

Morton K. Blaustein Department of Earth and Planetary Sciences

The Department of Earth and Planetary Sciences offers programs of study and research in the basic Earth sciences: in geology, the science of the solid Earth; in geochemistry, devoted to understanding the chemistry of the solid Earth and natural waters; in hydrogeology, the study of the role of groundwater in geologic processes and environmental hydrology; in geophysics, concerned with a quantitative description of physical processes in the Earth and planetary sciences; in physical oceanography, the study of ocean currents and waves, and their role in climate; in atmospheric sciences, particularly the dynamics of atmospheric circulation both on Earth and the outer planets and their satellites; and in paleoecology and evolutionary biology, the study of the relationships between organisms and their environment today and in the geologic past.

The department's primary goals are basic research and the training of scholars who will contribute to the future of these disciplines. The programs emphasize basic principles and concepts rather than applied aspects.

The flexible undergraduate program lets the student, in consultation with a faculty adviser, devise a program that is challenging, individual, and rigorous. The graduate program develops skill in research through independent investigation under the general guidance of one or more members of the faculty, backed up by relevant course work. The department gives particular emphasis to the integration of experimental investigation, theoretical calculation, and quantitative field observations.

The Faculty

John M. Ferry, Professor: metamorphic geology.

Grant Garven, Professor: groundwater geology and hydrology.

Thomas W. N. Haine, Associate Professor: physical oceanography.

Lawrence A. Hardie, Morton K. Blaustein Professor (Chair): geology (geochemistry and sedimentation).

A. Hope Jahren, Associate Professor: stable isotope geochemistry, paleoclimatology, and geobiology.

Bruce D. Marsh, Professor: igneous petrology and geophysics.

Peter L. Olson, Professor: geophysical fluid dynamics.

Thomas R. Osborn, Professor: physical oceanography.

Steven M. Stanley, Professor: paleobiology.

Darrell F. Strobel, Professor: planetary atmospheres and astrophysics.

Dimitri Sverjensky, Professor: geochemistry and environmental chemistry.

David R. Veblen, Professor: crystallography.

Darryn W. Waugh, Professor: atmospheric dynamics.

Other Faculty

Albert Arking, Principal Research Scientist: atmospheric sciences.

Linda Hinnov, Associate Research Professor: quantitative stratigraphy and paleoclimatology

Sakiko Olsen, Lecturer: metamorphic petrology.

Katalin Szlavecz, Senior Lecturer and Associate Research Scientist: soil ecology.

Joint Appointments

Robert A. Dalrymple, Professor, Civil Engineering.

Kevin J. Hemker, Professor, Mechanical Engineering.

Emeritus Appointments

George W. Fisher, Professor Emeritus: global earth systems and religious ethics.

Owen M. Phillips, Professor Emeritus: geophysics (fluid mechanics and oceanography).

Facilities

The Department of Earth and Planetary Sciences is housed in Olin Building, a modern building dedicated to the Earth sciences, nestled on a wooded knoll on the western edge of campus. Its facilities include state-of-the-art instrumentation, a departmental library, and modern computer equipment. There are laboratories for crystallography, evolutionary biology/ecology, stable isotope geochemistry, materials science, and fluid and solid mechanics. A JEOL 8600 electron microprobe in Olin Hall is available to all members of the department. Numerous personal computers and workstations provide in-house computational capabilities and access to mainframe computers elsewhere on campus. Olin Hall also contains equipment for modern petrographic work (including a computer-controlled image analysis system), darkroom facilities, and a laboratory for sectioning rocks. There is also a substantial collection of rocks, minerals, and fossils. Facilities are available for a wide spectrum of fluid mechanical experiments, including thermal convection and solidification.

Crystallographic facilities include a modern specimen preparation laboratory for transmission electron microscopy and single-crystal X-ray diffraction studies. The transmission electron microscopy laboratory houses state-of-the-art instruments capable of both high-resolution imaging at the atomic scale and microanalysis at the nanometer scale.

The department contains several computer laboratories containing clusters of workstations and personal computers, together with printers and scanners. These computers are used for numerical simulations, graphics applications, data manipulation, and word processing.

Field studies and excursions form an integral part of the program of instruction and research in geology and are closely integrated with the laboratory and course work. Situated at the fall line between the Coastal Plain and the Piedmont and only an hours ride from the Blue Ridge and Appalachians, Baltimore is an excellent location for a department with a field-oriented program in geology. The department has a permanent field station for geological research, Camp Singewald, in the Bear Pond Mountains of Washington County, Maryland, and a vehicle for field use.

Supporting facilities on campus include the Milton S. Eisenhower Library, the Space Telescope Science Institute, and the Homewood Academic Computing Center. In addition, the facilities of the Smithsonian Institution and the Geophysical Laboratory and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington are available by special arrangement for students qualified to use them. For students whose research requires substantial computation, special arrangements can be made to use the supercomputers at the Goddard Space Flight Center (NASA) and the Naval Research Laboratory.

Undergraduate Programs

The Department of Earth and Planetary Sciences offers programs of study for majors, joint majors, and minors in Earth and Planetary Sciences and in the Environmental Earth Sciences. In addition, the department offers students planning careers in the health professions an Earth and Planetary Science major consistent with those interests.

Depending on the student's background, it may be appropriate initially to take a freshman seminar or 100-level course designed for the non-major. Those who wish to be majors may proceed directly to a set of core courses at the 200-level. The core courses provide a broad educational base in the Earth and Planetary Sciences, and are followed by a set of required courses and electives at the

300-level, depending on the area of interest of the student in the Earth and Planetary Sciences major or the Environmental Earth Science major.

