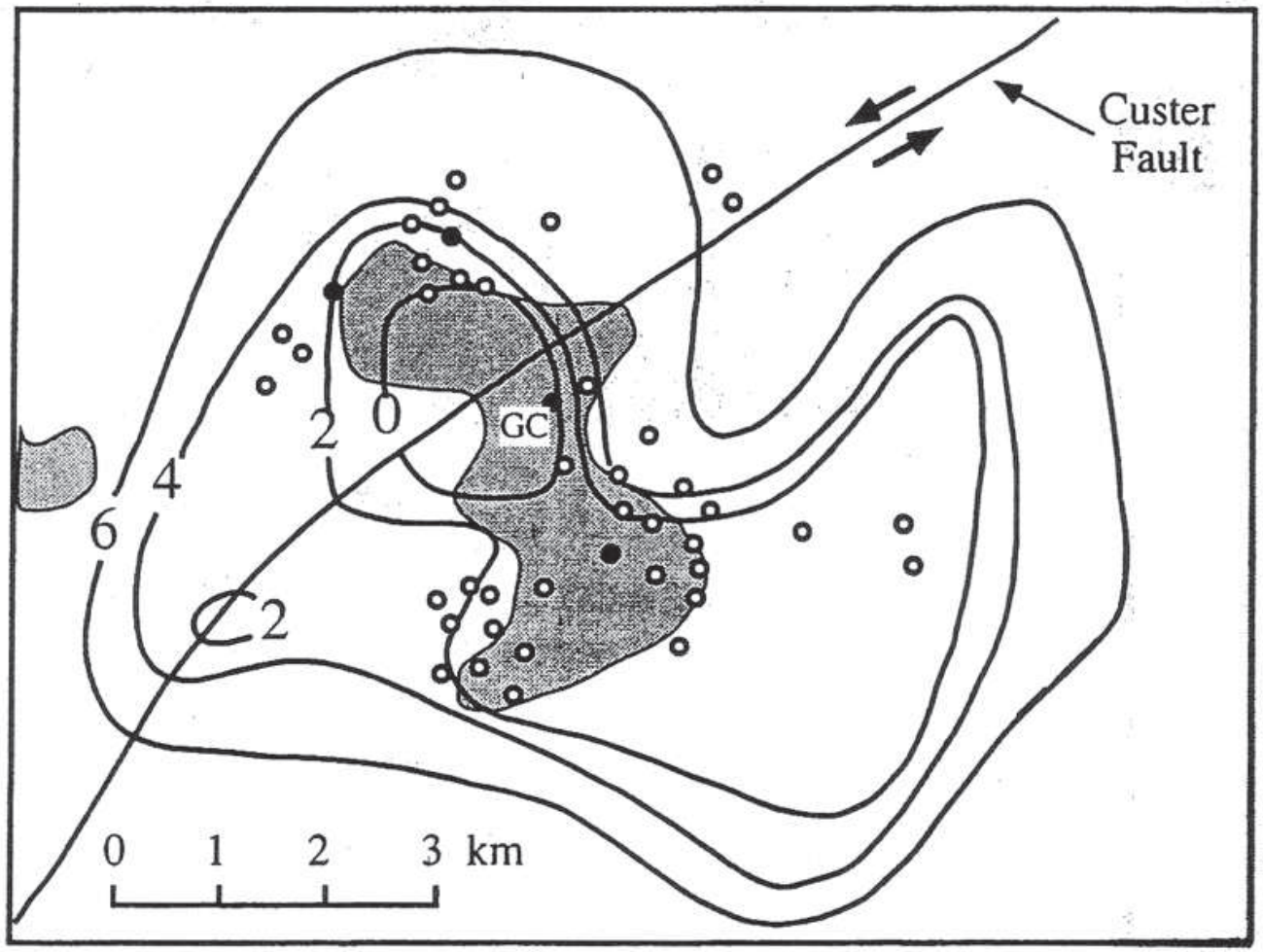


FIGURE 1. *Location of sites of mineralization in the Yankee Fork district, Idaho, relative to ^{18}O depletion halos (contoured in $\partial^{18}O$ values relative to SMOW) and rock magnetization anomalies (gray zones indicate low rock magnetization values). This reconstruction assumes a 2 km left-lateral displacement on the Custer Fault. Filled circles are former producing mines and open circles are other known sites of epithermal mineralization. GC indicates the site of the General Custer mine. (From Criss et al., 1985).*

Criss et al, 1985

Kilometer-scale ^{18}O halo to the General Custer Mine.

Epithermal Au-Ag

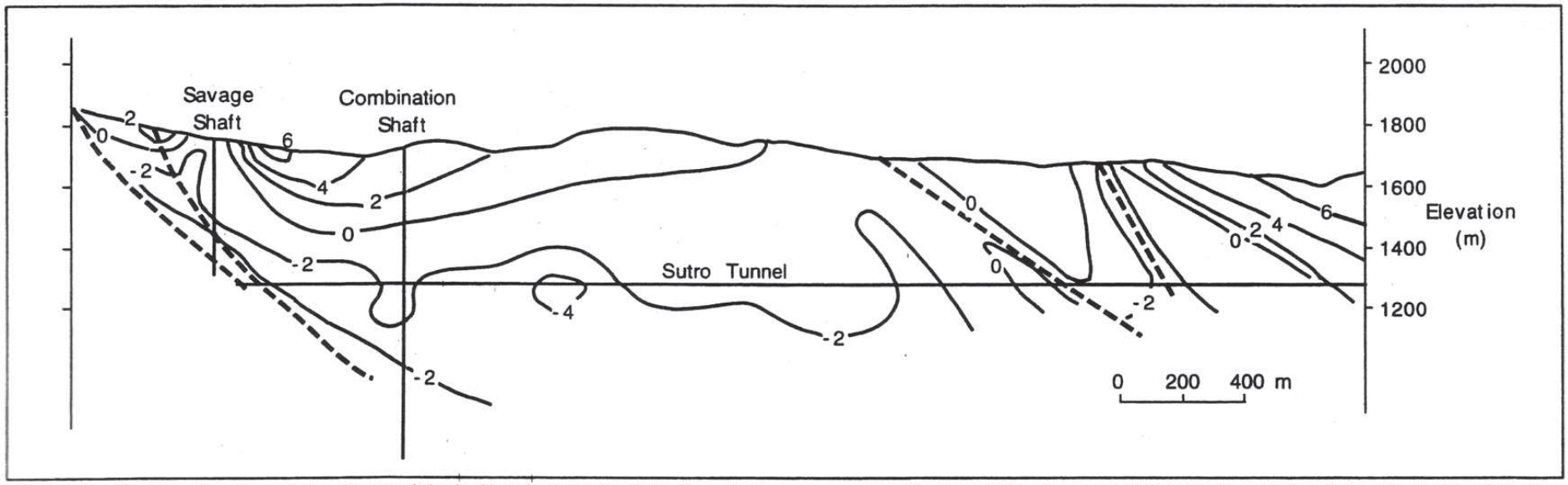


FIGURE 2. *Cross section through the Comstock Lode, Nevada along the Sutro Tunnel. Contours are of ∂¹⁸O values. Note close association of mineralization (heavy dashed lines) to sharp gradients in ∂¹⁸O values. (From Criss and Champion, 1991).*

Mineralization in Comstock Lode coincident with steep gradients in ^{18}O-depletion.

