Geological Sciences

Courses offered by the Department of Geological Sciences are listed under the subject code GES on the [Stanford Bulletin's CourseSearch](http://exploreourses.stanford.edu/CourseSearch/search?view=catalog&catalog=&page=0&q=GES&filter-catalognumber-GES=on) website. On April 16, 2015, the Senate of the Academic Council approved the change of name for the department to become the Department of Geological and Environmental Sciences. Prior to April 16, the department was named the Department of Geological Sciences.

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The geological and environmental sciences are naturally interdisciplinary, and include: the study of earth materials, earth processes, and how they have changed over Earth's 4.56 billion year history. More specifically, courses and research within the department address: the chemical and physical makeup and properties of minerals, rocks, soils, sediments, and water; the formation and evolution of Earth and other planets; the processes that deform Earth's crust and shape Earth's surface; the stratigraphic, paleobiological, and geochemical records of Earth history including changes in climate, oceans, and atmosphere; present-day, historical, and long-term feedbacks between the geosphere and biosphere, and the origin and occurrence of our natural resources.

The department's research is critical to the study of natural hazards (earthquakes, volcanic eruptions, landslides, and floods), environmental and geological engineering, surface and groundwater management, the assessment, exploration, and extraction of energy, mineral and water resources, ecology and conservation biology, remediation of contaminated water and soil, geological mapping and land use planning, and human health and the environment.

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

Mission of the Undergraduate Program in Geological Sciences

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

Learning Outcomes (Undergraduate)

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

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

Graduate Programs in Geological Sciences

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

Learning Outcomes (Graduate)

The purpose of the master's program in Geological Sciences is to continue a student's training in one of a broad range of earth science disciplines and to prepare students for either a professional career or doctoral studies. The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship, high attainment in a particular field of knowledge, and the ability to conduct independent research. To this end, the objectives of the doctoral program are to enable students to develop the skills needed to conduct original investigations in a particular discipline or set of disciplines in the earth sciences, to interpret the results, and to present the data and conclusions in a publishable manner.

On April 16, 2015, the Senate of the Academic Council approved the change of name for the department to become the Department of Geological and Environmental Sciences. Prior to April 16, the department was named the Department of Geological Sciences.

The major consists of five interrelated components:

1. **Earth Sciences Fundamentals**—Students must complete a set of core courses that introduce the properties of Earth materials, the processes that change the Earth, and the timescales over which those processes act. These courses provide a broad foundational knowledge that can lead to specialization in many different disciplines of the geological and environmental sciences.
2. **Quantitative and Analytical Skills**—Students must complete adequate course work in mathematics, chemistry, and physics or biology. In addition, they learn analytical techniques specific to the Earth sciences through the laboratory component of courses.
3. **Advanced Course Work and Research**—Students gain breadth and depth in upper-level electives and are encouraged to apply these skills
and knowledge to problems in the Earth sciences through directed research.

4. **Field Research Skills**—Most GES courses include field trips and/or field-based projects. In addition, students must complete at least six weeks of field research through departmental offerings (GES 105 Introduction to Field Methods and GES 190 Research in the Field), in which they learn and apply field techniques, field mapping, and prepare a written report.

5. **Communication Skills**—To fulfill the Writing in the Major requirement, students take a writing-intensive senior seminar (GES 150 Senior Seminar: Issues in Earth Sciences), in which they give both oral and written presentations that address current research in the earth sciences. The major requires at least 93 units; letter grades are required in all courses if available. Students interested in the GES major should consult with the undergraduate program coordinator for information about options within the curriculum.

## Course Sequence (93-110 units total)

### Core Requirement

Students are required to take all of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GES 1A</td>
<td>Introduction to Geology: The Physical Science of the Earth</td>
<td>4-5</td>
</tr>
<tr>
<td>GES 1B</td>
<td>Introduction to Geology</td>
<td></td>
</tr>
<tr>
<td>GES 1C</td>
<td>Introduction to Geology: Dynamic Earth</td>
<td></td>
</tr>
<tr>
<td>GES 4</td>
<td>Evolution and Extinction: Introduction to Historical Geology</td>
<td>4</td>
</tr>
<tr>
<td>GES 90</td>
<td>Introduction to Geochemistry</td>
<td>3-4</td>
</tr>
<tr>
<td>GES 102</td>
<td>Earth Materials: Introduction to Mineralogy</td>
<td>4</td>
</tr>
<tr>
<td>GES 103</td>
<td>Earth Materials: Rocks in Thin Section</td>
<td>3</td>
</tr>
<tr>
<td>GES 104</td>
<td>Introduction to Petrology</td>
<td>4</td>
</tr>
<tr>
<td>GES 105</td>
<td>Introduction to Field Methods</td>
<td>3</td>
</tr>
<tr>
<td>GES 150</td>
<td>Senior Seminar: Issues in Earth Sciences</td>
<td>3</td>
</tr>
<tr>
<td>GES 190</td>
<td>Research in the Field (see below for more information)</td>
<td>4</td>
</tr>
</tbody>
</table>

**Total Units** 32-34

### Breadth in the Discipline Requirement

To gain understanding of the breadth of subject areas within the geological and environmental sciences, students are required to take one course from each of the following seven groups (22-28 units).

#### Environmental Geology and Surface Processes

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

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EESS 155</td>
<td>Science of Soils</td>
<td>3-4</td>
</tr>
<tr>
<td>or GES 130</td>
<td>Soil Physics and Hydrology</td>
<td></td>
</tr>
<tr>
<td>or GES 131</td>
<td>Hydrologically-Driven Landscape Evolution</td>
<td></td>
</tr>
<tr>
<td>or GES 170</td>
<td>Environmental Geochemistry</td>
<td></td>
</tr>
</tbody>
</table>

### Structural Geology and Tectonics

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

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GES 110</td>
<td>Structural Geology and Tectonics</td>
<td>3-5</td>
</tr>
<tr>
<td>or GES 111</td>
<td>Fundamentals of Structural Geology</td>
<td></td>
</tr>
</tbody>
</table>

### Earth Materials and Geochemistry

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

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GES 107</td>
<td>Journey to the Center of the Earth</td>
<td>3-4</td>
</tr>
<tr>
<td>or GES 163</td>
<td>Introduction to Isotope Geochemistry</td>
<td></td>
</tr>
<tr>
<td>or GES 180</td>
<td>Igneous Processes</td>
<td></td>
</tr>
<tr>
<td>or GES 185</td>
<td>Volcanology</td>
<td></td>
</tr>
</tbody>
</table>

### Sedimentary Systems

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

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GES 151</td>
<td>Sedimentary Geology and Petrography: Depositional Systems</td>
<td>4</td>
</tr>
</tbody>
</table>

### Biogeosciences

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

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GES 123</td>
<td>Paleobiology</td>
<td>4</td>
</tr>
</tbody>
</table>

### Geophysics

The integration of physics, mathematics, and geology to study Earth processes using remote sensing, modeling, experiments, and direct observations.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEOPHYS 110</td>
<td>Earth on the Edge: Introduction to Geophysics</td>
<td>3-5</td>
</tr>
<tr>
<td>or GEOPHYS 120</td>
<td>Ice, Water, Fire</td>
<td></td>
</tr>
<tr>
<td>or GEOPHYS 130</td>
<td>Introductory Seismology</td>
<td></td>
</tr>
</tbody>
</table>

### Geospatial Statistics and Computer Science

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

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EARTHSCI 211</td>
<td>Introduction to Programming for Scientists and Engineers</td>
<td>3-4</td>
</tr>
<tr>
<td>or CS 106A</td>
<td>Programming Methodology</td>
<td></td>
</tr>
<tr>
<td>or ENERGY 125</td>
<td>Modeling and Simulation for Geoscientists and Engineers</td>
<td></td>
</tr>
<tr>
<td>or ENERGY 160</td>
<td>Modeling Uncertainty in the Earth Sciences</td>
<td></td>
</tr>
</tbody>
</table>
or EESS 164 Fundamentals of Geographic Information Science (GIS)
or GEOPHYS Exploring Geosciences with MATLAB

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**Depth in the Discipline Requirement (10 Units)**

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

- GES 192 Undergraduate Research in Geological and Environmental Sciences
- GES 197 Senior Thesis
- GES 198 Special Problems in Geological and Environmental Sciences

**Advanced Seminars**

Honors research (GES 199 Honors Program) may fulfill up to 4 elective units.

**Required Supporting Mathematics (15 Units)**

This requirement may also be fulfilled by Advanced Placement credit. Choose one of the following equivalent series:

Select one of the following series:

Series A
- MATH 19 Calculus
- & MATH 20 and Calculus
- & MATH 21 and Calculus

10 Units

Series B
- MATH 41 Calculus
- & MATH 42 and Calculus

And one of the following:
- MATH 51 Linear Algebra and Differential Calculus of Several Variables
- or MATH 52 Integral Calculus of Several Variables
- or MATH 53 Ordinary Differential Equations with Linear Algebra
- or CME 100 Vector Calculus for Engineers
- or CME 102 Ordinary Differential Equations for Engineers
- or CME 104 Linear Algebra and Partial Differential Equations for Engineers

**Units**

- GES 192  Undergraduate Research in Geological and Environmental Sciences  3
- GES 197  Senior Thesis  3
- GES 198  Special Problems in Geological and Environmental Sciences  3

**Advanced Seminars**

Honors research (GES 199 Honors Program) may fulfill up to 4 elective units.

