GEOLOGICAL AND ENVIRONMENTAL SCIENCES

Emeriti: (Professors) Robert Coleman,*** Robert R. Compton, William R. Evitt, John W. Harbaugh,*** Konrad B. Krauskopf,*** Ronald J. P. Lyon,*** George A. Parks,*** Irwin Remson, Tjeerd H. Van Andel
Chair: Jonathan F. Stebbins
Associate Chair: Robert B. Dunbar
Professors: Dennis K. Bird, Gordon E. Brown, Jr., C. Page Chamberlain, 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, Keith Loague, Donald R. Lowe, Gail A. Mahood, Pamela A. Matson,†† Elizabeth L. Miller, David D. Pollard, Jonathan F. Stebbins, Paul Switzer*
Associate Professor: Michael O. McWilliams
Assistant Professors: Scott E. Fendorf, Adina Paytan
Professors (Research): Atilla Aydin, J. Michael Moldowan
Associate Professor (Research): Christopher F. Chyba
Courtesy Professors: Peter G. Brewer, David A. Clague, Peter K. Kitanidis, James O. Leckie, Stephen G. Monismith, Charles K. Paul
Courtesy Associate Professors: James P. Barry, Ronaldo I. Borja, Francisco P. Chavez, David L. Freyberg, Simon L. Klemperer, Anders Nilsson, Alfred M. Spormann, Debra S. Stakes
Courtesy Assistant Professors: Kevin R. Arrigo, Gregory P. Asner
Lecturers: Bob Jones, Karen Seto
Consulting Professors: Thomas Bullen, Alan K. Cooper, Francois Farges, Thomas Holzer, Paul Hsieh, Carol Kendall
Consulting Associate Professors: Marco Antonellini, Trevor Dumitru, Joseph W. Ruetz, Joseph Wooden, Robyn Wright-Dunbar
Visiting Professors: Ian Farnan, Shige Maruyama, Hans Ruppert
Visiting Associate Professor: Chunmiao Zheng

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

Department Offices: Braun Hall, Building 320
Mail Code: 94305-2115
Department Phone: (650) 723-0874
Email: ges-dept@pangea.stanford.edu
Web site: http://pangea.stanford.edu/GES/

Courses given in Geological & Environmental Sciences have the subject code GES. For a complete list of subject codes, see Appendix B.

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 earth and environmental sciences, environmental engineering, land use planning, law, public service, teaching 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 GES, study of the environmental sciences emphasizes earth surface processes at present and in 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 urban and agricultural development, contamination of natural waters, and depletion of resources.

An important emphasis of most B.S. programs in GES 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. At the same time, geological and environmental sciences deal quantitatively with processes on and in the earth and other planets, and with interactions between chemical, biological, and physical systems. The curriculum thus includes courses in chemistry, physics and/or biology, and mathematics. The range of these requirements and experiences results in graduates with versatility and a broad range of skills.

The GES undergraduate major is designed to recognize the diversity of this field and to provide a great deal of flexibility, with a variety of course choices that should be made in consultation with a faculty adviser and/or the undergraduate program coordinator. The department also offers a specialized curriculum in Engineering Geology and Hydrogeology. Students whose educational objectives are within the scope of the department, but not encompassed in our predefined programs, may also design an independent curriculum with the help of a faculty adviser and the approval of the department chair.

The Writing in the Major (WIM) requirement may be fulfilled by taking one of the following courses designated (WIM): GES 47N, 54Q, 110, 131, 151, 152, or 185 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.

GES majors must complete a sequence of courses of at least 63 units which includes a core sequence, a flexible series of electives, and at least 6 units of field research; or, GES majors may choose to follow a designated specialized curriculum, such as the Engineering Geology and Hydrogeology Curriculum (see below). Subject to approval of the GES undergraduate program director, the 6-unit field research requirement may be satisfied by completion of a summer field course in geology at another university or by a faculty-directed field research project that involves learning and application of field techniques and the preparation of a written report. Up to 6 units of GES 198 or 199 may be counted toward the required 63 units if they are part of a research program leading to the preparation of an undergraduate thesis or an Honors degree. One of two, short field-based courses (GES 101 or 102) is also required for the major. These involve two to three weeks of off-campus field study prior to the start of classes in Autumn. In addition, students are required to choose a sequence of mathematics courses (10 units) and two sequences of courses in cognate sciences (7-10 units). Substitutions or changes to these requirements may be requested through a formal petition to the undergraduate program director accompanied by a supporting letter from the student's academic adviser. Letter grades are required in all courses, if available.

CORE COURSE SEQUENCE (76-90 UNITS TOTAL)

REQUIRED GEOLOGICAL & ENVIRONMENTAL SCIENCES (32-38 UNITS)

All of the following courses (19 units)

Course No. and Subject	*Units*
GES 1. Fundamentals of Geology	5
GES 2. Earth History	3
GES 80. Earth Materials	5
GES 101. Environmental and Geological Field Studies	3
or GES 102. Introduction to Field Geology	3
GES 190. Writing in the Major	1
GES 4. Undergraduate Seminar (2 quarters)	2 (total)

Four of the following courses (13-19 units)

GES 90. Introduction to Geochemistry	3
GES 110. Structural Geology and Tectonics	5
GES 151. Sedimentary Geology and Petrography	4
GES 175. Science of Soils	3
or GES 130. Environmental Earth Sciences I	5
GES 181. Igneous and Metamorphic Processes	3-5

REQUIRED SUPPORTING MATHEMATICS (10 UNITS)

Choose one of the following groups of mathematics courses. The third group is strongly recommended for students planning graduate study in science and engineering

Course No. and Subject	Units
MATH 19. Calculus	3
MATH 20. Calculus	3
MATH 21. Calculus	4
or MATH 41. Calculus	5
MATH 42. Calculus	5
or MATH 51. Multivariate Mathematics	5
MATH 52. Multivariate Mathematics	5
or MATH 53. Multivariate Mathematics	5

