

GEOLOGICAL SCIENCES

Courses offered by the Department of Geological Sciences are listed under the subject code GEOLSCI on the Stanford Bulletin's ExploreCourses web site (<https://explorecourses.stanford.edu/search/?q=GEOLSCI&view=catalog&page=0&academicYear=&filter-term-Autumn=on&filter-term-Winter=on&filter-term-Spring=on&filter-term-Summer=on&collapse=&filter-departmentcode=GEOLSCI=on&filter-catalognumber=GEOLSCI=on&filter-coursestatus=Active=on&filter-catalognumber=GEOLSCI=on>).

The geological sciences include the study of Earth materials and processes and how those materials and processes have changed over the planet's 4.56-billion-year history and vary across other planets. More specifically, courses and research within the department address: the chemical and physical makeup and properties of minerals, rocks, soils, sediments, and water; the formation and evolution of Earth and other planets; the processes that shape planetary surfaces and interiors; the stratigraphic, paleobiological, and geochemical records of Earth history including changes in climate, oceans, and atmosphere; the observation and robotic exploration of other planets; present-day, historical, and long-term feedbacks between the geosphere and biosphere; and the origin and occurrence of our natural resources.

Besides the fundamental nature of research performed within the department, it has critical implications for the study and remediation of natural hazards (earthquakes, volcanic eruptions, landslides, and floods); environmental and geological engineering; surface and groundwater management; the assessment, exploration, and extraction of energy, mineral and water resources; ecology and conservation biology; remediation of contaminated water and soil; geological mapping and land use planning; human health and the environment; and space exploration.

Mission of the Undergraduate Program in Geological Sciences

The purpose of the undergraduate program in Geological Sciences is to provide students with a broad background in the fundamentals of the Earth and planetary sciences and the quantitative, analytical, and communications skills necessary to conduct research and think critically about questions involving the Earth and other planets. The major provides excellent preparation for graduate school and careers in geological and environmental consulting, land use planning, law, teaching, and other professions in which a background in science and an understanding of our and other planets are important.

Learning Outcomes (Undergraduate)

The department expects undergraduate majors in the program to be able to demonstrate the following learning outcomes. These learning outcomes are used in evaluating students and the department's undergraduate program. Students are expected to develop and demonstrate:

1. an understanding of fundamental concepts in Earth and planetary science.
2. the ability to collect, analyze, and interpret geological and environmental data using a variety of techniques to test hypotheses.
3. the ability to address real geological and/or environmental problems in the field.
4. the ability to communicate scientific knowledge orally, visually, and in writing.

Graduate Programs in Geological Sciences

Graduate Studies in the Department of Geological Sciences involve academic course work and independent research. Students are prepared for careers as professional scientists in research, education, or the application of the Earth and planetary sciences to mineral, energy, water, and space resources. Programs lead to the M.S., Engineer, and Ph.D. degrees. Course programs in the areas of faculty interest are tailored to the student's needs and interests with the aid of his or her research adviser. Students are encouraged to include in their program courses offered in other departments in the School of Earth, Energy and Environmental Sciences as well as in other departments in the University.

Learning Outcomes (Graduate)

The purpose of the master's program in Geological Sciences is to continue a student's training in one of a broad range of Earth or planetary science disciplines and to prepare students for either a professional career or doctoral studies.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship, high attainment in a particular field of knowledge, and the ability to conduct independent research. To this end, the objectives of the doctoral program are to enable students to develop the skills needed to conduct original investigations in a particular discipline or set of disciplines in the Earth and planetary sciences, to interpret the results, and to present the data and conclusions in a publishable manner.

Bachelor of Science in Geological Sciences

The Department of Geological Sciences offers a Bachelor of Science in Geological Sciences. Eligible students may also pursue a Bachelor of Science with Honors (p. 2). The department also offers a minor in Geological Sciences (p. 3).

Degree Requirements

The major consists of four interrelated components:

1. *Geological and Planetary Sciences Foundation*—Students must complete a set of six courses that introduce the properties of planetary materials, the processes that change the Earth and other planets, and the timescales over which those processes act. These courses provide a broad foundational knowledge that can lead to specialization in many different disciplines of the geological and environmental sciences. While these courses are not considered pre-requisite for any other courses, all must be taken at some point during each student's program of study.
2. *Disciplinary Breadth*—Students choose from a series of electives that broaden exposure to the fields represented within geoscience. These courses consist of classroom lectures, which in many cases, are augmented by field and laboratory components. Students must take eight (8) of these courses during their program of study.
3. *Geoscience Research*—Each student must complete a total of nine (9) units of research, guided by one or more faculty mentors. Students are expected to produce a thesis, which may be suitable for submission to a disciplinary journal, at the conclusion of their research projects.
4. *Field training / Capstone Experience*—Each student's educational program culminates in a capstone experience as a senior. The capstone can take one of two forms. First, students may elect to take a course in which they will use the scientific knowledge they have gained to address a real-world, applied problem chosen by a faculty instructor. Students will work in design teams to use their

geoscience background to understand the particular problem, and to apply their knowledge to design workable solutions to the chosen problem. Students are expected to present this in the form of written reports and oral presentations, which may be evaluated by a panel of non-profit specialists in the chosen area. Second, students may elect to participate in a field study program to fulfill their capstone experience. In this case, students must complete at least six weeks of field research through either departmental offerings (Research in the Field, GEOLSCI 190 (<https://exploreddegrees.stanford.edu/search/?P=GEOLSCI%20190>) Research in the Field) or an approved outside offering, in which they learn and apply field techniques, field mapping, and then prepare a written report.

The major requires at between 58 and 74 units; letter grades are required in all courses if available. Students interested in the GS major should consult with the undergraduate program coordinator for information about options within the curriculum. It should also be recognized that the Geological Sciences are heavily dependent on the other sciences and that any undergraduate in the Geological Sciences should be looking to supplement their major course work with classes in Math, Physics, Chemistry, and Biology. However, those outside courses that might be most appropriate will depend on the background, goals, and interests of the individual student and can be explored with the faculty adviser.

Course Requirements

| | Units |
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| Geological and Planetary Sciences Foundation | 22 |
| Students are required to take all of the following: | |
| GEOLSCI 1 Introduction to Geology | 5 |
| GEOLSCI 2 Chemistry of the Earth and Planets | 3 |
| GEOLSCI 3 (Earth and Planetary Processes) | 3 |
| GEOLSCI 4 Coevolution of Earth and Life | 4 |
| GEOLSCI 6 Data Science for Geoscience | 3 |
| GEOLSCI 105 Introduction to Field Methods | 3 |
| Disciplinary Breadth | 23-34 |
| To gain an understanding of the breadth of subject areas within the geological sciences, students are required to take eight of the following courses (24-34 units). At least six of these courses must be 100-level courses from the "Geological Sciences" list below, while two may be from the "Supporting Disciplines" list. | |
| Geological Sciences | |
| GEOLSCI 40N Diamonds | |
| GEOLSCI 42 Moving and Shaking in the Bay Area | |
| GEOLSCI 106 Sediments: The Book of Earth's History | |
| GEOLSCI 107 Journey to the Center of the Earth | |
| GEOLSCI 110 Our Dynamic West | |
| GEOLSCI 112 Geomorphology | |
| GEOLSCI 118X Shaping the Future of the Bay Area | |
| GEOLSCI 119 Formation and Dynamics of Planets | |
| GEOLSCI 120 Planetary Surface Processes: Shaping the Landscape of the Solar System | |
| GEOLSCI TBD (Planetary Interiors) | |
| GEOLSCI 123 Evolution of Marine Ecosystems | |
| GEOLSCI 128 Evolution of Terrestrial Ecosystems | |
| GEOLSCI 132 Evolution of Earth Systems | |
| GEOLSCI 135 Sedimentary Geochemistry and Analysis | |
| GEOLSCI 163 Introduction to Isotope Geochemistry | |
| GEOLSCI 180 Igneous Processes | |
| Supporting Disciplines | |
| CEE 177 Aquatic Chemistry and Biology | |
| ESS 117 Earth Sciences of the Hawaiian Islands | |

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| ESS 152 | Marine Chemistry | |
| ESS 155 | Science of Soils | |
| ESS 158 | Geomicrobiology | |
| ESS 220 | Physical Hydrogeology | |
| ESS 256 | Soil and Water Chemistry | |
| GEOPHYS 110 | Introduction to the Foundations of Contemporary Geophysics | |
| GEOPHYS 120 | Ice, Water, Fire | |
| GEOPHYS 130 | Introductory Seismology | |
| GEOPHYS 150 | Geodynamics: Our Dynamic Earth | |
| GEOPHYS 182 | Reflection Seismology | |
| GEOPHYS 190 | Near-Surface Geophysics: Imaging Groundwater Systems | |
| Geoscience Research | | 9 |
| Gaining hands-on research with the scientific method under the guidance of a faculty mentor is a requirement for all majors. | | |
| GEOLSCI 192 | Undergraduate Research in Geological Sciences | 6 |
| GEOLSCI 197 | Senior Thesis | 3 |
| Field Training / Capstone Experience | | 3-9 |
| Each student major will participate in a capstone experience. For those interested in field research, students may take GEOLSCI 190 (Research in the Field) to satisfy the capstone experience. ¹ | | |
| GEOLSCI 190 | Research in the Field | 6 |
| GEOLSCI TBD | (Capstone Experience) | 3 |
| Additional Field Opportunities (optional) | | |
| GEOLSCI 5 | Living on the Edge | |
| GEOLSCI 135A | Sedimentary Geochemistry Field Trip | |
| OSPAUSTL 10 | Coral Reef Ecosystems | |
| Total Units | | 58-74 |

¹ This field course may be taken with the GEOLSCI faculty when offered, or alternatively, an approved field program may be used to satisfy this requirement. Alternatively, students may participate in a classroom-based capstone experience, during which they will use knowledge gained in the major to develop creative solutions to real-world problems in a cohort-based project. Ideally, both the field research experience and the capstone experience would be completed by all undergraduates; however, completion of only one of these courses is required to successfully complete the major.

Honors Program

The honors program provides an opportunity for year-long independent study and research on a topic of special interest, culminating in a written thesis. Students select research topics in consultation with the faculty adviser of their choosing. Research undertaken for the honors program may be of a theoretical, field, or experimental nature, or a combination of these approaches. The honors program is open to students with a GPA of at least 3.5 in GS courses and 3.0 in all University course work. Modest financial support is available from several sources to help defray laboratory and field expenses incurred in conjunction with honors research. Interested students must submit an application, including a research proposal, to the department by the end of their junior year.

Upon approval of the research proposal and entrance to the program, course credit for the honors research project and thesis preparation is assigned by the student's faculty adviser within the framework of GEOLSCI 199 Honors Program; the student must complete a total of 9 units over the course of the senior year. Up to 4 units of GEOLSCI 199 may be counted towards the elective requirement, but cannot be used as a substitute for regularly required courses.

Both a written and oral presentation of research results are required. The thesis must be read, approved, and signed by the student's faculty adviser and a second member of the faculty. In addition, honors students must participate in the GS Honors Symposium in which they present their research to the broader community. Honors students in GS are also eligible for the Firestone medal, awarded by Academic Advising (<http://advising.stanford.edu>) for exceptional theses.

Minor in Geological Sciences

The minor in GS consists of a set of foundational courses (19 units) and three elective courses (9-14 units), totaling 28-33 units. A wide variety of courses may be used to satisfy these elective requirements. All courses must be taken for a letter grade.

