GEOLOGICAL AND ENVIRONMENTAL SCIENCES

Emeriti: (Professors) Robert Coleman, John W. Harbaugh**, Konrad B. Krauskopf, Ronald J. P. Lyon***, George A. Parks***, Irwin Remson
Chair: Jonathan F. Stebbins
Associate Chair: Stephan A. Graham
Professors: Dennis K. Bird, Gordon E. Brown, Jr., Robert B. Dunbar, Marco T. Einaudi, W. Gary Ernst, Steven M. Gorelick†, Stephan A. Graham, James C. Ingle, Jr., Andre G. Journel**, Juhn G. Liou, Donald R. Lowe, Gail A. Mahood, Pamela A. Matson††, Elizabeth L. Miller, David D. Pollard, Jonathan F. Stebbins, Paul Switzer*
Associate Professors: Keith Loague, Michael O. McWilliams
Assistant Professors: Scott Fendorf, Adina Paytan
Professors (Research): Atilla Aydin, J. Michael Moldowan
Associate Professor (Research): Christopher Chyba
Courtesy Professors: Peter Brewer, David Clague, James O. Leckie
Courtesy Associate Professors: Ronaldo I. Borja, Simon Klemperer, Debra Stakes
Courtesy Assistant Professor: Kevin R. Arrigo
Senior Lecturer: George G. Mader
Consulting Professors: Richard Bernknopf, Paul Hsieh
Consulting Associate Professors: Joseph W. Ruetz, Joseph Wooden
Visiting Professor: Dennis L. Corwin

* Joint appointment with Statistics
† Joint appointment with Geophysics
** Joint appointment with Petroleum Engineering
†† Joint appointment with Institute for International Studies
*** Recalled to active duty

UNDERGRADUATE PROGRAMS

BACHELOR OF SCIENCE

The program leading to the Bachelor of Science degree in Geological and Environmental Sciences (GES) provides the background for a wide variety of careers. It prepares students for graduate studies in business administration, earth and environmental sciences, environmental engineering, land use planning, law, public service, and other professions in which an understanding of the earth and a background in science can be important. The geological sciences are broad and include study of the Earth's history and the evolution of life; the oceans and atmosphere; the processes that shape the Earth's mountains, continents, and landscape; the chemistry and physics of earth materials and their interactions with each other and with water; and sources of water, economic minerals, metals, and fuels. Within earth sciences, the environmental sciences emphasize the present and the future, particularly the ways in which humankind is affected by natural hazards such as volcanic eruptions and earthquakes and the ways in which we affect the planet and its viability by development, contamination of natural waters, and depletion of resources.

GES offers an undergraduate major leading to the bachelor's degree in Geological and Environmental Sciences and three formal opportunities for specialization: Geological Sciences, Environmental Sciences, Engineering Geology and Hydrogeology.

Students whose educational objectives are within the scope of the department, but not encompassed in a predefined program, may design an independent curriculum with the help of a faculty adviser and the approval of the department chair. All successful graduates receive the Bachelor of Science in GES. Students who enroll in a predefined program likewise may have the area of specialization designated as a field on their transcripts.

The Writing in the Major (WIM) requirement may be fulfilled by taking one of the following courses designated (WIM) for the larger unit total indicated: GES 110, 112, 151, 152, 185, 198 along with the 1-unit WIM Project course, GES 190. Students choosing to take a course for WIM credit should consult with the instructor early in the quarter; additional writing-intensive work is assigned.

GEOLOGICAL SCIENCES

The Geological Sciences curriculum leading to the B.S. degree in Geological and Environmental Sciences prepares students for professional careers and graduate studies in the earth sciences and other fields requiring an earth sciences background. The field of geological sciences is broad and involves the study of the physical and chemical processes that build continents, shape the earth's landscape, and determine: the distribution of elements in minerals, rocks, soils, and natural waters; the oceans and atmosphere; Earth's history and the evolution of life; and the materials that constitute the earth, including those of economic importance. Geological sciences are also concerned with the ways in which society is affected by natural hazards (for example, volcanic eruptions, landslides, and earthquakes) and the ways in which society affects the planet (for example, the pollution of groundwater and depletion of resources).

An important emphasis of the B.S. program in the Geological Sciences curriculum is the study of earth processes and history in the natural laboratory of the field. Stanford University's location near the Pacific continental margin, the Sierra Nevada mountain range, and the San Andreas fault system provides a nearly unparalleled setting for field studies.

The field of geological sciences has evolved over the last two centuries from mostly observational and descriptive into a quantitative science dealing with the chemistry and physics of the earth and other planets and with interactions between the biological and physical systems of the earth. Thus, the Geological Sciences curriculum includes significant course work in chemistry, physics, and mathematics. The diversity of these requirements and experience results in graduates with versatility and a broad range of skills. The program is designed to recognize the diversity of this field and to provide a great deal of flexibility. A significant proportion of the required courses can be selected by the student in consultation with his or her faculty adviser, allowing the B.S. program to be tailored to individual goals and interests while providing a solid background in basic earth sciences, the supporting sciences, and mathematics.

GES majors who select the Geological Sciences curriculum are expected to complete a set of courses in supporting sciences and mathematics, a core course sequence that defines the curriculum, and a set of electives chosen from the prescribed list below. Students who elect this major must also enroll in the joint San Jose State University/Stanford summer field camp (see Professor Miller). Substitutions for core courses must be approved by the adviser and the department chair. Letter grades are required, if available, in all courses.

CORE COURSE SEQUENCE

Course No. and Subject	*Qtr. and Units*	
GES 1. Fundamentals of Geology	A,W,S	5
or GES 2,3. Earth History and Lab	A	5
GES 80. Earth Materials	A	5
GES 90. Introduction to Geochemistry	W	3
GES 102. Introduction to Field Geology	Sum	3
GES 110. Structural Geology	S	5
or GES 111. Structural Geology and Rock Mechanics	A	4
GES 112. Mapping the Geologic Environment	S	3
GES 151. Sedimentary Geology	W	4
GES 152. Stratigraphy and Applied Paleontology	S	4
GES 160. Introduction to Statistical Methods for Earth and Environmental Science	S	4
GES 181. Igneous and Metamorphic Processes	S	3-5
GES 190. WIM Project	A,W,S	1
Subtotal		39-42

REQUIRED SUPPORTING SCIENCES AND MATHEMATICS

Chem. 31. Chemical Principles	A,W,Sum	4
Chem. 135. Physical Chemical Principles	W	3
or Chem. 171. Physical Chemistry	A	3
or GES 171. Geochemical Thermodynamics	A	3

Choose one of the following groups of mathematics courses:

Math. 19. Calculus	A,W,Sum	3
Math. 20. Calculus	W,S	3

Geological and Environmental Sciences

Math. 21. Calculus	S	4
Math. 51. Calculus	A,W,S	5
or		
Math. 41. Calculus*	A	5
Math. 42. Calculus*	A,W	5
Math. 51. Calculus	A,W,S	5

Choose one of the following groups of physics courses:

Physics 21. Mechanics and Heat	A	3
Physics 22. Mechanics and Heat Lab	A	1
Physics 23. Electricity and Optics	W	3
Physics 24. Electricity and Optics Lab	W	1
or		
Physics 41. Mechanics†	A	3
Physics 43. Electricity†	W	3
Physics 45. Magnetism†	S	3
Physics 46. Electricity and Magnetism Lab†	S	1
Physics 47. Light and Heat†	A	4
Subtotal		30-36

* Math. 41, 42, 51 are recommended for students planning graduate study in the sciences or engineering.

† Physics 41, 43, 45, 47 are recommended for students planning graduate study in the sciences or engineering.

ELECTIVES

Choose *four* courses from the following list or, with faculty approval, four related, but more advanced courses:

Biol. Sci. 117. Biology and Global Change	W	3
Chem. 33. Structure and Reactivity	W,S,Sum	4
Comp. Sci. 106A. Programming Methodology	A,W,S	5
GES 2, 3. Earth History and Lab (if not used above)	A	5
GES 8. Oceans	S	3
GES 140. Geomorphology	W	3
GES 170. Environmental Geochemistry	W	4
GES 185. Volcanology	S	4-5
GES 187. Introduction to Ore Deposits	A	4
GES 195. Integrating Remote Sensing and Geographic Information Systems (GIS)	A	3
GES 230. Physical Hydrogeology	A	5
Geophys. 183. Interpretation of Seismic Reflection Profiles	W	2-3
Geophys. 150. General Geophysics	A	3-4
Math. 103. Matrix Theory and its Applications	A,W,S,Sum	3
Subtotal		11-20
Total		81-98

ENVIRONMENTAL SCIENCES

Environmental Sciences in the School of Earth Sciences is concerned with the combined chemical, physical, and mathematical study of the outer crust of the earth and the hydrosphere as they are found today, and of the processes and stages through which our planet's surface has evolved. The program also deals with the impact of our use of land and natural resources, processes through which the earth may respond to this use, and the hazards these processes present to people on local and regional scales. In comparison, earth systems science focuses on some of the same topics on a global scale, and environmental engineering focuses on prevention, control, or mitigation of the negative aspects of human impact on the environment.

The Environmental Sciences curriculum provides a background in selected fundamental geological and physical sciences, basic quantitative analytical and problem-solving tools, and an introduction to the use of this background in anticipating, recognizing, and defining or diagnosing environmental problems. The primary focus is on earth sciences, the natural environment, and anthropogenic changes. Graduates should be equipped for positions in environmental consulting and remediation firms or government agencies or, with appropriate selection of electives, for graduate study in related fields including the geological sciences, environmental sciences or engineering, business or law, and others.

GES majors who elect the Environmental Sciences curriculum are expected to complete a core course sequence in supporting sciences and mathematics and a set of electives chosen from the prescribed list below. Substitutions for core and elective courses must be approved by the adviser and the department chair. Letter grades are required, if available, in all courses.