REQUIRED SUPPORTING COGNATE SCIENCES (15-19 UNITS)

Choose sequences listed below from two of the following three fields of cognate sciences:

Chemistry:	
CHEM 31. Chemical Principles	4
or CHEM 32. Frontiers of Chemical Science	*5*
CHEM 135. Physical Chemical Principles	3
or CHEM 171. Physical Chemistry	3
or GES 171. Geochemical Thermodynamics	*3*
Physics:	
PHYSICS 21. Mechanics and Heat	3
PHYSICS 22. Mechanics and Heat Lab.	1
PHYSICS 23. Electricity and Optics	3
PHYSICS 24. Electricity and Optics Lab.	1
or PHYSICS 51. Light and Heat	4
PHYSICS 52. Light and Heat Lab.	1
PHYSICS 53. Mechanics	4
or PHYSICS 53. Mechanics	4
PHYSICS 55. Electricity and Magnetism	3
PHYSICS 56. Electricity and Magnetism Lab.	1
Biology:	
BIOSCI 41. Evolution, Genetics, etc.	5
BIOSCI 42. Molecular Cell Biology, etc.	5
or BIOSCI 43. Physiology, Ecology, etc.	5

ELECTIVES (19-23 UNITS)

At least 19-23 additional units of GES courses numbered 90 through 290, not including GES 105, 200, and 201, are required. With approval of the Undergraduate Program Director, courses numbered 100 or above in other science and engineering fields may satisfy this requirement. A maximum of 3 of the required elective units may be taken in directed reading or non-required seminar courses.

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 undergraduate program director. In addition, four elective courses, consistent with the core curriculum and required of all majors, are to be selected with the advice and consent of the adviser. Typically, electives are selected from the list below. Letter grades are required, if available, in all courses.

CORE COURSE SEQUENCE (89-99 UNITS TOTAL)

REQUIRED GEOLOGICAL & ENVIRONMENTAL SCIENCES (35-37 UNITS)

Course No. and Subject	*Units*
GES 1. Fundamentals of Geology	5
GES 80. Earth Materials	5
GES 101. Environmental and Geological Field Studies	3
or GES 102. Introduction to Field Geology	3
GES 111. Structural Geology and Rock Mechanics	3
or GES 215. Advanced Structural Geology and Rock Mechanics	3-5
GES 115. Engineering Geology Practice	3
GES 160. Statistical Methods for Earth and Environmental Sciences: General Introduction	4
GES 190. WIM Project	1
GES 195. Integrating Remote Sensing and GIS	3
GES 230. Physical Hydrogeology	5
GEOPHYS 190. Applied Geophysical Methods	3

REQUIRED ENGINEERING (20 UNITS)

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

REQUIRED SUPPORTING SCIENCES AND MATHEMATICS (23 UNITS)

CHEM 31. Chemistry Principles	4
MATH 51. Multivariate Mathematics	5
MATH 52. Multivariate Mathematics	5
MATH 53. Multivariate Mathematics	5
PHYSICS 53. Mechanics	4

SUGGESTED ELECTIVES (11-19 UNITS)

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

CEE 180. Structural Analysis	3
CEE 270. Movement, Fate, and Effects of Contaminants in Surface Waters and Groundwater	3
CEE 293. Foundation Engineering	3
CEE 296. Experimental Soil Mechanics	2
ENGR 30. Engineering Thermodynamics	3
ENGR 50. Introductory Science of Materials	4
ENGR 155A,B. Mathematical and Computational Methods	5
GEOPHYS 150. General Geophysics	4
GES 130. Environmental Earth Sciences I	5
GES 131. Environmental Earth Sciences II	5
GES 217. Characterization and Hydraulics of Rock Fracture	3
GES 231. Contaminant Hydrogeology	4
GES 235. Role of Fluids in Geologic Processes	3
GES 237. Surface and Near-Surface Hydrologic Response	4
MATH 103. Matrix Theory and its Applications	3
ME 80. Stress, Strain, and Strength	3

MINORS

A minor in Geological and Environmental Sciences consists of a small set of required courses, plus 12 elective units.

Required courses are:

GES 1. Fundamentals of Geology
or GES 2. Earth History
or GES 130. Environmental Earth Sciences I
GES 80. Earth Materials
GES 101. Environmental and Geological Field Studies
or GES 102. Introduction to Field Geology

A minimum of 12 additional units in GES courses, including three courses from the list below:

GES 8. The Oceans
GES 90. Introduction to Geochemistry
GES 110. Structural Geology
or GES 111. Structural Geology and Rock Mechanics
GES 130. Environmental Earth Sciences I
GES 151. Sedimentary Geology and Petrography
GES 152. Stratigraphy and Applied Paleontology
GES 170. Environmental Geochemistry
GES 175. Science of Soils
GES 181. Igneous and Metamorphic Processes
GES 185. Volcanology
GES 195. Integrating Remote Sensing and GIS

All students pursuing a minor in GES are encouraged to take one of the freshman or sophomore seminars (courses with numbers 38-59) 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. Some 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. AND M.S. DEGREES

The coterminal B.S./M.S. program offers a special opportunity for students to pursue a graduate research experience and an 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 45 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 45-unit requirement must be designated as being primarily for graduate students, normally at the 200 level or above. No more than 15 units of thesis research may be used to satisfy the 45-unit requirement. Further information about this program may be obtained from the GES office.

GRADUATE PROGRAMS

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

The broad areas of faculty teaching and research are divided into two fields that have diploma designation and a number of other areas of specialization.

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

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 an 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.

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 $^{40}Ar/^{39}Ar$, fission-track, Sm/Nd, (U+Th)/He, U-Pb, and U-series geochronology; computer prediction and modeling; electron microprobe and sensitive high-resolution ion microprobe analysis; stable isotope geochemistry; 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, Chamberlain, Einaudi, Ernst, Fendorf, Liou, Mahood, Matson, McWilliams, Moldowan, and Stebbins.

