SCHOOL OF EARTH SCIENCES

GEOLOGICAL AND ENVIRONMENTAL SCIENCES

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Courses offered by the Department of Geological and Environmental Sciences are listed under the subject code GES on the *Stanford Bulletin's* ExploreCourses web site.

The geological and environmental sciences are naturally interdisciplinary, and include: the study of earth materials, earth processes, and how they changed over Earth's 4.56 billion year history. 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 deform Earth's crust and shape Earth's surface; the stratigraphic, paleobiological, and geochemical records of Earth history including changes in climate, oceans, and atmosphere; present-day, historical, and long-term feedbacks between the geosphere and biosphere, and the origin and occurrence of our natural resources.

The department's research is critical to the study 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, and human health and the environment.

A broad range of instrumentation for elemental and radiogenic/stable isotope analysis is available, including ion microprobe, electron microprobe, thermal and gas source mass spectrometry, inductively couped plasma mass spectrometry and nuclear magnetic resonance. The Center for Materials Research and facilities at the SLAC National Accelerator Laboratory, Stanford Synchrotron Radiation Laboratory (SSRL), and the U.S. Geological Survey in nearby Menlo Park are also available for the department's research. Branner Library, devoted exclusively to the Earth Sciences, represents one of the department's most important resources. The department maintains rock preparation (crushing, cutting, polishing), mineral separation, and microscopy facilities.

BACHELOR OF SCIENCE IN GEOLOGICAL AND ENVIRONMENTAL SCIENCES

The purpose of the undergraduate program in Geological and Environmental Sciences is to provide students with (1) a broad background in the fundamentals of the Earth sciences and (2) the quantitative, analytical, and communications skills necessary to conduct research and think critically about questions involving the Earth. The major provides excellent preparation for graduate school and careers in geological and environmental consulting, land use and planning, law, teaching, and other professions in which an understanding of the Earth and a background in science are important.

The major consists of five interrelated components:

Earth Sciences Fundamentals—Students must complete a set of core courses that introduce the properties of Earth materials, the processes that change the Earth, 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.

Quantitative and Analytical Skills—Students must complete adequate course work in mathematics, chemistry, and physics or biology. In addition, they learn analytical techniques specific to the Earth sciences through the laboratory component of courses.

Advanced Course Work and Research—Students gain breadth and depth in upper-level electives and are encouraged to apply these skills and knowledge to problems in the Earth sciences through directed research.

Field Research Skills—Most GES courses include field trips and/or field-based projects. In addition, students must complete at least six weeks of field research through departmental offerings or through a faculty-directed field research project that involves learning and application of field techniques, field mapping, and the preparation of a written report.

Communication Skills—To fulfill the Writing in the Major requirement, students take a writing-intensive senior seminar (GES 150), in which they give both oral and written presentations that address current research in the earth sciences.

The major requires at least 77 units; letter grades are required in all courses if available. Students interested in the GES major should consult with the Undergraduate Program Coordinator for information about options within the curriculum.

COURSE SEQUENCE (77-101 UNITS TOTAL)

CORE REQUIREMENT

Students are required to take all of the following (28-30 units):

Subject and Catalog Number	*Units*
GES 1A,B,C. Introduction to Geology	4-5
GES 4. Evolution and Extinction: Introduction to Historical Geology	4
GES 90. Introduction to Geochemistry	3-4
GES 102. Earth Materials	5
GES 103. Rocks in Thin Section	3
GES 105. Introduction to Field Methods	3
GES 150. Senior Seminar: Issues in the Earth Sciences (WIM)	3
GES 190, other field course, or field research (4 weeks, see below for more information)	6

GEOLOGICAL AND ENVIRONMENTAL SCIENCES

BREADTH IN THE DISCIPLINE REQUIREMENT

To gain understanding of the breadth of subject areas within the geological and environmental sciences, students are required to take one course from each of the following six groups (19-25 units). Courses with a * are offered every other year:

ENVIRONMENTAL GEOLOGY AND SURFACE PROCESSES

The chemical and physical properties of the solid, aqueous, and gaseous phases comprising Earth's surface environment, their natural compositional variations and biogeochemical interactions, and the processes that affect their distribution and stability.

EESS 155. Science of Soils	4
GES 130. Soil Physics and Hydrology	3
GES 131. Hydrologically-Driven Landscape Evolution	3
GES 170. Environmental Geochemistry	4

STRUCTURAL GEOLOGY AND TECTONICS

The nature, description, and modeling of deformation of earth materials in response to tectonic forces. Processes of plate tectonics, mountain building, and sedimentary basin formation. The origin and evolution of geologic structures including folds, faults, fabrics, and fractures.

GES 110. Structural Geology and Tectonics	5
GES 111a. Fundamentals of Structural Geology	3
GEOPHYS 150. General Geophysics and Physics of the Earth	3

EARTH MATERIALS AND GEOCHEMISTRY

The materials that comprise the Earth and how they can be used to deduce geological processes over time. The fundamental chemical and geologic processes responsible for the abundance and distribution of elements and their isotopes.

GES 163. Introduction to Isotope Geochemistry	3
*GES 180. Igneous Processes	4
*GES 185. Volcanology	3-4
GES 107. Journey to the Center of the Earth	3

SEDIMENTARY SYSTEMS

The processes of weathering, erosion, transportation, and deposition, interpretation of depositional environments, the formation and evolution of sediments and sedimentary basins, and the evolution of sedimentary systems over geologic time.

GES 151.Sedimentary Geology and Petrology	4

BIOGEOSCIENCES

The origin and evolution of life on Earth, the influence of biological processes on Earth's surface environments, and the role of geological processes in shaping large-scale evolutionary patterns.

*GES 123. Paleobiology	3

GEOSPATIAL STATISTICS AND COMPUTER SCIENCE

Statistical techniques specific to the geosciences that facilitate analysis of three- and four-dimensional data; computer programming and modeling.

CS 106A. Programming Methodology	3-5
EESS 160. Statistical Methods for Earth and Environmental Sciences: General Introduction	3
EESS 161. Statistical Methods for Earth and Environmental Sciences: Geostatistics	3-4
EESS 164. Fundamentals of Geographic Information Science (GIS)	4
ENERGY 125. Modeling and Simulation for Geoscientists and Engineers	3
ENERGY 211. Computer Programming in C++ for Earth Scientists and Engineers	4
GEOPHYS 112. Exploring Geosciences with MATLAB	3
*GEOPHYS 140. Introduction to Remote Sensing	3

DEPTH IN THE DISCIPLINE REQUIREMENT (10 UNITS)

To allow students to go into greater depth in the major, students must complete at least 10 units of electives drawn primarily from the list above and other upper-level courses in GES (including graduate-level courses). Additional courses in Geophysics, EESS, and ERE may be counted towards the elective units if they allow a student to pursue a topic in depth; these options should be discussed with an adviser. A maximum of 3 elective units may be fulfilled by GES 192, 197, 198, or advanced seminars. Honors research (GES 199) may fulfill up to 4 elective units.

