GEOLOGY AND GEOPHYSICS

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FACULTY OF THE DEPARTMENT OF GEOLOGY AND GEOPHYSICS

Professors  Jay Ague (Chair), David Bercovici, Ruth Blake, Mark Brandon, Derek Briggs, Peter Crane, David Evans, Alexey Fedorov, Debra Fischer, Jacques Gauthier, Shun-ichiro Karato, Jun Korenaga, Mark Pagani, Jeffrey Park, Danny Rye, Brian Skinner, Ronald Smith, John Wettlaufer

Associate Professors  William Boos, Kanani Lee, Mary-Louise Timmermans

Assistant Professors  Bhart-Anjun Bhullar, Pincelli Hull, Maureen Long, Noah Planavsky, Trude Storelvmo, Mary-Louise Timmermans, Nadine Unger

Lecturers  Michael Oritaglio, Frank Robinson, Lawrence Schwartz, Catherine Skinner, Ellen Thomas

The Geology and Geophysics program prepares students for the application of scientific principles and methods to the understanding of Earth, the environment, and life on a regional and a planetary scale. Subjects range from the history of Earth and life to present-day environmental processes, integrating the study of Earth’s deep interior, tectonic plates, oceans, atmosphere, climate, land surface, natural resources, and biota. The emphasis of the curriculum is on employing basic principles from the core sciences (physics, chemistry, biology) to further an understanding of Earth’s past and present, and addressing issues relating to its future. Students gain a broad background in the natural sciences, and also select a specific track to focus their work on planetary or environmental phenomena of particular interest. The B.S. tracks emphasize hands-on research experience in fieldwork, in laboratories, or in computer modeling. While some graduates continue on to research, consulting, or industrial careers in Earth, environmental, and planetary sciences, the major’s broad scientific training prepares students for a wide variety of other paths, including medicine, law, public policy, and teaching.

B.S. degree program  Majors in the B.S. program in Geology and Geophysics choose from four tracks: Atmosphere, Ocean, and Climate; Environmental and Energy Geoscience; Paleontology and Geobiology; and Solid Earth Science. The tracks are suggested pathways to professional careers and major areas of research in geology and geophysics. Students may change tracks during their course of study with guidance from the director of undergraduate studies.

1. The Atmosphere, Ocean, and Climate track provides a comprehensive understanding of the theory, observation, and prediction of the atmosphere-ocean-climate-system. Topics range from past climate changes, including the ice ages, to present-day storms and weather, to forecasting climate change and global warming. The prerequisites are a two-term lecture sequence in chemistry (or CHEM 118), physics (PHYS 180, 181 and PHYS 165L, 166L), computing (ENAS 130 or equivalent), and mathematics through differential equations (MATH 120 or ENAS 151, and ENAS 194). The major requirements consist of at least eleven term courses, for ten and one-half course credits, beyond the prerequisites, including either the senior essay or the senior thesis. To begin study of Earth processes, majors take an introductory course in G&G, with any accompanying laboratory, selected from G&G 100; 110 or 115, and 111L; 120; or 125 and 126L. A higher-level course in G&G can be substituted with the permission of the director of undergraduate studies. Six core courses, totaling five and one-half course credits, introduce students to Earth’s climate system (G&G 140 and 141L), meteorology (G&G 322), physical oceanography (G&G 335), fluid mechanics (MENG 361), and statistics or linear algebra (STAT 230 or 238 or MATH 222). Three electives are chosen from topics in the environment and in processes that govern the atmosphere, ocean, and land surface; physics; and statistics. A list of suggested electives is available from the office of the director of undergraduate studies or on the departmental Web site (http://earth.yale.edu/academics/undergraduate-program). At least one elective must be from G&G.