CORE COURSE SEQUENCE

Course No. and Subject	*Qtr. and Units*	
Civ. & Envir. Engr. 170. Environmental Science and Technology	A	3
GES 1. Fundamentals of Geology	A,W,S	5
GES 80. Earth Materials	A	5
GES 90. Introduction to Geochemistry	W	3
GES 102. Introduction to Field Geology	Sum	3
GES 110. Structural Geology	S	5
or GES 111. Structural Geology and Rock Mechanics	A	4
GES 112. Mapping the Geologic Environment	S	4
GES 151. Sedimentary Geology	W	4
GES 160. Introduction to Statistical Methods for Earth and Environmental Sciences	S	4
GES 170. Environmental Geochemistry	W	4
GES 190. WIM Project	A,W,S	1
GES 230. Physical Hydrogeology	A	5
Subtotal		45-46

REQUIRED SCIENCES AND MATHEMATICS

Chem. 31. Chemical Principles	A,W,Sum	4
Chem. 33. Structure and Reactivity	W,S,Sum	4
Chem. 135. Physical Chemical Principles	W	3
or Chem. 171. Physical Chemistry	A	3
or GES 171. Geochemical Thermodynamics	A	3

Choose one of the following groups of mathematics courses:

Math. 19. Calculus	A,W,Sum	3
Math. 20. Calculus	W,S	3
Math. 21. Calculus	S	4
Math. 51. Calculus	A,W,S	5
or		
Math. 41. Calculus	A	5
Math. 42. Calculus	A,W	5
Math. 51. Calculus	A,W,S	5

Choose one of the following groups of physics courses:

Physics 21. Mechanics and Heat	A	3
Physics 22. Mechanics and Heat Lab	A	1
Physics 23. Electricity and Optics	W	3
Physics 24. Electricity and Optics Lab	W	1
or		
Physics 41. Mechanics†	A	3
Physics 43. Electricity†	W	3
Physics 45. Magnetism†	S	3
Physics 46. Electricity and Magnetism Lab†	S	1
Physics 47. Light and Heat†	A	4
Subtotal		34-40

* Math. 41, 42, 51 are recommended for students planning graduate study in the sciences or engineering.

† Physics 41, 43, 45, 47 are recommended for students planning graduate study in the sciences or engineering.

ELECTIVES

Choose *four* courses from the following list or, with faculty approval, four related, but more advanced courses:

Biol. Sci. 117. Biology and Global Change	W	3
Civ. & Envir. Engr. 266. Environmental Policy Design and Implementation	S	4
Comp. Sci. 106A. Programming Methodology	A,W,S	5
Engr. 60. Engineering Economy	A,W, Sum	3
GES 2,3. Earth History and Lab	A	5
GES 8. Oceans	S	3
GES 115. Engineering Geology Practice	S	3
GES 132. Environmental Earth Sciences III	S	5
GES 140. Geomorphology	W	3
GES 171. Geochemical Thermodynamics (if not used above)	A	3
GES 185. Volcanology	S	4
Geophys. 170. Environmental and Geotechnical Geophysics	S	3
Hum. Bio. 148. Environmental Policy	S	3
Pet. Engr. 103. Energy Resources	S	3
Subtotal		12-19
Total		91-105

ENGINEERING GEOLOGY AND HYDROGEOLOGY

The Engineering Geology and Hydrogeology curriculum is intended for undergraduate students 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, and environmental geology, geology, geotechnical engineering, and hydrogeology. Students interested in this major track should contact faculty advisers Professors Pollard, Loague, or Gorelick.

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 two areas: Earth Sciences and Engineering. Any substitutions for core courses must be approved by the faculty adviser and the department chair. 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, in all courses.

CORE COURSE SEQUENCE

Course No. and Subject	*Qtr. and Units*	
GES 1. Fundamentals of Geology	A,W,S	5
GES 80. Earth Materials	A	5
GES 102. Introduction to Field Geology	Sum	3
GES 111. Structural Geology and Rock Mechanics	A	4
GES 112. Mapping the Geologic Environment	S	4
GES 115. Engineering Geology Practice	S	3
GES 160. Introduction to Statistical Methods for Earth and Environmental Sciences	S	4
GES 195. Integrating Remote Sensing and GIS	A	3
GES 190. WIM Project	A,W,S	1
GES 230. Physical Hydrogeology	A	5
Geophys. 190. Environmental and Applied Geophysics	S	3
Earth Science Subtotal		40
Civ. & Envir. Engr. 101A. Structural Systems	W	4
Civ. & Envir. Engr. 101B. Mechanics of Fluids	S	4
Civ. & Envir. Engr. 101C. Geotechnical Engineering	A	4
Comp. Sci. 106A. Programming Methodology	A,W,S	5
Engr. l4. Applied Mechanics: Statics and Deformables	A,W,S	5
Engineering Subtotal		22

REQUIRED SUPPORTING SCIENCES AND MATHEMATICS

Chem. 31. Chemistry Principles	A,W,Sum	4
Math. 51. Calculus	A,W,S	5
Math. 52. Calculus	W,S	5
Math. 53. Calculus	W,S	5
Physics 41. Mechanics	W	4
Subtotal		23

SUGGESTED ELECTIVES

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

Civ. & Envir. Engr. 170. Environmental Science and Technology	A	3
Civ. & Envir. Engr. 180A. Introduction to Structural Analysis	S	3
Civ. & Envir. Engr. 180B. Structural Analysis	A	4
Civ. & Envir. Engr. 270. Movement, Fate, and Effects of Contaminants in Surface Waters and Groundwater	A	3
Civ. & Envir. Engr. 291. Foundation Engineering	W	3
Civ. & Envir. Engr. 293. Experimental Soil Mechanics	W	2
Engr. 30. Engineering Thermodynamics	A,W	3
Engr. 50. Introductory Science of Materials	W,S	3
GES 133. Introduction to Assessment of Environmental Risk	W	3
GES 140. Geomorphology	W	3
GES 217. Characterization and Hydraulics of Rock Fracture	W	3
GES 231. Contaminant Hydrogeology	S	4
GES 235. Role of Fluids in Geologic Processes	S	3
GES 237. Surface and Near-Surface Hydrologic Response	W	4
Geophys. 150. General Geophysics	A	4
Math. 103. Matrix Theory and its Applications	A,W,S,Sum	3
Mech. Engr. 155A,B. Mathematical and Computational Methods	S	3
Mech. Engr. 111. Stress, Strain, and Strength	A	3
Subtotal		11-16
Total		96-101

All students pursuing a minor in GES are encouraged to take one of the freshman or sophomore seminars (courses with numbers 40-59) and to participate in the undergraduate seminar (GES 4). Up to 3 units of Stanford Introductory Seminar courses may be used in fulfilling the 12-unit requirement above.

Contact the GES department for further information. The variety of courses that may be used to satisfy the requirements should make it possible for students with a wide range of interests and backgrounds to complete a minor in GES.

HONORS PROGRAM

The Department of Geological and Environmental Sciences offers a program leading to the Bachelor of Science in Geological and Environmental Sciences with honors. The program provides an opportunity for independent study and research on a topic of special interest culminating in a written report. The honors program is open to all seniors with a grade point average (GPA) of at least 3.5 in earth and environmental science courses and a minimum of 3.0 in all University course work. Modest financial support is available to help defray laboratory and field expenses incurred in conjunction with honors research. Students intending to pursue the honors program must submit an application to the department before the beginning of their senior year.

A student selects a research topic and prepares a research proposal in consultation with a faculty adviser of his or her choosing. Research undertaken for the honors program can be of a theoretical, field, or experimental nature, or a combination of these approaches.

Upon approval of the research proposal and formal entrance to the program, course credit for the honors research project and report preparation is assigned by the student's faculty adviser within the framework of GES 199; 3 units each quarter are assigned to the project for three quarters of the student's senior year for a total of 9 units. Research undertaken for the honors program cannot be used as a substitute for regularly required courses.

Both a written and an oral presentation of research results are required of honors students. A formal written report must be submitted to the student's research adviser no later than the fourth week of the student's final senior quarter. To graduate with honors, the report must be read, approved, and signed by the student's faculty adviser and a second member of the faculty. Before the end of the senior year, each honors candidate gives a public seminar on his or her research results.

COTERMINAL B.S./M.S. PROGRAM

The coterminal B.S./M.S. program offers a special opportunity for students to pursue a graduate research experience and a M.S. degree concurrently with or subsequent to their B.S. studies. The master's degree is viewed as an entrance professional degree in a number of subdisciplines within the earth sciences (for example, engineering geology, environmental geology). Alternatively, graduate course work and the master's research experience can provide an intermediate step prior to pursuit of the Ph.D. Regardless of their professional goal, 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. Students should apply to the program after their seventh quarter (or after earning 105 units), but no later than their eleventh quarter. They are required to submit an application for entrance to the GES coterminal program including a statement of purpose, a copy of their current Stanford transcript, official Graduate Record Examination scores, letters of recommendation from two members of the Stanford faculty (at least one of whom must be in this department), and a list of courses in which they intend to enroll to fulfill degree requirements. Each student must complete a thesis or master's report describing the results of his or her research. Specific research interests should be noted in the statement of purpose and discussed with a member of the GES faculty prior to submission of an application to the coterminal program.

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 for the M.S. degree, or (2) complete a total of fifteen quarters during which the requirements of the two degrees are fulfilled concurrently. The student has the option of receiving the B.S. degree upon completion of that degree's requirements, or receiving the B.S. and M.S. degrees concurrently at the completion of the master's program. Unit requirements for the coterminal program are a minimum of 180 units for the B.S. degree and a minimum of 36 units of course work at the 100 level or above for the M.S. degree. At least half of the courses used to satisfy the 36-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 36-unit requirement. Further information about this program may be obtained from the GES office.

GRADUATE PROGRAMS

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 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**:** Geomathematics, Geostatistics in the Earth Sciences, and Hydrogeology.

The broad areas of faculty teaching and research are divided into three fields that have diploma designation and an additional six areas of specialization.

Admission—For admission to graduate work in the department, the applicant must have taken the Aptitude Test (verbal, quantitative, and analytical) 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. Previously admitted students who wish to change their degree objective from M.S. to Ph.D. must petition the GES Admissions Committee.