Epithermal Au-Ag

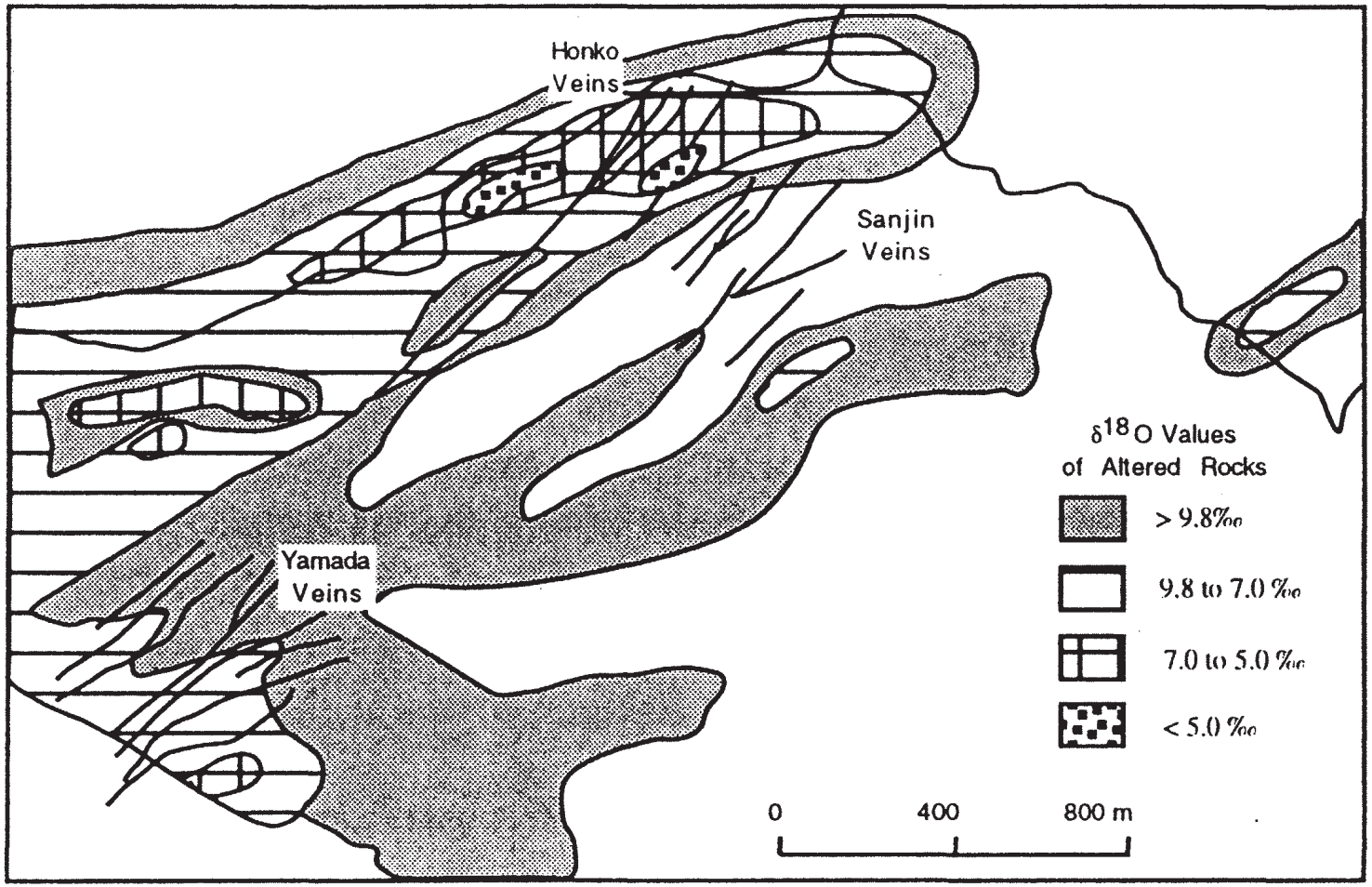
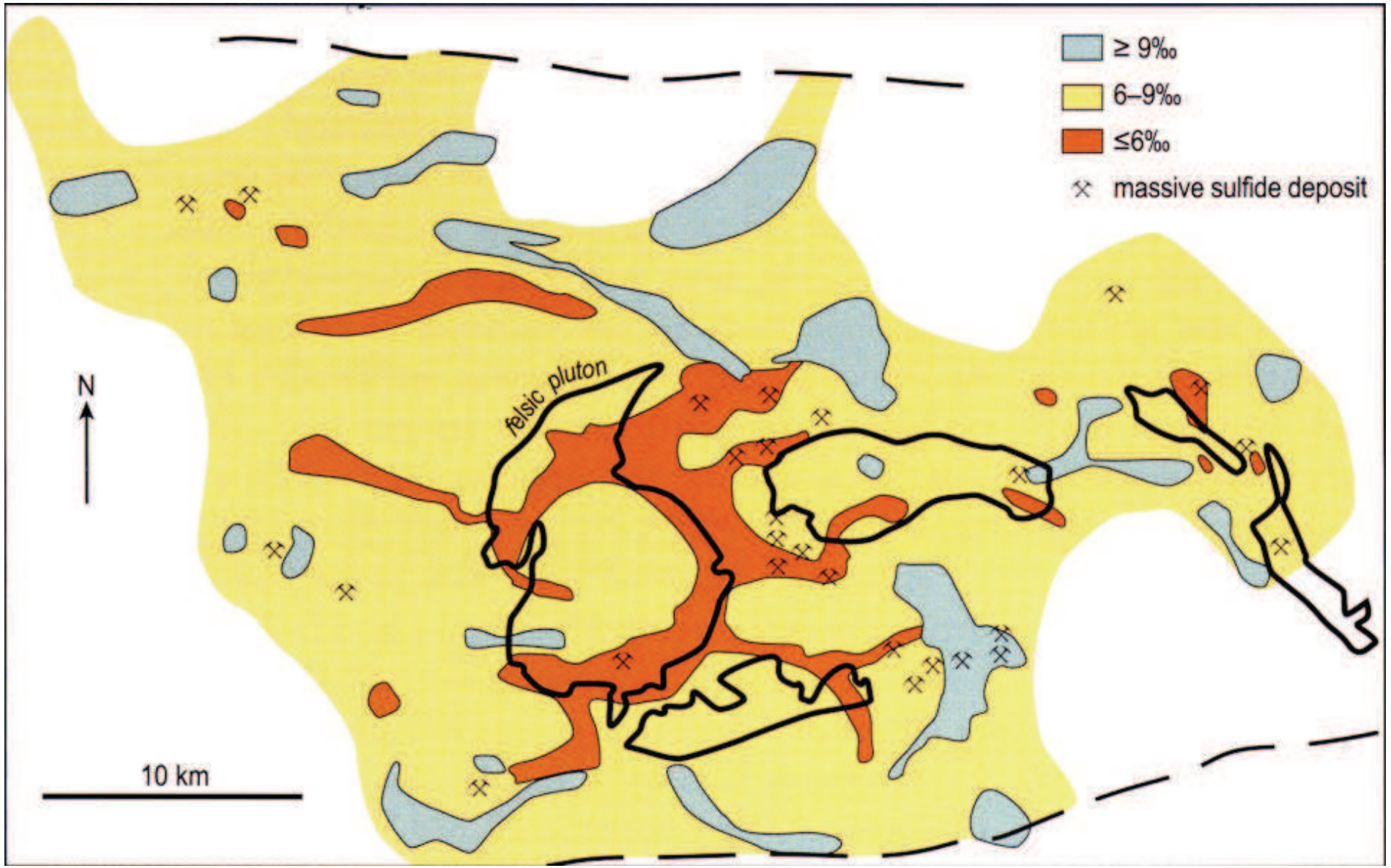


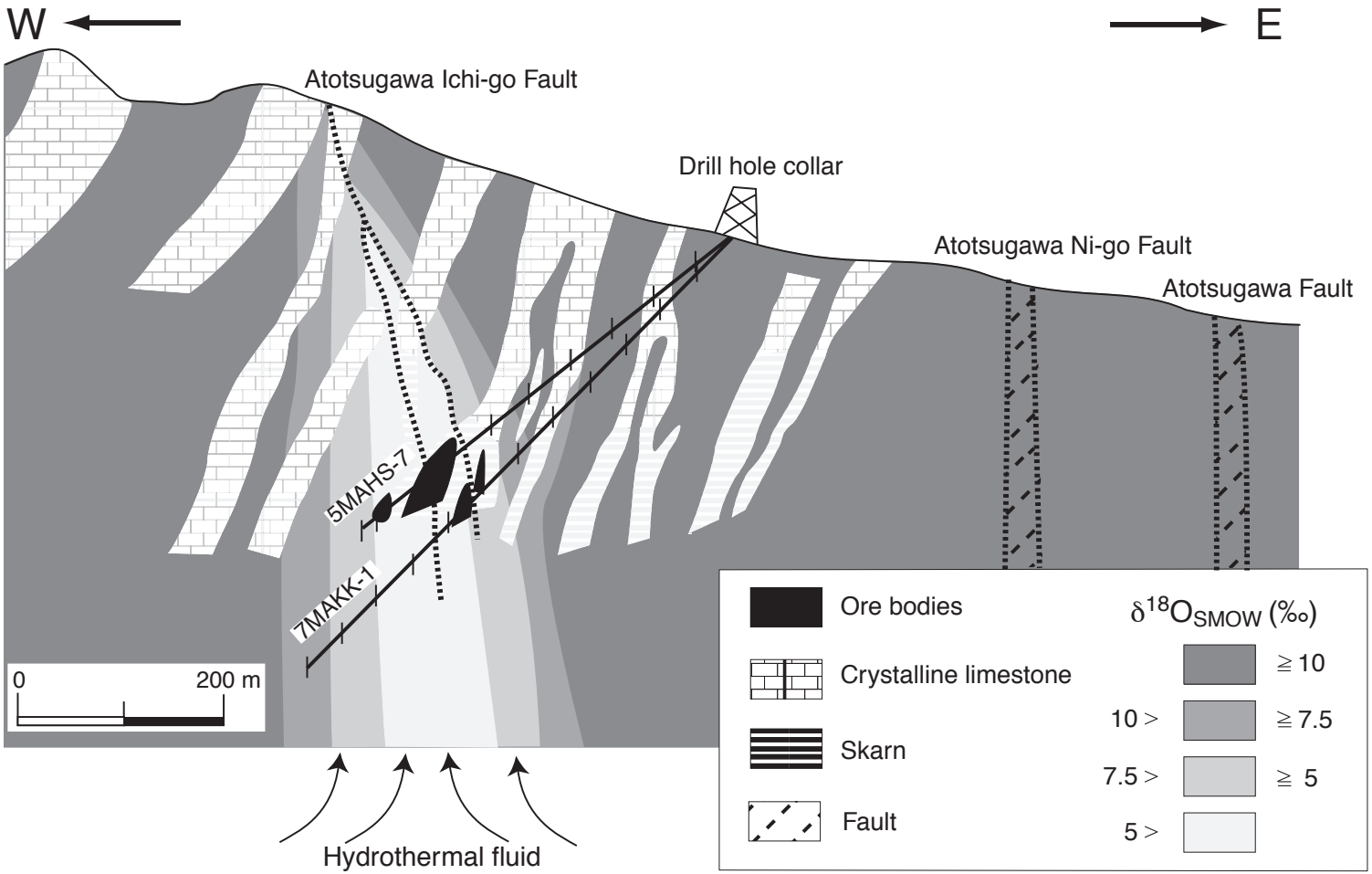
FIGURE 3. *Contours of ∂18O values around the epithermal Hishikari Au mine, Kyushu Island, Japan. Note close spacing of contours around mineralization (From Naito et al., 1993).*

VHMS Systems



Noranda Area, Abitibi Belt. Cathles (1993)

