

EARTH AND PLANETARY SCIENCES

Directors of undergraduate studies: Celli Hull (pincelli.hull@yale.edu); earth.yale.edu

The Earth and Planetary Sciences (EPS) program, formerly Geology and Geophysics, prepares students for the application of scientific principles and methods to the understanding of the Earth system and other planets. Subjects range from the history of Earth and life to present-day environmental processes and climate change, the deep interiors of Earth and other planets, tectonic plates, oceans, atmospheres, climates, land surface, natural resources, and biota. The emphasis of the curriculum is on employing basic principles from the core sciences (physics, chemistry, and 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 select a specific concentration to focus their work on planetary or environmental phenomena of particular interest. The four B.S. degree concentrations emphasize hands-on research experience in fieldwork, in laboratories, or in theoretical analyses and 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. There is also a B.A. degree, which is most suitable for students who wish to study Earth and Planetary Sciences as a second major, complementing other majors in, for example, mathematics, economics, physics, biology, or engineering, and who do so in preparation for a career in law, business, government, or environmental fields.

PREREQUISITES

With permission of the director of undergraduate studies (DUS), 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 DUS, be substituted for prerequisites and for specific required courses. For prerequisites specific for each concentration, see Requirements of the Major.

REQUIREMENTS OF THE MAJOR

B.A. degree program The B.A. degree in Earth and Planetary Sciences requires fewer upper-level courses than the B.S. degree. It may be more appropriate for students who plan to fulfill the requirements of two majors, who study Earth and Planetary Sciences in preparation for a career in law, business, government, or environmental fields, or who decide to pursue a science major only after the first year. The prerequisites include mathematics (MATH 1150), biology (BIOL 1010 and BIOL 1020 or EPS 2550), or physics (PHYS 1700, 1710; or PHYS 1800, 1810; or PHYS 2000, 2010), and a lecture course in chemistry. The major requirements consist of at least nine term courses for at least nine credits, beyond the prerequisites. These include two courses in EPS numbered 1000–1400, with any accompanying laboratories; courses in natural resources (EPS 2740 or EPS 2750 and geochemical processes (EPS 2200 or EPS 2320 or EPS 2610 or EPS 3100); and five additional courses at the 2000 level or higher in Earth and Planetary Sciences or related fields, approved by the DUS and including either

the senior essay or the senior thesis. Course selections can be guided by any of the B.S. concentrations described above.

B.S. degree program Majors in the B.S. program in Earth and Planetary Sciences choose from four concentrations: Atmosphere, Ocean, and Climate; Environmental and Energy Geoscience; Paleontology and Geobiology; and Solid Earth Science. The concentrations are suggested pathways to professional careers and major areas of research in earth and planetary sciences. Students may change concentrations during their course of study with guidance from the DUS.

1. The Atmosphere, Ocean, and Climate concentration provides a comprehensive understanding of the atmosphere-ocean-climate system. Topics range from past climate changes, including the ice ages, to present-day atmospheric and ocean circulation, to weather phenomena, to global warming projections. The prerequisites are CHEM 1650 or CHEM 1670; PHYS 1800, 1810 and PHYS 2050L, 2060L; ENAS 1300 or equivalent; and mathematics through differential equations (MATH 1200 or ENAS 1510, and ENAS 1940). The major requirements consist of at least eleven term courses, for at least eleven 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 EPS, selected from EPS 1000; EPS 1010; EPS 1100 with 1110L; or EPS 1250 with 1260L. EPS 1000 and 1010 do not require an accompanying lab. Five core courses, totaling five course credits, introduce students to Earth's climate system (EPS 1400), meteorology (EPS 3220), physical oceanography (EPS 3350), fluid mechanics (MENG 3422), and statistics or linear algebra (S&DS 2300 or 2380 or MATH 2220). Other higher-level courses in EPS can be substituted with the permission of the DUS. Four 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 DUS or on the department website. At least one elective must be from EPS.
2. The Environmental and Energy Geoscience concentration 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 CHEM 1650 or CHEM 1670 and mathematics through multivariate calculus (MATH 1200 or ENAS 1510). Depending on their area of focus, students may choose a prerequisite in physics (PHYS 1700, 1710; or PHYS 1800, 1810; or PHYS 2000, 2010), or they may choose cellular biology (BIOL 1010 and 1020, or MCDB 120) and evolutionary biology (BIOL 1030 and 1040 or EPS 1250 and 1260L). The major requirements consist of at least eleven term courses, for at least 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 EPS, selected from EPS 1000; EPS 1010; EPS 1100 with 1110L; EPS 1250 with 1260L; or EPS 1400. Four core courses are chosen from Earth's surface processes (EPS 2320), the microbiology of surface and near-surface environments (EPS 2550), fossil fuels and energy transitions (EPS 2740), renewable energies (EPS 2750), geochemical principles (EPS 3100), geology (EPS 2100 or EPS 2200 or EPS 3120), meteorology