FIELDS WITH DIPLOMA DESIGNATION

Hydrogeology—The Hydrogeology program, which leads to an M.S., Engineer, or Ph.D. degree in GES, balances research in the purely scientific and applied aspects of groundwater resources and near-surface processes. Key department faculty in hydrogeology are Professors Gorelick and Loague, but there are strong interactions with faculty in the departments of Civil and Environmental Engineering, Geophysics, and Petroleum Engineering and with scientists at the USGS. Investigations typically involve field sites and focus on topics ranging from understanding groundwater flow through large basins to optimal design of aquifer remediation strategies. The scales of interest extend from the domain of pores and fractures to vast regional flow systems. One important aim is to develop conceptual and quantitative predictive models. Such models enhance our understanding of the role of groundwater flow as a geologic process and provide means for evaluating and managing resources.

The program requires students to obtain a broad background in earth sciences and engineering. Students in the program must have a strong general scientific background in basic physics, chemistry, computer science, and mathematics, and a demonstrated aptitude for solving quantitative problems. They must complete a core curriculum involving courses in fluid mechanics, hydrogeology, hydrology, and water quality. A list of required and recommended courses is supplied upon request.

Geostatistics—The Geostatistics program, which leads to a M.S. or Ph.D. degree in GES, is under the direction of Professor Journel. It focuses on the probabilistic modeling of earth sciences phenomena such as oil reservoirs, ore deposits, and pollution sites in view of their development and management. As opposed to traditional mapping algorithms, stochastic imaging provides alternative, equiprobable, very high resolution numerical models of the phenomenon under study. These models integrate data from various sources such as well data, geophysical logs, and geological interpretation. Strong interactions have been developed with faculty and students in the departments of Geophysics and Petroleum Engineering.

The program requires a geological background and a fair level of calculus and programming (Fortran and/or C). Recent graduates have found jobs in the extractive (mining, oil) and environmental (EPA) fields.

Geomathematics—The Geomathematics program, under the direction of Professor Harbaugh, leads either to a M.S. or Ph.D. degree in GES. It focuses on the use of mathematics in simulating geologic processes in petroleum-bearing sedimentary basins. Geological processes are represented in terms of their underlying physical principles by differential equations that have been placed in finite-difference form for numerical solution by computer. The numerical solutions are linked with graphics workstations to create dynamic three-dimensional displays, which are then used in simulating actual sedimentary basins.

Students in the program should have demonstrated aptitude for mathematics and computer programming. A list of required and recommended courses is supplied upon request.

AREAS OF SPECIALIZATION

Geochemistry, Petrology, and Mineralogy—The research and teaching interests of a number of the faculty in the Department of Geological and Environmental Sciences involve biogeochemistry, cosmochemistry, environmental geochemistry, geochemistry and its applications in the atomic-level structure and properties of earth materials, hydrothermal systems, igneous and metamorphic petrology, mineralogy and mineral physics, mineral surface and colloid reactions, and ore deposits. Techniques include Ar-Ar, U-Pb, Sm-Nd, Rb-Sr, and U series geochronology; computer prediction and modeling; electron microprobe and sensitive high-resolution ion microprobe analysis; field-oriented studies; lab experimentation at high temperatures and pressures on phase equilibria and mineral-fluid interactions; and x-ray scattering and spectroscopic studies of organic and inorganic earth materials. The scale of problems studied ranges from global to atomic. Students with strong backgrounds in chemistry are especially urged to contact faculty in these fields, including Professors Bird, Brown, Einaudi, Ernst, Fendorf, Ireland, Liou, Mahood, Matson, McWilliams, Moldowan, and Stebbins.

Structural Geology and Geomechanics (http://pangea.stanford.edu/geomech/index.html)—Research opportunities in this specialization include: engineering geology; geomechanics; hydraulics of faults and fractures; reservoir description and characterization; rock fracture and fault mechanics; and structural geology. Program advisers are Professors Aydin and Pollard. Correspondence with the advisers before application is suggested to clarify the nature and requirements of the program. Other faculty members with related research interests are: Professor Bird, Gorelick, Graham, Journel, Loague, Miller, and Moldowan (from GES); Professors Beroza, Klemperer, Mavko, Nur, Segall, and Zoback (from Geophysics); Professor Aziz, Durlovsky, Hewett, and Orr (from Petroleum Engineering); and Professor Borja (from Civil and Environmental Engineering).

One focus of the program is on characterizing and modeling physical processes responsible for geological structures. Topics include the evolution of crustal structures such as faults, folds, and fractures, and natural hazards related to earthquakes and volcanoes. Another focus is on the role of geologic structures (faults, folds, and fractures) in fluid flow in groundwater aquifers and petroleum reservoirs. This research is under the umbrella of the Rock Fracture Project, an industrial affiliates program.

The methodologies used in this program include field mapping of ancient or active structures; laboratory investigations using physical models; seismic mapping and interpretation of crustal subsurface structures; and theoretical analyses based on solid, fluid, and fracture mechanics. Research goals include delineating stress, strain, and displacement fields associated with geological structures at scales ranging from laboratory samples to plate boundaries, and understanding the geological and hydraulic properties of fractures and faults.

Sedimentary Geology, Paleoclimatology, Marine Geology, and Paleontology—Research in sedimentary geology at Stanford spans a wide range of specialized studies in modern and ancient settings. Sedimentary processes are studied at scales ranging from single sediment-gravity flows to the mechanisms by which continental margin basins subside.

Time-dependent phenomena are investigated at levels that range from the deposition and organic geochemical and paleoecologic signatures of annually varved sediments to that of the fill of long-lived foreland basins. Venues span the globe from Asia, around the Pacific Rim to South America, and across to Africa in stratigraphic units that range from Archean to Recent; these are investigated with special focus on the tectonics, sedimentation, and paleoclimate of continental margins and sedimentary basins of the western U.S. These investigations employ the tools of many subdisciplines, including computer modeling/simulation, geochemistry, geochronology, micropaleontology, paleoecology, paleomagnetism, sedimentology, and seismic interpretation, with emphasis on interdisciplinary integration. Current projects include application of sedimentology to interpreting surface conditions and crustal evolution on the Archean earth, computer simulation of sediment flows and deposits, evolution of modern shallow carbonate depositional systems in the Gulf of California, organic geochemistry of paleoclimatic events such as El Niño, paleoclimatology and sedimentation of modern western Pacific marginal seas, research on the origins and evolution of sedimentary basins in Asia, sequence and seismic stratigraphic architecture of active margin basins, and sediment-gravity flow mechanisms and the structure of associated deposits. Core faculty are Dunbar, Graham, Ingle, Lowe, and Paytan; faculty with related or overlapping interests include Fendorf, Gorelick, Harbaugh, McWilliams, Miller, and Moldowan.

Structural Geology, Regional Geology, and Tectonics—Research in structural geology, regional geology, and tectonics overlaps the interests of many other research programs in the school and encompasses a broad spectrum of disciplines. Field-based studies address the evolution and deformation of continental crust and the relationship of plate tectonics to the genesis and evolution of mountain belts and sedimentary basins, with emphasis on the circum-Pacific region and North American Cordillera. The $^{40}Ar/^{39}Ar$ and fission-track geochronology laboratories support studies aimed at understanding the thermal history of sedimentary basins and of igneous and metamorphic terranes, determining rates of geologic processes, and calibrating the geological and geomagnetic time scales. Geophysical studies include seismic imaging of the crust and mantle, stress and strain measurement in regions of active deformation, and paleomagnetic measurement of crustal deformation and continental accretion. Faculty with general interests in these topics include Professors Aydin, Ernst, Graham, McWilliams, Miller, and Pollard in Geological and Environmental Sciences, and Klemperer, Nur, Segall, Sleep, Thompson, and Zoback in Geophysics.

Surface and Aqueous Geochemistry—Professors Brown and Parks (emeritus) lead the Surface and Aqueous Geochemistry Group (SAAG) in the alteration and partitioning reactions that determine the mobility, bioavailability, and ultimate fate of solutes and contaminants in natural waters. Research focuses on the fundamental physical and surface/interfacial chemistry underlying reactions among water, aqueous solutes, and minerals under earth-surface conditions, and how the composition and structure of the solutions and mineral surfaces influence them. Students study speciation or complexation, dissolution, precipitation, and especially sorption reactions using a variety of classical surface chemistry and surface-sensitive spectroscopic methods, as well as computer simulations of the macroscopic and molecular-scale behavior of solutes and properties of solute-surface complexes. Results can be used to understand mechanisms of element partitioning and cycling in geochemical systems; they have applications in a wide variety of contexts including hazardous waste management, petroleum migration and recovery, remediation of contaminated sites, and weathering under the influence of acid rain.

SAAG students are expected to accumulate a sound background in physical and inorganic chemistry as well as geochemistry, and at least one field of application such as environmental engineering, environmental geosciences, or hydrogeology. Preference is given to applicants who have a strong quantitative background in chemistry and physical chemistry and experience with computers and laboratory methods.

Volcanology—Professors Aydin, Mahood, and Pollard have overlapping interests with Professors Segall and Zebker in Geophysics in the deformation of volcanic edifices; eruption triggers; explosive volcanism and emplacement of pyroclastic flows; formation of dikes, geologic evolution of caldera systems; magma degassing and impact of volcanic gases on the atmosphere; the physics of magma transport in the crust; magma reservoirs and sills; planetary volcanology; and seismic signatures of volcanic activity.

MASTER OF SCIENCE

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 36 units of course work at the 100 level or above.
   a. Half of the courses used to satisfy the 36-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 36-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

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 72 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

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 '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 for 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 department appoints the research adviser and two other members of the research committee 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

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 '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.

COURSES

(WIM) indicates that the course meets the Writing in the Major requirements.

(AU) indicates that the course is subject to the University Activity Unit limitations (8 units maximum).

