B.2 Application of Oxygen and Hydrogen Isotopes in Mineral Industry Effluent and ARD Studies

Mory Ghomshei and Diana Allen

University of British Columbia
Department of Mining & Mineral Process Engineering

and

Simon Fraser University
Department of Geology

plus

M.M. Ghomshei and D.M. Allen. 2000. Hydrochemical and Stable Isotope Assessment of Tailings Pond Leakage, Nickel Plate Mine, British Columbia. Environmental Geology 39(8)

M.M. Ghomshei and D.M. Allen. 2000. Potential Application of Oxygen-18 and Deuterium in Mining Effluent and Acid Rock Drainage Studies. Environmental Geology 39(7)

Application of Oxygen and Hydrogen Isotopes
in
Mineral Industry effluent and ARD Studies:

Example - Nickel Plate Tailings pond

Mory Ghomshei: University of British Columbia, Department of Mining and Mineral Process Engineering

Diana Allen: Simon Fraser University, Department of Geology

- Oxygen and Hydrogen Isotopes
  - Overall importance as a tracer
  - Analysis and results

- Isotopic fractionation / equilibration

- Isotopic Signatures of solid and liquid phases

- Isotopic variations in hydrological systems

- Isotopic variations in mining environment

  - Mixing
  - Oxygen shift

- Example: Nickel Plate tailings pond
    - (Sulphate, ^{18}O and D)

- Hydro-chemical model
- Stable isotope Mixing model
- Calculation of leakage from the tailings pond

- Conclusion and prospects for future studies

Relative abundance and half-lives of oxygen and hydrogen isotopes

Isotope	Relative abundance	Nuclear stability	Half-life*
^{14}O		radioactive	tens of seconds
^{15}O		radioactive	tens of seconds
^{16}O	99.759%	stable	
^{17}O	0.037%	stable	
^{18}O	0.204%	stable	
^{19}O		radioactive	tens of seconds
^{1}H	99.9853%	stable	
^{2}H (deuterium, D)	0.0147%	stable	
^{3}H (tritium)		radioactive	12.26 years

*For radioactive isotopes only

Stable isotopes are analyzed using a mass spectrometer.

^{18}O is determined by equilibration with carbon dioxide

D is determined by uranium reduction

Analytical results are expressed as "permil" differences

(denoted by $\delta^{18}O‰$ and $\delta D‰$ from SMOW (Standard Mean Ocean Water)

Analytical precision is ± 0.15 for O^{18} and ± 1 permil for D.

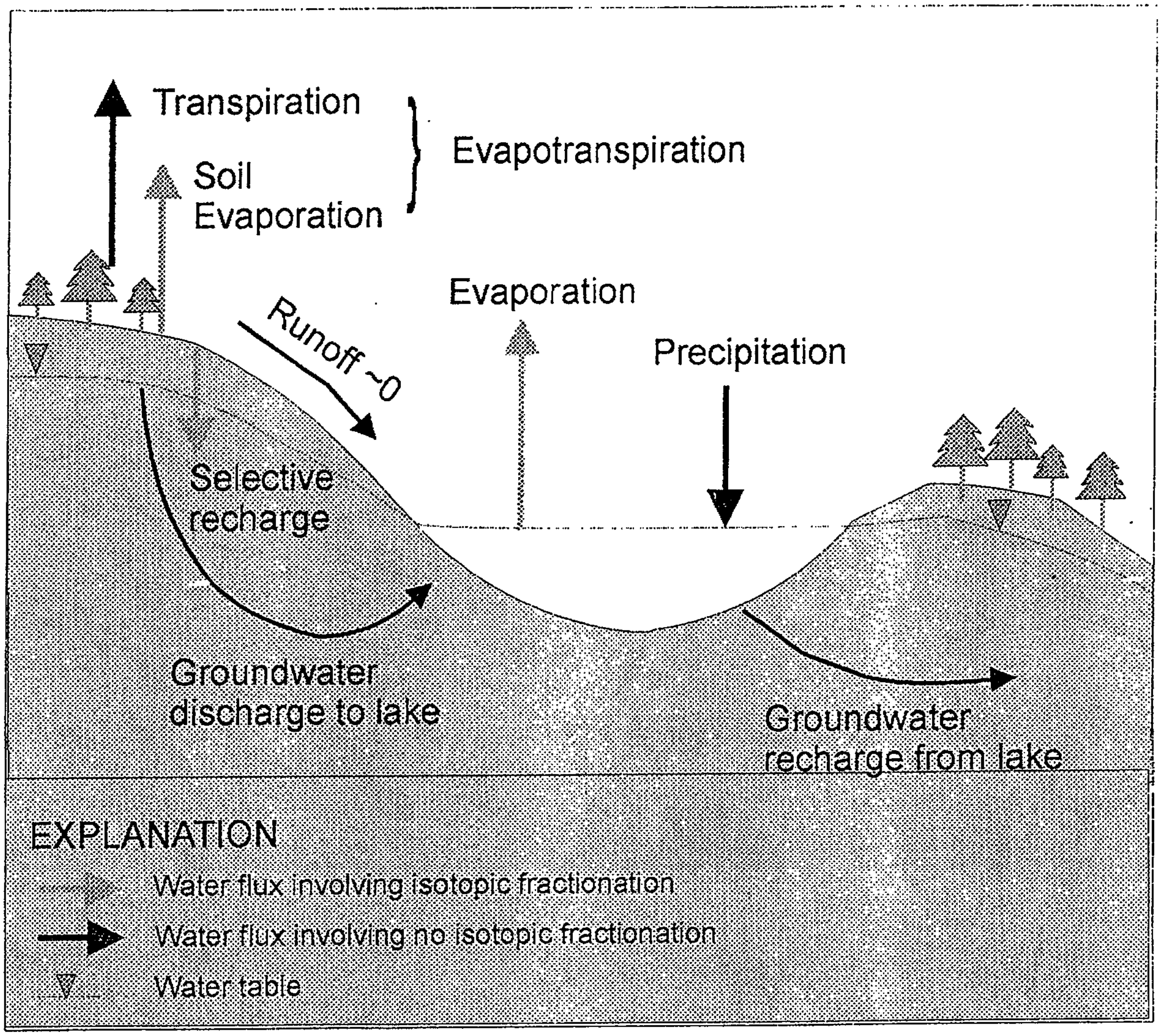
Permil differences from the SMOW are defined as follows:

$$\delta D = \{[(D/H)_{\text{sample}} - (D/H)_{\text{SMOW}}] / [(D/H)_{\text{SMOW}}]\} \text{ x}10^3\ ‰$$