REQUIRED SUPPORTING MATHEMATICS (5-15 UNITS) (MAY ALSO BE FULFILLED BY ADVANCED PLACEMENT CREDIT)

Choose one of the following equivalent series:

MATH 19. Calculus	3
MATH 20. Calculus	3
MATH 21. Calculus	4
or	
MATH 41. Calculus	5
MATH 42. Calculus	5

Choose at least one of the following (the entire series is recommended for students who plan to pursue graduate studies in the sciences or engineering):

MATH 51. Multivariate Mathematics	5
MATH 52. Multivariate Mathematics	5
MATH 53. Multivariate Mathematics	5

REQUIRED SUPPORTING COGNATE SCIENCES (15-21 UNITS)

Advanced placement credit may be accepted for these courses as determined by the relevant departments.

Chemistry:

CHEM 31A,B. Chemical Principles I/II	8
or CHEM 31X. Chemical Principles	4
CHEM 135. Physical Chemical Principles	3
or CHEM 171. Physical Chemistry	3
or GES 171. Geochemical Thermodynamics	3

In addition to chemistry, students may choose between introductory sequences in biology and physics. This choice should be made after discussion with an adviser and based on a student's interests.

Physics (choose one of the following series):

PHYSICS 21. Mechanics and Heat	3
PHYSICS 22. Mechanics and Heat Lab	1
PHYSICS 23. Electricity and Optics	3
PHYSICS 24. Electricity and Optics Lab	1
or	
PHYSICS 41 (formerly 53). Mechanics	4
PHYSICS 45 (formerly 51). Light and Heat	4
PHYSICS 46 (formerly 52). Light and Heat Lab	1
or	
PHYSICS 41 (formerly 53). Mechanics	4
PHYSICS 43 (formerly 55). Electricity and Magnetism	3
PHYSICS 44 (formerly 56). Electricity and Magnetism Lab	1

Biology:

BIO 41. Genetics, Biochemistry, and Molecular Biology	5
BIO 42. Cell Biology and Animal Physiology	5
or BIO 43. Plant Biology, Evolution, and Ecology	5
or BIO 101. Ecology	3

FIELD RESEARCH

Beyond GES 105, majors must complete four weeks of field research, preferably through departmental offerings (GES 190). With approval, up to two weeks may be fulfilled by GES 112, Geophys 190, BIOHOPK 182H, or other mentored field research projects that involve learning and application of field techniques and the preparation of a written report.

COGNATE COURSES

Many courses offered within the School of Earth 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 and Environmental 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 Sciences are particularly applicable:

BIOHOPK 182H. Stanford at Sea
BIO 121. Biogeography
BIO 136. Evolutionary Paleobiology
CEE 63. Weather and Storms

CEE 64. Air Pollution: From Urban Smog to Global Change
CEE 101A. Mechanics of Materials
CEE 101B. Mechanics of Fluids
CEE 101C. Geotechnical Engineering
CEE 161A. Rivers, Streams, and Canals
CEE 164. Introduction to Physical Oceanography
CEE 166A. Watersheds and Wetlands
CEE 173A. Energy Resources

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 GES 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 GES 199; the student must complete a total of 9 units over the course of the senior year. Up to 4 units of GES 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 GES Honors Symposium in which they present their research to the broader community. Honors students in GES are also eligible for the Firestone medal, awarded by Undergraduate Advising and Research for exceptional theses.

ENGINEERING GEOLOGY AND HYDROGEOLOGY UNDERGRADUATE SPECIALIZED CURRICULUM

The Engineering Geology and Hydrogeology curriculum is intended for undergraduates interested in the application of geological and engineering data and principles to the study of rock, soil, and water to recognize and interpret geological and environmental factors affecting engineering structures and groundwater resources. Students learn to characterize and assess the risks associated with natural geological hazards, such as landslides and earthquakes, and with groundwater flow and contamination. The curriculum prepares students for graduate programs and professional careers in engineering, environmental geology, geology, geotechnical engineering, and hydrogeology. Students interested in this curriculum should contact a faculty adviser: Professor Loague, Pollard, or Hilley.

GES majors who elect the Engineering Geology and Hydrogeology curriculum are expected to complete a core course sequence and a set of courses in supporting sciences and mathematics. The core courses come from Earth Sciences and Engineering. Any substitutions for core courses must be approved by the faculty adviser and through a formal petition to the undergraduate program director. In addition, four elective courses, consistent with the core curriculum and required of all majors, are to be selected with the advice and consent of the adviser. Typically, electives are selected from the list below. Letter grades are required if available.

COURSE SEQUENCE (90-101 UNITS TOTAL)

REQUIRED GEOLOGICAL AND ENVIRONMENTAL SCIENCES (36-38 UNITS)

Subject and Catalog Number	*Units*
GES 1A,B,C. Introduction to Geology	4-5
GES 102. Earth Materials	5
GES 111A. Fundamentals of Structural Geology	3
GES 115. Engineering Geology Practice	3
EESS 164. Fundamentals of GIS	4
GES 150. Senior Seminar: Issues in the Earth Sciences (WIM)	3
EESS 160. Statistical Methods for Earth and Environmental Sciences: General Introduction	4
or EESS 161. Statistical Methods for the Earth and Environmental Sciences: Geostatistics	3-4
EESS 220. Physical Hydrogeology	4
GEOPHYS 190. Applied Geophysical Methods	3

REQUIRED ENGINEERING (20 UNITS)

CEE 101A. Mechanics of Materials	4
CEE 101B. Mechanics of Fluids	4
CEE 101C. Geotechnical Engineering	4
CS 106A. Programming Methodology	5
ENGR 14. Applied Mechanics: Statics	3

REQUIRED SUPPORTING SCIENCES AND MATHEMATICS (23-27 UNITS)

CHEM 31A,B. Chemical Principles I/II	8
or CHEM 31X. Chemical Principles	4
MATH 51. Multivariate Mathematics	5
MATH 52. Multivariate Mathematics	5
MATH 53. Multivariate Mathematics	5
PHYSICS 41. Mechanics	4

SUGGESTED ELECTIVES (11-16 UNITS)

Choose four courses from the following list or, with faculty approval, four related courses:

CEE 101D. Computations in Civil and Environmental Engineering	3
CEE 180. Structural Analysis	4
CEE 270. Movement, Fate, and Effects of Contaminants in Surface Waters and Groundwater	3
CEE 293. Foundation Engineering	3
CEE 296. Experimental Soil Mechanics	2
EESS 221. Contaminant Hydrogeology	4
ENGR 30. Engineering Thermodynamics	3
ENGR 50. Introductory Science of Materials	4
GEOPHYS 112. Exploring Geosciences with MATLAB	1-3
GEOPHYS 150. General Geophysics	4
GES 111B. Fundamentals of Structural Geology	3
GES 130. Soil Physics and Hydrology	3
GES 131. Hydrologically-Driven Landscape Evolution	3
GES 217. Characterization and Hydraulics of Rock Fracture	3
GES 237. Surface and Near-Surface Hydrologic Response	3
MATH 103. Matrix Theory and its Applications	3
MATHSCI 151. Microstructure and Mechanical Properties	3-4
ME 80. Strength of Materials	3

MINOR IN GEOLOGICAL AND ENVIRONMENTAL SCIENCES

The minor in GES consists of a small set of required courses plus 12 elective units. A wide variety of courses may be used to satisfy these elective requirements.