Structural Geology and Geomechanics (http://pangea.stanford.edu/geomech/)—Research opportunities in this specialization include: structural geology; active tectonics; geomechanics; hydraulics of faults and fractures; reservoir description and characterization; rock fracture and fault mechanics. 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: Professors Bird, Gorelick, Graham, Journel, Loague, Miller, and Moldowan (from GES); Professors Beroza, Klemperer, Mavko, Nur, Segall, and Zoback (from Geophysics); Professors Aziz, Durlovsky, 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 these geologic structures 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 using GPS technology; laboratory investigations using physical models; seismic mapping and interpretation of 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, Holocene climate change in the Rocky mountains, and sediment-gravity flow mechanisms and the structure of associated deposits. Core faculty are Chamberlain, Dunbar, Graham, Ingle, Lowe, and Paytan; faculty with related or overlapping interests include Fendorf, Gorelick, 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 $^{40}Ar/^{39}Ar$, fission-track, SHRIMP, and (U+Th)/He 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, Chamberlain, 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) which studies the alteration and partitioning reactions that determine the mobility, bioavailability, and ultimate fate of solutes, organic matter, microbial organisms, 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 experience with computers and laboratory methods. Faculty with overlapping interest include Fendorf, Farges (consulting), and Nilsson (courtesy).

Volcanology—Professors Aydin, Mahood, McWilliams, 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; chronology of eruptions and magma chamber residence times; 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 satisfies the Writing in the Major requirements.

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

UNDERGRADUATE

GES 1. Fundamentals of Geology—For non-majors or prospective majors in Earth Systems or Geological and Environmental Sciences. 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

5 units, Aut (Surpless), Spr (McWilliams)

GES 2. Earth History—For non-majors and prospective Earth Systems or Geology majors. Overview of how the universe evolved from the creation of the elements to the origin of humans. The course consists of three modules. The first covers the origin of the universe, our solar system, and Earth's atmosphere, oceans, and continents. The second focuses on the origin of life, the evolution of life from its earliest beginnings to the rise of metazoans and development of humans, and the relationship between geological and biological evolution. The third module covers future scenarios for earth, including human impact on earth systems and how we are modifying the atmosphere, oceans, and land. GER:2a

3 units, Win (Chamberlain)

GES 4. Undergraduate Seminar—For undergraduate majors and prospective majors in Geological and Environmental Sciences. Informal lectures introduce students to the earth sciences: the scope of research at Stanford and other nearby institutions, career possibilities and special topics related to class field trips.

1 unit, Spr (Mahood)

GES 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)

1 unit, Aut, Win (Bird)

GES 7C. Advanced Wilderness Skills—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)

GES 8. The Oceans: An Introduction to the Marine Environment—For non-majors and prospective geology, earth systems, 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

3 units, Spr, Sum (Ingle)

GES 38N. *The Worst Journey in the World:* What Drives Polar Exploration?—Stanford Introductory Seminar. Preference to freshmen. Polar explorers spent months in isolation under the harshest conditions on Earth. Many explorers used this time to create a written record of scientific discovery and often dashed geographic hopes. The title of this seminar is a book by Aspley Cherry-Gerard who in 1911 participated in a mid-winter sledging trip in Antarctica to recover Emperor penguin eggs from a remote cape on Ross Island. The accounts of this and other Antarctic and Arctic journeys. Focus is on the main scientific and geographic achievements. The class jointly authors an essay. Optional field trip into the high Sierra in December.

3 units, Aut (Dunbar) alternate years, not given 2003-04

GES 39N. The Search for Life in the Solar System—Stanford Introductory Seminar. Preference to freshman. Current thinking on the origin of life and the search for life in the solar system and beyond. Topics: definitions of life, life as we know it, origins of life on Earth, contingency vs. necessity, Mars, Europa, interplanetary transfer of microorganisms, ethical issues in exploration, the evolution of complexity, and the Fermi paradox. Grading via student presentations and papers. GER:2a

3 units (Chyba) alternate years, given 2003-04

GES 41N. El Niño: History and Predictability of a Global Climate Pacemaker—Stanford Introductory Seminar. Preference to freshmen. The coupled El Niño-Southern Oscillation (ENSO) system is the dominant source of interannual climate variability worldwide. 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.

3 units (Dunbar) alternate years, given 2003-04

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

3 units, Aut (Lowe)

GES 44N. A Transition to Sustainability? Development and Environment in the 21st Century—Stanford Introductory Seminar. Preference to freshmen. What will it take to meet the needs of the human population while preserving Earth's life support systems? Trends and transitions in population growth, resource consumption, and environmental conditions at regional and global scales. Approaches that can move the world towards sustainability in energy, industry, urbanization, living resources, air, and water. Students prepare a case study of sustainable development in the area of their choice. GER:2a

3 units (Matson) alternate years, given 2003-04

GES 46N. The Beach—Stanford Introductory Seminar. Preference to freshmen. Open coast beaches represent one of the most complex and dynamic natural environments of Earth where ocean, atmosphere, and continent meet and interact on time scales of seconds to millennia. The beach environment and analysis in the field. Field work involves repeated measurement of waves, currents, and beach character, and sample collection at sites from Point Reyes to Monterey Bay, with the goals of assembling and analyzing a quantitative record of change. Required papers on a specific aspect of the beach environment. GER:2a

3 units (Ingle) alternate years, given 2003-04

GES 47N. Secrets in the Mud: A Look Into the Field of Paleoceanography—Stanford Introductory Seminar. Preference to freshmen. The oceans have major effects on climate; understanding how the oceans operated and responded to natural perturbations in the past helps 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 will be covered in class. Student lab projects: sediment sample preparation and analysis, description and interpretation of data, and presentation as oral and written reports. One-day field trip. GER: 2a (WIM; students must register concurrently for GES 190 to receive WIM credit.)