Undergraduates are strongly encouraged to become involved in research with the faculty. Such research may be taken for credit, and may lead to the completion of a senior thesis. Advice for those who wish to become involved in research can be obtained from the coordinator for undergraduate programs. Students who major in this department often attend graduate or professional school, and go on to careers in academic institutions, natural resource-oriented industries, or government agencies.

Requirements for the B.A. Degree

Undergraduates majoring in the department must satisfy the general university requirements for the B.A. degree (see General Requirements for Departmental Majors, page 46). In addition, students are required to take the following courses:

Required core courses in the Department of Earth and Planetary Sciences

- 270.220 Dynamic Earth (3)
- 270.221 Dynamic Earth Laboratory (1)
- 270.222 Earth Materials (4)
- 270.224 Oceans and Atmospheres (3)
- 270.225 Earth System History (3)
- 270.226 Earth System History Laboratory (1)

Required courses outside the Department of Earth and Planetary Sciences

- 030.101 Introductory Chemistry (4)
- 030.105 Introductory Chemistry Laboratory (1)
- 110.108 Calculus I (4)
- 110.109 Calculus II (4)
- 171.101 General Physics I (4)
- 173.111 General Physics Laboratory (1)
- 171.102 General Physics II (4)
- 173.112 General Physics Laboratory (1)

Note: Additional requirements are listed under the detailed descriptions of the majors, depending on the specific area of interest of the student.

In order to satisfy the university distribution requirements, and to enrich the educational background of the majors, the department strongly recommends taking some of the courses listed below.

- 600.107 Intro to Programming in Java (3) (E)
- 600.109 Intro to Programming in C/C++ (3) (E)
- 500.200 Computing for Engineers and Scientists (3) (E,Q)
- 500.211 Technical Communication (3) (H,S,W)
- 500.212 Effective Oral Presentations (3) (H,W)

- 550.291 Linear Algebra and Differential Equations (4) or an equivalent course
 570.107 Introduction to Geography (3) (H,N,S)
 570.108 Environmental Engineering (3) (E)
 570.239 Current and Emerging Environmental Issues (3)
 570.303 The Environment and Your Health (3) (E)
 270.201 Sustainability: Scientific and Religious Perspective (3) (S,H)
 270.320 Global Change and Human Health (3) (S)

Honors in Your Major

To graduate with honors in your major, you must complete and HONORS CLEARANCE CHECKLIST by April 1st in the year you expect to graduate in May. Most commonly, this means by April 1st of your senior year. Failure to submit this checklist by this date will mean that you will not receive honors in your major. You cannot complete the checklist before February 1st of the same year. Please note that these requirements are not related to "General University Honors". General University Honors are automatically assigned to all students who graduate with a 3.5 or higher.

To receive Honors in Earth and Planetary Sciences, you must have met the following criteria:

- Have taken a challenging set of courses during the four years of study.
- Have a GPA in your major requirements of a 3.5 or higher.
- Complete a Senior Thesis at a level judged to be sufficiently high by the faculty of the Department of Earth and Planetary Sciences.
- Present the results of the thesis orally in the Department of Earth and Planetary Sciences.

To notify us that you are eligible for honors you must:

1. Obtain an honors checklist by either downloading it from www.advising.jhu.edu or by picking one up in the Office of Academic Advising.
2. Complete the checklist after February 1st of your senior year and take it to Dr. Dimitri A. Sverjensky.
3. Return the signed checklist to the Office of Academic Advising by April 1st. You do not need to make an appointment to return the checklist, but it must be signed by the correct representative from your department or it will not be processed.

Earth and Planetary Sciences Major

In addition to the required courses listed above, the student can follow one of the three tracks in Earth and Planetary Sciences shown below. If none of these tracks meet the interests of the student, a specific plan of appropriate courses may be adopted in consultation with the coordinator for undergraduate programs in the department. For example, a schedule for students interested in future careers in the health professions is listed below as one possible alternative to the three tracks. Also, a single previously taken introductory 100-level Earth and Planetary Science course may be substituted for one of the recommended 300-level courses.

Geological Sciences Track

Required courses within the department

- 270.304 Igneous and Metamorphic Petrology
 270.306 Igneous and Metamorphic Petrology Laboratory
 270.311 Geobiology
 270.350 Sedimentary Environments
 270.351 Sedimentary Rocks Laboratory
 270.369 Introductory Geochemistry
 270.375 Groundwater

Additional courses can be chosen as electives from the 300-level offerings in the department. Recommended courses include:

- 270.301 Geochemical Thermodynamics
 270.302 Aqueous Geochemistry
 270.307 Combining Measurements with Models
 270.316 Invertebrate Fossils and Environments
 270.341 Crystallography and the Structure of Inorganic Solids
 270.395 Planetary Physics and Chemistry
 270.475 Groundwater Contamination

In addition, a Field Camp Course in the summer is strongly recommended.

A sample set of courses for a complete schedule is listed below.