(EPS 3220), and satellite-based image analysis (EPS 3620). Other higher-level courses in EPS can be substituted with the permission of the DUS. Four electives chosen from Earth & Planetary Sciences, Environmental Studies, Ecology and 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 DUS or on the department website. Electives may be chosen from the core courses, and at least two must be from EPS.

3. The Paleontology and Geobiology concentration 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 1010–1040), or CHEM 1650 or CHEM 1670, and mathematics through multivariate calculus (MATH 1200 or ENAS 1510). The major requirements consist of at least twelve term courses, for at least eleven and a half course credits, beyond the prerequisites, including either the senior essay or the senior thesis. Students take one of EPS 1000; EPS 1010; or EPS 1100 with 1110L, to gain geological and environmental context, and they also take EPS 1250 and 1260L as an introduction to the fossil record and evolution. Four core courses are chosen from topics in four of the following areas: in sedimentary processes (EPS 2320 or EPS 3550), the study of evolution (EEB 2225), vertebrates and vertebrate paleontology (EPS 2700 or EPS 3250 or EPS 3750), invertebrate paleontology (EPS 3130), paleoecology (EPS 3450), microbiology in past and present environments (EPS 2550), Earth's carbon cycle and climate (EPS 3100 or 4020), and statistical data analysis as applied to the life sciences. Other higher-level courses in EPS can be substituted with the permission of the DUS. Four electives selected from Earth and Planetary Sciences, Ecology and Evolutionary Biology, Molecular, Cellular, and 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 DUS or on the department website. At least four of the twelve term courses should be upper level (2000 or above) paleontology courses and at least one elective must be from EPS.
4. The Solid Earth Science concentration emphasizes an integrated geological, geochemical, and geophysical approach to the study of processes operating within Earth and their manifestations 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 of 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 timescales. The prerequisites are CHEM 1650 or CHEM 1670, physics (PHYS 1700, 1710; or PHYS 1800, 1810; or PHYS 2000, 2010), and mathematics through multivariate calculus (MATH 1200 or ENAS 1510). The major requirements consist of at least eleven courses, for at least 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 EPS, selected from EPS 1000; EPS 1010; EPS 1100 with 1110L; EPS 1250 with 1260L; or EPS 1400. The core of the concentration consists of four courses chosen from topics in mountain building and global tectonics (EPS 2100 or EPS 2120 or EPS 3500), rocks and minerals (EPS 2200), sedimentary rocks and processes (EPS 2320), isotope geochemistry (EPS 3100), and structural geology (EPS 3120). Other higher-level courses in EPS can be substituted with the permission of the DUS. Students also select four electives in geology, geochemistry, geophysics, or related topics. A list of suggested electives is available from the office of the DUS or on the department website. Electives may be chosen from core courses, and at least two must be from EPS.

Credit/D/Fail No course taken Credit/D/Fail may be applied to the prerequisites or the requirements of the major.

Outside credit Courses taken at another institution or during an approved summer or term-time study abroad program may count toward the major requirements with DUS approval.

SENIOR REQUIREMENT

Seniors in both degree programs must prepare either a senior essay based on one term of library, laboratory, or field research (EPS 4920) or, with the consent of the faculty, a two-term senior thesis (EPS 4900, EPS 4910), 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 DUS for approval of the thesis proposal. The petition should be submitted by the start of the senior year. If the two-term senior thesis is elected, EPS 4910 may count as an elective toward the major. A copy of each senior thesis or senior essay is made available on the department website.