**Required Supporting Cognate Sciences (15-23 Units)**

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

**Chemistry**
- CHEM 31A Chemical Principles I
- & CHEM 31B and Chemical Principles II
- or CHEM 31X Chemical Principles Accelerated
- or a score of 4-5 on the Chemistry AP exam

And one of the following:
- CHEM 135 Physical Chemical Principles

**Units**

- CHEM 171 Physical Chemistry I  5
- or GES 171 Geophysical Thermodynamics  5

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

**Biology**
- BIO 41 Genetics, Biochemistry, and Molecular Biology
- or BIO 44X Core Molecular Biology Laboratory

And one of the following:
- BIO 105A Ecology and Natural History of Jasper Ridge and Biological Preserve
- or BIO 105B Biological Preserve and Geology and Natural History of Jasper Ridge Biological Preserve
- or BIO 42 Cell Biology and Animal Physiology
- or BIO 43 Plant Biology, Evolution, and Ecology
- or BIO 44Y Core Plant Biology & Eco Evo Laboratory

**Units**

- GES 192 Undergraduate Research in Geological and Environmental Sciences  3
- GES 197 Senior Thesis  3
- GES 198 Special Problems in Geological and Environmental Sciences  3

**Advanced Seminars**

Honors research (GES 199 Honors Program) may fulfill up to 4 elective units.

**Required Supporting Mathematics (15 Units)**

This requirement may also be fulfilled by Advanced Placement credit. Choose one of the following equivalent series:

Select one of the following series:

Series A
- MATH 19 Calculus
- & MATH 20 and Calculus
- & MATH 21 and Calculus

10 Units

Series B
- MATH 41 Calculus
- & MATH 42 and Calculus

And one of the following:
- MATH 51 Linear Algebra and Differential Calculus of Several Variables
- or MATH 52 Integral Calculus of Several Variables
- or MATH 53 Ordinary Differential Equations with Linear Algebra
- or CME 100 Vector Calculus for Engineers
- or CME 102 Ordinary Differential Equations for Engineers
- or CME 104 Linear Algebra and Partial Differential Equations for Engineers

**Units**

- CHEM 171 Physical Chemistry I  5
- or GES 171 Geophysical Thermodynamics  5

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

**Biology**
- BIO 41 Genetics, Biochemistry, and Molecular Biology
- or BIO 44X Core Molecular Biology Laboratory

And one of the following:
- BIO 105A Ecology and Natural History of Jasper Ridge and Biological Preserve
- or BIO 105B Biological Preserve and Geology and Natural History of Jasper Ridge Biological Preserve
- or BIO 42 Cell Biology and Animal Physiology
- or BIO 43 Plant Biology, Evolution, and Ecology
- or BIO 44Y Core Plant Biology & Eco Evo Laboratory

**Units**

Select one of the following Series:

Series A
- PHYSICS 21 Mechanics and Heat
- & PHYSICS 22 and Mechanics and Heat Laboratory
- & PHYSICS 23 and Electricity and Optics
- & PHYSICS 24 and Electricity and Optics Laboratory

Series B
- PHYSICS 41 Mechanics
- & PHYSICS 43 and Electricity and Magnetism
- & PHYSICS 44 and Electricity and Magnetism Laboratory

Series C
- PHYSICS 41 Mechanics
- & PHYSICS 45 and Light and Heat
- & PHYSICS 46 and Light and Heat Laboratory

**Field Research**

Field research skills are a critical component of the undergraduate curriculum in GES. The conventional and most straightforward way for undergraduates to meet the field requirement is to take the two GES courses (GES 105 Introduction to Field Methods and GES 190 Research in the Field) that are offered every year:

- GES 105 Introduction to Field Methods, is a two-week introduction to field techniques and geologic mapping that is taught every year in the White Mountains of eastern California prior to the start of Autumn Quarter in September. This course gives students the tools to undertake geologic research in the field. GES 105 Introduction to Field Methods is required of all GES majors and is the framework upon which all subsequent undergraduate field-related instruction is based.
- GES 190 Research in the Field, gives GES undergraduates additional training in field research. This course provides undergraduates with a team-based experience of collecting data to answer research questions and is directed by faculty and graduate students. Offered in June and/or September.

By taking GES 105 Introduction to Field Methods and two iterations of GES 190 Research in the Field, GES undergraduates develop the broad experience and confidence necessary to go out and evaluate a geological or environmental geology question by collecting field-based data. The main goal is that, upon graduation, GES undergraduates will be able to plan and execute independent field research.

It is also possible to substitute non-Stanford courses to allow flexibility in fulfilling the field requirement. A modified version of an existing field-based course such as Stanford at Sea/Australia/Hawaii may fulfill one GES 190 Research in the Field requirement. To receive credit for GES 190, a
proposal must be filed at the end of Winter Quarter with the field program committee which evaluates it for suitability. Students subsequently enroll in GES 190 with a specific instructor or their faculty mentor who evaluates the final report from the fieldwork.

GES 190 Research in the Field can also be satisfied by enrolling in a single four-to-six week geology field camp offered by another institution. This externally administered experience can substitute for two GES 190 courses, subject to approval by the Undergraduate Curriculum Committee.

**Engineering Geology and Hydrogeology Undergraduate Specialized Curriculum**

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

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

**Course Sequence (85-101 Units Total)**

**Required Geological and Environmental Sciences (33-35 Units)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GES 1A</td>
<td>Introduction to Geology: The Physical Science of the Earth</td>
<td>4-5</td>
</tr>
<tr>
<td>or GES 1B</td>
<td>Introduction to Geology</td>
<td></td>
</tr>
<tr>
<td>or GES 1C</td>
<td>Introduction to Geology: Dynamic Earth</td>
<td></td>
</tr>
<tr>
<td>GES 102</td>
<td>Earth Materials: Introduction to Mineralogy</td>
<td>4</td>
</tr>
<tr>
<td>GES 104</td>
<td>Introduction to Petrology</td>
<td>4</td>
</tr>
<tr>
<td>GES 111</td>
<td>Fundamentals of Structural Geology</td>
<td>3</td>
</tr>
<tr>
<td>GES 115</td>
<td>Engineering Geology and Global Change</td>
<td>3</td>
</tr>
<tr>
<td>GES 150</td>
<td>Senior Seminar: Issues in Earth Sciences</td>
<td>3</td>
</tr>
<tr>
<td>EESS 164</td>
<td>Fundamentals of Geographic Information Science (GIS)</td>
<td>4</td>
</tr>
<tr>
<td>EESS 220</td>
<td>Physical Hydrogeology</td>
<td>4</td>
</tr>
<tr>
<td>ENERGY 160</td>
<td>Modeling Uncertainty in the Earth Sciences</td>
<td>3-4</td>
</tr>
<tr>
<td>GEOPHYS 190</td>
<td>Near-Surface Geophysics</td>
<td>3</td>
</tr>
</tbody>
</table>

**Total Units** 35-37

**Required Engineering (18-21 Units)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEE 101A</td>
<td>Mechanics of Materials</td>
<td>4</td>
</tr>
<tr>
<td>or ME 80</td>
<td>Mechanics of Materials</td>
<td></td>
</tr>
<tr>
<td>CEE 101B</td>
<td>Mechanics of Fluids</td>
<td>4</td>
</tr>
<tr>
<td>CEE 101C</td>
<td>Geotechnical Engineering</td>
<td>3-4</td>
</tr>
<tr>
<td>CS 106A</td>
<td>Programming Methodology</td>
<td>3-5</td>
</tr>
<tr>
<td>ENGR 14</td>
<td>Intro to Solid Mechanics</td>
<td>4</td>
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</table>

**Total Units** 18-21

**Required Supporting Sciences and Mathematics (23-29 Units)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 31A</td>
<td>Chemical Principles I</td>
<td>5</td>
</tr>
<tr>
<td>&amp; CHEM 31B</td>
<td>Chemical Principles II</td>
<td></td>
</tr>
<tr>
<td>or CHEM 31X</td>
<td>Chemical Principles Accelerated</td>
<td></td>
</tr>
<tr>
<td>MATH 51</td>
<td>Linear Algebra and Differential Calculus of Several Variables</td>
<td>5</td>
</tr>
<tr>
<td>MATH 52</td>
<td>Integral Calculus of Several Variables</td>
<td>5</td>
</tr>
<tr>
<td>MATH 53</td>
<td>Ordinary Differential Equations with Linear Algebra</td>
<td>5</td>
</tr>
<tr>
<td>PHYSICS 41</td>
<td>Mechanics</td>
<td>4</td>
</tr>
</tbody>
</table>

**Total Units** 24-29

**Suggested Electives Electives (11-16 Units)**

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

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEE 101D</td>
<td>Computations in Civil and Environmental Engineering</td>
<td>3</td>
</tr>
<tr>
<td>CEE 180</td>
<td>Structural Analysis</td>
<td>4</td>
</tr>
<tr>
<td>CEE 270</td>
<td>Movement and Fate of Organic Contaminants in Waters</td>
<td>3</td>
</tr>
<tr>
<td>CEE 293</td>
<td>Foundations and Earth Structures</td>
<td>3</td>
</tr>
<tr>
<td>CEE 296</td>
<td>Special Topics in Fluid-Solid Interactions</td>
<td>2</td>
</tr>
<tr>
<td>EESS 221</td>
<td>Contaminant Hydrogeology and Reactive Transport</td>
<td>4</td>
</tr>
<tr>
<td>ENGR 30</td>
<td>Engineering Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>ENGR 50</td>
<td>Introduction to Materials Science, Nanotechnology Emphasis</td>
<td>4</td>
</tr>
<tr>
<td>GEOPHYS 112</td>
<td>Exploring Geosciences with MATLAB</td>
<td>1-3</td>
</tr>
<tr>
<td>GES 130</td>
<td>Soil Physics and Hydrology</td>
<td>3</td>
</tr>
<tr>
<td>GES 131</td>
<td>Hydrologically-Driven Landscape Evolution</td>
<td>3</td>
</tr>
<tr>
<td>GES 217</td>
<td>Faults, Fractures, and Fluid Flow</td>
<td>3</td>
</tr>
<tr>
<td>GES 237</td>
<td>Surface and Near-Surface Hydrologic Response</td>
<td>3</td>
</tr>
<tr>
<td>MATSCI 151</td>
<td>Microstructure and Mechanical Properties</td>
<td>3-4</td>
</tr>
<tr>
<td>ME 80</td>
<td>Mechanics of Materials</td>
<td>4</td>
</tr>
</tbody>
</table>

**Honors Program**

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

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

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

On April 16, 2015, the Senate of the Academic Council approved the minor in Geological Sciences. Students who declared the minor in Geological and Environmental Sciences have the option of changing the name of their minor to Geological Sciences. Minor requirements remain the same.