2. The Environmental and Energy Geoscience track provides a scientific understanding of the natural and anthropogenic processes that shape the Earth-atmosphere-biosphere system, including energy and material flows among its components. It emphasizes comparative studies of past and current Earth processes to inform models of humankind’s role within the environment’s future. The prerequisites are broad and flexible and include a two-term lecture sequence in chemistry (or CHEM 118), and mathematics through multivariate calculus (MATH 120 or ENAS 151). Depending on their area of focus, students may choose a prerequisite in physics (PHYS 170, 171; 180, 181; or 200, 201), or they may choose cellular biology (BIOL 101 and 102, or MCD 120) and evolutionary biology (BIOL 103 and 104, or E&EB 122, or G&G 125 and 126L). The major requirements consist of at least eleven term courses, for eleven course credits, beyond the prerequisites, including either the senior essay or the senior thesis. To begin study of the Earth system, majors take two introductory courses in G&G, with any accompanying laboratories, selected from G&G 100; 110 or 115, and 111L; 120; or 140 and 141L (G&G 125 and 126L may count toward this requirement if not selected as the evolutionary biology prerequisite). Higher-level courses in G&G can be substituted with the permission of the director of undergraduate studies. Four core courses are chosen from topics in general resource use and sustainability (G&G 205), the microbiology of surface and near-surface environments (G&G 255), fossil fuels and energy transitions (G&G 274), renewable energies (G&G 275), geochemical principles (G&G 301), climate physics (G&G 332), and satellite-based image analysis (G&G 362). Four electives chosen from Geology and Geophysics, Environmental Studies (http://catalog.yale.edu/yeps/subjects-of-instruction/environmental-studies), Ecology and Evolutionary Biology (http://catalog.yale.edu/yeps/subjects-of-instruction/ecology-evolutionary-biology), engineering, or related fields provide a broad approach to scientific study of the environment. A list of suggested electives is available from the office of
the director of undergraduate studies or on the departmental Web site (http://earth.yale.edu/academics/undergraduate-program).

Electives may be chosen from the core courses, and at least two must be from G&G.

3. The Paleontology and Geobiology track focuses on the fossil record of life and evolution, geochemical imprints of life, and interactions between life and Earth. Topics range from morphology, function, relationships, and biogeography of the fossils themselves, through the contexts of fossil finds in terms of stratigraphy, sediment geochemistry, paleoecology, paleoclimate, and geomorphology, to analysis of the larger causes of paleontological, geobiological, and evolutionary patterns. Integrative approaches are emphasized that link fossil evidence with the physical and chemical evolution of Earth. The prerequisites are college-level biology (BIOL 101–104; or MCDB 120 and E&EB 122); a two-term lecture sequence in chemistry, (or CHEM 118) and mathematics through multivariate calculus (MATH 120 or ENAS 151). The major requirements consist of at least thirteen term courses, for twelve course credits, beyond the prerequisites, including either the senior essay or the senior thesis. Students take G&G 110 or 115, and 111L, to gain geological and environmental context, and they are introduced to the fossil record and evolution in G&G 125 and 126L; higher-level courses in G&G can be substituted with the permission of the director of undergraduate studies. Four core courses give majors a comprehensive background in sedimentary rocks and rock correlation (G&G 230 or equivalent), the study of evolution (G&G 250), microbiology in past and present environments (G&G 255), and statistical data analysis as applied to the life sciences (STAT 101). Four electives selected from Geology and Geophysics, Ecology and Evolutionary Biology (http://catalog.yale.edu/ycps/subjects-of-instruction/ecology-evolutionary-biology), Molecular, Cellular, and Developmental Biology (http://catalog.yale.edu/ycps/subjects-of-instruction/molecular-cellular-developmental-biology), and related fields offer students flexibility in pursuing their specific interests. A list of suggested electives is available from the office of the director of undergraduate studies or on the departmental Web site (http://earth.yale.edu/academics/undergraduate-program). At least one elective must be from G&G.

4. The Solid Earth Science track emphasizes an integrated geological, geochemical, and geophysical approach to the study of processes operating within Earth and their manifestation on the surface. It includes the structure, dynamics, and kinetics of Earth’s interior and their impacts on our environment both in the long term (e.g., the evolution of the land surface) and in the short term (e.g., the causes for natural disasters such as earthquakes, tsunamis, and volcanic eruptions). Students acquire a fundamental understanding of the solid Earth system, both as it exists today and as it has evolved over geologic time scales. The prerequisites are a two-term lecture sequence in chemistry (or CHEM 118); physics (PHYS 170, 171; 180, 181; or 200, 201); and mathematics through multivariate calculus (MATH 120 or ENAS 151). The major requirements consist of at least eleven courses, for eleven course credits, beyond the prerequisites, including either the senior essay or the senior thesis. To begin study of the Earth system, majors take two introductory courses in G&G, with any accompanying laboratories, selected from G&G 100; 110 or 115, and 111L; 120; 125 and 126L; or 140 and 141L. Higher-level courses in G&G can be substituted with the permission of the director of undergraduate studies. The core of the track consists of four courses chosen from topics in mantle dynamics, earthquakes, and volcanoes (G&G 290), mountain building and global tectonics (G&G 212), rocks and minerals (G&G 220), sedimentary rocks and processes (G&G 230 or equivalent), and geochemical principles (G&G 301). Students also select four electives in geology, geochemistry, geophysics, or related topics. A list of suggested electives is available from the office of the director of undergraduate studies or on the departmental Web site (http://earth.yale.edu/academics/undergraduate-program). Electives may be chosen from core courses, and at least two must be from G&G.