UNDERGRADUATE

1. Fundamentals of Geology—For non-majors or prospective majors in Earth Systems or Geological and Environmental Sciences. Introduction to and survey of the processes that shape the earth's landforms, produce the minerals and rocks that comprise the earth, create soils, deform the earth's crust, and move continents. Surficial processes involving water, wind, and ice, and their role in erosion and in the production of sediment. The processes acting within the earth's interior, emphasizing global tectonics. How geologists determine the ages of rocks and geologic events. Geologic hazards: earthquakes, volcanic eruptions, flooding, landslides, and their mitigation. Nonrenewable resources, energy, environmental problems. Lectures, one all-day field trip, and weekly lab. Recommended: high school chemistry and physics. GER:2a (DR:5)

5 units, Aut (Mahood)
Win (Ernst)
Spr (Staff)

2. Earth History—For non-majors or prospective Earth Systems or geology majors. The earth is a dynamic planet, its surface continuously remolded by changing patterns of plate movements, climatic variation, the rise and fall of sea level, mountain building, volcanism, erosion, and sedimentation. It has hosted an evolutionary parade of organisms, from self-replicating molecules to man, that have interacted with and strongly modified surrounding environments. The evolution of the earth and its biosphere, hydrosphere, and atmosphere represent active areas of current research and discussion. Topics: the formation of the earth, origin of life, evolution of the continents, oxygenation of the atmosphere, development of metazoans, history of glaciations and climate, the role of extraterrestrial events in geological and biological evolution. Non-required lab in GES 3 examines the materials and organisms discussed. Majors in geology must take 3 concurrently or in a subsequent year. $10 field trip fee required. GER:2a (DR:5)

3 units (Lowe) alternate years, given 2001-02

3. Earth History Laboratory—Introduction to the methods and materials of historical geology. Lab sessions on stratigraphic interpretation, geologic maps and cross sections, sedimentary environments, and metazoan evolution and fossils. Recommended for students taking GES 2; required for geology majors who took Geology 2 in 1985-86 or later. Pre- or corequisite: 2.

2 units (Lowe) alternate years, given 2001-02

4. Undergraduate Seminar—For prospective majors in the School of Earth Sciences and non-majors. Informal lectures introduce students to the earth sciences: the scope of research and teaching in the School of Earth Sciences at Stanford, career possibilities, and the importance of studying the Earth. (AU)

1 unit, Aut, Win (Staff)

7A,B. An Introduction to Wilderness Skills—Introduction to living, traveling, and working in the wilderness for those planning fieldwork in the backcountry. In-class topics: geological processes, land management, environmental ethics, first aid, animal tracking, and plant ecology. Four weekend outings focus on minimum impact backcountry skills including backcountry ski techniques, backpacking, caving, food preparation, orienteering, rock climbing, snow shelter building, and telemarking. Students research the geological history of trip locations and make short presentations on their findings. 7A emphasizes navigation on foot and rock climbing, and 7B emphasizes winter camping skills and backcountry skiing. Food, group, and major personal gear provided. Students provide own clothing. Fee for food and transportation. (AU)

7A. *1 unit, Aut (Bird)*
7B. *1 unit, Win (Bird)*

7C. Advanced Wilderness Skills: An Introduction to Mountaineering—Introduction to mountaineering techniques and issues. AWS addresses topics and skills of interest to those more experienced with outdoor travel, focusing on the techniques and skills applicable to mountaineering. Fee for food and transportation. (AU)

1 unit, Spr (Bird)

8. The Oceans: An Introduction to the Marine Environment—For non-majors and prospective geology, earth science, and environmental majors. Topics: topography and geology of the sea floor, evolution of ocean basins, the circulation of the ocean and atmosphere, the nature of sea water, waves, 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. The relationships between the distribution of inorganic constituents, ocean circulation, biologic productivity, and marine environments from deep sea to the coast. Lectures and required one-day field trip to measure and analyze waves and currents. GER:2a (DR:5)

3 units, Spr (Ingle)

40N. Stanford Introductory Seminar: Bon Appetite! Chemistry and Physics in the Kitchen—Preference to freshmen. The applications of scientific concepts and reasoning to the art of cookery and culinary traditions and practice. Why do we add eggs when making mayonnaise? How can we make ice cream using liquid nitrogen? Why is pressure cooking faster than boiling? How can we soften beans fast? Examples and "practical training."

3 units (Paytan) alternate years, given 2001-02

41N. Stanford Introductory Seminar: El Niño—History and Predictability of a Global Climate Pacemaker—Preference to freshmen. The coupled El Niño-Southern Oscillation (ENSO) system is the dominant source of interannual climate variability worldwide. Participants probe the workings and impacts of El Niño through readings and analysis of primary climatic data. Topics: principles of air-sea interaction, mechanisms of El Niño, simple simulations of ENSO warm and cool events, teleconnected responses in California and the U.S., past El Niño disasters, future predictability of ENSO, and possible El Niño manifestations in a greenhouse world. Grading via class projects. GER:2a (DR:5)

3 units (Dunbar) alternate years, given 2001-02

42N. Stanford Introductory Seminar: Early Life on Earth—Preference to freshmen. An exploration of the first billion years of earth history, with emphasis on the environments, conditions, and processes that led to the origin of life on earth; the likelihood that life has evolved elsewhere in the solar system; examination and discussion of the geologic record of the oldest preserved life forms, and the environments in which they lived. Term paper. Use of Stanford's of rock collection containing the oldest evidence for life on earth. GER:2a (DR:5)

3 units, Aut (Lowe) alternate years, not given 2001-02

43N. Stanford Introductory Seminar: Environmental Problems—Preference to freshmen. Groundwater contamination from point and nonpoint sources, cumulative watershed effects related to timber and mining practices, acid rain, subsurface disposal of nuclear waste, the Alaska pipeline, slope stability, and oil-tanker spills.

3 units, Win (Loague)

44N. Stanford Introductory Seminar: Emerging Issues in Global Environmental Change—Preference to freshmen. Surveys the current understanding of environmental issues that are global in extent or effect, developing skills in researching primary literature and presenting the results of research in writing and orally. Topics: atmospheric change, climate change, land use change, change in biotic resources, change in biogeochemistry, and the interaction of these changes with local and regional changes. Structure: six weeks of lecture/discussions focused on global changes and their causes and consequences at global and local scales; four weeks of oral presentations and discussions of student research. Team project exploring the social or natural science research in specific changes; students critique draft papers and give an oral presentation on their own research.

3 units (Matson) alternate years, given 2001-02

45N. Stanford Introductory Seminar: Environment Quality, is it Getting Better or Worse?—Preference given to freshmen. How do scientists address questions about environmental change? How do our governments set standards for environmental quality? What are some strategies for monitoring environmental quality? How can we distinguish between long term trends and random fluctuations? How can we predict the effects of national policy on environmental quality? What is the evidence for climate change over the past century? How do we predict the effects of climate change on society? The scientific tools and data needed to address these questions. Student pairs select a project area, assemble information, and provide oral progress reports and written final reports.

3 units, Win (Switzer) alternate years, not given 2001-02

46N. Stanford Introductory Seminar: The Beach—Preference to freshmen. Open coast beaches represent one of the most complex and dynamic natural environments of Earth: a triple point where the ocean, atmosphere, and continent meet and interact on time scales of seconds to millennia. The beach environment through lectures and reading, and by study in the field. Field work involves repeated measurement of waves, currents, and beach character and sample collection at sites from Point Reyes south to Monterey Bay, California, with the goals of assembling and analyzing a quantitative record of environmental change. Required papers on a specific aspect of the beach environment.

3 units (Ingle) alternate years, given 2001-02

47N. Stanford Introductory Seminar: "Secrets in the Mud"—A Look into the Field of Paleoceanography—Preference to freshmen. The oceans have major effects on climate; understanding how the oceans operated and responded to natural perturbations in the past help us predict and plan for the potential consequences of changes humankind induces on the environment. The kinds of information deduced from marine sediments about Earth's environment in the past. Student lab projects: sediment sample preparation and analysis, description and interpretation of data, and presentation as oral and written reports.

3 units, Win (Paytan) alternate years, not given 2001-02

48N. Stanford Introductory Seminar: Volcanoes of the Eastern Sierra Nevada—Preference to freshmen. Develop skills in researching primary sources in scientific literature and presenting the results of that research orally and in writing. Topics: young volcanoes, hot springs, earthquake faults, glacial features, paleoclimatology, and saline lakes of the eastern Sierra Nevada. Four-day field trip over the Memorial Day weekend. Term project is written as a chapter for a class-produced field trip guidebook. Students give an oral presentation on the outcrop at the field trip stop described in the guidebook chapter. Introduction to the basics of related geology. Camping and light hiking. GER: 2a (DR: 5)

3 units, Spr (Mahood) alternate years, not given 2001-02

49N. Stanford Introductory Seminar: Field Trip to Death Valley—Preference to freshmen. California's Death Valley and Owens Valley are natural laboratories for exploring a billion years of earth history: the sediments of ancient ocean/s, large-scale crustal deformation and mountain building, recent earthquake faulting, and volcanic eruptions. Their desert environments reveal prehistoric climate changes and historic human impacts. Six-day field trip to these areas during Spring Break. Introduction to the basics of geology. Individual projects on specific topics are presented during the trip. Camping and moderate hiking required.

3 units, Win (Mahood, Miller)

50Q. Stanford Introductory Seminar: The Coastal Zone Environment—Preference to sophomores. The oceanographic, geological, and biological character of coastal zone environments, including continental shelves, estuaries, and coastal wetlands, with emphasis on San Francisco Bay. Five required field trips examine the estuarine and coastal environments of the Bay region, and agencies and facilities concerned with monitoring and management of these resources. Original research on a selected aspect of the coastal zone results in a written and oral report.

