Introduction

Earth 281

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Medical Geology
(Geosciences and Health)

1. It describes or examines the effects of geological materials (rock, soil, water, gas) as they impact humans, animals and plants-ecosystems. There are both good and bad aspects.

   For example:

   - deficiencies of elements such as Iodine (goiter – thyroid) or Selenium (aspects of growth)
   - volcanic gases, dust (recycle the earth's elements or disasters)
   - organic compounds – hydrocarbons (unhealthy, BUT?) (hydrogen?, e.g. Microbial life processes)
   - radionuclides Rn (Heat flow – Earth's Heat Engine) (mutation – life)

Medical Geology
(Geosciences and Health)

2. Cross Disciplinary: Geologists, Geochemists working on "big teams" with medical researchers, dentists, veterinary scientists, biologists, etc.
3. Difference: For example, Geochemistry – here chemical principals are applied to geological problems.
4. Likewise, geophysics and its' relationship to physics.

Medical Geology (Geosciences and Health)

5. However, in health we are not applying, for example, medicine to geology, but instead use geological knowledge and tools (e.g. mass spectrometry and isotopes) to trace pathways and find the natural and contaminant sources that impact health.
6. Geologists – geologists are trained to be "detectives", e.g. How old is the earth? How do we know? How do we know that there might have been surface water on Mars based on pictures of rocks? (e.g. Flow – ripple marks or xbeds in rocks)

Medical Geology (Geosciences and Health)

a. So, you want to work in "Medical Geology", e.g. Who are your partners – health specialists and you are a rock, soil, geochemistry type. Not much in common here? In the course we will also study some of the case histories that got the health and biological community interested in multi-disciplinary approaches to the subject.

Medical Geology (Geosciences and Health)

b. Interestingly:

i) The IAGC (International Association of Geochemistry) has a medical geology working group – 20+ years.

ii) Society for Environmental Geochemistry and Health – longer yet

iii) Many societies in chemistry and biology (e.g. toxicology) regularly use geochemical and geology/soil tools and approaches, but do not mention geology in any of their subfields.

iv) The major funding agencies are now emphasizing and pushing for full spectrum multidisciplinary research. As a result some of the examples we discuss may not stop at the "gates" of the near field environment.

Far field → geological, hydrological and atmospheric environment

Near field → "the living thing"

Medical Geology & Environmental Management

a. ‘chemical time bombs’ often due to erosion and transport
b. global change – warming – e.g. permafrost and gas hydrates or pathogens that are 10,000 to millions of years old. – NASA astrobiology, their interest in permafrost and microbes – impacts on elemental cycles
c. groundwater and geochange -mining, river diversion, tunnels, etc. (old time bombs, e.g. Pb – San Francisco similar idea to Flint Michigan ; BUT – old mine tailings)
d. surface water use and salinization, e.g. Aral Sea (four good years then disaster)
e. catastrophic events, Earth Management – geology and time (So? What happens, life goes on – KT – meteorite/comet hits)

Chapter 1 in Essentials of Medical Geology, Selinus *et al.* 2013

HISTORICAL USE OF GEOLOGY IN HEALTH ISSUES

Historical Use of Geology in Health Issues

a. Old Chinese references to environment and health, e.g. lung disease and rock crushing (silicosis), lead poisoning and other heavy metals.

b. Many isotope geochemists are involved in anthropogenic, anthropologic and archaeologic studies.
-We see cases of hair (7000 years old) with very high Hg, Cd, Se levels.
-Tyrolean ice man had very bad lungs from soot and dust, dust was glacial in nature.. Most mummies both Eurasian and American show evidence of poor health and deficiencies, -we use isotopes of teeth, bones, hair Sr-C.
-For example, iodine – we take for granted, but sea salt and by-products (marine fish, seaweed) were once $$$.

Historical Use of Geology in Health Issues

c. Examples of Hippocrates and Greeks. Thermal springs and metals could be bad for your health (People and Spa's – Radioactivity---Radium (Ra) Hot Springs (Md Currie).

d. Aristotle wrote about lead poisoning in miners.

e. For example in the book of Marco Polo. There was a region where you could not take your horse as the plants were poisonous and the animal's hoofs would fall off if it ate these plants – selenium poisoning? (Se poisoning – e.g. birds in California drainage area – irrigation problem)

Historical Use of Geology in Health Issues

f. Roman's and their use of lead containers for wine and lead as a preservative – plumbism – birth control and mental problems – fall of the Roman Empire. Also Tin (Sn) – British Navy food preserves.
g. In many cases by-products of rock and mineral powders and certain elements were used as treatments for plague, smallpox, fevers, etc. (As – for some diseases)
h. The study of geology linked to health issues really began about 300 years ago. It was not popular with the medical profession (they were still into bleeding and leeching patients). But in the last few decades there has been a large resurgence.

Some Examples of Myths and Geology (Missed or Misdiagnosed)

a. Mercury and placer gold mining in Brazil

- severe Hg problems associated with gold mining operations? (*Hg to recover gold in smelting)
- well partly, but much of the mercury is bound in organic rich sediments in the area and is naturally released slowly to the ecological system by microbial processes
- process of erosion and transport naturally slow
- the problem was severely exacerbated by the placer mining due to dredging and increase in erosion and sediment transport (*Hg was entombed in sediments and is now released in greater quantities than natural systematics). No preliminary surveys to assess potential threats.

Some Examples of Myths and Geology (Missed or Misdiagnosed)

b. Natural Hg in Haliburton Ontario Lakes—fish

- Thought to be long range transport of aerosols from mining.
- Detailed geochemistry studies found Hg related to gaseous transport along faults to surface – Problem was natural.
- Man made – build a dam, pressure on the rock sometimes causes volatile release e.g. Hg

Some Examples of Myths and Geology (Missed or Misdiagnosed)

c. Finland: Drain old agricultural land to plant trees – ph7↓ to 3 (acid rain) – release of heavy metals entombed in the old glacial muds. (Where does the mud – glacial clay come from – ground up Shield rocks rich in Metals

e.g. $FeS \rightarrow S \rightarrow$ Sulphur Acids).

Some Examples of Myths and Geology (Missed or Misdiagnosed)

Quote

"Every day we eat, drink, breathe minerals and trace elements." Paracelsus – Medical Geology, Selinus *et al.* 2013

- Do we think about the environment those compounds come from?
- Usually harmless, mostly beneficial (essential nutrients) – BUT in many cases it can be very bad.

Some Examples of Myths and Geology (Missed or Misdiagnosed)

What do you look for?

a. Safe – landslides – stable – no threat of fire
b. Water supply – what do you test? (NO_3, F, metals, Na/Ca, HCO_3/SO_4) (Hard Water Ca+HCO_3)
c. What do we know BC is famous for? (hot springs – one is called Radium hot springs)
d. What have you forgotten? Radiation – Radon

Overview

- Dust (covered extensively later – Asthma or Silicates)
- Most sensational is asbestos but dust particles are taxi's for pathogens, fungus spores, toxins, pesticides, heavy metals.
- Because of our ability to analyze more precisely and at nano-concentrations -- the world of dust has become a much more complex area of study.

Overview

1. Aside: asbestos: a term for many different minerals.

- The actual serpentine mineral – chrysotile – is relatively harmless compared to the amphibole minerals.
- In some cases the “blue” asbestos minerals have caused huge health problems as they are intergrown with the other asbestos minerals.

Overview

1. Aside: asbestos: many different minerals cont'd.

- For example, at high temperatures and magmatic conditions (1000's °C) you form minerals such as **olivine and pyroxene** (see formula below). These are building block minerals of dark or mafic-ultramafic rocks.
- They are unstable rocks/minerals and later as hot solutions move through the rock they alter.

Olivine → Serpentine (chrysotile)

$$3Mg_2\,SiO_4 + 4H_2O + SiO_2 \rightarrow 2\ Mg_3\,Si_2\,O_5\,(OH)_4$$

…also alters further to TALC

Overview

1. Aside: asbestos: many different minerals cont'd.

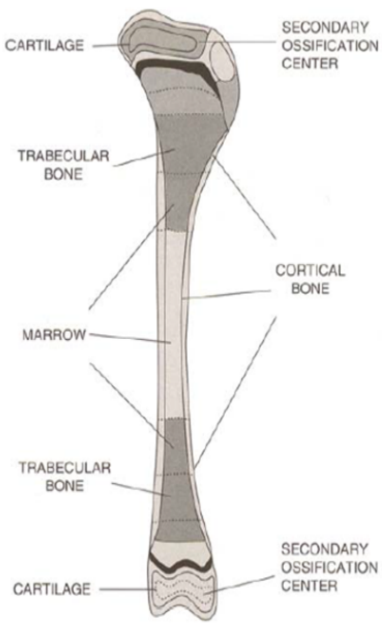
- Other minerals and the serpentine can further alter and in some cases such as at Libby, Montana, the valuable clay mineral vermiculite (Mg, Ca, Fe, Al, Si, O, OH, and H_2O) forms. Also a manufacturing plant in Minneapolis, Minnesota – shipped worldwide)

- The miners and the town did not realize for a long time that much of the non-vermiculite waste minerals were "blue" asbestos/amphiboles, tremolite which can be very carcinogenic. A geological time bomb. Worse yet "free piles of fill for gardens, driveways etc. 18% of the people affected, 24 died – many still not free of the problem.

Overview

2. Pathogens: In 1994 a series of landslides in southern California (Simi Valley) created a large amount of dust. The dust carried a soil fungus (coccidioides immitis) which caused a severe condition called “valley fever”. Not only people got sick, but the sea otter population is now infected as well.

You are What You Eat



Numerous examples:

1. First – your bones – This is a longer term situation than some others we will discuss.
   a. Bones – store elements
   b. Main building block – Hydroxylapatite

   $Ca_5\ (PO_4)_3\ (OH, F, Cl)$ vs. Mineral Apatite

   c. So to form this you need Ca-P which are in most diets.

BUT: What happens if you live in an environment that either has a lack of Ca or P ; OR an excess of an element that can substitute into the structure.