Degree Requirements

| | Units |
|---|--------------|
| Geological and Planetary Sciences Foundation | 19 |
| Students are required to take all of the following: | |
| GEOLSCI 1 Introduction to Geology | 5 |
| GEOLSCI 2 Chemistry of the Earth and Planets | 3 |
| GEOLSCI 3 (Earth and Planetary Processes) | 3 |
| GEOLSCI 4 Coevolution of Earth and Life | 4 |
| GEOLSCI 6 Data Science for Geoscience | 3 |
| Electives | 9-14 |
| Students must take a minimum of 9 additional units drawn primarily from the Breadth in the Discipline list in the GS major; a majority of units must be from classes within the GS department. | |
| To gain an understanding of the breadth of subject areas within the geological sciences, students are required to take three of the following courses (9-14 units). At least two of these courses must be from the "Geological Sciences" list below, while one may be from the "Supporting Disciplines" list. | |
| Geological Sciences | |
| GEOLSCI 40N Diamonds | |
| GEOLSCI 42 Moving and Shaking in the Bay Area | |
| GEOLSCI 105 Introduction to Field Methods | |
| GEOLSCI 106 Sediments: The Book of Earth's History | |
| GEOLSCI 107 Journey to the Center of the Earth | |
| GEOLSCI 110 Our Dynamic West | |
| GEOLSCI 112 Geomorphology | |
| GEOLSCI 118X Shaping the Future of the Bay Area | |
| GEOLSCI 119 Formation and Dynamics of Planets | |
| GEOLSCI 120 Planetary Surface Processes: Shaping the Landscape of the Solar System | |
| GEOLSCI TBD (Planetary Interiors) | |
| GEOLSCI 123 Evolution of Marine Ecosystems | |
| GEOLSCI 128 Evolution of Terrestrial Ecosystems | |
| GEOLSCI 132 Evolution of Earth Systems | |
| GEOLSCI 135 Sedimentary Geochemistry and Analysis | |
| GEOLSCI 163 Introduction to Isotope Geochemistry | |
| GEOLSCI 180 Igneous Processes | |
| Supporting Disciplines | |
| CEE 177 Aquatic Chemistry and Biology | |
| ESS 117 Earth Sciences of the Hawaiian Islands | |
| ESS 152 Marine Chemistry | |
| ESS 155 Science of Soils | |
| ESS 158 Geomicrobiology | |
| ESS 220 Physical Hydrogeology | |
| ESS 256 Soil and Water Chemistry | |

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| GEOPHYS 110 | Introduction to the Foundations of Contemporary Geophysics |
| GEOPHYS 120 | Ice, Water, Fire |
| GEOPHYS 130 | Introductory Seismology |
| GEOPHYS 150 | Geodynamics: Our Dynamic Earth |
| GEOPHYS 182 | Reflection Seismology |
| GEOPHYS 190 | Near-Surface Geophysics: Imaging Groundwater Systems |
| Additional Field Opportunities (optional) | |
| GEOLSCI 5 | Living on the Edge |
| GEOLSCI 135A | Sedimentary Geochemistry Field Trip |
| OSPAUSTL 10 | Coral Reef Ecosystems |
| Total Units | 28-33 |

On April 16, 2015, the Senate of the Academic Council approved the Master of Science in Geological Sciences. Students who matriculated into the Master of Science in Geological and Environmental Sciences have the option of changing the name of their degree to Geological Sciences. Degree requirements remain the same.

Coterminal Master of Science Degree in Geological Sciences

The coterminal B.S./M.S. program offers students the opportunity to pursue graduate research and an M.S. degree concurrently with or subsequent to their B.S. studies. The M.S. degree can serve as an entrance to a professional degree in subdisciplines within the Earth sciences such as engineering geology and environmental geology, or to graduate course work and research as an intermediate step in pursuit of the Ph.D. Regardless of professional goals, coterminal B.S./M.S. students are treated as members of the graduate community and are expected to meet all of the standards set for regular M.S. students. Applicants must have earned no fewer than 120 units toward graduation, and must submit their application no later than the quarter prior to the expected completion of their undergraduate degree, normally the Winter Quarter prior to Spring Quarter graduation. The application includes a statement of purpose, a current Stanford transcript, official Graduate Record Examination (GRE) scores, letters of recommendation from two members of the Stanford faculty (at least one of whom must be in the GS department), and a list of courses in which they intend to enroll to fulfill the M.S. degree requirements. Specific research interests should be noted in the statement of purpose and discussed with a member of the GS faculty prior to submission of the application. Coterminal students must complete a thesis describing research results.

Students must meet all requirements for both the B.S. and M.S. degrees. Students may either:

1. complete 180 units required for the B.S. degree and then complete three full-time quarters (45 units at the 100-level or above) for the M.S. degree
2. or. complete a total of fifteen quarters during which the requirements of the two degrees are fulfilled concurrently.

At least half of the courses used to satisfy the 45-unit requirement must be designated as being primarily for graduate students, normally at the 200-level or above. No more than 15 units of thesis research may be used to satisfy the 45-unit requirement. Further information about this program may be obtained from the GS office.

University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the "Coterminal Master's Program (<http://exploreddegrees.stanford.edu/cotermdegrees/>)" section. University requirements for the

master's degree are described in the "Graduate Degrees (<http://exploreddegrees.stanford.edu/graduatedegrees/#masterstext>)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken during or after the first quarter of the sophomore year are eligible for consideration for transfer to the graduate career; the timing of the first graduate quarter is not a factor. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate advisor be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

Admission

For admission to graduate work in the department, the applicant must have taken the Aptitude Test (verbal, quantitative, and analytical writing assessment) of the Graduate Record Examination. In keeping with University policy, applicants whose first language is not English must submit TOEFL (Test of English as a Foreign Language) scores from a test taken within the last 18 months. Individuals who have completed a B.S. or two-year M.S. program in the U.S. or other English-speaking country are not required to submit TOEFL scores.

Master of Science in Geological Sciences Objectives

The purpose of the master's program in Geological Sciences is to continue a student's training in one of a broad range of earth science disciplines and to prepare students for either a professional career or doctoral studies.

Procedures

In consultation with the adviser, the student plans a program of course work for the first year. The student should select a thesis adviser within the first year of residence and submit to the thesis adviser a proposal for thesis research as soon as possible. The academic adviser supervises completion of the department requirements for the M.S. program (as outlined below) until the research proposal has been accepted; responsibility then passes to the thesis adviser. The student may change either thesis or academic advisers by mutual agreement and after approval of the Director of Graduate Studies.

Requirements

The University's requirements for M.S. degrees are outlined in the "Graduate Degrees (<http://www.stanford.edu/dept/registrar/bulletin/4901.htm>)" section of this bulletin. Practical training (GEOLSCI 385 Practical Experience in the Geosciences) may be required by some programs, with adviser approval, depending on the background of the student. Additional department requirements include the following:

1. A minimum of 45 units of course work at the 100 level or above.
 - a. Half of the courses used to satisfy the 45-unit requirement must be intended as being primarily for graduate students, usually at the 200 level or above.

- b. No more than 15 units of thesis research may be used to satisfy the 45-unit requirement.
 - c. Some students may be required to make up background deficiencies in addition to these basic requirements.
2. By the end of Spring Quarter of their first year in residence, students must complete at least three graduate level courses taught by a minimum of two different GS faculty members.
3. Each student must have a research adviser who is a faculty member in the department and is within the student's thesis topic area or specialized area of study.
4. M.S. students must complete at least one TA appointment (25%). Additional TA quarters may be considered and/or required in consultations with the research advisor, depending on academic goals, funding availability, or the requirements of individual graduate programs.
5. Each student must complete a thesis describing his or her research. Thesis research should begin during the first year of study at Stanford and should be completed before the end of the second year of residence.
6. Early during the thesis research period, and after consultation with the student, the thesis adviser appoints a second reader for the thesis, who must be approved by the Director of Graduate Studies; the thesis adviser is the first reader. The two readers jointly determine whether the thesis is acceptable for the M.S. degree in the department.

Engineer Degree in Geological Sciences

The Engineer degree is offered as an option for students in applied disciplines who wish to obtain a graduate education extending beyond that of an M.S., yet do not have the desire to conduct the research needed to obtain a Ph.D. A minimum of two years (six quarters) of graduate study is required. The candidate must complete 90 units of course work, no more than 10 of which may be applied to overcoming deficiencies in undergraduate training. The student must prepare a substantial thesis that meets the approval of the thesis adviser and the graduate coordinator.

On April 16, 2015, the Senate of the Academic Council approved the Doctor of Philosophy in Geological Sciences. Students who matriculated into the Doctor of Philosophy in Geological and Environmental Sciences have the option of changing the name of their degree to Geological Sciences. Degree requirements remain the same.

Doctor of Philosophy in Geological Sciences

Objectives

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship, high attainment in a particular field of knowledge, and the ability to conduct independent research. To this end, the objectives of the doctoral program are to enable students to develop the skills needed to conduct original investigations in a particular discipline or set of disciplines in the earth sciences, to interpret the results, and to present the data and conclusions in a publishable manner.

Admission

For admission to graduate work in the department, the applicant must have taken the Aptitude Test (verbal, quantitative, and analytical writing assessment) of the Graduate Record Examination. In keeping with University policy, applicants whose first language is not English must submit TOEFL (Test of English as a Foreign Language) scores from a test taken within the last 18 months. Individuals who have completed a B.S. or two-year M.S. program in the U.S. or other English-speaking country are not required to submit TOEFL scores. Previously admitted students who

wish to change their degree objective from M.S. to Ph.D. must petition the GS Admissions Committee.

Requirements

The University's requirements for the Ph.D. degree are outlined in the "Graduate Degrees (<http://exploreddegrees.stanford.edu/graduatedegrees/>)" section of this bulletin. Practical training (GEOLSCI 385 Practical Experience in the Geosciences) may be required by some programs, with advisor approval, depending on the background of the student. A summary of additional department requirements is presented below:

Students are required to take six graded graduate level courses with at least 3 units to be completed with a grade point average (GPA) of 3.0 (B) or higher. By the end of Spring Quarter of their first year in residence, students must complete at least three graduate level courses taught by a minimum of two different GS faculty members. The remaining courses can be any graded course of at least 3-units within the University. First year students are also required to take GEOLSCI 307 Research Proposal Development and Delivery.

An incoming student with a relevant master of science degree may apply for a departmental waiver for up to two of the graduate level courses to fulfill these requirements, as approved by their departmental graduate faculty advisor and the GSC. Transfer credits cannot be used to fulfill the first year requirement.

Ph.D. students must complete at least one TA appointment (25%).

Additional TA quarters may be considered and/or required in consultations with the research advisor, depending on academic goals, funding availability, or the requirements of individual doctoral programs.

Each student must qualify for candidacy for the Ph.D. by the end of the sixth quarter in residence, excluding summers. Department procedures require selection of a faculty thesis advisor, preparation of a written research proposal, approval of this proposal by the thesis advisor, selection of a committee for the Ph.D. qualifying examination, and approval of the membership by the graduate coordinator and chair of the department. The research examination consists of three parts: oral presentation of a research proposal, examination on the research proposal, and examination on subject matter relevant to the proposed research. The exam should be scheduled prior to May 1, so that the outcome of the exam is known at the time of the annual spring evaluation of graduate students.

Upon qualifying for Ph.D. candidacy, the student and thesis advisor, who must be a department faculty member, choose a research committee that includes a minimum of two faculty members in the University in addition to the advisor.

During orientation, first-year students meet with the Graduate Studies Committee to discuss their proposed plan of coursework and potential research directions. Prior to the qualification exam, the student is required to organize two meetings with a research committee. During Spring Quarter of the first year, the student meets to present a brief progress report covering the past year and use of the upcoming Summer in the context of developing research topics. During the following Autumn or Winter Quarter of the second year, the student presents an update on their progress and receives feedback for planning of their qualification exam. Upon passing the qualification exams, the student is required to organize an annual Spring Quarter meeting with the research committee to present a progress report and plan for the upcoming year.

Under the supervision of the research advisory committee, the candidate must prepare a doctoral dissertation that is a contribution to knowledge and is the result of independent research. The format of the dissertation must meet University guidelines. The student is strongly urged to prepare

dissertation chapters that, in scientific content and format, are readily publishable.

The doctoral dissertation is defended in the University oral examination. The research advisor and two other members of the research committee are determined to be readers of the draft dissertation. The readers are charged to read the draft and to certify in writing to the department that it is adequate to serve as a basis for the University oral examination. Upon obtaining this written certification, the student is permitted to schedule the University oral examination.