Prerequisite: introductory course in the earth or biological sciences. GER:2a (DR:5)
3 units, Aut (Ingle)

52Q. Stanford Introductory Seminar: Geologic Development of California—Preference to sophomores, and to students who have completed introductory geology. Field-based, on the crustal evolution of California in post-Paleozoic time, and covering the geotectonic development of most of the state. Weekend field trips to the Diablo Range (two days); the central Klamath Mountains (three days); Point Lobos (one day); the White-Inyo Range, Owens Valley, and the eastern Sierra (three days). Camping and hiking.
4 units, Spr (Ernst)

53Q. Stanford Introductory Seminar: In the Beginning—Theories of the Origin of the Earth, Solar System, and Universe—Preference to sophomores. What happened in the first few seconds following the Big Bang? Where did all the elements in the periodic table come from? When and how did the Earth, Moon, and solar system form? When and where did life begin on Earth? Answers to these questions have been sought for centuries, and continues today. The history and evolution of theories of the origin of the Earth, Moon, solar system, and the Universe.
3 units, Win (McWilliams)

54Q. Stanford Introductory Seminar: California Landforms and Plate Tectonics—Preference to sophomores. The forces of plate tectonics at work on the landscape of California. The principles of rock deformation are introduced in hands-on experiments. Landforms resulting from deformation of the earth are analyzed with digital and photographic images. Field trips relate these large-scale structures to what one sees from the human perspective on the ground. Literature research on the tectonics of a region of the student's choice. GER:2a (DR:5)
3 units, Aut (Miller)

55Q. Stanford Introductory Dialogue: The California Gold Rush—Geologic Background and Environmental Impact—Preference to sophomores, and to students who have completed introductory geology. The geologic processes that led to the concentration of gold in the river gravels and rocks of the Mother Lode region of California. The environmental impact of the Gold Rush population increase and of mining operations, including the effects of placer mining on the landscape, rivers, and fisheries, and the concentration of arsenic and mercury in surface sediments and soils due to hard rock mining and milling operations. Field trip to the Mother Lode region; term paper and oral presentation required.
2 units, Spr (Bird)

56Q. Stanford Introductory Dialogue: Change in the Coastal Ocean—The View from Monterey Bay—Preference to sophomores. The issue of recent changes in the California Current, using Monterey Bay as an example. Current literature is an introduction to several principles of oceanography. Visits from researchers from MBARI, Hopkins, and UCSC. Optional field trip to MBARI and Monterey Bay.
2 units, Spr (Dunbar)

57Q. Stanford Introductory Seminar: How to Critically Read and Discuss Scientific Literature—Preference to sophomores. The ability to read and evaluate scientific primary literature is crucial for success in undergraduate or graduate school, or in the scientific work force. Topics: how to approach the reading of scientific articles, and how to understand and critically evaluate the information contained in them through guided and instructed reading, and a review of such papers.
3 units, Win (Paytan)

80. Earth Materials—Identification, classification, and interpretation of rock-forming minerals and the igneous, sedimentary, and metamorphic rocks they comprise. Rock cycles are related to earth systems. Lab work emphasizes use of the hand lens in making observations; overnight field trip demonstrates mineral and rock identification in the field, a variety of different pressure and temperature environments where minerals and rocks have formed, and genetic associations. Prerequisite: 1. Recommended: introductory chemistry.
5 units, Aut (Brown, Liou)

81. Petrography Tutorial—Practice and instruction in identifying minerals and rocks using a petrographic microscope. One three-hour lab per week. Prerequisite: 80 or equivalent.
2 units, Spr (Miller, Staff)

90. Introduction to Geochemistry—Introduction to 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.
3 units, Win (Stebbins)

102. Introduction to Field Geology—Instruction and practice in the basic methods of geologic investigation in the field. Emphasis is on techniques of systematic observations and the construction of geologic maps and sections from the data obtained with a written geologic report on one of the study areas. Field area sites display a variety of rock types and landforms related to clearly defined geologic structures and events. Conducted from White Mountains Research Station in Bishop, CA for the two weeks preceding the beginning of Autumn Quarter. Contact GES, or see *Summer Session Catalogue* for schedule. Prerequisites: 1, 80.
3 units, Sum (Ruetz)

105. Geologic and Environmental Problems—Supervised reading, field and/or lab work; written reports thereon.
1-10 units, any quarter (Staff)

110. Structural Geology: Introduction to Deformation in the Earth's Crust—The basic theory, principles, and techniques used to interpret and measure structures in naturally deformed rocks. Topics: the properties, rheology, and mechanisms of the deformation of rocks and minerals; techniques of data collection in the field; lab and computer analysis of structural data; geometry and development of faults and folds; interpretation of geologic maps and construction of geologic cross-sections; strain measurement and structural analysis of metamorphic tectonites; the evolution of mountain belts, formation of rift-related sedimentary basins, and development of strike-slip fault systems. Prerequisites: 1, calculus. Recommended: 80, 102. (WIM)
5 units, Spr (Miller)

111. Structural Geology and Rock Mechanics—(Same as Civil and Environmental Engineering 195.) Observational techniques, analysis methods, and the theoretical foundations of structural geology, engineering geology, and rock mechanics. Computer exercises are integrated with field data to understand the role of geologic structures in the evolution of the earth's crust (folding, faulting, flow, and fracturing of rock) and geologic hazards (earthquakes, landslides, and volcanoes). Topics: structural quantities and dimensional analysis; use of stress, strain, displacement, and velocity fields in structural analysis; the concept and measurement of deformation; mechanical properties of rock (elasticity, viscosity, strength, friction, fracture toughness); case studies of typical geologic structures using continuum mechanics. Computer labs. Prerequisites: 1, calculus, Macintosh skills.
5 units, Aut (Pollard)

112. Mapping the Geological Environment—Introduction to modern techniques for the mapping and measurement of geological features associated with natural resources recovery, geological hazards, and environmental problems. Use of descriptive geometry and stereographic projections to analyze geological field data. Total Positioning System (TPS) and the satellite-based Global Positioning System (GPS) are used for field data acquisition. Compilation, visualization, and presentation of 2D and 3D field data is implemented using computer graphics applications and Geographic Information Systems (GIS). Field trips. (WIM)

4 units, Spr (Einaudi, Pollard)

115. Engineering Geology Practice—(Same as Civil and Environmental Engineering 196.) The application of geologic fundamentals to the planning and design of civil engineering projects. Emphasis is on the development of geologic skills to identify, describe, and map earth materials and geologic structures as a means of determining the impact on site development. Topics: weathering and soil-forming processes, soil and rock mechanics, site investigation techniques, surface and groundwater regimes, stream and coastal processes, quaternary tectonics, deposits and geomorphology, environmental concerns, and geologic and geotechnical hazards. Field/lab exercises and case history studies emphasize the impact of site geology on the safe planning, design, and construction of civil engineering projects such as foundations, transportation facilities, excavations, tunnels and underground storage space, water supply facilities, and marine works. Prerequisite: 111 or consent of instructor.

3 units (Holzer) alternate years, not given 2001-02

120. Geosphere—(Same as Earth Systems 110.) Geological processes, from local to global, affect people and civilization. The reverse is also true; civilization is beginning to influence the geosphere. The processes experienced at the earth's surface (catastrophic earthquakes, volcanic eruptions, and longer term atmospheric and climate changes) are linked to what goes on in the earth's deep interior. How geochemical, geophysical, and biological processes interact over time scales ranging from 4.5 billion years to the nearly instantaneous. Topics: the origin and evolution of the atmosphere and oceans, heat flow and global tectonics and how they have changed over time, geochemical cycles, climate change, catastrophic impacts, and the roles played by organisms. Prerequisite: 1 or 2.

3 units, Aut (Paytan, Stebbins, McWilliams)

133. Introduction to Assessment of Environmental Risk—Interdisciplinary approach to evaluate environmental and natural hazard risks, combining economics with earth-science information. The earth sciences, applied statistics, geographic information systems (GIS) and microeconomics are integrated in a decision framework (cost-benefit analysis) to address site-specific issues (e.g., locating a waste-disposal facility), and regional issues (e.g., reducing earthquake-related damage). Techniques developed are applied in an in-class bargaining exercise to evaluate a current land-use issue. Prerequisite: 160 or equivalent, or consent of instructor.

3 units, Win (Bernknopf)

140. Geomorphology—Focus is on the materials and surface/near-surface processes of fluvial landscapes. Topics: hillslope hydrology, weathering of rocks and soils, erosion, sediment transport, flow failures, mass wasting, and conceptual models of landscape evolution. Prerequisite: 1. Recommended: 151. (WIM)

3 units, Win (Loague) alternate years, not given 2001-02

147. Controlling Climate Change in the 21st Century—(Enroll in Human Biology 147.)

3 units, Aut (Schneider, Rosencranz)

151. Sedimentary Geology and Petrography: Depositional Systems—Topics: weathering, erosion and transportation, deposition, the 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 required. Prerequisites: 1, 2. (WIM)

4 units, Win (Lowe, Graham)

152. Stratigraphy and Applied Paleontology—The rudiments of interpreting sedimentary sequences. Emphasis is on the integration of paleontologic and sedimentologic evidence to reconstruct depositional environments, basin history, and paleogeographic and paleo-oceanographic settings. The nature of the fossil record, the use of fossils for dating, correlation, and paleo-environmental and paleo-oceanographic reconstructions. Characteristic variations of modern and ancient biofacies and lithofacies. Biostratigraphy, magnetostratigraphy, and radiometric dating and correlation. Term paper. Lectures supplemented by classic and current scientific literature. Weekly lab; two required field trips. Prerequisites: 1, 2. (WIM)

4 units, Spr (Ingle)

159. Marine Chemistry—(Same as Earth Systems 159.) For upper-division undergraduates and graduate students in the earth, biology, and environmental sciences. The oceans are in interactive contact with the atmosphere, biosphere, and lithosphere, and virtually all elements pass through the ocean at some point in their cycles. The first-order processes take place within the sea, which affects its chemistry. What controls the distribution of chemical species in water and sediments? How long do different elements spend, on average, in the ocean? How do marine chemical processes interact with the biological, geological, and physical processes in the oceans? Prerequisite: 8 or the consent of the instructor.

3 units, Spr (Paytan)

160. Introduction to Statistical Methods for Earth and Environmental Sciences—Data summaries, graphical display of data, measures of association sampling, quantification of uncertainty, statistical models, testing, and prediction. Analysis of spatial and temporal data. Examples from geologic and environmental science.

4 units, Spr (Switzer)

163. Introduction to Isotope Geology—Introduces the use of stable and radiogenic isotopes in earth and planetary sciences; intended as a foundation for 164 and/or 165. Basic cosmochemistry and nucleosynthesis; the origin, abundance, and distribution of the elements in the solar system; factors that control elemental abundance and distribution; isotope systematics; nuclear and chemical processes affecting isotope distribution. Mass spectrometry and introduction to isotopic measurements including ion counting, thermal ionization mass spectrometry (TIMS), secondary ion mass spectrometry (SIMS), noble gas mass spectrometry, accelerator mass spectrometry (AMS), and inductively coupled plasma mass spectrometry (ICP-MS). Prerequisites: undergraduate-level physics, chemistry, and differential calculus.