You are What You Eat

$_{1}$H																	$_{2}$He
$_{3}$Li	$_{4}$Be											$_{5}$B	$_{6}$C	$_{7}$N	$_{8}$O	$_{9}$F	$_{10}$Ne
$_{11}$Na	$_{12}$Mg											$_{13}$Al	$_{14}$Si	$_{15}$P	$_{16}$S	$_{17}$Cl	$_{18}$Ar
$_{19}$K	$_{20}$Ca	$_{21}$Sc	$_{22}$Ti	$_{23}$V	$_{24}$Cr	$_{25}$Mn	$_{26}$Fe	$_{27}$Co	$_{28}$Ni	$_{29}$Cu	$_{30}$Zn	$_{32}$Ga	$_{32}$Ge	$_{33}$As	$_{34}$Se	$_{36}$Br	$_{36}$Kr
$_{37}$Rb	$_{38}$Sr	$_{39}$Y	$_{40}$Zr	$_{41}$Nb	$_{42}$Mo	$_{43}$Tc	$_{44}$Ru	$_{45}$Rh	$_{46}$Pd	$_{47}$Ag	$_{48}$Cd	$_{49}$In	$_{50}$Sn	$_{51}$Sb	$_{52}$Te	$_{53}$I	$_{54}$Xe
$_{55}$Cs	$_{56}$Ba	57-71	$_{72}$Hf	$_{73}$Ta	$_{74}$W	$_{75}$Re	$_{76}$Os	$_{77}$Ir	$_{78}$Pt	$_{79}$Au	$_{80}$Hg	$_{81}$Tl	$_{82}$Pb	$_{83}$Bi	$_{84}$Po	$_{85}$At	$_{86}$Rn
$_{87}$Fr	$_{88}$Ra	89-103	$_{104}$Db	$_{105}$Jo	$_{106}$Rf	$_{107}$Bh	$_{108}$Hn	$_{109}$Mt	110	111							
		$_{57}$La	$_{58}$Ce	$_{59}$Pr	$_{60}$Nd	$_{61}$Pm	$_{62}$Sm	$_{63}$Eu	$_{64}$Gd	$_{65}$Tb	$_{66}$Dy	$_{67}$Ho	$_{68}$Er	$_{69}$Tm	$_{70}$Yb	$_{71}$Lu	
		$_{89}$Ac	$_{90}$Th	$_{91}$Pa	$_{92}$U	$_{93}$Np	$_{94}$Pu	$_{95}$Am	$_{96}$Cm	$_{97}$Bk	$_{98}$Cf	$_{99}$Es	$_{100}$Fm	$_{101}$Md	$_{102}$No	$_{108}$Lr	

Figure 1 Periodic table illustrating major elements (*pink*), minor elements (*blue*), trace elements (*yellow*), and noble gases (*gray*) in the biosphere. Those in green are essential trace elements. Known established toxic elements are shown in *red*

(Selinus *et al.* 2013)

All substances are poisons; there is none which is not a poison. The right dose differentiates a poison from a remedy. ~ Paracelsus (1493-1541)

You are What You Eat

i. Periodic Table: Ca – (Mg ~ 1% of bone)

ii. Mg is important in other metabolic reactions.

iii. So bones are a storehouse – if Mg missing we consume bone Mg. Later if Mg is available re-deposited in bone.

iv. Ca – Sr (can form $(Sr, Ca)_5 (PO_4)_3 OH$) strontium apatite

v. Very small amounts, but what if the available Sr was ^{90}Sr the radioactive isotope, e.g. bomb testing, reactor problems

vi. Finally, OH site OH^-

vii. Note halides F, Br, Cl, I

viii. F → in very small amounts strengthens teeth, etc. BUT in higher concentrations mottled teeth, embrittlement, flurosis.

You are What You Eat

2. Arsenic: one example from China
   - in some areas chili peppers are important in diet so villagers have to dry them to store them for long term use
   - run out of wood because of overuse
   - turn to using cheap lignite coal (brown coal). Organic coal accumulates and concentrates many trace metals, e.g. As (arsenic) up to 35,000 ppm
   - in the process of drying, chilies take up As and many now suffer from arsenic poisoning hyperpigmentation (flushed skin, freckles)
   - hyperkeratosis (scaly skin – hands, feet) also in advanced cases squamous cell carcinoma

You are What You Eat

WORSE YET: The coal is loaded with fluorine and many more people (10 million) in the area now suffer from fluorosis – severe skeletal deformation. (In the category that you just cannot win, the bricks used in the drying ovens were made from a limestone ($CaCO_3$) that contained extremely high F levels).

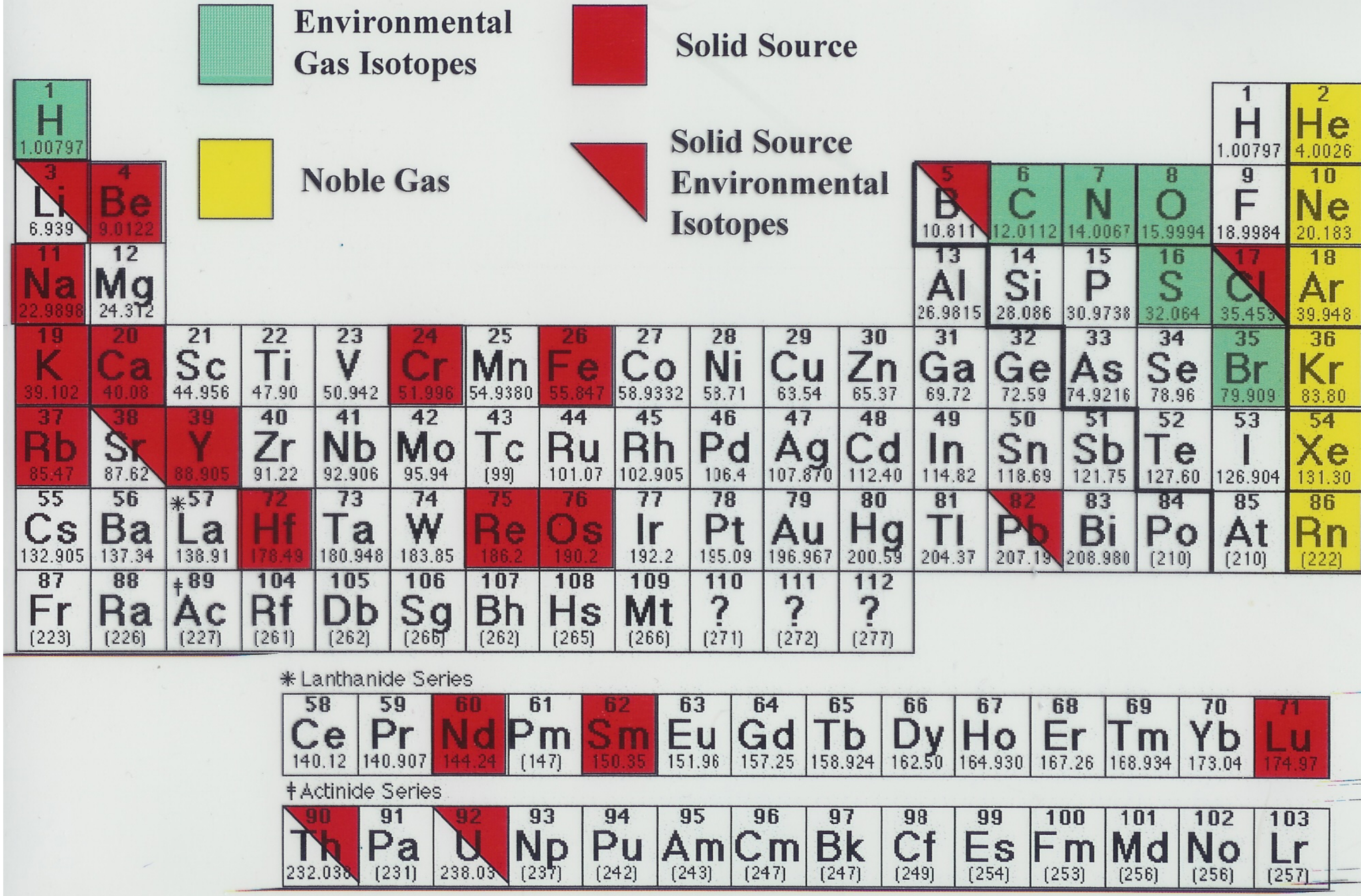
Isotope Theory Background

- Isotope fractionation due to different masses = differences in physical and chemical processes
- Fractionation due to:
  - Exchange Reactions
  - Kinetic Processes – Reaction Rates
- Mass spectrometry
- Measure ratios and express relative differences in per-mil:
- δ (‰) = $[(R_{sample} - R_{standard}) / R_{standard}] \times 1000$