ADVISING

Qualified juniors and seniors are encouraged to enroll in graduate courses, with permission of the instructor, the DUS, and the director of graduate studies. Descriptions of graduate courses are available at the office of the DUS.

Practical experience In addition to prerequisites and required courses in Earth and Planetary Sciences, candidates for the B.A. and B.S. degrees are strongly encouraged to gain practical experience. 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 Earth and Planetary Sciences, by other academic institutions, or by certain government agencies and private industries. Consult the DUS or see the department website for further information.

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 Academic Regulations, section L, Special Academic Arrangements, "Simultaneous Award of the Bachelor's and Master's Degrees." Interested students should consult the DUS prior to the sixth term of enrollment for specific requirements in Earth and Planetary Sciences.

Physics and Geosciences major The Department of Earth and Planetary Sciences also offers a combined major with the Department of Physics. For more information, see Physics and Geosciences.

SUMMARY OF MAJOR REQUIREMENTS

Prerequisites *B.A.* — MATH 1150; biology (BIOL 1010 and 1020, or EPS 2550) or physics (PHYS 1700, 1710; or PHYS 1800, 1810; or PHYS 2000, 2010); and a lecture course in chem; *B.S. — All concentrations* — CHEM 1650 or CHEM 1670; MATH 1200 or ENAS 1510; *Atmosphere, Ocean, and Climate concentration* — ENAS 1300 or equivalent; ENAS 1940; PHYS 1800, 1810, 2050L, 2060L; *Environmental and Energy Geoscience concentration* — physics (PHYS 1700, 1710, or PHYS 1800, 1810, or PHYS 2000, 2010) or biology (BIOL 1010 and 1020; and BIOL 1030 and 1040, or EPS 1250 and EPS 1260L); *Paleontology and Geobiology concentration* — BIOL 1010–1040; *Solid Earth Science concentration* — PHYS 1700, 1710, or PHYS 1800, 1810, or PHYS 2000, 2010

Number of courses *B.A.* — at least 9 courses beyond prereqs for letter grades (incl senior req); *B.S. — Atmosphere, Ocean, and Climate, Environmental and Energy Geoscience, and Solid Earth Science concentrations* — at least 11 courses, for 11 credits, beyond prereqs for letter grades (incl senior req); *Paleontology and Geobiology concentration* — at least 12 courses, for 11.5 credits, beyond prereqs for letter grades (incl senior req)

Specific core courses *B.A.* — EPS 2740 or EPS 2750; 1 from EPS 2200, 2320, 2610, or 3100; *B.S. — Atmosphere, Ocean, and Climate concentration* — EPS 1400, 3220, 3350, MENG 3422, S&DS 2300 or 2380 or MATH 2220; *Paleontology and Geobiology concentration* — EPS 1250, 1260L

Distribution of courses *B.A.* — 2 intro courses in EPS, with labs; 5 addtl courses at 2000 level or higher in EPS or related fields inc sen req; *B.S. concentrations* — 1 or 2 intro courses in EPS, with labs, as specified; 4 or 5 core courses, as specified; 4 electives, as specified

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

Senior requirement *All programs* — senior essay (EPS 4920) or, with permission of faculty, two-term senior thesis (EPS 4900, 4910)

FACULTY OF THE DEPARTMENT OF EARTH AND PLANETARY SCIENCES

Professors Jay Ague, David Bercovici, Ruth Blake, Mark Brandon, Derek Briggs, David Evans, Alexey Fedorov, Debra Fischer, Jacques Gauthier, Shun-ichiro Karato, Jun Korenaga, Maureen Long (*Chair*), Jeffrey Park, Noah Planavsky, Peter Raymond, Danny Rye (*Emeritus*), James Saiers, Ronald Smith (*Emeritus*), Mary-Louise Timmermans, John Wettlaufer

Associate Professors Bhart-Anjun Bhullar, Matthew Eisaman, Pincelli Hull

Assistant Professors Juan Lora, Alan Rooney, Lidya Tarhan, Jordan Wostbrock

Lecturer Michael Oristaglio