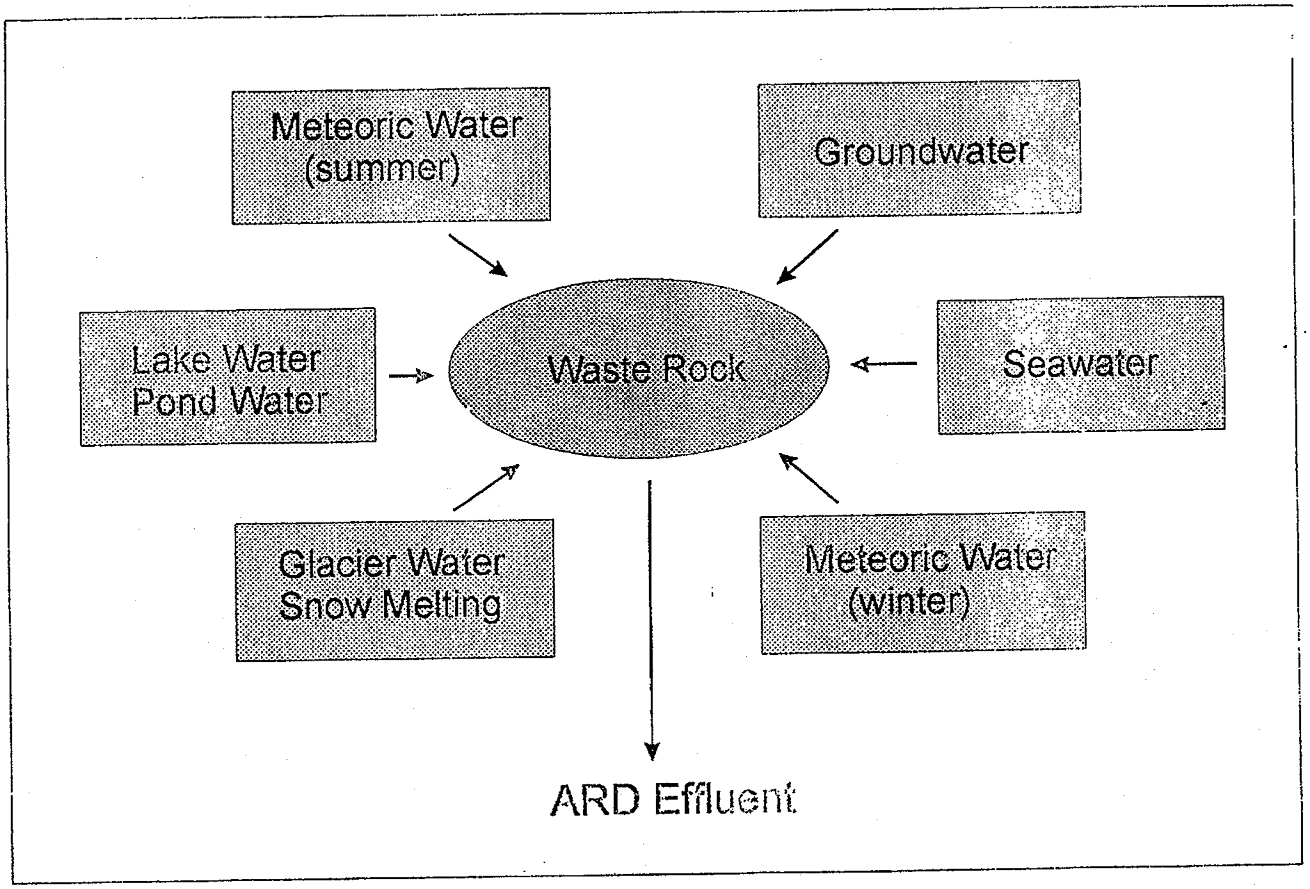
$$\delta^{18}O = \{[(^{18}O/^{16}O)_{\text{sample}} - (^{18}O/^{16}O)_{\text{SMOW}}] / [(^{18}O/^{16}O)_{\text{SMOW}}]\} \text{ x}10^3\ ‰$$

While naturally-occurring tritium has been rarely reported, tritium fallout derived from hydrogen bomb tests conducted in the 1950's is still detectable in the long-cycled groundwater systems. Detectable concentrations of tritium in groundwater indicate that the groundwater was recharged less than 45 years.