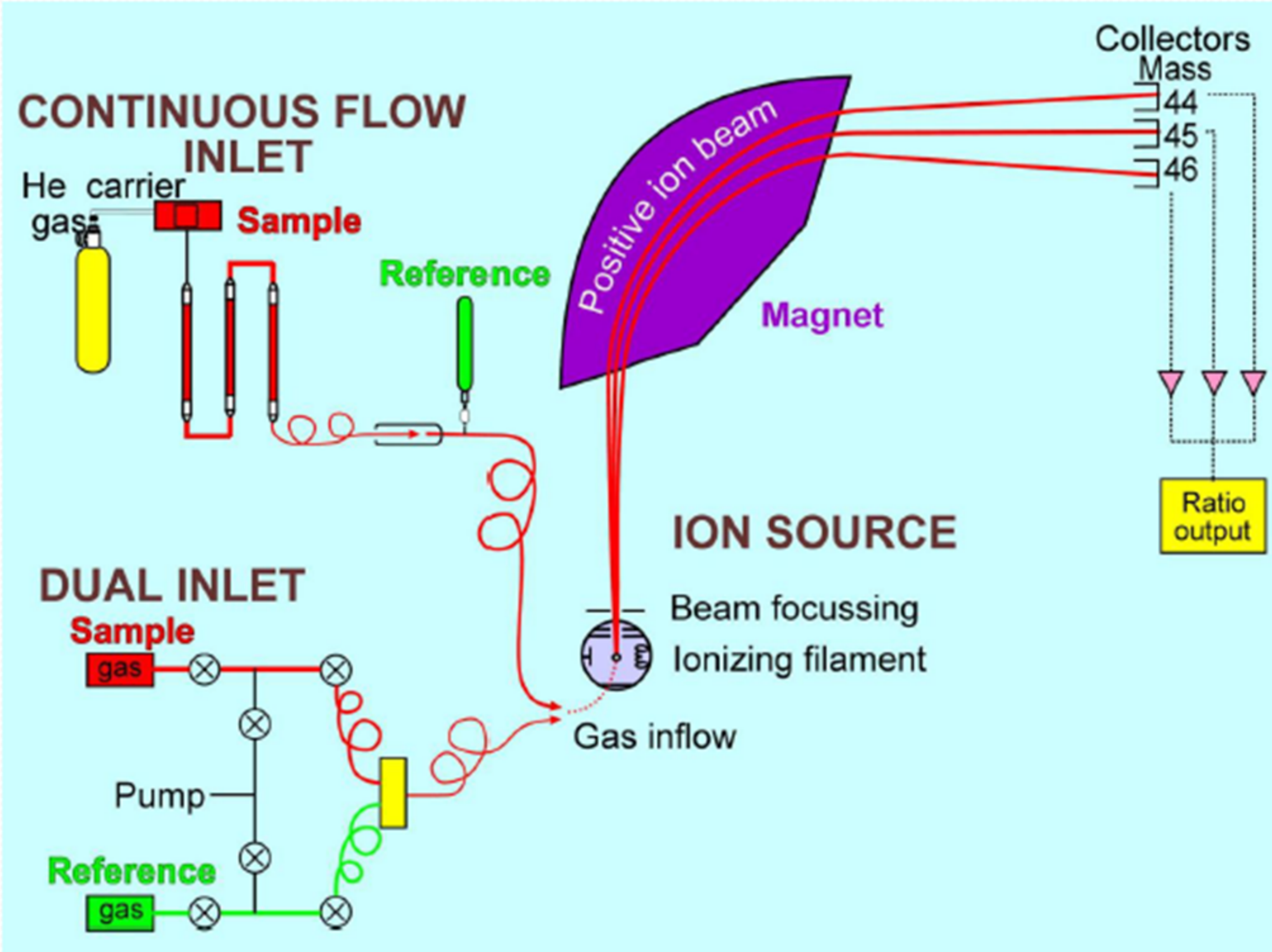
Isotopes and Elements

Atoms

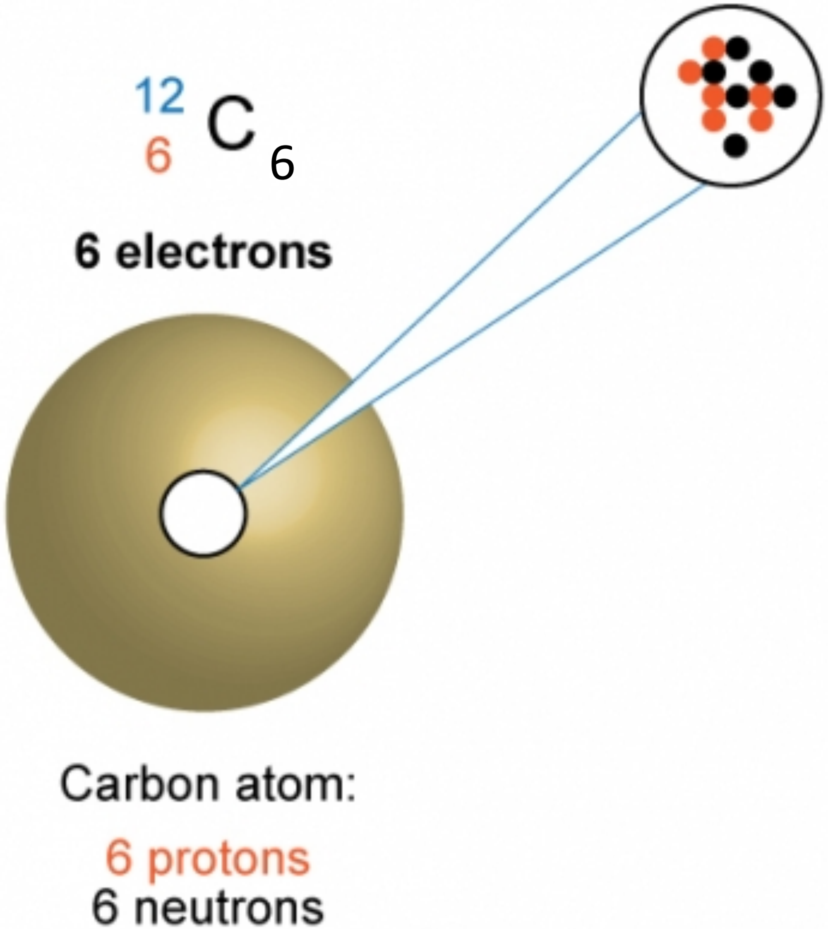
- Protons (Z) define element
- Neutrons (N) define isotope of element
- A (Atomic weight) = Z+N
- Notation: ${}^{A}_{Z}X_{N}$
- Example: ${}^{16}_{8}O_{8}$ *versus* ${}^{18}_{8}O_{10}$

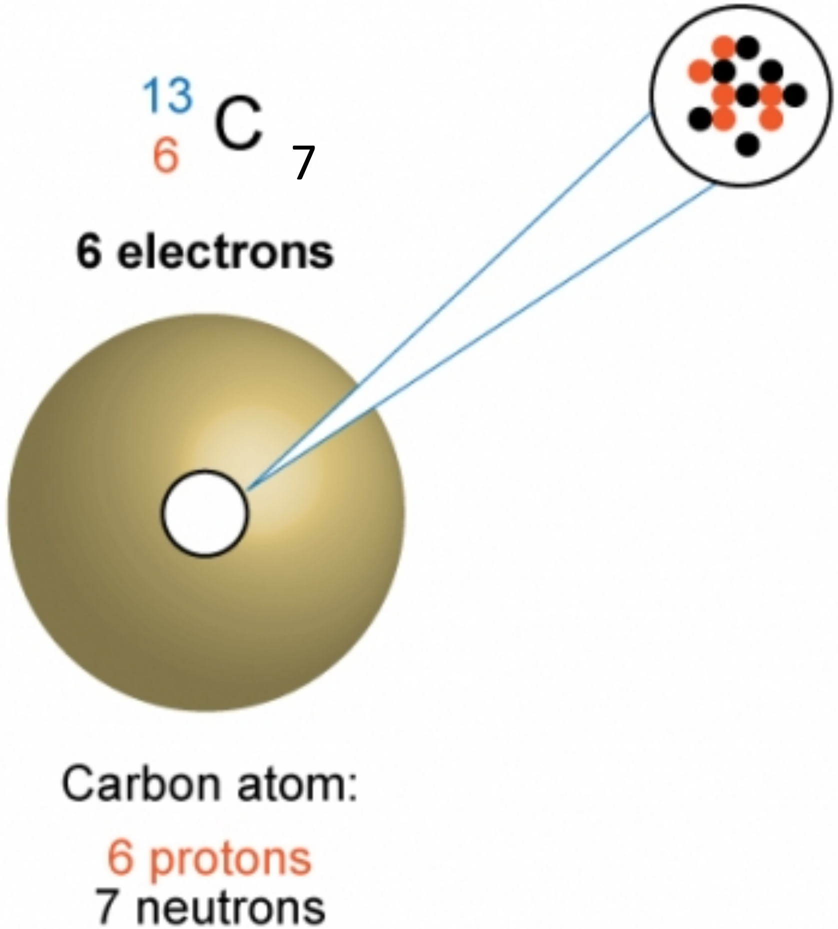

Environmental Gas Isotopes
Solid Source
Noble Gas
Solid Source Environmental Isotopes
1 H 1.00797
1 H 1.00797 | 2 He 4.0026
3 Li 6.939 | 4 Be 9.0122 | 5 B 10.811 | 6 C 12.0112 | 7 N 14.0067 | 8 O 15.9994 | 9 F 18.9984 | 10 Ne 20.183
11 Na 22.9898 | 12 Mg 24.312 | 13 Al 26.9815 | 14 Si 28.086 | 15 P 30.9738 | 16 S 32.064 | 17 Cl 35.453 | 18 Ar 39.948
19 K 39.102 | 20 Ca 40.08 | 21 Sc 44.956 | 22 Ti 47.90 | 23 V 50.942 | 24 Cr 51.996 | 25 Mn 54.9380 | 26 Fe 55.847 | 27 Co 58.9332 | 28 Ni 58.71 | 29 Cu 63.54 | 30 Zn 65.37 | 31 Ga 69.72 | 32 Ge 72.59 | 33 As 74.9216 | 34 Se 78.96 | 35 Br 79.909 | 36 Kr 83.80
37 Rb 85.47 | 38 Sr 87.62 | 39 Y 88.905 | 40 Zr 91.22 | 41 Nb 92.906 | 42 Mo 95.94 | 43 Tc (99) | 44 Ru 101.07 | 45 Rh 102.905 | 46 Pd 106.4 | 47 Ag 107.870 | 48 Cd 112.40 | 49 In 114.82 | 50 Sn 118.69 | 51 Sb 121.75 | 52 Te 127.60 | 53 I 126.904 | 54 Xe 131.30
55 Cs 132.905 | 56 Ba 137.34 | *57 La 138.91 | 72 Hf 178.49 | 73 Ta 180.948 | 74 W 183.85 | 75 Re 186.2 | 76 Os 190.2 | 77 Ir 192.2 | 78 Pt 195.09 | 79 Au 196.967 | 80 Hg 200.59 | 81 Tl 204.37 | 82 Pb 207.19 | 83 Bi 208.980 | 84 Po (210) | 85 At (210) | 86 Rn (222)
87 Fr (223) | 88 Ra (226) | †89 Ac (227) | 104 Rf (261) | 105 Db (262) | 106 Sg (266) | 107 Bh (262) | 108 Hs (265) | 109 Mt (266) | 110 ? (271) | 111 ? (272) | 112 ? (277)
* Lanthanide Series
58 Ce 140.12 | 59 Pr 140.907 | 60 Nd 144.24 | 61 Pm (147) | 62 Sm 150.35 | 63 Eu 151.96 | 64 Gd 157.25 | 65 Tb 158.924 | 66 Dy 162.50 | 67 Ho 164.930 | 68 Er 167.26 | 69 Tm 168.934 | 70 Yb 173.04 | 71 Lu 174.97
† Actinide Series
90 Th 232.038 | 91 Pa (231) | 92 U 238.03 | 93 Np (237) | 94 Pu (242) | 95 Am (243) | 96 Cm (247) | 97 Bk (247) | 98 Cf (249) | 99 Es (254) | 100 Fm (253) | 101 Md (256) | 102 No (256) | 103 Lr (257)

Isotope Ratio Mass Spectrometry



Carbon





https://online.science.psu.edu/

Plants and Plant Products in Relation to $\delta^{13}C$

Methodology:

Standard = PDB
CO_2 gas in to mass spectrometer

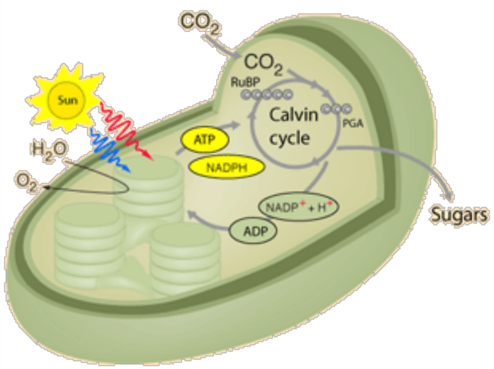
$$\delta^{13}C‰ = \frac{R_{(sample)} - R_{(standard)}}{R_{(standard)}}$$

Plants: Fix carbon due to different enzyme constraints or pathways during photosynthesis.

C_3 plants (Calvin)

$\delta^{13}C$ = -35 to -22‰

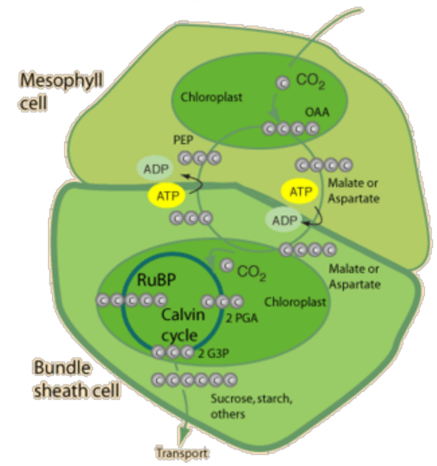
Potato	-27.7
Tomato	-25.0
Maple	-27.7
Orange	-26.0



