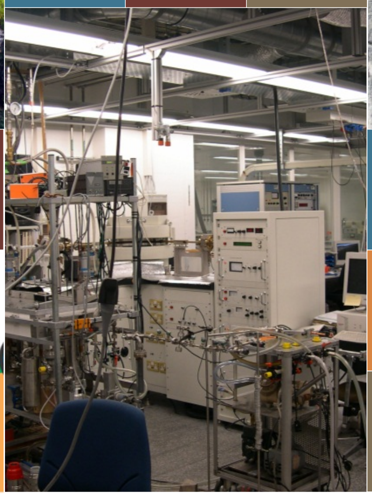
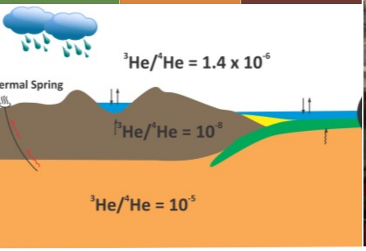
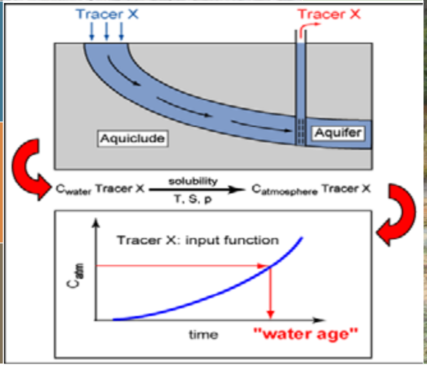
TETRA TECH EBA

Environmental Tracers in Hydrogeology: Powerful yet Underutilized Tools

Overview and Case Study







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Outline

- Environmental Tracers in Hydrogeology
- Dating Young Groundwater
  - Tritium (^3H)
  - $^3H/^3He$
  - CFCs, SF_6
- Dating Old Groundwater
  - Radiocarbon (^{14}C)
  - Helium-4 (^4He)
- Case Study
  - Geothermal Exploration in Yukon

Environmental Tracers

What are environmental tracers?

- Chemically inert trace substances (e.g., transient or radioactive) which are present in the water cycle and allow physical processes to be studied in aquatic systems

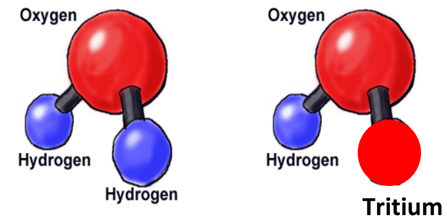
Environmental Tracers in Hydrogeology

- Stable Isotopes: Oxygen-18 (^{18}O), Deuterium(^{2}H)
- Radioisotopes: ^{3}H, ^{14}C, ^{85}Kr, ^{81}Kr, ^{37}Ar, ^{39}Ar, ^{222}Rn
- Noble Gases: He, Ne, Ar, Kr, Xe
- Transient Atmospheric Trace Gases: CFCs (CFC-11, CFC-12, CFC-113), SF_6
- Others…