**Minor in Geological and Environmental Sciences**

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

### Required Courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GES 1A</td>
<td>Introduction to Geology: The Physical Science of the Earth</td>
<td>4-5</td>
</tr>
<tr>
<td>or GES 1B</td>
<td>Introduction to Geology</td>
<td>4</td>
</tr>
<tr>
<td>or GES 1C</td>
<td>Introduction to Geology: Dynamic Earth</td>
<td>4</td>
</tr>
<tr>
<td>GES 4</td>
<td>Evolution and Extinction: Introduction to Historical Geology</td>
<td>4</td>
</tr>
<tr>
<td>GES 102</td>
<td>Earth Materials: Introduction to Mineralogy</td>
<td>4</td>
</tr>
<tr>
<td>GES 104</td>
<td>Introduction to Petrology</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total Units</strong></td>
<td></td>
<td><strong>16-17</strong></td>
</tr>
</tbody>
</table>

### Electives (12 Units)

Students must take a minimum of 12 additional units drawn primarily from the Breadth in the Discipline list in the GES major (http://www.stanford.edu/dept/registrar/bulletin/5038.htm); a majority of units must be from classes within the GES department. Up to 3 units of Stanford Introductory Seminars in GES may be counted.

Students pursuing a minor in GES are encouraged to participate in the senior seminar (GES 150 Senior Seminar: Issues in Earth Sciences) and in field research (GES 105 Introduction to Field Methods).

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

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**Coterminal B.S. and M.S. Degrees in Geological and Environmental Sciences**

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

The University requirements for the coterminal M.A. are described in the “Coterminal Bachelor’s and Master’s Degrees” section of this bulletin. For University coterminal degree program rules and University application forms, also see the Publications and Online Guides (http://studentaffairs.stanford.edu/registrar/publications/#Coterm) web site.

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

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

**Admission**

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

**Master of Science in Geological and Environmental Sciences**

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 (http://www.stanford.edu/dept/registrar/ bulletin/4901.htm)” section of this bulletin. Practical training (GES 385 Practical Experience in the Geosciences) may be required by some programs, with adviser approval, depending on the background of the student. Additional department requirements include the following:

1. A minimum of 45 units of course work at the 100 level or above.
   a. Half of the courses used to satisfy the 45-unit requirement must be intended as being primarily for graduate students, usually at the 200 level or above.
   b. No more than 15 units of thesis research may be used to satisfy the 45-unit requirement.
   c. Some students may be required to make up background deficiencies in addition to these basic requirements.
2. By the end of Winter Quarter of their first year in residence, students must complete at least three graduate level courses taught by a minimum of two different GES faculty members.
3. Each student must have a research adviser who is a faculty member in the department and is within the student’s thesis topic area or specialized area of study.
4. Each student must complete a thesis describing his or her research. Thesis research should begin during the first year of study at Stanford and should be completed before the end of the second year of residence.
5. Early during the thesis research period, and after consultation with the student, the thesis adviser appoints a second reader for the thesis, who must be approved by the graduate coordinator; the thesis adviser is the first reader. The two readers jointly determine whether the thesis is acceptable for the M.S. degree in the department.

Engineer Degree in Geological and Environmental Sciences

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

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

Doctor of Philosophy in Geological and Environmental Sciences

Objectives

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

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.

Requirements

The University’s requirements for the Ph.D. degree are outlined in the “Graduate Degrees (http://exploredegrees.stanford.edu/archive/2014-15/graduatedegrees)” section of this bulletin. Practical training (GES 385 Practical Experience in the Geosciences) may be required by some programs, with adviser approval, depending on the background of the student. A summary of additional department requirements is presented below:

1. Ph.D. students must complete the required courses in their individual program or in their specialized area of study with a grade point average (GPA) of 3.0 (B) or higher, or demonstrate that they have completed the equivalents elsewhere. Ph.D. students must complete a minimum of four graduate level, 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 Spring Quarter of their first year in residence, students must complete at least three graduate level courses taught by a minimum of two different GES faculty members.
2. Each student must qualify for candidacy for the Ph.D. by the end of the sixth quarter in residence, excluding summers. Department procedures require selection of a faculty thesis adviser, preparation of a written research proposal, approval of this proposal by the thesis adviser, selection of a committee for the Ph.D. qualifying examination, and approval of the membership by the graduate coordinator and chair of the department. The research examination consists of three parts: oral presentation of a research proposal, examination on the research proposal, and examination on subject matter relevant to the proposed research. The exam should be scheduled prior to May 1, so that the outcome of the exam is known at the time of the annual spring evaluation of graduate students.
3. Upon qualifying for Ph.D. candidacy, the student and thesis adviser, who must be a department faculty member, choose a research committee that includes a minimum of two faculty members in the University in addition to the adviser. Annually, in the month of
March or April, the candidate must organize a meeting of the research committee to present a brief progress report covering the past year.

4. Under the supervision of the research advisory committee, the candidate must prepare a doctoral dissertation that is a contribution to knowledge and is the result of independent research. The format of the dissertation must meet University guidelines. The student is strongly urged to prepare dissertation chapters that, in scientific content and format, are readily publishable.

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

Ph.D. Minor in Geological and Environmental Sciences

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

Emeriti (Professors): Attila Aydin, Robert Coleman, Robert R. Compton, Marco T. Einaudi, W. Gary Ernst, John W. Harbaugh, James C. Ingle, Jr., Andre G. Journel, John G. Liou, Ronald J. P. Lyon, Michael McWilliams, Michael Moldovan, George A. Parks

Chair: Gordon E. Brown, Jr.

Associate Chair: Jonathan Payne

Professors: Dennis K. Bird, Gordon E. Brown, Jr., Rodney C. Ewing, Stephan A. Graham, Keith Loague, Donald R. Lowe, Gail A. Mahood, Elizabeth L. Miller, David D. Pollard, Jonathan F. Stebbins

Associate Professors: C. Kevin Boyce, George Hilley, Wendy Mao, Jonathan Payne

Assistant Professors: Katherine Maher, Jessica Warren

Professors (Research): Martin J. Grove


Lecturer: Kenneth Befus, Sina Cina, Bob Jones


Consulting Associate Professor: Jorge A. Vazquez

Visiting Professors: James Badro, Carl Jacobson, Friedhelm von Blanckenburg, Sandra Wyld

* Recalled to active duty

Cognate Courses

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

The following courses outside the School of Earth Sciences are particularly applicable:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIO 121</td>
<td>Biogeography</td>
<td>3</td>
</tr>
<tr>
<td>BIO 136</td>
<td>Evolutionary Paleobiology</td>
<td>4</td>
</tr>
<tr>
<td>BIOHOPK 182H</td>
<td>Stanford at Sea</td>
<td>16</td>
</tr>
<tr>
<td>CEE 63</td>
<td>Weather and Storms</td>
<td>3</td>
</tr>
<tr>
<td>CEE 64</td>
<td>Air Pollution and Global Warming: History, Science, and Solutions</td>
<td>3</td>
</tr>
<tr>
<td>CEE 101A</td>
<td>Mechanics of Materials</td>
<td>4</td>
</tr>
<tr>
<td>CEE 101B</td>
<td>Mechanics of Fluids</td>
<td>4</td>
</tr>
<tr>
<td>CEE 101C</td>
<td>Geotechnical Engineering</td>
<td>3-4</td>
</tr>
<tr>
<td>CEE 161A</td>
<td>Rivers, Streams, and Canals</td>
<td>3-4</td>
</tr>
<tr>
<td>CEE 164</td>
<td>Introduction to Physical Oceanography</td>
<td>4</td>
</tr>
<tr>
<td>CEE 166A</td>
<td>Watersheds and Wetlands</td>
<td>3</td>
</tr>
<tr>
<td>CEE 173A</td>
<td>Energy Resources</td>
<td>3-5</td>
</tr>
</tbody>
</table>

Overseas Studies Courses in Geological and Environmental Sciences

The Bing Overseas Studies Program (http://bosp.stanford.edu) manages Stanford study abroad programs for Stanford undergraduates. Students should consult their department or program’s student services office for applicability of Overseas Studies courses to a major or minor program.

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

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

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSPFLOR 52</td>
<td>Mass Extinctions and the Geology of Italy</td>
<td>4</td>
</tr>
</tbody>
</table>

Courses

GES 1A. Introduction to Geology: The Physical Science of the Earth. 5 Units.

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

GES 1B. Introduction to Geology. 4 Units.

For non-majors and prospective majors or minors in the Earth Sciences. Introduction to physical geology. Lectures and lab exercises focus on understanding the dynamics of Earth’s physical processes: ongoing physical and chemical processes. Major themes include plate tectonics, the rock cycle, the hydrologic cycle, and mineral resources. We will employ local CA geology, current events, and the state-of-the-art to drive discussions on landscapes, hazards, and economics. Only one of GES 1A, 1B, or 1C may be taken for credit. Recommended: high school chemistry.
GES 1C. Introduction to Geology: Dynamic Earth. 4 Units.
For non-majors or prospective majors in the Earth Sciences. Integrated lecture-lab includes hands-on activities and local field trips. Focus is on reading the dynamic geological landscape, with an emphasis on California—primarily Bay Area—geology. Topics include plate tectonics, earthquakes and volcanoes, Earth materials, geologic time, stream processes, and climate change over geologic time. Only one of GES 1A, 1B, or 1C may be taken for credit.

