

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

Fall Term 2019

When: Monday, Wednesday, and Friday, 11:30 to 12:30 pm,
Where: Arts and Humanities Building -1B08
Instructor: Dr. Liz Webb, 0168 Biology and Geology Building
ewebb5@uwo.ca, 519-661-2111 x 80208
Office hours: by appointment

Teaching Assistant:

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: | 25% |
| Final examination: | 35% |
| Review paper | 25% |
| Problem sets | 15% |

Text Book: Sharp Z. (2007) Stable Isotope Geochemistry. Pearson Prentice Hall. 344 p.

You can buy this book through Amazon.ca or download the digital version for free at this site: https://digitalrepository.unm.edu/unm_oer/1/ (click on the title)
This book is also on hold for short term loan in the Taylor Library.

There are short readings associated with most lectures and you are expected to read this material. Other materials and hand-outs for this course can be found online on the OWL system: <https://owl.uwo.ca/portal>

Important dates:

1. Mid-term test: Wednesday **October 23, 2019** (during regular class time)
2. Topic for the review paper to be approved by **October 9, 2019**
3. Review paper due Wednesday **November 20, 2019**
4. Refer to the lecture timetable for due dates of problem sets
5. Final exam date will be set by the Registrar's office

The Midterm date is firm and make-up exams will not be permitted. Please talk to the instructor if you have valid reason for missing the exam. Late essays will suffer a 5% reduction per day on the final grade for the first 4 days. Essays submitted more than 4 days late will not be accepted.

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.

Statement on Use of Electronic Devices: During exams electronic devices (e.g. computers, phones) will not be allowed. You may use a calculator provided it does not connect with the internet (e.g. no calculator apps on your phone).

Statement on Academic Offences: 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.

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 assignments in their own words. Whenever students take an idea, or a passage from another author, they must acknowledge their debt both by using proper referencing such as citations. For more information see Scholastic Offence Policy in the Western Academic Calendar.

Plagiarism detection software: All required papers will 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>).

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

SDC's Learning Skills Services: Rm 4100 WSS, <http://www.sdc.uwo.ca/learning>
LS counsellors are ready to help you improve your learning skills. We offer presentations on strategies for improving time management, multiple-choice exam preparation/writing, textbook reading, and more. Individual support is offered throughout the Fall/Winter terms in the drop-in Learning Help Centre, and year-round through individual counselling.

Student's responsibilities in the event of a medical issue or missed exam/assignment:

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. A student requiring academic accommodation due to illness should use the Student Medical Certificate when visiting an off-campus medical facility or request a Records Release Form (located in the

Course Outline:

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

Part A – Stable Isotopes

1. Introduction

Importance to geological studies, isotopes of interest and some general principles, the atom, chart of the nuclides and isotopes, atomic mass units and atomic weight, binding energy, nuclear stability, cosmic abundance of the elements, the history of stable isotope geochemistry, definitions (the δ -value, α , $10^3 \ln \alpha$, Δ -value), standards, method of study, extraction techniques, mass spectrometry, lab tour.

2. Stable isotopes in the atmosphere and hydrosphere

Equilibrium fractionation of isotopes, kinetic processes, the meteoric water line, Rayleigh distillation, oxygen and hydrogen isotopes in rain, snow and ice, the oceans (evaporation, ice cap effects, pore waters in oceanic sediments), ground water, soil water, geothermal waters, formation waters in sedimentary basins, glaciers, paleothermometry in the oceans and on land, the isotopic composition of the oceans through time.

3. Stable isotope variations in igneous rocks

Introduction, oxygen reservoirs (water, sedimentary rocks, the mantle and derivative rock types), mineral ordering, fractional crystallization, the oxygen-isotope geochemistry of granitoid rocks (normal ^{18}O , low- ^{18}O and meteoric water interaction, high ^{18}O rocks and the role of sediments, isotopic exchange between granitic rocks and their country rocks), oxygen-isotope geothermometry in igneous rocks, meteorites, mass independent fractionation.

4. Stable isotope variations in weathering and diagenetic processes

Submarine weathering, oxygen- and hydrogen-isotopes in soil clays and chemical weathering, carbonates and patinas, diagenesis (sandstone) and the Western Canada Sedimentary Basin

5. Carbon-, nitrogen - and sulphur-isotope studies of organic matter, fossil fuels and related materials

Introduction to carbon isotopes, carbon in modern biosphere (photosynthesis) and in soils, fossil fuels, and carbonates, study of diet and migration, atmospheric CO_2 , carbon in the lithosphere. Introduction to nitrogen isotopes. Nitrogen isotopes in diet, soils and plants. Introduction to sulphur isotopes, biogenic fractionation, sulphur in recent sediments, hydrocarbons, coal, igneous and sedimentary rock, ore deposits and the environment.