3 units, Win (Paytan)

GES 48N. Volcanoes of the Eastern Sierra Nevada—Stanford Introductory Seminar. Preference to freshman. 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. Camping and light hiking.

2 units (Mahood) alternate years, given 2003-04

GES 49N. Field Trip to Death Valley and Owens Valley—Stanford Introductory Seminar. 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 oceans, mountain building, recent earthquake faulting, glacial landscapes, and volcanic eruptions. Desert environments reveal prehistoric climate changes and historic human impacts. Introduction to the basics of plate tectonics and geology. Six-day field trip to these areas during Spring Break. 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. Camping and moderate hiking required. GER:2a

3 units, Win (Mahood)

GES 50Q. The Coastal Zone Environment—Stanford Introductory Seminar. 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 written and oral reports. Prerequisite: any beginning course in Biology (e.g., BIOSCI 51), Chemistry (CHEM 30, 31), Earth Sciences (GES 1,2), or Earth Systems (EARTHSYS 10); willingness to get your feet cold, wet, and muddy for sustained periods. GER:2a

3 units, Aut (Ingle)

GES 51Q. Geologic Environment and Human Health—Stanford Introductory Seminar. Preference to sophomores. The natural environment exposes human beings and other organisms to potentially harmful chemical compounds. This situation is exacerbated by human activities. Focus is on the biospheric inputs of potentially harmful chemical compounds from natural and anthropogenic sources; distinguishing between natural versus anthropogenic sources of these compounds; geographic distribution of common environmental pollutants and geologic factors affecting human impacts and bioavailability; physical, biological, and chemical factors affecting potential bioavailability; and the relative dangers of the most common environmental pollutants in terms of their impacts on human health and longevity. Recommended: GES 1, BIOSCI 41, high school chemistry.

3 units, Win (Ernst, Brown)

GES 52Q. Geologic Development of California—Stanford Introductory Seminar. Preference to sophomores, and to students who have completed introductory geology. Field-based study of the crustal evolution of California in post-Paleozoic time, and covering the geotectonic development of most of the state. Weekend field trips to the Coast 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. Term paper required. GER:2a

5 units, Spr (Ernst)

GES 53Q. In the Beginning: Theories of the Origin of the Earth, Solar System, and Universe—Stanford Introductory Seminar. 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. The history and evolution of theories of the origin of the Earth, Moon, solar system, and the Universe. GER:2a

3 units, Win (McWilliams)

GES 54Q. California Landforms and Plate Tectonics—Stanford Introductory Seminar. Preference to sophomores. The forces of plate tectonics at work on the landscape of California. The principles of rock deformation are introduced with laboratory experiments. Landforms resulting from deformation of the earth are analyzed with digital and photographic images. Field trips relate these large-scale structures to the human perspective on the ground. Final paper involves literature research on active deformation and earthquakes in a region of the student's choice. GER:2a (WIM; students must register concurrently for GES 190 to receive WIM credit.)

3 units, Aut (Miller)

GES 55Q. The California Gold Rush: Geologic Background and Environmental Impact—Stanford Introductory Seminar. 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. GER:2a

3 units, Spr (Bird)

GES 56Q. Change in the Coastal Ocean: The View From Monterey Bay—Stanford Introductory Seminar. 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.

3 units (Dunbar) alternate years, given 2003-04

GES 57Q. How to Critically Read and Discuss Scientific Literature—Stanford Introductory Seminar. 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. GER:2a

3 units, Aut (Paytan)

GES 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)

GES 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)

GES 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)

GES 101. Environmental and Geological Field Studies in the Rocky Mountains—Introduction to research possibilities in the geological sciences. Three and a half-week field-based program from September 1-22 emphasizing environmental and geological problems. Weekly meetings on campus during Autumn Quarter. Field portion is based in the Greater Yellowstone/Teton and Bighorn Mountain region of Wyoming and Montana. Topics include the basics of structural geology and petrology, economic geology, glacial geology, regional western cordillera geology, paleoclimatology, chemical weathering and the carbon cycle, aqueous geochemistry, and environmental issues. Examination of earth/environmental science questions in three different settings: the Precambrian granitic and glacial terranes of the Wind Rivers of Wyoming; the Laramide fold/thrust belt of the Bighorn basin; and the mid-tertiary volcanic center of Northeastern Yellowstone National Park. Research papers based on the results of work in the field.

3 units, Aut (Chamberlain) alternate years, not given 2003-04

GES 102. Introduction to Field Geology—Experience in collecting data in the field and producing maps, sections and reports from that data is essential to the critical evaluation and use of geologic map and data bases. GES 102 is a focused, two-week field based course that provides instruction in methods of geologic investigation in the field, with emphasis on techniques of systematic observations and construction of geologic maps and sections from the data obtained. Several sites are investigated displaying a variety of rock types and landforms related to clearly defined geologic structures and events. Based on the results of the fieldwork and literature, the geologic history of the area is unraveled and described in a geologic report prepared during the course. GES 102 is based out of the White Mountain Research Station (http://www.wmrs.edu) in Bishop, California during the two weeks preceding Autumn Quarter. Travel from Stanford is provided. Contact GES, or see *Summer Session Catalogue* for schedule. Prerequisite: 1.

3 units, Sum (Ruetz)

GES 105. Geologic and Environmental Problems—Supervised reading, field and/or lab work; written reports thereon.

1-10 units, any quarter (Staff)

GES 110. Structural Geology and Tectonics—The basic theory, principles, and techniques used to interpret and measure structures in naturally deformed rocks. Topics: the properties, rheology, and mechanisms of 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; students must register concurrently for GES 190 to receive WIM credit.)

5 units, Spr (Miller)

GES 111. Structural Geology and Rock Mechanics—Observational techniques, laboratory methods, and the theoretical concepts of structural geology and rock mechanics are introduced 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). Prerequisites: GES 1, calculus.