Dating Young Groundwater

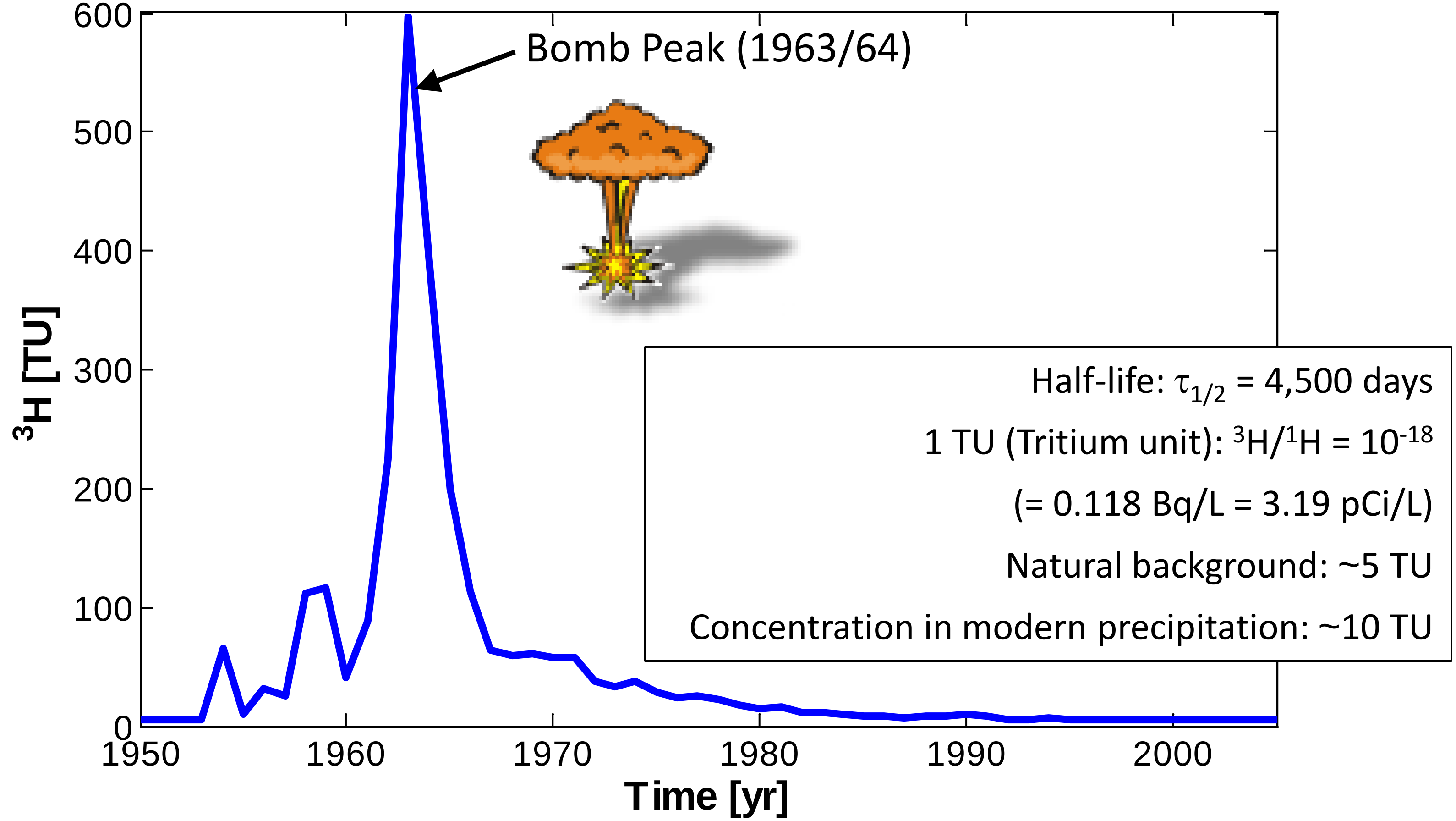
- Young Groundwater: mean residence time less than about 50 to 60 years
- Potential application of dating methods:
  - Aquifer vulnerability studies
  - Wellhead and aquifer protection plans
  - Contaminated site assessments
  - Geothermal assessments (geothermometry)
  - Quantification of groundwater mixing
  - Calibration/verification of numerical models
  - Determination of recharge rate
  - Many others…
- Several available methods; relatively inexpensive

Tritium (^3H)



^1H_2O $^3H^1HO$

Atmospheric Input Function



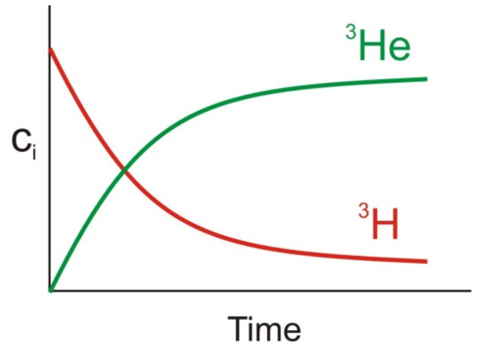
Dating Groundwater Using Tritium

- Sample contains tritium
  ’ residence time <60 years
- Sample does not contain any tritium (detection limit!)
  ’ residence time >60 years
- “Classic” dating method: comparison of measured tritium concentration with decay-corrected local atmospheric input function (often non-unique)