B.A. degree program The B.A. degree in Geology and Natural Resources requires fewer upper-level courses than the B.S. degree. It may be more appropriate for students who wish to major in two separate Yale programs, who study geoscience in preparation for a career in law, business, government, or environmental fields, or who decide to pursue a science major only after the freshman year. The prerequisites include mathematics (MATH 115), biology (BIOL 101 and 102, or MCDB 120, or G&G 255), and a lecture course in chemistry. The major requirements consist of at least nine term courses beyond the prerequisites. These include two courses in G&G numbered 100–150, with any accompanying laboratories; courses in natural resources (G&G 205) and geochmistry (G&G 301); and five additional courses at the 200 level or higher in Geology and Geophysics or related fields, approved by the director of undergraduate studies and including either the senior essay or the senior thesis. Course selections can be guided by any of the B.S. tracks described above.

Senior requirement Seniors in both degree programs must prepare either a senior essay based on one term of library, laboratory, or field research (G&G 492) or, with the consent of the faculty, a two-term senior thesis (G&G 490, 491), which involves innovative field, laboratory, or theoretical research. Students electing to do a senior thesis must first select a topic and obtain the consent of a faculty member to act as an adviser. They must then petition the faculty through the director of undergraduate studies for approval of the thesis proposal. The petition should be submitted by the end of the junior year. If the two-term senior thesis is elected, G&G 491 may count as an elective toward the major. A copy of each senior thesis or senior essay is made available on the departmental Web site (http://earth.yale.edu).

Selection of courses Geology and Geophysics majors may not employ the Credit/D/Fail option for prerequisites or for courses in the major. With permission of the director of undergraduate studies, acceleration credits awarded at matriculation for high scores on national or international examinations (such as Advanced Placement subject tests) may be used to satisfy prerequisites, even if the student does not choose to accelerate. Higher-level courses may, with the permission of the director of undergraduate studies, be substituted for prerequisites and for specific required courses. Qualified juniors and seniors are encouraged to enroll in graduate courses, with permission of the instructor and of the directors of graduate and undergraduate studies. Descriptions of graduate courses are available at the office of the director of undergraduate studies.
**Practical experience** In addition to prerequisites and required courses in Geology and Geophysics, candidates for the B.A. and B.S. degrees are strongly encouraged to gain practical experience in the Earth sciences. This can be done in two ways: (1) by attending a summer field course at another academic institution, or (2) by participating in summer research opportunities offered by the Department of Geology and Geophysics, by other academic institutions, or by certain government agencies and private industries. Consult the director of undergraduate studies or see the departmental Web site (http://earth.yale.edu) for further information.

**Physics and Geosciences major** The Department of Geology and Geophysics also offers a combined major with the Department of Physics. For more information, see under Physics and Geosciences (http://catalog.yale.edu/ycps/subjects-of-instruction/physics-geosciences).

**Combined B.S./M.S. degree program** Exceptionally able and well-prepared students may complete a course of study leading to the simultaneous award of the B.S. and M.S. degrees after eight terms of enrollment. See “Simultaneous Award of the Bachelor’s and Master’s Degrees” under section K, Special Arrangements (http://catalog.yale.edu/ycps/academic-regulations/special-arrangements), in the Academic Regulations. Interested students should consult the director of undergraduate studies prior to the sixth term of enrollment for specific requirements in Geology and Geophysics.