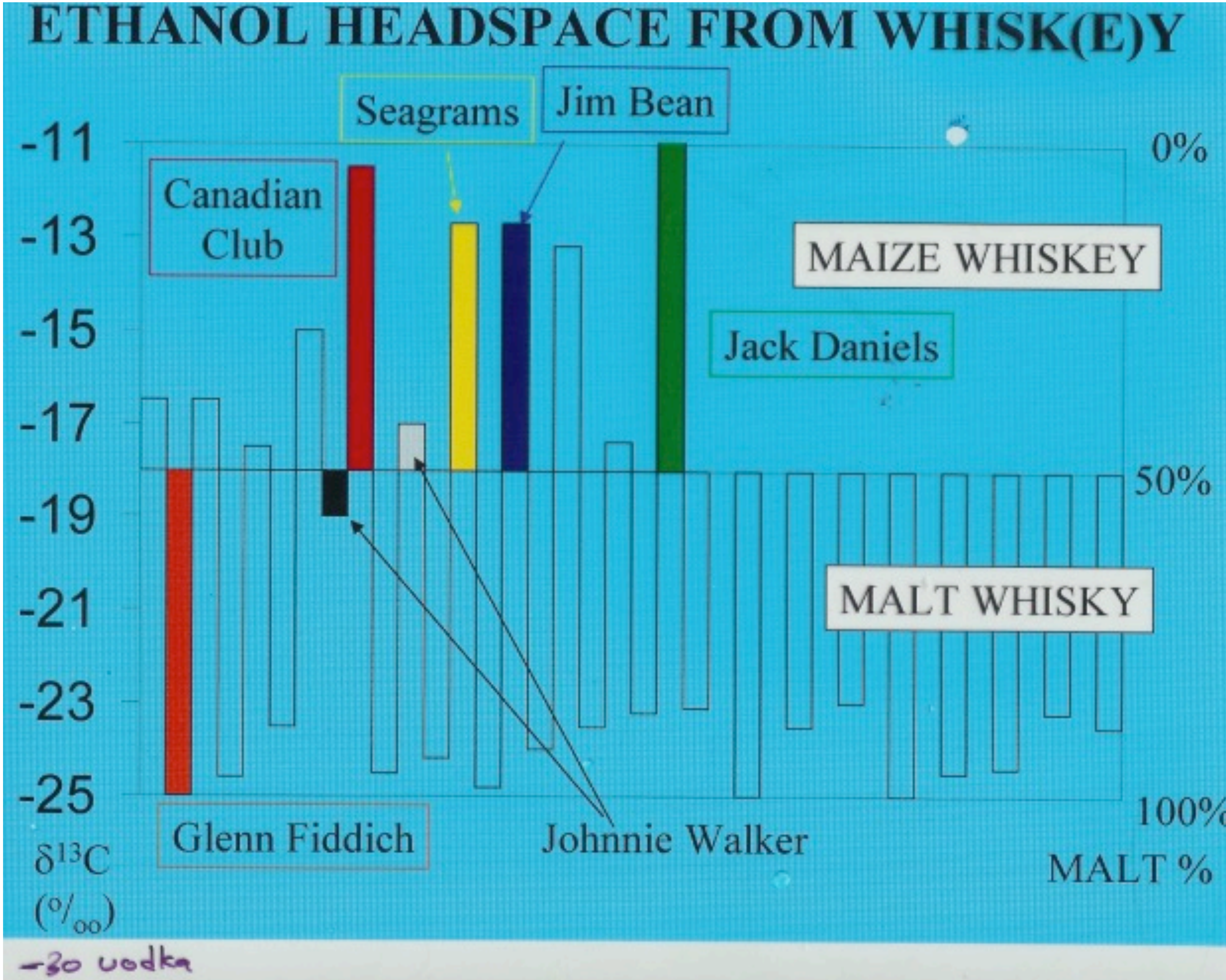
C_4 plants (Hatch-Slack)

$\delta^{13}C$ = -16 to -8‰

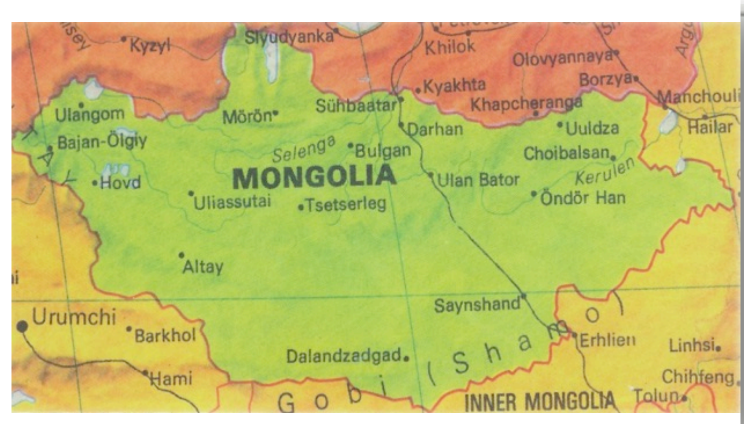
Maize	-11.2
Corn	-9.5
Grasses	-7 to -10



Calvin Cycle and Hatch-Slack Cycle
http://www.majordifferences.com/2013/05/difference-between-c3-and-c4-cycle.



ETHANOL HEADSPACE FROM WHISK(E)Y
Seagrams
Jim Bean
Canadian Club
MAIZE WHISKEY
Jack Daniels
MALT WHISKY
Glenn Fiddich
Johnnie Walker
-11
-13
-15
-17
-19
-21
-23
-25
$\delta^{13}C$ (°/oo)
0%
50%
100%
MALT %
-30 vodka



You are what you eat…

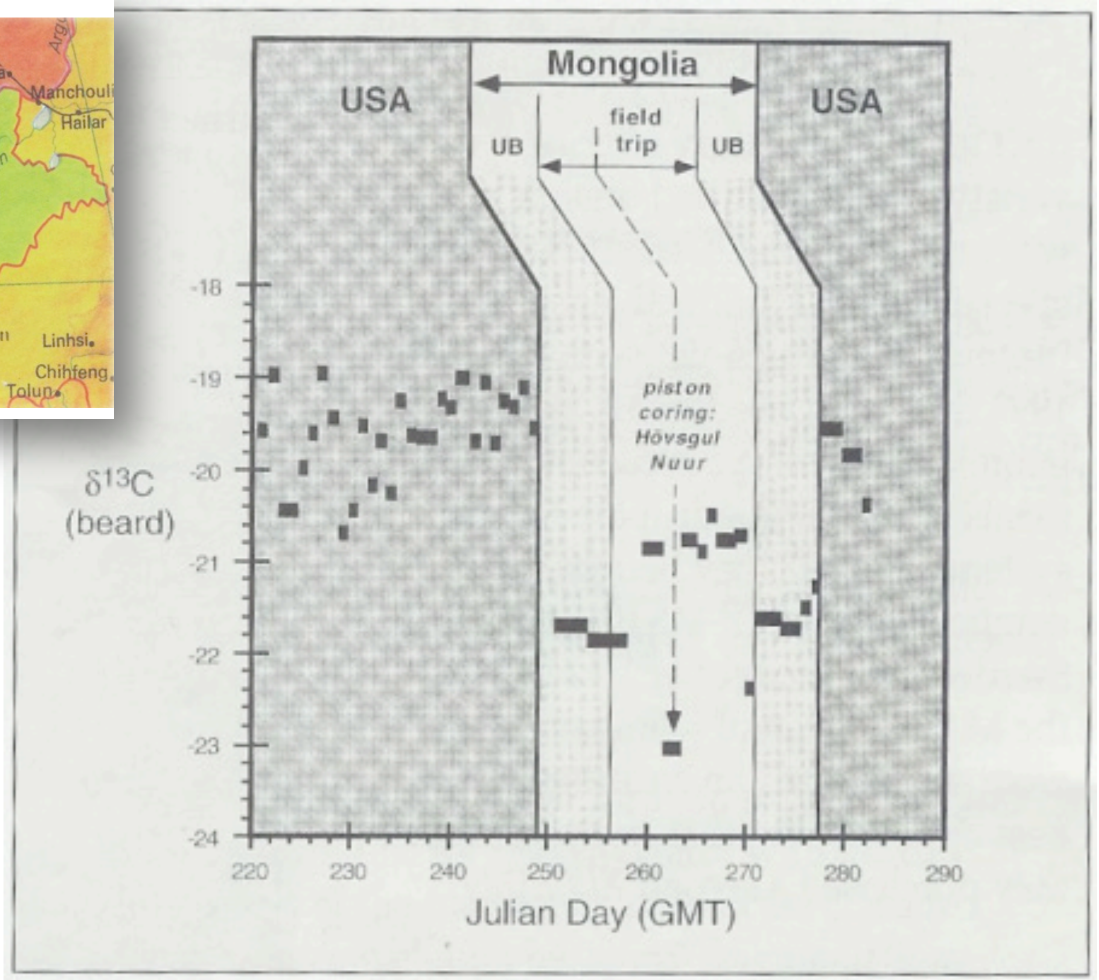


Figure 1: This figure plots the carbon isotopic composition of beard hair (expressed as $\delta^{13}C$) vs date that the hair was collected. The kinks in the Mongolian time lines correspond to the six-day time lag between hair formation and its eruption through the skin surface.

Why a shift in beard composition?

1. Hairs grow fast (any fast growing cells will substitute)
2. North America
   - C_4 plants dominate
   - food chain, e.g. corn and corn fed animals
3. Mongolia
   - C_3 plants dominate
4. $\delta^{13}C$ (C_3 = -22 to -35 permil) (C_4 = -8 to -16 permil)
5. Author avoided soft drinks (sugar cane C_4) and ate local diet – mutton, mare's milk
6. Mid session shift – field trip where imported sausage and cheese were combined with mutton. (vodka)

Environmental Isotopes Hydrogeology

a. "Complement Geochemical and Physical Hydrogeological Investigations"

b. Water = H_2O = $(^2H/^1H)_2$ $(^{18}O/^{16}O)$
Composed of Stable Isotopes

c. "Stable isotopic composition of water is modified by meteoric processes and therefore waters in a particular environment will have a characteristic isotopic signature."

d. Radioisotopes (e.g. tritium – ^3H) decay and can be used to measure flow times, "age" or renewability.

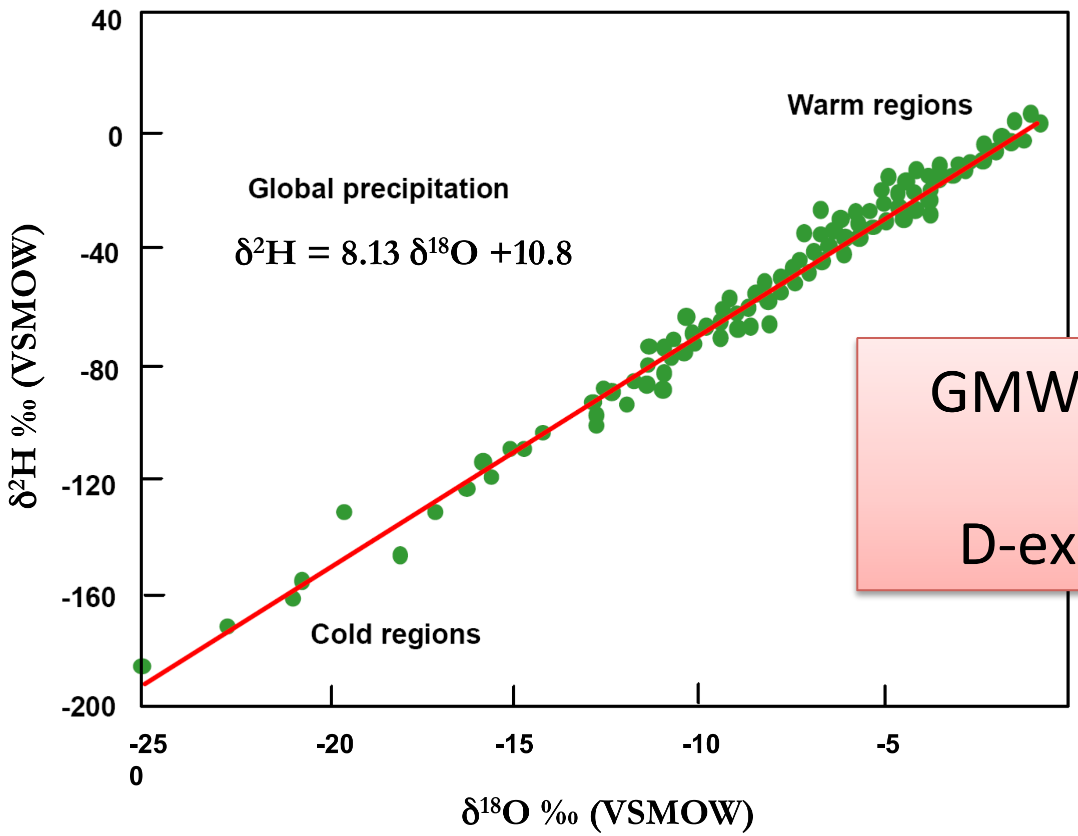
e. Uses: Provenance and age, also groundwater quality, geochemical evolution, recharge processes, rock-water interaction, origin of salinity, contaminant processes