Carbonate-hosted Pb-Zn



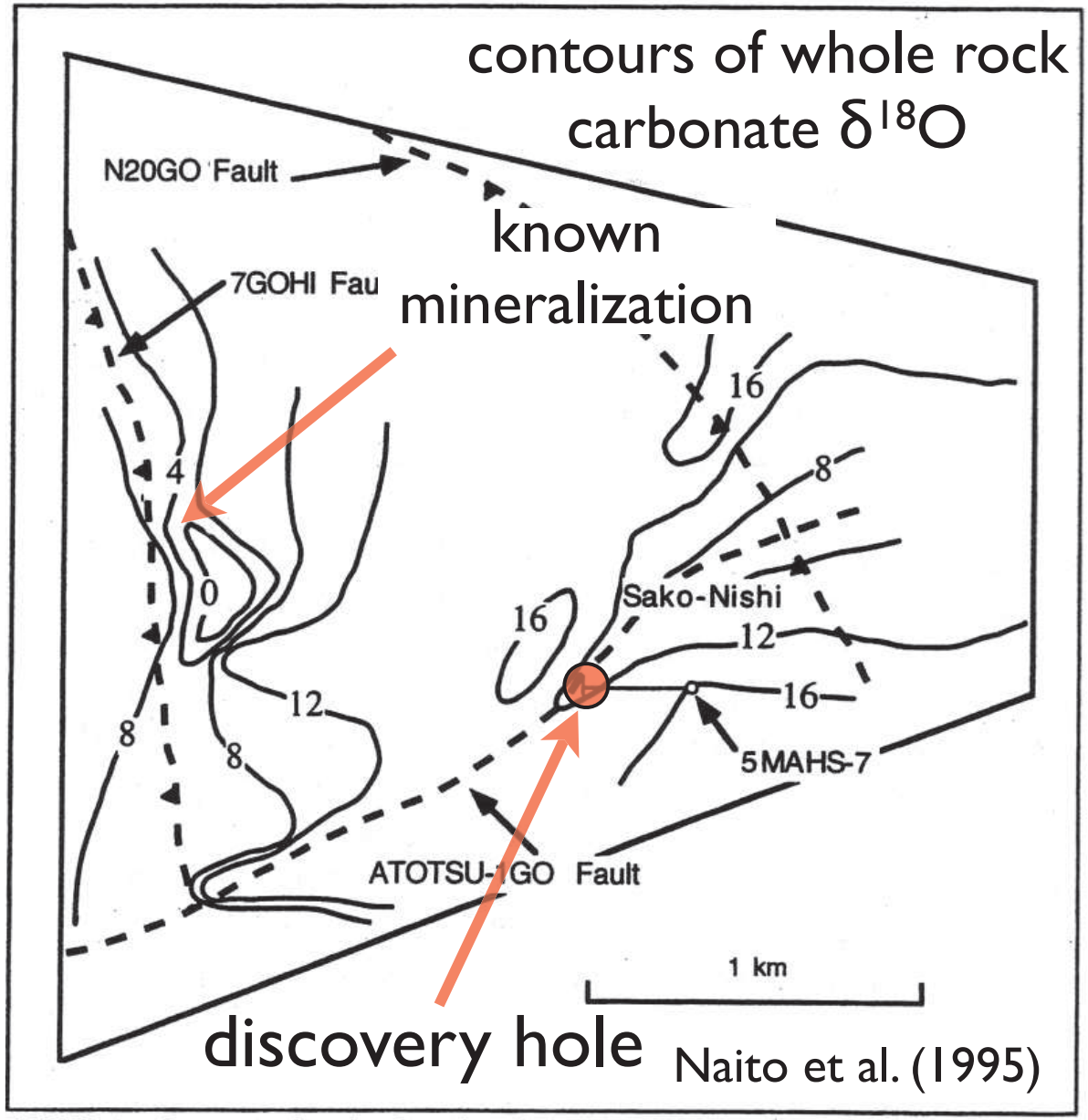
Morishita, 1991, Resource Geology

Fig. 13 Schematic profile with drill holes 5MAHS-7 and 7MAKK-1 in the Sakonishi area.

Carbonate-hosted ore deposits

- Carbonate-hosted ore bodies often have subtle visual and lithogeochemical alteration
- Carbonate-hosted ore deposits are particularly suited for isotopic analysis - large signals, easiest analytical approach

Pb-Zn-Ag Skarn, Kamioka, Japan



The old way.....

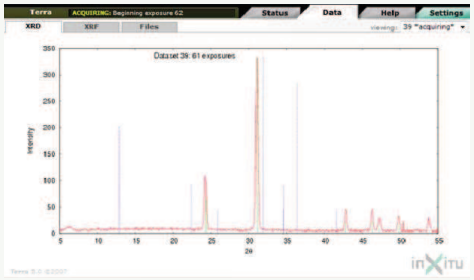
iX-T "Terra"

Portable X-Ray Diffraction & X-Ray Fluorescence

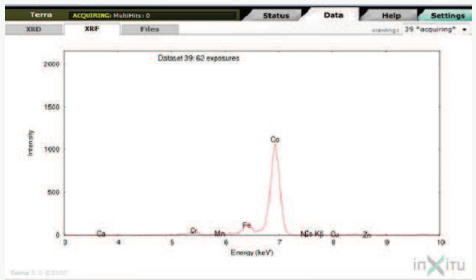
The inXitu iX-T "Terra" is the first truly portable XRD system designed specifically for rock and mineral analysis. Now "field work" can really be done in the field. Terra can be configured with everything you need to acquire and analyze diffraction data in a rugged compact case. With our patented sample handling system not only is sample preparation time minimized but accuracy in peak identification previously only available using laboratory based systems can be achieved.

XRD is the technique of choice for accurate identification of minerals. XRD data from Terra can be readily analyzed using the software of a laboratory XRD instrument, or third party applications like Jade (MDI), XPowder, Match! (Crystal Impact), CrystalSleuth (Univ. of Arizona), etc. Identification of phases also requires the use of a library such as the ICDD Powder Diffraction Files or the American Mineralogist Crystal Structure Databases.

The iX-T "Terra" operates off software embedded in the unit itself. The user accesses the operating system through a wireless connection (802.11 b/g). This unique method of operation allows for a wide degree of flexibility in controlling the instrument and subsequent data handling



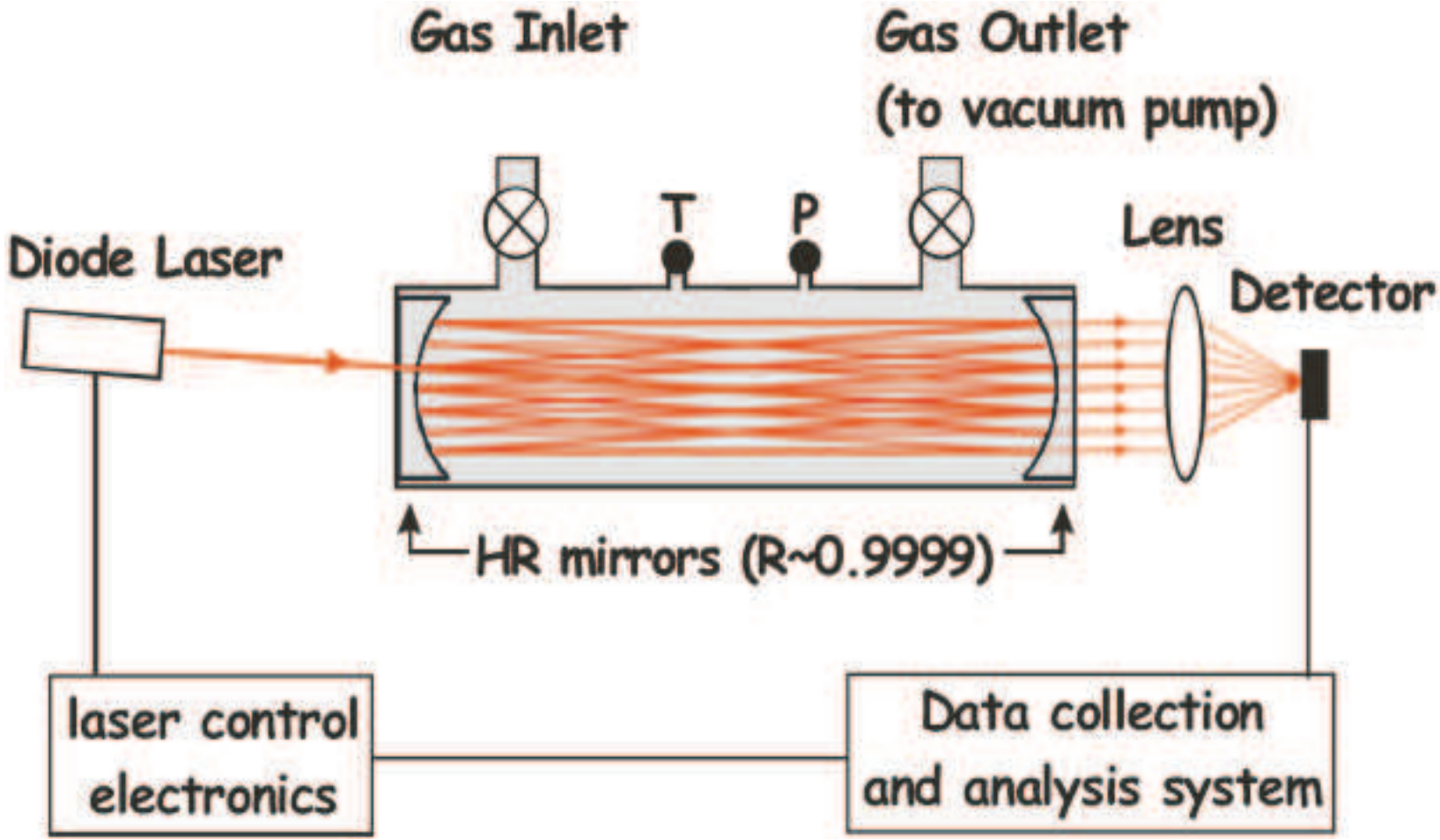
Terra XRD two-theta display

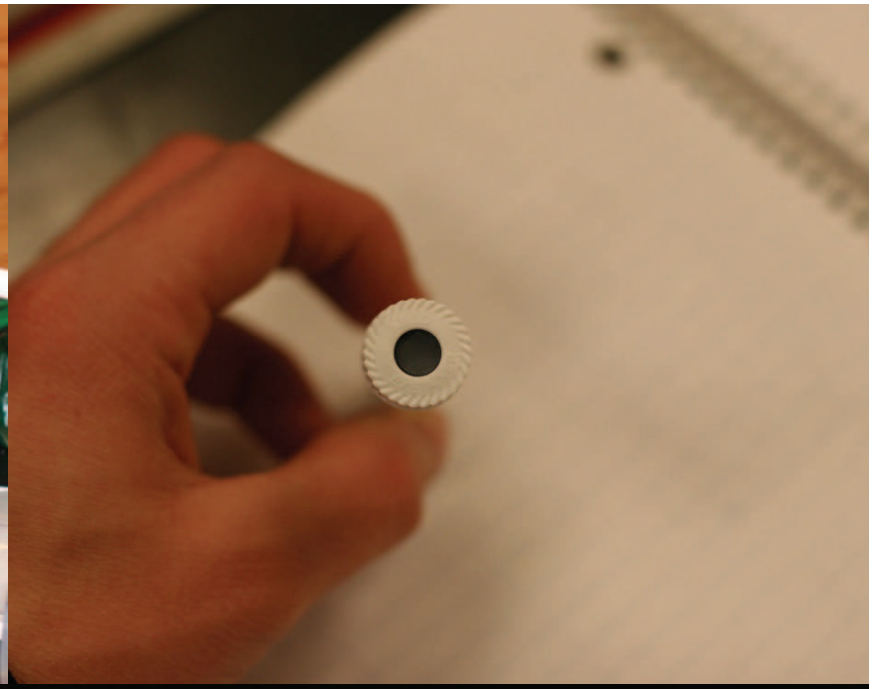


Terra XRF energy spectrum

inXitu Inc. 2251 Casey Ave, Ste A, Mountain View, CA 94043 USA Tel (650) 567 0081 FAX (650) 567 0082
www.inXitu.com email: Sales @inXitu.com

There have been advances in light stable isotope analysis that are based on infrared absorption laser spectroscopy.