References:

- Attendorn H.G. and Bowen R.N.C. (1987) *Radioactive and Stable Isotope Geology*. Chapman and Hall, London. QE501.4.N9 B69
- 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. editors (1996) *Mass Spectrometry of Soils*. Marcel Dekker Inc, New York. S593.M4415
- Dicken A.P. (1995) *Radiogenic Isotope Geology*. Cambridge University Press. QE501.4.N9 D53
- Coleman D.C. and Fry B. editors (1991) *Carbon Isotope Techniques*. Academic Press Inc. San Diego. QH 324.3.C37
- Faure G. (1986) *Principles of Isotope Geology*. John Wiley and Sons, New York.
- Hall A. (1996) *Igneous Petrology*. Longman Group Limited, Essex, England. QE461.H256
- Hoefs J (1997) *Stable Isotope Geochemistry*. Springer, Berlin. QE515.H67
- 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. editors (1993) *Nitrogen Isotope Techniques*. Academic Press, Inc. San Diego. QH324.35.N1 N57
- Lajtha K. and Michener R.H. editors (1994) *Stable Isotopes in Ecology and Environmental Science*. Blackwell Scientific Publishing. QH541.15.S68 L35
- Lewis C.L.E. and Knell S.J. editors (2001) *The Age of the Earth: From 4004 BC to AD 2002*. The Geological Society of London. QE508.A33
- Longstaffe F.J. editor (1981) *Short Course in Clays and the Resource Geologist*. MAC Short Course May, 1981, 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, Saskatoon, May 1987. volume 13, p 187-257. QE501.4.N9 S725
- Longstaffe F.J. (1989) Stable isotopes as tracers in clastic diagenesis. In: *Short Course in Burial Diagenesis* (ed. I. E. Hutcheon) Mineralogical Association of Canada, Montreal, May 1989. volume 15, p 201-277
- Mellon F.A., Self R. and Startin J.R. (2000) *Mass Spectrometry of Natural Substances in Foods*. Royal Society of Chemistry. TX 547.M45
- Sharp Z. (2007) *Principles of Stable Isotope Geochemistry*. Pearson Prentice Hall, New York.
- Valley J.W. and Cole D.R. editors (2001) *Stable Isotope Geochemistry*. Mineralogical Society of America, *Reviews in Mineralogy and Geochemistry*, volume 43. QE501.4.N9 S724