• **Year 1**

Fall

030.101 Intro Chemistry	4
030.105 Intro Chemistry Lab	1
110.108 Calculus I	4
Freshman Seminar	2
Distribution requirements	<u>4</u>
Total	15

Spring

110.107 Calculus II for Biological Sciences	4
270.220 Dynamic Earth	3
270.221 Dynamic Earth Lab	1
Elective Courses	5
Distribution requirements	<u>2</u>
Total	15

• **Year 2**

Fall

171.101 General Physics I	4
173.111 General Physics Lab	1
270.222 Earth Materials	4
270.225 Earth System History	3
270.226 Earth System History Lab	1
Distribution requirements	<u>3</u>
Total	16

Spring

171.102 General Physics II	4
173.112 General Physics Lab	1
550.291 Linear Algebra and Differential Equations	4
270.369 Geochemistry of the Earth & Environment	3
Distribution requirements	<u>4</u>
Total	16

• **Year 3**

Fall

270.311 Geobiology	3
270.375 Groundwater	3
Elective courses	3
Distribution requirements	<u>6</u>
Total	15

Spring

270.224 Oceans and Atmospheres	3
270.350 Sedimentary Environments	3
270.351 Sedimentary Rocks Lab	1
Elective courses	3
Distribution requirements	<u>6</u>
Total	16

• **Year 4**

Fall

270.304 Igneous and Metamorphic Petrology	3
270.306 Igneous and Metamorphic Petrology Lab	1
270.394 Global Geochemical Cycles and Climate Change	3
Elective Courses	4
Distribution requirements	<u>3</u>
Total	14

Spring

Elective courses	11
Distribution requirements	<u>2</u>
Total	13

Total – 120 credits

Geophysical Sciences Track

For this track, at least four 300-level courses from within the department are required, as well as courses from outside the department.

• **In the Department of Earth and Planetary Sciences**

270.307 Combining Measurements with Models	3
270.321 Introductory Oceanography	3
270.394 Global Geochemical Cycles and Climate Change	3
270.395 Planetary Physics and Chemistry	3
270.410 Global Climate Change	3

• **Outside the Department of Earth and Planetary Sciences**

171.105 Introduction to Classical Physics I and 171.106 Introduction to Classical Physics II are strongly recommended instead of 171.101 and 171.102 for this track.	
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In addition, the following three courses are required:

110.202 Calculus III	3
171.201 Special Relativity and Waves	3
171.204 Classical Mechanics	3

• **Two of the following courses are required:**

030.301 Physical Chemistry	3
171.312 Statistical Physics and Thermodynamics	3
530.405 Mechanics of Solids and Structures	3
570.351 Introduction to Fluid Mechanics	3

Additional courses can be chosen as electives from the 300-level offerings in the department. Recommended courses include:

270.315 Principles of Natural Catastrophes	3
270.327 Introduction to Seismology	3

270.329 Introduction to Seismology Laboratory	
270.475 Groundwater Contamination	

A sample set of courses for a complete schedule is listed below.

• **Year 1**

Fall

030.101 Intro Chemistry	4
030.105 Intro Chemistry Lab	1
110.108 Calculus I	4
Freshman Seminar	2
Distribution requirements	<u>4</u>
Total	15

Spring

110.109 Calculus II	4
270.220 Dynamic Earth	3
270.221 Dynamic Earth Lab	1
Elective courses	5
Distribution requirements	<u>2</u>
Total	15

• **Year 2**

Fall

171.105 Intro Classical Physics I 4	
173.111 General Physics Lab	1
550.291 Linear Algebra and Differential Equations	4
270.222 Earth Materials	4
Distribution requirements	<u>3</u>
Total	16

Spring

171.106 Intro Classical Physics II	4
173.112 General Physics Lab	1
110.202 Calculus III	4
270.224 Oceans and Atmospheres	3
Distribution requirements	<u>4</u>
Total	16

• **Year 3**

Fall

171.201 Special Relativity and Waves	4
270.225 Earth System History	3
270.226 Earth System History Lab	1
270.307 Combining Measurements with Models	3
Distribution requirements	<u>5</u>
Total	16

<i>Spring</i>	
270.321 Intro Oceanography	3
171.204 Classical Mechanics	4
Elective courses	3
Distribution requirements	<u>5</u>
Total	15

• **Year 4**

Fall

270.394 Global Geochemical Cycles and Climate Change	3
270.410 Global Climate Change	3
570.351 Intro Fluid Mechanics	3
Distribution requirements	<u>5</u>
Total	14

Spring

171.312 Statistical Physics and Thermodynamics	4
270.395 Planetary Physics and Chemistry	3
Elective courses	3
Distribution requirements	<u>3</u>
Total	13

Total – 120 credits

Geocology Track

For this track, the following courses from within the department and two from outside the department are required.

• **In the Department of Earth and Planetary Sciences**

270.308 Population and Community Ecology	
270.311 Geobiology	
270.321 Introductory Oceanography	
270.350 Sedimentary Environments	
270.351 Sedimentary Rocks Laboratory	
270.369 Geochemistry of the Earth & Environment	
270.394 Global Geochemical Cycles and Climate Change	

• **Outside the Department of Earth and Planetary Sciences**

020.151 General Biology I	
020.152 General Biology II	

Additional courses can be chosen as electives from the 200- and 300-level offerings in the department. Recommended courses include:

270.307 Combining Measurements with Models	
270.231 Ecology of a Changing Planet	
270.316 Invertebrate Fossils and Environments	
270.323 Darwin and the Origin of Species	

A sample set of courses for a complete schedule is listed below.