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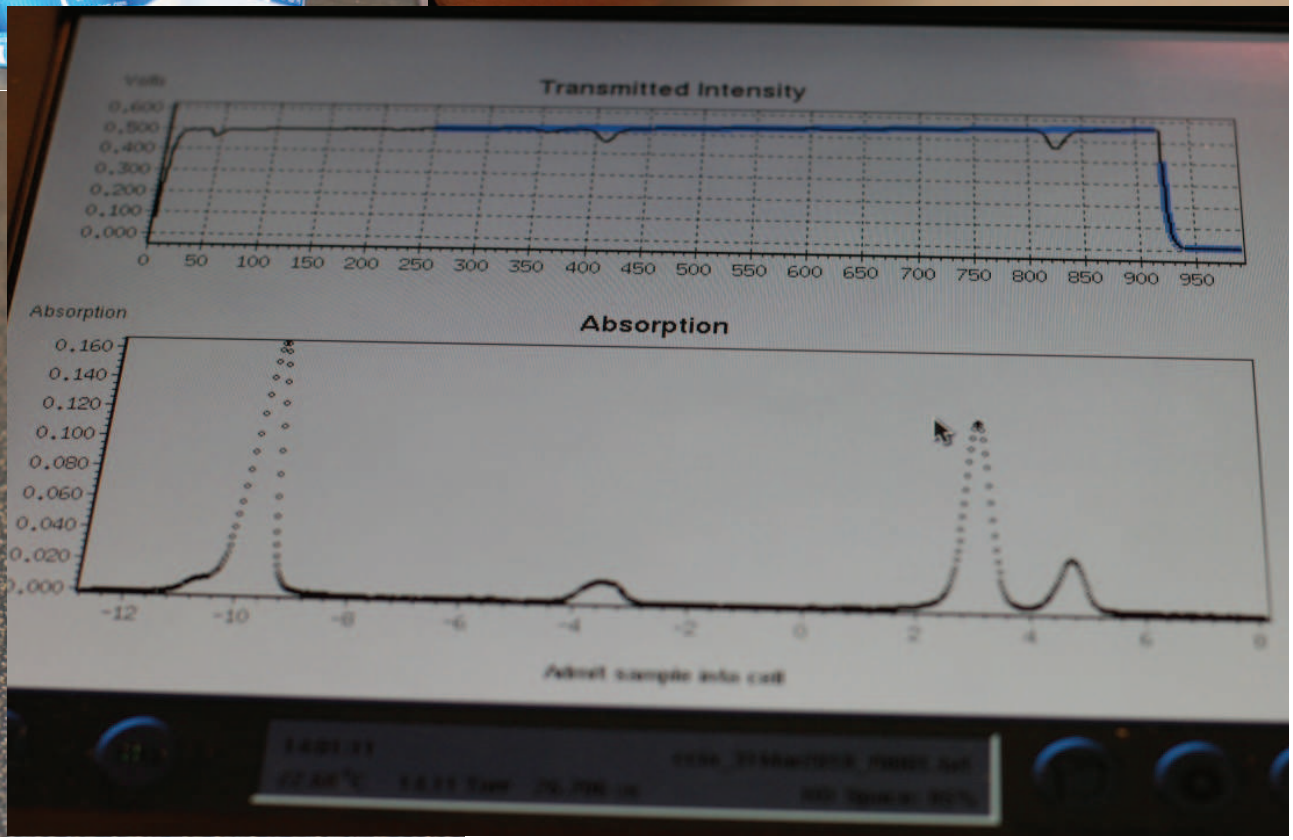
Shift


Transmitted Intensity
Volts
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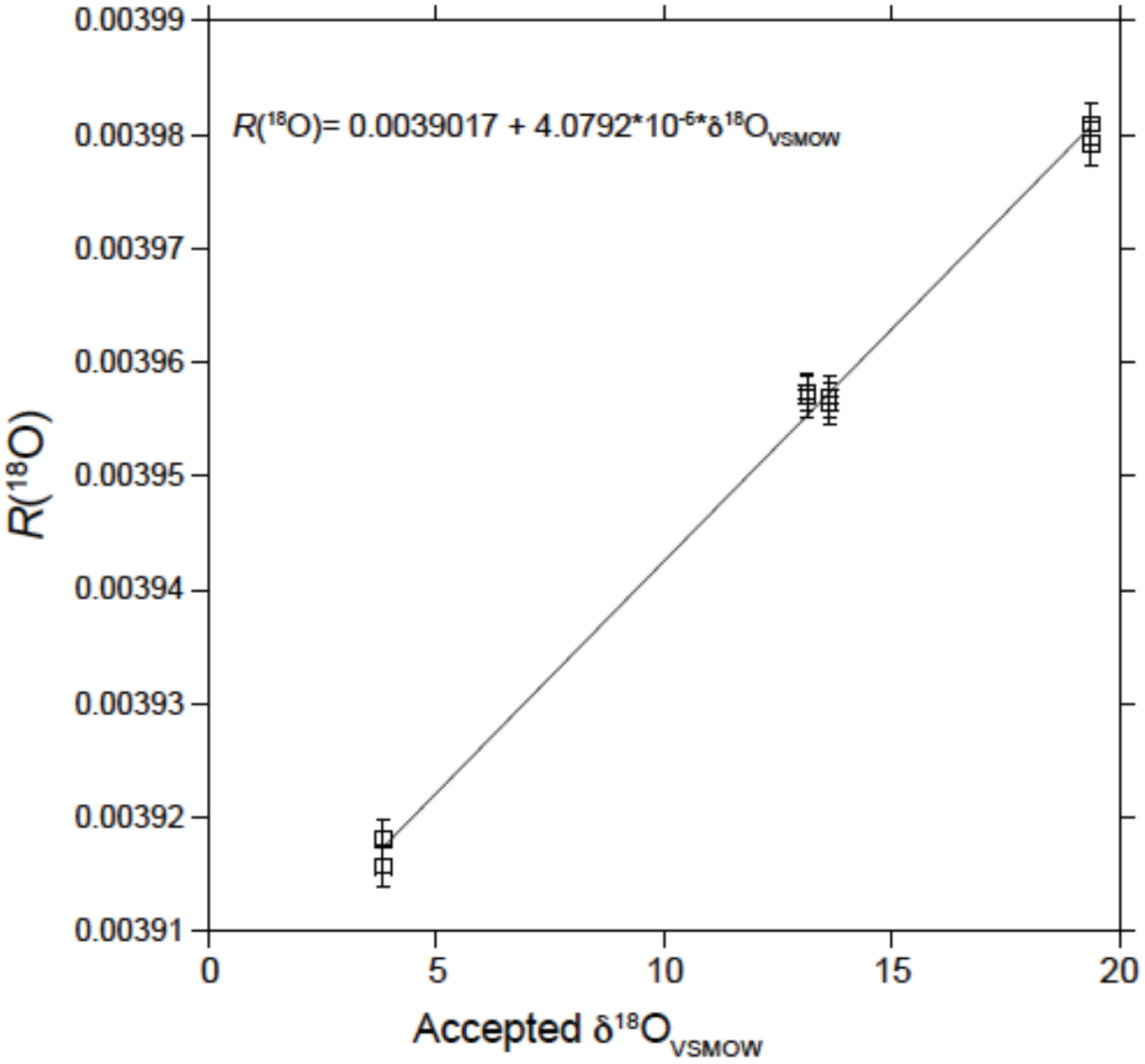
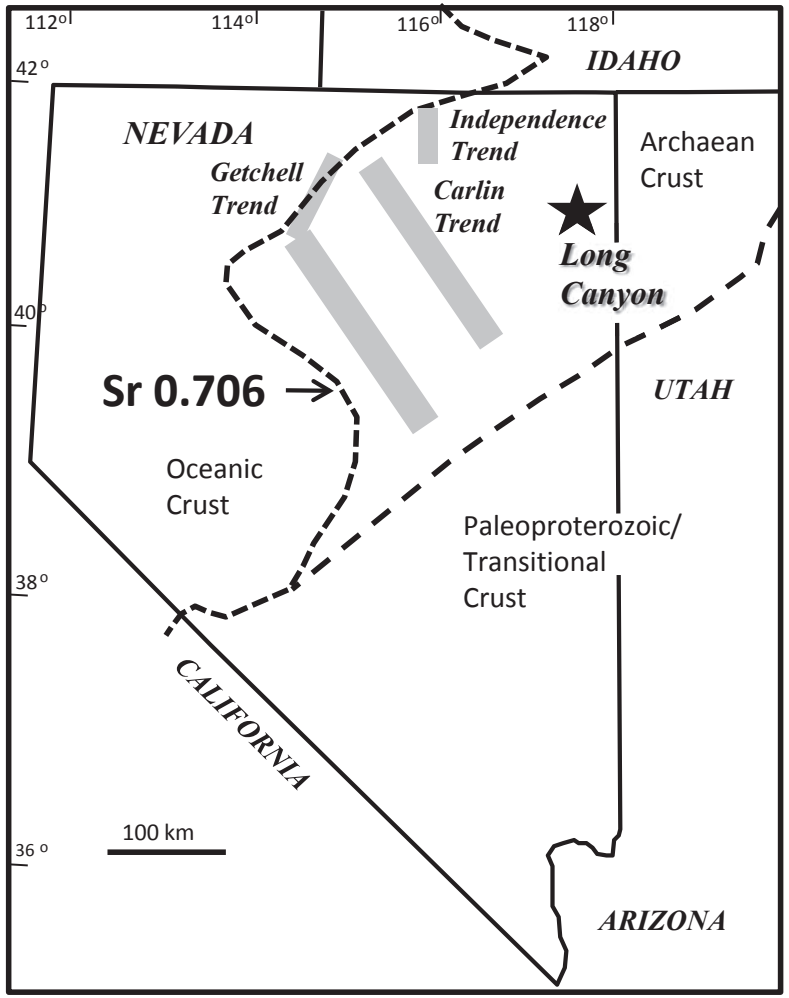
0.500
0.400
0.300
0.200
0.100
0.000
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950
Absorption
Absorption
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-12 -10 -8 -6 -4 -2 0 2 4 6 8
Abort sample into cell



