Geology 9506a. Stable Isotope Geochemistry in Earth & Environmental Sciences

When: Monday, Wednesday, Friday, 11:30 to 12:20 pm,
Where: TBA *(lectures are combined with Earth Sciences 4431a)*
Instructor: Fred J. Longstaffe, 1023 BGS (Biological and Geological Sciences)
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Office hours: by appointment

Teaching Assistants: TBA

Prerequisites: Some undergraduate experience in chemistry, geochemistry and/or biology, or permission of the instructor.

Anti-requisite: Earth Sciences 4431a or 431a

Grading:

Mid-term test:	20%
Final examination:	40%
Graduate Project:	20%
Problem sets (7):	20%

Text Book: Sharp, Z. (2007) Principles of Stable Isotope Geochemistry, Pearson Prentice Hall, 344 p. ISBN-13 978-0-13-009139-0

This textbook is permanently out of print. Its author, however, has acquired all rights back from the publisher, and has provided me with permission to use pdfs of the chapters in this course. These will be provided as needed. You may also wish to acquire a used copy – which still can be found on-line.

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

As needed, other materials for this course will be placed on-line on the OWL system: https://owl.uwo.ca/portal

Important dates:

1. Mid-term test: Wednesday, **October 25, 2017** (during regular class time)
2. Graduate project due: Friday, **November 10, 2017**
   This project will require you to assess an isotopic data set and provide an interpretation. The data and guidelines on how to begin will be provided to you in mid-October.
3. Due dates of problem sets will be announced in class and indicated on OWL.
4. Final examination date will be set by the Registrar's office and will be held at the same time as Earth Sciences 4431a.

The Midterm examination date is firm and make-up examinations will not be permitted. Please consult the instructor if you have valid reason for missing the examination. Five % per day will be deducted from the mark assigned to late projects for the first 5 days. Projects submitted more than 5 days late will not be accepted.

Illness and Other Circumstances: If you are unable to meet a course requirement due to illness or other serious circumstances, you must provide valid medical or other supporting documentation to the Dean's office as soon as possible and contact your instructor

immediately. It is the student's responsibility to make alternative arrangements with their instructor once the accommodation has been approved and the instructor has been informed. In the event of a missed final exam, a "Recommendation of Special Examination" form must be obtained from the Dean's Office immediately. For further information please see: http://www.uwo.ca/univsec/handbook/appeals/accommodation_medical.pdf

A UWO Student Medical Certificate (SMC) is required where a student is seeking academic accommodation. This documentation should be obtained at the time of the initial consultation with the physician or walk-in clinic. An SMC can be downloaded under the Medical Documentation heading of the following web site: https://studentservices.uwo.ca/secure/index.cfm.

Accessibility Statement: Please contact the course instructor if you require material in an alternate format or if you require any other arrangements to make this course more accessible to you. You may also wish to contact Services for Students with Disabilities (SSD) at 661-2111 x.82147 for any specific question regarding an accommodation.

Plagiarism: Plagiarism is a serious academic offence. The UWO Senate Academic Handbook defines plagiarism as "The act of appropriating the literary composition of another, or parts or passages of his writings, or the ideas or language of the same, and passing them off as the product of one's own mind." Students must write their essays and assignments in their own words. Whenever students take an idea, or a passage from another author, they must acknowledge their debt both by using quotation marks where appropriate and by proper referencing such as citations. For more information see Scholastic Offence Policy in the Western Academic Calendar. 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/handbook/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 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).

Electronic devices: Scientific calculators are mandatory for all exams. No other electronic devices will be permitted.

Support Services:	Registrarial Services	http://www.registrar.uwo.ca/
	Student Support Center:	http://www.sdc.uwo.ca/

Course Outline: This outline is a guide only. *Stable Isotope Science* is a dynamic tool applied to scientific research 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 to explain 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 (southwestern 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-isotope fractionation, speciation effects on S-isotope compositions ($f[O_2]$ and pH), comparison with C-isotope system.