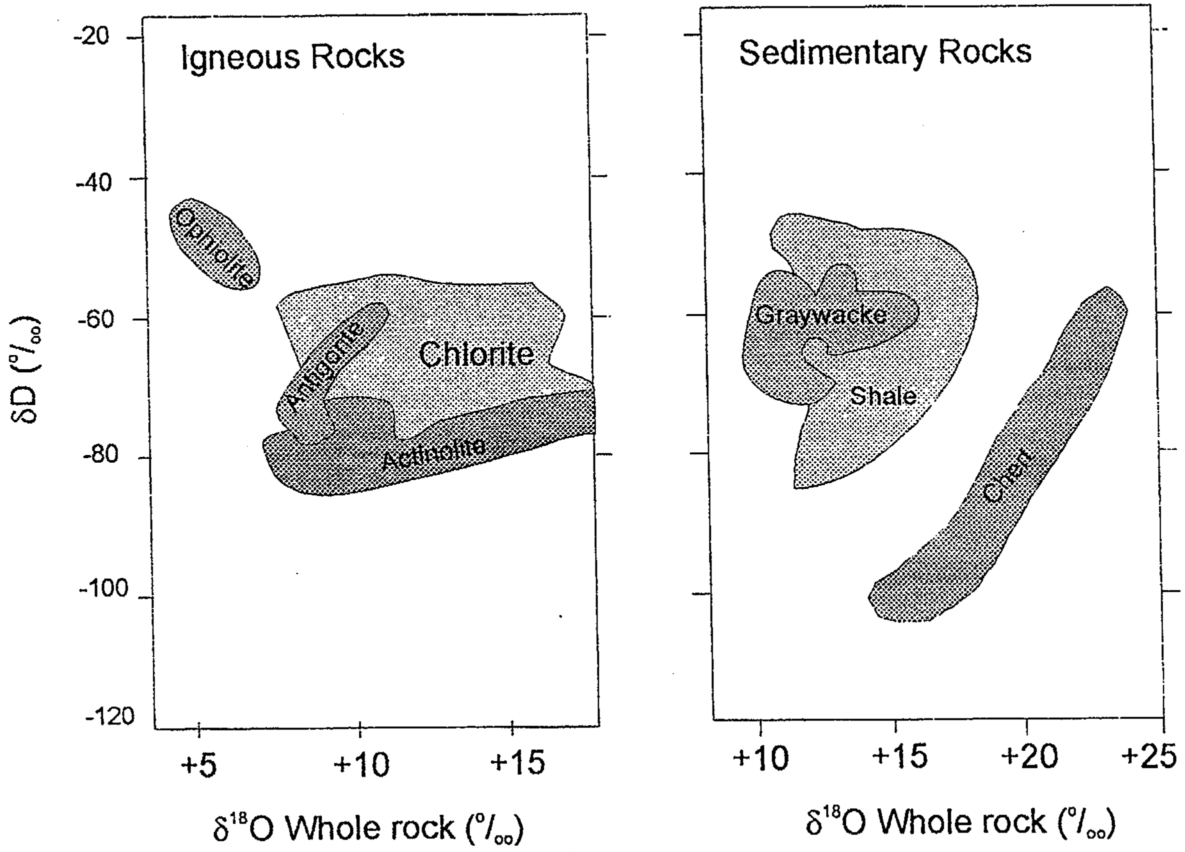
Tritium concentrations are expressed in tritium units ($1\ TU = 1\ {}^{1}H \text{ x } 10^{-18}\ {}^{1}H$)


Transpiration
Soil Evaporation
Evapotranspiration
Evaporation
Runoff ~0
Precipitation
Selective recharge
Groundwater discharge to lake
Groundwater recharge from lake
EXPLANATION
Water flux involving isotopic fractionation
Water flux involving no isotopic fractionation
Water table

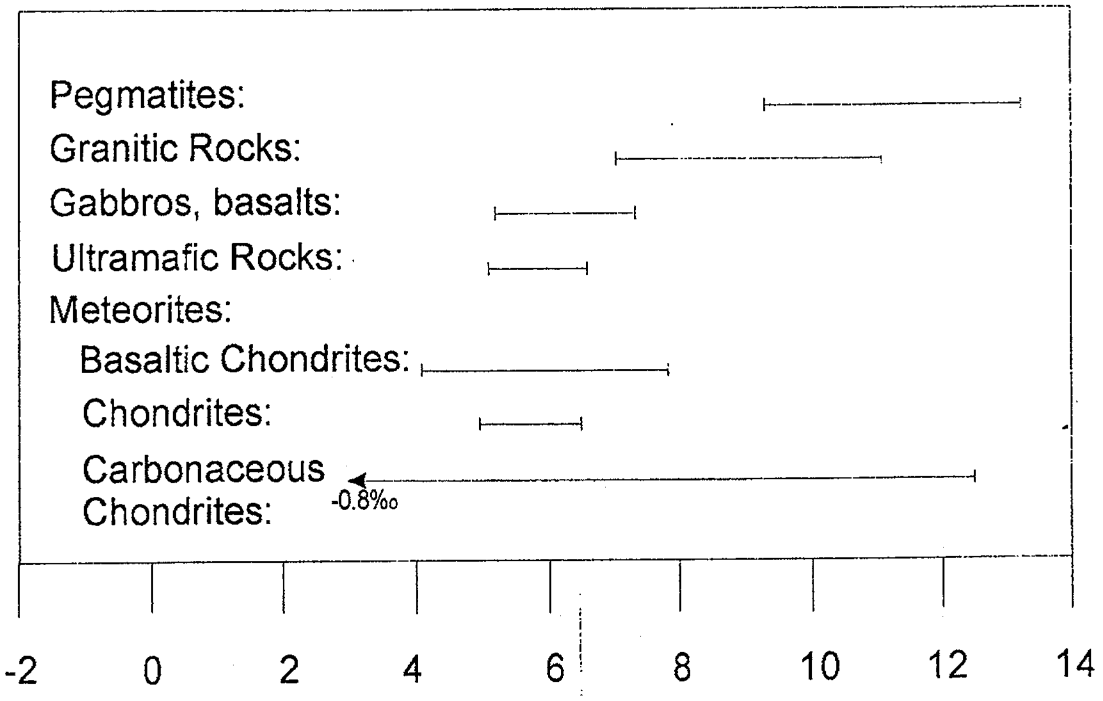
Schematic diagram of the hydrological components of a groundwater - lake system


Meteoric Water (summer)
Groundwater
Lake Water
Pond Water
Waste Rock
Seawater
Glacier Water
Snow Melting
Meteoric Water (winter)
ARD Effluent