Barker et al, Analytical Chemistry, vol 83, pp 2220-2226

Long Canyon Gold Deposit, Nevada



Carbonate-rock hosted gold deposit

Use of different sampling scales and materials to evaluate hydrothermal fluid flow pathways and alteration haloes

Will Lepore, MSc Thesis, 2012

Hand sampling vs pulps

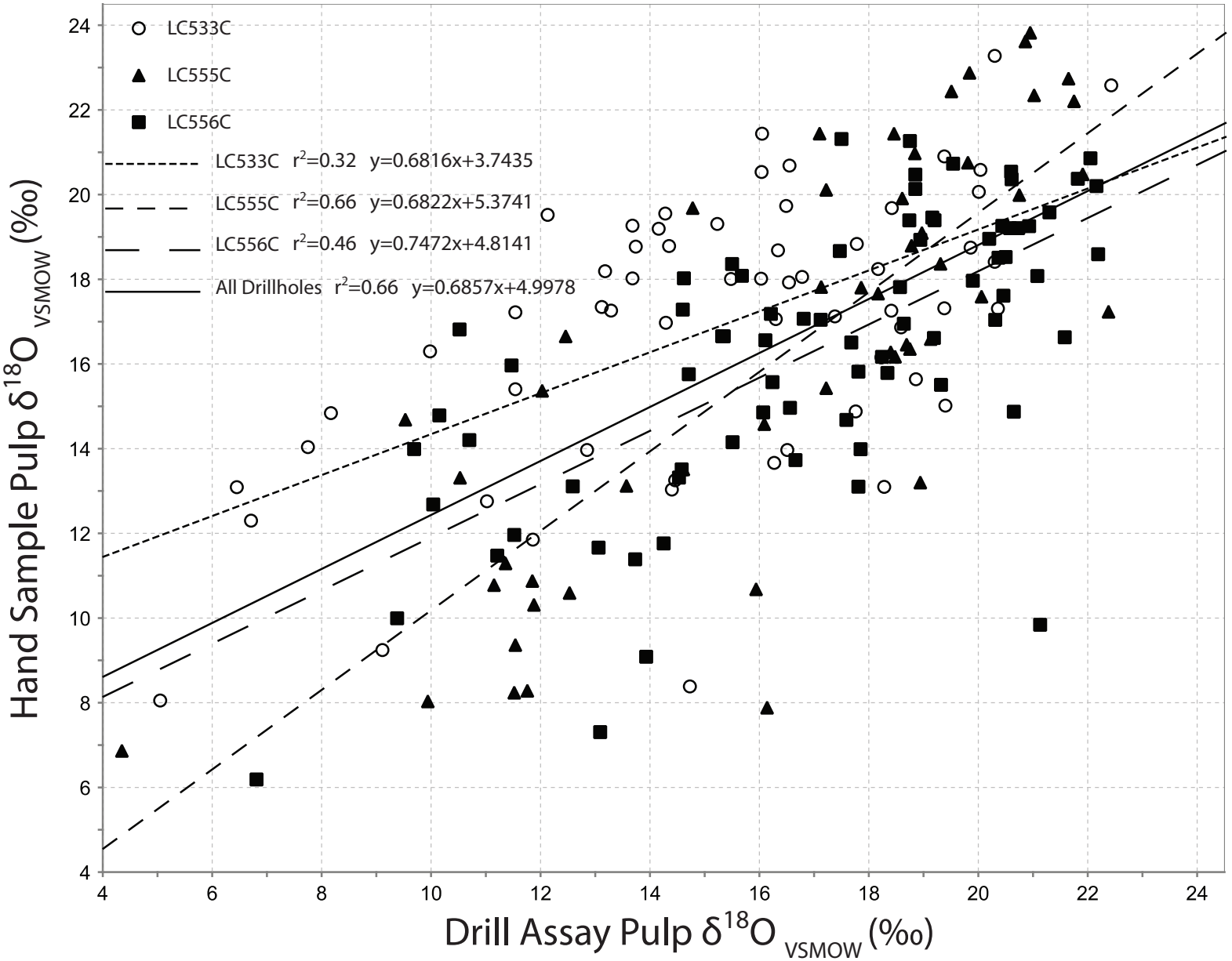
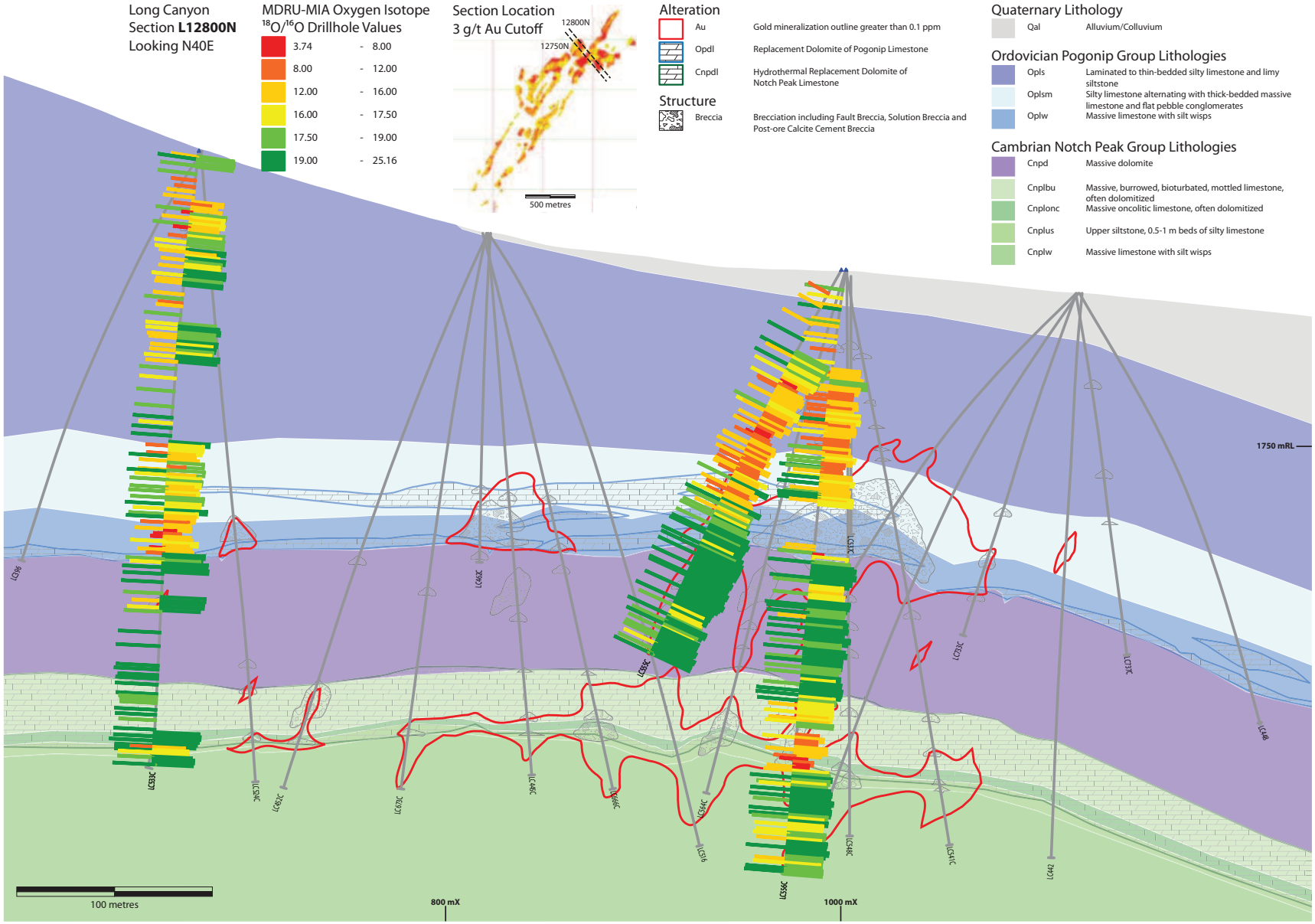
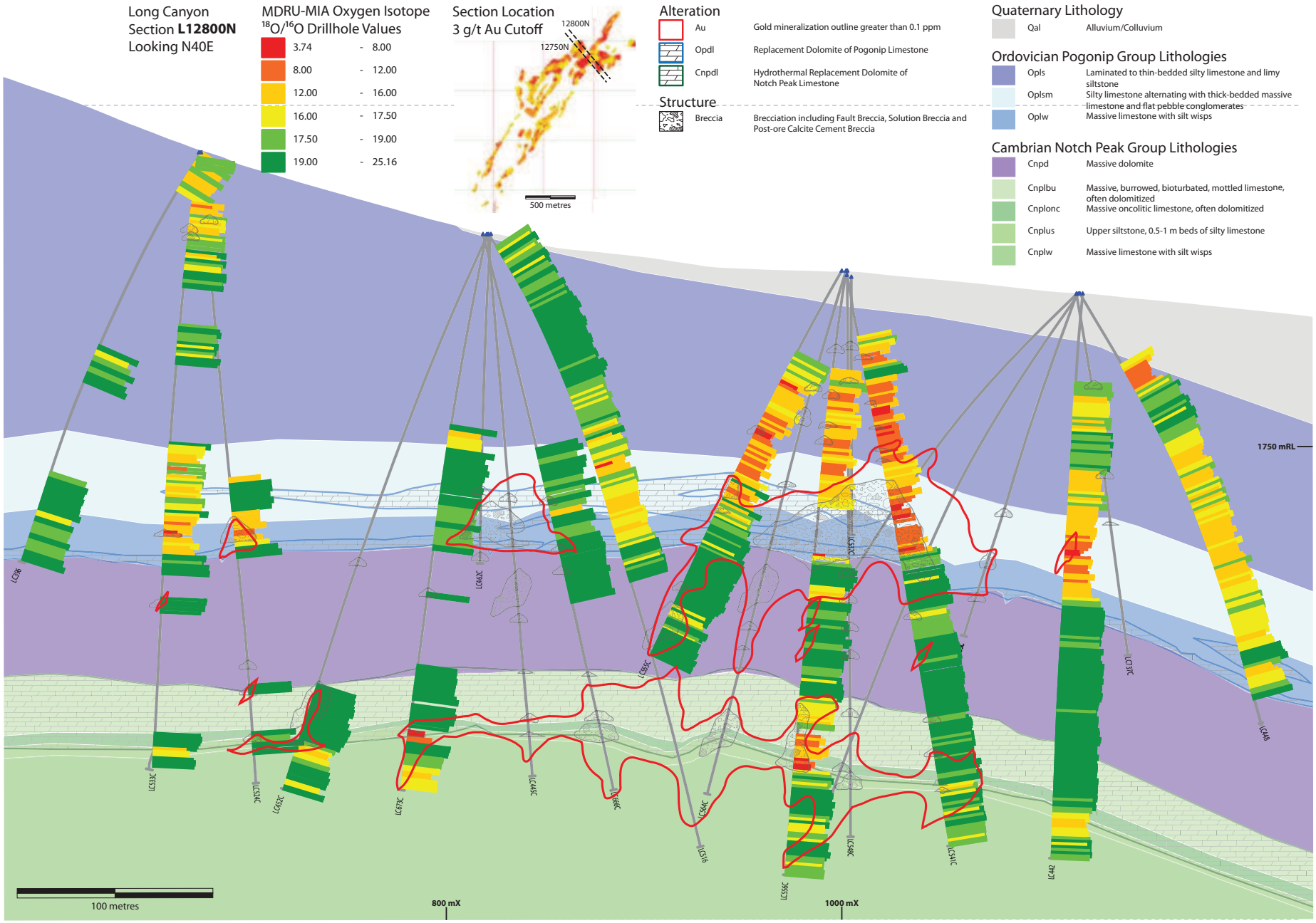