Oxygen-18 (^{18}O)

- The Oxygen-18 composition of a sample is expressed in terms of *delta* (δ), calculated using the equation below and reported relative to a standard (VSMOW)

$$\delta^{18}O_{sample} = \left(\frac{\left(^{18}O/^{16}O\right)_{sample}}{\left(^{18}O/^{16}O\right)_{s\tan dard}} - 1 \right) \times 1000 \qquad \text{‰ VSMOW}$$

Oxygen-18 versus Deuterium in Precipitation



GMWL $\delta^2H = 8\delta^{18}O + 10$

D-excess = $\delta^2H - 8\delta^{18}O$

(Clark and Fritz, 1997)

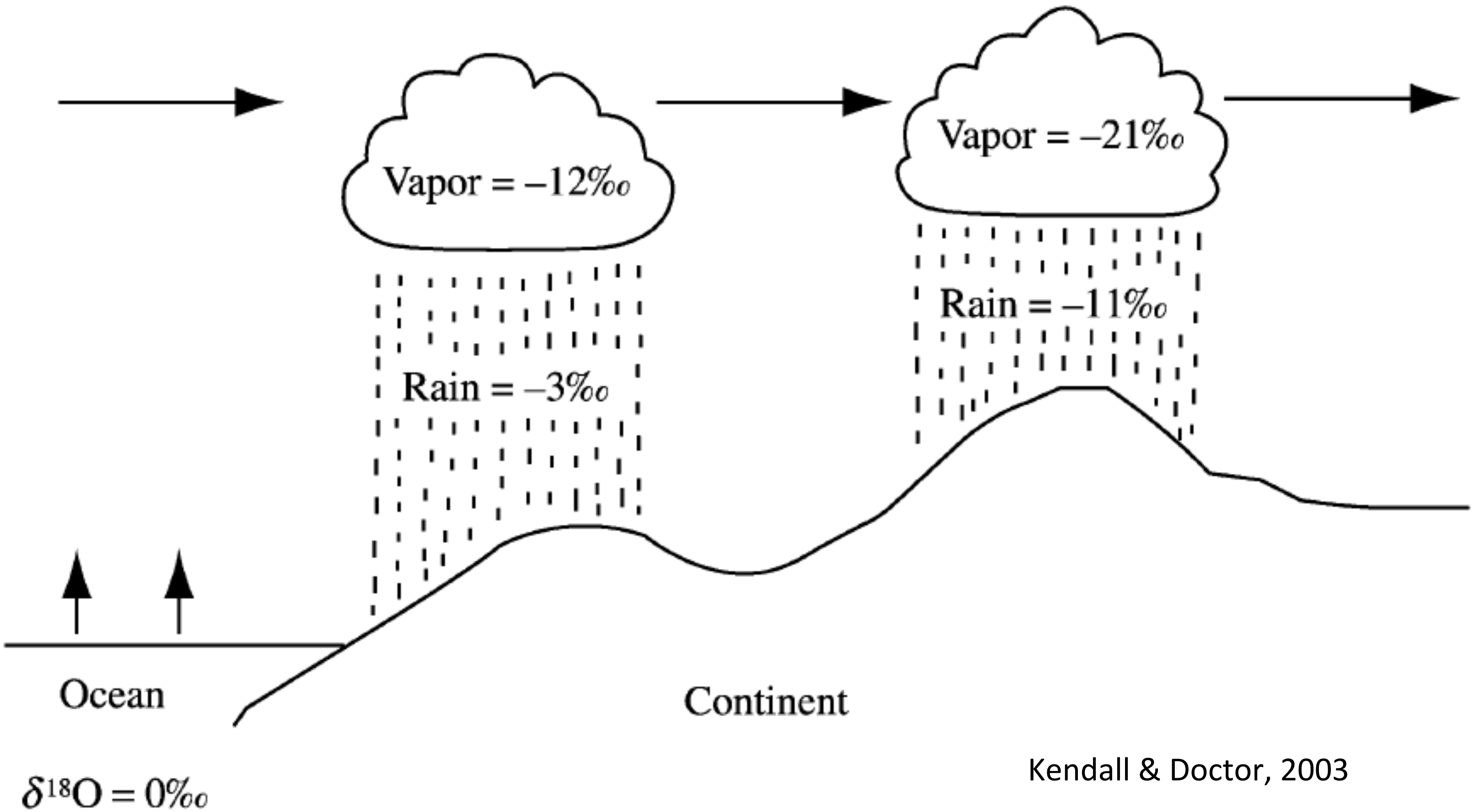
Climate Effects on Isotopic Signature

- Stable Isotope signature of precipitation depends on:
  - the temperature and relative humidity at the precipitation site.
  - Latitude, altitude and distance inland.
- D-excess depends on:
  - ocean surface temperature, air temperature and relative humidity

Climate Effects on Isotopic Signature

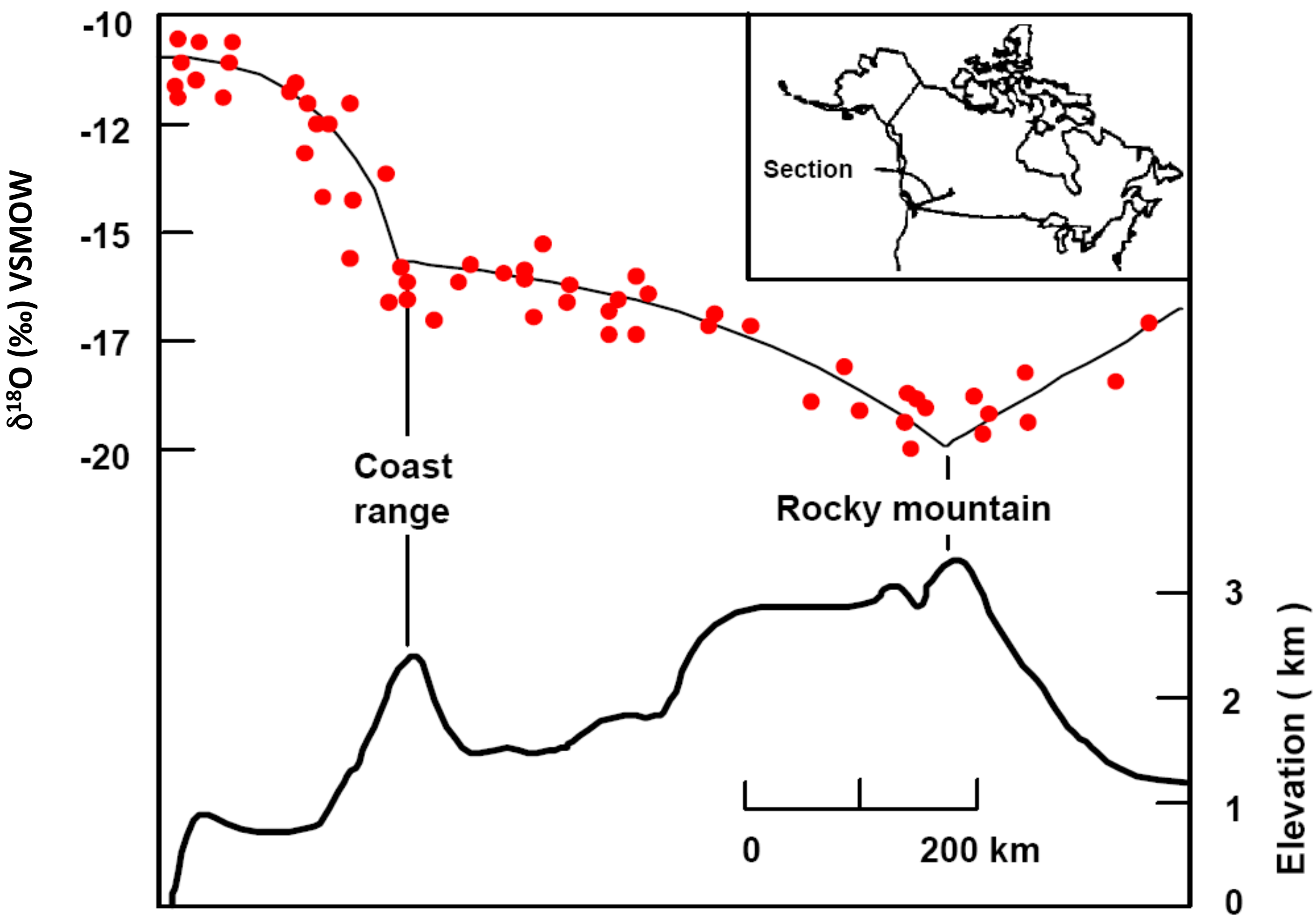
- Effects manifest themselves on several scales:
  - Isotopic composition of individual precipitation events can vary greatly from one another.
  - Seasonal changes
  - Long term climatic changes: glacial – interglacial cycles.

Water cycle



Kendall & Doctor, 2003

Mean ^{18}O in Precipitation from West Coast to Alberta Plains



(Clark and Fritz, 1997)