Ph.D. Minor in Geological Sciences

Candidates for the Ph.D. degree in other departments who wish to obtain a minor in Geological Sciences must complete, with a GPA of 3.0 (B) or better, 20 units in the geosciences in lecture courses intended for graduate students. The selection of courses must be approved by the student's GS advisor and the department chair.

COVID-19 Policies

On July 30, the Academic Senate adopted grading policies effective for all undergraduate and graduate programs, excepting the professional Graduate School of Business, School of Law, and the School of Medicine M.D. Program. For a complete list of those and other academic policies relating to the pandemic, see the "COVID-19 and Academic Continuity (<http://exploreddegrees.stanford.edu/covid-19-policy-changes/#tempdeptemplatetabtext>)" section of this bulletin.

The Senate decided that all undergraduate and graduate courses offered for a letter grade must also offer students the option of taking the course for a "credit" or "no credit" grade and recommended that deans, departments, and programs consider adopting local policies to count courses taken for a "credit" or "satisfactory" grade toward the fulfillment of degree-program requirements and/or alter program requirements as appropriate.

Undergraduate Degree Requirements

Grading

Classes taken CR/NC for the 2020-21 academic year will be accepted for credit towards a GS major. However, the department also encourages each student to discuss the choice of graded versus CR/NC with their faculty advisor, the Director of the Undergraduate Curriculum, George Hilley, and/or our Assistant Director of Student Service, Lauren Mendoza-Tabinas, in order to assess the best approach in the context of individual degree and career objectives.

Graduate Degree Requirements

Grading

Classes taken during the 2020-21 academic year must be taken on a graded basis in order to count toward the requirements for graded coursework for Ph.D. candidacy.

The Department of Geological Sciences is committed to providing academic advising in support of graduate student scholarly and professional development. The department strives to ensure everyone in the department has a fulfilling experience by creating an inclusive culture. The School of Earth, Energy, and Environmental Sciences shares this commitment as reflected in the Stanford Earth Policy on Respectful and Inclusive Behavior. With respect to the advising relationship, this entails collaborative and sustained engagement by both the advisor and the advisee. Both the advisor and the advisee are expected to maintain professionalism and integrity.

Inclusivity and Diversity

The Department of Geological Sciences strives to ensure that graduate students feel safe, secure, and supported during their graduate experience. It does not tolerate any form of harassment targeting race, gender identity and expression, sexual orientation, physical and mental ability, physical appearance, age and/or religion. Any experience of discrimination, harassment, or inequity in the department will not be tolerated and met with appropriate consequences in accordance with Stanford University's Harassment and Discrimination policy. (<https://adminguide.stanford.edu/chapter-1/subchapter-7/>) Students can seek support from the Associate Chair of Diversity and Inclusion, Jef Caers, or the Assistant Director of Student Services, Lauren Mendoza-Tabinas.

Mental Health

Members of the Geological Sciences department recognize that challenges to mental health are real and can come from both inside and outside the academic setting. We support and encourage each other to seek resources towards mental health and well-being. If any event during the graduate experience places a student under undue stress that inhibits their performing to their potential, the department encourages the student to seek support from the Director of Graduate Studies (Wendy Mao), Assistant Director of Student Services (Lauren Mendoza-Tabinas) or University services (Counseling and Psychological Services (<https://vaden.stanford.edu/caps/>)).

Academic Accommodations

The Office of Accessible Education (OAE) is the campus office designated to work with Stanford students with disabilities. To comply with Stanford's academic accommodations process, faculty should not attempt to arrange accommodations by themselves with the student. Students with questions about accommodations should contact OAE to initiate a disability-related request for accommodations. When a student presents an OAE Accommodation Letter, that letter should be followed or the faculty member should work with the student and OAE to implement and/or modify the recommended accommodations. Students are expected to initiate accommodations requests in a timely manner and to provide prompt notification of changes to approved accommodations. Faculty are responsible for maintaining student confidentiality and treating all disability-related information as confidential.

Establishing Advisor-Advisee Expectations

Both advisor and advisee are expected to take responsibility in actively discussing the nature of the graduate experience. For first year students, the results of the discussion regarding the nature of the graduate experience and the expectations of each party is summarized in a document that is signed by both advisor and advisee. The relationship and expectations evolve as the student progresses through their graduate experience. Regularly scheduled advisor-advisee interactions are an important component of this relationship. Advisors are expected to check in with their students every quarter to discuss how the expectations are met and if any expectations need updating. Students are encouraged to revisit these conversations when the advisor-advisee relationship is not meeting their needs and/or expectations are not met. Additionally, a written review is held in Spring Quarter that covers the student's academic progress with their advisor(s) and committee members.

Graduate students are expected to proactively seek academic and professional guidance and take responsibility for informing themselves of policies and degree requirements for their graduate program. In addition to the primary advisor, students are highly encouraged to seek advice from other faculty in the department, as well as other faculty and researchers (Stanford or external) who align with their research

interest. For a statement of University policy on graduate advising, see the "Graduate Advising (<http://exploreddegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext>)" section of this bulletin. When needed, students can seek support and assistance from the Assistant Director of Student Services (Lauren Mendoza-Tabinas).

Guidelines for advisor-advisee interactions

The advisor-advisee relationship is mutual. Graduate students and faculty can expect mutual respect, high professional standards, and the sharing of ideas and research. Advisors should strive continuously to improve their mentoring abilities. Group dynamics can be complex; advisors should strive to be equitable in the treatment of students, including the distribution of opportunities in group, classroom, field, and laboratory settings. Further information regarding guidelines and best practices on advising and mentoring is available from the Office of the Vice Provost for Graduate Education and School-wide documents like the Minimum Graduate Advising Guidelines Earth, Energy & Environmental Sciences: School-wide Suggestions. Graduate students are expected to exercise high professional standards in their academic work, research, and mentoring partnerships and to be proactive in seeking advice and keeping the advisor informed about academic and research progress. Students and advisors are expected to both take responsibility for meeting timelines, policies, and milestones that impact degree progress. We expect respect and equity in our department at all levels from one-on-one interactions to department-wide events.

Students in need of assistance should contact the Assistant Director of Student Services, Lauren Mendoza-Tabinas, or the Assistant Dean for Student Services, Alyssa Ferree, to be informed about a clearly articulated path of contacts for their questions, concerns, and challenges around advising that they may experience. Students may also contact any school representatives listed below to discuss issues regarding advisor-advisee interactions:

- Other faculty members of your advisory committee
- Wendy Mao, Director of Graduate Studies in Geological Sciences
- Kevin Boyce, Department Chair of Geological Sciences
- Robyn Dunbar, Associate Dean for Educational Affairs
- Sue Crutcher, Associate Dean for Human Resources and Faculty Affairs
- Graduate Student Advisory Council representatives in Geological Sciences

Emeriti: (Professors) Atilla Aydin, Dennis K. Bird, Gordon E. Brown, W. Gary Ernst, James C. Ingle, Jr., Juhn G. Liou, Gail A. Mahood, Jonathan F. Stebbins, David D. Pollard

Chair: C. Kevin Boyce

Associate Chair: Wendy Mao

Director of Graduate Studies: Wendy Mao

Director of Undergraduate Studies: George Hilley

Professors: C. Kevin Boyce, Jef Caers, Page Chamberlain, Rodney C. Ewing, Stephan A. Graham, George Hilley, Donald R. Lowe, Wendy Mao, Elizabeth L. Miller, Jonathan Payne

Associate Professors: Jane Willenbring

Assistant Professors: Mathieu Lapôtre, Andrew Leslie, Ayla Pamukcu, Laura Schaefer, Erik Sperling

Professors (Research): Martin J. Grove

Courtesy Professors: Elizabeth Hadly, Simon L. Klemperer, Kate Maher, Tapan Mukerji, Sonia Tikoo

Cognate Courses

Many courses offered within the School of Earth, Energy and Environmental Sciences, as well as courses in other schools with a significant Earth sciences component, may be used in satisfaction of optional requirements for the Geological Sciences degree. Undergraduates should discuss the options available to them with the undergraduate program coordinator; graduate students should discuss options with their advisers.

The following courses outside the School of Earth, Energy and Environmental Sciences are particularly applicable:

| | | Units |
|--------------|---|--------------|
| BIOHOPK 182H | Stanford at Sea | 16 |
| CEE 63 | Weather and Storms | 3 |
| CEE 64 | Air Pollution and Global Warming: History, Science, and Solutions | 3 |
| CEE 101A | Mechanics of Materials | 4 |
| CEE 101B | Mechanics of Fluids | 4 |
| CEE 101C | Geotechnical Engineering | 3-4 |
| CEE 166A | Watershed Hydrologic Processes and Models | 3 |

Overseas Studies Courses in Geological Sciences

The Bing Overseas Studies Program (<http://bosp.stanford.edu>) (BOSP) manages Stanford international and domestic study away programs for Stanford undergraduates. Students should consult their department or program's student services office for applicability of Overseas Studies courses to a major or minor program.

The BOSP course search site (<https://undergrad.stanford.edu/programs/bosp/explore/search-courses/>) displays courses, locations, and quarters relevant to specific majors.

For course descriptions and additional offerings, see the listings in the Stanford Bulletin's ExploreCourses (<http://explorecourses.stanford.edu>) or Bing Overseas Studies (<http://bosp.stanford.edu>).

Due to COVID-19, all BOSP programs have been suspended for Autumn Quarter 2020-21. All courses and quarters of operation are subject to change.

Units

explorecourses:OSP gs

Courses

GEOLSCI 1. Introduction to Geology. 5 Units.

Why are earthquakes, volcanoes, and natural resources located at specific spots on the Earth surface? Why are there rolling hills to the west behind Stanford, and soaring granite walls to the east in Yosemite? What was the Earth like in the past, and what will it be like in the future? Lectures, hands-on laboratories, in-class activities, and one field trip will help you see the Earth through the eyes of a geologist. Topics include plate tectonics, the cycling and formation of different types of rocks, and how geologists use rocks to understand Earth's history.

Same as: EARTHSYS 11

GEOLSCI 2. Chemistry of the Earth and Planets. 3 Units.

Chemistry of the Earth and Planets Course Description: Introduction to chemical principles with an emphasis on applications in the Earth Sciences. Topics include: origin and distribution of the elements in the solar system and on Earth, origin and structure of the Earth, its oceans and atmosphere, crystal chemistry, structure, and transformations, predicting and balancing reactions; thermodynamics, phase diagrams, high temperature and aqueous geochemistry, weathering, isotope geochemistry, and organic geochemistry. Students will also be exposed to analytical methods used in the Earth sciences.

GEOLSCI 4. Coevolution of Earth and Life. 4 Units.

Earth is the only planet in the universe currently known to harbor life. When and how did Earth become inhabited? How have biological activities altered the planet? How have environmental changes affected the evolution of life? Are we living in a sixth mass extinction? In this course, we will develop and use the tools of geology, paleontology, geochemistry, and modeling that allow us to reconstruct Earth's 4.5 billion year history and to reconstruct the interactions between life and its host planet over the past 4 billion years. We will also ask what this long history can tell us about life's likely future on Earth. We will also use One half-day field trip.

Same as: EARTHSYS 4

GEOLSCI 5. Living on the Edge. 1 Unit.

A weekend field trip along the Pacific Coast. Tour local beaches, geology, and landforms with expert guides from the School of Earth, Energy & Environmental Sciences. Enjoy a BBQ dinner and stay overnight in tents along the coast. Get to know faculty and graduate students in Stanford Earth. Transportation, meals, and camping equipment are provided at no cost to student participants. AY2020-21 offering is dependent on the COVID-19 health situation.

Same as: EARTH 15

GEOLSCI 6. Data Science for Geoscience. 3 Units.

