

Earth Sciences 4431a. Isotope Geochemistry in Earth and Environmental Sciences

When: Monday, Wednesday, Friday, 11:30 to 12:20 pm,
Where: P&AB, Room 150
Instructor: Dr. Fred J. Longstaffe, 1023 BGS (Biological and Geological Sciences)
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Office hours: by appointment

Teaching Assistant: tba

Prerequisites: Earth Sciences 2230A/B or 3341A/B or completion of any 2000 level half-course in Chemistry; or registration in the third or fourth year of an Environmental Sciences module; or permission of the Department. Unless you have either the requisites for this course or written special permission from your Dean to enroll in it, you may be removed from this course and it will be deleted from your record. This decision may not be appealed. You will receive no adjustment to your fees in the event that you are dropped from a course for failing to have the necessary prerequisites.

Grading:

Mid-term test:	20%
Final examination:	40%
Review paper:	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 available at the UWO Bookstore or through other retail vendors. 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: Friday, **October 24, 2014** (during regular class time)
2. Topic for the review paper to be approved by Monday, **October 20, 2014**
3. Review paper due Friday, **November 14, 2014**
4. Due dates of problem sets will be announced in class and indicated on OWL
5. Final examination date will be set by the Registrar's office

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 essays for the first 4 days. Essays submitted more than 4 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, cosmic abundance of the elements, 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), laboratory tour.

2. Stable isotopes in the atmosphere and hydrosphere

Equilibrium fractionation of isotopes, kinetic processes, O and H 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), 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, oxygen-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), oxygen-isotope geothermometry, high temperature concordancy, Pegmatite Paradise, retrograde isotopic exchange and disequilibrium; meteorites, mass independent fractionation.

4. Stable isotopes in sedimentary rocks, weathering and diagenesis

Chemical sediments (carbonate, chert), clastic sediments, submarine weathering (halmyrolysis), oxygen isotopic 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, oxygen and hydrogen isotopic variation in soil and weathering clays

5. Carbon- and nitrogen-isotopes in organic matter

Introduction to carbon isotopes on Earth, photosynthesis (C3, C4, CAM and aquatic plants), carbon isotopic fractionation during photosynthesis (diffusive, enzymatic), fractionation during organic synthesis, carbon isotope behaviour during vegetation shifts and climate change (Pinery Problem), isotopic alteration of soil organic matter (oxidation, microbial), humic substances, tracking carbon storage in soils (Maya

examples), nitrogen isotopic variations in air, soil, plants and animals, diet and paleodiet (collagen, structural carbonate in bioapatite, keratin), carbon and nitrogen isotopic trophic effects, food webs, N-isotope baselines, *are you what you eat?*

6. Carbon-isotopes in the carbon cycle

Carbon cycle (long- versus short-term), carbon reservoirs (δ -values and fluxes), Earth carbon isotope budget, atmospheric CO₂, coal, petroleum, natural gas, biogenic methane, tracing hydrocarbon leaks, ice core carbon dioxide, equilibrium carbon-isotope fractionation, the long-term carbon cycle (carbonates, biological pump, glacial versus interglacial marine productivity), Phanerozoic C-isotope secular variations (atmospheric oxygen, extinction events, Strangelove Ocean, PETM)

7. Sulphur isotopes

Introduction to sulphur 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 sulphur-isotope fractionation, sulphur isotopes in ore deposits, crystal chemistry and bond-strength controls on sulphur isotopic fractionation, speciation effects on sulphur isotopic compositions ($f[O_2]$ and pH), comparison with carbon isotopic system

8. Thinking like an Isotopist

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

Boutton T.W. and Yamasaki S. (eds.) (1996) Mass Spectrometry of Soils. Marcel Dekker Inc, New York. S593.M4415

Bowen, R. (1988) Isotopes in the Earth Sciences. Elsevier Applied Science, New York. ISMN 1-85166-145-X

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

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

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
- 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
- Longstaffe F.J. (1987) Stable isotope studies of diagenetic processes. In: *Stable Isotope Geochemistry of Low Temperature Fluids* (ed. T.K. Kyser) Mineralogical Association of Canada 13, p 187-257. Montreal QE501.4.N9 S725.
- Longstaffe F.J. (1989) Stable isotopes as tracers in clastic diagenesis. In: *Burial Diagenesis* (ed. I. E. Hutcheon). Mineralogical Association of Canada Short Course 15, p. 201-277. Montreal.
- Longstaffe F.J. (2000) Chapter 6. An introduction to stable oxygen and hydrogen isotopes and their use as fluid tracers in sedimentary systems. In: *Fluids and Basin Evolution* (ed. T.K. Kyser). Mineralogical Association of Canada Short Course Series, v. 28, p. 115-162.
- Mazor E. (1991) *Applied Chemical and Isotopic Groundwater Hydrology*. Open University Press. ISBN 0-335-15212-0
- Mitchener R. and Lajtha K. (eds.) (2007) *Stable Isotopes in Ecology and Environmental Science*, 2nd Edition. Blackwell Publishing, Malden. ISBN-13 978-1-4051-2680-9
- Mellon F.A., Startin J.R. and Self R. (2000) *Mass Spectrometry of Natural Substances in Foods*. Royal Society of Chemistry. TX 547.M45
- 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.) *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
- West J.B., Bowen G.J., Dawson T.E. and Tu K.P. (eds.) (2010) *Isoscapes – Understanding Movement, Pattern, and Processes on Earth through Isotope Mapping*. Springer. ISBN 978-90-481-3356-6