3 units, Aut (Pollard)

GES 115. Engineering Geology Practice—(Same as CEE 196.) The application of geologic fundamentals to the planning and design of civil engineering projects. Emphasis is on understanding the potential impact on engineering design of geologic processes and materials. Topics: geologic hazards, Quaternary tectonics, formation of surficial deposits and weathering, classification of soil and rock, site investigation techniques, and shallow ground-water regimes. Field/lab exercises and case studies emphasize the impact of site geology on the planning, design, and construction of civil works such as buildings, foundations, transportation facilities, excavations, tunnels and underground storage space, and water supply facilities. Prerequisite: GES 111 or consent of instructor.

3 units, Spr (Holzer) alternate years, not given 2003-04

GES 130. Environmental Earth Sciences I: Soil Physics and Hydrology—First of a two-part introductory sequence on surface and near-surface processes. Focus is on the waters of the Earth, their occurrence, distribution, circulation, and reaction with the environment. Topics: precipitation, evapotranspiration, infiltration and vadose zone, groundwater, surface water and streamflow generation, lakes, water supply and use, and water balance and flood frequency estimates. Current and classic theory in soil physics and hydrology. Urban, rangeland, and forested environments. Project throughout sequence involves the preparation of a report on selected case study. Students individually or in groups prepare and present a reconnaissance report on a selected topic. Field trips to project area and San Mateo County coast.

5 units, Aut (Loague)

GES 131. Environmental Earth Sciences II: Fluvial Systems and Landscape Evolution—Second of a two-part introductory sequence on surface and near-surface processes. Focuses on the materials of the Earth and hydrologically driven landscapes processes. Topics: hillslope hydrology, weathering of rocks and soils, erosion, flow failures, mass wasting, and conceptual models of landscape evolution. Current and classic theory in geomorphology is covered. Groups prepare and present a final case study report for the project area (e.g., Devil's slide). Field trips to project area and San Mateo County coast. (WIM; students must register concurrently for GES 190 to receive WIM credit.)

5 units, Win (Loague)

GES 147. Controlling Climate Change in the 21st Century—(Enroll in EARTHSYS 147/247, BIOSCI 147/247.)

3 units, Spr (Schneider, Rosencranz)

GES 151. Sedimentary Geology and Petrography: Depositional Systems—Topics: weathering, erosion and transportation, deposition, origins of sedimentary structures and textures, sediment composition, diagenesis, sedimentary facies, tectonics and sedimentation, and the characteristics of the major siliciclastic and carbonate depositional environments. Lab: methods of analysis of sediments in hand specimen and thin section. Field trips required. Prerequisites: 1. GER:2a (WIM; students must register concurrently for GES 190 to receive WIM credit.)

4 units, Win (Lowe, Graham)

GES 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 paleo-oceanographic settings. The nature of the fossil record, the use of marine 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. Required research paper. Lectures supplemented by classic and current scientific literature. Weekly lab; two required field trips. Prerequisites: 1, 2. GER:2a (WIM; students must register concurrently for GES 190 to receive WIM credit.)

4 units, Spr (Ingle)

GES 159. Marine Chemistry—(Same as EARTHSYS 259, EARTHSYS 159; graduate students register for 259.) 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.

2-4 units, Spr (Paytan)

GES 160. Statistical Methods for Earth and Environmental Sciences: General Introduction—Extracting information from data using statistical summaries and graphical visualization, statistical measures of

association and correlation, distribution models, sampling, error estimation and confidence intervals, linear models and regression analysis, introduction to time-series and spatial data with geostatistics, applications including environmental monitoring, natural hazards, and experimental design. Either or both of 160 and 161 may be taken.
3-4 units, Aut (Switzer)

GES 161. Statistical Methods for the Earth and Environmental Sciences: Geostatistics—(Same as PETENG 161.) Statistical analysis and graphical display of data, common distribution models, sampling, and regression. The variogram as a tool for modeling spatial correlation; variogram estimation and modeling; introduction to spatial mapping and prediction with kriging; integration of remote sensing and other ancillary information using co-kriging models; spatial uncertainty; introduction to geostatistical software applied to large environmental, climatological, and reservoir engineering databases; emphasis is on practical use of geostatistical tools.
3-4 units, Win (Caers)

GES 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 2002-03

GES 164L. Stable Isotopes Laboratory—Practical laboratory for GES 164, Stable Isotopes.
2-3 units (Dunbar)

GES 165. Geochronology and Thermochronology—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 (U+Th)/He, and cosmogenic isotope methods. Recommended: undergraduate training in calculus, chemistry, geology, and physics.
3 units, Spr (McWilliams) alternate years, not given 2003-04

GES 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 will be discussed.
3 units, Win (Fendorf) alternate years, not given 2003-04

GES 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 the 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)

GES 171. Geochemical Thermodynamics—Introduction to the application of chemical principles and concepts to geologic systems. The chemical behavior of fluids, minerals, and gases using simple equilibrium approaches to modeling the geochemical consequences of diagenetic, hydrothermal, metamorphic, and igneous processes. Topics: reversible thermodynamics, solution chemistry, mineral-solution equilibria, reaction kinetics, and the distribution and transport of elements by geologic processes. Prerequisite: 80.
3 units, Aut (Bird)

GES 175. Science of Soils—Physical, chemical, and biological processes that occur within soil systems are covered. Emphasis is on factors governing nutrient availability, plant growth/production, land-resource management, and pollution within soils.
4 units, Aut (Fendorf)

GES 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.
3-5 units (Liou) alternate years, given 2003-04

GES 182. Field Seminar on Continental-Margin Volcanism—For juniors, seniors, and graduate students in the earth sciences and archeology. One weekend-long, and two one-day 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. Prerequisite: 1 or equivalent.
2 units (Mahood) alternate years, given 2003-04

GES 184. Field Seminar on Eastern Sierran Volcanism—For juniors, seniors, and graduate students in the earth sciences and archaeology. Four-day trip over Memorial Day weekend to study silicic and mafic volcanism associated with the western margin of the Basin and Range province. The basaltic lavas and cinder cones erupted along normal faults bounding Owens Valley. Long Valley caldera-lake sedimentation, post-caldera 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, video viewing assignments. Prerequisite: 1 or equivalent.
2 units (Mahood) alternate years, given 2003-04

GES 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; students must register concurrently for GES 190 to receive WIM credit.)

