Western Science

Department of Earth Sciences

Syllabus for Geology 9506a *(v. 1.0, September 1, 2021)*

1. Course Information

Geology 9506a. Stable Isotope Geochemistry in Earth & Environmental Sciences
(offered concurrently with Earth Sciences 4431a)

- Fall Term
- In person, Monday, Wednesday and Friday from 11:30 am to 12:20 pm.
- Location: UC 2105

Prerequisites

- Some undergraduate experience in chemistry, geochemistry and/or biology, or permission of the Instructor.

Anti-requisite
- Earth Sciences 4431a

2. Instructor Information

- Instructor: Fred J Longstaffe, Department of Earth Sciences
- Graduate Teaching Assistant: Minger Guo, Department of Earth Sciences

- Students must use their Western (@uwo.ca) email addresses when contacting their instructors.
- Weekly e-office hours with Graduate Teaching Assistant (Minger Guo): mguo85@uwo.ca
  Mondays, 10:00 – 11:00; format virtual
  Wednesday, 10:00 – 11:00; format virtual
  Minger will provide Zoom details via the OWL course site.
- office hours with Fred – by appointment
  Contact flongsta@uwo.ca to arrange

3. Course Syllabus, Schedule, Delivery Mode

Atoms of many elements come in different varieties known as isotopes. Isotopes of an atom have the same number of protons and electrons, but a different number of neutrons. Stable isotopes of an atom do not decay to form another element. Because of the difference in mass arising from different numbers of neutrons, stable isotopes of a given element behave (“ fractionate”) in slightly different ways during reactions such as (i) evaporation of water, (ii) carbon dioxide fixation during photosynthesis, (iii) crystallization of a magma, and (iv) transfer of a donut’s isotopic signature to your fingernails and hair. This course addresses the principles governing the fractionation of stable isotopes,

and focuses on how the stable isotopes of oxygen, hydrogen, carbon, nitrogen and sulphur allow us to trace interactions within the atmosphere-hydrosphere-biosphere-lithosphere Earth System.

You will learn that you are what you eat – isotopically. You will learn that your hair and teeth retain isotopic signals of where you have lived. And you will learn that it is not all about you. Minerals have a history too, and you will learn how to decode that history using stable isotopes, in terms of temperatures and fluids involved in mineral formation. You will learn what sorts of water-rock-organic interaction might make you rich and at what cost to Earth. Stable isotopes hold the key to understanding much of past climate change, paleo-ecological shifts and extinctions. You will learn to think like an ***Isotopist***. Your life will never be the same thereafter.

Learning Outcomes

Upon successful completion of this course students will be able to:

1. Use the oxygen- and hydrogen-isotope compositions of water to determine its source and the hydrological processes that have shaped the water's isotopic composition, as evaluated through assignments, tests and written examination
2. Identify the sources (mantle, crust) that have contributed to magma generation, and recognize the nature of rock-water interaction that may have affected an igneous rock after its crystallization, as evaluated through assignments, tests and written examination
3. Calculate the stable isotope fractionation factor between two phases (e.g., mineral and water), use these data to establish whether the system is in equilibrium, and for equilibrium systems, determine the temperature at which equilibration occurred, as evaluated through assignments, tests and written examination
4. Use the oxygen- and hydrogen-isotope composition of clay minerals to determine conditions of weathering and hydrothermal alteration, and interpret these results within the larger framework of diagenesis, ore mineralization and / or climate change over Earth history, as evaluated through assignments, tests and written examination
5. Identify photosynthetic pathways in vegetation using stable carbon-isotope compositions, recognize land use changes based on stable carbon-isotope compositions of organic matter, and determine the diet and trophic level of animals based on the stable carbon- and nitrogen-isotope compositions of their tissues, as evaluated through tests and written examination.
6. Use the stable carbon- and oxygen-isotope compositions of Earth's biosphere, atmosphere and hydrosphere to identify changes in Earth's carbon and water cycles at geological and Anthropocene time-scales, as evaluated through tests and written examination
7. Devise methods using light stable isotope signatures to trace Earth System interactions across the lithosphere, pedosphere, hydrosphere, biosphere and atmosphere continuum, as evaluated through a written major essay (undergraduate) or a written, data-based major project (graduate students)

• Delivered in person: Monday, Wednesday and Friday from 11:30 am to 12:20 pm.