Tritium/Helium-3 Method

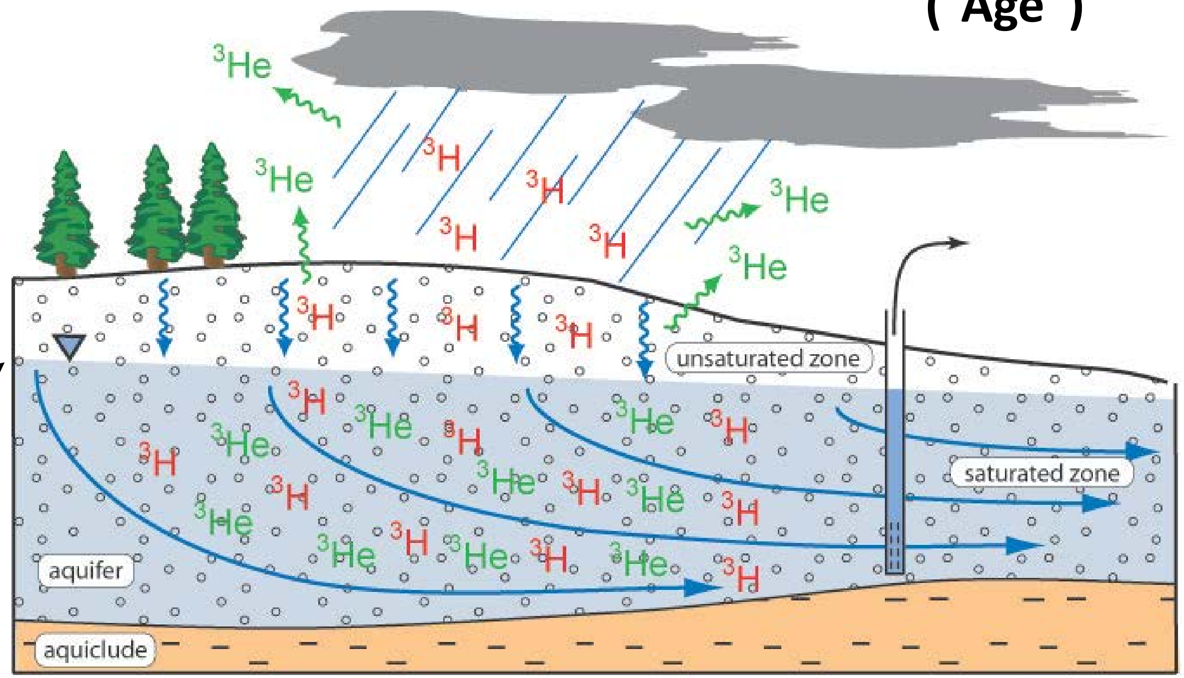
$$^{3}\mathrm{H} \xrightarrow{\beta} {}^{3}\mathrm{He}$$