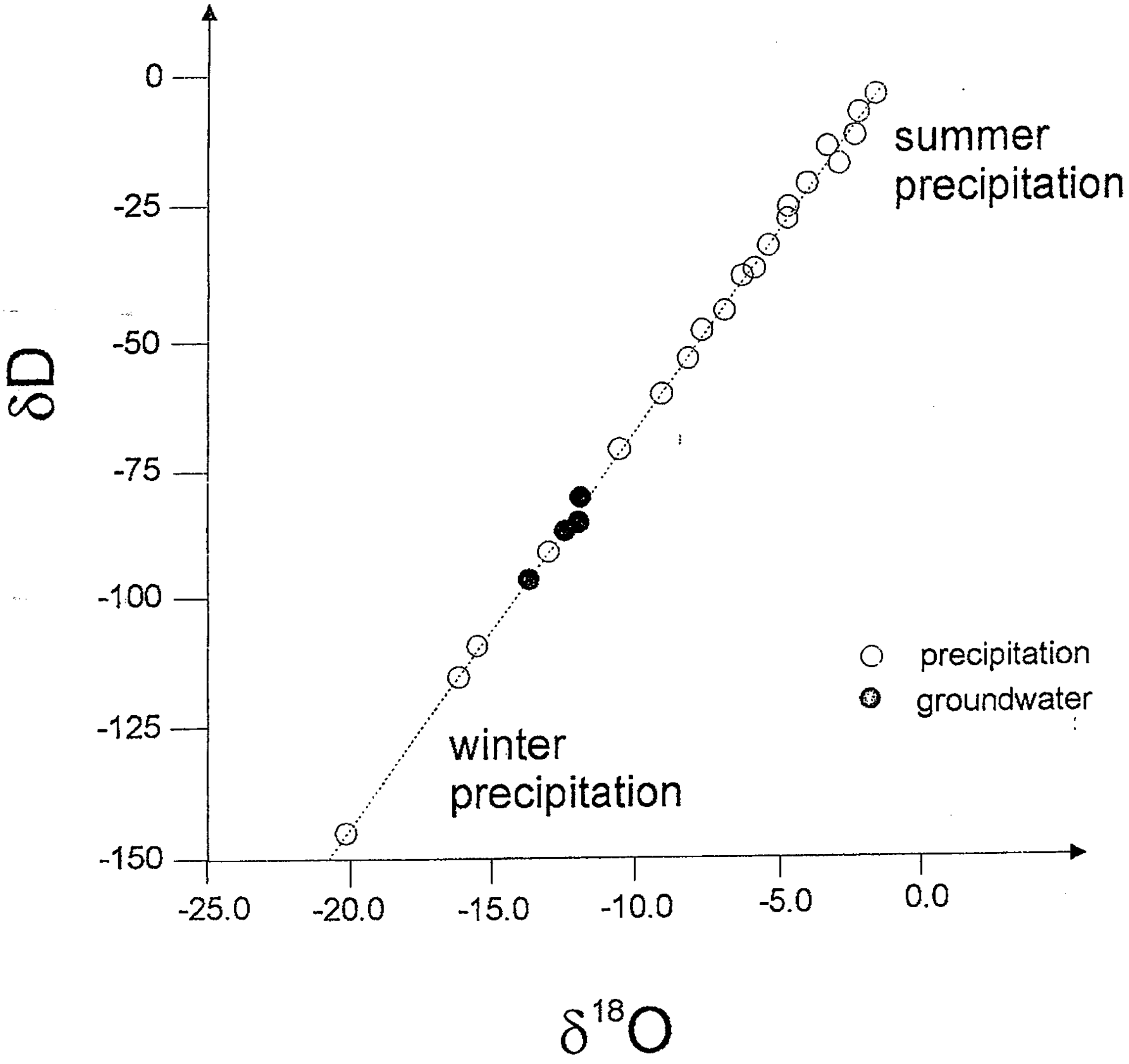
Water types that may be at the origin or ARD effluent.



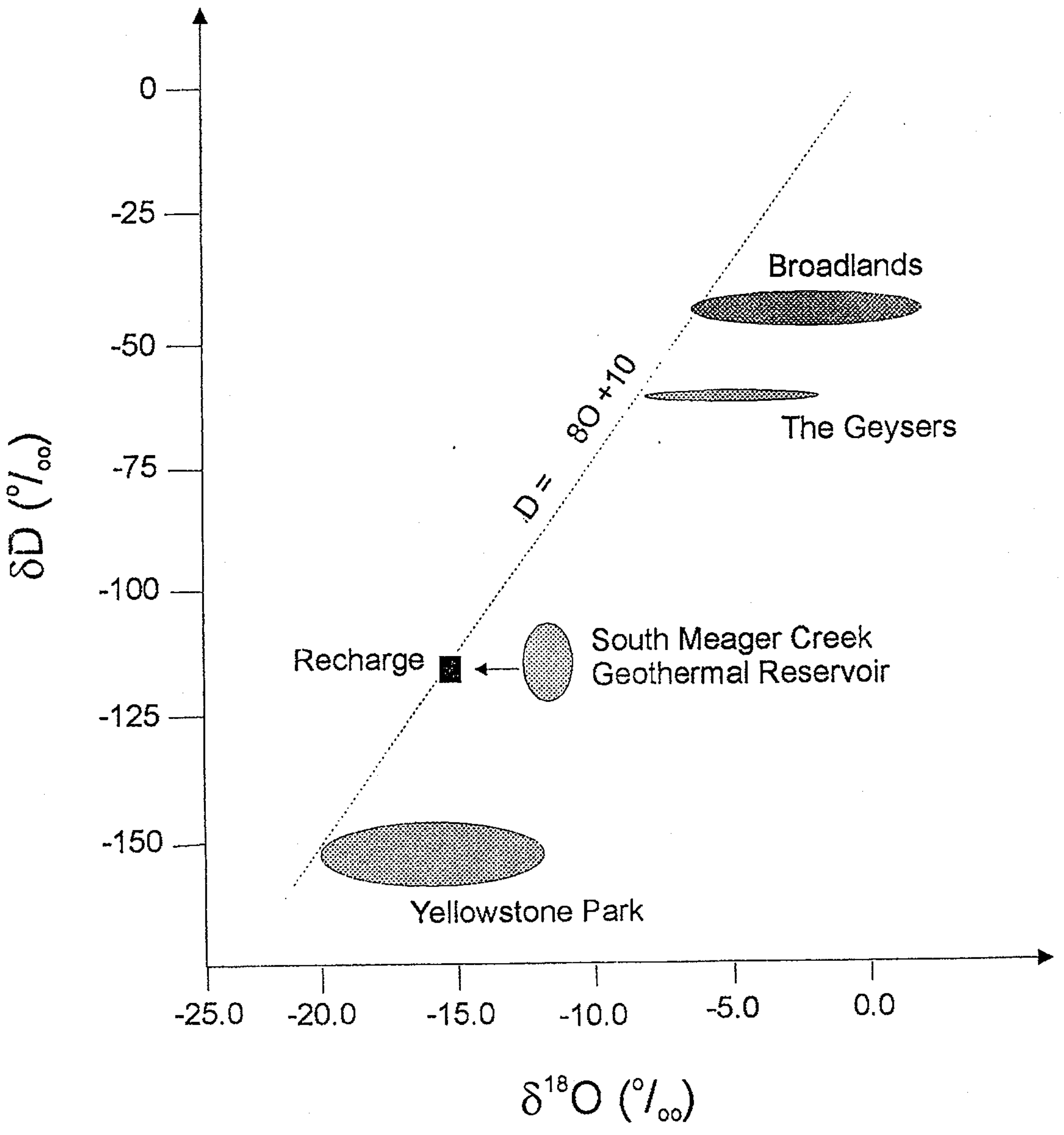
δD vs $\delta^{18}O$ for igneous and sedimentary rocks.
(after Taylor, 1977).