GES 4. Evolution and Extinction: Introduction to Historical Geology. 4 Units.
Introduction to the history of the Earth, with a focus on processes that maintain or threaten habitability. Principles of stratigraphy, correlation, the geological timescale, the history of biodiversity, and the interpretation of fossils. The use of data from sedimentary geology, geochemistry, and paleontology to test theories for critical events in Earth history such as mass extinctions. One half-day field trip.
Same as: EARTHSYS 4

GES 5. Living on the Edge. 1 Unit.
A weekend field trip along the Pacific Coast. Tour local beaches, geology, and landforms with expert guides from the Department of Geological and Environmental Sciences. Enjoy a BBQ dinner and stay overnight in cabins along the Santa Cruz coast. Get to know faculty and graduate students in the Earth Sciences. Requirements: Two campus meeting and weekend field trip to Pacific Coast. Enrollment limited to 25. Freshman have first choice.

GES 8. Oceanography: An Introduction to the Marine Environment. 3 Units.
For non-majors and earth science and environmental majors. Topics: topography and geology of the sea floor; evolution of ocean basins; circulation of ocean and atmosphere; nature of sea water, waves, and tides; and the history of the major ocean basins. The interface between continents and ocean basins, emphasizing estuaries, beaches, and continental shelves with California margin examples. Relationships among the distribution of inorganic constituents, ocean circulation, biologic productivity, and marine environments from deep sea to the coast. One-day field trip to measure and analyze waves and currents.

GES 12SC. Environmental and Geological Field Studies in the Rocky Mountains. 2 Units.
The Rocky Mountain area, ecologically and geologically diverse, is being strongly impacted by changing land-use patterns, global and regional environmental change, and societal demands for energy and natural resources. This three-week field program emphasizes coupled environmental and geological problems in the Rocky Mountains and will cover a broad range of topics including the geologic origin of the American West from three billion years ago to the recent: paleoclimatology and the glacial history of this mountainous region; the long- and short-term carbon cycle and global climate change; and environmental issues in the American West that are related to changing land-use patterns and increased demand for its abundant natural resources. These broad topics are integrated into a coherent field study by examining earth/environmental science-related questions in three different settings: 1) the three-billion-year-old rocks and the modern glaciers of the Wind River Mountains of Wyoming; 2) the sediments in the adjacent Wind River basin that host abundant gas and oil reserves and also contain the long-term climate history of this region; and 3) the volcanic center of Yellowstone National Park and mountainous region of Teton National Park, and the economic and environmental problems associated with gold mining and extraction of oil and gas in areas adjoining these national parks. Students will complete six assignments based upon field exercises, working in small groups to analyze data and prepare reports and maps. Lectures will be held in the field prior to and after fieldwork.
Note: This course involves one week of backpacking in the Wind Rivers and hiking while staying in cabins near Jackson Hole, Wyoming, and horseback riding in the Dubois area of Wyoming. Students must arrive in Salt Lake City on Monday, Sept. 1. (Hotel lodging will be provided for the night of Sept. 1, and thereafter students will travel as a Sophomore College group.) We will return to campus on Sunday, Sept. 21. Sophomore College Course: Application required, due noon, April 7, 2015. Apply at http://soco.stanford.edu.
Same as: EARTHSYS 12SC, EESS 12SC

GES 38N. The Worst Journey in the World: The Science, Literature, and History of Polar Exploration. 3 Units.
This course examines the motivations and experiences of polar explorers under the harshest conditions on Earth, as well as the chronicles of their explorations and hardships, dating to the 1500s for the Arctic and the 1700s for the Antarctic. Materials include The Worst Journey in the World by Aspley Cherry-Garrard who in 1911 participated in a midwinter Antarctic sledging trip to recover emperor penguin eggs. Optional field trip into the high Sierra in March.
Same as: EARTHSYS 38N, EESS 38N

GES 39N. Forensic Geoscience: Stanford CSI. 3 Units.
Preference to freshmen. Geological principles, materials, and techniques indispensable to modern criminal investigations. Basic earth materials, their origin and variability, and how they can be used as evidence in criminal cases and investigations such as artifact provenance and environmental pollution. Sources include case-based, simulated forensic exercises and the local environments of the Stanford campus and greater Bay Area. Local field trips; research presentation and paper.

GES 40N. Diamonds. 3 Units.
Preference to freshmen. Topics include the history of diamonds as gemstones, prospecting and mining, and their often tragic politics. How diamond samples provide clues for geologists to understand the Earth’s deep interior and the origins of the solar system, Diamond’s unique materials properties and efforts in synthesizing diamonds.

GES 42N. Landscapes and Tectonics of the San Francisco Bay Area. 4 Units.
Active faulting and erosion in the Bay Area, and its effects upon landscapes. Earth science concepts and skills through investigation of the valley, mountain, and coastal areas around Stanford. Faulting associated with the San Andreas Fault, coastal processes along the San Mateo coast, uplift of the mountains by plate tectonic processes, and landsliding in urban and mountainous areas. Field excursions; student projects.
GES 43Q. Environmental Problems. 3 Units.
Preference to sophomores. Components of multidisciplinary environmental problems and ethical questions associated with decision making in the regulatory arena. Students lead discussions on environmental issues such as groundwater contamination from point and nonpoint sources, cumulative watershed effects related to timber and mining practices, acid rain, and subsurface disposal of nuclear waste.

GES 46Q. Environmental Impact of Energy Systems: What are the Risks?. 3 Units.
In order to reduce CO2 emissions and meet growing energy demands during the 21st Century, the world can expect to experience major shifts in the types and proportions of energy-producing systems. These decisions will depend on considerations of cost per energy unit, resource availability, and unique national policy needs. Less often considered is the environmental impact of the different energy producing systems: fossil fuels, nuclear, wind, solar, and other alternatives. One of the challenges has been not only to evaluate the environmental impact but also to develop a systematic basis for comparison of environmental impact among the energy sources. The course will consider fossil fuels (natural gas, petroleum and coal), nuclear power, wind and solar and consider the impact of resource extraction, refining and production, transmission and utilization for each energy source. Same as: EARTHSYS 46Q

GES 50Q. The Coastal Zone Environment. 3 Units.
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 estuarine and coastal environments, and agencies and facilities that manage these resources. Students present original research. Prerequisite: beginning course in Biology such as BIOSCI 51, Chemistry such as CHEM 30 or 31, Earth Sciences such as GES 1 or 2, or Earth Systems such as EARTHSYS 10.

GES 55Q. The California Gold Rush: Geologic Background and Environmental Impact. 3 Units.
Preference to sophomores. Topics include: geologic processes that led to the concentration of gold in the river gravels and rocks of the Mother Lode region of California; and environmental impact of the Gold Rush due to population increase, mining operations, and high concentrations of arsenic and mercury in sediments from hard rock mining and milling operations. Recommended: introductory geology.

GES 90. Introduction to Geochemistry. 3-4 Units.
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.

GES 101. Environmental and Geological Field Studies in the Rocky Mountains. 3 Units.
Three-week, field-based program in the Greater Yellowstone/Teton and Wind River Mountains of Wyoming. Field-based exercises covering topics including: basics of structural geology and petrology; glacial geology; western cordillera geology; paleoclimatology; chemical weathering; aqueous geochemistry; and environmental issues such as acid mine drainage and changing land-use patterns. Same as: EARTHSYS 100, EESS 101

GES 102. Earth Materials: Introduction to Mineralogy. 4 Units.
The minerals and materials that comprise the earth and their uses in modern society. How to identify, classify, and interpret rock-forming minerals. Emphasis is on information provided by common minerals about the nature of the Earth's interior and processes such as magmatism and metamorphism that operate there, as well as the major processes of weathering and erosion that link plate tectonics to earth cycles. Required lab section. Prerequisite: introductory geology course. Recommended: introductory chemistry.

GES 103. Earth Materials: Rocks in Thin Section. 3 Units.
Use of petrographic microscope to identify minerals and common mineral associations in igneous, metamorphic, and sedimentary rocks. Crystallization histories, mineral growth and reaction relations, deformation textures in metamorphic rocks, and provenance of siliciclastic rocks. Prerequisite 102.

GES 104. Introduction to Petrology. 4 Units.
The origin of different rock types as a function of geologic and plate tectonic setting. How to identify rocks and interpret their conditions of formation. Required lab section. Prerequisite: introductory geology course; GES102.

GES 105. Introduction to Field Methods. 3 Units.
Two-week, field-based course in the White Mountains of eastern California. Introduction to the techniques for geologic mapping and geologic investigation in the field: systematic observations and data collection for lithologic columns and structural cross-sections. Interpretation of field relationships and data to determine the stratigraphic and deformational history of the region. Prerequisite: GES 1, recommended: GES 102.

GES 107. Journey to the Center of the Earth. 3 Units.
The interconnected set of dynamic systems that make up the Earth. Focus is on fundamental geophysical observations of the Earth and the laboratory experiments to understand and interpret them. What earthquakes, volcanoes, gravity, magnetic fields, and rocks reveal about the Earth's formation and evolution. Offered every other year, winter quarter. Next offering Winter 2013-14.
Same as: GEOPHYS 184, GEOPHYS 274, GES 207

GES 110. Structural Geology and Tectonics. 3-5 Units.
Theory, principles, and practical techniques to measure, describe, analyze, and interpret deformation-related structures on Earth. Collection of fault and fold data in the field followed by lab and computer analysis; interpretation of geologic maps and methods of cross-section construction; structural analysis of fault zone and metamorphic rocks; measuring deformation; regional structural styles and associated landforms related to plate tectonic convergence, rifting, and strike-slip faulting; the evolution of mountain belts and formation of sedimentary basins. Prerequisite: GES 1, calculus. Recommended: 102.