### REQUIREMENTS OF THE MAJOR

#### Prerequisites

**B.A.** — MATH 115; BIOL 101 and 102, or MCDB 120, or G&G 255; a lecture course in chem; **B.S.** — All tracks — a two-term lecture sequence in chem, or CHEM 118; **B.S.** — Atmosphere, Ocean, and Climate track — ENAS 151; **B.S.** — Solid Earth Science track — ENAS 194; **B.S.** — Environmental and Energy Geoscience track — PHYS 170, 171, or 180, 181, or 200, 201 or biology (BIOL 101 and 102, or MCDB 120; and BIOL 103 and 104, or E&EB 122, or G&G 125 and 126L); **B.S.** — Paleontology and Geobiology track — BIOL 101–104, or MCDB 120 and E&EB 122; **B.S.** — Solid Earth Science track — PHYS 170, 171, or 180, 181, or 200, 201

**Number of courses** **B.A.** — at least 9 courses beyond prereqs for letter grades (incl senior req); **B.S.** — Atmosphere, Ocean, and Climate track — at least 11 courses, for 10½ credits, beyond prereqs for letter grades (incl senior req); **B.S.** — Environmental and Energy Geoscience and Solid Earth Science tracks — at least 11 courses beyond prereqs for letter grades (incl senior req); **Paleontology and Geobiology track** — at least 13 courses, for 12 credits, beyond prereqs for letter grades (incl senior req)

**Specific courses required** **B.A.** — G&G 205, 301; **B.S.** — Atmosphere, Ocean, and Climate track — at least 11 courses, for 10½ credits, beyond prereqs for letter grades (incl senior req); **B.S.** — Environmental and Energy Geoscience and Solid Earth Science tracks — at least 11 courses beyond prereqs for letter grades (incl senior req); **Paleontology and Geobiology track** — at least 13 courses, for 12 credits, beyond prereqs for letter grades (incl senior req)

#### Distribution of courses

**B.A.** — 2 intro courses in G&G, with labs, as specified; 5 addtl courses at 200 level or higher in G&G or related fields; **B.S.** — Atmosphere, Ocean, and Climate track — 1 intro course in G&G, with lab, as specified; 3 electives as specified; **Environmental and Energy Geoscience and Solid Earth Science tracks** — 2 intro courses in G&G, with labs, as specified; 4 electives as specified; **Paleontology and Geobiology track** — 4 electives as specified

**Substitution permitted** All programs — with DUS permission, higher-level courses for prereqs or required courses

**Senior requirement** All programs — senior essay (G&G 492) or, with permission of faculty, two-term senior thesis (G&G 490, 491)

### Courses

**[ G&G 010, Earth, Resources, Energy, and the Environment ]**

**[ G&G 020, Origins of Everything ]**

**G&G 100a, Natural Disasters** David Bercovici and Maureen Long
Natural events and their impact on humanity and the built environment. Earthquakes, volcanoes, tsunamis, landslides, coastal flooding, tornadoes, hurricanes, and meteoritic impacts. Hazard mitigation strategies. Consequences of global warming. **SC**

*G&G 105a / APHY 100a / ENAS 100a / EVST 100a / PHYS 100a, Energy Technology and Society* Daniel Prober
The technology and use of energy. Impacts on the environment, climate, security, and economy. Application of scientific reasoning and quantitative analysis. Intended for non–science majors with strong backgrounds in math and science. Enrollment limited to 24. For application instructions, visit the course site on Classes*V2 (http://classesv2.yale.edu). **QR, SC**

**G&G 110a, Dynamic Earth** Danny Rye
An introduction to the processes that shape Earth’s environment through the interactions of rocks, soils, the atmosphere, and the hydrosphere. Field trips and practical sessions in the properties of natural materials. Topics include evolution of landscapes; hydrologic and tectonic cycles; extreme geologic events such as earthquakes, floods, volcanism, and landslides; society’s economic dependence on natural materials such as soils, minerals, and fossil fuels; and human influences on the natural environment. **SC**

**G&G 111La, Dynamic Earth Laboratory and Field Methods** Danny Rye
Practical exercises in the laboratory and in the field to complement G&G 110 or 115. Identification of minerals and rocks; construction of geologic maps and cross sections to determine Earth-system processes and histories. Includes a field trip to the northern Appalachians during the October recess. After or concurrently with G&G 110, or after G&G 115. **SC** ½ Course cr
* G&G 115b / EVST 200b, Earth System Science  Jeffrey Park
A survey of geoscience. Interaction of lithosphere, hydrosphere, atmosphere, and Earth’s deep interior; natural controls on environment and climate in past, present, and future; rocks, minerals, glaciers, earthquakes, and volcanoes; natural hazards and natural resources. (Formerly G&G 200)  SC