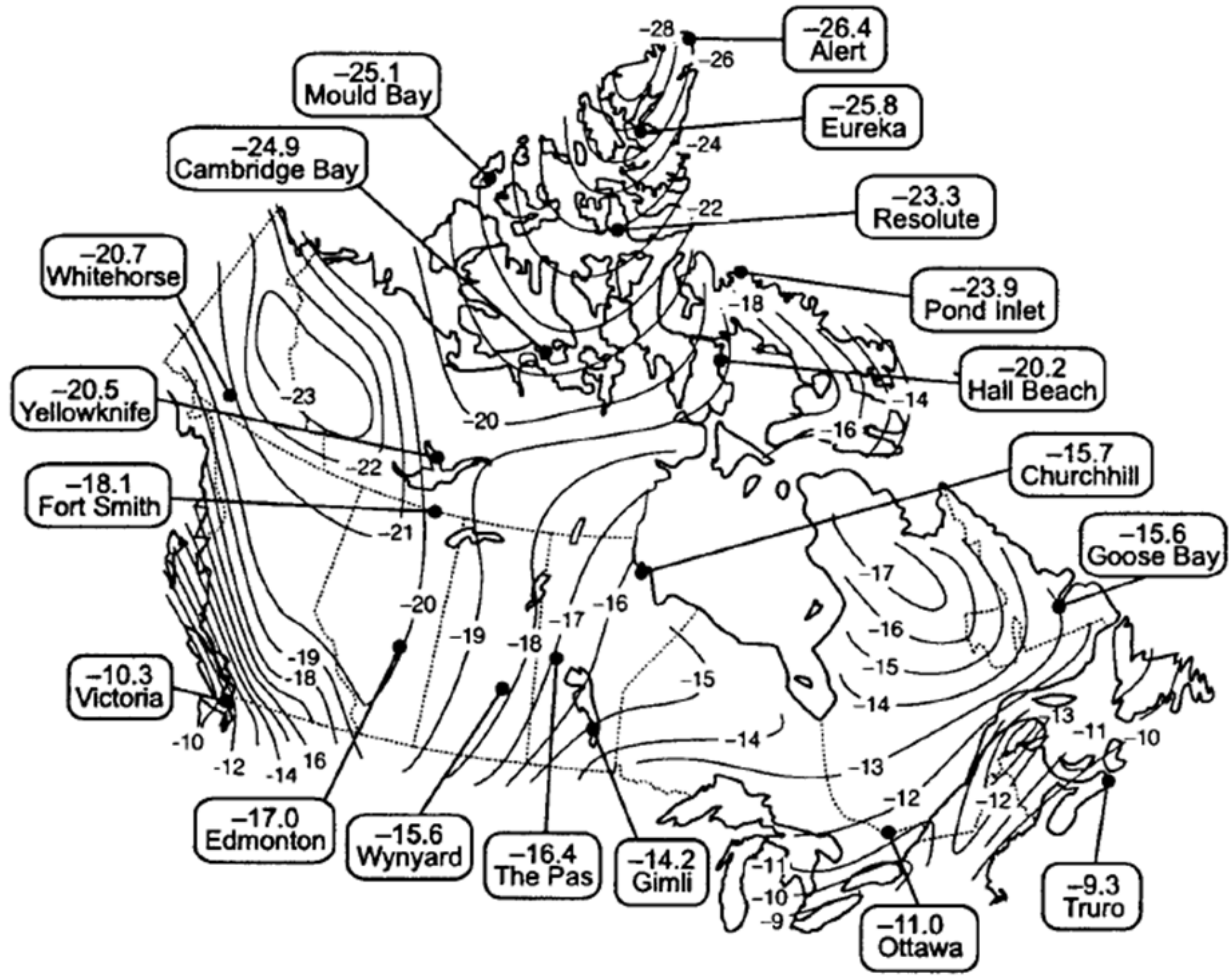


Fig. 4-5 The distribution of $\delta^{18}O$ values in locally recharged groundwater across Canada, and the weighted mean values for $\delta^{18}O$ in precipitation at monitoring stations (modified from Fritz et al., 1987a with additional regional groundwater data; Arctic precipitation data from Moorman et al., 1996).

Clark & Fritz, 1997

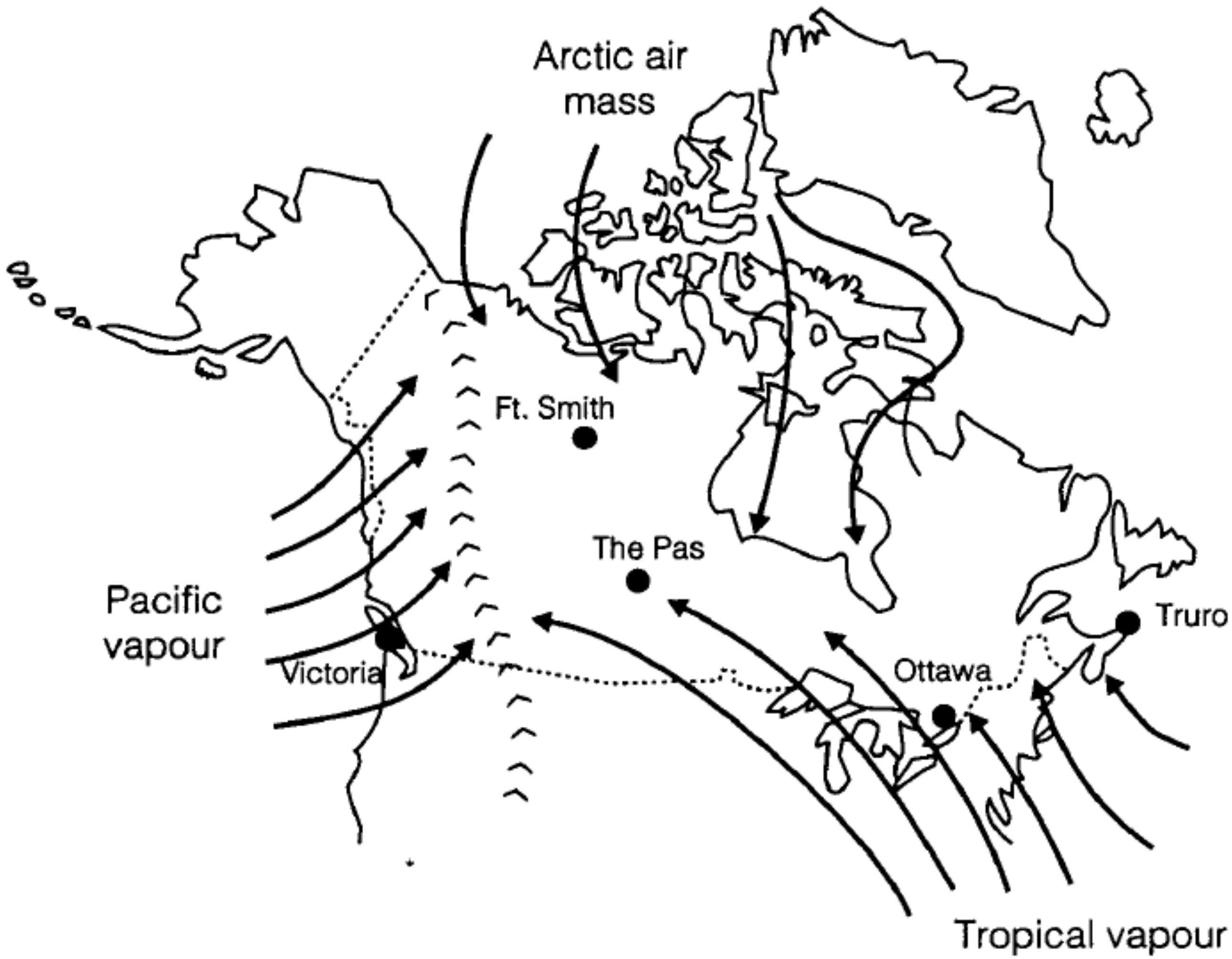


Fig. 2-19 Meteoric regimes in Canada. The effect of these systems on precipitation is seen in the local meteoric water lines for stations across the country. The Arctic air stream brings no moisture, except locally in the north during summer.

Clark & Fritz, 1997

Hydrogen and oxygen isotope ratios in human hair are related to geography

James R. Ehleringer*†‡, Gabriel J. Bowen†§, Lesley A. Chesson*†, Adam G. West†¶, David W. Podlesak*, and Thure E. Cerling*†‡

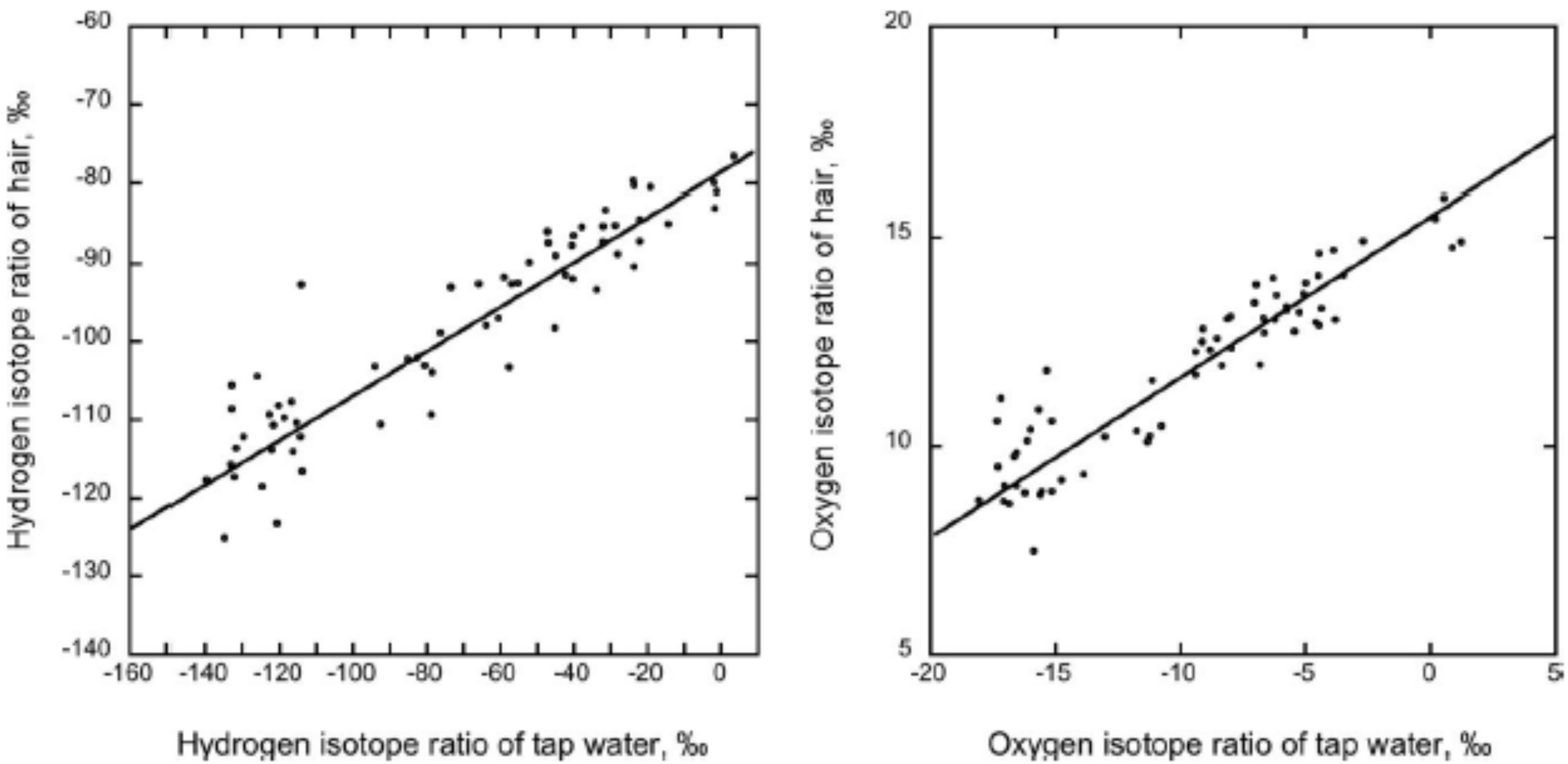


Fig. 1. Plots of the relationships between mean H isotope ratios (δ^2H) *(Upper)* and mean O isotope ratios (δ^{18}O) *(Lower)* of human scalp hair and tap water for samples randomly acquired in cities representing 18 states across the United States. The lines through the data in each plot represent model-predicted values based on local tap water and a continental supermarket diet.