4 units, Spr (Mahood) alternate years, not given 2003-04

GES 186. Geoarchaeology—(Graduate students register for 286.) For juniors, seniors, and beginning graduate students with interests in archaeology and/or geosciences. Introduction to the use of geological concepts, techniques, and data in the study of artifacts and the interpretation of the archaeological record. Topics include: sediments and soils; sedimentary settings of site formation; postdepositional processes that disturb sites; paleoenvironmental reconstruction of past climates and landscapes using plant and animal remains and isotopic studies; raw materials (minerals, metals, stone, shells, clay, building materials) and methods used in sourcing; estimating age based on stratigraphic and radiometric techniques. Weekly lab; weekend field trips to local archaeological/geological localities.

5 units, Spr (Mahood)

GES 189. Field Studies in Earth Systems—(Same as EARTHSYS 189, BIOSCI 206.) For advanced upper-division undergraduates and graduate students in Earth Systems, Biological Sciences, or Geological and Environmental Sciences. Field-based, focusing on the components and processes by which terrestrial ecosystems function. Topics from biology, chemistry, ecology, geology, and soil science. Lecture, field, and lab studies emphasize standard field techniques, experimental design, analysis of data, and written and oral presentation. Admission by application; see *Time Schedule*. Prerequisites: BIOSCI 141 or GES 160, or equivalent.

5 units, Spr (Chiariello, Fendorf, Ackerly, Matson, Miller)

GES 190. WIM project—Students in a GES WIM course (47N, 54Q, 110, 131, 151, 152, or 185), register for 190 using the section number of the appropriate faculty member.

1 unit, any quarter (Staff)

GES 192. Undergraduate Research in Geological and Environmental Sciences—Supervised reading, field, and/or lab research with written reports.

1-10 units, any quarter (Staff)

GES 194. Electronic Communications for Earth Scientists—For upper division and graduate students. Electronic publishing of research proposals and results, using HTML and PDF. Data visualization tools and the integration of illustrations and text in various media. Writing assignments target different audiences: pre-college, college, post-graduate scientists. Hands-on computer workshops.

1 unit, Win (Weiland)

GES 195. Integrating Remote Sensing and Geographic Information Systems (GIS)—(Graduate students register for 295.) 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.

1-5 units, Aut (Lyon)

GES 196. Introduction to Geographic Information Systems (GIS): Using ARC-View—(Same as GEOPHYS 196/296; graduate students register for 296.) Hands-on experience with ESRI's Arc-View GIS packages. Topics: setting up geographic databases and manipulating spatial data, including database query and analysis. Hands-on computer-based exercises using sample data sets on workstations. Guest lectures on GIS applications in the environmental, geological, and biological sciences; and in town planning.

2 units, Spr (Klemperer)

GES 197. Remote Sensing of Land Use and Land Cover Change—(Same as EARTHSYS 197/297; graduate students register for 297.) The use of satellite remote sensing and digital image processing techniques to monitor terrestrial land cover and land use change. Data from a range of sensors is used to explore a variety of applications: deforestation, urbanization, and wildfires. Labs include a case study of a local land use issue. Prerequisite: 195, GEOPHYS 40, or consent of instructor.

5 units, Spr (Seto)

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

1-10 units, any quarter (Staff)

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

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

GRADUATE

GES 200. Professional Development in Geoscience Education

1 unit, Aut, Spr (Ernst)

GES 201. Geoscience Course Design—Students design a complete geoscience short course of their choosing. Those courses with appropriate format (one field day combined with 5-6 hours of classroom instruction) may become eligible for offering in the Continuing Studies Program. Preparatory topics: how people learn, field versus classroom teaching, the inquiry process in science learning, and the use of active learning strategies in geoscience education.

1-2 units, Aut (Wright-Dunbar)

GES 202. Reservoir Geomechanics—(Enroll in GEOPHYS 202.)

3 units, Win (Zoback)

GES 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 N. Pacific region, and marine ecologic responses. Participation by marine scientists from various marine research groups and organizations including the Monterey Bay Aquarium Research Institute.

3 units (Dunbar) alternate years, given 2003-04

GES 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 (Dunbar, Cooper)

GES 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, subduction, 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 all provide insight into the crustal-scale processes and driving mechanisms common to mountain chains.

2-3 units, Win (Miller) alternate years, not given 2003-04

GES 211. Topics in Regional Geology and Tectonics—Seminar.
2 units (Miller)

GES 215. Advanced Structural Geology and Rock Mechanics—(Same as CEE 297G, GEOPHYS 215.) Observational techniques, laboratory methods, and the theoretical concepts of structural geology and rock mechanics. Solutions to initial and boundary-value problems of continuum mechanics are integrated with field and laboratory data to develop computational models for geological structures and to understand the mechanics of geological hazards (earthquakes and volcanoes). Topics include: differential geometry to characterize structures; dimensional analysis; use of stress, strain, displacement, and velocity fields in structural analysis; and mechanical properties of rock (elasticity, viscosity, strength, friction, fracture toughness). Prerequisites: 1, calculus, MATLAB or equivalent.
3-5 units, Aut (Pollard)

GES 216. Rock Fracture Mechanics—(Same as GEOPHYS 216.) Principles and tools of elasticity theory and fracture mechanics are applied to the origins and physical behaviors of faults, dikes, joints, veins, solution surfaces, and other natural structures in rock. Field observations, engineering rock fracture mechanics, and the elastic theory of cracks. The role of natural fractures in brittle rock deformation, and fluid flow in the earth's crust with applications to crustal deformation, structural geology, petroleum geology, engineering, and hydrogeology. Prerequisite: 215 or equivalent.
5 units (Pollard) alternate years, given 2003-04