* G&G 125b / E&EB 125b, History of Life  Derek Briggs
Examination of fossil and geologic evidence pertaining to the origin, evolution, and history of life on Earth. Emphasis on major events in the history of life, on what the fossil record reveals about the evolutionary process, on the diversity of ancient and living organisms, and on the evolutionary impact of Earth’s changing environment.  SC

G&G 140a / EVST 201a, Atmosphere, Ocean, and Environmental Change  Ronald Smith
Physical processes that control Earth’s atmosphere, ocean, and climate. Quantitative methods for constructing energy and water budgets. Topics include clouds, rain, severe storms, regional climate, the ozone layer, air pollution, ocean currents and productivity, the seasons, El Niño, the history of Earth’s climate, global warming, energy, and water resources. Must be taken concurrently with EVST 202L.  QR, SC

* G&G 141La / EVST 202La, Laboratory for Atmosphere, Ocean, and Environmental Change  Ronald Smith
Laboratory and field exercises to accompany EVST 201. Must be taken concurrently with EVST 201.  SC ½ Course cr

* G&G 205b, Natural Resources and Their Sustainability  Jay Ague
The formation and distribution of renewable and nonrenewable energy, mineral, and water resources. Topics include the consequences of extraction and use; depletion and the availability of substitutes; and economic and geopolitical issues. Recommended preparation: introductory chemistry and geology.  SC

G&G 211b / EVST 211b / HIST 416 / HSHM 211b, Global Catastrophe since 1750  William Rankin
A history of the geological, atmospheric, and environmental sciences, with a focus on predictions of global catastrophe. Topics range from headline catastrophes such as global warming, ozone depletion, and nuclear winter to historical debates about the age of the Earth, the nature of fossils, and the management of natural resources. Tensions between science and religion; the role of science in government; environmental economics; the politics of prediction, modeling, and incomplete evidence.  HU

* G&G 212b, Global Tectonics  Mark Brandon
The architecture of continents and oceans; detailed geology of lithospheric plate margins and mountain chains. Examples of plate-interaction histories from the ancient geological record emphasize the interdisciplinary approaches used to determine interlinked Earth-system processes involving the mantle, crust, hydrosphere, atmosphere, and biosphere. The course features a field trip during spring break. Prerequisite: one course in G&G (preferably 100, 110, or 115), or permission of instructor. Enrollment limited to 15.  SC

[ G&G 215, Global Warming: The Carbon Cycle ]
[ G&G 216, Global Warming: Climate Physics ]

[ G&G 220, Petrology and Mineralogy ]

G&G 232b, Paleoenvironments  Noah Planavsky and Mark Brandon
Introduction to sedimentary rocks as paleoenvironmental archives. Reconstruction of depositional conditions and paleoclimatic conditions using chemical and sedimentological tools. Topics include sedimentology, stratigraphy, basin analysis, diagenesis, and sedimentary geochemistry. Prerequisite: G&G 100, 110, or 115, or permission of instructor.  SC

[ G&G 235, Geomorphology and Surface Processes ]

[ G&G 240, Forensic Geoscience ]

G&G 247b / AMTH 247b / MATH 247b, Partial Differential Equations  Stefan Steinerberger
Introduction to partial differential equations, wave equation, Laplace’s equation, heat equation, method of characteristics, calculus of variations, series and transform methods, and numerical methods. Prerequisites: MATH 222 or 225, MATH 246, and ENAS 194, or equivalents.  QR

* G&G 261a / EVST 261a / F&ES 261a, Minerals and Human Health  Ruth Blake
Study of the interrelationships between Earth materials and processes and personal and public health. The transposition from the environment of the chemical elements essential for life. After one year of college-level chemistry or with permission of instructor; G&G 110 recommended.  SC