| 4431a and 9506 - Assigned Readings | | | | | | | | | | |
|--|---------------------------------|---------|---------|--------------------------------------|------------|----------|--------------|---------------------------------|--|--|
| Sharp, Z. (2018, e-edition) Stable Isotope Geochemistry. Pearson Prentice Hall | | | | | | | | | | |
| Chapter | pages | # pages | Section | Topic | Importance | | | Notes | | |
| | | | | | Important | Slightly | for interest | | | |
| STABLE ISOTOPES | | | | | | | | | | |
| 1 | 1 - 5 | 4 | 1.2 | historical background | | | X | | | |
| | 5 - 9 | 4 | 1.3 | Scope of Discipline | X | | | | | |
| | 9 - 10 | 1 | 1.4 | Abundances of Isotopes | X | | | | | |
| | 10 - 11 | 1 | 1.5 | Elements that Fractionate | X | | | | | |
| | 12 - 13 | 1 | 1.6 | Application | X | | | | | |
| | 13 - 15 | 2 | 1.7 | Isotope Effects | X | | | | | |
| TERMINOLOGY | | | | | | | | | | |
| 2 | 1 - 2 | 1 | 2.1 | Overview | | | X | | | |
| | 1 - 2 | 1 | 2.2 | Terminology | X | | | | | |
| | 2 - 7 | 5 | 2.3 | Delta Value | X | | | | | |
| | 8 - 9 | 1 | 2.4 | Fractionation factor | X | | | | | |
| | 10 - 11 | 1 | 2.5 | 1000lna | X | | | | | |
| | 12 - 19 | 7 | 2.6 | Reference standards | | X | | | | |
| | 19 - 32 | 13 | 2.7 | Mass spectrometry | X | X | | focus on mass spectrometry | | |
| | FRACTIONATION | | | | | | | | | |
| 3 | 1 - 2 | 1 | 3.1 | Introduction | | | X | | | |
| | 2 - 8 | 6 | 3.2 | Fractionation factors | X | X | | study equations from lectures | | |
| | 9 - 10 | 1 | 3.3 | Relationship to temperature | X | | | | | |
| | 10 - 14 | 4 | 3.4 | Determining fractionation factors | X | | | | | |
| | 14 - 15 | 1 | 3.5 | Empirical fractionation factors | X | | | | | |
| | 19 - 23 | 4 | 3.7 | Multiple isotope systems | X | | | applies to meteorites | | |
| METEORIC WATER | | | | | | | | | | |
| 4 | 1 - 2 | 1 | 4.1 | Hydrosphere Overview | | | X | | | |
| | 2 - 3 | 1 | 4.2 | Isotopologues of water | X | | | | | |
| | 3 - 4 | 1 | 4.3 | Meteoric water | X | | | | | |
| | 4 - 10 | 6 | 4.4 | Meteoric water line (MWL) | X | | | | | |
| | 10 - 12 | 2 | 4.5 | Deuterium excess | X | | | | | |
| | 12 - 18 | 6 | 4.6 | Evaporation and Condensation | X | | | | | |
| | 19 - 24 | 5 | 4.7 | factors affecting precipitation | X | | | | | |
| | 24 - 26 | 2 | 4.8 | Ground water | X | | | | | |
| | 26 - 28 | 2 | 4.9 | Geothermal Systems | X | | | | | |
| | 28 - 30 | 2 | 4.10 | Formation Waters | X | | | | | |
| | 30 - 36 | 6 | 4.11 | Glacial Ice | X | | | | | |
| | 36 - 38 | 2 | 4.12 | Triple isotopes in water | | X | | if we have time | | |
| | OCEANS | | | | | | | | | |
| | 5 | 1 - 2 | 1 | 5.1 | Overview | | X | | | |
| 2 - 6 | | 4 | 5.2 | Modern Oceans | X | | | | | |
| 6 - 7 | | 1 | 5.3 | Depth profiles | | X | | carbon is later in the course | | |
| 7 - 8 | | 1 | 5.4 | Productivity | | X | | | | |
| 9 - 11 | | 2 | 5.5 | Ancient Oceans | X | | | | | |
| 11 - 14 | | 3 | 5.6 | Seawater-basalt buffering | X | | | | | |
| 15 - 17 | | 2 | 5.7 | Buffering again! | X | | | | | |
| CARBONATES | | | | | | | | | | |
| 6 | 1 - 2 | 1 | 6.1 | Introduction | | | X | | | |
| | 2 - 5 | 3 | 6.2 | Phosphoric Acid method | | | X | | | |
| | 6 - 10 | 4 | 6.3 | Paleothermometer Scale | X | | | | | |
| | 11 - 19 | 8 | 6.4 | factors affecting paleothermometry | X | | | | | |
| | 19 - 25 | 6 | 6.5 | applications of paleothermometry | X | | | | | |
| | 25 - 27 | 2 | 6.6 | Clumped isotope paleothermometry | X | | | | | |
| CARBON | | | | | | | | | | |
| | 1 - 1 | 0 | 7.1 | Introduction | | | X | | | |
| | 1 - 2 | 1 | 7.2 | The carbon cycle | | | X | | | |
| | 3 - 12 | 9 | 7.3 | Carbon reservoirs | X | | | focus on plants and organics | | |
| | 12 - 22 | 10 | 7.4 | carbon isotopes in carbonates | X | | | | | |
| | 22 - 23 | 1 | 7.5 | terrestrial carbonates | X | | | | | |
| | LOW TEMPERATURE MINERALS | | | | | | | | | |
| 8 | 1 - 1 | 0 | 8.1 | Introduction | | | X | | | |
| | 1 - 10 | 9 | 8.2 | Phosphates | X | | | focus on mammals | | |
| | 10 - 15 | 5 | 8.3 | Cherts | X | | | focus on diatoms and phytoliths | | |
| | 16 - 19 | 3 | 8.4 | Clay minerals | X | | | | | |
| | 19 - 21 | 2 | 8.5 | Iron oxides | | | X | | | |
| NITROGEN | | | | | | | | | | |
| 9 | 1 - 2 | 1 | 9.1 | Introduction | X | | | | | |
| | 2 - 3 | 1 | 9.2 | The nitrogen cycle | X | | | | | |
| | 3 - 6 | 3 | 9.3 | N-isotope fractionation | X | | | | | |
| | 6 - 11 | 5 | 9.4 | Nitrogen isotope values of materials | X | | | | | |
| | 11 - 15 | 4 | 9.5 | Nitrogen in animals | X | | | | | |
| SULFUR | | | | | | | | | | |
| 10 | 1 - 2 | 1 | 10.1 | Introduction | | X | | | | |
| | 2 - 3 | 1 | 10.2 | Analytical techniques | | | X | | | |
| | 4 - 6 | 2 | 10.3 | Equilibrium Fractionation | X | | | | | |
| | 7 - 10 | 3 | 10.4 | Sedimentary Sulfur | | X | | | | |
| | 10 - 15 | 5 | 10.5 | secular variations in sulfur | X | | | | | |
| | 15 - 16 | 1 | 10.6 | S in the terrestrial environment | | X | | | | |
| | 16 - 17 | 1 | 10.7 | Oxygen isotopes in sulphates | X | | | | | |
| IGNEOUS PETROLOGY | | | | | | | | | | |
| 11 | 1 - 1 | 0 | 11.1 | Introduction | | | X | | | |
| | 1 - 7 | 6 | 11.2 | The mantle | X | | | oxygen only | | |
| | 14 - 20 | 6 | 11.3 | Plutonic rocks | X | | | | | |
| | 20 - 22 | 2 | 11.4 | Fluid-rock ratios | | X | | | | |
| | 22 - 26 | 4 | 11.5 | other processes | | X | | | | |
| EXTRA TERRESTRIAL MATERIAL | | | | | | | | | | |
| 13 | 1 - 2 | 1 | 13.1 | Introduction | | X | | | | |
| | 1 - 3 | 2 | 13.2 | Classification of meteorites | X | | | | | |
| | 3 - 11 | 8 | 13.3 | Oxygen isotopes of the solar system | X | | | | | |