Figure 12800N HandsamplePulp

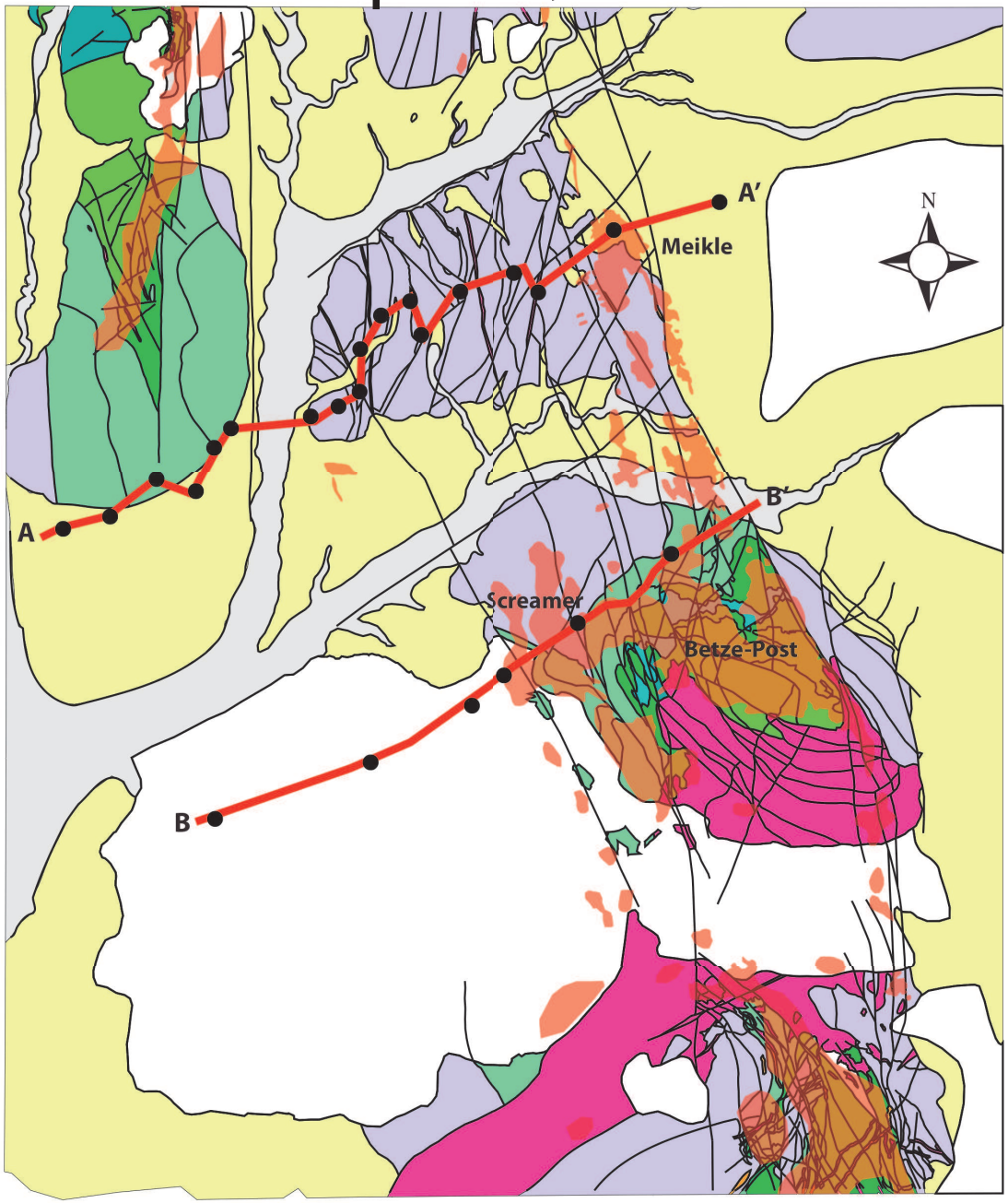


- Spatial correlation is strong between pulp and hand samples
- **Distal** - Fluid flow becomes isolated to highly permeable beds
- Pulps become **background**, individual hand samples still **altered**

Figure 12800N IsoPulpAu



Case study - isotopic alteration around Carlin-type gold deposits, northern Carlin Trend, Nevada