REQUIRED COURSES:

GES 1A,B,C. Introduction to Geology	4-5
GES 4. Evolution and Extinction: Introduction to Historical Geology	4
GES 102. Earth Materials	5

ELECTIVES (12 UNITS)

Students must take a minimum of 12 additional units drawn primarily from the "Breadth in the Discipline" list in the GES major; a majority of units must be from classes within the GES department. Up to 3 units of Stanford Introductory Seminars in GES may be counted.

Students pursuing a minor in GES are encouraged to participate in the senior seminar (GES 150) and in field research (GES 190).

COTERMINAL B.S. AND M.S. DEGREES IN GEOLOGICAL AND ENVIRONMENTAL 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 GES 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 GES faculty prior to submission of the application. Coterminal students must complete a thesis describing research results. For University coterminal degree program rules and University application forms, see http://registrar.stanford.edu/shared/publications.htm#Coterm.

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, or (2) 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 GES office.

GRADUATE PROGRAMS IN GEOLOGICAL AND ENVIRONMENTAL SCIENCES

Graduate Studies in the Department of Geological and Environmental Sciences (GES) involve academic course work and independent research. Students are prepared for careers as professional scientists in research, education, or the application of the earth sciences to mineral, energy, and water 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 Sciences as well as in other departments in the University. Diplomas designate degrees in Geological and Environmental Sciences and may also indicate the following specialized fields of study: Geostatistics and Hydrogeology.

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 GES Admissions Committee.

MASTER OF SCIENCE IN GEOLOGICAL AND ENVIRONMENTAL SCIENCES

Objectives—The purpose of the master's program in Geological and Environmental 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—The graduate coordinator of the department appoints an academic adviser during registration with appropriate consideration of the student's background, interests, and professional goals. 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 graduate coordinator.

Requirements—The University's requirements for M.S. degrees are outlined in the "Graduate Degrees" section of this bulletin. Practical training (GES 385) 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 Winter Quarter of their first year in residence, students must complete at least three courses taught by a minimum of two different GES 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. 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.
5. 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 graduate coordinator; 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 AND ENVIRONMENTAL 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.

DOCTOR OF PHILOSOPHY IN GEOLOGICAL AND ENVIRONMENTAL 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.

Requirements—The University's requirements for the Ph.D. degree are outlined in the "Graduate Degrees" section of this bulletin. Practical training (GES 385) may be required by some programs, with adviser approval, depending on the background of the student. A summary of additional department requirements is presented below:

1. Ph.D. students must complete the required courses in their individual program or in their specialized area of study with a grade point average (GPA) of 3.0 (B) or higher, or demonstrate that they have completed the equivalents elsewhere. Ph.D. students must complete a minimum of four letter-grade courses of at least 3 units each from four different faculty members on the Academic Council in the University. By the end of Winter Quarter of their first year in residence, students must complete at least three courses taught by a minimum of two different GES faculty members.
2. 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 adviser, preparation of a written research proposal, approval of this proposal by the thesis adviser, 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.
3. Upon qualifying for Ph.D. candidacy, the student and thesis adviser, 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 adviser. Annually, in the month of March or April, the candidate must organize a meeting of the research committee to present a brief progress report covering the past year.
4. 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.
5. The doctoral dissertation is defended in the University oral examination. The research adviser 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 AND ENVIRONMENTAL SCIENCES

Candidates for the Ph.D. degree in other departments who wish to obtain a minor in Geological and Environmental 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 GES adviser and the department chair.

GEOLOGICAL AND ENVIRONMENTAL SCIENCES (GES)

UNDERGRADUATE COURSES IN GEOLOGICAL AND ENVIRONMENTAL SCIENCES

GES 1A. Introduction to Geology: The Physical Science of the Earth

For non-majors or prospective majors in the Earth Sciences. Lectures, hands-on laboratories, and three one-day weekend field trips. Focus is on the physical and chemical processes of heat and mass transfer within the earth and its fluid envelopes, including deep-earth, crustal, surface, and atmospheric processes. Topics include the dynamics of and interactions between the inner earth, plate tectonics, surface processes, and atmospheric processes such as climate change and global warming. Only one of GES 1A, 1B, or 1C may be taken for credit. Prerequisites: Math 19 or equivalent.

5 units, Aut (Hilley, G)

GES 1B. Introductory to Geology: California Desert Field Geology

California's Death Valley and Owens Valley are used as natural laboratories for studying active geologic processes and a billion years of earth history: ancient ocean sediments, mountain building, earthquake faulting, glacial landscapes, volcanic eruptions, hot springs and ore deposits, prehistoric climate changes, and historic human impacts. The course culminates in a 6-day field trip to these areas during Spring Break. Class lectures provide the basics of plate tectonics and physical geology. Laboratory exercises involve rock identification and interpreting topographic and geologic maps and remote sensing imagery. Camping and moderate hiking required. Limited enrollment. Only one of GES 1A, 1B, or 1C may be taken for credit. Recommended: high school chemistry. GER: DB-NatSci

4 units, Win (Mahood, G)

GES 1C. Introduction to Geology: Dynamic Earth

For non-majors or prospective majors in the Earth Sciences. Activity-based; field trips. Focus is on reading the dynamic geological landscape, with an emphasis on California geology. Plate tectonics, earthquakes and volcanoes, earth materials, geologic time, stream processes, erosion, climate change, and natural resources. Only one of GES 1A, 1B, or 1C may be taken for credit. GER: DB-NatSci

4 units, Spr (Egger, A)

GES 4. Evolution and Extinction: Introduction to Historical Geology

Focus is on the end-Cretaceous mass extinction. Principles of stratigraphy, correlation, the geological timescale, the history of biodiversity, and the interpretation of fossils. The use of data from sedimentary geology, geochemistry, and paleontology to test theories to explain the mass extinction event. Two half-day field trips. GER: DB-NatSci

4 units, Win (Payne, J)

GES 7A. An Introduction to Wilderness Skills

Living, traveling, and working in the wilderness for those planning fieldwork in the backcountry. Local geology, environmental ethics, trip planning, first aid, and leadership techniques. Four mandatory weekend outings focus on backcountry travel, minimum impact camping, equipment use and maintenance, rock climbing, and navigation. 7A emphasizes wilderness travel and climbing. 7B emphasizes winter camping skills and backcountry skiing. Food, group, and major personal gear provided. Guest speakers. Fee. See http://www.stanford.edu/class/ges7, or email oep-teachers@lists.stanford.edu.

