GEL 146: Radiogenic Isotope Geochemistry and Cosmochemistry
Fall Quarter, 2020
Instructor:
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Professor
(Office Location: EPS 3129/Home)
Office Hours: TBA

Class Location: Zoom Online. Tuesdays/Thursdays 12:10 pm-1:30 pm

(The exact sequence and coverage in each lecture may vary as we move along)

Lecture 1
- Definition of Isotopes
- Binding Energy, how to calculate it.
- Which element has the highest BE?
- Chart of Nuclide
- Valley of Stability
- Modes of radioactive decays (α, β, and EC or e+)
- Brief history of our field. Brief history of the Universe (Chemical Evolution)

Lecture 2
- Nuclear Stability
- Fusion, Fission, and alpha-decay
- Law of radioactivity
- Half-life, mean-life, and "5 half-life rule of thumb"
- Isochron concept

Lecture 3
- How elements are made?
  - From H-Fe (fusion)
  - From Fe and above (neutron addition)
  - Cannot add too much neutron: fission occurs
- s-process, r-process, and p-process for heavy elements
- Neutron drip line
- s- and r-processes peaks, "magic neutron numbers"

Lecture 4
- Cosmic chemical abundance "9th symphony of Goldschmidt"
- Oddo-Harkins rule
- Atomic Weight Calculations (with radiogenic isotope)

Lecture 5
- Column Chemistry
- Mass Spectrometry Principles

- Energy Filtering
- How a high resolution is achieved

Lecture 6

- How a high resolution is achieved (revisited)
- How charged particle signals are recorded and converted as voltage, how the calculation is done
- Small signal (for small sample) amplification through Secondary Electron Multiplier (SEM)
- How the isotopic/atomic P/D ratio is calculated.
- Isotope Dilution and Isotope Mixing
- Error Magnification in isotope dilution

Lecture 7

- Instrumental Mass Fractionation Correction
- Cases when isotope dilution does not apply.
- Advantages and disadvantages of isotope dilution.
- Linear Regression (Conceptual, more to follow)
- Conservation Laws for Nuclear Reactions
- Terminology
- Completion of Part I
- Start of Part II Radiogenic Isotope Geochronology
- Chapter 3: Rb-Sr method

Lecture 8

- What is BABI, how it is defined and what does it mean? What is ADOR, ALL?
- Plotting $^{87}Sr/^{86}Sr$ vs. $^{87}Rb/^{86}Sr$ (isochron diagram): slope is time (function of t)
- Plotting $^{87}Sr/^{86}Sr$ vs. time (evolution diagram): slope is $^{87}Rb/^{86}Sr$ times decay constant
- Model Ages: how to calculate and how to represent it geometrically in evolution diagram
- Metamorphic resetting: mineral vs. whole rock
- Sr in seawater (sources and sinks) and its evolution over geologic time
- Glacial erosion and Sr isotopic evolution in seawater
- Divergence at 2.5 Ga vs. the building up of continents
- Himalayan uplift and high resolution Sr isotope chronology
- Improving Sr isotope seawater curve in deep time.
- Residence time and how to calculate it.

Lecture 9

- Least square fit (unweighted vs. weighted regression)
- MSWD and its meaning
- Simple/Practical Error Propagation
- What is CHUR? What does it represent?

- What is $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$ value for CHUR?
- Evolution diagram: Difference with Rb-Sr system
- Epsilon Nd? $\varepsilon(0)$ vs. $\varepsilon(T)$
- $f_{Sm/Nd}$?

Lecture 10

- Mixing Theory
- Two component mixture: Chemical Expression
- Two component mixture: Isotopic Expression (for one element)
- Examples at micro- and mega-scale
- Fictitious isochron (mixing line)
- Dissect the mixing equation
- Binary mixing of two elements with different concentration and isotopic compositions.
- Examples
- Nd model ages relative to CHUR or DM (Depleted Mantle). Which one is older?
- Intra-crustal melting and mixed provenance.
- Nd model age vs. Stratigraphic age. Deviation and its significance
- Very early differentiation at ~4Ga ago: +4 epsilon

Lecture 11

- Seawater Nd: residence time
- Why there is difference in Nd isotopes between Pacific, Indian, and Atlantic. What does it tell us?
- Crustal Growth Problem
- ^{238}U, ^{235}U and ^{232}Th decay chain and their positions in the chart of nuclide
- Three decay equations for the U-Th-Pb systems and three independent age constraints
- How the primordial Pb isotopic compositions are defined and determined (troilite from Canyon Diablo)

Lecture 12

- The μ and κ values
- Pb-Pb isochron and Pb-Pb age
- Why Pb-Pb age is so precise in the beginning?
- Clair Patterson's "Age of Earth" (1956) and its limitation
- Concordia Diagram, a.k.a. Wetherill Diagram
- Discordia: upper and lower intercept ages
- Suitable minerals for U-Pb geochronology
- Common lead corrections
- In-situ analyses: ion-probe vs. laser ablation

Mid-term (in class)
Close book. You may bring hand calculator. No computer/laptop, please.