This space reserved for isotopic $^{2}H^{18}O^{16}O^{2}Hli^{14}Ng$
(First one to solve the riddle and tell Fred by e-mail gets 1 bonus mark)

Course Outline

This outline is a guide only. *Stable Isotope Science* is a dynamic tool applied to research and scholarship in many different fields. Course content may change depending on class feedback and current topics. If you have interest in a subject not covered here, please contact the instructor.

1. **Introduction**
   Importance to earth and environmental sciences, isotopes of interest, some general principles, the atom, chart of the nuclides, atomic mass units, atomic weight, binding energy, nuclear stability, abundance of the elements in the solar system, brief history of stable isotope geochemistry, definitions (δ, α, $10^3 \ln\alpha$, Δ), standards, introduction to analytical methods and instruments (extraction techniques, mass spectrometry), virtual laboratory tour.

2. **Stable isotopes in the atmosphere and hydrosphere**
   Equilibrium fractionation of isotopes, kinetic processes, O and H isotopes in water and water vapour, Rayleigh distillation, Global Meteoric Water Line, kinetic isotope fractionation and *d*-excess, evaporation line, regional effects (latitude, altitude, continentality, temperature, precipitation amount), Kuhn, in-cloud processes and O and H isotopes of precipitation, shallow ground water, atmospheric oxygen and carbon dioxide, juvenile water, geothermal water, rock-water ratio, oceanic pore water, formation water, brines (SW Ontario examples), ocean water (salinity, evaporation, dilution, ice-cap effects, ocean currents, climatic effects), snow and ice, marine paleoclimate reconstruction (ice cores, marine foraminifera), terrestrial and lacustrine paleoenvironmental reconstruction (speleothems, mammalian teeth and bones, ostracodes, diatoms), plant phytoliths, tree rings.

3. **Stable isotopes in igneous rocks**
   Introduction to igneous rocks, oxygen reservoirs (water, sediments, mantle and derivative rock types), mineral ordering, fractional crystallization, O-isotope geochemistry of granitoid rocks (normal ^{18}O, low-^{18}O, meteoric water interaction, high ^{18}O, role of sediments, isotopic exchange with country rocks), O-isotope geothermometry, high temperature concordancy, retrograde isotopic exchange and disequilibrium, Pegmatite Paradise; meteorites, mass independent fractionation.

4. **Stable isotopes in sedimentary rocks, weathering and diagenesis**
   Chemical sediments (carbonate, chert), clastic sediments, submarine weathering (halmyrolysis), O-isotope composition of the ocean through time and its significance, clay mineral structures, controls on clay mineral isotopic compositions during weathering and diagenesis, clay isotope geothermometry, O- and H-isotope variation in soil and weathering clays.

5. **Stable carbon and nitrogen isotopes in organic matter**
   Introduction to stable C isotopes on Earth, photosynthesis (C_3, C_4, CAM and aquatic plants), C-isotope fractionation during photosynthesis (diffusive, enzymatic), fractionation during organic synthesis, C-isotope behaviour during vegetation shifts and climate change, isotopic alteration of soil organic matter (oxidation, microbial), humic substances, tracking carbon storage in soils (Maya examples), N-isotope variations in air, soil, plants and animals, diet and paleodiet (collagen,

structural carbonate in bioapatite, keratin), C- and N- isotope trophic effects, food webs, N-isotope baselines, *are you what you eat*?