GES 111. Fundamentals of Structural Geology. 3 Units.
Techniques for mapping using GPS and differential geometry to characterize structures; dimensional analysis and scaling relations; kinematics of deformation and flow; measurement and analysis of stress; elastic deformation and properties of rock; brittle deformation including fracture and faulting; linear viscous flow including folding and magma dynamics; model development and methodology. Models of tectonic processes are constructed and solutions visualized using MATLAB. Prerequisites: GES 1, MATH 51.
Same as: CEE 195
GES 115. Engineering Geology and Global Change. 3 Units.
The application of geology and global change to the planning, design, and operation of engineering projects. Case histories taught in a seminar setting and field trips emphasize the impact of geology and global change on both individual engineering works and the built environment by considering Quaternary history and tectonics, anthropogenic sea level rise, active geologic processes, engineering properties of geologic deposits, site exploration, and professional ethics. Prerequisite: GES 1 or consent of instructor.
Same as: CEE 196

GES 118. Understanding Natural Hazards, Quantifying Risk, Increasing Resilience in Highly Urbanized Regions. 3 Units.
Integrating the science of natural hazards, methods for quantitatively estimating the risks that these hazards pose to populations and property, engineering solutions that might best ameliorate these risks and increase resilience to future events, and policy and economic decision-making studies that may increase long-term resilience to future events. Panel discussions by outside experts exploring the science, engineering, policy, and economics that underly the hazards, risks, and strategies for increasing resilience. Group assignments to evaluate the way in which natural hazards, and human population and developing interact in megacities to produce risk, and what strategies might be adopted in each area to reduce risks posed by the specific hazards faced by these urban areas.
Same as: EESS 118, EESS 218, GEOPHYS 118, GEOPHYS 218, GES 218

GES 119. A Solar System Odyssey: Introduction to Planetary Geology. 3 Units.
How could planetary bodies such as Earth, Moon and Mars form so close together, with such similar starting products have such drastically different outcomes? Did Mars ever have standing water? Does Europa have a subsurface ocean teeming with life? In this course, you will study the formation and evolution of planets and moons, and how differences such as mass and composition have led to a diverse selection of terrain. Through our exploration of selected topics in planetary geology (volcanism, cratering, tectonics), we will actively debate contemporary controversies in planetary geology. GES 1 required or permission of the instructor.

GES 120. Planetary and Early Biological Evolution Seminar. 2-3 Units.
Interdisciplinary. For upper division science undergraduates and graduate students. Synthesis of biology, geology, physics, and chemistry. Recent approaches for identifying traces of past life on Earth. How to look for life on other planets such as Mars, Europa, and Titan. May be repeated for credit.
Same as: GES 220

GES 121. What Makes a Habitable Planet? 3 Units.
Physical processes affecting habitability such as large impacts and the atmospheric greenhouse effect, comets, geochemistry, the rise of oxygen, climate controls, and impact cratering. Detecting and interpreting the spectra of extrasolar terrestrial planets. Student-led discussions of readings from the scientific literature. Team taught by planetary scientists from NASA Ames Research Center.
Same as: GES 221

GES 122. Planetary Systems: Dynamics and Origins. 3-4 Units.
(Students with a strong background in mathematics and the physical sciences should register for 222.) Motions of planets and smaller bodies, energy transport in planetary systems, composition, structure and dynamics of planetary atmospheres, cratering on planetary surfaces, properties of meteorites, asteroids and comets, extrasolar planets, and planetary formation. Prerequisite: some background in the physical sciences, especially astronomy, geophysics, or physics.

GES 123. Paleobiology. 4 Units.
Introduction to the fossil record with emphasis on marine invertebrates. Major debates in paleontological research. The history of animal life in the oceans. Topics include the nature of the fossil record, evolutionary radiations, mass extinctions, and the relationship between biological evolution and environmental change. Fossil taxa through time. Exercises in phylogenetics, paleoecology, biostratigraphy, and statistical methods.
Same as: EARTH SYS 122

GES 128. Evolutionary History of Terrestrial Ecosystems. 4 Units.
The what, when, and how do we know it regarding life on land? Including plants, fungi, invertebrates, and vertebrates (yes, dinosaurs) and how all of those components interact with each other and with changing climates, continental drift, atmospheric composition, and environmental perturbations like glaciation and mass extinction.
Same as: EARTH SYS 128, GES 228

GES 130. Soil Physics and Hydrology. 3 Units.

GES 131. Hydrologically-Driven Landscape Evolution. 3 Units.

GES 150. Senior Seminar: Issues in Earth Sciences. 3 Units.
Focus is on written and oral communication in a topical context. Topics from current frontiers in earth science research and issues of concern to the public. Readings, oral presentations, written work, and peer review.
Same as: GEOPHYS 199

GES 151. Sedimentary Geology and Petrography: Depositional Systems. 4 Units.
Topics: weathering, erosion and transportation, deposition, origins of sedimentary structures and textures, sediment composition, diagenesis, sedimentary facies, tectonics and sedimentation, and the characteristics of the major siliciclastic and carbonate depositional environments. Lab: methods of analysis of sediments in hand specimen and thin section. Field trips. Prerequisites: 1, 102, 103.

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

GES 170. Environmental Geochemistry. 4 Units.
Solid, aqueous, and gaseous phases comprising the environment, their natural compositional variations, and chemical interactions. Contrast between natural sources of hazardous elements and compounds and types and sources of anthropogenic contaminants and pollutants. Chemical and physical processes of weathering and soil formation. Chemical factors that affect the stability of solids and aqueous species under earth surface conditions. The release, mobility, and fate of contaminants in natural waters and the roles that water and dissolved substances play in the physical behavior of rocks and soils. The impact of contaminants and design of remediation strategies. Case studies. Prerequisite: 90 or consent of instructor.
Same as: EARTH SYS 170, GES 270
GES 171. Geochemical Thermodynamics. 3 Units.
Introduction to the application of chemical principles and concepts to geologic systems. The chemical behavior of fluids, minerals, and gases using simple equilibrium approaches to modeling the geochemical consequences of diagenetic, hydrothermal, metamorphic, and igneous processes. Topics: reversible thermodynamics, solution chemistry, mineral-solution equilibria, reaction kinetics, and the distribution and transport of elements by geologic processes. Prerequisite: GES 102.

GES 180. Igneous Processes. 4 Units.
For juniors, seniors and beginning graduate students in Earth Sciences. Structure and physical properties of magmas; use of phase equilibria and mineral barometers and thermometers to determine conditions of magmatic processes; melting and magmatic lineages as a function of tectonic setting; processes that control magma composition including fractional crystallization, partial melting, and assimilation; petrogenetic use of trace elements and isotopes. Labs emphasize identification of volcanic and plutonic rocks in thin section and interpretation of rock textures. Prerequisite 102, 103, or consent of instructor.

GES 181. Metamorphic Processes. 3-5 Units.
For juniors, seniors and beginning graduate students in Earth Sciences. Thermodynamics and phase equilibria of multiple component systems; use of phase equilibria to determine pressure and temperature of metamorphic assemblages; geochronology of metamorphic rocks; heat flow in the lithosphere; links between tectonics and metamorphism; and the role of heat and mass transfer in the Earth's crust and mantle. Labs emphasize identification of metamorphic rocks and minerals for common pelitic and basic rocks and interpretation of rock textures. May be taken for 3 units without lab. Prerequisites: 102, 103, or consent of instructor.

GES 183. California Desert Geologic Field Trip. 1 Unit.
Field seminar. Three class meetings during Winter quarter followed by a 6-day field trip over Spring Break to Mojave Desert, Death Valley, and Owens Valley. Basin-and-range faulting, alluvial fans, playas, sand dunes, metamorphic rocks, granites of the Sierra Nevada, lava flows and and the deposits of supervolcanic eruptions, hot springs, ore deposits, and desert landscapes. Involves camping and some hiking. Recommended: introductory geology. Enrollment limited to 25 students; preference given to freshman and sophomores; additionally graduate students in the School of Earth Sciences.

GES 184. Field Seminar on Eastern Sierran Volcanism. 1 Unit.
For nonmajors and prospective majors in the earth sciences and archaeology. Four-day trip over Memorial Day weekend to study silicic and mafic volcanism in the eastern Sierra Nevada: basaltic lavas and cinder cones erupted along normal faults bounding Owens Valley; Long Valley caldera, postcaldera rhyolite lavas, hydrothermal alteration and hot springs, Holocene rhyolite lavas of the Inyo and Mono craters, subaqueous basaltic cones erupted along normal faults bounding Owens Valley, Long Valley caldera, postcaldera rhyolite lavas, hydrothermal alteration and hot springs, Holocene rhyolite lavas of the Inyo and Mono craters, subaqueous basaltic cones erupted along normal faults bounding Owens Valley. Recommended: 1 or equivalent.

GES 185. Volcanology. 3-4 Units.
For juniors, seniors, and beginning graduate students in earth sciences. Eruptive processes that create volcanic deposits and landforms; relation to physical properties of magmas. Volcanic hazards and the effects of eruptions on climate; volcanic-hosted geothermal systems and mineral resources. Required 4-day field trip over Memorial Day weekend to study silicic and mafic volcanism in the eastern Sierra Nevada. Those taking the class for 4 units will complete a 3-hour weekly lab involving hand specimen and thin section identification and interpretation, which emphasizes recognizing types of lavas and products of explosive eruptions. Prerequisite: 1, for those taking the course for 3 units; 103 and 104 or equivalent for those taking the course for 4 units.