* G&G 274a, Fossil Fuels and Energy Transitions  Michael Oriistaglio
The origins, geologic settings, exploration, distribution, and extraction of fossil fuels as finite Earth resources. Energy use today; transitions to future renewable resources. Topical issues include peak oil, deep-water exploration, carbon sequestration, and shale gas. Prerequisites: high school chemistry, mathematics, and Earth science. Recommended preparation: G&G 110 or 205.  SC

* G&G 275b, Renewable Energy  Ronald Smith
Introduction to renewable energy, including physical principles, existing and emerging technologies, and interaction with the environment. Energy demand; transmission and storage; generation by hydroelectric, wind, solar, biofuel, and geothermal sources, as well as waves and tidal generation. Includes field trips to conventional, hydroelectric, and wind power facilities in Connecticut. Prerequisites: high school physics, chemistry, and mathematics; college-level science, engineering, and mathematics recommended.  SC
[ G&G 280, Organic Geochemistry ]
[ G&G 290, Earthquakes and Volcanoes ]
[ G&G 310, Isotope Geochemistry ]
[ G&G 312, Structural Geology ]

G&G 310a, Introduction to the Physics and Chemistry of Earth Materials  Shun-ichiro Karato
Basic principles that control the physical and chemical properties of Earth materials. Thermodynamics, equation of state, phase transformations, elastic properties and phase diagrams. After CHEM 161, 165, or 167 (or CHEM 115), MATH 120, and PHYS 181, or equivalents. QR, SC

G&G 322a, Physics of Weather and Climate  Trude Storelvmo
The climatic system; survey of atmospheric behavior and climatic change; meteorological measurements and analysis; formulation of physical principles governing weather and climate with selected applications to small- and large-scale phenomena. After PHYS 181 and MATH 120 or equivalents. QR, SC

[ G&G 323, Climate Dynamics ]

G&G 324a, Vertebrate Paleontology  Jacques Gauthier
Phylogeny and evolution of the major clades of vertebrates from Cambrian to recent, as inferred mainly from the fossilized remains of the musculoskeletal system (cranial, axial, and appendicular skeletons). Special attention to the evolution of vertebrate feeding, locomotor, and sensory systems. Prerequisite: E&EB 225, or with permission of instructor. SC 1½ Course cr

G&G 326b, Introduction to Earth and Planetary Physics  Jun Korenaga
An introduction to the structure and dynamics of Earth and other planets in the context of cosmic evolution. Review of basic physical principles and their applications to geophysics and planetary physics. Star formation and nucleosynthesis; planetary accretion and the birth of the solar system; heat flow, plate tectonics, and mantle dynamics; seismology and geodesy; core dynamics, geomagnetism, and planetary magnetism. Prerequisites: PHYS 181b and MATH 120a or b, or equivalents. QR, SC

G&G 327a / ENVE 327a / F&ES 327a, Atmospheric Chemistry  Nadine Unger
The chemical and physical processes that determine the composition of the atmosphere; implications for climate, ecosystems, and human welfare. Origin of the atmosphere; photolysis and reaction kinetics; atmospheric transport of trace species; stratospheric ozone chemistry; tropospheric hydrocarbon chemistry; oxidizing power, nitrogen, oxygen, sulfur, and carbon cycles; interactions between chemistry, climate, and biosphere; aerosols, smog, and acid rain. Prerequisites: CHEM 161, 165, or 167 (or CHEM 115 or 118), and MATH 120, or equivalents. ENAS 194 recommended. QR, SC

G&G 335a, Physical Oceanography  Alexey Fedorov
An introduction to ocean dynamics and physical processes controlling large-scale ocean circulation, the Gulf Stream, wind-driven waves, tsunamis, tides, coastal upwelling, and other phenomena. Modern observational, theoretical, and numerical techniques used to study the ocean. The ocean's role in climate and global climate change. After PHYS 181 and MATH 120 or equivalents, or with permission of instructor. QR, SC

G&G 342a / PHYS 342a, Introduction to Earth and Environmental Physics  John Wettlaufer
A broad introduction to the processes that affect the past, present, and future features of the Earth. Examples include climate and climate change and anthropogenic activities underlying them, planetary history, and their relation to our understanding of Earth's present dynamics and thermodynamics. Prerequisite: PHYS 170, 171, or 180, 181, or 200, 201, or 260, 261, or permission of instructor. Recommended preparation: familiarity with basic calculus and differential equations. QR, SC