This course provides an overview of the most relevant areas of data science to address geoscientific challenges and questions as they pertain to the environment, earth resources & hazards. The focus lies on the methods that treat common characters of geoscientific data: multivariate, multi-scale, compositional, geospatial and space-time. In addition, the course will treat those statistical method that allow a quantification of the human dimension by looking at quantifying impact on humans (e.g. hazards, contamination) and how humans impact the environment (e.g. contamination, land use). The course focuses on developing skills that are not covered in traditional statistics and machine learning courses.

Same as: EARTHSYS 100A

GEOLSCI 14. Our National Parks. 2 Units.

Explore the history and natural science of three national parks proximal to Stanford. Under the guidance of instructors, students will work in teams to learn about chosen aspects of these parks, develop dynamic self-guided tours for public consumption, and implement (and publish) these tours using the XibitEd app for iPhones. Students will learn how to present their findings to a general, non-scientific audience, delineate physical locations at which storytelling will take place through the XibitEd system, and create and configure the content for the system. The course will culminate in the publishing of the experiential learning tours, as well as a weekend-long field trip to the Pinnacles National Park.

Same as: EARTH 14, EARTH 114A, GEOLSCI 114A

GEOLSCI 30N. Science Fiction Worlds. 3 Units.

Science fiction writers, with limited knowledge of what technologies or discoveries about space might exist in the future, must build entire worlds in their minds and craft underlying physical laws about how these fantastical places might operate and the types of environments that they could sustain. In this course, we will use popular works of science fiction from film, television, and literature as conversation starters to discuss real discoveries that have been made about how planets form and evolve over time. The class will focus on the following overarching questions: (1) What conditions are required for habitable planets to form? (2) What types of planets may actually exist, including desert worlds, lava planets, ice planets, and ocean worlds? (3) What kinds of life could inhabit such diverse worlds? (3) What types of catastrophic events such as supernovas, asteroid impacts, climate changes can nurture or destroy planetary habitability?.

Same as: GEOPHYS 30N

GEOLSCI 38N. The Worst Journey in the World: The Science, Literature, and History of Polar Exploration. 3 Units.

This course examines the motivations and experiences of polar explorers under the harshest conditions on Earth, as well as the chronicles of their explorations and hardships, dating to the 1500s for the Arctic and the 1700s for the Antarctic. Materials include *The Worst Journey in the World* by Aspley Cherry-Garrard who in 1911 participated in a midwinter Antarctic sledging trip to recover emperor penguin eggs. Optional field trip into the high Sierra in March.

Same as: EARTHSYS 38N, ESS 38N

GEOLSCI 40N. Diamonds. 3 Units.

Preference to freshmen. Topics include the history of diamonds as gemstones, prospecting and mining, and their often tragic politics. How diamond samples provide clues for geologists to understand the Earth's deep interior and the origins of the solar system. Diamond's unique materials properties and efforts in synthesizing diamonds.

GEOLSCI 42. Moving and Shaking in the Bay Area. 4 Units.

Active faulting and erosion in the Bay Area, and its effects upon landscapes. Earth science concepts and skills through investigation of the valley, mountain, and coastal areas around Stanford. Faulting associated with the San Andreas Fault, coastal processes along the San Mateo coast, uplift of the mountains by plate tectonic processes, and landsliding in urban and mountainous areas. Field excursions; student projects.

Same as: EARTH 42

GEOLSCI 45. Developing and maintaining a habitable Earth: A global challenge?. 3 Units.

Did you ever wonder how we got here and where we are going? This course examines how the Earth became habitable for humans after 4.5 billion years of history and where we are headed as we continue to alter the Earth's livable environment. The Earth as we know it today is itself a highly tuned system of linked fluid (oceans and atmosphere) and solid (rock) envelopes that interact to maintain a highly hospitable environment for advanced life forms and civilization. From water to food to energy and mineral resources, we rely on our planet. Was this synergy always the case? Will it continue this way? We will explore how the Earth became habitable, specifically examining how those conditions arose and how they might change in the future, exploring what might happen when we perturb this system. How will the Earth respond and over what time scales? This course, taught by earth scientists who want to continue making our planet habitable for future generations, will also give you the hands on working knowledge of the Earth system and its evolution, and the tools and models we use to understand today's delicately balanced Earth system. It is our hope that at the end of this course you will have deep insights into your origins, your place in the universe, and how best to ensure that Earth remains our home.

GEOLSCI 46Q. Environmental Impact of Energy Systems: What are the Risks?. 3 Units.

In order to reduce CO₂ emissions and meet growing energy demands during the 21st Century, the world can expect to experience major shifts in the types and proportions of energy-producing systems. These decisions will depend on considerations of cost per energy unit, resource availability, and unique national policy needs. Less often considered is the environmental impact of the different energy producing systems: fossil fuels, nuclear, wind, solar, and other alternatives. One of the challenges has been not only to evaluate the environmental impact but also to develop a systematic basis for comparison of environmental impact among the energy sources. The course will consider fossil fuels (natural gas, petroleum and coal), nuclear power, wind and solar and consider the impact of resource extraction, refining and production, transmission and utilization for each energy source.

Same as: EARTHSYS 46Q

GEOLSCI 59N. Earthquake 9.0: The Heritage of Fukushima Daiichi 6 Years Later. 3 Units.

We will consider the case for nuclear power as an energy source through the lens of the Fukushima disaster. Specific topics will include the cause of the earthquake and tsunami, the causes for the nuclear power plant failure, the mechanisms for the release of radioactivity at the time of the accident and today, and the ongoing human impact of this tragedy. In addition to the details of the accident and the release of radioactivity, class discussions and readings will explore the health and economic impacts of nuclear power and examine how the accident has affected the future prospects of nuclear power in Japan, the U.S., and around the world.

GEOLSCI 103. Earth Materials: Rocks in Thin Section. 3 Units.

Use of petrographic microscope to identify minerals and common mineral associations in igneous, metamorphic, and sedimentary rocks. Crystallization histories, mineral growth and reaction relations, deformation textures in metamorphic rocks, and provenance of siliciclastic rocks. Required lab section. Prerequisite 102.

Same as: GEOLSCI 203

GEOLSCI 105. Introduction to Field Methods. 3 Units.

Two-week, field-based course in the White Mountains of eastern California. Introduction to the techniques for geologic mapping and geologic investigation in the field: systematic observations and data collection for lithologic columns and structural cross-sections. Interpretation of field relationships and data to determine the stratigraphic and deformational history of the region. Prerequisite: GEOLSCI 1, recommended: GEOLSCI 102.

GEOLSCI 106. Sediments: The Book of Earth's History. 3 Units.

Topics: weathering, erosion and transportation, deposition, origins of sedimentary structures and textures, sediment composition, diagenesis, sedimentary facies, tectonics and sedimentation, and the characteristics of the major siliciclastic and carbonate depositional environments. Required Lab Section: methods of analysis of sediments in hand specimen and thin section. There is a required field problem trips to the field site(s) during the quarter, data collection and analysis, and preparation of a final written and oral report. Prerequisites: 1, 102, 103.

GEOLSCI 107. Journey to the Center of the Earth. 3 Units.

The interconnected set of dynamic systems that make up the Earth. Focus is on fundamental geophysical observations of the Earth and the laboratory experiments to understand and interpret them. What earthquakes, volcanoes, gravity, magnetic fields, and rocks reveal about the Earth's formation and evolution.

Same as: GEOLSCI 207, GEOPHYS 184, GEOPHYS 274

GEOLSCI 110. Our Dynamic West. 5 Units.

Theory, principles, and practical techniques to measure, describe, analyze, and interpret deformation-related structures on Earth. Collection of fault and fold data in the field followed by lab and computer analysis; interpretation of geologic maps and methods of cross-section construction; structural analysis of fault zones and metamorphic rocks; measuring deformation; regional structural styles and associated landforms related to plate tectonic convergence, rifting and strike-slip faulting; the evolution of mountain belts and formation of sedimentary basins. Prerequisite: GEOLSCI 1, calculus. Recommended: 102, 105. Same as: GEOLSCI 294

GEOLSCI 112. Geomorphology. 3 Units.

Development of earth's landscapes and landforms by processes by rock uplift, weathering, hill slopes and flowing water, wind and ice. Analysis of the imprint, role, and legacy of climate and tectonics in shaping modern landscapes. Application of earth's surface processes to the evaluation of hazards posed by these phenomena.

GEOLSCI 114A. Our National Parks. 2 Units.

Explore the history and natural science of three national parks proximal to Stanford. Under the guidance of instructors, students will work in teams to learn about chosen aspects of these parks, develop dynamic self-guided tours for public consumption, and implement (and publish) these tours using the XibitEd app for iPhones. Students will learn how to present their findings to a general, non-scientific audience, delineate physical locations at which storytelling will take place through the XibitEd system, and create and configure the content for the system. The course will culminate in the publishing of the experiential learning tours, as well as a weekend-long field trip to the Pinnacles National Park. Same as: EARTH 14, EARTH 114A, GEOLSCI 14

GEOLSCI 118X. Shaping the Future of the Bay Area. 3-5 Units.

The complex urban problems affecting quality of life in the Bay Area, from housing affordability and transportation congestion to economic vitality and social justice, are already perceived by many to be intractable, and will likely be exacerbated by climate change and other emerging environmental and technological forces. Changing urban systems to improve the equity, resilience and sustainability of communities will require new collaborative methods of assessment, goal setting, and problem solving across governments, markets, and communities. It will also require academic institutions to develop new models of co-production of knowledge across research, education, and practice. This XYZ course series is designed to immerse students in co-production for social change. The course sequence covers scientific research and ethical reasoning, skillsets in data-driven and qualitative analysis, and practical experience working with local partners on urban challenges that can empower students to drive responsible systems change in their future careers. The Autumn (X) course is specifically focused on concepts and skills, and completion is a prerequisite for participation in the Winter (Y) and/or Spring (Z) practicum quarters, which engage teams in real-world projects with Bay Area local governments or community groups. X is composed of four modules: (A) participation in two weekly classes which prominently feature experts in research and practice related to urban systems; (B) reading and writing assignments designed to deepen thinking on class topics; (C) fundamental data analysis skills, particularly focused on Excel and ArcGIS, taught in lab sessions through basic exercises; (D) advanced data analysis skills, particularly focused on geocomputation in R, taught through longer and more intensive assignments. X can be taken for 3 units (ABC), 4 units (ACD), or 5 units (ABCD). Open to undergraduate and graduate students in any major. For more information, visit <http://bay.stanford.edu>.

Same as: CEE 118X, CEE 218X, ESS 118X, ESS 218X, GEOLSCI 218X, GEOPHYS 118X, GEOPHYS 218X, POLISCI 218X, PUBLPOL 118X, PUBLPOL 218X

GEOLSCI 118Y. Shaping the Future of the Bay Area. 3-5 Units.

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 118Y, CEE 218Y, ESS 118Y, ESS 218Y, GEOLSCI 218Y, GEOPHYS 118Y, GEOPHYS 218Y, POLISCI 218Y, PUBLPOL 118Y, PUBLPOL 218Y

GEOLSCI 118Z. Shaping the Future of the Bay Area. 3-5 Units.

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 118Z, CEE 218Z, ESS 118Z, ESS 218Z, GEOLSCI 218Z, GEOPHYS 118Z, GEOPHYS 218Z, POLISCI 218Z

GEOLSCI 119. Formation and Dynamics of Planets. 3-4 Units.

This course will cover formation of planets within a protoplanetary disk, dynamical evolution of planetary systems (Grand Tack and Nice models, planet migration), condensation chemistry within the solar nebula and meteorite classification, classical accretion models and pebble accretion, melting, magma ocean formation and core formation on rocky objects. Topics will be discussed in the context of both the Solar system and extrasolar planet observations.

Same as: GEOLSCI 219, GEOPHYS 109, GEOPHYS 209

GEOLSCI 120. Planetary Surface Processes: Shaping the Landscape of the Solar System. 4 Units.