GES 190. Research in the Field. 3 Units.
Two to three-week long courses that provide students with the opportunity to collect data in the field as part of a team-based investigation of research questions or topics under the expert guidance of knowledgeable faculty and graduate students. Topics and locations vary. May be taken multiple times for credit. Prerequisites: GES 1, GES 102, GES 105.

GES 191. GES Field Trips. 1 Unit.
Four- to seven-day field trips to locations of geologic and environmental interest. Includes trips offered during Thanksgiving and Spring breaks. May be repeated for credit. See http://pangea.stanford.edu/GES/undergraduates/courses/.
Same as: EARTHSCI 191

GES 192. Undergraduate Research in Geological and Environmental Sciences. 1-10 Unit.
Field-, lab-, or literature-based. Faculty supervision. Written reports. May be repeated for credit.

GES 197. Senior Thesis. 3-5 Units.
For seniors who wish to write a thesis based on research in 192 or as a summer research fellow. May not be repeated for credit; may not be taken if enrolled in 199.

GES 198. Special Problems in Geological and Environmental Sciences. 1-10 Unit.
Reading and instruction under faculty supervision. Written reports. May be repeated for credit.

GES 199. Honors Program. 1-10 Unit.
Research on a topic of special interest. See "Undergraduate Honors Program” above.
May be repeated for credit.

GES 204. Introduction to Petrology. 4 Units.
The origin of different rock types as a function of geologic and plate tectonic setting. How to identify rocks and interpret their conditions of formation. Required lab section. Prerequisite: introductory geology course; GES102.
Same as: GES 104

GES 204A. Extraordinary Glimpses of Past Life. 1 Unit.
Soft bodied fossils are a major source of information on the history of life. Focus on exceptional preservation and the factors that contribute to and control it. Topics include: exceptionally preserved biotas, experimental taphonomy, ediacaran death masks, Burgess Shale-type preservation, the Herefordshire fossils, Mazon Creek, fossils in glass, the preservation of color, and conodonts.

GES 206. Topics in Organismal Paleobiology. 2-3 Units.
Seminar course covering an area of structural biology, physiology, and ecology relevant to understanding the fossil record. Topic will change each time the course is offered. Examples of potential topics are biomineralization, fluid mechanics, biomechanics, taphonomy & biochemical preservation, and photosynthesis in air and water.

GES 207. Journey to the Center of the Earth. 3 Units.
The interconnected set of dynamic systems that make up the Earth. Focus is on fundamental geophysical observations of the Earth and the laboratory experiments to understand and interpret them. What earthquakes, volcanoes, gravity, magnetic fields, and rocks reveal about the Earth’s formation and evolution. Offered every other year, winter quarter. Next offering Winter 2013-14.
Same as: GEOPHYS 184, GEOPHYS 274, GES 107

GES 208. Topics in Geobiology. 1 Unit.
Reading and discussion of classic and recent papers in the field of Geobiology. Co-evolution of Earth and life; critical intervals of environmental and biological change; geomicrobiology; paleobiology; global biogeochemical cycles; scaling of geobiological processes in space and time.
Same as: EESS 208
GES 210. Geologic Evolution of the Western U.S. Cordillera. 1-3 Unit.
The geologic and tectonic evolution of the U.S. Cordillera based on its rock record through time. This region provides good examples of large-scale structures and magmatic activity generated during crustal shortening, extension, and strike-slip faulting and affords opportunity to study crustal-scale processes involved in mountain building in context of plate tectonic motions.

GES 211. Topics in Regional Geology and Tectonics. 2-3 Units.
May be repeated for credit.

GES 212. Topics in Tectonic Geomorphology. 2 Units.
For upper-division undergraduates and graduate students. Topics vary and may include coupling among erosional, tectonic, and chemical weathering processes at the scale of orogens; historical review of tectonic geomorphology; hillside and fluvial process response to active uplift; measures of landscape form and their relationship to tectonic uplift and bedrock lithology. May be repeated for credit.

GES 213. Topics in Sedimentary Geology. 2 Units.
For upper division undergraduates and graduate students. Topics vary each year but the focus is on current developments and problems in sedimentary geology, sedimentology, and basin analysis. These include issues in deep-water sediments, their origin, facies, and architecture; sedimentary systems on the early Earth; and relationships among tectons, basin development, and basin fill. May be repeated for credit.

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

GES 215. Structural Geology and Rock Mechanics. 4 Units.
Quantitative field and laboratory data integrated with solutions to boundary value problems of continuum mechanics to understand tectonic processes in Earth's crust that lead to the development of geological structures including folds, faults, fractures and fabrics. Topics include: techniques and tools for structural mapping; differential geometry to characterize structures; dimensional analysis and scaling relations; kinematics of deformation and flow; traction and stress analysis; conservation of mass and momentum in a deformable continuum; linear elastic deformation and stress; brittle deformation including fracture and faulting; model development and methodology. Data sets analyzed using MATLAB. Prerequisites: GES 1, MATH 53, MATLAB or equivalent. Same as: CEE 297R, GEOPHYS 251

GES 216. Rock Fracture Mechanics. 3 Units.
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.

GES 217. Faults, Fractures, and Fluid Flow. 3 Units.
Process-based approach to rock failure; the microstructures and overall architectures of the failure products including faults, joints, solution seams, and types of deformation bands. Fluid flow properties of these structures are characterized with emphasis on sealing and transmitting of faults and their role in hydrocarbon flow, migration, and entrapment. Case studies of fracture characterization experiments in aquifers, oil and gas reservoirs, and waste repository sites. Guest speakers; weekend field trip. Prerequisite: first-year graduate student in Earth Sciences.

GES 218. Understanding Natural Hazards, Quantifying Risk, Increasing Resilience in Highly Urbanized Regions. 3 Units.
Integrating the science of natural hazards, methods for quantitatively estimating the risks that these hazards pose to populations and property, engineering solutions that might best ameliorate these risks and increase resilience to future events, and policy and economic decision-making studies that may increase long-term resilience to future events. Panel discussions by outside experts exploring the science, engineering, policy, and economics that underly the hazards, risks, and strategies for increasing resilience. Group assignments to evaluate the way in which natural hazards, and human population and developing interact in megacities to produce risk, and what strategies might be adopted in each area to reduce risks posted by the specific hazards faced by these urban areas. Same as: EESS 118, EESS 218, GEOPHYS 118, GEOPHYS 218, GES 118

GES 220. Planetary and Early Biological Evolution Seminar. 2-3 Units.
Interdisciplinary. For upper division science undergraduates and graduate students. Synthesis of biology, geology, physics, and chemistry. Recent approaches for identifying traces of past life on Earth. How to look for life on other planets such as Mars, Europa, and Titan. May be repeated for credit. Same as: GES 120

GES 221. What Makes a Habitable Planet?. 3 Units.
Physical processes affecting habitability such as large impacts and the atmospheric greenhouse effect, comets, geochemistry, the rise of oxygen, climate controls, and impact cratering. Detecting and interpreting the spectra of extrasolar terrestrial planets. Student-led discussions of readings from the scientific literature. Team taught by planetary scientists from NASA Ames Research Center. Same as: GES 121

GES 222. Planetary Systems: Dynamics and Origins. 3-4 Units.
(For students with a strong background in mathematics and the physical sciences; other should register for 122.) Motions of planets, moons, and small bodies; energy transport in planetary systems; meteorites and the constraints they provide on the formation of the solar system; asteroids and Kuiper belt objects; comets; planetary rings; planet formation; and extrasolar planets. In-class presentation of student papers. Prerequisite: 222, or consent of instructor. Same as: GEOPHYS 183, GEOPHYS 223

GES 224. Modeling Transport and Transformations in the Environment. 2-3 Units.
An introduction to geochemical and reactive transport modeling using Geochemist's Workbench and other appropriate models. Working knowledge of geochemical and hydrologic principles is assumed. Throughout the quarter the students will use the principles and tools to develop and analyze an environmental problem as part of a simulated consulting exercise. Topics covered include contaminant transport, mineral dissolution/precipitation and aquifer microbiology. An additional focus of the course will be to develop presentation skills through practice, feedback and discussions. Prerequisites: Either EESS 221 (CEE 260C) or EESS 220 (CEE 260A) and either GES 90, 170, or 171, or permission from instructors.
GES 225. Contaminant Hydrogeology and Reactive Transport. 4 Units.
For earth scientists and engineers. Environmental, geologic, and water resource problems involving migration of contaminated groundwater through porous media and associated biogeochemical and fluid-rock reactions. 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 reactive transport modeling using geochemical transport software. Some Matlab programming / program modification required. Prerequisite: Physical Hydrogeology EESS 220 / CEE 260A (Gorelick) or equivalent. Recommended: course work in environmental chemistry or geochemistry (e.g., one or more of the following: EESS 155, EESS 156/256, GE 90, GE 170/279, GE 171, CEE 177 or CEE 270). Same as: CEE 260C, EESS 221

GES 226. At the intersection of geochemistry, sedimentary geology, and paleobiology. 3 Units.
Recent work in geochemistry, sedimentary geology, and paleobiology increasingly supports the notion that common geological factors control long-term biogeochemical cycles, the erosion and deposition of sedimentary rocks, and the evolution of the marine biosphere. During this course students will read and discuss recent primary literature addressing the possible mechanisms underlying these patterns. Questions addressed will include: Why do sedimentary rock area and biodiversity covary? How are these records linked to biogeochemical cycles, as inferred from the stable isotope compositions of elements such as carbon and sulfur? What are the relative roles of biotic interactions vs. physical environmental changes in shaping the macroevolutionary history of life?.