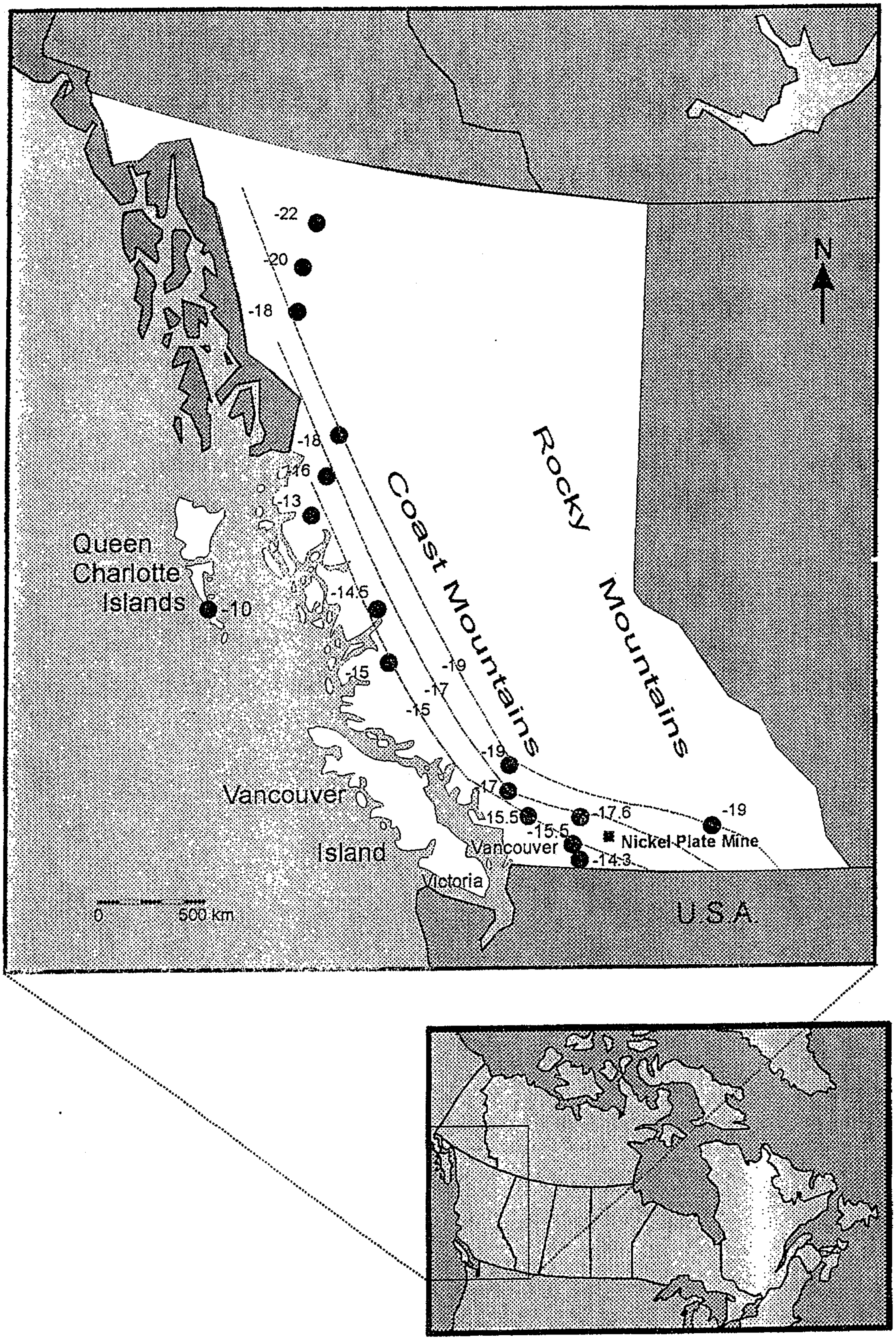
Range of $\delta^{18}O$ values of igneous and stony meteorites.
(after Jager and Hunziker, 1979).



Schematic graph showing isotopic compositions of precipitation (wide range) and groundwater (narrow range).