3 units, Aut (McWilliams)

164. Stable Isotopes—Light stable isotopes and their application to geological and geophysical problems. Isotopic systematics of hydrogen, carbon, nitrogen, oxygen, and sulfur; chemical and biogenic fractionation of light isotopes in the atmosphere, hydrosphere, and in minerals. Isotopic composition of water in the oceans. Paleothermometry and paleoclimatology. Isotope fractionation in igneous, sedimentary, and metamorphic rocks, and in ore-forming fluids. Prerequisite: 163 or consent of the instructor.

3 units (Dunbar) alternate years, given 2001-02

165. Geochronology—The principles of geochronology and thermochronology and their application to geological and geophysical problems. Topics: nuclear structure, isotope systematics, decay schemes for the principal nuclides used in earth sciences, equilibrium and disequilibrium, diffusion and transport phenomena, blocking (closure) of isotopic and magnetic systems, creation and annealing of fission tracks, neutron activation, a review of geologic timescales, chronostratigraphy, magnetostratigraphy, and cosmogenic exposure ages. Alpha counting, mass spectrometry by gas source, solid source, ion probe and accelerator methods. Fundamentals of K-Ar, Ar-Ar, Rb-Sr, U-Pb fission track and cosmogenic isotope methods. Recommended: undergraduate training in calculus, chemistry, geology, and physics.

3 units, Spr (McWilliams)

166. Soil Chemistry—Practical and quantitative treatment of soil processes affecting chemical reactivity, transformation, retention, and bioavailability. The three primary areas of soil chemistry: inorganic and organic soil components, complex equilibria in soil solutions, and adsorption phenomena at the solid-water interface. The special considerations required for acid, saline, and wetland soils.
3 units, Win (Fendorf)

170. Environmental Geochemistry—Introduction to the solid, aqueous, and gaseous phases comprising the environment, their natural compositional variations, and their chemical interactions, emphasizing the contrast between natural sources of hazardous elements and compounds and the types and sources of anthropogenic contaminants and pollutants. Identification of chemical and physical processes that result in weathering and soil formation. Chemical factors that affect the stability of solids and aqueous species under earth surface conditions. Emphasis is on processes that control 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 scientific basis for evaluation of the impact of contaminants and the design of remediation strategies. Case studies: mercury on the San Francisco Peninsula, heavy metals in the Sierra Nevada and Central Valley of California, and high-level radioactive waste disposal sites in the U.S. Prerequisite: 90 or consent of instructor.
4 units, Win (Brown)

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: 80.
3 units, Aut (Bird)

175. Science of Soils—The physical, chemical, and biological processes that occur within soil systems. The factors governing nutrient availability, plant growth/production, land-resource management, and pollution within soils.
3 units, Aut (Fendorf)

181. Igneous and Metamorphic Processes—The origin of igneous and metamorphic rocks, emphasizing magmatic differentiation and subsolidus recrystallization processes and their imposed physio-chemical and tectonic conditions. The physical properties of magmas, role of volatile components, applications of trace elements and isotopes to igneous processes, geodynamics, and evolution of the crust-mantle system modeling of crystal fractionation and partial melting, relevant experimental data and phase diagrams, and relations of magma types to tectonic settings. Mineral paragenesis, phase relations, metamorphic reactions, fluid/rock interactions, P-T-time paths and their imposed tectonic settings. Lab hand-specimen and petrographic examinations of suites of igneous and metamorphic rocks. Graduate students may take without lab for 3 units. Prerequisites: 80, 90, or equivalents.
3 or 5 units (Liou) alternate years, given 2001-02

182. Field Seminar on Continental-Margin Volcanism—For juniors, seniors, and graduate students in the earth sciences and archeology. Three weekend-long field trips to study Cenozoic volcanism associated with subduction and with passage of the Mendocino Triple Junction off the west coast of California: Mt. Lassen/Mt. Shasta/Modoc Plateau; Clear Lake/Sonoma Volcanics; Pinnacles National Monument. Features visited and studied: andesite and basalt lavas, cinder cones, mixed magmas, blast deposit, debris avalanches, volcanic mudflows, hydrologic controls of springs in volcanic terrains, hydrothermal alteration and modern geothermal systems, Hg mineralization, obsidian source. Prep lectures, reading assignments, and video-viewing assignments. Light hiking and camping required. Prerequisite: 1 or equivalent.
2 units (Mahood) alternate years, given 2001-02

184. Field Seminar on Eastern Sierran Volcanism—For juniors, seniors, and graduate students in the earth sciences and archeology. Five-day trip over Memorial Day weekend to study silicic and mafic volcanism associated with the western margin of the Basin and Range province. The basaltic lavas and cinder cones erupted along normal faults bounding Owens Valley. Long Valley caldera-lake sedimentation, postcaldera rhyolite lavas, hydrothermal alteration, and hot springs. The 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. Prep lectures, reading assignments, and video-viewing assignments. Prerequisite: 1 or equivalent.
2 units (Mahood) alternate years, given 2001-02

185. Volcanology—For juniors, seniors, and beginning graduate students in all the earth sciences. Eruptive mechanisms; models of the emplacement of pyroclastic flows and characteristics of resulting deposits; volcanic landforms and their relation to the composition and physical properties of magmas; calderas; volcanic gases; volcanic hazards and the effects of facies models for volcanic centers eruptions on climate and the atmosphere; volcanic-hosted geothermal systems and mineral resources. One four-day field trip over Memorial Day weekend required. Prerequisite: 1 or equivalent. (WIM)
4 units, Spr (Mahood) alternate years, not given 2001-02

185L. Volcanology Laboratory—Hand sample and petrographic microscope examination of volcanic rocks. Labs keyed to 185 lectures taken concurrently. Prerequisite: some experience with a petrographic microscope.
1 unit (Mahood) alternate years, not given 2001-02

187. Introduction to Ore Deposits—The geology of hydrothermal systems, their products and processes: chemical, fluid inclusion, and isotopic characterization of fractures/veins and altered rocks, mineralogical and structural; distribution, geologic settings, and temporal evolution; and general models and interpretation of metasomatic processes. Focus is on understanding active hydrothermal systems in continental and oceanic settings and applications to ancient analogues: hot springs and mercury deposits, geothermal reservoirs and gold-silver deposits, volcanic fumaroles and magmatic-hydrothermal systems, mid-ocean-ridge hot springs and submarine massive sulfide deposits, and sedimentary basin brines and stratabound sulfide deposits. Lab: methods of study and description of veins and altered rocks; introduction to fluid inclusion microthermometry. Field trips required. Prerequisites: 80, 90.
4 units (Einaudi) alternate years, not given 2001-02

190. WIM Project—Students in a GES WIM (110, 112, 151, 152 or 185), enroll in 190 using the section # of the appropriate faculty member.
1 unit (Staff)

192. Special Projects in Geological and Environmental Sciences—Supervised reading, field, and/or lab research with written reports.
1-10 units, any quarter (Staff)

195. Integrating Remote Sensing and Geographic Information Systems (GIS)—Entry-level survey of remote sensing and GIS; weekly computer-based lab session involving both subjects, stressing the interrelationships of the information from remotely sensed environmental data with the techniques and methodology of GIS. Lab enrollment limited to 20.
3 units, Aut (Staff)

196. Introduction to GIS: ARC/Info and Arc-View—(Graduate students enroll in 296; same as Geophysics 196.) Hands-on experience with

ESRI's ARC/INFO or Arc-View commercial GIS packages. Topics: setting up geographic databases and manipulating spatial data, including database query and analysis. Hands-on computer-based exercises using sample ARC datasets on workstations. Guest lectures on GIS applications in the environmental, geological, and biological sciences, and in town planning. Students unable to register for 196 may sign up, with consent of instructor, for a self-paced computer tutorial version in 197, any quarter.

2 units, Win (Klemperer)

197. Research in the Application of Geographic Information Systems (GIS)

1-5 units, Aut, Win, Spr (Klemperer)

198. Special Problems in Geological and Environmental Sciences—Supervised reading, field, and/or lab research with written reports.

1-10 units, any quarter (Staff)

199. Honors Program—Research on a topic of special interest. See "Undergraduate Honors Program" above.

3 units, Aut, Win, Spr, Sum (Staff)

GRADUATE

200. Issues in Geoscience Education

1 unit, Aut, Win, Spr (Staff)

202. Reservoir Geomechanics—(Enroll in Geophysics 202.)

3 units, Win (Zoback)

205. Advanced Oceanography—For upper-division undergraduates and graduate students in the earth, biologic, and environmental sciences. Topical issues in marine science/oceanography. Topics vary each year following or anticipating research trends in oceanographic research. Focus is on links between the circulation and physics of the ocean with climate in the North Pacific region, and marine ecologic responses. Lectures/discussion, with participation by marine scientists from various marine research groups and organizations including the Monterey Bay Aquarium Research Institute.

3 units (Dunbar) alternate years, given 2001-02

206. Antarctic Marine Geology—For upper-division undergraduates and graduate students. Intermediate and advanced topics in marine geology and geophysics, focusing on examples from the Antarctic continental margin and adjacent Southern Ocean. Topics: glaciers, icebergs, and sea ice as geologic agents (glacial and glacial marine sedimentology, Southern Ocean current systems and deep ocean sedimentation), Antarctic biostratigraphy and chronostratigraphy (continental margin evolution). Students interpret seismic lines and sediment core/well log data. Examples from a recent scientific drilling expedition to Prydz Bay, Antarctica. Up to two students may have an opportunity to study at sea in Antarctica during Winter Quarter.