6. **Stable carbon isotopes in the carbon cycle**
   Carbon cycle (long- versus short-term), carbon reservoirs (δ and fluxes), long-term carbon cycle, carbonates, equilibrium C-isotope fractionation, vital effects, coal, petroleum, natural gas, biogenic methane, tracing hydrocarbon leaks, short-term carbon cycle (atmospheric CO_2, atmosphere-biosphere-hydrosphere transfer, ice-cores, biological pump, ocean productivity), Phanerozoic C-isotope secular variations (atmospheric oxygen, extinction events, Strangelove Ocean, PETM), Earth C-isotope budget.

7. **Sulphur isotopes**
   Introduction to S isotopes, fractionation in abiotic and biotic systems, Rayleigh distillation, Recent sediments, ocean water, secular variation, atmospheric sulphur, petroleum, coal, S isotopes as a tracer (petroleum migration, air pollution), mass independent S-isotope fractionation, S isotopes in ore deposits, crystal chemistry and bond-strength controls on S isotopic fractionation, speciation effects on sulphur isotopic compositions ($f[O_2]$ and pH), comparison with C-isotope system.

8. **Thinking like an Isotopist**

Key Sessional Dates:
Classes begin: September 8, 2021
Reading Week: November 1–7, 2021
Classes end: December 8, 2021

Contingency plan for an in-person class pivoting to 100% online learning
In the event of a COVID-19 resurgence during the course that necessitates the course delivery moving away from face-to-face interaction, all remaining course content will be delivered entirely online, either synchronously (i.e., at the times indicated in the timetable) or asynchronously (e.g., posted on OWL for students to view at their convenience). The grading scheme will **not** change. Any remaining assessments will also be conducted online as determined by the course instructor.

4. Course Materials

• Text Book: Sharp, Z. (2nd Edition) Principles of Stable Isotope Geochemistry, Electronic Edition.

*You can obtain a copy at **no cost** from: csi.unm.edu under the web site's publications tab.*

There are assigned readings from this textbook associated with most lectures.

• As needed, other materials for this course will be placed on-line on OWL: http://owl.uwo.ca.

• Students are responsible for checking the course OWL site (http://owl.uwo.ca) on a regular basis for news and updates. This is the primary method by which information will be disseminated to all students in the class.
• All course material will be posted to OWL: http://owl.uwo.ca.

• If students need assistance with the course OWL site, they can seek support on the OWL Help page. Alternatively, they can contact the Western Technology Services Helpdesk. They can be contacted by phone at 519-661-3800 or ext. 83800.

Technical Requirements *(only in case of shift to on-line status)*
• Computer and stable internet connection
• If possible, computer with working microphone and/or webcam
• Patience

5. Methods of Evaluation

The overall course grade will be calculated as listed below:

Assignments (5)	20 %
Midterm Test	30 %
Graduate Project	20 %
Final Examination	30 %

• Assignments and their due dates will be delivered and received via OWL. Normally one week is allowed to complete each problem set. For a few assignments, two weeks are allowed.

• *Topics to be included on the Mid-term Test:* All material up to the lecture before the Mid-term Test.

• The Mid-term Test will occur during regular class time on **Wednesday, October 13, 2021**. In case of a shift back to 'on-line' learning, the Mid-term Test will still be administered during the regularly scheduled class time. Those details would follow on the course's OWL site.

• The Graduate Project will require you to assess an isotopic data set, provide an interpretation and summarize your findings in a short report. The data and guidelines on how to begin will be posted on OWL no later than October 8, 2021.

• The Graduate Project is due by **4:30 pm, Friday, November 12, 2021**, and will be received via OWL.

• *Topics to be included on the Final Examination:* Entire course but with emphasis on material covered after the Mid-term Test.

• The final examination date and location will be scheduled by the Registrar's Office during the normal December examination period. In case of a shift back to 'on-line' learning, the final examination will be administered in a 'take-home' format. Those details would follow on the course's OWL site.

Accommodated Evaluations

• The Mid-term Test date is firm and make-up Mid-term Tests are not offered. If you have self-reported an absence or your Faculty's Academic Counselling Office has approved your

circumstances, then the value of the midterm test will be shifted to the Final Examination. Please ensure that the instructor is informed of either circumstance surrounding your absence, using flongsta@uwo.ca .