Hydrogen and oxygen isotope ratios in human hair are related to geography

James R. Ehleringer[*†‡], Gabriel J. Bowen[†§], Lesley A. Chesson[*†], Adam G. West[†¶], David W. Podlesak[*],
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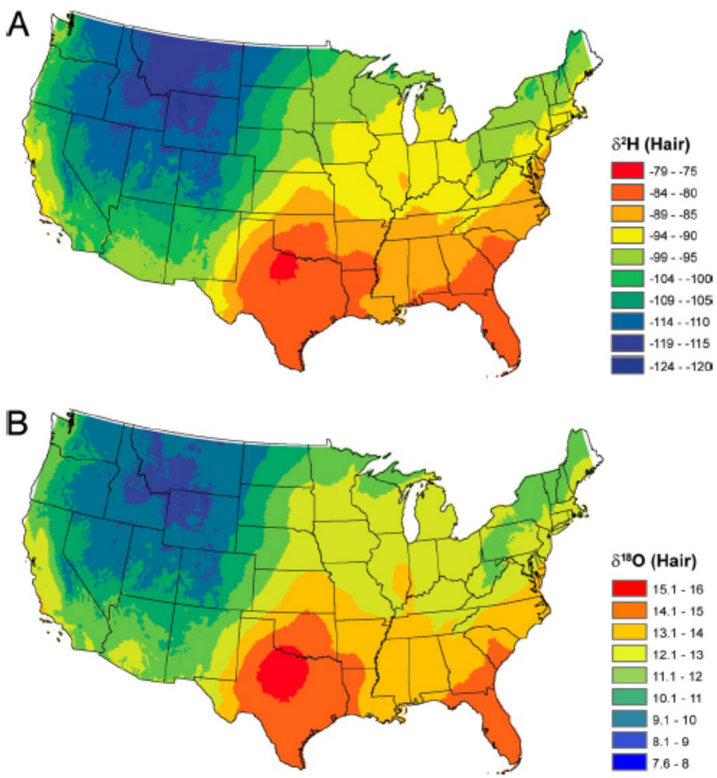
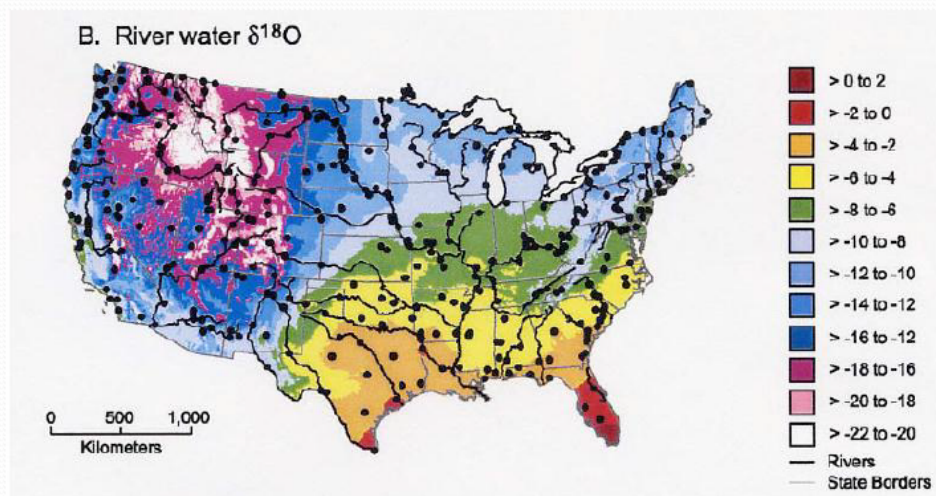


Fig. 3. Geographic Information System-generated maps of the predicted average H isotope ratios (δ^2H_h) (*A*) and average O isotope ratios ($\delta^{18}O_h$) (*B*) of human scalp hair across the coterminous United States.

Continental Effect for $\delta^{18}O$ in precipitation



Hydrogen and oxygen isotope ratios in human hair are related to geography

James R. Ehleringer*†‡, Gabriel J. Bowen†§, Lesley A. Chesson*†, Adam G. West†¶, David W. Podlesak*, and Thure E. Cerling*†‡

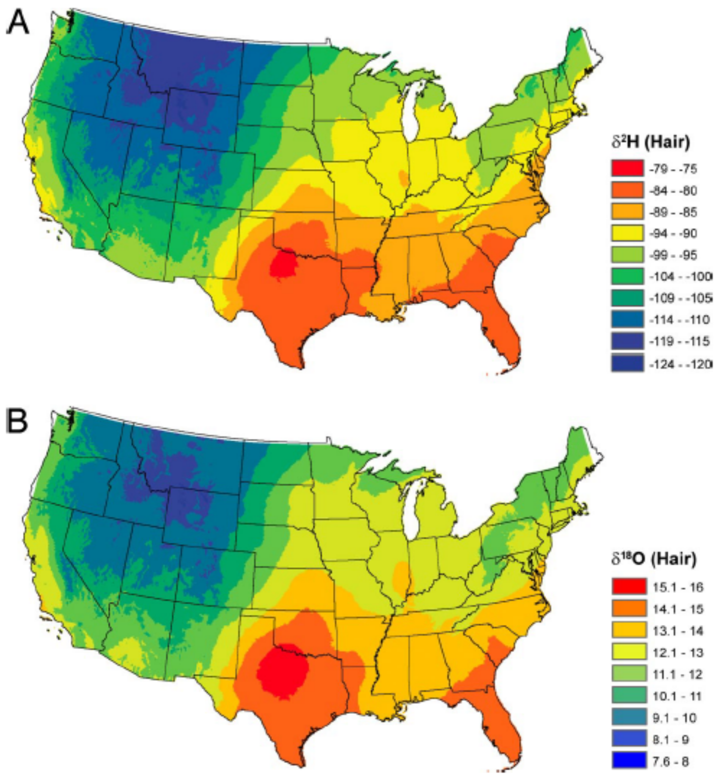
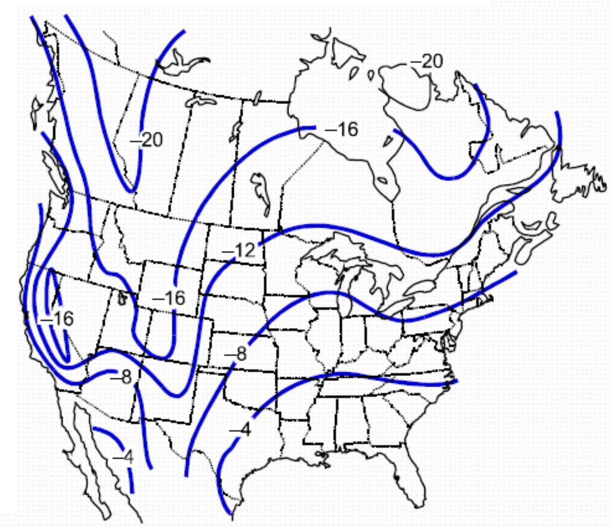


Fig. 3. Geographic Information System-generated maps of the predicted average H isotope ratios (δ^2H_h) (*A*) and average O isotope ratios ($\delta^{18}O_h$) (*B*) of human scalp hair across the coterminous United States.

Continental Effect for δ^{18}O in precipitation



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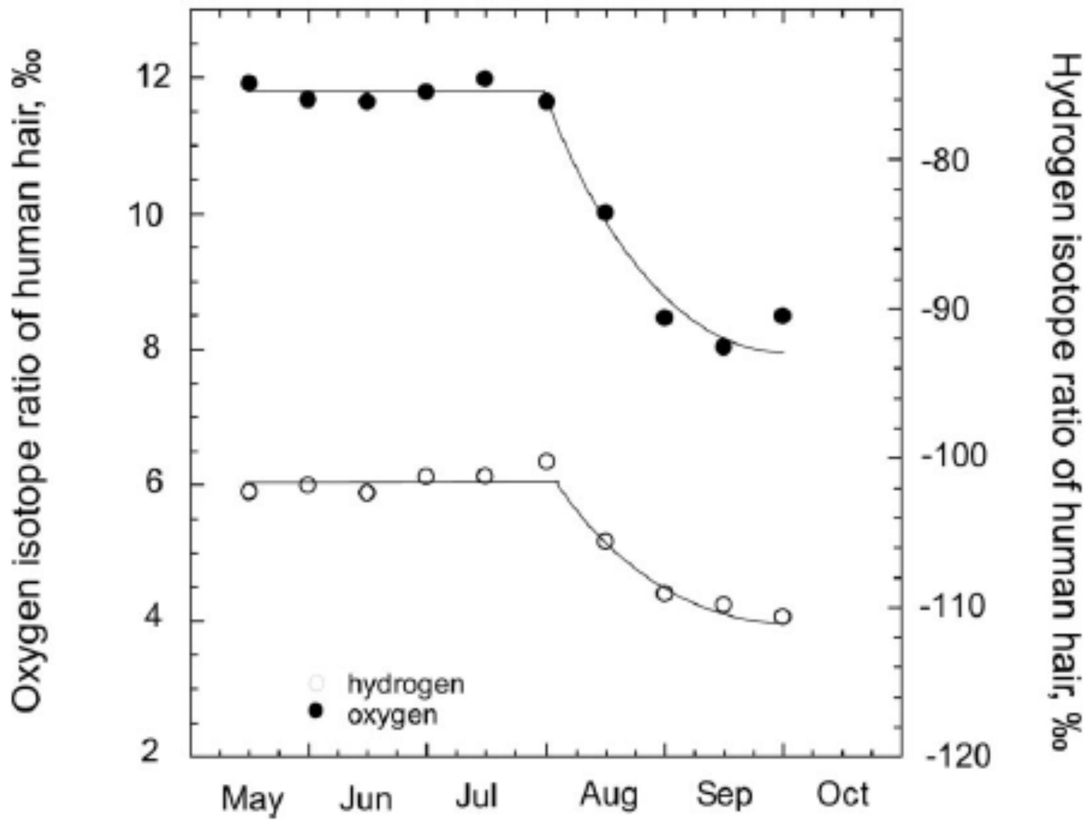
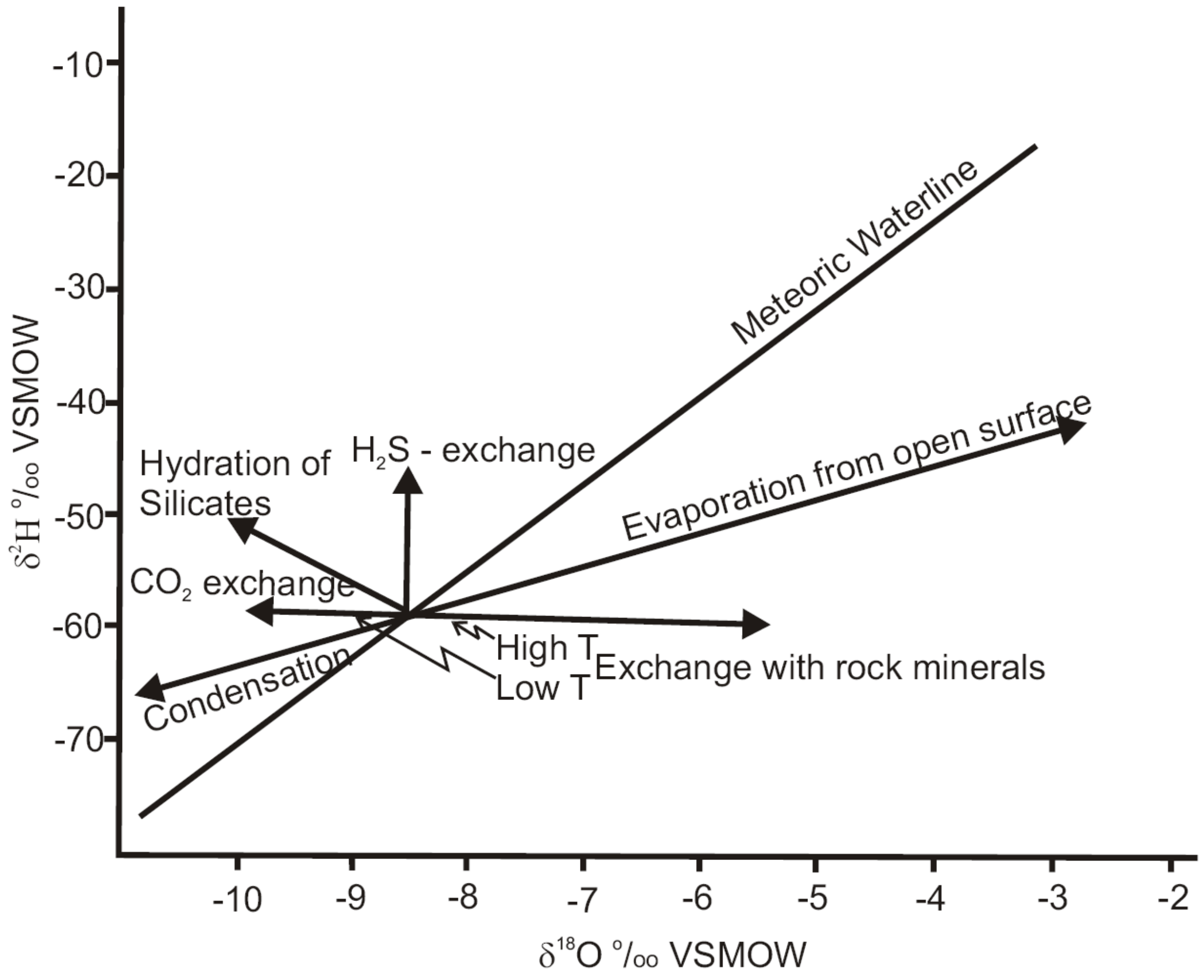