8. Thinking like an Isotopist

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)

Useful reference materials

Barrie A. and Prosser S.J. (1996) Automated analysis of light-element stable isotopes by isotope ratio mass spectrometry. In: Mass Spectrometry of Soils (eds: T.W. Boutton and S. Yamasaki). Marcel Dekker Inc. New York, p. 1-46. S593.M4415

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Bowen, R. (1991) Isotopes and Climates. Elsevier Applied Science, New York. ISBN 1-85166-409-2

Clark I. and Fritz P. (1997) Environmental Isotopes in Hydrogeology. CRC Press, Boca Raton. ISBN 1-56670-249-6

Coleman D.C. and Fry B. (eds.) (1991) Carbon Isotope Techniques. Academic Press, San Diego. QH 324.3.C37

Ding, T. et al. (1996) Silicon Isotope Geochemistry. , Geological Publishing House, Beijing, China. ISBN 7-116-02019-5

Ehleringer, J.R., Hall, A.E. and Farquhar, G.D. (Eds.) (1993) Stable Isotopes and Plant Carbon-Water Relations. Academic Press, Inc. ISBN 0-12-233380-2

Faure G. and Mensing T.M. (2005) Isotopes. Principles and Applications, 3rd Edition. John Wiley and Sons, New York. ISBN 0-471-38437-2

Fry B. (2006) Stable Isotope Ecology. Springer, New York. ISBN 10 0-387-30513-0

Griffiths, H. (ed.) (1998) Stable Isotopes. Integration of Biological, Ecological and Geochemical Processes. Bios Scientific Publishers, Oxford, United Kingdom. ISBN 1-85996-135-5

Hobson K.A. and Wassenaar L.I. (eds.) (2008) Tracking Animal Migration with Stable Isotopes. Elsevier, Amsterdam. ISBN 978-0-12-373867-7
Hoefs J (2004) Stable Isotope Geochemistry, 5th Edition. Springer, Berlin. QE515.H67

Johnson C.M., Beard B.L. and Albarède, F. (2004) Geochemistry of Non-Traditional Stable Isotopes. Reviews in Mineralogy, v. 55. ISBN 093995067-7

Kendall C. and McDonnell, J.J. (eds.) (1998) Isotope Tracers in Catchment Hydrology. Elsevier, Amsterdam. ISBN 0-444-81546-5

Koch P. L., Fogel M. L. and Tuross N. (1994) Tracing the diets of fossil animals using stable isotopes. In: Lajtha K. and Michener R.H. editors (1994) Stable Isotopes in Ecology and Environmental Science. Blackwell Scientific Publishing, p. 63-93. QH541.15.S68 L35

Knowles R. and Blackburn T.H. (eds.) (1993) Nitrogen Isotope Techniques. Academic Press, Inc. San Diego. QH324.35.N1 N57

Krouse, H.R. and Grinenko, V.A. (eds.) (1991) Stable Isotopes: Natural and Anthropogenic Sulphur in the Environment. John Wiley and Sons, New York. ISBN 0-471-92646-9

Kyser T.K. (ed.) (1987) Stable Isotope Geochemistry of Low Temperature Fluids. Mineralogical Association of Canada Short Course 13, Saskatoon.

Lajtha K. and Michener R.H. (eds.) (1994) Stable Isotopes in Ecology and Environmental Science. Blackwell Scientific Publishing. QH541.15.S68 L35

Lewis C.L.E. and Knell S.J. (eds.) (2001) The Age of the Earth: From 4004 BC to AD 2002. The Geological Society of London. QE508.A33

Longstaffe F.J. (ed.) (1981) Clays and the Resource Geologist. Mineralogical Association of Canada Short Course 7, Calgary. QE471.3.C55

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Mook W.G. (2006) Introduction to Isotope Hydrology. Taylor & Francis, London. ISBN 10 0-415-38197-5

Ohkouchi N., Tayasu I. and Koba K. (eds.) (2010) Earth, Life, and Isotopes. Kyoto University Press. ISBN978-4-87698-960-7

Valley J.W. and Cole D.R. (eds.) (2001) Stable Isotope Geochemistry. Mineralogical Society of America, Reviews in Mineralogy and Geochemistry 43. QE501.4.N9 S724

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Western's Laboratory for Stable Isotope Science (LSIS)