$\tau_{1/2}$ = 12.3 yr



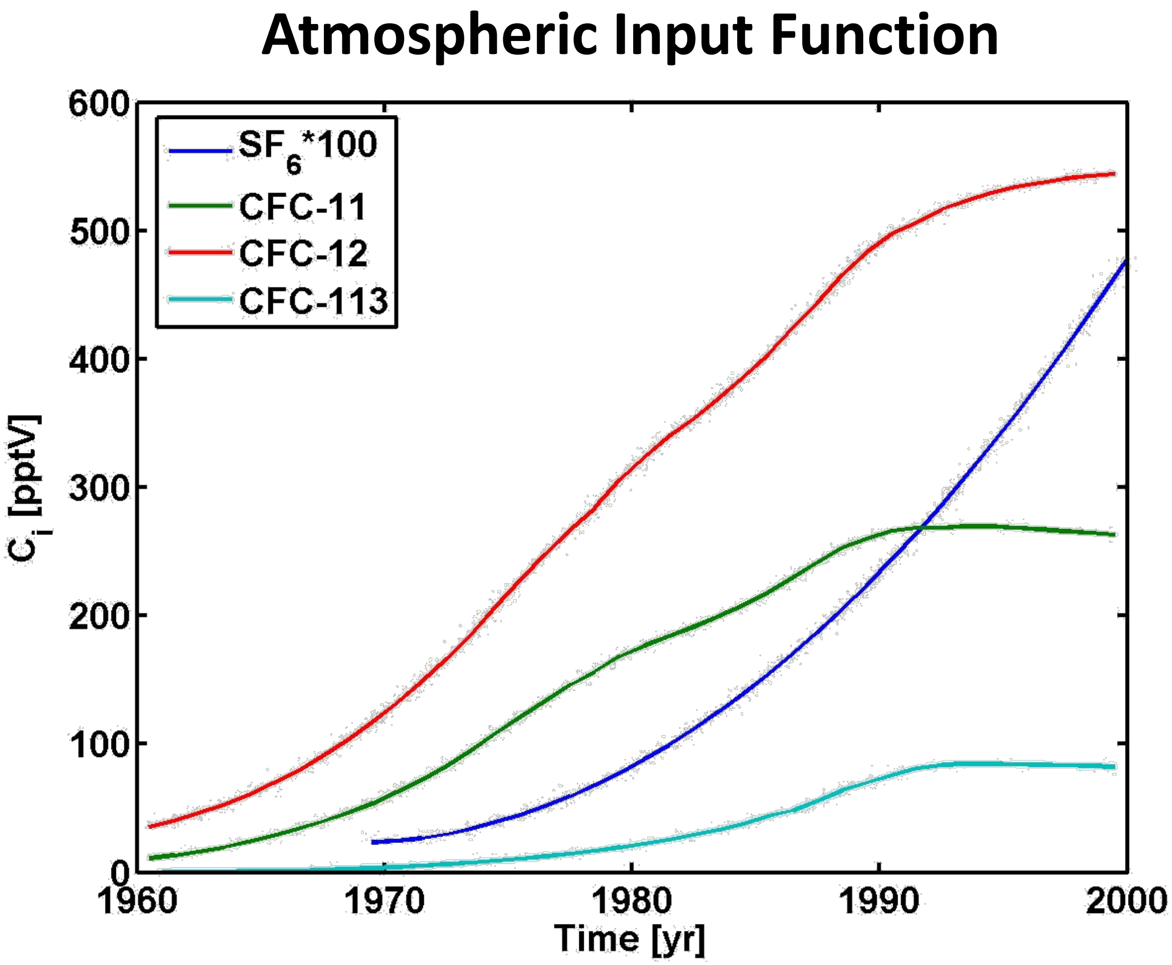
$$\tau = \frac{1}{\lambda} \cdot \ln\left(1 + \frac{[^{3}\mathrm{He}_{tri}]}{[^{3}\mathrm{H}]}\right)$$

Residence Time (“Age”)