3 units, Aut (Dunbar, Cooper)

210. Geologic Evolution of the Western U.S. Cordillera—For undergraduates and graduates. Overview of the geology of the western states. The evolution of the mountain belt from its inception in the Precambrian to its contemporary history of extension and strike-slip faulting, based on the description, analysis, and interpretation of the rock record through time. The characteristic structural styles developed during crustal shortening, extension, and strike-slip tectonic regimes; tectonic controls on sedimentary basin formation; plate margin magmatism and metamorphism; and the relation of plate motions to the land geologic record provide insight into the crustal-scale processes and driving mechanisms common to mountain chains.

2-3 units (Miller) alternate years, given 2001-02

211. Topics in Regional Geology and Tectonics—Seminar.

2 units, Win (Miller)

215. Advanced Structural Geology and Rock Mechanics—(Same as Geophysics 215.) The observational techniques, analysis methods, and theoretical foundations of structural geology, engineering geology, and rock mechanics. Computer exercises are integrated with field data to understand the role of geologic structures in the evolution of the earth's crust (folding, faulting, flow, and fracturing of rock) and geologic hazards (earthquakes and volcanoes). Topics: structural quantities and dimensional analysis; use of stress, strain, displacement, and velocity fields in structural analysis; concept and measurement of deformation; mechanical properties of rock (elasticity, viscosity, strength, friction, fracture toughness); case studies of typical geologic structures using continuum mechanics. Computer labs.

5 units, Aut (Pollard)

216. Rock Fracture Mechanics—(Same as Geophysics 216.) Theoretical and experimental principles of continuum and fracture mechanics are applied to the origin and physical behavior 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, fluid flow, and heat transport in the earth's crust with applications to crustal deformation and tectonophysics, structural geology, petroleum geology and engineering, and hydrogeology. Prerequisite: 215 or equivalent.

5 units (Pollard) alternate years, given 2001-02

217. Characterization and Hydraulics of Rock Fractures—Interdisciplinary survey of natural fractures (faults, joints, veins, and solution seams) and their geological, geophysical, geomechanical, stochastic, and hydraulic properties. Case studies of fracture characterization experiments and problems related to fluid flow in aquifers, oil and gas reservoirs, and waste repository sites in fractured rock. Invited lecturers from various disciplines and one weekend field trip. Prerequisite: equivalent of first-year graduate student in Geological and Environmental Sciences, Geophysics, or Petroleum Engineering.

3 units (Aydin) alternate years, given 2001-02

219. Paleoceanography—For upper-division undergraduates and graduate students in the earth, biology, and environmental sciences. How can we learn about the chemistry, circulation, biology, and geology of past oceans and why is this of interest? Evidence for substantial changes in earth's climate and surficial environment is contained in the sedimentary record. The fundamentals of gathering and interpreting this information in the context of understanding how earth processes functioned in the past and their relevance for the habitability of our planet in the future.

3 units, Aut (Paytan)

220. Terrestrial Biogeochemistry—For upper-division undergraduates and graduate students in the earth and biological sciences. The processes by which components of terrestrial ecosystems interact, drawing on areas of geology, soil science, hydrology, chemistry, biology, and ecology, and emphasizing nutrient cycling.

3 units (Matson, Vitousek) alternate years, given 2001-02

221. The Origins of Life in the Solar System—Interdisciplinary seminar for upper-division undergraduates and graduate students in the physical and biological sciences. Current topics in exobiology and the origins of life from a planetary sciences perspective. Definitions of life and the origin of information; water, carbon, and energy; phylogenetic and fossil inferences about early life on Earth; the early terrestrial environment, including asteroid and comet impacts; prebiotic organic syntheses and the RNA world; panspermia; the search for life on Mars; Europa, including prospects for an ocean and speculative ecologies; upcoming spacecraft missions and mission planning; planetary protection, back contamination, and legal and ethical issues; and student-suggested topics. Student presentations, group discussion, and lectures.

3 units, Spr (Chyba)

223. Seminar in Sustainable Agriculture—(Same as Earth Systems 223.) For upper-division undergraduates and graduate students in the earth and biological sciences.

2-3 units (Matson, Naylor) alternate years, given 2001-02

225. Isotopes in Geological and Environmental Research—For upper-division undergraduates and graduate students in the earth, biology, and environmental sciences. The applications of different isotopic systems in geological, oceanographic and environmental studies at low temperature. The use of isotopes as tracers for weathering rate, biogeochemical cycling, food-web structures, ecology, paleo-chemistry, provenance, circulation, anthropogenic and extraterrestrial inputs, etc. Isotopic systems: S, Sr, Nd, Ra, Os, B, Th, Pb, Ca, Se, Si, He, Be, and Fe. Emphasis is on developing skills in reading and evaluation of scientific papers, preparing oral presentations, conducting literature searches, manuscript reviews, and proposal preparation. Prerequisite: 163, 164, or consent of the instructor.

3 units (Paytan) alternate years, given 2001-02

230. Physical Hydrogeology—(Same as Civil and Environmental Engineering 260A.) Theory of underground water, analysis of field data and pumping tests, geologic groundwater environments, solution of field problems, groundwater modeling. Introduction to groundwater contaminant transport and unsaturated flow. Lab. Prerequisite: elementary calculus.

5 units, Aut (Gorelick)

231. Contaminant Hydrogeology—(Same as Civil and Environmental Engineering 260C.) For earth scientists and engineers interested in environmental and water resource problems involving contaminated groundwater. The processes affecting contaminant migration through porous media including interactions between dissolved substances and solid media. Conceptual and quantitative treatment of advective-dispersive transport with reacting solutes. Predictive models of contaminant behavior controlled by local equilibrium and kinetics. Modern methods of contaminant transport simulation and optimal aquifer remediation. Recommended: 230.

4 units, Spr (Gorelick)

235. Role of Fluids in Geologic Processes—The principles governing groundwater flow and its interaction with crustal stress, heat flow, and chemical mass transport. Topography-driven flow of groundwater on a regional scale; compaction-driven flow in the sedimentary basin; development of anomalous fluid pressure; the role of fluid in tectonism; migration and entrapment of petroleum; density driven flow and thermal anomaly; formation of mineral deposits. Prerequisite: 230.

3 units, Spr (Hsieh) alternate years, not given 2001-02

236. Hydraulic and Tracer Tests for Groundwater Resource Evaluation—Theory and application of hydraulic and tracer tests to determine flow and the transport properties of aquifers. Analysis of well tests in single-layer aquifers and multiple aquifer-aquitard systems; water table conditions; anisotropy; double-porosity; effects due to wellbore storage, wellbore skin, aquifer boundaries, and heterogeneities such as faults and fracture zones; natural and forced gradient tracer tests. Prerequisite: 230.

3 units (Hsieh) alternate years, given 2001-02

237. Surface and Near-Surface Hydrologic Response—(Same as Civil and Environmental Engineering 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, erosion and mass wasting, and physically-based simulation of coupled surface and near-surface hydrologic response and landscape evolution. Links hydrogeology, soil physics, and surface water hydrology.

4 units (Loague) alternate years, given 2001-02

238. Soil Physics—Advanced level, focusing on the physical and chemical properties of the soil solid phase, with emphasis on the transport, retention, and transformation of water, heat, gases, and solutes in the unsaturated subsurface. Agricultural systems. Field techniques and classic experiments demonstrated and reproduced in the lab. Prerequisite: elementary calculus.

4 units, Aut (Loague) alternate years, not given 2001-02

239. Advanced Geomorphology—Advanced level, focusing on the surface/near-surface hydrologic processes governing landscape evolution. Topics: channel networks and landscape dissection. Current and classic theory. Case histories and experimental studies. Prerequisites: elementary calculus, 140.

3 units (Loague) alternate years, given 2001-02

240. Geostatistics for Spatial Phenomena—(Same as Petroleum Engineering 240.) Probabilistic modeling of spatial and/or time dependent phenomena. Kriging and cokriging for gridding and spatial interpolation. Integration of heterogeneous sources of information. Stochastic imaging of reservoir/field heterogeneities. Introduction to GSLIB software. Case studies from the oil and mining industry and environmental sciences. Prerequisites: introductory calculus and linear algebra, Statistics 116 or equivalent.

3-4 units, Win (Caers)

241. Practice of Geostatistics and Seismic Data Integration—(Same as Petroleum Engineering 241.) Students build a synthetic 3D fluvial channel reservoir model with layer depths, channel geometry, and facies-specific petrophysic and seismic properties, stressing the physical significance of geophysical data. Reference data set is sparsely sampled providing the sample data typically available for an actual reservoir assessment. Geostatistical reservoir modeling uses well and seismic data, with results checked against the reference data base. All software provided (Gslib and SRBtools). Recommended: basic prior experience with Unix, Matlab/Fortran programming. Prerequisite: 240.

3-4 units, Spr (Caers, Mukerji)

242A. Topics in Advanced Geostatistics—(Same as Petroleum Engineering 242.) Conditional expectation theory and projections in Hilbert spaces; parametric vs. non-parametric geostatistics; Boolean, Gaussian, fractal, indicator, annealing approaches to stochastic imaging; multiple point statistics inference and reproduction; neural net geostatistics; Bayesian methods for data integration; techniques for upscaling hydrodynamic properties. May be repeated for credit. Prerequisites: 240, advanced calculus, Fortran/Unix.

3 units, Aut (Journel) alternate years, not given 2001-02

246. Reservoir Characterization and Flow Modeling with Outcrop Data—(Same as Petroleum Engineering 246.) Project provides earth science students with an understanding of how to use outcrop observations in quantitative geological modeling and flow simulation, and addresses a specific reservoir management problem by studying a suitable outcrop analogue (weekend field trip), constructing geostatistical reservoir models, and performing flow simulation. An introduction, through an applied example, to the relationship between the different disciplines. A different reservoir management question and outcrop analogue is studied each year.

3 units, Aut (Aziz, Graham, Journel)

249. Biological Markers—The basic atomic building block for life as we know it is carbon. Biological markers (molecular fossils, biomarkers) are known from the Archean to the Present as biologically derived carbon compounds that provide information on the paleoenvironment, geologic age and stratigraphy, thermal maturity, and diagenesis of sediments, rocks, and petroleum. Biomarker "fingerprints" are useful to monitor and determine the environmental fate of petroleum and to understand and map petroleum systems. They are key biogeochemical proxies for monitoring, discovering, and explaining paleoenvironmental conditions and changes. Recently, they have been a focus in the search for extraterrestrial life. The fundamentals to understanding, interpreting, and applying biomarkers and their "fingerprints."