GES 227. Modern Turbidite Systems as Analogues for Deep-water Petroleum Plays. 3 Units.
This seminar is designed for earth science upperclassmen and graduate students. Marine geophysical and geological techniques will be used to illustrate and understand source-to-sink characteristics of modern turbidite systems. The course will examine a wide variety of small-scale base-of-apron (km) to large-scale (100's of km) sand-rich to mud-rich systems. New research on mass transport deposits, hybrid beds, and turbidite paleoecology will be presented. Variations in turbidite system architecture, that are dependent upon tectonic setting, sediment supply, climate, sea level change, and contour currents will be discussed. The utility and pitfalls of model-driven approaches are also explored. Same as: EESS 227

GES 228. Evolutionary History of Terrestrial Ecosystems. 4 Units.
The what, when, and how do we know it regarding life on land? iquest;including plants, fungi, invertebrates, and vertebrates (yes, dinosaurs) iquest;and how all of those components interact with each other and with changing climates, continental drift, atmospheric composition, and environmental perturbations like glaciation and mass extinction. Same as: EARTHY SY 128, GE 128

GES 237. Surface and Near-Surface Hydrologic Response. 3 Units.
Quantitative review of process-based hydrology and geomorphology. Introduction to finite-difference and finite-element methods of numerical analysis. Topics: climate, energy, and environmental processes, soil physics, and surface water hydrology. Links to climate, energy, and environmental processes. Topics: climate, energy, and environmental processes, soil physics, and surface water hydrology. Same as: CEE 260B

GES 238. Soil Physics. 3 Units.
Physical properties of the soil solid phase emphasizing the transport, retention, and transformation of water, heat, gases, and solutes in the unsaturated subsurface. Field experiments.
GES 253. Petroleum Geology and Exploration. 3 Units.
The origin and occurrence of hydrocarbons. Topics: thermal maturation history in hydrocarbon generation, significance of sedimentary and tectonic structural setting, principles of accumulation, and exploration techniques. Prerequisites: 110, 151. Recommended: GEOPHYS 223.

GES 254. Carbonate Sedimentology. 3-4 Units.
Processes of precipitation and sedimentation of carbonate minerals with emphasis on marine systems. Topics include: geographic and bathymetric distribution of carbonates in modern and ancient oceans; genesis and environmental significance of carbonate grains and sedimentary textures; carbonate rocks and sediments as sources of geochemical proxy data; carbonate diagenesis; changes in styles of carbonate deposition through Earth history; carbonate depositional patterns and the global carbon cycle. Lab exercises emphasize petrographic and geochemical analysis of carbonate rocks including map and outcrop scale, hand samples, polished slabs, and thin sections.

GES 255. Basin and Petroleum System Modeling. 3 Units.
For advanced undergraduates or graduate students. Students use stratigraphy, subsurface maps, and basic well log, lithologic, paleontologic, and geochemical data to construct 1-D, 2-D, and 3-D models of petroleum systems that predict the extent of source-rock thermal maturity, petroleum migration paths, and the volumes and compositions of accumulations through time (4-D). Recent software such as PetroMod designed to reconstruct basin geohistory. Recommended: 251 or 253.

GES 256. Quantitative Methods in Basin and Petroleum System Modeling. 1-3 Unit.
Examine the physical processes operating in sedimentary basins by deriving the basic equations of fundamental, coupled geologic processes such as fluid flow and heat flow, deposition, compaction, mass conservation, and chemical reactions. Through hands-on computational exercises and instructor-provided "recipes," students will deconstruct the black box of basin modeling software. Students write their own codes (Matlab) as well as gain expertise in modern finite-element modeling software (PetroMod, COMSOL).
Same as: ENERGY 275

GES 257. Clastic Sequence Stratigraphy. 3 Units.
Sequence stratigraphy facilitates integration of all sources of geologic data, including seismic, log, core, and paleontological, into a time-stratigraphic model of sediment architecture. Tools applicable to regional and field scales. Emphasis is on practical applications and integration of seismic and well data to exploration and field reservoir problems. Examples from industry data; hands-on exercises.

GES 258. Introduction to Depositional Systems. 3 Units.
The characteristics of the major sedimentary environments and their deposits in the geologic record, including alluvial fans, braided and meandering rivers, aeolian systems, deltas, open coasts, barred coasts, marine shelves, and deep-water systems. Emphasis is on subdivisions; morphology; the dynamics of modern systems; and the architectural organization and sedimentary structures, textures, and biological components of ancient deposits.

GES 259. Stratigraphic Architecture. 1 Unit.
The stratigraphic architecture of deposits associated with a spectrum of depositional environments, using outcrop and subsurface data. Participants read and discuss selected literature.

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

GES 261. Physics and Chemistry of Minerals and Mineral Surfaces. 4 Units.
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.

GES 262. Thermodynamics and Disorder in Minerals and Melts. 3 Units.
The thermodynamic properties of crystalline, glassy, and molten silicates and oxides in light of microscopic information about short range structure and ordering. Measurements of bulk properties such as enthalpy, density, and their pressure and temperature derivatives, and structural determination by spectroscopies such as nuclear magnetic resonance and Mössbauer. Basic formulations for configurational entropy, heats of mixing in solid solutions, activities; and the energetics of exsolution, phase transitions, and nucleation. Quantitative models of silicate melt thermodynamics are related to atomic-scale views of structure. A general view of geothermometry and geobarometry. Prerequisites: introductory mineralogy and thermodynamics.

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

GES 264. Mathematical Modeling in Biogeochemistry. 3 Units.
The basics of translating a conceptual model into a numerical model is presented. Emphasis on building models, box modeling, methods of solving models. Lab exercises draw from examples in biogeochemistry, including modeling global biogeochemical cycles, sediment biogeochemistry, and microbial processes.

GES 266. Managing Nuclear Waste: Technical, Political and Organizational Challenges. 3 Units.
The essential technical and scientific elements of the nuclear fuel cycle, focusing on the sources, types, and characteristics of the nuclear waste generated, as well as various strategies for the disposition of spent nuclear fuel - including reprocessing, transmutation, and direct geologic disposal. Policy and organizational issues, such as: options for the characteristics and structure of a new federal nuclear waste management organization, options for a consent-based process for locating nuclear facilities, and the regulatory framework for a geologic repository. A technical background in the nuclear fuel cycle, while desirable, is not required.
Same as: IPS 266
GES 267. Solution-Mineral Equilibria: Theory. 3 Units.
Procedures for calculating and evaluating the thermodynamic properties of reversible and irreversible reactions among rock-forming minerals and aqueous solutions in geologic systems. Emphasis is on the generation and utility of phase diagrams depicting solution-mineral interaction relevant to phase relations associated with weathering diagenetic, hydrothermal, and metamorphic processes, and the prediction of temperature, pressure, and the chemical potential of thermodynamic components compatible with observed mineralogic phase relations in geologic outcrops. Individual research topics. Prerequisite: 171.

GES 270. Environmental Geochemistry. 4 Units.
Solid, aqueous, and gaseous phases comprising the environment, their natural compositional variations, and chemical interactions. Contrast between natural sources of hazardous elements and compounds and types and sources of anthropogenic contaminants and pollutants. Chemical and physical processes of weathering and soil formation. Chemical factors that affect the stability of solids and aqueous species under earth surface conditions. The release, mobility, and fate of contaminants in natural waters and the roles that water and dissolved substances play in the physical behavior of rocks and soils. The impact of contaminants and design of remediation strategies. Case studies. Prerequisite: 90 or consent of instructor.
Same as: EARTHSYS 170, GES 170

GES 272. Biominaleralization. 3 Units.
The functional properties of many animal and plant skeletons are dependent largely on mineralization. The relationship between mineralization processes and adaptation for all the animal phyla is reviewed. The sedimentologic contribution of mineralized skeletons, especially in carbonate reefs and pelagic sedimentation is considered. Synthesis of organic matrix and the composite nature of many animal and plant skeletons, and their development and morphogenesis are described. The mechanisms of crystal nucleation and growth are considered. The macroevolutionary history of biominaleralization, and mass extinctions and the diversification of well skeletonized groups in the geologic record are considered.

GES 273. Isotope Geochemistry Seminar. 1-3 Unit.
Current topics including new analytical techniques, advances in isotopic measurements, and new isotopic approaches and systems. May be repeat for credit for total completion of 5 and total unit allowed 15.

GES 275. Electron Probe Microanalytical Techniques. 2-3 Units.
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.

GES 276. Earth's Weathering Engine. 3 Units.
The complex interactions between the chemical, biological, hydrologic and tectonic process that control the chemical and isotopic flux of material to the oceans, and ultimately the long-term composition of both the atmosphere and the hydrosphere. Through a literature review and discussions students will identify key outstanding questions regarding global chemical weathering fluxes. Through data collection, data analysis, and application of appropriate modeling tools students will produce novel analyses and conclusions regarding the operation of the Earth's weathering engine. Permission of instructor required.

GES 277. Flood Basalts and Mass Extinctions. 3 Units.
Recent work in geochronology and paleobiology supports the temporal coincidence of the eruption of continental flood basalts with mass extinction in the marine and terrestrial realms. The mechanisms and timescale of flood basalt eruptions, their likely environmental and biological consequences, and the evidence for flood basalt eruptions as the triggers of many mass extinction events. Sources include recent primary literature.

GES 278. Mantle Processes. 1-3 Unit.
The mantle is the largest reservoir on Earth and is fundamental to a variety of plate tectonic processes, from convection to the generation of crust. This course reviews current knowledge of the mantle based on the geochemistry and rheology of rocks derived from the upper mantle. Focus is on processes at ocean ridges and subduction zones. The tools used for studying the mantle, including radiogenic isotopes, trace elements, melting equations, diffusion coefficients and rheological flow laws, are explored in detail. Prerequisites: basic geology, petrology and chemistry or consent of the instructor.