The surfaces of planets, moons, and other bodies are shaped and modified by a wide array of physical and chemical processes. Understanding these processes allows us to decipher the history of the Solar System. This course offers a quantitative examination of both exogenous processes - such as impact cratering and space weathering - and endogenous processes - such as tectonics, weathering, and volcanic, fluvial, eolian, and periglacial activity - as well as a brief introduction to the fundamentals of remote sensing in the context of planetary exploration. As we develop a basic mechanistic framework for these processes, we will apply our acquired knowledge through thematic discussions of the surfaces of Mercury, Venus, Earth, the Moon, Mars, asteroids, Io, Titan, Europa, Enceladus, Pluto, and comets. For upper-division undergraduates and graduate students.

Same as: GEOLSCI 220, GEOPHYS 119, GEOPHYS 219

GEOLSCI 121. What Makes a Habitable Planet?. 3 Units.

Physical processes affecting habitability such as large impacts and the atmospheric greenhouse effect, comets, geochemistry, the rise of oxygen, climate controls, and impact cratering. Detecting and interpreting the spectra of extrasolar terrestrial planets. Student-led discussions of readings from the scientific literature. Team taught by planetary scientists from NASA Ames Research Center.

Same as: GEOLSCI 221

GEOLSCI 122. Planetary Systems: Dynamics and Origins. 2-4 Units.

(Students with a strong background in mathematics and the physical sciences should register for 222.) Motions of planets and smaller bodies, energy transport in planetary systems, composition, structure and dynamics of planetary atmospheres, cratering on planetary surfaces, properties of meteorites, asteroids and comets, extrasolar planets, and planetary formation. Prerequisite: some background in the physical sciences, especially astronomy, geophysics, or physics. Students need instructor approval to take the course for 2 or 4 units.

Same as: GEOLSCI 222, GEOPHYS 122

GEOLSCI 123. Evolution of Marine Ecosystems. 3-4 Units.

Life originally evolved in the ocean. When, why, and how did the major transitions occur in the history of marine life? What triggered the rapid evolution and diversification of animals in the Cambrian, after more than 3.5 billion years of Earth's history? What caused Earth's major mass extinction events? How do ancient extinction events compare to current threats to marine ecosystems? How has the evolution of primary producers impacted animals, and how has animal evolution impacted primary producers? In this course, we will review the latest evidence regarding these major questions in the history of marine ecosystems. We will develop familiarity with the most common groups of marine animal fossils. We will also conduct original analyses of paleontological data, developing skills both in the framing and testing of scientific hypotheses and in data analysis and presentation.

Same as: BIO 119, EARTHYSYS 122, GEOLSCI 223B

GEOLSCI 124. INTRODUCTION TO PLANETARY SCIENCE. 3-4 Units.

This course provides an introduction to planetary science through the exploration of processes that formed and modified planetary bodies within the Solar System and beyond. Each lecture will be given by an expert in a specific subfield of planetary sciences, with topics ranging from planetary materials and formation, planetary dynamics, planetary structure and tectonics, planetary atmospheres, impact cratering, surface processes, and astrobiology. We will also discuss how scientists investigate planets both near and far through sample analysis, telescopic and orbital remote sensing as well as in situ through robotic instruments. Although there are no prerequisites for this course, it is primarily directed towards undergraduate students who are majoring (or plan to) in the sciences or engineering. A minimum level of mathematics equivalent to high school algebra and introductory calculus will be necessary.

Same as: ESS 125, GEOPHYS 124

GEOLSCI 127. PLANETARY SCIENCE READING. 1 Unit.

The course will meet once a week to discuss a recent journal article related to the broad field of planetary science, including but not limited to cosmochemistry, planet formation, planetary geology, planetary atmospheres, Earth history, astrobiology, and exoplanets. Students will be expected to lead the group discussion at least once per quarter. No formal presentations will be required. There are no prerequisites for this course, but students should have some facility with reading scientific literature.

Same as: GEOLSCI 227, GEOPHYS 126, GEOPHYS 226

GEOLSCI 128. Evolution of Terrestrial Ecosystems. 4 Units.

The what, when, where, and how do we know it regarding life on land through time. Fossil plants, fungi, invertebrates, and vertebrates (yes, dinosaurs) are all covered, including how all of those components interact with each other and with changing climates, continental drift, atmospheric composition, and environmental perturbations like glaciation and mass extinction. The course involves both lecture and lab components. Graduate students registering at the 200-level are expected to write a term paper, but can opt out of some labs where appropriate.

Same as: BIO 148, BIO 228, EARTHYSYS 128, GEOLSCI 228

GEOLSCI 132. Evolution of Earth Systems. 4 Units.

This course examines biogeochemical cycles and how they developed through the interaction between the atmosphere, hydrosphere, biosphere, and lithosphere. Emphasis is on the long-term carbon cycle and how it is connected to other biogeochemical cycles on Earth. The course consists of lectures, discussion of research papers, and quantitative modeling of biogeochemical cycles. Students produce a model on some aspect of the cycles discussed in this course. Grades based on class interaction, student presentations, and the modeling project.

Same as: EARTHYSYS 132, EARTHYSYS 232, ESS 132, ESS 232, GEOLSCI 232

GEOLSCI 135. Sedimentary Geochemistry and Analysis. 1-4 Unit.

Introduction to research methods in sedimentary geochemistry. Proper laboratory techniques and strategies for generating reliable data applicable to any future labwork will be emphasized. This research-based course will examine how the geochemistry of sedimentary rocks informs us about local and global environmental conditions during deposition. Students will collect geochemical data from a measured stratigraphic section in the western United States. These samples will be collected during a four-day field trip at the end of spring break (attendance encouraged but not required). In lab, students will learn low-temperature geochemical techniques focusing on the cycling of biogeochemical elements (O, C, S, and Fe) in marine sediments throughout Earth history. The focus will be on geochemistry of fine-grained siliciclastic rocks (shale) but the geochemistry of carbonates will also be explored. This is a lab-based course complemented with lectures. Students who wish to take the course for less than 4 units must receive approval from the instructor. This course must be taken for a minimum of 3 units and a letter grade to be eligible for Ways credit.

Same as: GEOLSCI 235

GEOLSCI 135A. Sedimentary Geochemistry Field Trip. 1 Unit.

Field trip to a sedimentary succession of geobiological interest. Students will measure the stratigraphic section, describe any fossils and trace fossils, and collect samples for geochemical analysis. Offered over spring break.

GEOLSCI 136. Macroevolution. 3 Units.

The course will focus on the macroevolution of animals. We will be exploring how paleobiology and developmental biology/genomics have contributed to our understanding of the origins of animals, and how patterns of evolution and extinction have shaped the diversity of animal forms we observe today.

Same as: BIO 136, BIO 236, GEOLSCI 236

GEOLSCI 141. Machine Learning for Visual Recognition in Geosciences. 1 Unit.

Analyzing images is a big part of day-to-day life of geoscientists, such as conducting seismic interpretation or lithofacies identification and classification. Furthermore, visual representation, recognition and feature extraction play a crucial role in providing a foundation to solve different geosciences research questions, including reconstructing depositional environment, marine ecosystem and tectonic history. Image analysis is often costly, time consuming and requires in-depth knowledge of specific geological sub-fields (igneous, metamorphic, sedimentary petrography, and micropaleontology). Recent improvements in machine learning techniques, in particular deep learning, have led to excellent performance in different computer vision tasks (e.g., image classification, segmentation) that significantly increase efficiency and reproducibility. In this course, we will go through the basics of machine learning for visual recognition by analyzing different real-world geoscience problems and try to understand how machine learning algorithms can be used to help solve these problems. This course is intended to provide an introduction to visual recognition with machine learning. No prior knowledge of machine learning and python programming are required.

Same as: GEOLSCI 241

GEOLSCI 150. Senior Seminar: Issues in Earth Sciences. 3 Units.

Focus is on written and oral communication in a topical context. Topics from current frontiers in earth science research and issues of concern to the public. Readings, oral presentations, written work, and peer review. Same as: GEOPHYS 199

GEOLSCI 161. Quantitative Methods in Paleobiology. 3 Units.

The advent of large, publicly accessible sources of data relevant to paleobiology has opened new avenues for quantifying large-scale patterns in the history of life and for identifying their underlying causes. How and why has biodiversity changed over time? What factors control evolutionary trends within clades? How have environmental changes affected the evolution of life? In this course, we will introduce several of the most widely accessed sources of data for paleobiological analysis, such as the Paleobiology Database and Macrostrat, develop techniques for downloading and cleaning these data, and then explore several of the most commonly used statistical techniques in paleobiology, including phylogenetic analysis, phylogenetic regression and model fitting, logistic regression, ordination, and subsampling to analyze these data. Same as: GEOLSCI 261

GEOLSCI 163. Introduction to Isotope Geochemistry. 3 Units.

Isotopic variations in nature provide key insights into the age of the Earth and its rocks, as well as the evolution of Earth's major reservoirs, including the mantle, crust and hydrosphere. How do we know the age of the Earth? When did continents first form? How have the oceans changed through time? This course will address these and related topics by focusing on the fundamental processes that govern isotopic variations, including radioactive decay, mass dependent isotope fractionation and dynamic transfers between reservoirs. Same as: GEOLSCI 263

GEOLSCI 180. Igneous Processes. 3-4 Units.

For juniors, seniors and beginning graduate students in Earth Sciences. Structure and physical properties of magmas; use of phase equilibria and mineral barometers and thermometers to determine conditions of magmatic processes; melting and magmatic lineages as a function of tectonic setting; processes that control magma composition including fractional crystallization, partial melting, and assimilation; petrogenetic use of trace elements and isotopes. Optional labs emphasize identification of volcanic and plutonic rocks in thin section and interpretation of rock textures. Students taking the lab component should enroll in 4 units, as required for the Geological Sciences major; for the lab, GS 102, 103, or consent of instructor are prerequisites. Same as: GEOLSCI 280

GEOLSCI 190. Research in the Field. 3-6 Units.

Month long courses that provide students with the opportunity to collect data in the field as part of a team-based investigation of research questions or topics under the expert guidance of knowledgeable faculty and graduate students. Topics and locations vary. May be taken multiple times for credit. Prerequisites: GS 1, GS 102, GS 105. Same as: GEOLSCI 295

GEOLSCI 191. Stanford EARTH Field Courses. 1-2 Unit.

Four- to seven-day field trips to locations of geologic and environmental interest. Includes trips offered during Spring break. May be repeated for credit. Same as: EARTH 191

GEOLSCI 192. Undergraduate Research in Geological Sciences. 1-10 Unit.

Field-, lab-, or literature-based. Faculty supervision. Written reports. May be repeated for credit.

GEOLSCI 197. Senior Thesis. 3-5 Units.

For seniors who wish to write a thesis based on research in 192 or as a summer research fellow. May not be repeated for credit; may not be taken if enrolled in 199.

GEOLSCI 198. Special Problems in Geological Sciences. 1-10 Unit.

Reading and instruction under faculty supervision. Written reports. May be repeated for credit.

GEOLSCI 199. Honors Program. 1-10 Unit.

Research on a topic of special interest. See "Undergraduate Honors Program" above. May be repeated for credit.

GEOLSCI 203. Earth Materials: Rocks in Thin Section. 3 Units.

Use of petrographic microscope to identify minerals and common mineral associations in igneous, metamorphic, and sedimentary rocks. Crystallization histories, mineral growth and reaction relations, deformation textures in metamorphic rocks, and provenance of siliciclastic rocks. Required lab section. Prerequisite 102. Same as: GEOLSCI 103

GEOLSCI 205. Fundamentals of Geobiology. 3 Units.

Lecture and discussion covering key topics in the history of life on Earth, as well as basic principles that apply to life in the universe. Co-evolution of Earth and life; critical intervals of environmental and biological change; geomicrobiology; paleobiology; global biogeochemical cycles; scaling of geobiological processes in space and time. Same as: EARTHSYS 205A, ESS 205

GEOLSCI 206. Topics in Organismal Paleobiology. 2-3 Units.

Seminar course covering an area of structural biology, physiology, or ecology relevant to understanding the fossil record, with the topic changing each time the course is offered. Examples of potential topics are biomineralization, fluid mechanics, biomechanics, taphonomy & biochemical preservation, and the functional morphology/fossil history of specific evolutionary groups such as vertebrates, insects, or plants.