Mine workings

Qal
Quaternary alluvium & landslide deposits

Tmc
Miocene Carlin Formation

Jurassic granodiorite & quartz diorite stocks; lamprophyric & rhyodacite dykes

DOw
Undifferentiated Ordovician-Devonian siliciclastic dominated assemblage

Drc
Devonian Rodeo Creek Formation

Dp
Devonian Popovich Formation

DSb
Silurian-Devonian Bootstrap limestone

DSr
Silurian-Devonian Roberts Mountains Formation

PalSe
Undifferentiated Lower Plate carbonate dominated assemblage

Faults

Sampled drill holes

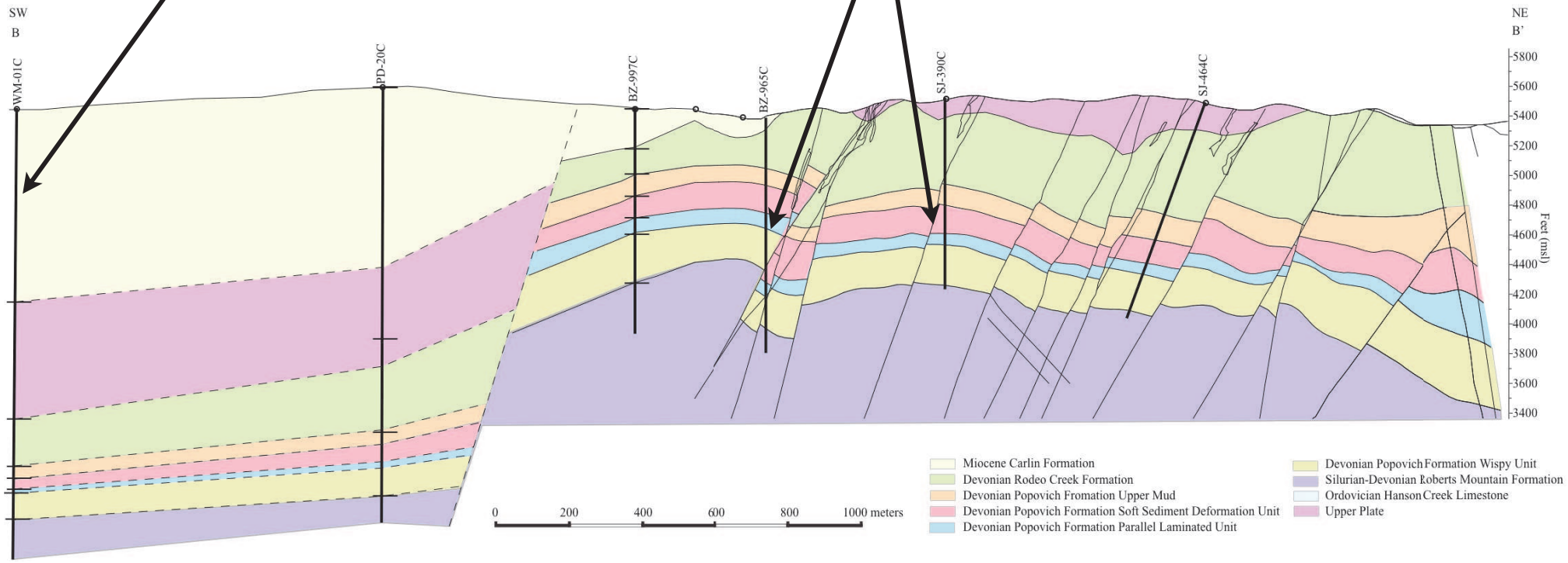
Au deposits projected to surface

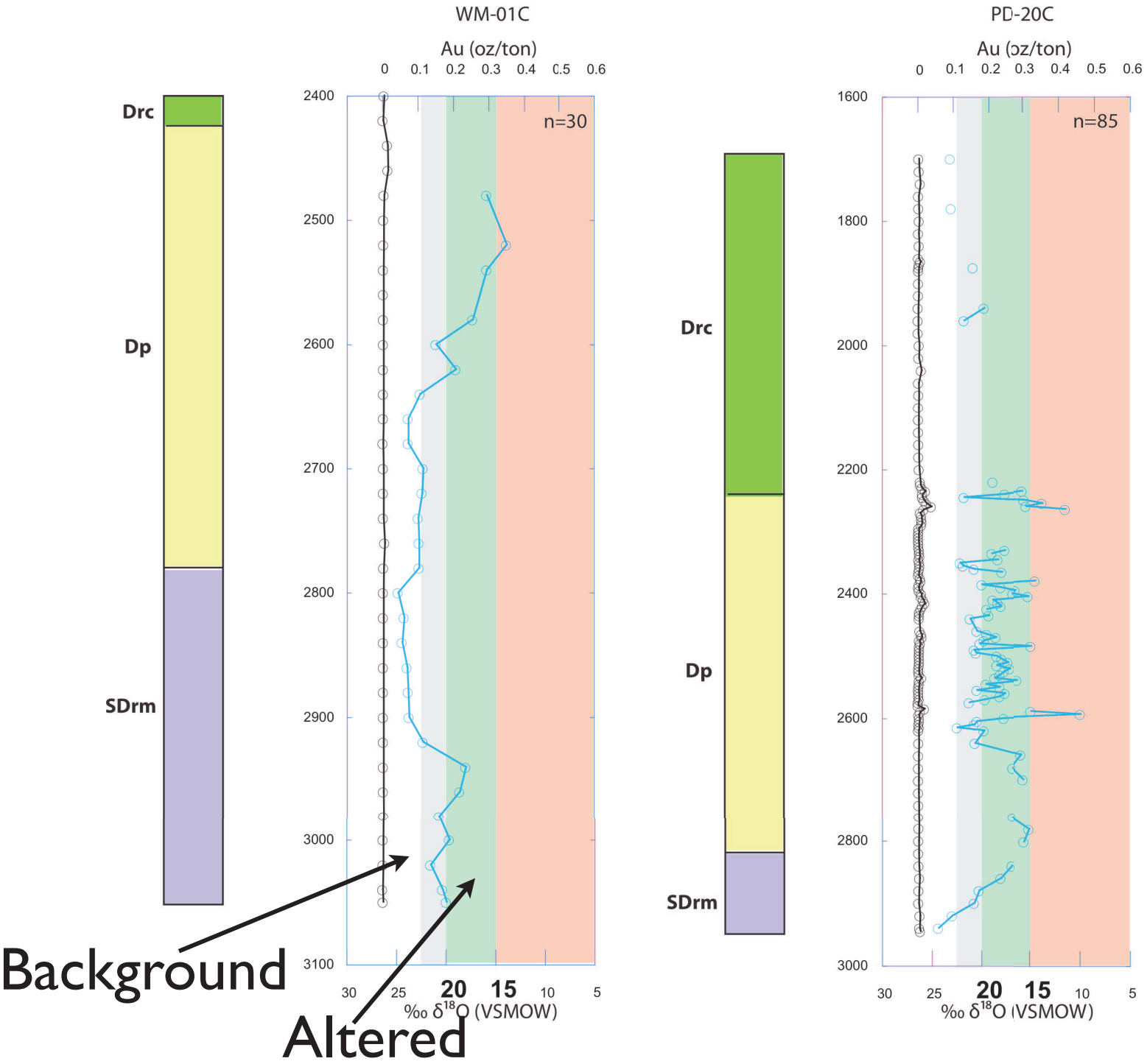
0 500 1000 1500 2000 2500 meters

Vaughan, 2013 PhD Thesis

Most distal drilling available

Significant gold intercepts




WM-01C
Au (oz/ton)
0 0.1 0.2 0.3 0.4 0.5 0.6
n=30
Drc
Dp
SDrm
2400
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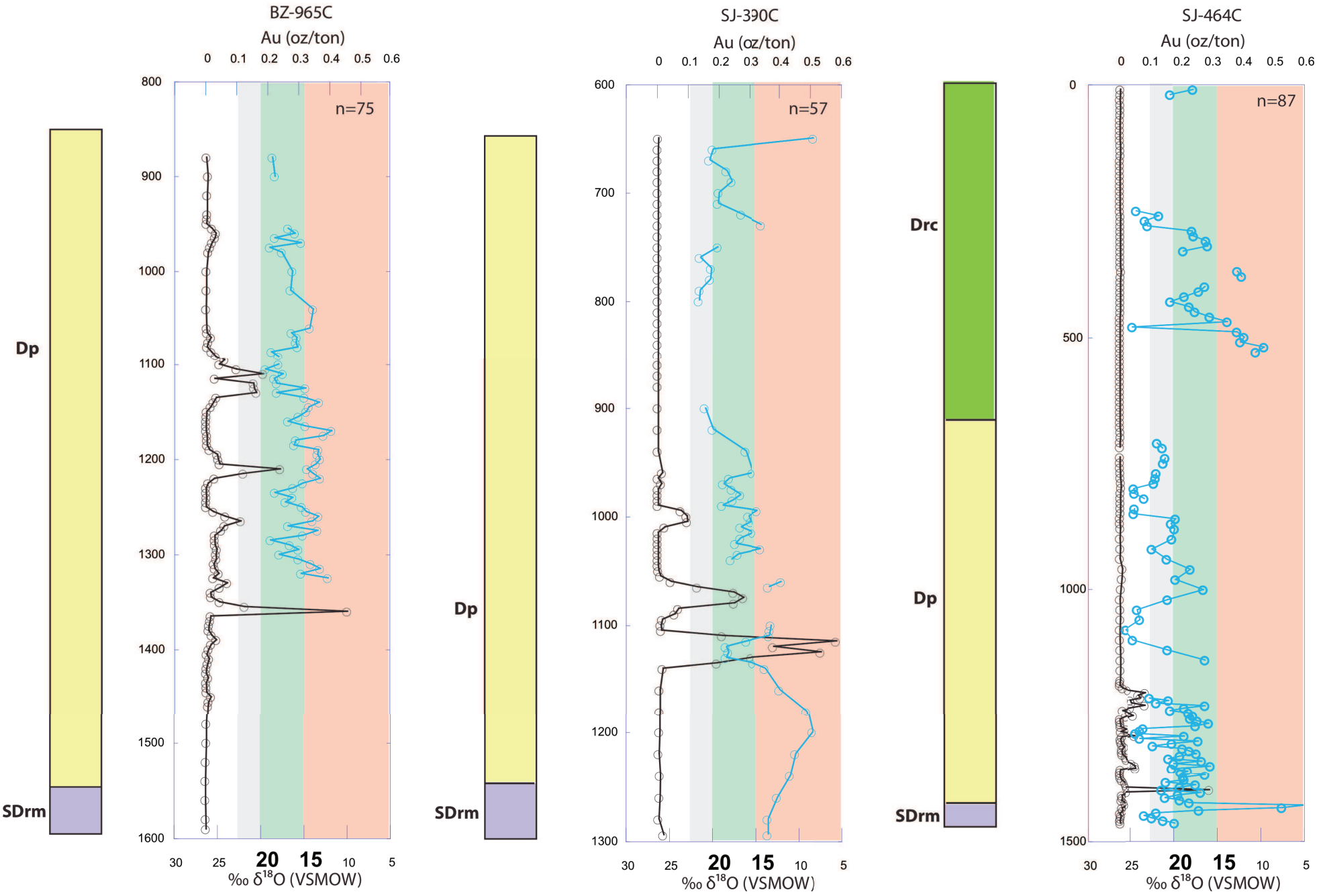
2600
2700
2800
2900
3000
3100
30 25 20 15 10 5
‰ δ18O (VSMOW)
Background
Altered
PD-20C
Au (oz/ton)
0 0.1 0.2 0.3 0.4 0.5 0.6
n=85
Drc
Dp
SDrm
1600
1800
2000
2200
2400
2600
2800
3000
30 25 20 15 10 5
‰ δ18O (VSMOW)