• **Year 1**

Fall

030.101 Intro Chemistry	4
030.105 Intro Chemistry Lab	1
110.106 Calculus I for Biological Sciences	4
Freshman Seminar	2
Distribution requirements	<u>4</u>
Total	15

Spring

110.107 Calculus II for Biological Sciences	4
270.220 Dynamic Earth	3
270.221 Dynamic Earth Lab	1
Elective courses	5
Distribution requirements	<u>2</u>
Total	15

• **Year 2**

Fall

171.103 General Physics I for Biological Sciences	4
173.111 General Physics Lab	1
020.151 General Biology I	4
270.222 Earth Materials	4
Distribution requirements	<u>3</u>
Total	16

Spring

171.104 General Physics II for Biological Sciences	4
173.112 General Physics Lab	1
020.152 General Biology II	4
270.369 Intro Geochemistry	3
Distribution requirements	<u>3</u>
Total	15

• **Year 3**

Fall

550.291 Linear Algebra and Differential Equations	4
270.225 Earth System History	3
270.226 Earth System History Lab	1
270.308 Population and Community Ecology	3
Distribution requirements	<u>5</u>
Total	16

Spring

270.224 Oceans and Atmospheres	3
270.350 Sedimentary Environments	3
270.351 Sedimentary Rocks Lab	1
Elective courses	3
Distribution requirements	<u>6</u>
Total	16

• **Year 4**

Fall

270.394 Global Geochemical Cycles and Climate Change	3
270.311 Geobiology	3
Elective courses	5
Distribution requirements	<u>3</u>
Total	14

Spring

Elective courses	9
Distribution requirements	<u>4</u>
Total	13

Total – 120 credits

Students interested in the health professions

After the core courses listed above, it is recommended that students will take **four** of the following courses in the Department of Earth and Planetary Sciences.

270.308 Population and Community Ecology
270.311 Geobiology
270.320 Global Change and Human Health
270.369 Geochemistry of the Earth & Environment
270.375 Groundwater
270.394 Global Geochemical Cycles and Climate Change

A sample set of courses for a complete schedule is listed below.

• **Year 1**

Fall

030.101 Intro Chemistry	4
030.105 Intro Chemistry Lab	1
110.106 Calculus I for Biological Sciences	4
Freshman Seminar	2
Distribution requirements	<u>4</u>
Total	15

<i>Spring</i>	
030.205 Intro Organic Chemistry	4
030.225 Intro Chemistry Lab	1
110.107 Calculus II for Biological Sciences	4
270.220 Dynamic Earth	3
270.221 Dynamic Earth Lab	1
Distribution requirements	<u>2</u>
Total	15

• **Year 2**

<i>Fall</i>	
020.305 Biochemistry	4
020.315 Biochemistry Lab	2
030.201 Intermediate Organic Chemistry	4
030.225 Introductory Organic Chemistry Lab	<u>3</u>
Total	13

<i>Spring</i>	
020.306 Cell Biology	4
020.316 Cell Biology Laboratory	2
030.204 Intermediate Chemistry	3
270.308 Population and Community Ecology	3
Distribution requirements	<u>2</u>
Total	14

• **Year 3**

<i>Fall</i>	
171.103 General Physics I for Biological Sciences	4
173.111 General Physics Lab	1
550.291 Linear Algebra and Differential Equations	4
270.222 Earth Materials	4
Distribution requirements	<u>3</u>
Total	16

<i>Spring</i>	
171.104 General Physics II for Biological Sciences	4
173.112 General Physics Lab	1
270.224 Oceans and Atmospheres	3
Elective courses	3
Distribution requirements	<u>5</u>
Total	16

• **Year 4**

<i>Fall</i>	
270.225 Earth System History	3
270.226 Earth System History Lab	1
270.311 Geobiology	3
270.394 Global Geochemical Cycles and Climate Change	3
Distribution requirements	<u>6</u>
Total	16

<i>Spring</i>	
270.320 Global Change and Human Health	3
Elective courses	4
Distribution requirements	<u>8</u>
Total	15

Total – 120 credits

Environmental Earth Sciences Major

This major is for undergraduates interested in a thorough study of the processes which shape Earths environment, drawing on the disciplines of geology, geochemistry, hydrology, ecology, geobiology, oceanography, and atmospheric science. In addition to the core courses listed above, the student will take the following courses in Earth and Planetary Sciences. Depending on the specific needs of the student, some of these may be substituted in consultation with the coordinator for undergraduate programs in the department.

• **In the Department of Earth and Planetary Sciences**

270.308 Population and Community Ecology
270.311 Geobiology
270.320 Global Change and Human Health
270.321 Introductory Oceanography
270.369 Geochemistry of the Earth & Environment
270.375 Groundwater

Additional courses can be chosen as electives from the following offerings in and outside the department. Recommended courses include:

• **In the Department of Earth and Planetary Sciences**

270.301 Geochemical Thermodynamics
270.302 Aqueous Geochemistry
270.307 Combining Measurements with Models
270.322 Soil Ecology
270.315 Principles of Natural Catastrophes
270.350 Sedimentary Environments
270.351 Sedimentary Rocks Laboratory

270.369 Geochemistry of the Earth & Environment	
270.375 Groundwater	
270.394 Global Geochemical Cycles and Climate Change	
270.395 Planetary Physics and Chemistry	
270.475 Groundwater Contamination	

• **Outside the Department of Earth and Planetary Sciences**

570.239 Current and Emerging Environmental Issues	
570.303 The Environment and Your Health	
570.411 Engineering Microbiology	
570.423 Principles of Geomorphology	

In addition, a field course in the summer is strongly recommended.

A sample set of courses for a complete schedule is listed below.