GES 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 2003-04

GES 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.
1-3 units (Paytan) alternate years, given 2003-04

GES 220. Terrestrial Biogeochemistry—(Enroll in BIOSCI 216.)
3 units, Spr (Vitousek) not given 2003-04

GES 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 (Chyba) not given 2002-03

GES 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.
1-3 units, Win (Paytan) alternate years, not given 2003-04

GES 230. Physical Hydrogeology—(Same as CEE 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. GER:2a
5 units, Aut (Gorelick)

GES 231. Contaminant Hydrogeology—(Same as CEE 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 or CEE 260A.
4 units, Spr (Gorelick)

GES 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.
2-3 units, Spr (Hsieh) alternate years, not given 2003-04

GES 236. Hydraulic and Tracer Tests for Groundwater Resource Evaluations—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.
2-3 units (Hsieh) alternate years, given 2003-04

GES 237. Surface and Near-Surface Hydrologic Response—(Same as CEE 260B.) Quantitative review of process-based hydrology and geomorphology. Introduction to finite-difference and finite-element methods of numerical analysis. Topics: biometeorology, unsaturated and saturated subsurface fluid flow, overland and open channel flow, 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, Aut (Loague) alternate years, not given 2003-04

GES 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 (Loague) alternate years, not given 2002-03

GES 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, 131.

4 units, Win (Loague) alternate years, not given 2003-04

GES 240. Geostatistics for Spatial Phenomena—(Same as PETENG 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, STATS 116, GES 161 or equivalent.

3-4 units, Win (Journel)

GES 241. Geostatistics for Spatial Phenomena—(Enroll in GEOPHYS 241, PETENG 241.)

3-4 units, Spr (Caers, Mukerji)

GES 242. Topics in Advanced Geostatistics—(Same as PETENG 242.) Conditional expectation theory and projections in Hilbert spaces; parametric vs. non-parametric geostatistics; Boolean, Gaussian, fractal, indicator, and 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.

3-4 units, Aut (Journel) alternate years, not given 2003-04

GES 246. Reservoir Characterization and Flow Modeling with Outcrop Data—(Same as PETENG 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)

GES 249. Biological Markers—The fundamentals of understanding, interpreting, and applying biomarkers and their fingerprints. Carbon is the basic atomic building block for life as we know it. 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.

2-3 units, Win (Moldowan)

GES 250. Sedimentation Mechanics—The mechanics of sediment transport and deposition and the origins of sedimentary structures and textures as applied to interpreting ancient rock sequences. Dimensional analysis, fluid flow, drag, boundary layers, open channel flow, particle settling, erosion, sediment transport, sediment gravity flows, soft sediment deformation, and fluid escape. Field trip required.

3 units (Lowe) alternate years, given 2003-04

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

3 units (Graham) alternate years, given 2003-04

GES 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, Aut (Lowe) alternate years, not given 2003-04

GES 253. Petroleum Geology and Exploration—The basics of petroleum geology. The origin and occurrence of hydrocarbons. Topics: thermal maturation history in hydrocarbon generation, significance of sedimentary and tectonic structural setting, principles of accumulation, exploration techniques. Prerequisites: 110, 151. Recommended: GEOPHYS 184.

3 units (Graham) alternate years, given 2003-04

GES 254. Diagenesis and Transfer Processes in Sedimentary Basins—Diagenetic alteration processes of sedimentary units affect their hydraulic, mechanical, and petrophysical properties with implications on ground- and formation water flow, the migration of hydrocarbons, brittle rock deformation, and reservoir engineering. Topics: basic concepts of diagenetic reactions and their occurrence in a variety of settings ranging from early marine diagenesis and authigenesis to deep-burial diagenesis; analytical tools used to study effects of mineral diagenesis, including cathodoluminescence petrography, electron microscopy, X-ray diffraction, and selected aspects of isotopic analyses; case studies illustrating diagenetic aspects of modern and paleo-fluid flow in basins and along continental margins, faulting and fracturing, and reservoir properties. For senior undergraduate and graduate students. Recommended: 151.

2 units, Aut (Eichhubl) given 2002-03 only

GES 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. Weekly lab.

5 units (Ingle) alternate years, given 2003-04

GES 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 2003-04

GES 258. Introduction to Depositional Systems—The characteristics of the major sedimentary environments and their deposits in the geologic record, including alluvial fans, braided and meandering rivers, aeolian systems, deltas, open coasts, barred coasts, marine shelves, and deep-water systems. Emphasis is on subdivisions; morphology; the dynamics of modern systems; and the architectural organization and sedimentary structures, textures, and biological components of ancient deposits.

3 units (Lowe) alternate years, not given 2003-04

GES 259. Marine Chemistry—(Same as EARTHSYS 259.) For graduate students; see 159.

2-4 units, Spr (Paytan)

GES 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 environ-

mental 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, Spr (Moldowan)

GES 261. Physics and Chemistry of Minerals and Mineral Surfaces—The concepts of symmetry and periodicity in crystals; the physical properties of crystals and their relationship to atomic-level structure; basic structure types; crystal chemistry and bonding in solids and their relative stability; the interaction of x-rays with solids and liquids (scattering and spectroscopy); structural variations in silicate glasses and liquids; UV-visible spectroscopy and the color of minerals; review of the mineralogy, crystal chemistry, and structures of selected rock-forming silicates and oxides; mineral surface and interface geochemistry.
4 units (Brown) alternate years, given 2003-04

GES 262. Thermodynamics and Disorder in Minerals and Melts—The thermodynamic properties of crystalline, glassy, and molten silicates and oxides in light of microscopic information about short range structure and ordering. Measurements of bulk properties, 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 2003-04