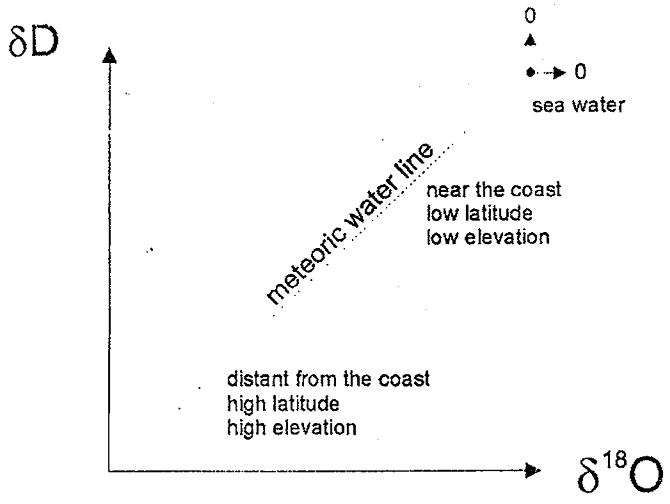


Oxygen-18 and deuterium compositions of geothermal waters. Prominant oxygen shifts observed (after Truesdell and Hulston, 1980; and Ghomshei and Clark, 1993). Recharge composition determined by trajectory backtracing.

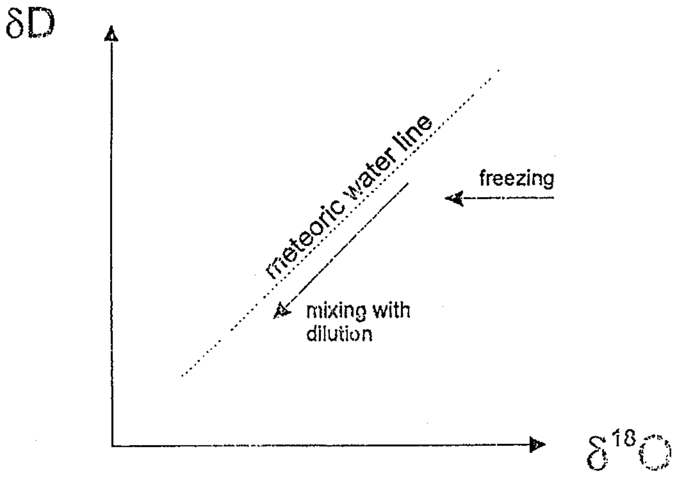

-22
-20
-18
N
-18
-16
-13
Rocky
Coast Mountains
Queen Charlotte Islands
-10
-14.5
Mountains
-15
-19
-17
-15
-19
-17
Vancouver
-15.5
-17.6
-19
-15.5
Nickel Plate Mine
Island
Vancouver
-14.3
Victoria
0
500 km
U.S.A.

Mean $\delta^{18}O$ ‰ for modern meteoric waters in Western British Columbia, Canada. (after Ghomshei and Clark, 1993).

a) TOPOLOGICAL PARAMETERS

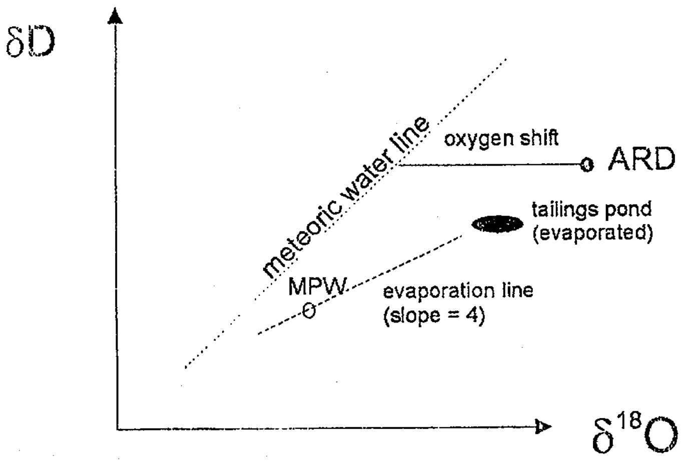

δD
0
0
sea water
meteoric water line
near the coast
low latitude
low elevation
distant from the coast
high latitude
high elevation
$\delta^{18}O$

