

EARTH AND PLANETARY SCIENCES

Directors of undergraduate studies: Celli Hull (pincelli.hull@yale.edu); Jeffrey Park (jeffrey.park@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.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 165 or CHEM 167; PHYS 180, 181 and PHYS 205L,

206L; 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 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 100; EPS 101; EPS 110 with 111L; or EPS 125 with 126L. EPS 100 and 101 do not require an accompanying lab. Five core courses, totaling five course credits, introduce students to Earth's climate system (EPS 140), meteorology (EPS 322), physical oceanography (EPS 335), fluid mechanics (MENG 361), and statistics or linear algebra (S&DS 230 or 238 or MATH 222). 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 165 or CHEM 167 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; or PHYS 180, 181; or PHYS 200, 201), or they may choose cellular biology (BIOL 101 and 102, or MCDB 120) and evolutionary biology (BIOL 103 and 104, or E&EB 122, or EPS 125 and 126L). 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 100; EPS 101; EPS 110 with 111L; EPS 125 with 126L; or EPS 140. Four core courses are chosen from Earth's surface processes (EPS 232), the microbiology of surface and near-surface environments (EPS 255), fossil fuels and energy transitions (EPS 274), renewable energies (EPS 275), geochemical principles (EPS 310), geology (EPS 210 or EPS 220 or EPS 312), meteorology (EPS 322), and satellite-based image analysis (EPS 362). 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 101–104, or MCDB 120 and E&EB 122), CHEM 165 or CHEM 167, and mathematics through multivariate calculus (MATH 120 or ENAS 151). 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 100; EPS 101; or EPS 110 with 111L, to gain geological and environmental context, and they also take EPS 125 and 126L 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 232 or EPS 355), the study of evolution (E&EB 225), vertebrates and vertebrate paleontology (EPS 270 or EPS 325 or EPS 375), invertebrate paleontology (EPS 313), paleoecology (EPS 345), microbiology in past and present environments (EPS 255), Earth's carbon cycle and climate (EPS 310 or 402), and statistical data analysis as applied to the life sciences (S&DS 101 or equivalent). 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 (200 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 165 or CHEM 167, physics (PHYS 170, 171; or PHYS 180, 181; or PHYS 200, 201), and mathematics through multivariate calculus (MATH 120 or ENAS 151). 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 100; EPS 101; EPS 110 with 111L; EPS 125 with 126L; or EPS 140. The core of the concentration consists of four courses chosen from topics in mountain building and global tectonics (EPS 210 or EPS 212 or EPS 350), rocks and minerals (EPS 220), sedimentary rocks and processes (EPS 232), isotope geochemistry (EPS 310), and structural geology (EPS 312). 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.

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 115), biology (BIOL 101 and 102, or MCDB 120, or EPS 255), or physics (PHYS 170, 171; or PHYS 180, 181; or PHYS 200, 201), 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 100–140, with any accompanying laboratories; courses in natural resources (EPS 274 or EPS 275) and geochemical processes (EPS 220 or EPS 232 or EPS 261 or EPS 310); and five additional courses at the 200 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.

Credit/D/Fail Courses taken Credit/D/Fail may not be applied to the prerequisites or to the requirements of the major.

SENIOR REQUIREMENT

Seniors in both degree programs must prepare either a senior essay based on one term of library, laboratory, or field research (EPS 492) or, with the consent of the faculty, a two-term senior thesis (EPS 490, EPS 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 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 491 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 115; biology (BIOL 101 and 102, or MCDB 120, or EPS 255) or physics (PHYS 170, 171; or PHYS 180, 181; or PHYS 200, 201); and a lecture course in chem; *B.S.* — *All concentrations* — CHEM 165 or CHEM 167; MATH 120 or ENAS 151; *Atmosphere, Ocean, and Climate concentration* — ENAS 130 or equivalent; ENAS 194; PHYS 180, 181, 205L, 206L; *Environmental and Energy Geoscience concentration* — physics (PHYS 170, 171, or PHYS 180, 181, or PHYS 200, 201) or biology (BIOL 101 and 102, or MCDB 120; and BIOL 103 and 104, or E&EB 122, or EPS 125 and EPS 126L); *Paleontology and Geobiology concentration* — BIOL 101–104, or MCDB 120 and E&EB 122; *Solid Earth Science concentration* — PHYS 170, 171, or PHYS 180, 181, or PHYS 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, 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 274 or EPS 275; 1 from EPS 220, 232, 261, or 310; *B.S.* — *Atmosphere, Ocean, and Climate concentration* — EPS 140, 322, 335, MENG 361, S&DS 230 or 238 or MATH 222; *Paleontology and Geobiology concentration* — EPS 125, 126L

Distribution of courses *B.A.* — 2 intro courses in EPS, with labs; 5 addtl courses at 200 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 492) or, with permission of faculty, two-term senior thesis (EPS 490, 491)