1 unit, Aut (Bird, D)

GES 7B. An Introduction to Wilderness Skills

Living, traveling, and working in the wilderness for those planning fieldwork in the backcountry. Local geology, environmental ethics, trip planning, first aid, and leadership techniques. Four mandatory weekend outings focus on backcountry travel, minimum impact camping, equipment use and maintenance, rock climbing, and navigation. 7A emphasizes wilderness travel and climbing. 7B emphasizes winter camping skills and backcountry skiing. Food, group, and major personal gear provided. Guest speakers. Fee. See http://www.stanford.edu/class/ges7, or email oep-teachers@lists.stanford.edu.

1 unit, Win (Bird, D)

GES 7C. Advanced Wilderness Skills

For students with prior backcountry experience. Backcountry skiing, mountaineering, climbing, first aid, and trip planning. Focus is on outdoor leadership experience and trip management techniques. Food, group, and major personal gear provided. Four mandatory weekend trips. Fee. See http://www.stanford.edu/class/ges7/ for information or contact oep-teachers@lists.stanford.edu. Prerequisite: application.

1 unit, Spr (Bird, D)

GES 8. Oceanography: An Introduction to the Marine Environment

For non-majors and earth science and environmental majors. Topics: topography and geology of the sea floor; evolution of ocean basins; circulation of ocean and atmosphere; nature of sea water, waves, and tides; and the history of the major ocean basins. The interface between continents and ocean basins, emphasizing estuaries, beaches, and continental shelves with California margin examples. Relationships among the distribution of inorganic constituents, ocean circulation, biologic productivity, and marine environments from deep sea to the coast. One-day field trip to measure and analyze waves and currents. GER: DB-NatSci

3 units, Sum (Ingle, J)

GES 39N. Forensic Geoscience: Stanford CSI

(F,Sem) Stanford Introductory Seminar. Preference to freshmen. Geological principles, materials, and techniques indispensable to modern criminal investigations. Basic earth materials, their origin and variability, and how they can be used as evidence in criminal cases and investigations such as artifact provenance and environmental pollution. Sources include case-based, simulated forensic exercises and the local environments of the Stanford campus and greater Bay Area. Local field trips; research presentation and paper. GER: DB-NatSci

3 units, Spr (Maher, K)

GES 40N. Diamonds

(F,Sem) Stanford Introductory Seminar. Preference to freshmen. Topics include the historyof 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. GER: DB-NatSci

3 units, Spr (Mao, W)

GES 43Q. Environmental Problems

(S,Sem) Stanford Introductory Seminar. Preference to sophomores. Components of multidisciplinary environmental problems and ethical questions associated with decision making in the regulatory arena. Students lead discussions on environmental issues such as groundwater contamination from point and nonpoint sources, cumulative watershed effects related to timber and mining practices, acid rain, and subsurface disposal of nuclear waste. GER: DB-NatSci

3 units, Win (Loague, K)

GES 55Q. The California Gold Rush: Geologic Background and Environmental Impact

(S,Sem) Stanford Introductory Seminar. Preference to sophomores. Topics include: geologic processes that led to the concentration of gold in the river gravels and rocks of the Mother Lode region of California; and environmental impact of the Gold Rush due to population increase, mining operations, and high concentrations of arsenic and mercury in sediments from hard rock mining and milling operations. Recommended: introductory geology. GER: DB-NatSci

3 units, Win (Bird, D)

GES 90. Introduction to Geochemistry

The chemistry of the solid earth and its atmosphere and oceans, emphasizing the processes that control the distribution of the elements in the earth over geological time and at present, and on the conceptual and analytical tools needed to explore these questions. The basics of geochemical thermodynamics and isotope geochemistry. The formation of the elements, crust, atmosphere and oceans, global geochemical cycles, and the interaction of geochemistry, biological evolution, and climate. Recommended: introductory chemistry. GER: DB-NatSci

3-4 units, Win (Stebbins, J)

GES 101. Environmental and Geological Field Studies in the Rocky Mountains

(Same as EESS 101) Three-week, field-based program in the Greater Yellowstone/Teton and Wind River Mountains of Wyoming. Field-based exercises covering topics including: basics of structural geology and petrology; glacial geology; western cordillera geology; paleoclimatology; chemical weathering; aqueous geochemistry; and environmental issues such as acid mine drainage and changing land-use patterns.

3 units, Aut (Chamberlain, P; Graham, S)

GES 102. Earth Materials

The minerals, rocks, soils, and liquids that comprise the earth. How to identify, classify, and interpret rock-forming minerals and igneous, metamorphic, and sedimentary rock types. Emphasis is on information provided by common minerals and rocks about the earth's major processes including magmatism, metamorphism, weathering, erosion, and deposition; the relationship of these processes to plate tectonics and earth cycles. Prerequisite: introductory geology course. Recommended: introductory chemistry. GER: DB-NatSci

5 units, Aut (Brown, G; Mahood, G)

GES 103. Rocks in Thin Section

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. Prerequisite 102.

3 units, Win (Miller, E)

GES 105. Introduction to Field Methods

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: GES 1. Recommended: GES 102.

3 units, Aut (Miller, E; Grove, M)

GES 107. Journey to the Center of the Earth

(Same as GES 207, GEOPHYS 107, GEOPHYS 207) 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.