BZ-965C
Au (oz/ton)
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Dp
SDrm
800 900 1000 1100 1200 1300 1400 1500 1600
30 25 20 15 10 5
‰ δ18O (VSMOW)
SJ-390C
Au (oz/ton)
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SDrm
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‰ δ18O (VSMOW)
SJ-464C
Au (oz/ton)
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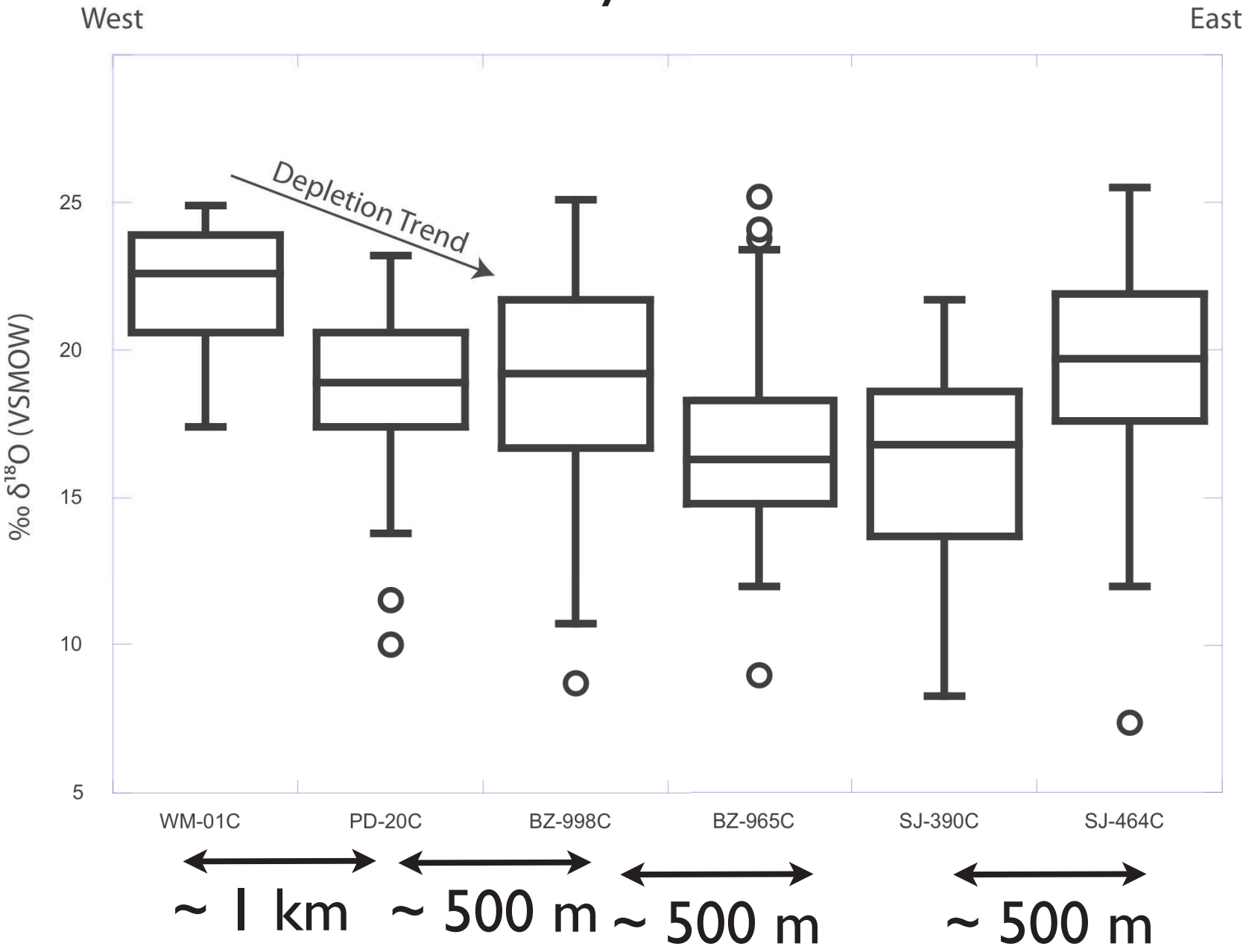
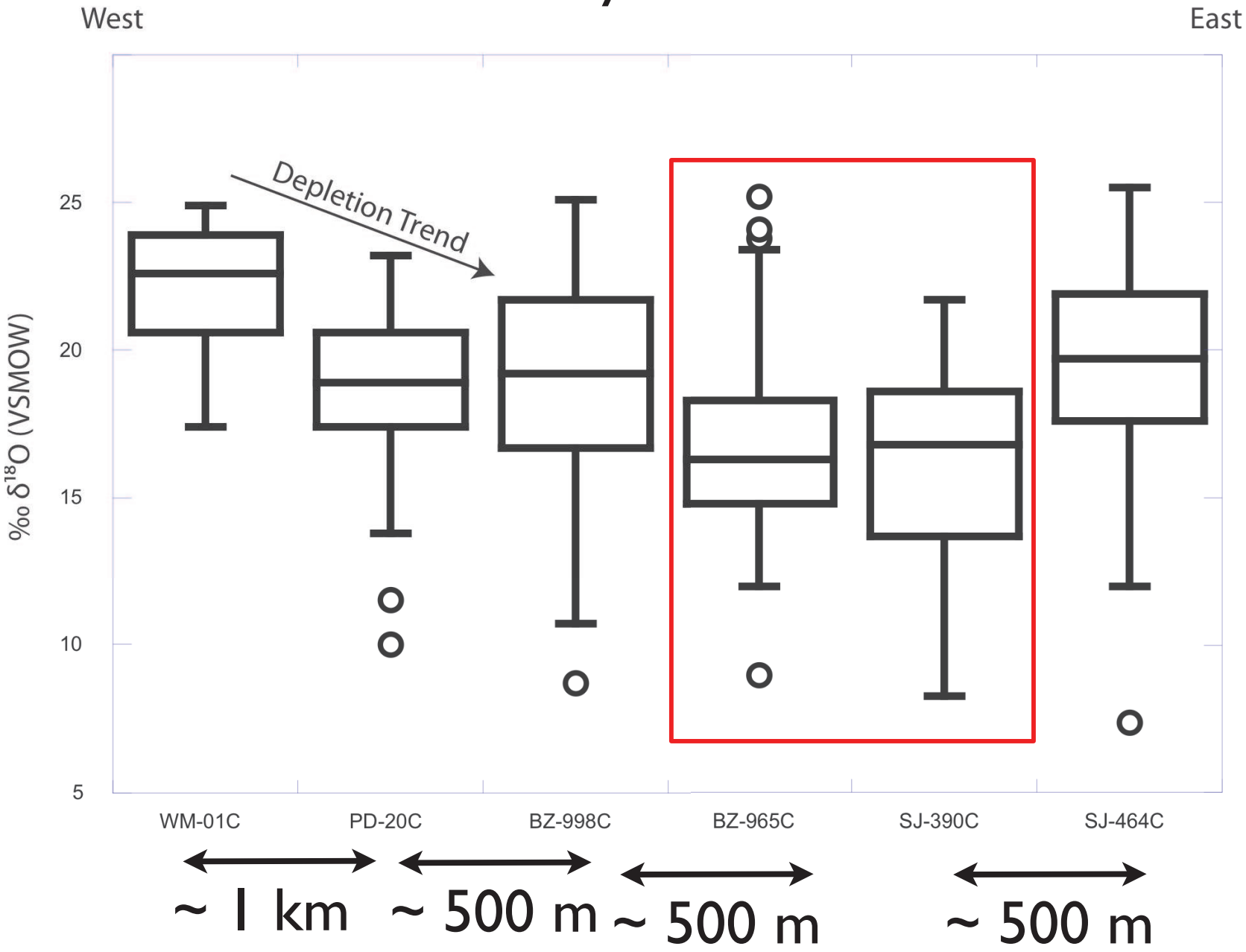
‰ δ18O (VSMOW)

> 2 km halo laterally around mineralization



Barker et al, Economic Geology, 2013, vol. 108 pp 1-8

> 2 km halo laterally around mineralization



Barker et al, Economic Geology, 2013, vol. 108 pp 1-8

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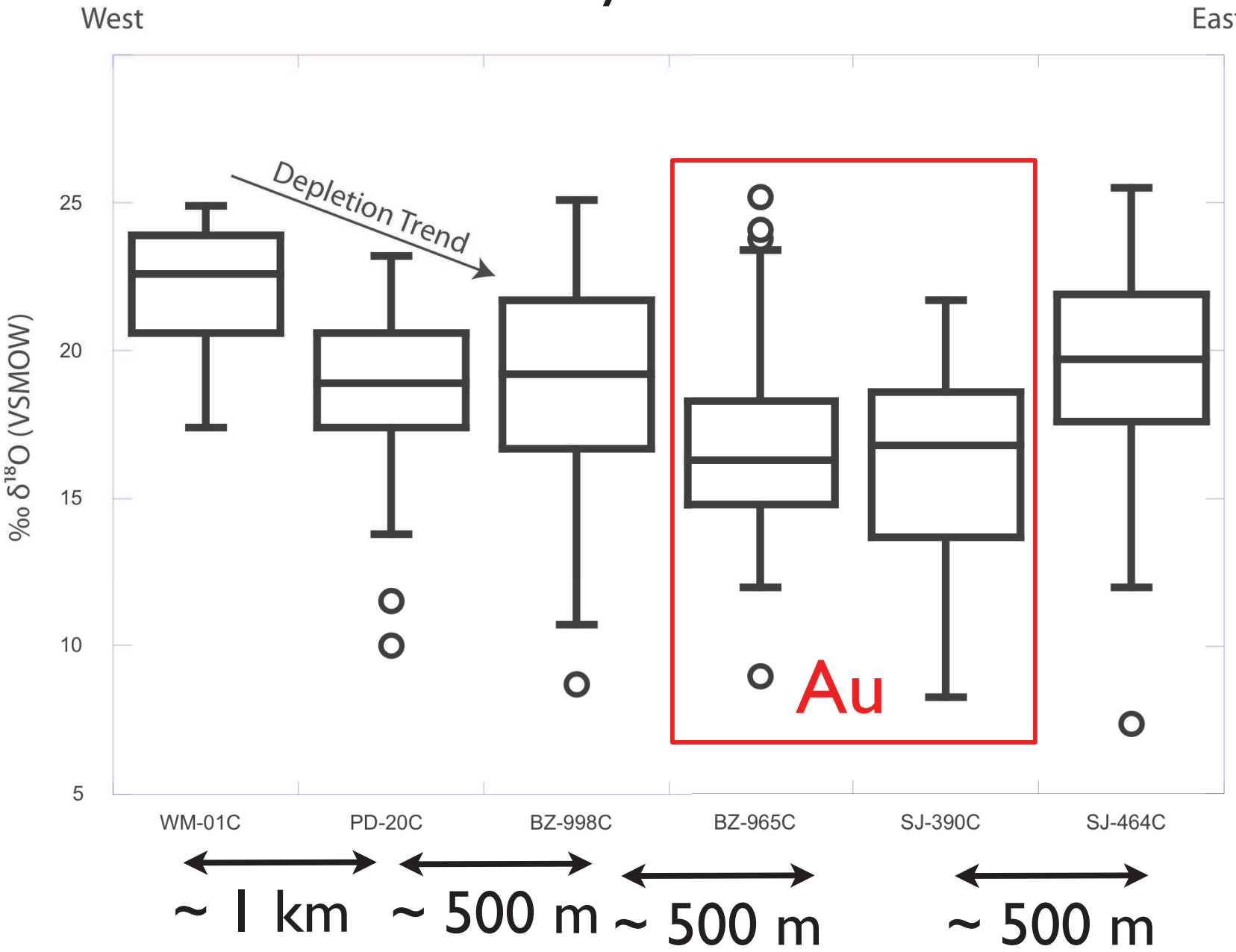

Barker et al, Economic Geology, 2013, vol. 108 pp 1-8

Conclusions

- Stable isotope alteration haloes are real (lots of case studies) - strong theoretical understanding from 60 years of academic research
- Isotope alteration haloes well outside traditional alteration vectors, providing larger targets and potential vectors to ore
- Now have a tool for the job - mineral industry relevant
- Substantial case studies still required to determine best practice, where most value can be extracted for exploration
- Potential exploration impacts:
    - Near miss?
    - Target ranking (e.g. bigger halo = bigger hydrothermal system = more fluid = more ore)?
    - Ground sterilization?
    - Vectoring up fluid pathways towards ore?

The next step(s)?

- Approach appears to have value in carbonate-hosted deposits - but what about the rest? - literature says useful, but methods lacking - S, O, H not yet available
- Potential to look at propylitic alteration that involves formation of secondary carbonate minerals (see work of Kyser group in South America on porphyry deposits)
- Orogenic gold?? Not many case studies relevant to exploration.
- Work just beginning on applying similar technology at U of Waikato to analyze O and H in O-H-bearing minerals (relevant to epithermal, porphyry, orogenic?).
- Emphasis on fast, cheap and easy - relevant cost and utility for industry