2-3 units, Aut (Moldowan)

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.

3 units (Lowe) alternate years, given 2001-02

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 (Graham) alternate years, given 2001-02

252. Sedimentary Petrography—Examination/interpretation of siliciclastic sediments and sedimentary rocks. Lectures/readings stress 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. Class is topical and varies yearly. Prerequisite: 151 or equivalent.

4 units (Lowe) alternate years, not given 2001-02

253. Petroleum Geology and Exploration—The basics of petroleum geology. The origin, occurrence, and exploration for hydrocarbons. Topics: thermal maturation history in hydrocarbon generation, significance of sedimentary and tectonic structural setting, principles of accumulation, geological and geophysical exploration techniques. Prerequisites: 110, 151. Recommended: Geophysics 183.

3 units (Graham) alternate years, given 2001-02

254. Advanced Paleoceanography—Paloechemistry and paleocirculation of the oceans as deduced from the study of marine sediments.

3 units (Dunbar) alternate years, given 2001-02

255. Introduction to Micropaleontology—Microscopic marine fossils, including diatoms, ostracods, and radiolaria, with emphasis on foraminifera. The principles of classification, evolutionary trends, common genera, ecology, and environmental distribution of foraminifera. Application of planktonic and benthic foraminifera to interpretation of paleoenvironments, paleoceanographic and paleoclimatic analysis, and correlation of marine sequences. Paleoenvironmental and age analysis of an unknown microfossil sample serves as a term research project. Lab on microfossil groups.

5 units (Ingle) alternate years, given 2001-02

256. Advanced Micropaleontology—The use of marine microfossils (mainly benthic and planktonic foraminifera) to solve fundamental geologic and oceanographic problems. Applications to geochronology, correlation, paleoecology, and paleoceanography. Individual analysis of a series of unknown samples provides intensive experience in applying basic concepts of biostratigraphy and paleoenvironmental analysis to interpretation of Paleozoic, Mesozoic, and Cenozoic microfossil assemblages. Lectures on classic and current examples of research in this field. Prerequisite: 255.

3 units (Ingle) alternate years, given 2001-02

257. Climate Variability and Forcing Mechanisms of the Last 10,000 Years: Implications for Life in the 21st Century—Open to graduate students and seniors in the earth sciences, earth systems, ecology, and anthropology. Overview of large-scale features of the climate systems that control interannual variability in temperature and rainfall. Recent studies in climate reconstruction and the influence of climate change on man. Lectures/readings and discussions.

3 units (Dunbar) alternate years, given 2001-02

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 (Lowe) given 2001-02

260. Laboratory Methods in Organic Geochemistry—Organic materials in the Earth and its surface environments generally occur as complex mixtures. Detailed knowledge of specific components in geochemical mixtures is useful 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 detect and quantify various components of these mixtures. The lab provides a basic understanding and hands-on experience of methods used for the separation and detailed analysis of organic compounds in geologic samples: extraction, liquid chromatography, absorption by zeolites, gas chromatography and gas chromatography-mass spectrometry. Student samples are considered as material for analysis. Recommended: 249.

2-3 units, Win, Spr (Moldowan)

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 (Brown) alternate years, given 2001-02

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, e.g., 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 (Stebbins) alternate years, not given 2001-02

264. Low Temperature Aqueous Geochemistry—(Same as Civil and Environmental Engineering 273.) Chemical principles and their application to the analysis and solution of problems in aqueous geochemistry (temperatures near 25°C and atmospheric pressure). Emphasis is on the analysis of natural water systems and the understanding and solution of specific chemical problems in water purification technology and water pollution control. Prerequisites: Chemistry 31 and 33, or equivalents.

3 units, Aut (Leckie)

265. Soil Chemical Dynamics—Chemical and biologically mediated chemical processes within soils and surface waters; emphasis is on oxidation-reduction reactions and processes at the solid-water interface. Topics: electron transfer processes, dissimilatory metal reduction, ion exchange, electrified interfaces, specific adsorption, and dissolution/precipitation.

3 units, Win (Fendorf)

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. 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 (Bird) alternate years, not given 2001-02

270. Petrologic Phase Equilibria—The principles of phase equilibrium determined by lab experimentation and thermochemical calculation, as applied to igneous and metamorphic petrology. Focus is on the underlying principles of classical thermodynamics which govern mineral equilibria. Introduction to phase relations, element partitioning, chemical kinetics, and order-disorder phenomena in geologic systems.
4 units (Ernst) alternate years, given 2001-02

275. Electron 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.
3 units, Win (Jones)

285. Petrogenesis of Crustal Magmatism—Radiogenic isotopes (Rb-Sr, Sm-Nd, Re-Os, U-Pb, and U-series disequilibrium systems), stable isotopes, and trace elements applied to igneous processes; evidence for the nature of basalt sources; 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; sources of ore forming metals. Topics emphasize the interests of students. Prerequisite: 181, or its equivalent.
3 units, Win (Mahood) alternate years, not given 2001-02

290. Numerical Analysis of Geological Time Series—Seminar for graduate students interested in a variety of statistical tools appropriate for analysis of time series. Topics: fourier transform techniques, singular spectrum analysis, evolutionary spectral analysis, and filtering. Prerequisite: some knowledge of UNIX.
3 units (Dunbar) alternate years, not given 2001-02

295. Integrating Remote Sensing and Geographic Information Systems (GIS)—For graduate students; see 195.

296. Introduction to GIS: ARC/Info and ARC-View—(Same as Geophysics 296.) For graduate students; see 196.

297. Research in the Application of Geographic Information Systems (GIS)—For graduate students; see 197.

314A,P. Research Seminar: Structural Geology and Geomechanics—Selected topics. May be repeated for credit.
1 unit, Aut, Win, Spr (Pollard, Aydin)

322A,B,C. Seminar in Biogeochemistry—Presentations and discussion of current topics in biogeochemistry. May be repeated for credit.
1-2 units, Aut, Win, Spr (Matson)

329A,B. Advanced Topics in Near-Surface Hydrologic Processes—Classic studies and current research in hydrology, geomorphology, and soil physics. Topics: nonpoint source groundwater contamination (agriculture), evapotranspiration, unsaturated fluid flow and solute transport, rainfall-runoff mechanisms, slope stability, restoration geomorphology.
1-2 units, Aut, Win, (Loague)

330A,B,C. Advanced Topics in Hydrogeology—Critical discussion of modern topics in groundwater hydrology. Topics: questioning classic explanations of physical processes; consideration of coupled physical, chemical, and biological processes effecting heat and solute transport.
1-2 units, Aut, Win, Spr (Gorelick)

332A,B. Seminar in Hydrogeology
1 unit, Aut (Gorelick)
Win (Loague)

333. CESIR Seminar—The Center for Earth Science Information Research seminars are a multi-disciplinary lecture series. Emphasis is on the utilization of science for policy analysis and decision making. Speakers are from the physical and social sciences.
1-2 units, Spr (Bernknopf)

335. Special Topics in Earth Sciences Seminar—Presentation and discussion of current topics in the earth sciences. Suggested topics: gas hydrates, paleoproductivity, the glacial world, mass extinctions, the K/T boundary, hydrothermal vents, paleocirculation, warm climates in Earth's history, geomicrobiology, evaporite deposits. Each year a different topic is given with lectures by guest speakers.
1-2 units (Paytan) alternate years, given 2001-02

342A,B,C. Seminar: Geostatistics—Discussion of classic results and current research in geostatistics. Topics selected on basis of interest and timeliness. May be repeated for credit.
1-2 units, Aut, Win, Spr (Journel)

350. Seminar in Sedimentary Geology
1-3 units, Win, Spr (Staff)

360. Topics in Low Temperature Surface and Aqueous Geochemistry—Guided independent study, analysis, and critical oral and written reports on selected topics in environmental, surface, and/or aqueous geochemistry under earth-surface conditions. Prerequisites: 80 and 264; consent of instructor.
2-4 units, one quarter annually (Brown, Parks)

362. Seminar on Silicate Glasses and Liquids
2-3 units, Spr (Stebbins)

373. Seminar in Metamorphic Petrology—Selected topics in metamorphic and tectonic processes, research problems, and methods of study of metamorphic rocks and their tectonometamorphic evolutions. Prerequisite: consent of instructor.
1-2 units, Spr (Liou, Ernst)

384. Seminar on Igneous Petrogenesis—Selected topics on the origins and evolution of magmas and their use in tectonic analysis. May be repeated for credit.
1-2 units, Aut, Win, Spr (Mahood)

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 INS requirements for F-1 curricular practical training.
1 unit, any quarter (Staff)

Problems in Various Fields of Geological and Environmental Sciences

313. Problems in Structural Geology and Geomechanics
319. Problems in Structural Geology
339. Problems in Hydrogeology
349. Problems in Geomathematics

357. Problems in Sedimentary Geology
358. Problems in Oceanography and Paleoclimatology
363. Problems in Organic Geochemistry
369. Problems in Geochemistry
377. Problems in Ore Deposits and Exploration
379. Problems in Metamorphic Petrology
386. Problems in Volcanology and Igneous Petrology
389. Problems in Geochronology and Isotope Geology

Research in Various Fields of Geological and Environmental Sciences

413. Research in Structural Geology and Geomechanics
419. Research in Structural Geology
422. Research in Biogeochemistry
438. Research Methods in Hydrology
439. Research in Hydrogeology
440. Research in Geostatistics for Natural Resources Management
449. Research in Geomathematics
452. Research in Basin Analysis Petroleum Geology
457. Research in Sedimentary Geology
458. Research in Oceanography and Paleoclimatology
460. Research in Low Temperature Surface and Aqueous Geochemistry
463. Research in Organic Geochemistry
465. Research in Soil Chemistry
469. Research in Geochemistry
477. Research in Ore Deposits and Exploration
479. Research in Metamorphic Petrology
480. Research in Remote Sensing
486. Research in Volcanology and Igneous Petrology
489. Research in Geochronology and Isotope Geology