3 units, Win (Lawrence, J; Mao, W)

GES 110. Structural Geology and Tectonics

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 zone 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: GES 1, calculus. Recommended: 102. GER: DB-NatSci

5 units, Spr (Miller, E)

GES 111A. Fundamentals of Structural Geology
(Same as CEE 195A) Techniques for structural mapping; using differential geometry to characterize structures; dimensional analysis and scaling relations; kinematics of deformation and flow; measurement and analysis of stress. Sources include field and laboratory data integrated with conceptual and mechanical models. Models of tectonic processes are constructed and solutions visualized using MATLAB. Prerequisites: GES 1, MATH 51, 52. GER: DB-NatSci
3 units, Aut (Pollard, D)

GES 111B. Fundamentals of Structural Geology
(Same as CEE 195B) Continuation of GES 111A/CEE 195A. Conservation of mass and momentum in a deformable continuum; linear elastic deformation and elastic properties of rock; brittle deformation including fracture and faulting; linear viscous flow including folding and magma dynamics; model development and methodology. Sources include field and laboratory data integrated with conceptual and mechanical models. Models of tectonic processes are constructed and solutions visualized using MATLAB. Prerequisite: GES 111A/CEE 195B.
3 units, Win (Pollard, D)

GES 112. Mapping the Geological Environment
Geological mapping tools and techniques. Field training with GPS and laser ranging tools. Data sets from modern surveying and mapping campaigns employing lab and field-based laser scanning, field-based total stations, airborne photography and laser swath mapping (ALSM), the satellite Global Positioning System (GPS), and 3D seismic reflection surveys. These data analyzed using elementary differential geometry. MATLAB introduced as the computational and graphics engine. Prerequisites: GES 1, MATH 51, 52. GER: DB-NatSci
3 units, Win (Staff), alternate years, not given next year

GES 115. Engineering Geology Practice
(Same as CEE 196) The application of geology and global change to the planning, design, and operation of engineering projects. Case histories taught in a seminar setting and field trips emphasize the impact of geology and global change on both individual engineering works and the built environment by considering Quaternary history and tectonics, anthropogenic sea level rise, active geologic processes, engineering properties of geologic deposits, site exploration, and professional ethics. Prerequisite: GES 1 or consent of instructor. GER: DB-NatSci
3 units, Spr (Holzer, T)

GES 120. Planetary and Early Biological Evolution Seminar
(Same as GES 220) Interdisciplinary. For upper division science undergraduates and graduate students. Synthesis of biology, geology, physics, and chemistry. Recent approaches for identifying traces of past life on Earth. How to look for life on other planets such as Mars, Europa, and Titan. May be repeated for credit.
2-3 units, not given this year

GES 121. What Makes a Habitable Planet?
(Same as GES 221) 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.
3 units, Aut (Staff), alternate years, not given next year

GES 122. Planetary Systems: Dynamics and Origins
(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.
3-4 units, Aut (Marley, M; Lissauer, J)

GES 123. Paleobiology
Introduction to the fossil record with emphasis on marine invertebrates. Major debates in paleontological research. The history of animal life in the oceans. Topics include the nature of the fossil record, evolutionary radiations, mass extinctions, and the relationship between biological evolution and environmental change. Fossil taxa through time. Exercises in phylogenetics, paleoecology, biostratigraphy, and statistical methods. GER: DB-NatSci
4 units, alternate years, not given this year

GES 130. Soil Physics and Hydrology
The occurrence, distribution, circulation, and reaction of water at the surface and within the near surface. Topics: precipitation, evapotranspiration, infiltration and vadose zone, groundwater, surface water and streamflow generation, and water balance estimates. Current and classic theory in soil physics and hydrology. Urban, rangeland, and forested environments. GER: DB-NatSci
3 units, Aut (Loague, K)

GES 131. Hydrologically-Driven Landscape Evolution
Materials of the Earth and hydrologically driven landscape processes. Topics: hillslope hydrology, weathering of rocks and soils, erosion, flow failures, mass wasting, and conceptual models of landscape evolution. Current and classic theory in geomorphology. GER: DB-NatSci
3 units, Win (Loague, K)

GES 150. Senior Seminar: Issues in Earth Sciences
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.
3 units, Aut (Bird, D; Egger, A)

GES 151. Sedimentary Geology and Petrography: Depositional Systems
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. Lab: methods of analysis of sediments in hand specimen and thin section. Field trips. Prerequisites: 1, 102, 103. GER: DB-NatSci
4 units, Win (Graham, S; Lowe, D)

GES 163. Introduction to Isotope Geochemistry
(Same as GES 263) Stable, cosmogenic, and radiogenic isotopes; processes that govern isotopic variations. Application of isotopes to geologic, biologic, and hydrologic questions. Major isotopic systems and their applications. Simple modeling techniques used in isotope geochemistry.
3 units, Aut (Maher, K)

GES 170. Environmental Geochemistry
Solid, aqueous, and gaseous phases comprising the environment, their natural compositional variations, and chemical interactions. Contrast between natural sources of hazardous elements and compounds and types and sources of anthropogenic contaminants and pollutants. Chemical and physical processes of weathering and soil formation. Chemical factors that affect the stability of solids and aqueous species under earth surface conditions. The release, mobility, and fate of contaminants in natural waters and the roles that water and dissolved substances play in the physical behavior of rocks and soils. The impact of contaminants and design of remediation strategies. Case studies. Prerequisite: 90 or consent of instructor. GER: DB-NatSci
4 units, Win (Brown, G)

GES 171. Geochemical Thermodynamics
Introduction to the application of chemical principles and concepts to geologic systems. The chemical behavior of fluids, minerals, and gases using simple equilibrium approaches to modeling the geochemical consequences of diagenetic, hydrothermal, metamorphic, and igneous processes. Topics: reversible thermodynamics, solution chemistry, mineral-solution equilibria, reaction kinetics, and the distribution and transport of elements by geologic processes. Prerequisite: GES 102. GER: DB-NatSci
3 units, Aut (Bird, D)

GES 172. Nontraditional Stable Isotope Geochemistry
(Same as GES 272) Elements other than C, N, O, S, and H that exhibit mass-dependent and non mass-dependent isotopic fractionation; examples include Mg, Ca, Si, Fe, Cr, Mo, Cu, Zn, and Hg. These systems represent a new frontier in isotope geochemistry and Earth Sciences as new tools for understanding geochemical, environmental and biological cycles. The theoretical calculations that form the basis for predicting fractionation, as well as the current state and applications of non-traditional isotope systems.
3 units, Win (Staff), alternate years, not given next year

GES 173. Isotope Geochemistry Seminar
(Same as GES 273) Current topics including new analytical techniques, advances in isotopic measurements, and new isotopic approaches and systems.
1-3 units, Spr (Maher, K)

GES 180. Igneous Processes
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. Labs emphasize identification of volcanic and plutonic rocks in thin section and interpretation of rock textures. May be taken for 3 units without lab. Prerequisite 102, 103, or consent of instructor.
4 units, Spr (Stebbins, J)

GES 183. California Desert Geology
Field seminar. For upper division undergraduates and graduate students in the earth sciences and archaeology. Six-day field trip over Spring Break to Mojave Desert, Death Valley, and Owens Valley. Basin-and-range faulting, alluvial fans, playas, sand dunes, metamorphic rocks, granites of the Sierra Nevada, obsidian lava flows and the deposits of major explosive eruptions, hot springs and ore deposits, and desert landscapes. Camping and moderate hiking. May be repeated for credit.
1 unit, Win (Staff)