G&G 350a, Thermodynamics of Mountain Belts  Jay Ague
The fundamental principles governing the formation of metamorphic and igneous rocks during mountain building. Topics include processes of heat and mass transfer in orogenic belts, generation of igneous rocks in continental and subduction settings, ultrahigh pressure and ultrahigh temperature metamorphism, spatial and temporal patterns of petrologic processes throughout geologic time, and pressure-temperature-time paths of metamorphic and igneous rocks. Prerequisites: G&G 220 or equivalent, MATH 120, and CHEM 161, 165, or 167 (or CHEM 115, 118); or with permission of instructor. SC RP

G&G 355a, Extraordinary Glimpses of Past Life  Derek Briggs
Study of exceptionally well-preserved fossil deposits (lagerstätten) that contain nonmineralized animal skeletons and casts of the soft parts of organisms. Examples such as the Burgess Shale and Solnhofen limestones; what they can reveal about the history and evolution of life, ancient lifestyles and environments, and preservational processes. After G&G 230. SC

* G&G 362b / ARCG 362b / EVST 362b, Observing Earth from Space  Ronald Smith
A practical introduction to satellite image analysis of Earth's surface. Topics include the spectrum of electromagnetic radiation, satellite-borne radiometers, data transmission and storage, computer image analysis, the merging of satellite imagery with GIS and applications to weather and climate, oceanography, surficial geology, ecology and epidemiology, forestry, agriculture, archaeology, and watershed management. Prerequisites: college-level physics or chemistry, two courses in geology and natural science of the environment or equivalents, and computer literacy. QR, SC
*G&G 370, Regional Perspectives on Global Geoscience*  
Mark Pagani  
A study of the dynamic evolution of Earth’s climate. Topics include warm (the Cretaceous, the Eocene, the PETM, the Pliocene) and cold (the "snowball Earth") climates of the past, glacial cycles, abrupt climate changes, the climate of the past thousand years, and the climate of the twentieth century. After PHYS 181 and one course in meteorology or oceanography, or with permission of instructor.  

SC  

G&G 421b, Geophysical Fluid Dynamics  
David Bercovici  
A survey of fluid dynamics, with applications to circulation in the ocean, atmosphere, mantle, and core. Mathematical models illustrate the fundamental dynamical principles of geophysical fluid phenomena such as convection, waves, boundary layers, flow stability, turbulence, and large-scale flows. After or concurrently with MENG 361 or equivalent and one course in meteorology or oceanography, or with permission of instructor.  

SC  

G&G 428a / AMTH 428a / E&EB 428a / PHYS 428a, Science of Complex Systems  
Jun Korenaga  
Introduction to the quantitative analysis of systems with many degrees of freedom. Fundamental components in the science of complex systems, including how to simulate complex systems, how to analyze model behaviors, and how to validate models using observations. Topics include cellular automata, bifurcation theory, deterministic chaos, self-organized criticality, renormalization, and inverse theory. Prerequisite: PHYS 301, MATH 247, or equivalent.  

QR, SC  

*G&G 450, Deformation of Earth Materials*  

[ G&G 456, Introduction to Seismology ]  

G&G 487a or b, Individual Study in Geology and Geophysics  
David Bercovici  
Individual study for qualified undergraduates under faculty supervision. To register for this course, each student must submit a written plan of study, approved by the adviser, to the director of undergraduate studies. May be taken more than once for credit.  

½ Course cr  

G&G 488a and G&G 489b, Research in Geology and Geophysics  
David Bercovici  
Individual study for qualified juniors and seniors under faculty supervision. To register for this course, each student must submit a written plan of study, approved by the adviser, to the director of undergraduate studies.  

G&G 490a and G&G 491b, Research and Senior Thesis  
David Bercovici  
Two terms of independent library, laboratory, field, or modeling-based research under faculty supervision. To register for this course, each student must submit a written plan of study, approved by a faculty adviser, to the director of undergraduate studies by the end of the junior year. The plan requires approval of the full G&G faculty.  

G&G 492a or b, The Senior Essay  
David Bercovici  
One term of independent library, laboratory, field, or modeling-based research under faculty supervision. To register for this course, each student must submit a written plan of study, approved by a faculty adviser, to the director of undergraduate studies at the beginning of the term in which the essay is to be written.