Lecture 13

- Evaporation method (Kober method)
- Tera-Wasserburg diagram
- U-Pb, Th-Pb, vs. Pb-Pb isochrons: open systems
- It is all about μ and κ values
- Holmes-Houtermans Model (Single-stage Pb isotope evolution)
- Conformable Pb
- Two stage Pb isotope evolution model
- Pb-Pb dating and crustal evolution
- Closed system Pb isotope evolution of the Mantle
- Open System Pb Isotope Evolution of the Mantle
- Stacey and Kramers (1975) model
- Terrestrial Pb Paradox I
- Pb Isotopes and Core formation
- U-Pb modeling of core formation and its limitations: two equations, three unknowns

Lecture 14

- Pb isotope growth curve vs. Concordia curve
- Short-lived radioactivities in the early Solar System and the birth place of solar neighborhood
- How the "fossil isochron" for extinct radionuclides works
- Discovery of ^{129}I and ^{26}Al
- Supernova trigger vs. X-wind theory
- High resolution relative chronology
- Scientific motivation
- Standard model of planet formation
- Canonical $^{26}Al/^{27}Al$ in the early Solar System
- Dating the first stage of planet formation with ^{53}Mn-^{53}Cr system (half-life 3.5 Ma)

Lecture 15

- Dating planetary accretion and differentiation through ^{182}Hf-^{182}W, ^{129}I-^{244}Pu-Xe and ^{146}Sm-^{142}Nd clocks
    - Dating the last stage of planet formation with ^{182}Hf-^{182}W system ($t_{1/2}$=9 Ma)
    - Magma oceanography with ^{146}Sm-^{142}Nd system.
    - Missing reservoirs and geochemical paradoxes
- ^{187}Re-^{187}Os and ^{190}Pt-^{186}Os systems
- Geochemical behavior of Re, Os, and Pt and their distribution in nature, and the corresponding Os isotopic compositions

Lecture 16

- γOs (percent deviation of ^{187}Os) and $\varepsilon^{186}Os$
- $f_{Re/Os}$ and $f_{Pt/Os}$
- Mantle evolution defined by OsIr alloy

- Model Ages: relative to CHUR(T_{CHUR}), Depleted Mantle(T_{DM}) and T_{RD} (Re Depletion Age: minimum age)
- Core contribution from ^{186}Os signature vs. alternative interpretation.
- Combining geothermetry (T) and geobarometry (P) with Os model ages to construct continental root structure
- Dating sediments (black shales), ore deposits (MoS), and crude oils with Re-Os system
- Seawater Os evolution compared with Sr

Lecture 17

- ^{176}Lu-^{176}Hf decay system
- Half-life issue
- Elemental compatibility pattern for Rare Earth Elements (consider Hf next to Sm)
- CHUR for Lu-Hf compared with Sm-Nd
- Depleted cumulate eucrites in Lu-Hf and Sm-Nd spaces
- Jack Hills zircons on Lu-Hf evolution diagram
- CHUR parameter issue
- ε_{Hf} and ε_{Nd} correlation for MORBs and OIBs
- Is there a hidden reservoir we are not sampling?
- Model ages relative to CHUR or DM
- Lu/Hf fractionation in sediments: zircon is to blame
- ^{40}K-^{40}Ar-^{40}Ca branched decay system
- Atmospheric ^{40}Ar contamination and corrections using $(^{40}Ar/^{36}Ar)_{atms}=295.5$
- ^{40}Ar* budget of the Earth and un-degassed mantle
- High ^{40}Ar/^{36}Ar of MORB vs. low ^{40}Ar/^{36}Ar for OIBs
- ^{40}Ar-^{39}Ar method of dating
- J value for the standard monitor with known age
- Step wise Ar release pattern and plateau age
- Grain size distribution and diffusional loss of Ar: theory and observations
- Cooling rate, closure temperature and thermochronology
- ^{40}K-^{40}Ca system: Evolution diagram, isochron, and ε_{Ca} vs. ε_{Nd} mixing line
- ^{138}La-^{138}Ce-^{138}Ba branched decay systems
- Branched decay equations
- Opposite partition behaviors for La/Ce and Sm/Nd or Lu/Hf
- Negative correlation between ε_{Ce} and ε_{Nd} vs. positive correlation between ε_{Nd} and ε_{Hf}.

Lecture 18

U-series (I)

Lecture 19

U-series (II)

Instruction End: Dec. 10, 2020
Finals week (week of Dec. 14, 2020)

Final Exam
Date/Time/Location: Dec. 16, 2020. Wednesday 3:30 pm – 5:30 pm