GES 281. Principles of 40Ar/39Ar Thermochronometry. 3-4 Units.
The 40Ar/39Ar method is based upon the K-Ar decay scheme and allows high precision geochronology and thermochronology to be performed with K-bearing minerals. Provides a detailed exploration of the method including all practical considerations and laboratory procedures for standardization and instrument calibration. A laboratory component allows practical experience in making measurements and interpreting results.

GES 282. Interpretative Methods in Detrital Geochronology. 3 Units.
Over the past decade, the number of studies that make use of isotopic provenance data has sky-rocketed. This type of data is now routinely used throughout the geosciences to solve a broad range of geologic problems. This seminar examines the state-of-the-art of existing interpretative methods for detrital geo/thermochronology data in provenance studies and critically examines their strengths and weaknesses. While this course will touch upon sampling approaches analytical aspects of data collection, focus is primarily upon data interpretation.

GES 283. Thermochronology and Crustal Evolution. 4 Units.
Thermochronology analyzes the competition between radioactive ingrowth and temperature-dependant loss of radiogenic isotopes within radioactive mineral hosts in terms of temperature-time history. Coupled with quantitative understanding of kinetic phenomena and crustal- or landscape-scale interpretational models, thermochronology provides an important source of data for the Earth Sciences, notably tectonics, geomorphology, and petrogenesis. Focus on recent developments in thermochronology, specifically analytical and interpretative innovations developed over the past decade. Integrates the latest thermochronology techniques with field work in a small-scale research project focused upon crustal evolution.

GES 284. Field Seminar on Eastern Sierran Volcanism. 1 Unit.
For graduate students in the earth sciences and archaeology. Four-day trip over Memorial Day weekend to study silicic and mafic volcanism in the eastern Sierra Nevada: basaltic lavas and cinder cones erupted along normal faults bounding Owens Valley, Long Valley caldera, postcaldera rhyolite lavas, hydrothermal alteration and hot springs, Holocene rhyolite lavas of the Inyo and Mono craters, subaqueous basaltic and silicic eruptions of Mono Basin, floating pumice blocks. If snow-level permits, silicic volcanism associated with the Bodie gold district. Recommended: 1 or equivalent.

GES 285. Igneous Petrogenesis of the Continents. 2-4 Units.
Radiogenic isotopes, stable isotopes, and trace elements applied to igneous processes; interaction of magmas with mantle and crust; convergent-margin magmatism; magmatism in extensional terrains; origins of rhyolites; residence times of magmas and magma chamber processes; granites as imperfect mirrors of their source regions; trace element modeling of igneous processes; trace element discriminant diagrams in tectonic analysis; phase equilibria of partial melting of mantle and crust; geothermometry and geobarometry. Topics emphasize student interest. Prerequisite: 180 or equivalent.
GES 286. Secondary Ionization Mass Spectrometry. 3 Units.
Secondary ionization mass spectrometry (SIMS) is a versatile method capable of performing elemental and isotopic analysis in the solid-state at the nanogram to picogram scale. SIMS offers the most favorable combination of high spatial resolution, sensitivity, and mass resolving power. This course explores the ion optics of the primary and secondary columns of SIMS instruments and explains instrumental mass fractionation and standardization methods for both positive and negative secondary ions. Ion imaging and depth profiling approaches are also covered. Practical experience using Stanford's SHRIMP-RG and NanoSIMS instruments is provided.

GES 287. Fundamentals of Mass Spectrometry. 3 Units.
This course explains ion creation, mass separation, and ion detection in mass spectrometry methods commonly used in the Earth Sciences. Gas source (C-O-H-S stable isotope, 40Ar/39Ar, and (U-Th)-He), secondary ionization (SIMS), laser ablation and solution-based mass inductively coupled (ICP-MS) and thermal ionization (TIMS) mass spectrometry techniques are also explored. Additional topics include ion optics, vacuum generation, and pressure measurement, instrument calibration, data reduction, and error propagation methods.

GES 290. Departmental Seminar in Geological and Environmental Sciences. 1 Unit.
Current research topics. Presentations by guest speakers from Stanford and elsewhere. May be repeated for credit.

GES 291. GES Field Trips. 1 Unit.
Field trips for teaching and research purposes. Trips average 5-10 days. Prerequisite: consent of instructor.

GES 292. Directed Reading with Geological and Environmental Sciences Faculty. 1-10 Unit.
May be repeated for credit.

GES 299. Field Research. 2-4 Units.
Two-three week field research projects. Written report required. May be repeated three times.

GES 310. Climate Change, Climate Variability, and Landscape Development. 1 Unit.
The impact of long-term climate change on erosional processes and the evolution of Cenozoic landscapes. Climate data that highlight recurring climate variability on inter-annual to decadal timescales. The behavior of climate on multi-decadal to tectonic timescales over which significant changes in topography take place. The effects of climate change and variability on landscape development, sedimentary environments, and the deposits of these events. May be repeated for credit.

GES 311. Interpretation of Tectonically Active Landscapes. 3 Units.
Focuses on interpreting various topographic attributes in terms of horizontal and vertical tectonic motions. Topics include identification, mapping, and dating of geomorphic markers, deducing tectonic motions from spatial changes in landscape steepness, understanding processes that give rise to different landscape elements, interrogating the role of climate and lithology in producing these landscape elements, and understanding relationships between tectonic motions, surface topography, and the spatial distribution of erosion. Consists of two one hour lectures per week and one laboratory section that help students gain proficiency in Quaternary mapping and interpretation of topographic metrics.

GES 312. Analysis of Landforms. 3 Units.
Quantitative methods to analyze digital topography and to interpret rates of tectonic and geomorphic processes from topographic metrics. Topics include analysis of digital topography using local and neighborhood-based methods, spectral methods, and wavelet methods. Course consists of two one hour lectures per week and one laboratory section that will help students gain proficiency in calculating topographic metrics using ArcGIS and Matlab.

GES 313. Modeling of Landforms. 3 Units.
Geomorphic-transport-rule-based, as well as mass- and momentum-conservation based models to understand the evolution of Earthquakes topography. Topics include formulation of land-sculpting processes as geomorphic transport rules, coupling this mass-conservation approach with mechanical models of crustal deformation, and analysis of landscape forms in terms of events for which mass and momentum of fluid and sediment can be conserved. Both analytical, as well as numerical (finite-volume) treatments of particular problems in tectonic geomorphology will be covered. The specific problems addressed as part of the course will be tailored to those currently investigated by class participants.

GES 315. Literature of Structural Geology. 1 Unit.
Classic studies and current journal articles. May be repeated for credit.

GES 325. The Evolution of Body Size. 2 Units.
Preference to graduate students and upper-division undergraduates in GES and Biology. The influence of organism size on evolutionary and ecological patterns and processes. Focus is on integration of theoretical principles, observations of living organisms, and data from the fossil record. What are the physiological and ecological correlates of body size? Is there an optimum size? Do organisms tend to evolve to larger size? Does productivity control the size distribution of consumers? Does size affect the likelihood of extinction or speciation? How does size scale from the genome to the phenotype? How is metabolic rate involved in evolution of body size? What is the influence of geographic area on maximum body size?.
Same as: BIO 325

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

GES 336. Stanford Alpine Project Seminar. 1 Unit.
Seminar on the geology of Italy. Weekly student presentations on continental collision tectonics, sedimentology, petrology, geomorphology, climate, culture, and other topics of interest. Students create a guidebook of geologic stops in advance of field trip. May be repeated for credit.

GES 340. Seminar on the Earth's Interior. 1 Unit.
Seminar to review and discuss current research in mineral physics, seismology, geochemistry and geodynamics on understanding the distribution, form, and role of volatiles in Earth's mantle.

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

GES 373. METAMORPHIC PETROLOGY. 3 Units.
Metamorphic petrology is concerned with the range of solid-state recrystallization and chemical mass transfer processes under physical conditions ranging from those prevalent at the Earth's surface to crustal melting. This course explores the phenomenology of these processes from mineralogic, textural, structural, geochemical, and geodynamic perspectives. The focus is on subduction, arc magmatic, rift magmatic and regional tectonic (collisional and extensional) settings. Important concepts and methods in phase equilibria, thermobarometry, geo/thermochronology, and fabric analysis are explored.

GES 373L. Metamorphic Petrology Laboratory. 1 Unit.
Teaches petrographic methods for characterizing recrystallization of common clastic and chemically precipitated sedimentary, mafic and felsic igneous, and ultramafic mantle rocks. Features suites from contact and regional metamorphic settings including arc magmatic, subduction, convergent, and extensional metamorphic settings.

GES 381. Igneous Petrology and Petrogenesis Seminar. 1-2 Unit.
Topics vary by quarter. May be repeated for credit.

GES 384. Volcanology Seminar. 1 Unit.
GES 384. Volcanology Seminar. 1 Unit.
GES 385. Practical Experience in the Geosciences. 1 Unit.
On-the-job training in the geosciences. May include summer internship;
emphasizes training in applied aspects of the geosciences, and technical,
organizational, and communication dimensions. Meets USCIS requirements
for F-1 curricular practical training. (Staff).

GES 399. Advanced Projects. 1-10 Unit.
Graduate research projects that lead to reports, papers, or other products
during the quarter taken. On registration, students designate faculty member
and agreed-upon units.

GES 400. Graduate Research. 1-15 Unit.
Faculty supervision. On registration, students designate faculty member and
agreed-upon units.

GES 801. TGR Project. 0 Units.

GES 802. TGR Dissertation. 0 Units.