Fig. 4. Time sequence plots of the H (δ^2H_h) and O ($\delta^{18}O_h$) isotope ratios of human scalp hair along a basal-to-tip transect for an individual that moved from Beijing, China, to Salt Lake City, Utah.

^2H and ^{18}O in Groundwater

- Other processes can affect the isotopic signature:
  - Evaporation and condensation
  - Exchange with geologic materials
  - CO_2 exchange
  - Hydration of silicates
  - H_2S - exchange

Outline of Stable Isotope Fractionation from Meteoric Waterline



Environmental Radioisotopes

Isotope	Half-life (years)	Decay mode	Principle Sources	Commonly Measured Phases
^{3}H	12.43	ß$^{-}$	Cosmogenic, weapons testing	H_2O,CH_2O
^{14}C	5730	ß$^{-}$	Cosmogenic, weapons testing, nuclear reactions	DIC, DOC, CO_2, $CaCO_3$, CH_2O
^{36}Cl	301,000	ß$^{-}$	Cosmogenic and subsurface	Cl^-, surface Cl-salts

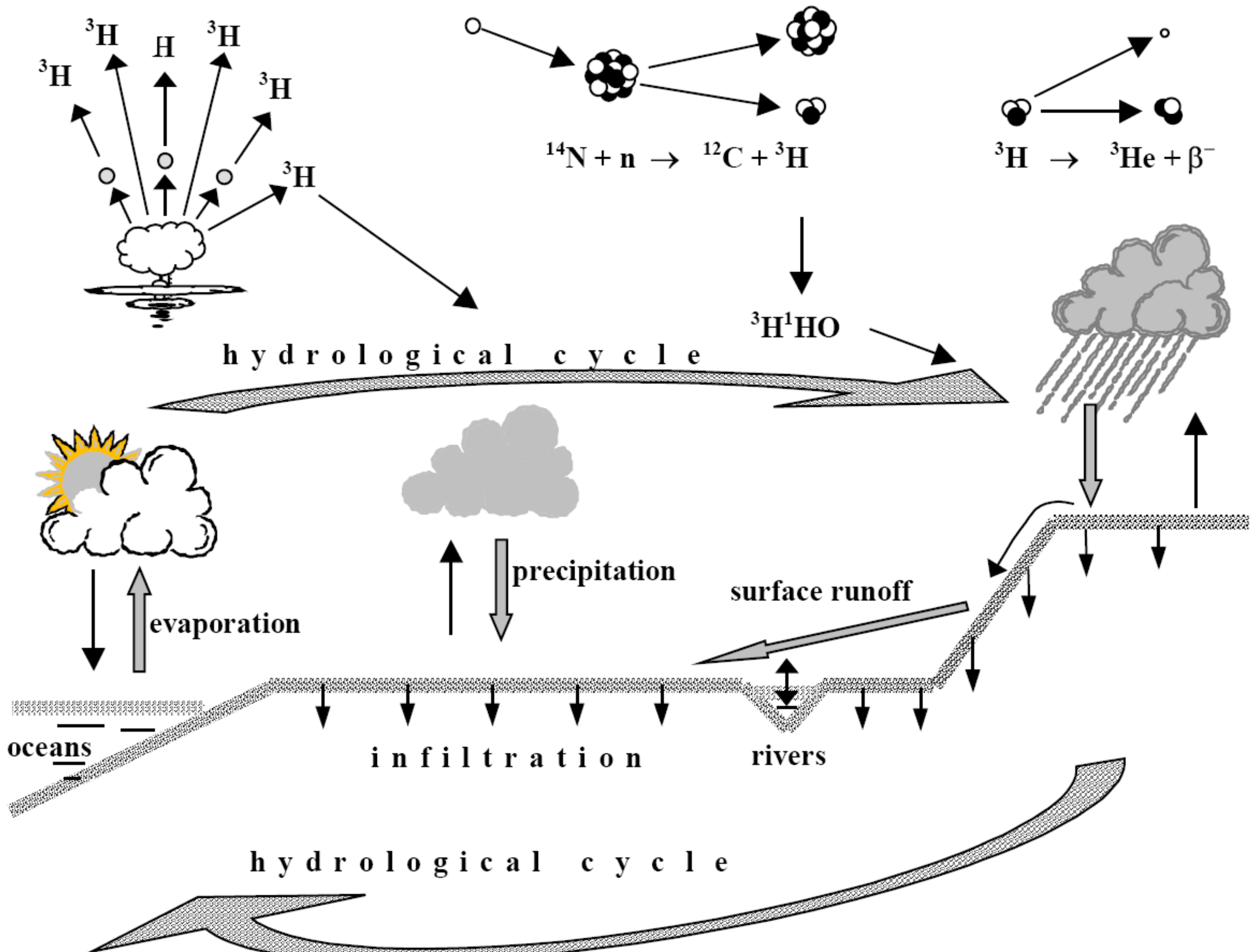
Tritium ^3H Theory

- Radioactive isotope
- Half life (time for half of mass to decay)
  - Tritium half life = 12.43 years
- Expressed as Tritium Units (TU's)
- 1 TU = 1 ^3H atom per 10^{18} atoms of hydrogen

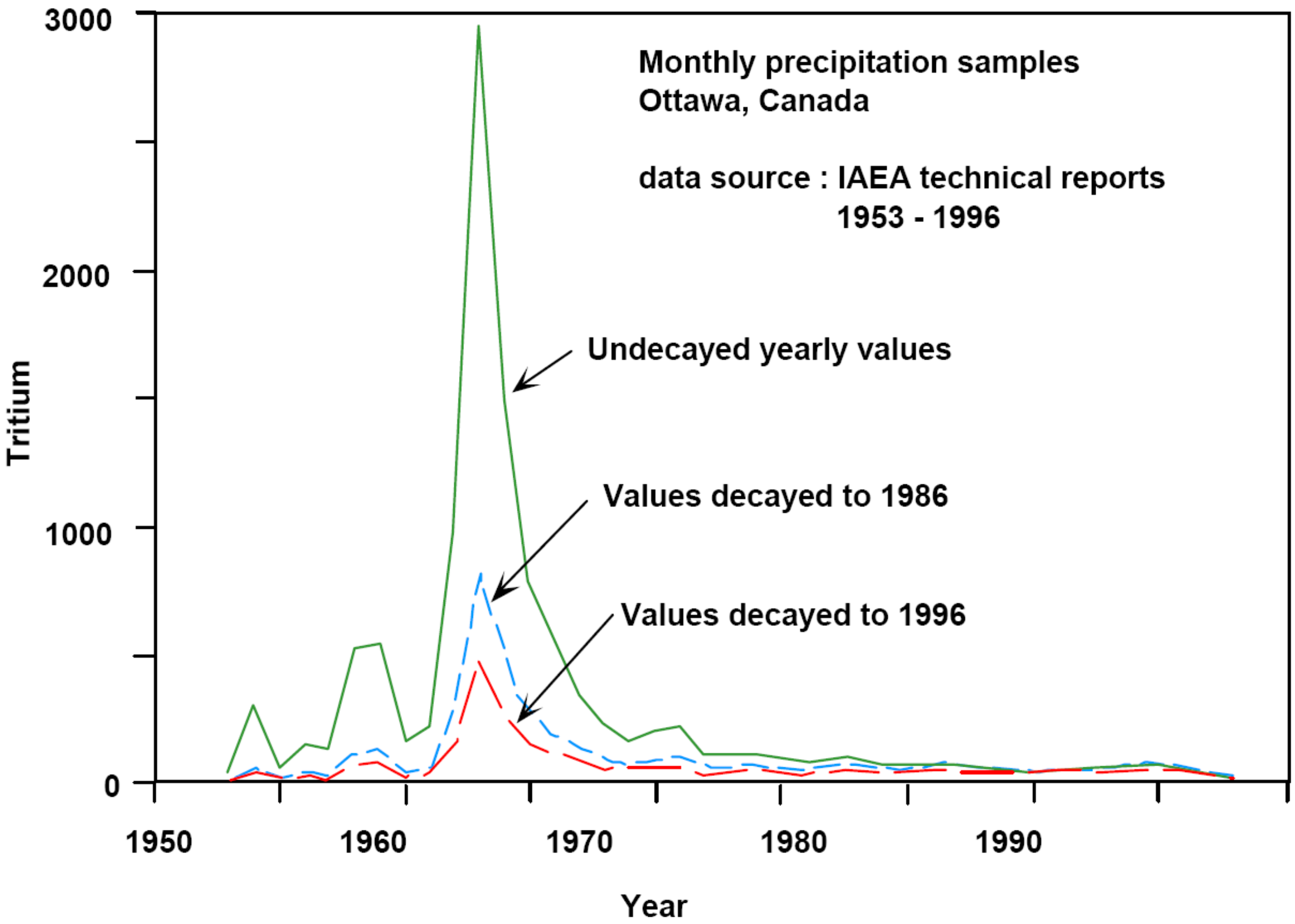
Tritium ^3H Theory

- Occurs naturally at low concentrations
- Occurs in precipitation since 1952 at elevated concentrations due to atmospheric testing of weapons (nuclear devices)
- Age estimation:
  - <10 TU recharged before 1950
  - High levels recharged during bomb testing period.
  - Intermediate levels recharged after 1960s or mixture of waters.

Origin and Distribution of ^3H in Nature.



Monthly precipitation samples Ottawa, Canada



(Burke, 1997)

Some Uses of Tritium in Groundwater Studies

- Semi-quantitative tracer of "young" groundwater
- Identification of groundwater zone recharged since mid 1950's
- Estimate mean recharge rate since mid – 1960's and/or since mid –1950's
- Identification of zones of most rapid groundwater flow

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