• **Year 1**

<i>Fall</i>	
030.101 Intro Chemistry	4
030.105 Intro Chemistry Lab	1
110.108 Calculus I	4
Freshman Seminar	2
Distribution requirements	<u>4</u>
Total	15

<i>Spring</i>	
110.109 Calculus II	4
270.220 Dynamic Earth	3
270.221 Dynamic Earth Lab	1
Elective courses	5
Distribution requirements	<u>2</u>
Total	15

• **Year 2**

<i>Fall</i>	
171.101 General Physics I	4
173.111 General Physics Lab	1
270.222 Earth Materials	4
270.225 Earth System History	3
270.226 Earth System History Lab	1
Distribution requirements	<u>3</u>
Total	16

<i>Spring</i>	
171.102 General Physics II	4
173.112 General Physics Lab	1
550.291 Linear Algebra and Differential Equations	4
270.308 Population and Community Ecology	3
Distribution requirements	<u>4</u>
Total	16

• **Year 3**

<i>Fall</i>	
270.311 Geobiology	3
270.375 Groundwater	3
Elective courses	3
Distribution requirements	<u>6</u>
Total	15

<i>Spring</i>	
270.224 Oceans and Atmospheres	3
270.369 Introductory Geochemistry	3
Elective courses	3
Distribution requirements	<u>6</u>
Total	15

• **Year 4**

<i>Fall</i>	
270.321 Introductory Oceanography	3
270.394 Global Geochemical Cycles and Climate	3
570.411 Engineering Microbiology	4
Elective Courses	2
Distribution requirements	<u>3</u>
Total	15

<i>Spring</i>	
270.320 Global Change and Human Health	3
570.239 Current and Emerging Environmental Issues	3
Elective courses	5
Distribution requirements	<u>2</u>
Total	13

Total – 120 credits

Minor in Environmental Earth Sciences

The Environmental Earth Sciences minor (EPS) is for science undergraduates interested in applying their major discipline to Earth's environment through geology, geochemistry, hydrology, ecology, geobiology, oceanography, and atmospheric science. Students are expected to have at least 16 credits in (N), (Q), or (E) courses. Students will take at least four courses at the 200- or 300-levels, at least two of which are at the 300-level, selected from the following list:

270.220 Dynamic Earth	
270.221 Dynamic Earth Laboratory	
270.222 Earth Materials	
270.224 Oceans and Atmospheres	
270.225 Earth System History	
270.226 Earth System History Laboratory	
270.231 Ecology of a Changing Planet	
270.308 Population and Community Ecology	
270.311 Geobiology	

- 270.315 Principles of Natural Catastrophes
- 270.320 Global Change and Human Health
- 270.321 Introductory Oceanography
- 270.369 Introductory Geochemistry
- 270.375 Groundwater
- 270.394 Global Geochemical Cycles and Climate Change

Minor in Environmental Studies

This minor is for international studies majors and other social science or humanities majors who wish a general introduction to the disciplines which are concerned with Earth's environment. Students will take three classes at the 200-level or above selected from the following list:

- 270.201 Sustainability: Scientific and Religious Perspectives
- 270.220 Dynamic Earth
- 270.221 Dynamic Earth Laboratory
- 270.224 Oceans and Atmospheres
- 270.225 Earth System History
- 270.226 Earth System History Laboratory
- 270.231 Ecology of a Changing Planet

and at least one class from the following list:

- 270.320 Global Change and Human Health
- 570.632 Environmental History

In addition, students will take a senior seminar

- 270.404 Environmental Seminar
- or an approved internship.

Graduate Programs

Requirements for Admission

Applicants must submit transcripts, Graduate Record Examination scores (aptitude exam only), and supporting letters to show their ability to do advanced study. The applicant should have his/her GRE scores, verbal and quantitative aptitude, sent to the department before the January 15 deadline for filing applications for admission.

The department expects applicants for advanced degrees to have completed undergraduate training in the basic sciences and mathematics. Normally this includes mathematics through at least integral calculus and a years course each in physics, chemistry, and biology. Further undergraduate study in one or more of these subjects or in mathematics is highly desirable for all programs in the Earth sciences; additional mathematics is essential for geophysics, atmospheric sciences, and dynamical oceanography. Extensive undergraduate work in Earth sciences is not a requirement for admission. If students lack formal training in this area or have deficiencies in the other related sciences, they may

be admitted but will have to allow additional time in the graduate program to make up for deficiencies in their preparation.

Requirements for Advanced Degrees

Candidates for the Ph.D. must take courses and meet requirements specified by their advisory committee, must pass a comprehensive examination before a departmental committee and an oral examination administered by the Graduate Board of the University, and must submit an acceptable dissertation involving significant original research. A minimum of two consecutive terms registered as a full-time student is required.

The department rarely accepts candidates for the M.A. degree alone, but Ph.D. students can, with the consent of their advisers, complete a program that will qualify them for the M.A. degree at the end of the second year. Candidates for this degree must pass a comprehensive examination before a departmental committee, and must satisfy the residency requirement specified above for the Ph.D. degree. A student's adviser may require an essay demonstrating research capability.

For further information about graduate study in the Earth and planetary sciences contact the Chair, Department of Earth and Planetary Sciences.

Fields of Graduate Study and Research

The department offers numerous graduate fields: sedimentology, geochemistry and petrology, mineralogy and crystallography, groundwater geology, paleobiology, solid Earth geophysics, oceanography, atmospheric sciences, and planetary astrophysics. Descriptions of these fields and their various programs are given below.