GES 264. Aquatic Chemistry—(Enroll in CEE 273.)
3 units, Aut (Leckie)

GES 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) alternate years, not given 2003-04

GES 267. Solution-Mineral Equilibria: Theory—Procedures for calculating and evaluating the thermodynamic properties of reversible and irreversible reactions among rock-forming minerals and aqueous solutions in geologic systems. Emphasis is on the generation and utility of phase diagrams depicting solution-mineral interaction relevant to phase relations associated with weathering diagenetic, hydrothermal, and metamorphic processes. 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, Win (Bird) alternate years, not given 2003-04

GES 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. Term paper optional.
4 units (Ernst) alternate years, given 2003-04

GES 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.
2-3 units, Win (Jones)

GES 285. Petrogenesis of Crustal Magmatism—Radiogenic isotopes, stable isotopes, and trace elements applied to igneous processes; interaction of magmas with mantle and crust; convergent-margin magmatism; magmatism in extensional terrains; origins of rhyolites; residence times of magmas and magma chamber processes; granites as imperfect mirrors of their source regions; trace element modeling of igneous processes; trace element discriminant diagrams in tectonic analysis; sources of ore forming metals. Topics emphasize the interest of students. Prerequisite:181, or equivalent.
3 units, Spr (Mahood)

GES 286. Geoarchaeology—For graduate students; see 186.
5 units, Spr (Mahood)

GES 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 2003-04

GES 295. Integrating Remote Sensing and Geographic Information Systems (GIS)—For graduate students; see 195.
1-5 units, Aut (Lyon)

GES 296. Introduction to Geographic Information Systems (GIS): Using ARC-View—For graduate students; see 196.
2 units, Spr (Klemperer)

GES 297. Remote Sensing of Land Use and Land Cover Change—For graduate students; see 197.
5 units, Spr (Seto)

GES 314. Structural Geology and Geomechanics—Research seminar on selected topics. May be repeated for credit.
1 unit (Staff)

GES 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)

GES 323. Stanford at SEA—(Same as BIOHOPK 323H, EARTHSYS 323.) Five weeks of marine science including oceanography, marine physiology, policy, conservation, and nautical science at Hopkins Marine Station, followed by five weeks at sea aboard a sailing research vessel in the Pacific Ocean. The shore component is comprised of three multidisciplinary courses, each of which meets daily and continues through the shipboard experience. Students develop an independent research project plan while ashore, and carry out the research at sea. The class at Stanford is offered in collaboration with the Sea Education Association of Woods Hole, MA. The Hopkins and shipboard experience and its emphasis on student research projects create a focused and unique learning experience.
18 units, Spr (Dunbar, Block, Gilly) alternate years, not given 2003-04

GES 324. Seminar in Oceanography—Presentations and discussion of current topics in oceanography. May be repeated for credit.
1-2 units, Aut, Win, Spr (Paytan)

GES 326. Isotopes and Biogeochemical Tracers in Hydrological Cycle—Practical applications of environmental isotopes. The systematics of isotope fractionations and the distributions of selected isotopes in natural systems. Focus is on applications of isotopes for tracing waters, solutes, and biogeochemical reactions in hydrologic systems. Wide variety of isotope systems including O, H, C, N, S, Cl, Sr, B, Li, Fe, Cr, Ca, Se, Ra; hydrological topics including tracing sources of groundwater and surface water, isotope hydrograph separations, groundwater influence on coastal systems, rock-water interactions, recharge rate, and ground-water dating; and biogeochemical topics including sources of contaminants, biogeochemical reaction mechanisms, nutrient sources and pathways, and food web studies.

3 units, Aut (Paytan, Kendall, Bullen)

GES 327. The Glacial World—(Same as GEOPHYS 327.) The environmental changes that took place on Earth between the last glacial maximum (LGM) and the present day. Focus is on the cause of the low atmospheric CO_2 concentrations characteristic of the LGM and what conditions might explain these reduced CO_2 levels. Literature from various disciplines that illustrate, for example, how changes in sea level, marine primary production, ocean circulation, and elemental cycling may have contributed to past global changes.

2-3 units, Aut (Arrigo, Paytan) alternate years, not given 2003-04

GES 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)

GES 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 affecting heat and solute transport.

1-2 units, Aut, Win, Spr (Gorelick)

GES 332A,B,C. Seminar in Hydrogeology—Presentations and discussion of current topics in hydrogeology. May be repeated for credit.

1 unit, Aut, Spr (Gorelick), Win (Loague)

GES 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, not given 2003-04

GES 342A,B,C. 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)

GES 350. Sedimentary Geology—Presentations and discussion of current topics in sedimentary geology. May be repeated for credit.

1 unit, Win, Spr (Staff)

GES 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)

GES 362. Silicate Glasses and Liquids—Presentations and discussion of current topics. May be repeated for credit.

2-3 units (Stebbins) alternate years, given 2003-04

GES 373. 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) alternate years, not given 2003-04

GES 385. Practical Experience in the Geosciences—On-the-job training in the geosciences. May include summer internship; emphasizes training in applied aspects of the geosciences, and technical, organizational, and communication dimensions. Meets 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 Quantitative Structural Geology, Active Tectonics, and Geomechanics
319. Problems in Structural Geology
337. Problems in Geomorphology
338. Problems in Hydrology
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 Quantitative Structural Geology, Active Tectonics, and Geomechanics
419. Research in Structural Geology and Tectonics
422. Research in Biogeochemistry
437. Research in Geomorphology
438. Research 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
459. Research in Global Change
460. Research in Low Temperature Aqueous and Interfacial 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

This file has been excerpted from the *Stanford Bulletin, 2002-03*, pages 56-69. Every effort has been made to insure accuracy; late changes (after print publication of the bulletin) may have been made here. Contact the editor of the *Stanford Bulletin* via email at arod@stanford.edu with changes, corrections, updates, etc.