b) MIXING FREEZING

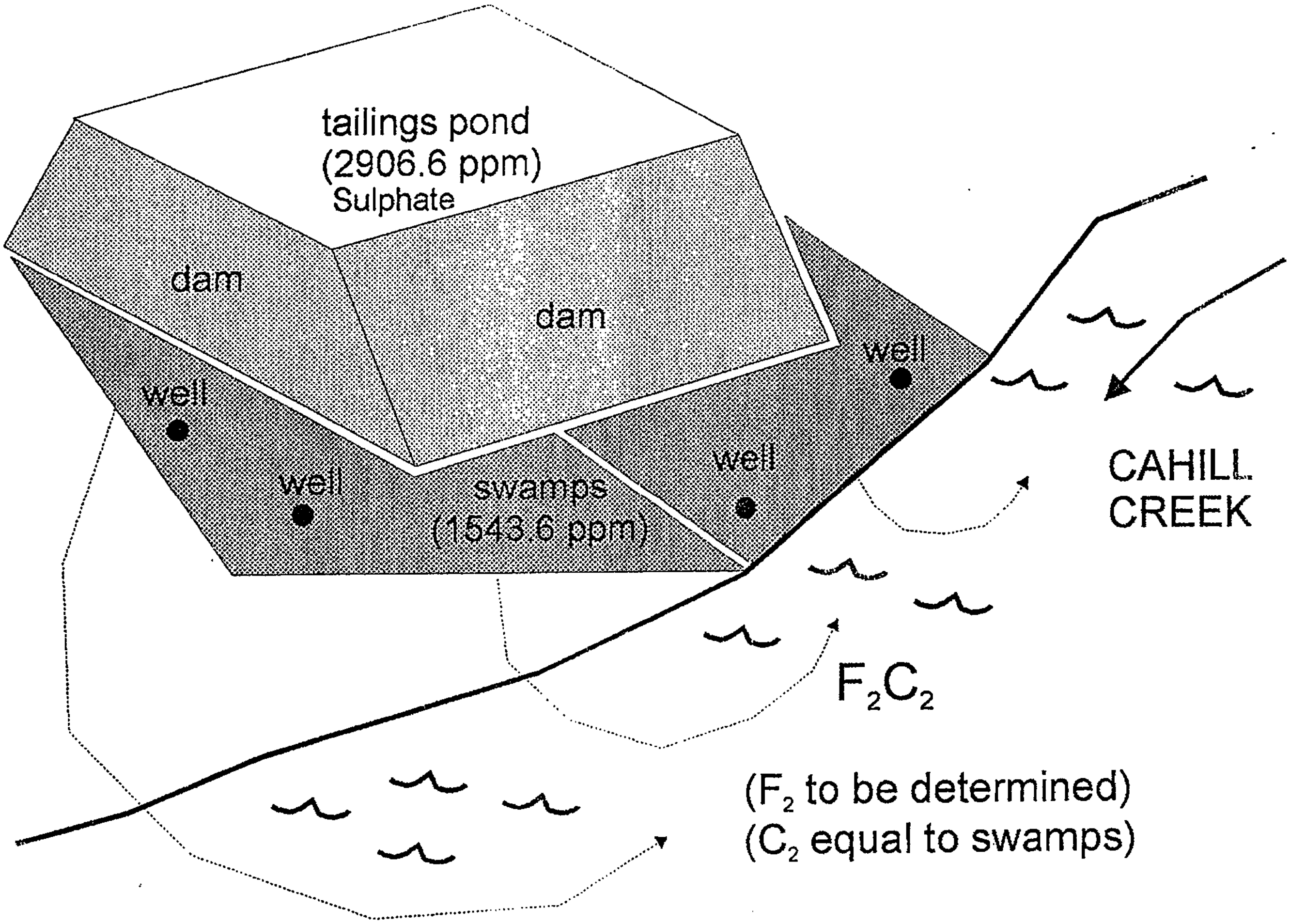

δD
meteoric water line
freezing
mixing with
dilution
$\delta^{18}O$

c) EVAPORATION

WATER/ROCK INTERACTION (oxygen shift)


δD
meteoric water line
oxygen shift
ARD
tailings pond
(evaporated)
MPW
evaporation line
(slope = 4)
$\delta^{18}O$

Qualitative variations of δD and $\delta^{18}O$ in different environmental processes

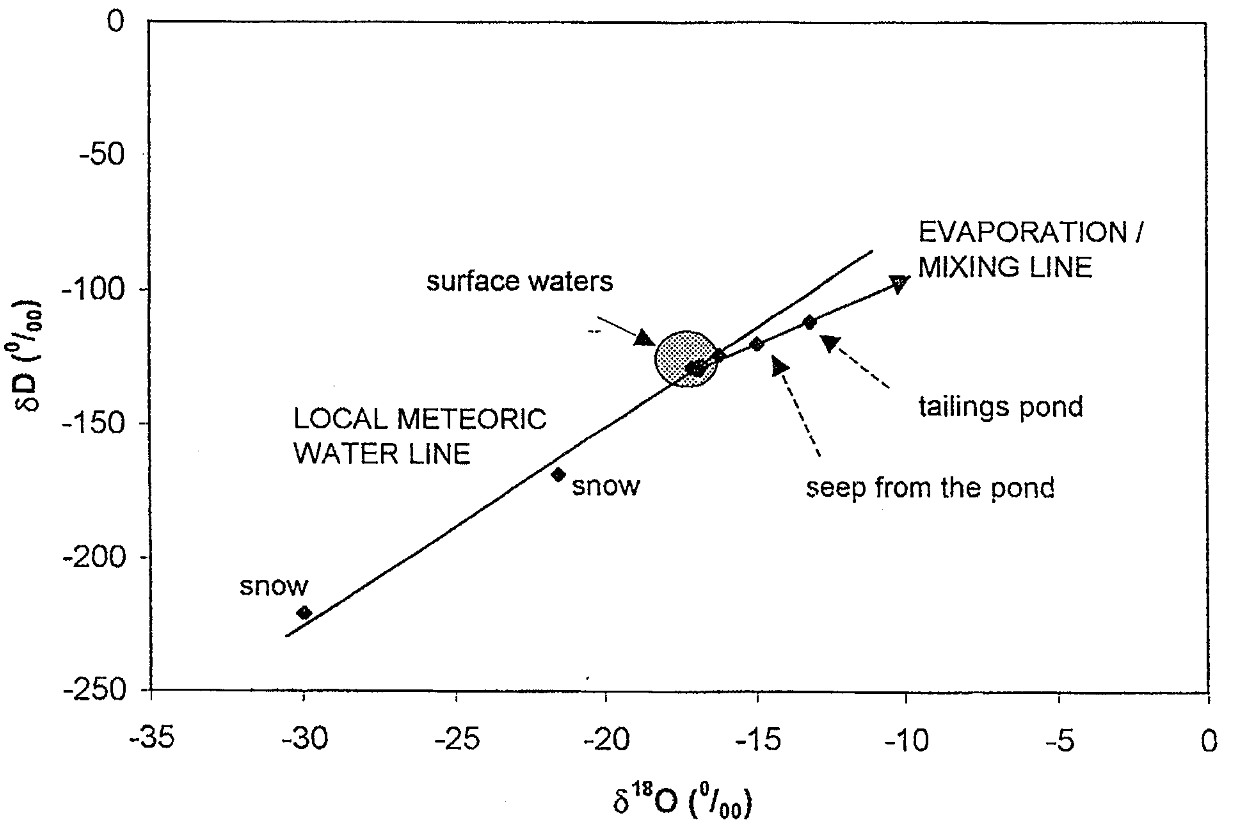

tailings pond
(2906.6 ppm)
Sulphate
dam
dam
well
well
well
well
swamps
(1543.6 ppm)
CAHILL
CREEK
F_2C_2
(F_2 to be determined)
(C_2 equal to swamps)

Schematic diagram of tailings pond, dams, swamps, extraction wells and possible leakage paths.