Sedimentology

The teaching and research program in sedimentology is dedicated to seeking fundamental principles of deposition and diagenesis of carbonate, siliciclastic and chemical sediments and sedimentary rocks. The field is where geologic questions are defined and where they ultimately must be answered. Ours is a field and petrography oriented program in the tradition established by Francis Pettijohn, but thermodynamics, fluid dynamics, computer modeling, chemical and isotopic analysis, and experimental work are basic tools. We rely heavily on comparative sedimentology principles established through studies of modern depositional environments.

Students have always been encouraged to develop and follow their own research interests, and the result is a wide pool of ideas and a wide range of thesis projects. The sedimentology student group

normally ranges from three to five doctoral candidates in residence at any one time. There is no masters program. The main menu of sedimentology courses offered consists of Sedimentary Environments, Carbonate Rock Environments, Diagenesis Seminar, and Stratigraphy Seminar, all of which are given by Professor Hardie and involve field trips to the wide spectrum of sedimentary rocks exposed in the nearby Appalachians. Supporting courses in paleontology are offered by Professor Stanley; in thermodynamics and aqueous geochemistry by Professor Sverjensky and Professor Alan Stone, of the Department of Geography and Environmental Engineering (DOGEE); in hydrology by Professor Garven; in geomorphology by Professor M. Gordon Wolman, of DOGEE; and in sediment transport and hydraulics by Professor Peter R. Wilcock, also of DOGEE. Emphasis is placed on acquisition of additional skills in a field outside of traditional sedimentology but fundamental to its advance. For example, students interested in diagenesis must become facile in thermodynamics, aqueous geochemistry, and hydrology.

Geochemistry and Petrology

Modern research in geochemistry and petrology requires a flexible approach combining thermodynamics, solution chemistry, experimental petrology, and careful field observation. The department offers a broad range of courses that provide a thorough background in these areas and a detailed review of research to date. In addition to the facilities available on campus, those at the Geophysical Laboratory of the Carnegie Institution of Washington and at the U.S. Geological Survey in Reston are available to students and faculty through a cooperative arrangement.

The program in geochemistry emphasizes fundamental research in areas contributing to the general problem of how natural waters evolve chemically through water-rock interactions at both low and high temperatures. Aqueous geochemistry, the partitioning of trace elements between minerals and waters, and surface geochemistry, including its application to adsorption at the mineral-water interface and the kinetics of mineral dissolution, are all research topics that provide a basis for addressing geologic and environmental processes such as weathering, the chemical alteration of the oceanic crust, the generation of hydrothermal ore-forming solutions, and the migration of toxic and nuclear wastes in the environment. Students are encouraged to undertake quantitative studies integrating field, laboratory, and theoretical methods that permit a predictive approach

to geochemistry and to develop expertise in the groundwater geology program.

The program in economic geology is focused on the origin of hydrothermal ore deposits. Particular emphasis is placed on integration of field, laboratory, and theoretical studies of hydrothermal ore-forming processes, including the genesis of hydrothermal ore-forming fluids in both modern and ancient geothermal settings, the chemical evolution of hydrothermal ore-forming fluids via water-rock interactions during migration, the physics of fluid flow through porous media, and the nature of hydrothermal ore deposition and associated wall-rock alteration reactions.

The program in igneous petrology is concerned with the chemistry and physics of the origin and evolution of magma. All aspects of the generation, extraction, ascension, cooling, kinetics of crystallization, convection, differentiation, eruption, and flow are considered in detail. The results of high temperature melting experiments as well as detailed chemical analysis are applied to these problems. A nontraditional approach to petrological problems is emphasized through an analytical treatment of volcanological field work. Students are encouraged to take thermodynamics, fluid mechanics, and heat transfer, in addition to Igneous Petrology 270.690, Principles of Earth and Planetary Sciences 270.395, Physics of Magma 270.652, and Geophysical Petrology Seminar 270.604.

The program in metamorphic petrology emphasizes studies of petrogenesis involving field work, chemical, and stable isotope analysis of rocks and minerals, fluid inclusion studies, interpretation of textures and structures, laboratory phase equilibrium studies, and computer modeling of metamorphic processes. Analytical data from mineral assemblages are rigorously interpreted within the framework of chemical thermodynamics and transport theory. All chemical aspects of metamorphism are of concern, including mineral-fluid reactions and reaction mechanisms; the role of heat-rock vs. fluid-rock interaction in driving metamorphism; the scale and mechanism of fluid-rock interaction; major and minor element mobility; pressure-temperature paths followed by rocks during metamorphism; and the interplay between metamorphism and deformation.

Mineralogy and Crystallography

An understanding of crystal structure and the subsolidus behavior of minerals is fundamental to the interpretation of many geological phenomena. The program in mineralogy and crystallography

stresses the application of crystallographic theory and experimental approaches to petrologically, environmentally, and geophysically relevant mineral systems.

Research in crystal chemistry utilizes X-ray techniques but more strongly emphasizes the application of high-resolution transmission electron microscopy, electron diffraction, and analytical transmission electron microscopy. The electron microscopy laboratory in the Department of Earth and Planetary Sciences is used to investigate the defects and mechanisms of solid-state reactions in minerals, mechanisms of crystal growth, the structures of fine-grained and disordered geological materials, the chemical and structural variations in synthetic run products and the structures of grain boundaries in rocks.