GES 185. Volcanology
For juniors, seniors, and beginning graduate students in Earth Sciences and Archaeology. How volcanic landforms and deposits relate to the composition and physical properties of magmas and the modes of emplacement. Labs emphasize recognizing types of lavas and products of explosive eruptions. Volcanic hazards and the effects of eruptions on climate and the atmosphere; volcanic-hosted geothermal systems and mineral resources. Required four-day field trip over Memorial Day weekend to study silicic and mafic volcanism associated with the western margin of the Basin and Range province. Prerequisite: 1, 102 or equivalent. GER: DB-NatSci
3-4 units, Spr (Staff), alternate years, not given next year

GES 190. Field Research
Two-three week field research projects. Written report required. May be repeated three times.
2-4 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GES 191. GES Field Trips
Four- to seven-day field trips to locations of geologic and environmental interest. Includes trips offered during Thanksgiving and Spring breaks. May be repeated for credit. See http://pangea.stanford.edu/GES/undergraduates/courses/.
1 unit, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GES 192. Undergraduate Research in Geological and Environmental Sciences
Field-, lab-, or literature-based. Faculty supervision. Written reports. May be repeated for credit.
1-10 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GES 197. Senior Thesis
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.
3-5 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GES 198. Special Problems in Geological and Environmental Sciences
Reading and instruction under faculty supervision. Written reports. May be repeated for credit.
1-10 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GES 199. Honors Program
Research on a topic of special interest. See "Undergraduate Honors Program" above. May be repeated for credit.
1-10 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GRADUATE COURSES IN GEOLOGICAL AND ENVIRONMENTAL SCIENCES

GES 207. Journey to the Center of the Earth
(Same as GES 107, GEOPHYS 107, GEOPHYS 207) 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.
3 units, Win (Lawrence, J; Mao, W)

GES 209. Microstructures
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.
3-5 units, not given this year

GES 210. Geologic Evolution of the Western U.S. Cordillera
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.
2-3 units, Aut (Staff), alternate years, not given this year

GES 211. Topics in Regional Geology and Tectonics
May be repeated for credit.
2-3 units, Aut (Miller, E)

GES 212. Topics in Tectonic Geomorphology
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.
2 units, Aut (Hilley, G)

GES 213. Topics in Sedimentary Geology
For upper division undergraduates and graduate students. Topics vary each year but the focus is on current developments and problems in sedimentary geology, sedimentology, 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.
2 units, by arrangement

GES 214. Topics in Paleobiology
For upper division undergraduates and graduate students. Topics vary each year; focus is on paleontological, sedimentological, and geochemical approaches to the history of life. Topics may include: mass extinction events; evolutionary radiations; the history of global biodiversity; links between evolutionary histories of primary producers and consumers; and the quality of the fossil record. Term paper. May be repeated for credit.
2 units, offered occasionally

GES 215A. Structural Geology and Rock Mechanics
(Same as CEE 297G) Quantitative field and laboratory data integrated with solutions to initial and boundary-value problems of continuum mechanics introduce tectonic processes in Earth's crust that lead to the development of geological structures including folds, faults, fractures and fabrics. Topics include: techniques and tools for structural mapping; using differential geometry to characterize structures; dimensional analysis and scaling relations; kinematics of deformation and flow; traction and stress analysis. Data sets analyzed using MATLAB. Prerequisites: GES 1, MATH 53, MATLAB or equivalent.
3-5 units, Aut (Pollard, D)

GES 215B. Structural Geology and Rock Mechanics
(Same as CEE 297H) Field equations for elastic solids and viscous fluids derived from conservation laws to develop mechanical models for tectonic processes and their structural products. Topics include: conservation of mass and momentum in a deformable continuum; linear elastic deformation and elastic properties of rock; brittle deformation including fracture and faulting; linear viscous flow including folding, model development, and methodology. Models constructed and solutions visualized using MATLAB. Prerequisite: GES 215A.
3-5 units, Win (Pollard, D)

GES 216. Rock Fracture Mechanics
Principles and tools of elasticity theory and fracture mechanics are applied to the origins and physical behaviors of faults, dikes, joints, veins, solution surfaces, and other natural structures in rock. Field observations, engineering rock fracture mechanics, and the elastic theory of cracks. The role of natural fractures in brittle rock deformation, and fluid flow in the earth's crust with applications to crustal deformation, structural geology, petroleum geology, engineering, and hydrogeology. Prerequisite: 215 or equivalent.
3-5 units, Spr (Staff), not given next year

GES 217. Faults, Fractures, and Fluid Flow
Process-based approach to rock failure; the microstructures and overall architectures of the failure products including faults, joints, solution seams, and types of deformation bands. Fluid flow properties of these structures are characterized with emphasis on sealing and transmitting of faults and their role in hydrocarbon flow, migration, and entrapment. Case studies of fracture characterization experiments in aquifers, oil and gas reservoirs, and waste repository sites. Guest speakers; weekend field trip. Prerequisite: first-year graduate student in Earth Sciences.
3 units, Win (Staff), alternate years, not given next year

GES 220. Planetary and Early Biological Evolution Seminar
(Same as GES 120) Interdisciplinary. For upper division science undergraduates and graduate students. Synthesis of biology, geology, physics, and chemistry. Recent approaches for identifying traces of past life on Earth. How to look for life on other planets such as Mars, Europa, and Titan. May be repeated for credit.
2-3 units, not given this year

GES 221. What Makes a Habitable Planet?
(Same as GES 121) 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.
3 units, Aut (Staff), alternate years, not given next year

GES 222. Planetary Systems: Dynamics and Origins
(For students with a strong background in mathematics and the physical sciences; other should register for 122.) Motions of planets, moons, and small bodies; energy transport in planetary systems; meteorites and the constraints they provide on the formation of the solar system; asteroids and Kuiper belt objects; comets; planetary rings; planet formation; and extrasolar planets. In-class presentation of student papers.
3-4 units, Aut (Staff)

GES 223. Planetary Systems: Atmospheres, Surfaces, and Interiors
Physical processes, such as radiation transport, atmospheric dynamics, thermal convection, and volcanism, shaping the interiors, surfaces, and atmospheres of the major planets in the solar system. How these processes manifest themselves under various conditions in the solar system. Case study of the surface and atmosphere of Mars. Application of comparative planetary science to extrasolar planets and brown dwarfs. In-class presentation of student papers.
3 units, by arrangement