• Special final examinations will be held as mandated by the University on **Thursday, January 6, 2022**, with details to be provided by the Registrar.

• There are no 'make-up' options for missed Assignments. Ten percent per day is deducted for late assignments, and assignments received more than five days late will not be accepted.

• There are no 'make-up' options for a missed Review Paper. Ten percent per day is deducted for late Review Papers, and Review Papers received more than five days late will not be accepted.

Western's Laboratory for Stable Isotope Science (LSIS)

6. Student Absences

Academic Consideration for Student Absences
Students who experience an extenuating circumstance (illness, injury or other extenuating circumstance) sufficiently significant to temporarily render them unable to meet academic requirements may submit a request for academic consideration. Please contact your home department's Academic Co-ordinator for further details (Amy Wickham for Earth Sciences graduate students: awickham@uwo.ca)

Students are required to contact their instructors within 24 hours of the end of the absence period covered.

Individual instructors are not permitted to receive documentation directly from a student, whether in support of an application for consideration on medical grounds, or for other reasons.

Religious Accommodation
When a course requirement conflicts with a religious holiday that requires an absence from the University or prohibits certain activities, students should request accommodation for their absence in writing at least two weeks prior to the holiday to the course instructor and/or their home department Academic Coordinator. Please consult University's list of recognized religious holidays (updated annually) at:

https://multiculturalcalendar.com/ecal/index.php?s=c-univwo.

Absences from Final Examinations
If you miss the Final Examination, please contact the Academic Co-ordinator of your home department as soon as you are able to do so. They will assess your eligibility to write the Special Examination (the name given by the University to a makeup Final Examination).

You may also be eligible to write the Special Examination if you are in a "Multiple Exam Situation" (e.g., more than 2 exams in 23-hour period, more than 3 exams in a 47-hour period).

If a student fails to write a scheduled Special Examination, the date of the next Special Examination (if granted) normally will be the scheduled date for the final examination the next time this course is offered.

7. Accommodation and Accessibility

Accommodation Policies
Students with disabilities work with Accessible Education (formerly SSD), which provides recommendations for accommodation based on medical documentation or psychological and cognitive testing. The policy on Academic Accommodation for Students with Disabilities can be found at:

https://www.uwo.ca/univsec/pdf/academic_policies/appeals/Academic Accommodation_disabilities.pdf,

8. Academic Policies

The website for Registrarial Services is http://www.registrar.uwo.ca.

In accordance with policy,

https://www.uwo.ca/univsec/pdf/policies_procedures/section1/mapp113.pdf,

the centrally administered e-mail account provided to students will be considered the individual's official university e-mail address. It is the responsibility of the account holder to ensure that e-mail received from the University at his/her official university address is attended to in a timely manner.

Scientific calculators are allowed for both the Mid-term Test and the Final Examination.

Scholastic offences are taken seriously and students are directed to read the appropriate policy, specifically, the definition of what constitutes a Scholastic Offence, at the following Web site:

http://www.uwo.ca/univsec/pdf/academic_policies/appeals/scholastic_discipline_undergrad.pdf.

All required papers may be subject to submission for textual similarity review to the commercial plagiarism detection software under license to the University for the detection of plagiarism. All papers submitted for such checking will be included as source documents in the reference database for the purpose of detecting plagiarism of papers subsequently submitted to the system. Use of the service is subject to the licensing agreement, currently between The University of Western Ontario and Turnitin.com (http://www.turnitin.com).

9. Support Services

Please contact the course instructor if you require lecture or printed material in an alternate format or if any other arrangements can make this course more accessible to you. You may also wish to contact Accessible Education at (519) 661-2147 if you have any questions regarding accommodations.

Students who are in emotional/mental distress should refer to Mental Health@Western (http://www.health.uwo.ca/mentalhealth) for a complete list of options about how to obtain help.