Geobiology and Paleoclimatology

Research emphases within this discipline include soil ecology, soil formation, biohydrology, plant-soil-animal interactions, paleoecology, and paleoclimatology. Students are invited to participate in ongoing collaborations with the Baltimore Ecosystem Study (Long-Term Ecological Research Site), Smithsonian Environmental Research Center, or to design an original research project under the advisement of our faculty. In conjunction with the Department of Geography and Environmental Engineering, Earth and Planetary Sciences offers course work opportunities in Aquatic Chemistry, Plant and Animal Ecology, Geobiology, Analytical Environmental Chemistry, Sedimentary Geochemistry, Evolution, Paleontology, Groundwater Geology, and a Field Course in Soil Formation. Instrumentation in the Department of Earth and Planetary Sciences includes stable isotope mass spectrometry, scanning electron microscopy, microprobe and transmission electron microscopy; fieldwork is ongoing at several international sites.

Groundwater Hydrology

Groundwater geology or hydrogeology involves the study of groundwater from an Earth science perspective. The research and teaching in hydrogeology at Johns Hopkins is unique in its attempt to bridge the methodology of modern hydrology, geochemistry, continuum mechanics, and mathematical modeling to problems involving the role of groundwater in geologic processes. Current research includes work on the development of three-dimensional flows in sedimentary basins, hydrogeology of Australian ore deposits, fluid flow in submarine Hawaiian aprons, deep groundwater flow in coastal California, numerical analysis of groundwater flow with reactions in the Dead Sea

rift, Israel, and studies of ancient hot springs and faults in northern Alaska.

Students majoring in hydrogeology are expected to attain a high level of expertise in the theory and practice of fluid flow and heat and mass transport in porous and fractured media by the end of the second year of graduate study. A core program of courses in groundwater hydrology, applied mathematics, aqueous geochemistry, fluid mechanics, and numerical methods can be taken to achieve this level of expertise. Students are encouraged to develop their own special research interests, and also acquire a strong background in at least one other subject area of geology, geochemistry, or geophysics.

Paleobiology

The paleobiology program combines the concepts and methodologies of biology, paleontology, and sedimentology to study the processes that control the distribution and abundance of organisms and the direction and rate of evolutionary change. Methods of stable isotope geochemistry are used to investigate changes in the cycling of C, H, N, and O through Earth history. When biological principles are used to interpret fossil assemblages, the fossil record becomes a rich source of data for generating evolutionary hypotheses.

Students in paleobiology are encouraged to employ functional morphology, biometrics, and sedimentology to reconstruct the interactions within fossil communities and the shifting milieu of natural selection through geologic time. Study of communities and individual lineages is seen as a tool for the analysis of larger patterns of speciation, diversification, and extinction.

All Ph.D. students are expected to have a background of physics, chemistry, calculus, general biology, and sedimentary geology. Deficiencies can be made up in the first semesters at Hopkins. Students take a core program of statistics, Earth history, macroevolution, stable isotope geochemistry, geobiology, and introductions to evolutionary biology.

Oceans and Atmospheres

The atmospheres and oceans program focuses on the study of fluid motions, wave phenomena, and transport in atmospheres and oceans. The philosophy underlying the departments program is a rigorous and thorough background in the physics of fluids, and radiation, and their applications to climate and environmental problems, applied mathematics, laboratory experiments, and observations. Problems in radiative transfer and the dynamics of atmospheres and oceans are attacked by theory, laboratory or numerical experiments, and field observations. The

University is a member of the University Corporation for Atmospheric Research.

The best preparation for graduate study in this program is an undergraduate degree in physics, applied mathematics, mechanical engineering, or another parent science such as chemistry or geology/geophysics. Prior course work in fluid dynamics, while highly desirable, is not mandatory to pursue graduate study in this area. It is essential to have a broad background in the parent sciences, specialization in one of them, and at least three years of undergraduate mathematics.

Current research interests in dynamical oceanography include the structure of surface waves generated by winds and remote sensing of the sea surface, understanding internal gravity waves and turbulence in stably stratified fluids, and turbulent boundary layers. Thorough attention is given to different aspects of air-sea interaction processes, in particular problems such as gas transfer between ocean and atmosphere, wave breaking, wave-turbulence interactions, and mixing processes in the upper ocean and atmospheric boundary layers.

Research in physical oceanography addresses the processes that maintain the global ocean circulation and the oceans role in climate. In particular, attention is on the role of waves, eddies, and small-scale mixing in controlling the oceans part in Earth's heat balance. We also study advection, stirring, and mixing processes in the interior ocean and their roles in dispersing atmospheric trace gases.

Research in atmospheric dynamics focuses on large-scale dynamics, the transport of trace constituents, and understanding the composition of the global atmosphere (e.g., distributions of stratospheric ozone and tropospheric water vapor). Current interests include stratospheric vortex dynamics, troposphere-stratosphere couplings, transport and mixing processes, and global modeling of chemical constituents.

Research on climate and radiation include study of the global climate system and its response to radiative forcing due to changes in greenhouse gases and solar luminosity, the feedback effects of water vapor and clouds, and the radiative and hydrological effects of aerosols. These studies involve global and regional scale modeling, and the analysis and interpretation of satellite observations.

A new program of research, combining physical oceanography and atmospheric science, focuses on the role of ocean-atmosphere interactions in the climate of the North Atlantic region. The task is to isolate and understand the predictable mechanisms that govern mid-latitude climate oscillations lasting several years.