GES 224. Modeling Environmental Transformations
Quantitative overview of chemical and physical transport and transformation processes that govern elemental and contaminant concentrations in solids, fluids, and gases. Topics include the kinetics of mass transfer across environmental interfaces, formulation of reactor models, and elementary transport phenomena. Emphasis is on reactive transport modeling of fluid-mineral, isotopic, and microbial processes in the context of water-rock systems. Quantitative techniques for conceptualizing environmental processes from simple finite difference approaches to more sophisticated numerical reactive transport models.
3 units, Win (Staff), alternate years, not given next year

GES 237. Surface and Near-Surface Hydrologic Response
(Same as CEE 260B) Quantitative review of process-based hydrology and geomorphology. Introduction to finite-difference and finite-element methods of numerical analysis. Topics: biometeorology, unsaturated and saturated subsurface fluid flow, overland and open channel flow, and physically-based simulation of coupled surface and near-surface hydrologic response. Links hydrogeology, soil physics, and surface water hydrology.
3 units, Aut (Loague, K)

GES 238. Soil Physics
Physical properties of the soil solid phase emphasizing the transport, retention, and transformation of water, heat, gases, and solutes in the unsaturated subsurface. Field experiments.
3 units, Aut (Staff), alternate years, not given next year

GES 240. Geostatistics for Spatial Phenomena
(Same as ENERGY 240) Probabilistic modeling of spatial and/or time dependent phenomena. Kriging and cokriging for gridding and spatial interpolation. Integration of heterogeneous sources of information. Multiple-point geostatistics and training image-based stochastic imaging of reservoir/field heterogeneities. Introduction to GSLIB and SGEMS software. Case studies from the oil and mining industry and environmental sciences. Prerequisites: introductory calculus and linear algebra, STATS 116, GES 161, or equivalent.
3-4 units, Win (Journel, A)

GES 246. Reservoir Characterization and Flow Modeling with Outcrop Data
(Same as ENERGY 146, ENERGY 246) Project addressing a reservoir management problem by studying an outcrop analog, constructing geostatistical reservoir models, and performing flow simulation. How to use outcrop observations in quantitative geological modeling and flow simulation. Relationships between disciplines. Weekend field trip.
3 units, Aut (Graham, S; Tchelepi, H; Boucher, A)

GES 249. Petroleum Geochemistry in Environmental and Earth Science
How molecular fossils in crude oils, oil spills, refinery products, and human artifacts identify their age, origin, and environment of formation. The origin and habitat of petroleum, technology for its analysis, and parameters for interpretation, including: origins of molecular fossils; function, biosynthesis, and precursors; tectonic history related to the evolution of life, mass extinctions, and molecular fossils; petroleum refinery processes and the kinds of molecular fossils that survive; environmental pollution from natural and anthropogenic sources including how to identify genetic relationships among crude oil or oil spill samples; applications of molecular fossils to archaeology; worldwide petroleum systems through geologic time.
3 units, Win (Moldowan, J)

GES 250. Sedimentation Mechanics
The mechanics of sediment transport and deposition and the origins of sedimentary structures and textures as applied to interpreting 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. Field trip required.
4 units, Aut (Lowe, D)

GES 251. Sedimentary Basins
Analysis of the depositional framework and tectonic evolution of sedimentary basins. Topics: tectonic and environmental controls on facies relations, synthesis of basin development through time in terms of depositional systems and tectonic settings. Weekend field trip required. Prerequisites: 110, 151.
3 units, Aut (Graham, S)

GES 252. Sedimentary Petrography
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. Topics vary yearly. Prerequisite: 151 or equivalent.
4 units, Aut (Staff), alternate years, not given next year

GES 253. Petroleum Geology and Exploration
The origin and occurrence of hydrocarbons. Topics: thermal maturation history in hydrocarbon generation, significance of sedimentary and tectonic structural setting, principles of accumulation, and exploration techniques. Prerequisites: 110, 151. Recommended: GEOPHYS 184.
3 units, Spr (Staff), alternate years, not given next year

GES 254. Carbonate Sedimentology
Processes of precipitation and sedimentation of carbonate minerals 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 rocks and sediments as sources of geochemical proxy data; carbonate diagenesis; changes in styles of carbonate deposition through Earth history; carbonate depositional patterns and the global carbon cycle. Lab exercises emphasize petrographic and geochemical analysis of carbonate rocks including map and outcrop scale, hand samples, polished slabs, and thin sections.
3-4 units, Spr (Payne, J)

GES 255. Basin and Petroleum System Modeling
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.
3 units, Win (Staff), alternate years, not given next year

GES 257. Clastic Sequence Stratigraphy
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.
3 units, Spr (Staff), alternate years, not given next year

GES 258. Introduction to Depositional Systems
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.
3 units, Spr (Lowe, D)

GES 260. Laboratory Methods in Organic Geochemistry
Knowledge of components in geochemical mixtures to understand geological and environmental samples. The presence and relative abundance of these compounds provides information on the biological source, depositional environment, burial history, biodegradation, and toxicity of organic materials. Laboratory methods to detect and quantify components of these mixtures. Methods for separation and analysis of organic compounds in geologic samples: extraction, liquid chromatography, absorption by zeolites, gas chromatography and gas chromatography-mass spectrometry. Student samples considered as material for analysis. Recommended: 249.
2-3 units, Spr (Moldowan, J)

GES 261. Physics and Chemistry of Minerals and Mineral Surfaces
The concepts of symmetry and periodicity in crystals; the physical properties of crystals and their relationship to atomic-level structure; basic structure types; crystal chemistry and bonding in solids and their relative stability; the interaction of x-rays with solids and liquids (scattering and spectroscopy); structural variations in silicate glasses and liquids; UV-visible spectroscopy and the color of minerals; review of the mineralogy, crystal chemistry, and structures of selected rock-forming silicates and oxides; mineral surface and interface geochemistry.
4 units, Spr (Brown, G)

GES 262. Thermodynamics and Disorder in Minerals and Melts
The thermodynamic properties of crystalline, glassy, and molten silicates and oxides in light of microscopic information about short range structure and ordering. Measurements of bulk properties such as enthalpy, density, and their pressure and temperature derivatives, and structural determination by spectroscopies such as nuclear magnetic resonance and Mössbauer. Basic formulations for configurational entropy, heats of mixing in solid solutions, activities; and the energetics of exsolution, phase transitions, and nucleation. Quantitative models of silicate melt thermodynamics are related to atomic-scale views of structure. A general view of geothermometry and geobarometry. Prerequisites: introductory mineralogy and thermodynamics.
3 units, Win (Staff), alternate years, not given next year

GES 263. Introduction to Isotope Geochemistry
(Same as GES 163) Stable, cosmogenic, and radiogenic isotopes; processes that govern isotopic variations. Application of isotopes to geologic, biologic, and hydrologic questions. Major isotopic systems and their applications. Simple modeling techniques used in isotope geochemistry.
3 units, Aut (Maher, K)