GEOLSCI 207. Journey to the Center of the Earth. 3 Units.

The interconnected set of dynamic systems that make up the Earth. Focus is on fundamental geophysical observations of the Earth and the laboratory experiments to understand and interpret them. What earthquakes, volcanoes, gravity, magnetic fields, and rocks reveal about the Earth's formation and evolution. Same as: GEOLSCI 107, GEOPHYS 184, GEOPHYS 274

GEOLSCI 208. Topics in Geobiology. 1 Unit.

Reading course addressing current topics in geobiology. Topics will vary from year to year, but will generally cover areas of current debate in the primary literature, such as the origin of life, the origin and consequences of oxygenic photosynthesis, environmental controls on and consequences of metabolic innovations in microbes, the early evolution of animals and plants, and the causes and consequences of major extinction events. Participants will be expected to read and present on current papers in the primary literature. Same as: ESS 208

GEOLSCI 209. Microstructures. 3-5 Units.

Microstructures in metamorphic rocks reveal temperature, pressure, and rates of deformation in the crust and variations in its thermo-mechanical behavior. Topics include the rheology of rocks and minerals, strain partitioning, shear zones and brittle-ductile transition in the crust, mechanisms of foliation and lineation development, preferred crystallographic fabrics, and geochronologic methods useful for dating deformation. Labs involve microstructure analysis of suites of rocks from classic localities. 5 units for extra project.

GEOLSCI 210. Geologic Evolution of the Western U.S. Cordillera. 1-3 Unit.

The geologic and tectonic evolution of the U.S. Cordillera based on its rock record through time. This region provides good examples of large-scale structures and magmatic activity generated during crustal shortening, extension, and strike-slip faulting and affords opportunity to study crustal-scale processes involved in mountain building in context of plate tectonic motions.

GEOLSCI 211. Topics in Regional Geology and Tectonics. 2-3 Units.

May be repeated for credit.

GEOLSCI 212. Topics in Tectonic Geomorphology. 2 Units.

For upper-division undergraduates and graduate students. Topics vary and may include coupling among erosional, tectonic, and chemical weathering processes at the scale of orogens; historical review of tectonic geomorphology; hillslope and fluvial process response to active uplift; measures of landscape form and their relationship to tectonic uplift and bedrock lithology. May be repeated for credit.

GEOLSCI 213. Topics in Sedimentary Geology. 1 Unit.

For upper division undergraduates and graduate students. Topics vary each year but the focus is on current developments and problems in sedimentary geology, sedimentology, Archean geology, and basin analysis. These include issues in deep-water sediments, their origin, facies, and architecture; sedimentary systems on the early Earth; and relationships among tectonics, basin development, and basin fill. May be repeated for credit.

GEOLSCI 214. Quantitative Dynamic Stratigraphy. 1-2 Unit.

This seminar will address how numerical modeling of depositional systems can be used to test geological hypotheses and improve our understanding of subsurface reservoirs. What are some of the advantages as well as challenges of using computational models and Monte Carlo methods? Students will read key literature as well as develop an understanding of available software such as SEDSIM and others. 2 unit option will require completing a weekend workshop.

GEOLSCI 215. Topics in Geobiodiversity and Stable Isotopes. 1 Unit.

This course exams the key questions of biodiversity through time (Geobiodiversity) and examines how we might tackle these questions using isotope biogeochemistry. The course consists of two interwoven components. First, what are the drivers of biodiversity - such as global and regional climate change, rise of topographic barriers, supply of nutrients, etc. Second, how do organisms obtain their isotopic signatures and how these might be used to differentiate between the drivers of biodiversity. The course will use case studies of biodiversity questions in key areas such as the Cenozoic of Asia, North America, and South America to develop research questions and approaches. The course will consist of lectures, work groups, and selected readings. Grade: Credit, No Credit.

GEOLSCI 216. Chemical Kinetics and Basin Modeling. 2-3 Units.

Students will explore the structure of sedimentary organic matter and the chemical and thermodynamic requirements for generating petroleum. A wide variety of thermal maturity indicators will be explored, paying particular attention to optical indicators and predictive kinetics of Tmax and %Ro. Students will understand the advantages and pitfalls of kinetic measurements in the lab. Hands-on exercises reinforce learning targets. An optional class project allows students to take the class for 3 units instead of 2. Course readings come from the literature and Burnham's textbook.

Same as: ENERGY 282, GEOPHYS 216

GEOLSCI 218X. Shaping the Future of the Bay Area. 3-5 Units.

The complex urban problems affecting quality of life in the Bay Area, from housing affordability and transportation congestion to economic vitality and social justice, are already perceived by many to be intractable, and will likely be exacerbated by climate change and other emerging environmental and technological forces. Changing urban systems to improve the equity, resilience and sustainability of communities will require new collaborative methods of assessment, goal setting, and problem solving across governments, markets, and communities. It will also require academic institutions to develop new models of co-production of knowledge across research, education, and practice. This XYZ course series is designed to immerse students in co-production for social change. The course sequence covers scientific research and ethical reasoning, skillsets in data-driven and qualitative analysis, and practical experience working with local partners on urban challenges that can empower students to drive responsible systems change in their future careers. The Autumn (X) course is specifically focused on concepts and skills, and completion is a prerequisite for participation in the Winter (Y) and/or Spring (Z) practicum quarters, which engage teams in real-world projects with Bay Area local governments or community groups. X is composed of four modules: (A) participation in two weekly classes which prominently feature experts in research and practice related to urban systems; (B) reading and writing assignments designed to deepen thinking on class topics; (C) fundamental data analysis skills, particularly focused on Excel and ArcGIS, taught in lab sessions through basic exercises; (D) advanced data analysis skills, particularly focused on geocomputation in R, taught through longer and more intensive assignments. X can be taken for 3 units (ABC), 4 units (ACD), or 5 units (ABCD). Open to undergraduate and graduate students in any major. For more information, visit <http://bay.stanford.edu>.

Same as: CEE 118X, CEE 218X, ESS 118X, ESS 218X, GEOLSCI 118X, GEOPHYS 118X, GEOPHYS 218X, POLISCI 218X, PUBLPOL 118X, PUBLPOL 218X

GEOLSCI 218Y. Shaping the Future of the Bay Area. 3-5 Units.

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 118Y, CEE 218Y, ESS 118Y, ESS 218Y, GEOLSCI 118Y, GEOPHYS 118Y, GEOPHYS 218Y, POLISCI 218Y, PUBLPOL 118Y, PUBLPOL 218Y

GEOLSCI 218Z. Shaping the Future of the Bay Area. 3-5 Units.

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 118Z, CEE 218Z, ESS 118Z, ESS 218Z, GEOLSCI 118Z, GEOPHYS 118Z, GEOPHYS 218Z, POLISCI 218Z

GEOLSCI 219. Formation and Dynamics of Planets. 3-4 Units.

This course will cover formation of planets within a protoplanetary disk, dynamical evolution of planetary systems (Grand Tack and Nice models, planet migration), condensation chemistry within the solar nebula and meteorite classification, classical accretion models and pebble accretion, melting, magma ocean formation and core formation on rocky objects. Topics will be discussed in the context of both the Solar system and extrasolar planet observations.

Same as: GEOLSCI 119, GEOPHYS 109, GEOPHYS 209

GEOLSCI 220. Planetary Surface Processes: Shaping the Landscape of the Solar System. 4 Units.

The surfaces of planets, moons, and other bodies are shaped and modified by a wide array of physical and chemical processes. Understanding these processes allows us to decipher the history of the Solar System. This course offers a quantitative examination of both exogenous processes - such as impact cratering and space weathering - and endogenous processes - such as tectonics, weathering, and volcanic, fluvial, eolian, and periglacial activity - as well as a brief introduction to the fundamentals of remote sensing in the context of planetary exploration. As we develop a basic mechanistic framework for these processes, we will apply our acquired knowledge through thematic discussions of the surfaces of Mercury, Venus, Earth, the Moon, Mars, asteroids, Io, Titan, Europa, Enceladus, Pluto, and comets. For upper-division undergraduates and graduate students.

Same as: GEOLSCI 120, GEOPHYS 119, GEOPHYS 219

GEOLSCI 221. What Makes a Habitable Planet?. 3 Units.

Physical processes affecting habitability such as large impacts and the atmospheric greenhouse effect, comets, geochemistry, the rise of oxygen, climate controls, and impact cratering. Detecting and interpreting the spectra of extrasolar terrestrial planets. Student-led discussions of readings from the scientific literature. Team taught by planetary scientists from NASA Ames Research Center.

Same as: GEOLSCI 121

GEOLSCI 222. Planetary Systems: Dynamics and Origins. 2-4 Units.

(Students with a strong background in mathematics and the physical sciences should register for 222.) Motions of planets and smaller bodies, energy transport in planetary systems, composition, structure and dynamics of planetary atmospheres, cratering on planetary surfaces, properties of meteorites, asteroids and comets, extrasolar planets, and planetary formation. Prerequisite: some background in the physical sciences, especially astronomy, geophysics, or physics. Students need instructor approval to take the course for 2 or 4 units.

Same as: GEOLSCI 122, GEOPHYS 122

GEOLSCI 223. Reflection Seismology Interpretation. 1-4 Unit.

The structural and stratigraphic interpretation of seismic reflection data, emphasizing hydrocarbon traps in two and three dimensions on industry data, including workstation-based interpretation. Lectures only, 1 unit. Prerequisite: 222, or consent of instructor. (Geophys 183 must be taken for a minimum of 3 units to be eligible for Ways credit).

Same as: GEOPHYS 183, GEOPHYS 223

GEOLSCI 223B. Evolution of Marine Ecosystems. 3-4 Units.

Life originally evolved in the ocean. When, why, and how did the major transitions occur in the history of marine life? What triggered the rapid evolution and diversification of animals in the Cambrian, after more than 3.5 billion years of Earth's history? What caused Earth's major mass extinction events? How do ancient extinction events compare to current threats to marine ecosystems? How has the evolution of primary producers impacted animals, and how has animal evolution impacted primary producers? In this course, we will review the latest evidence regarding these major questions in the history of marine ecosystems. We will develop familiarity with the most common groups of marine animal fossils. We will also conduct original analyses of paleontological data, developing skills both in the framing and testing of scientific hypotheses and in data analysis and presentation.

Same as: BIO 119, EARTHSYS 122, GEOLSCI 123

GEOLSCI 224. Rivers: The Arteries of Earth's Continents. 3 Units.

Rivers are the arteries of Earth's continents, conveying water, sediments, and solutes from the headwaters to the oceans. They provide a haven for life and have been at the heart of the world's economy by generating fertile floodplains, human habitats, as well as by facilitating international commerce. This course offers a quantitative examination of rivers, from headwaters to deltas. We will first develop a basic mechanistic understanding of fluvial processes, including flow hydraulics, erosion, sediment transport, and deposition. We will then apply our acquired knowledge through thematic discussions of relevant issues. Possible themes include deltas and climate change, rivers and human activity (damming, sand mining, deforestation), rivers and the evolution of land plants, rivers and biogeochemical cycles, submarine channels, and the alien rivers of Mars and Titan.

Same as: ESS 225, GEOPHYS 221

GEOLSCI 225A. Fundamentals of Geochemical Modeling. 3 Units.

A class devoted to geochemical models and the computational and analytical tools required to successfully construct and solve them. Topics include: box models, impulse responses, transfer functions, eigenvalues, advection-diffusion-reaction models, discretization schemes, numerical methods (Euler, Runge-Kutta, Gauss-Seidel), Green's function, Laplace and Fourier transforms. The class will include a final project in which students will have the opportunity to apply the above tools to their own research or a problem of their choice.

GEOLSCI 226. The Geologic Carbon Cycle. 3 Units.