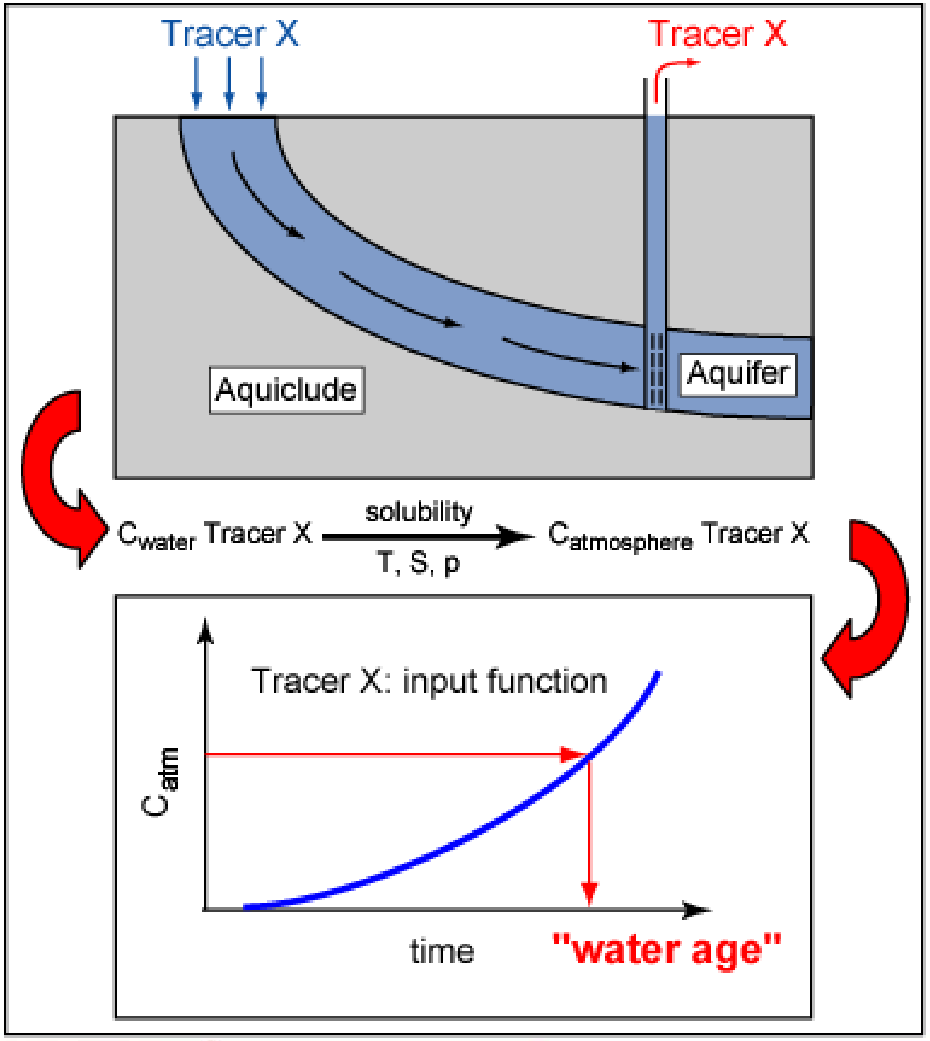


Chlorofluorocarbons (CFCs) and Sulfur Hexafluoride (SF_6)

- Transient, atmospheric trace gases
- Man-made (small amount of natural SF_6)
- Inert gases
- CFCs are "ozone killers"
- SF_6 is the most potent greenhouse gas and has a very long atmospheric lifetime