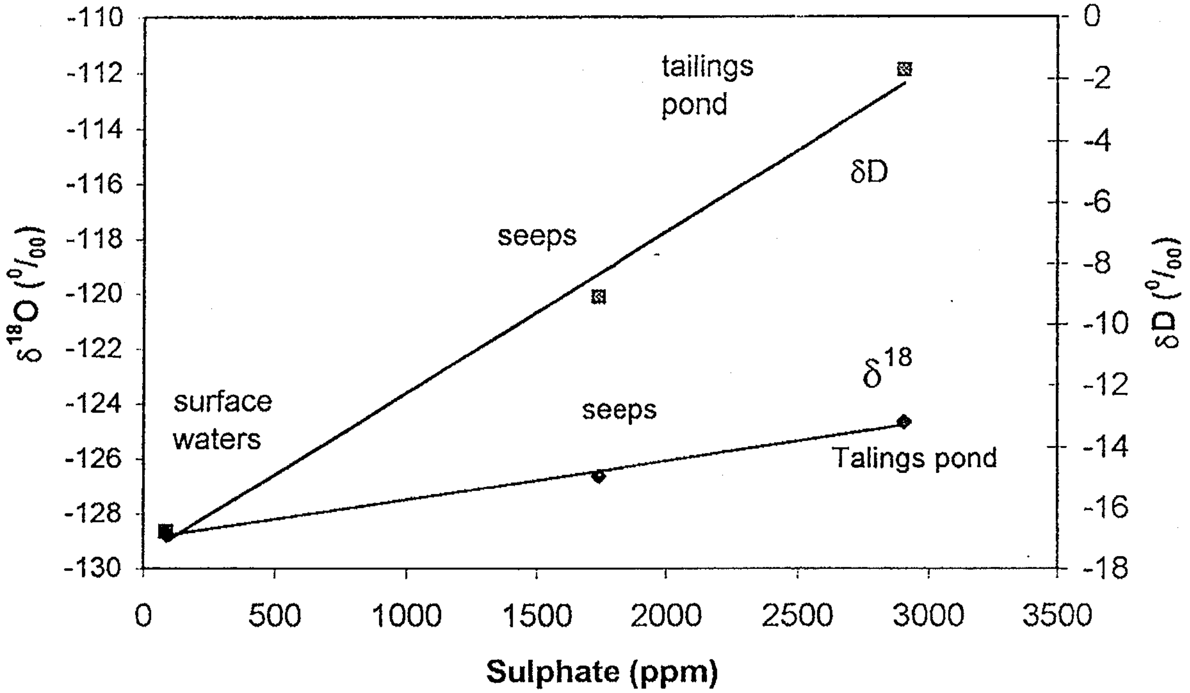
Nickel Plate Mine

Nickel Plate Stable Isotope Data

				statistics		
Sample	del O-18	del D			stdev	average
RTG (Feb 3)	-16.79	-128.6		del O (srf)	0.074632	-16.878
NPM Cr	-16.93	-128.5		del D (srf)	0.66106	-128.82
Cahill 1	-16.88	-129.5		del O (all)	4.450466	-17.94091
Canty Pit	-16.97	-129.5		del D (all)	30.78022	-138.0727
Cahil 3	-16.82	-128				
S-dmp snow	-29.96	-220.7				
Spring @ H. Rd. (Feb 3)	-16.21	-124.4				
Cahil 3 Snow	-21.52	-168.7				
Seep from Pond	-14.96	-120.1				
SS upper	-17.12	-128.9				
Iso Tailings	-13.19	-111.9				



0
-50
-100
-150
-200
-250
δD (‰)
-35
-30
-25
-20
-15
-10
-5
0
δ18O (‰)
surface waters
EVAPORATION / MIXING LINE
LOCAL METEORIC WATER LINE
tailings pond
snow
seep from the pond
snow


δ18O (0/00)
-110
-112
-114
-116
-118
-120
-122
-124
-126
-128
-130
0
500
1000
1500
2000
2500
3000
3500
Sulphate (ppm)
δD (0/00)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
tailings pond
δD
seeps
surface waters
seeps
δ18
Talings pond

Isotopic Modelling of ARD

What affects isotopic values of ARD?

1) **Original waters**
2) **Oxidation rate** **($\delta^{18}O_{atm} = +14‰$)**
3) **Neutralization**
4) **Residence time (i.e. hydraulic permeability)**

Observations:

1) **Pyrite oxidation under laboratory conditions suggests a positive $\delta^{18}O$ shift in the water (Taylor and others 1984).**
2) **ARD Effluent from Sullivan Mine shows an oxygen shift (Lepitre et al. 2000).**

How to model?

A vector can define the chemistry of each original water type, rock, and air.
In the case of δD and $\delta^{18}O$, chemical vectors are defined in a two-dimensional space

Mixing is mathematically simulated by addition of two vector compositions.

Water/rock/air interaction is simulated by a scalar product.

$$[ARD] = \{s[S] + p[P] + g[G]\} \bullet \{r[R]\} \odot \{a[A]\}$$

[S], [P], [G], [R], [A] and [ARD] are chemical vectors for surface waters, precipitation, ground water, rock, air and ARD effluent respectively

Conclusions

Oxygen-18 and deuterium analysis contributes to the understanding of a variety of problems in mineral industry effluent studies, such as:

- The source of the effluent (recharge) and its seasonal variations
- Oxidation rate, neutralization efficiency
- Hydrological parameters (e.g. leakage and mixing rates)

Oxidation and water/rock interaction can leads to an oxygen shift (i.e. ^{18}O enrichment) in the fluid phase.

Interpretation of isotope data is commonly quantitative.
Data modelling is based on distinct isotopic values of different phases.

In Nickel Plate Mine, stable isotope data indicates that tailings pond waters have undergone extensive isotopic fractionation (defining an evaporation slope of D/^{18}O = 3.9). A slope close to 8 defines local meteoric waters.

Seepage waters plot along the evaporation line midway between the surface waters and the tailings pond sample, indicating a 1 to 1 mixing between groundwater and tailings pond waters.

A mixing model based on stable isotopes and sulphate indicate that the leakage from the dam by-passes the collection and pump-back system at a rate of) 0.1 l/s.

A stable isotope study is a cost-effective method for assessment of mineral industry effluent problems, especially when the problem is dominantly hydrological (e.g. recharge, discharge, and mixing).

Current and Future Research Projects on application of stable isotopes include areas related to hydroelectric reservoirs engineering and Water Resource Engineering.