In this course, we will (1) review the cycling of carbon between Earth's rock and surface reservoirs on timescales ranging from thousands to billions of years; (2) learn how processes within the carbon cycle partition carbon into various organic and inorganic reservoirs, and how carbon cycling influences the isotope composition of the reservoirs; and (3) learn how ancient carbon cycle dynamics can be reconstructed by combining isotope and rock volume measurements with numerical models of carbon cycling. The class will include lecture, reading and discussion of classic and current papers on the geologic carbon cycle, and modeling exercises.

GEOLSCI 227. PLANETARY SCIENCE READING. 1 Unit.

The course will meet once a week to discuss a recent journal article related to the broad field of planetary science, including but not limited to cosmochemistry, planet formation, planetary geology, planetary atmospheres, Earth history, astrobiology, and exoplanets. Students will be expected to lead the group discussion at least once per quarter. No formal presentations will be required. There are no prerequisites for this course, but students should have some facility with reading scientific literature.

Same as: GEOLSCI 127, GEOPHYS 126, GEOPHYS 226

GEOLSCI 228. Evolution of Terrestrial Ecosystems. 4 Units.

The what, when, where, and how do we know it regarding life on land through time. Fossil plants, fungi, invertebrates, and vertebrates (yes, dinosaurs) are all covered, including how all of those components interact with each other and with changing climates, continental drift, atmospheric composition, and environmental perturbations like glaciation and mass extinction. The course involves both lecture and lab components. Graduate students registering at the 200-level are expected to write a term paper, but can opt out of some labs where appropriate.

Same as: BIO 148, BIO 228, EARTHSYS 128, GEOLSCI 128

GEOLSCI 232. Evolution of Earth Systems. 4 Units.

This course examines biogeochemical cycles and how they developed through the interaction between the atmosphere, hydrosphere, biosphere, and lithosphere. Emphasis is on the long-term carbon cycle and how it is connected to other biogeochemical cycles on Earth. The course consists of lectures, discussion of research papers, and quantitative modeling of biogeochemical cycles. Students produce a model on some aspect of the cycles discussed in this course. Grades based on class interaction, student presentations, and the modeling project.

Same as: EARTHSYS 132, EARTHSYS 232, ESS 132, ESS 232, GEOLSCI 132

GEOLSCI 233A. Microbial Physiology. 3 Units.

Introduction to the physiology of microbes including cellular structure, transcription and translation, growth and metabolism, mechanisms for stress resistance and the formation of microbial communities. These topics will be covered in relation to the evolution of early life on Earth, ancient ecosystems, and the interpretation of the rock record. Recommended: introductory biology and chemistry. Same as: BIO 180, EARTHSYS 255, ESS 255

GEOLSCI 235. Sedimentary Geochemistry and Analysis. 1-4 Unit.

Introduction to research methods in sedimentary geochemistry. Proper laboratory techniques and strategies for generating reliable data applicable to any future labwork will be emphasized. This research-based course will examine how the geochemistry of sedimentary rocks informs us about local and global environmental conditions during deposition. Students will collect geochemical data from a measured stratigraphic section in the western United States. These samples will be collected during a four-day field trip at the end of spring break (attendance encouraged but not required). In lab, students will learn low-temperature geochemical techniques focusing on the cycling of biogeochemical elements (O, C, S, and Fe) in marine sediments throughout Earth history. The focus will be on geochemistry of fine-grained siliciclastic rocks (shale) but the geochemistry of carbonates will also be explored. This is a lab-based course complemented with lectures. Students who wish to take the course for less than 4 units must receive approval from the instructor. This course must be taken for a minimum of 3 units and a letter grade to be eligible for Ways credit. Same as: GEOLSCI 135

GEOLSCI 236. Macroevolution. 3 Units.

The course will focus on the macroevolution of animals. We will be exploring how paleobiology and developmental biology/genomics have contributed to our understanding of the origins of animals, and how patterns of evolution and extinction have shaped the diversity of animal forms we observe today. Same as: BIO 136, BIO 236, GEOLSCI 136

GEOLSCI 240. Data science for geoscience. 3 Units.

This course provides an overview of the most relevant areas of data science (applied statistics, machine learning & computer vision) to address geoscience challenges, questions and problems. Using actual geoscientific research questions as background, principles and methods of data scientific analysis, modeling, and prediction are covered. Data science areas covered are: extreme value statistics, multi-variate analysis, factor analysis, compositional data analysis, spatial information aggregation models, spatial estimation, geostatistical simulation, treating data of different scales of observation, spatio-temporal modeling (geostatistics). Application areas covered are: process geology, hazards, natural resources. Students are encouraged to participate actively in this course by means of their own data science research challenge or question. Same as: EARTHSYS 240, ENERGY 240, ESS 239

GEOLSCI 241. Machine Learning for Visual Recognition in Geosciences. 1 Unit.

Analyzing images is a big part of day-to-day life of geoscientists, such as conducting seismic interpretation or lithofacies identification and classification. Furthermore, visual representation, recognition and feature extraction play a crucial role in providing a foundation to solve different geosciences research questions, including reconstructing depositional environment, marine ecosystem and tectonic history. Image analysis is often costly, time consuming and requires in-depth knowledge of specific geological sub-fields (igneous, metamorphic, sedimentary petrography, and micropaleontology). Recent improvements in machine learning techniques, in particular deep learning, have led to excellent performance in different computer vision tasks (e.g., image classification, segmentation) that significantly increase efficiency and reproducibility. In this course, we will go through the basics of machine learning for visual recognition by analyzing different real-world geoscience problems and try to understand how machine learning algorithms can be used to help solve these problems. This course is intended to provide an introduction to visual recognition with machine learning. No prior knowledge of machine learning and python programming are required. Same as: GEOLSCI 141

GEOLSCI 246. Reservoir Characterization and Flow Modeling with Outcrop Data. 3 Units.

Course gives an overview of concepts from geology and geophysics relevant for building subsurface reservoir models. Includes a required 1-day field trip and hands-on lab exercises. Target audience: MS and 1st year PhD students in PE/ERE/GS with little or no background in geology or geophysics. Topics include: basin and petroleum systems, depositional settings, deformation and diagenesis, introduction to reflection seismic data, rock and fluid property measurements, geostatistics, and flow in porous media. Same as: ENERGY 146, ENERGY 246

GEOLSCI 247. Architecture of Turbidite Depositional Systems. 3 Units.

This course considers the research that has led to current architectural models of turbidite deposits as we examine diverse data sets that allow us to test these models. Intense exploration and exploitation activities by the petroleum industry have significantly advanced understanding of turbidite systems. These activities stimulated research aimed at developing predictive models of the three common turbidite reservoir types: (1) confined channel systems, (2) weakly confined channel systems, and (3) unconfined lobe systems. Each of these reservoir types are examined in detail considering recognition criteria, internal structure, reservoir characteristics, and important issues related to reservoir potential and performance. Topics of discussion include controlling processes, hierarchy, variability, uncertainty and active areas of research.

GEOLSCI 248. The Petroleum System: Investigative method to explore for conventional & unconventional hydrocarbons. 1 Unit.

How the petroleum system concept can be used to more systematically investigate how hydrocarbon fluid becomes an unconventional accumulation in a pod of active source rock and how this fluid moves from this pod to a conventional pool. How to identify, map, and name a petroleum system. The conventional and unconventional accumulation as well as the use of modeling.

GEOLSCI 250. Sedimentation Mechanics. 3-4 Units.

The mechanics of sediment transport and deposition and the origins of sedimentary structures and textures as applied to interpreting modern sediments and ancient rock sequences. Dimensional analysis, fluid flow, drag, boundary layers, open channel flow, particle settling, erosion, sediment transport, sediment gravity flows, soft sediment deformation, and fluid escape. Required field trip and lab section.

GEOLSCI 251. Sedimentary Basins. 3 Units.

Analysis of the sedimentary fill and tectonic evolution of sedimentary basins. Topics: tectonic and environmental controls on depositional systems, detrital composition, burial history, and stratigraphic architecture; synthesis of basin development through time. One weekend field trip required. Prerequisites: 110, 151.

GEOLSCI 252. Sedimentary Petrography. 4 Units.

Siliciclastic sediments and sedimentary rocks. Research in modern sedimentary mineralogy and petrography and the relationship between the composition and texture of sediments and their provenance, tectonic settings, and diagenetic histories. Prerequisite: 106 or equivalent or instructor approval. Required lab section.

GEOLSCI 253. Petroleum Geology and Exploration. 3 Units.

The origin and occurrence of hydrocarbons. Topics: thermal maturation history in hydrocarbon generation, significance of sedimentary, structural and tectonic setting, trapping geometries and principles of accumulation, and exploration techniques. Prerequisites: 110, 151. Recommended: GEOPHYS 223.

GEOLSCI 254. Sedimentology and Rock Physics of Carbonates. 3-4 Units.

Processes of precipitation and sedimentation of carbonate minerals as well as their post-depositional alteration with emphasis on marine systems. Topics include: geographic and bathymetric distribution of carbonates in modern and ancient oceans; genesis and environmental significance of carbonate grains and sedimentary textures; carbonate diagenesis; changes in styles of carbonate deposition through Earth history; reservoir quality and properties defined by storage capacity, flow (permeability) and connectivity of pores (effective porosity); the interplay between these properties, the original depositional characteristics of the carbonate sediments and post-depositional alteration; relationships between dissolution processes, cementation processes, and the resulting connectivity of the flow pathways. Lab exercises emphasize petrographic and rock physics analysis of carbonate rocks at scales ranging from map and outcrop to hand sample and thin section.
Same as: GEOPHYS 254

GEOLSCI 255. Basin and Petroleum System Modeling. 3-4 Units.

For advanced undergraduates or graduate students. Students use stratigraphy, subsurface maps, and basic well log, lithologic, paleontologic, and geochemical data to construct 1-D, 2-D, and 3-D models of petroleum systems that predict the extent of source-rock thermal maturity, petroleum migration paths, and the volumes and compositions of accumulations through time (4-D). Recent software such as PetroMod designed to reconstruct basin geohistory. Recommended: 251 or 253.

GEOLSCI 257. Clastic Sequence Stratigraphy. 3 Units.

Sequence stratigraphy facilitates integration of all sources of geologic data, including seismic, log, core, and paleontological, into a time-stratigraphic model of sediment architecture. Tools applicable to regional and field scales. Emphasis is on practical applications and integration of seismic and well data to exploration and field reservoir problems. Examples from industry data; hands-on exercises.

GEOLSCI 258. Introduction to Depositional Systems. 3 Units.

The characteristics of the major sedimentary environments and their deposits in the geologic record, including alluvial fans, braided and meandering rivers, aeolian systems, deltas, open coasts, barred coasts, marine shelves, and deep-water systems. Emphasis is on subdivisions; morphology; the dynamics of modern systems; and the architectural organization and sedimentary structures, textures, and biological components of ancient deposits.

GEOLSCI 259. Stratigraphic Architecture. 1 Unit.

The stratigraphic architecture of deposits associated with a spectrum of depositional environments, using outcrop and subsurface data. Participants read and discuss selected literature.

GEOLSCI 260. Quantifying Uncertainty in Subsurface Systems. 3 Units.

Broad conceptual overview of the various components required to uncertainty quantification (UQ) for decision making in subsurface engineering problems such as oil/gas production, groundwater management, contaminant remediation, geothermal energy and mineral deposits. The emphasis lies on learning how to synthesize rather than the details of each individual discipline. The class will cover the basic data science for UQ: dimension reduction methods, Monte Carlo & global sensitivity analysis. Introduction to Bayesianism and how it applies to subsurface prediction problems, in particular, the formulation of geological prior models and the role of geostatistics. Strategies for integrating geological science, geophysics, data science and decision science into decision making under uncertainty. Team work on real field applications.

GEOLSCI 261. Quantitative Methods in Paleobiology. 3 Units.