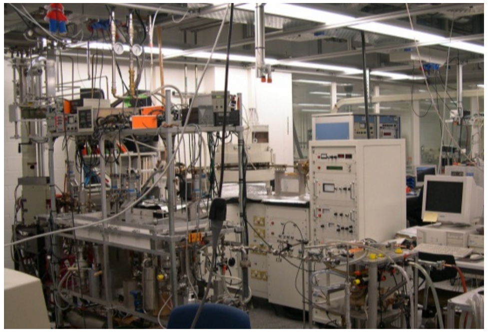


Groundwater dating by CFCs, SF_6



Sampling

Analysis



“Age“ calculation

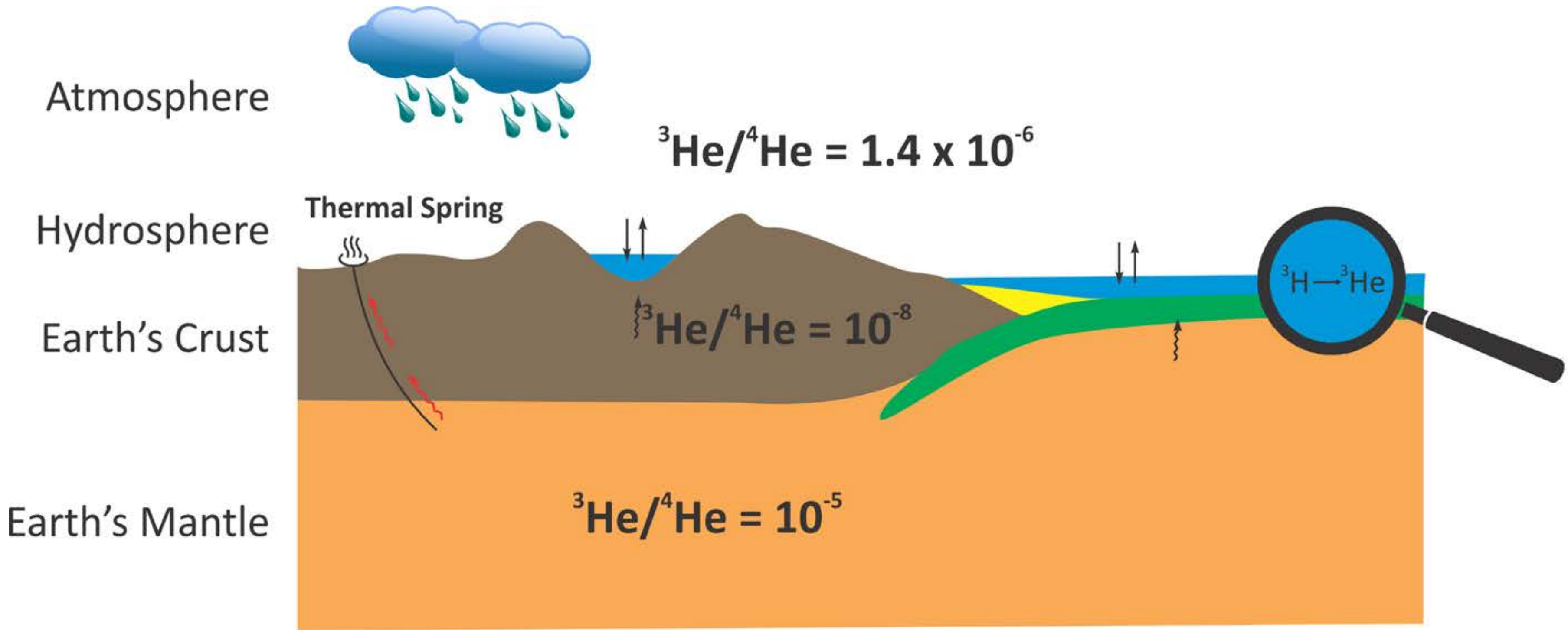
Dating Old Groundwater

- Radiocarbon (^{14}C)
  - Dating range: ~1,000 to 45,000 years
  - AMS technology has reduced required sample size to about 1 L (depending on HCO_3^- concentration)

- Helium-4 (^{4}He)
  - Produced by the decay of U and Th
  - Accumulates in groundwater as a function of residence time on timescales of hundreds to thousands of years, and U/Th concentration in aquifer matrix
  - Usually use as a qualitative dating tool because ^{4}He accumulation rate is unknown and difficult to determine

Helium Reservoirs

- Helium isotope ratio is characteristic for helium source
- High isotope ratios often indicate deep fluid circulation
- Use as geothermal exploration tool?



