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

Noranda Area, Abitibi Belt. Cathles (1993)

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Isn't it stupid that the world economy is based on gold?

Yeah... no matter how advanced civilization gets, we still use rocks for money.

The dumb part is using a rock that's so hard to find.

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

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  ★ Greg Dipple, Craig Hart, Ken Hickey - MDRU
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Distal Alteration Footprints

Kelley et al, 2006, Econ. Geol.

Kelley et al, 2006, Econ. Geol.
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.

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Haloes and vectoring

Isotope halo, $\delta^{18}O$

mineralogical alteration

heat

ore
Haloes and vectoring

- Isotope halo, $\delta^{18}O$
- Mineralogical alteration
- Heat
- Ore
What are isotopes?

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Stable isotope: isotopes that are stable and do not decay.
Long-lived radioisotope: isotopes that decay slowly.
Short-lived radioisotope: isotopes that decay quickly.

http://www2.bnl.gov/CoN/
δ¹⁸O for Earth Materials

- Meteoric waters
- Ocean water
- Sedimentary rocks
- Metamorphic rocks
- Granitic rocks
- Basaltic rocks

δ¹⁸O [%]

40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70

Hoefs, 2009
What isotope systems?

- Most hydrothermal fluids are very water (H₂O) 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).
Kilometer-scale $^{18}\text{O}$ halo to the General Custer Mine.

Criss et al, 1985
Mineralization in Comstock Lode coincident with steep gradients in $^{18}$O-depletion.

**Figure 2.** Cross section through the Comstock Lode, Nevada along the Sutro Tunnel. Contours are of $\delta^{18}$O values. Note close association of mineralization (heavy dashed lines) to sharp gradients in $\delta^{18}$O values. (From Criss and Champion, 1991).
FIGURE 3. Contours of $\delta^{18}O$ 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

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

Morishita, 1991, Resource Geology
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
The old way......
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), CrystalSight (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.

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.
$R^{(18\text{O})} = 0.0039017 + 4.0792 \times 10^{-5} \delta^{18\text{O}}_{\text{VSMOW}}$
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

\[ y = 0.6822x + 5.3741 \]
\[ y = 0.6816x + 3.7435 \]
\[ y = 0.7472x + 4.8141 \]
\[ r^2 = 0.46 \]

\[ y = 0.6857x + 4.9978 \]
\[ r^2 = 0.66 \]

LC533C
LC555C
LC556C

Drill Assay Pulp $\delta^{18}O_{\text{VSMOW}}$ (%)

Hand Sample Pulp $\delta^{18}O_{\text{VSMOW}}$ (%)

All Drillholes $r^2=0.66$ $y=0.6857x+4.9978$
• 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**
Case study - isotopic alteration around Carlin-type gold deposits, northern Carlin Trend, Nevada

Vaughan, 2013 PhD Thesis
Most distal drilling available

Significant gold intercepts
> 2 km halo laterally around mineralization

> 2 km halo laterally around mineralization

> 2 km halo laterally around mineralization

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