The advent of large, publicly accessible sources of data relevant to paleobiology has opened new avenues for quantifying large-scale patterns in the history of life and for identifying their underlying causes. How and why has biodiversity changed over time? What factors control evolutionary trends within clades? How have environmental changes affected the evolution of life? In this course, we will introduce several of the most widely accessed sources of data for paleobiological analysis, such as the Paleobiology Database and Macrostrat, develop techniques for downloading and cleaning these data, and then explore several of the most commonly used statistical techniques in paleobiology, including phylogenetic analysis, phylogenetic regression and model fitting, logistic regression, ordination, and subsampling to analyze these data.
Same as: GEOLSCI 161

GEOLSCI 263. Introduction to Isotope Geochemistry. 3 Units.

Isotopic variations in nature provide key insights into the age of the Earth and its rocks, as well as the evolution of Earth's major reservoirs, including the mantle, crust and hydrosphere. How do we know the age of the Earth? When did continents first form? How have the oceans changed through time? This course will address these and related topics by focusing on the fundamental processes that govern isotopic variations, including radioactive decay, mass dependent isotope fractionation and dynamic transfers between reservoirs.
Same as: GEOLSCI 163

GEOLSCI 264. Geochemical Thermodynamics. 3-4 Units.

This course covers equilibrium thermodynamics relevant to geological systems with emphasis on practical numerical approaches. Students will learn how to perform Gibbs-energy minimization to define the equilibrium state of simple systems. Additional topics include: phase equilibrium, phase transitions (including melting), solution chemistry, mineral-solution equilibria, equations of state, gas phase chemistry, and element partitioning. Prerequisites: GEOLSCI 90 and GEOLSCI 102, or permission of the instructor.

GEOLSCI 266. Managing Nuclear Waste: Technical, Political and Organizational Challenges. 3 Units.

(Formerly IPS 266) The essential technical and scientific elements of the nuclear fuel cycle, focusing on the sources, types, and characteristics of the nuclear waste generated, as well as various strategies for the disposition of spent nuclear fuel - including reprocessing, transmutation, and direct geologic disposal. Policy and organizational issues, such as: options for the characteristics and structure of a new federal nuclear waste management organization, options for a consent-based process for locating nuclear facilities, and the regulatory framework for a geologic repository. A technical background in the nuclear fuel cycle, while desirable, is not required.
Same as: INTLPOL 266

GEOLSCI 280. Igneous Processes. 3-4 Units.

For juniors, seniors and beginning graduate students in Earth Sciences. Structure and physical properties of magmas; use of phase equilibria and mineral barometers and thermometers to determine conditions of magmatic processes; melting and magmatic lineages as a function of tectonic setting; processes that control magma composition including fractional crystallization, partial melting, and assimilation; petrogenetic use of trace elements and isotopes. Optional labs emphasize identification of volcanic and plutonic rocks in thin section and interpretation of rock textures. Students taking the lab component should enroll in 4 units, as required for the Geological Sciences major; for the lab, GS 102, 103, or consent of instructor are prerequisites. Same as: GEOLSCI 180

GEOLSCI 281. Principles of ⁴⁰Ar/³⁹Ar Thermochronometry. 3-4 Units.

The ⁴⁰Ar/³⁹Ar method is based upon the K-Ar decay scheme and allows high precision geochronology and thermochronology to be performed with K-bearing minerals. Provides a detailed exploration of the method including all practical considerations and laboratory procedures for standardization and instrument calibration. A laboratory component allows practical experience in making measurements and interpreting results.

GEOLSCI 282. Interpretative Methods in Detrital Geochronology. 3 Units.

Over the past decade, the number of studies that make use of isotopic provenance data has sky-rocketed. This type of data is now routinely used throughout the geosciences to solve a broad range of geologic problems. This seminar examines the state-of-the-art of existing interpretative methods for detrital geo/thermochronology data in provenance studies and critically examines their strengths and weaknesses. While this course will touch upon sampling approaches analytical aspects of data collection, focus is primarily upon data interpretation.

GEOLSCI 283. Thermochronology and Crustal Evolution. 4 Units.

Thermochronology analyzes the competition between radioactive in-growth and temperature-dependant loss of radiogenic isotopes within radioactive mineral hosts in terms of temperature-time history. Coupled with quantitative understanding of kinetic phenomena and crustal- or landscape-scale interpretational models, thermochronology provides an important source of data for the Earth Sciences, notably tectonics, geomorphology, and petrogenesis. Focus on recent developments in thermochronology, specifically analytical and interpretative innovations developed over the past decade. Integrates the latest thermochronology techniques with field work in a small-scale research project focused upon crustal evolution.

GEOLSCI 287. Fundamentals of Mass Spectrometry. 3 Units.

This course explains ion creation, mass separation, and ion detection in mass spectrometry methods commonly used in the Earth Sciences. Gas source (C-O-H-S stable isotope, ⁴⁰Ar/³⁹Ar, and (U-Th)-He), secondary ionization (SIMS), laser ablation and solution-based mass inductively coupled (ICP-MS) and thermal ionization (TIMS) mass spectrometry techniques are also explored. Additional topics include ion optics, vacuum generation, and pressure measurement, instrument calibration, data reduction, and error propagation methods.

GEOLSCI 290. Departmental Seminar in Geological Sciences. 1 Unit.

Current research topics. Presentations by guest speakers from Stanford and elsewhere. May be repeated for credit.

GEOLSCI 291. GS Field Trips. 1 Unit.

Field trips for teaching and research purposes. Trips average 5-10 days. Prerequisite: consent of instructor.

GEOLSCI 292. Directed Reading with Geological Sciences Faculty. 1-10 Unit.

May be repeated for credit.

GEOLSCI 293. Advanced structural mapping in the field. 1-2 Unit.

Advanced geologic mapping techniques, approaches and methods of data collection in the field. 7-10 days in the field with lectures prior to the trip and follow up mapping and data analysis after the trip. Across the Cordillera September 2018.

GEOLSCI 293A. Geology of Oman Field Trip. 1 Unit.

Reading and discussion of papers addressing current topics related to the geology of Oman, including Neoproterozoic and Permian-Triassic environmental change. By invitation only. May be repeat for credit.

GEOLSCI 293B. Geology of Spain Field Trip. 1 Unit.

Reading and discussion of papers addressing current topics related to the geology of Spain. By invitation only. May be repeated for credit.

GEOLSCI 293C. Geology of Spain Field Trip. 1 Unit.

Reading and discussion of papers addressing current topics related to the geology of Spain, including the Cenozoic structure and stratigraphy of the Tabernas-Sorbas Basin, SE Spain. By invitation only. May be repeat for credit.

GEOLSCI 294. Our Dynamic West. 5 Units.

Theory, principles, and practical techniques to measure, describe, analyze, and interpret deformation-related structures on Earth. Collection of fault and fold data in the field followed by lab and computer analysis; interpretation of geologic maps and methods of cross-section construction; structural analysis of fault zones and metamorphic rocks; measuring deformation; regional structural styles and associated landforms related to plate tectonic convergence, rifting and strike-slip faulting; the evolution of mountain belts and formation of sedimentary basins. Prerequisite: GEOLSCI 1, calculus. Recommended: 102, 105. Same as: GEOLSCI 110

GEOLSCI 295. Research in the Field. 3-6 Units.

Month long courses that provide students with the opportunity to collect data in the field as part of a team-based investigation of research questions or topics under the expert guidance of knowledgeable faculty and graduate students. Topics and locations vary. May be taken multiple times for credit. Prerequisites: GS 1, GS 102, GS 105. Same as: GEOLSCI 190

GEOLSCI 299. Field Research. 2-4 Units.

Two-three week field research projects. Written report required. May be repeated three times.

GEOLSCI 306. Virtual Scientific Presentation and Public Speaking. 2 Units.

The ability to present your research in a compelling, concise, and engaging manner will enhance your professional career. Virtual presentations make it harder to connect and interact with the audience, and to overcome this requires new skills, including video, sound, lighting, live vs. pre-recorded content, and virtual posters. These elements will be the focus of this class. But regardless of format, I will work to convince you that the best way to capture an audience and leave a lasting impression is to tell a story, do a demo, or pick a fight. The course is taught as a series of stand-and-deliver exercises with class feedback and revision on the fly, supplemented by one-on-one coaching. We will have sessions on virtual conference presentations, virtual job interviews and job talks, departmental seminars, webinars, press interviews, and funding pitches. My pledge is that everyone will come away a more skilled and confident speaker than they were before. Grades are optional: 70% in-class exercises, 30% final project, such as your upcoming AGU, GSA, or SEG presentation. It's best to take the course when you have research to present. (<http://syllabus.stanford.edu>). Same as: ESS 204, GEOPHYS 205

GEOLSCI 307. Research Proposal Development and Delivery. 2 Units.

In this class students will learn how to write rigorous, high yield, multidisciplinary proposals targeting major funding agencies. The skills gained in this class are essential to any professional career, particularly in research science. Students will write a National Science Foundation style proposal involving testable hypotheses, pilot data or calculations, and broader impact. Restricted to ESS and GS first-year graduate students. Same as: ESS 307

GEOLSCI 311. Interpretation of Tectonically Active Landscapes. 3 Units.

Focuses on interpreting various topographic attributes in terms of horizontal and vertical tectonic motions. Topics include identification, mapping, and dating of geomorphic markers, deducing tectonic motions from spatial changes in landscape steepness, understanding processes that give rise to different landscape elements, interrogating the role of climate and lithology in producing these landscape elements, and understanding relationships between tectonic motions, surface topography, and the spatial distribution of erosion. Consists of two one hour lectures per week and one laboratory section that help students gain proficiency in Quaternary mapping and interpretation of topographic metrics.

GEOLSCI 312. Analysis of Landforms. 3 Units.

Quantitative methods to analyze digital topography and to interpret rates of tectonic and geomorphic processes from topographic metrics. Topics include analysis of digital topography using local and neighborhood-based methods, spectral methods, and wavelet methods. Course consists of two one hour lectures per week and one laboratory section that will help students gain proficiency in calculating topographic metrics using ArcGIS and Matlab.

GEOLSCI 313. Modeling of Landforms. 3 Units.

Geomorphic-transport-rule-based, as well as mass- and momentum-conservation based models to understand the evolution of Earth's topography. Topics include formulation of land-sculpting processes as geomorphic transport rules, coupling this mass-conservation approach with mechanical models of crustal deformation, and analysis of landscape forms in terms of events for which mass and momentum of fluid and sediment can be conserved. Both analytical, as well as numerical (finite-volume) treatments of particular problems in tectonic geomorphology will be covered. The specific problems addressed as part of the course will be tailored to those currently investigated by class participants.

GEOLSCI 328. Seminar in Paleobiology. 1 Unit.

For graduate students. Current research topics including paleobotany, vertebrate and invertebrate evolution, paleoecology, and major events in the history of life on Earth.

GEOLSCI 336. Stanford Alpine Project Seminar. 1 Unit.

Weekly student presentations on continental collision tectonics, sedimentology, petrology, geomorphology, climate, culture, and other topics of interest. Students create a guidebook of geologic stops in advance of field trip. May be repeated for credit.

GEOLSCI 385. Practical Experience in the Geosciences. 1 Unit.

On-the-job training in the geosciences. May include summer internship; emphasizes training in applied aspects of the geosciences, and technical, organizational, and communication dimensions. Meets USCIS requirements for F-1 curricular practical training.n (Staff).

GEOLSCI 386. Graduate Teaching Experience in Geological Sciences. 1 Unit.

Practical teaching experience by serving as the primary instructor in a student-led course. Graduate student instructors are mentored by at least one faculty mentor.

GEOLSCI 398. Teaching in Geological Sciences. 1 Unit.

Practical experience in teaching by serving as a teaching assistant in a geological sciences course.

GEOLSCI 399. Advanced Projects. 1-10 Unit.

Graduate research projects that lead to reports, papers, or other products during the quarter taken. On registration, students designate faculty member and agreed-upon units.

GEOLSCI 400. Graduate Research. 1-15 Unit.

Faculty supervision. On registration, students designate faculty member and agreed-upon units.

GEOLSCI 801. TGR Project. 0 Units.

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GEOLSCI 802. TGR Dissertation. 0 Units.

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