GES 267. Solution-Mineral Equilibria: Theory
Procedures for calculating and evaluating the thermodynamic properties of reversible and irreversible reactions among rock-forming minerals and aqueous solutions in geologic systems. Emphasis is on the generation and utility of phase diagrams depicting solution-mineral interaction relevant to phase relations associated with weathering diagenetic, hydrothermal, and metamorphic processes, and the prediction of temperature, pressure, and the chemical potential of thermodynamic components compatible with observed mineralogic phase relations in geologic outcrops. Individual research topics. Prerequisite: 171.
3 units, alternate years, not given this year

GES 272. Nontraditional Stable Isotope Geochemistry
(Same as GES 172) Elements other than C, N, O, S, and H that exhibit mass-dependent and non mass-dependent isotopic fractionation; examples include Mg, Ca, Si, Fe, Cr, Mo, Cu, Zn, and Hg. These systems represent a new frontier in isotope geochemistry and Earth Sciences as new tools for understanding geochemical, environmental and biological cycles. The theoretical calculations that form the basis for predicting fractionation, as well as the current state and applications of non-traditional isotope systems.
3 units, Win (Staff), alternate years, not given next year

GES 273. Isotope Geochemistry Seminar
(Same as GES 173) Current topics including new analytical techniques, advances in isotopic measurements, and new isotopic approaches and systems.
1-3 units, Spr (Maher, K)

GES 275. Electron Probe Microanalytical Techniques
The practical and theoretical aspects of x-ray generation and detection, and the behavior of electron beams and x-rays in solids. The basic principles needed to quantitatively analyze chemically complex geological materials. Operation of the JEOL 733 electron microprobe and associated computer software for quantitatively analyzing materials. X-ray chemical mapping. Enrollment limited to 8.
2-3 units, Win (Jones, R)

GES 277. Flood Basalts and Mass Extinctions
Recent work in geochronology and paleobiology supports the temporal coincidence of the eruption of continental flood basalts with mass extinction in the marine and terrestrial realms. The mechanisms and timescale of flood basalt eruptions, their likely environmental and biological consequences, and the evidence for flood basalt eruptions as the triggers of many mass extinction events. Sources include recent primary literature.
3 units, Aut (Staff), alternate years, not given next year

GES 283. Thermochronology and Crustal Evolution
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. The underpinning concepts and key developments in thermochronology, focusing upon analytical and interpretative innovations developed over the past decade.
4 units, Spr (Staff), alternate years, not given this year

GES 284. Field Seminar on Eastern Sierran Volcanism
For graduate students in the earth sciences and archaeology. Four-day trip over Memorial Day weekend to study silicic and mafic volcanism associated with the western margin of the Basin and Range province: basaltic lavas and cinder cones erupted along normal faults bounding Owens Valley, Long Valley caldera, post-caldera rhyolite lavas, hydrothermal alteration and hot springs, Holocene rhyolite lavas of the Inyo and Mono craters, volcanism of the Mono Basin with subaqueous basaltic eruptions, floating pumice blocks, and cryptodomes punching up lake sediments. If snow-level permits, silicic volcanism associated with the Bodie gold district. Prerequisite: 1, 102 or equivalent.
1 unit, Spr (Staff), alternate years, not given next year

GES 285. Igneous Petrogenesis
Radiogenic isotopes, stable isotopes, and trace elements applied to igneous processes; interaction of magmas with mantle and crust; convergent-margin magmatism; magmatism in extensional terrains; origins of rhyolites; residence times of magmas and magma chamber processes; granites as imperfect mirrors of their source regions; trace element modeling of igneous processes; trace element discriminant diagrams in tectonic analysis; phase equilibria of partial melting of mantle and crust; geothermometry and geobarometry. Topics emphasize student interest. Prerequisite: 180 or equivalent.
4 units, offered occasionally

GES 290. Departmental Seminar in Geological and Environmental Sciences
Current research topics. Presentations by guest speakers from Stanford and elsewhere. May be repeated for credit.
1 unit, Aut (Maher, K; Mao, W), Win (Maher, K; Mao, W), Spr (Maher, K; Mao, W)

GES 291. GES Field Trips
Field trips for teaching and research purposes. Trips average 5-10 days. Prerequisite: consent of instructor.
1 unit, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GES 292. Directed Reading with Geological and Environmental Sciences Faculty
May be repeated for credit.
1-10 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GES 299. Field Research
Two-three week field research projects. Written report required. May be repeated three times.
2-4 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GES 310. Climate Change, Climate Variability, and Landscape Development
The impact of long-term climate change on erosional processes and the evolution of Cenozoic landscapes. Climate data that highlight recurring climate variability on inter-annual to decadal timescales. The behavior of climate on multi-decadal to tectonic timescales over which significant changes in topography take place. The effects of climate change and variability on landscape development, sedimentary environments, and the deposits of these events. May be repeated for credit.
1 unit, not given this year

GES 314. Structural Geology and Geomechanics
Research seminar. May be repeated for credit. (Staff)
1-5 units, Aut (Staff), Win (Staff), Spr (Staff)

GES 315. Literature of Structural Geology
Classic studies and current journal articles. May be repeated for credit.
1 unit, Aut (Pollard, D), Win (Pollard, D), Spr (Pollard, D)

GES 328. Seminar in Paleobiology
For graduate students. Current research topics including paleobotany, vertebrate and invertebrate evolution, paleoecology, and major events in the history of life on Earth.
1 unit, Spr (Payne, J)

GES 333. Water Policy Colloquium
(Same as CEE 333) Student-organized interdisciplinary colloquium. Creation, implementation, and analysis of policy affecting the use and management of water resources. Weekly speakers from academia and local, state, national, and international agencies and organizations.
1 unit, Spr (Staff)

GES 336. Stanford Alpine Project Seminar
Seminar on Iceland geology. Weekly student presentations on Icelandic hot-spot and mid-ocean ridge volcanism, geothermal power, culture, and other topics of interest. Students create a guidebook of geologic stops in advance of field trip in summer 2009. May be repeated for credit.
1 unit, offered occasionally

GES 355. Advanced Stratigraphy Seminar and Field Course
Student-led presentations; poster-sized display on assigned topic; field trip.
1-3 units, offered occasionally

GES 381. Igneous Petrology and Petrogenesis Seminar
Topics vary by quarter. May be repeated for credit.
1-2 units, Spr (Mahood, G)

GES 384. Volcanology Seminar
Specialized and advanced topics vary by offering. May be repeated for credit.
1-2 units, Spr (Mahood, G)

GES 385. Practical Experience in the Geosciences
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. (Staff)
1 unit, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GES 399. Advanced Projects
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.
1-10 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GES 400. Graduate Research
Faculty supervision. On registration, students designate faculty member and agreed-upon units.
1-15 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

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