Case Study

Geothermal Exploration, Yukon

Ground Reconnaissance

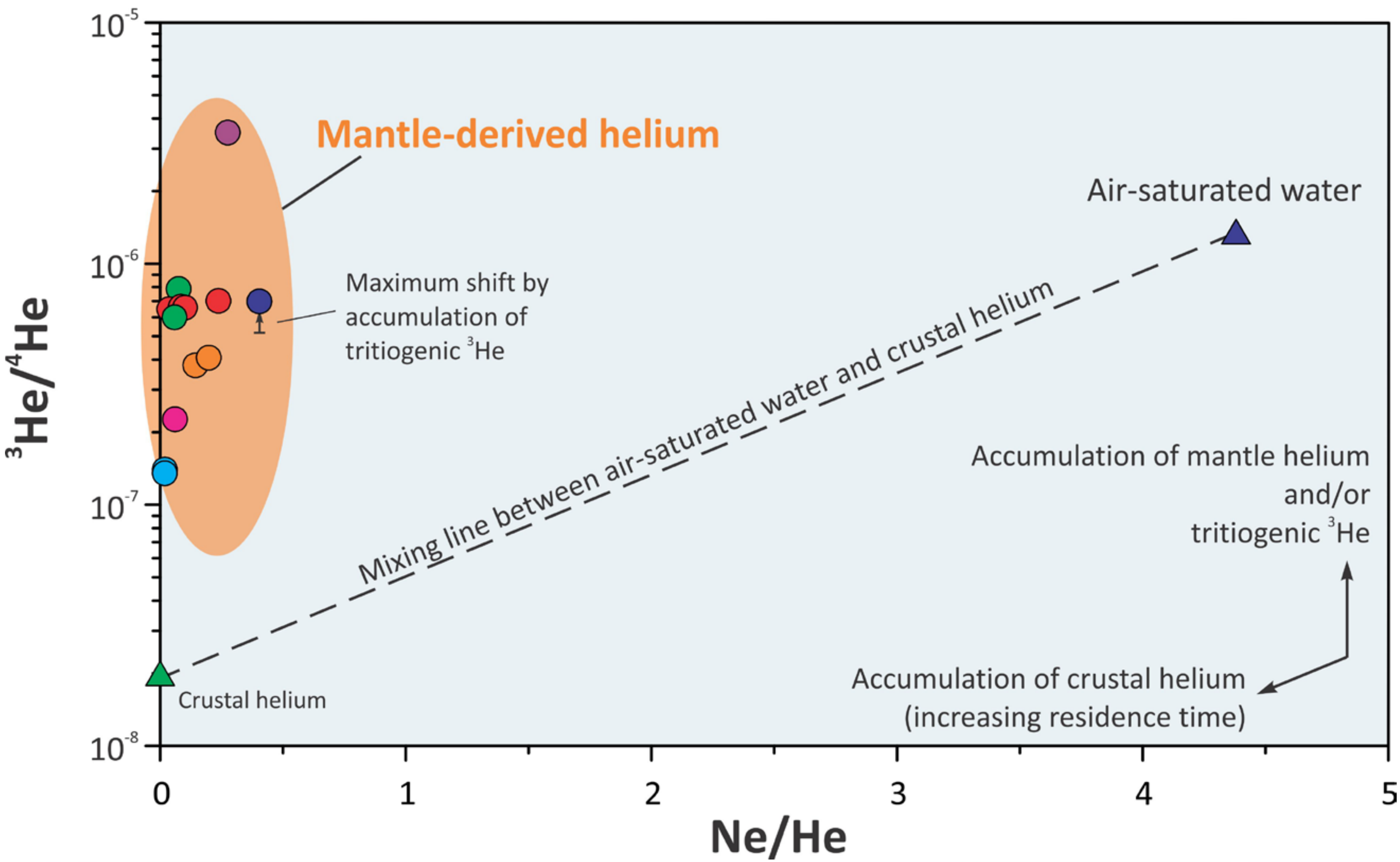
- Preliminary geological mapping
- Documentation of surface features
- Water sampling and flow estimates
- Temperature and other field parameter measurements


Hot Spring, Central Yukon

Thermal Water Analysis

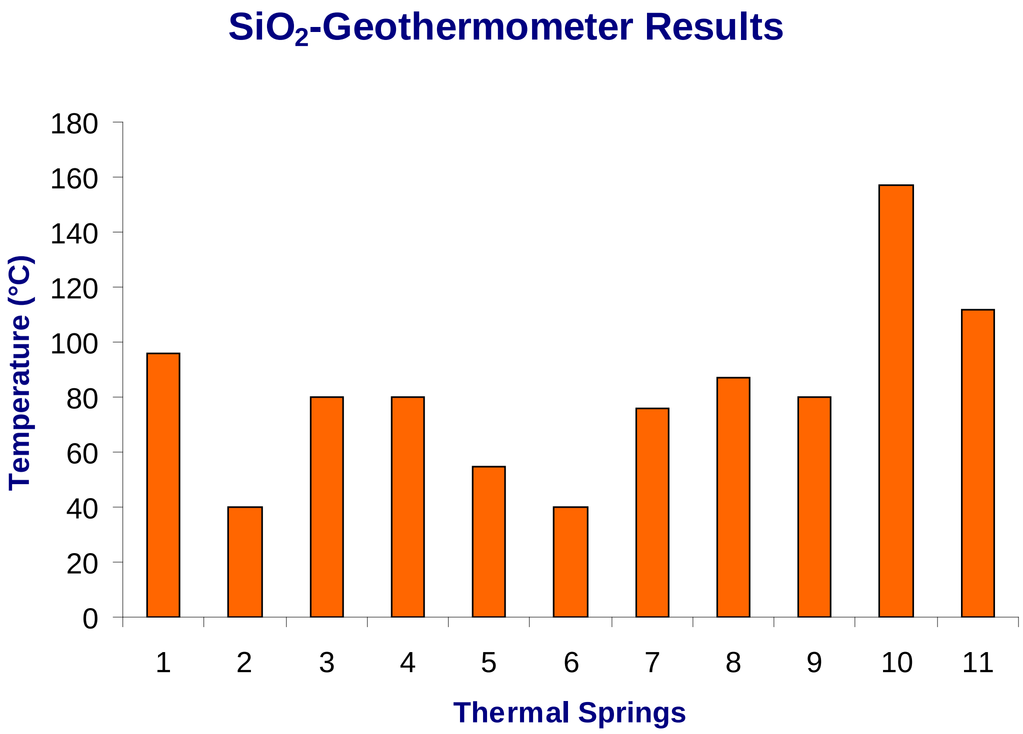
- Field: pH, temperature, electrical conductivity
- Lab: alkalinity (total, HCO_3, CO_3, OH), hardness, F, Cl, NO_2, NO_3, SO_4, dissolved metals
- Environmental isotopes: ^{18}O, ^{2}H, ^{3}H, ^{14}C, He-Xe

Helium Isotopes: Thermal Springs in Yukon



Geothermometer

- Estimate of subsurface temperature
- Assumptions:
  - Dissolved ions in equilibrium with reservoir rocks
  - Chemical equilibrium is mainly temperature-controlled
  - Fast conduit from reservoir to surface without time for chemical re-equilibration
- Most common geothermometer methods are based on Na-K-Ca ion ratios and Si concentration



Water Dating with ^{3}H and ^{14}C

- Tritium concentration was below detection limit (<0.8 TU)
  - Residence time >60 years
  - No significant admixture of young, shallow groundwater
- Radiocarbon concentration was very low (2.24 pmc)
  - Conventional radiocarbon age is ~30,000 years
  - Large residence time indicates long, deep flow path of thermal water
  - No significant admixture of young, shallow groundwater

➢ Thermal water has not been significantly diluted with shallow, cold groundwater

➢ Geothermometer temperatures are probably representative of subsurface reservoir temperatures

Summary and Conclusions

- Groundwater dating can provide significant information regarding the dynamics of groundwater systems (residence time, recharge rate, flow regime, etc.)
- This information can be useful for a large range of hydrogeological projects (aquifer vulnerability, contaminated sites, groundwater resource assessments, sustainability studies, geothermal assessments, etc.)
- Methods are widely underutilized in practical hydrogeology (high costs, unavailability of labs, long sample turnaround, lack of knowledge and experience)
- Opportunity for innovation…

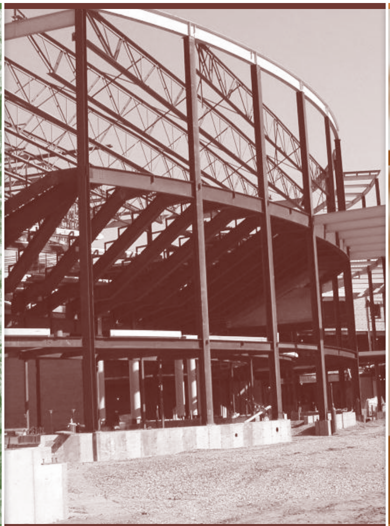
THANKS FOR YOUR ATTENTION

Questions?


WATER


NATURAL RESOURCES


ENVIRONMENT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