Solid Earth Geophysics

This field is concerned with the composition, structure and evolution of Earth, and with the large-scale internal motions of the mantle and core, their interaction, and their relationship to plate tectonics. Insight into such problems comes from an integrated application of geology, fluid mechanics, seismology, gravity, and magnetism and through comparative planetology. Students following this program are encouraged to take advanced mathematics, fluid mechanics, geophysics, and, if possible, electricity and magnetism.

Planetary Atmospheres/Astrophysics

The program in planetary astrophysics emphasizes the study of planetary atmospheres and magnetospheres. A broad range of fundamental problems in atmospheric chemistry, dynamics, physics and radiation pertinent to the atmospheres of the giant planets and their satellites are addressed with the goal to understand the global structure of composition, pressure, temperature, and winds. The study of magnetospheric plasma interactions with extended satellite atmospheres is focused on the energy balance, ionospheric structure, and radiative output of their upper atmospheres, and the mass loading rates of the parent planets magnetospheres. The atmospheres and magnetospheres of the planets are investigated with the aid of theoretical models and the analysis and interpretation of data acquired by ground-based, Hubble Space Telescope, and satellite observations. Professor Strobel is an Interdisciplinary Scientist on the Cassini/Huygens Mission. An in-depth study of the Saturnian system is being conducted with the Cassini Spacecraft. The successful descent and landing of the Huygens Probe in January 2005 provided a wealth of data on Titan's atmosphere and surface.

The research program in planetary atmospheres and astrophysics is closely coordinated with the astrophysics program in the Department of Physics and Astronomy. Students are encouraged to take courses in astrophysics, chemistry, physics, and applied mathematics to gain the comprehensive background necessary for interdisciplinary research. The best undergraduate preparation is a broad background in physics, applied mathematics, and physical chemistry with a minimum of three years of course work in two of these fields. Advanced undergraduate courses in classical mechanics, fluid mechanics, electricity and magnetism, thermodynamics, and quantum mechanics are strongly recommended. The facilities of the Center for Astrophysical Sciences and the Space Telescope Science Institute are available for thesis research.

Financial Aid

The University makes available to the department a number of Gilman Fellowships, which provide for complete payment of tuition, together with University fellowships and graduate assistantships that carry a nine-month stipend. Graduate assistantships cannot require more than 10 hours a week of service to the department, and all recipi-

ents of financial aid carry a full program of study. In addition, a number of special and endowed fellowships pay as much or more. In many areas of study, summer support is also available.

Applications for admission to graduate study and financial aid (including all supporting documents and GRE scores) should be submitted to the department before January 15.

Undergraduate Courses

Courses listed as prerequisites serve to indicate the degree of proficiency that is expected. They need not have been taken at Johns Hopkins.

270.102 (N) Freshman Seminar: Conversation with the Earth

A discussion of current topics on Earth's origin, evolution, and habitability. Topics will include extinction of life from meteorite impact, global warming, ozone depletion, volcanism, ice ages, and catastrophic floods, among others. Section 1 (270.102-01) is for 2 credits for normal participation. Section 2 (270.102-02) is for 3 credits and has the requirement of a term paper.

Marsh, and other faculty

270.103 (N) Earth's Environments

The structure, composition, and dynamics of the Earth and how we learn about them. Sea floor spreading, continental drift, mountain building, earthquakes, volcanoes, and other internal processes. Surface processes including weathering, erosion, sedimentation, and the record of climate change. No prerequisites.

Olson, Hardie 3 credits

270.109(N) Exploring Earth's History Through Fossils

This freshman seminar seeks to expose students to the most timely and exciting issues of paleontology, as well as to field geology. We will learn the sequence of the early land plant evolution, and see examples of how this information was obtained from rock records. We will also study maps and geological descriptions related to the field trip site, and prepare for and perform a one-week field trip (usually in early December). Must be declared EPS major or have strong interest in becoming an EPS major to take this course.

Jahren 2 credits

270.114 (N) A Guided Tour of the Planets

An introduction to planetary science and planetary exploration primarily for nonscience majors. A survey of concepts from astronomy, chemistry, geology, and physics applied to the study of the solar system. No prerequisites.

Marsh, Strobel 3 credits

270.120 (N) The Extinction of the Dinosaurs

A study of current and past theories concerning what caused the extinction of the dinosaurs; emphasis placed on potential linkages between climate change and extinc-

tion. Open to all JHU students; no prerequisites; limit 100; high school math, chemistry and physics strongly recommended.

Jahren 3 credits

270.201 (S,H) Sustainability: Scientific and Religious Perspectives

An exploration of the problem of achieving a sustainable global community from the complementary perspectives of the Earth sciences and religious ethics.

Staff 3 credits fall

270.220 (N) The Dynamic Earth: An Introduction to Geology

An introduction to the basic concepts of geology. Topics include Earth's internal structure; geologic time; minerals and rocks; erosion and deposition by oceans, rivers, wind, and glaciers; sedimentary environments; volcanism and plutonism; metamorphism; faults and folds; earthquakes and seismology; geomagnetism; plate tectonics. Pre- or corequisites: 030.101 or 171.101-102; 270.221 is corequisite for Earth science majors, optional for others.

Veblen, Ferry 3 credits 3 hours lecture

270.221 (N) The Dynamic Earth Laboratory

Laboratory exercises to illustrate the concepts developed in 270.220. Corequisite: 270.220.

Staff 1 credit 2 hours lab

270.222 (N) Earth Materials

An introduction to the properties, occurrence, and origin of the basic constituents of the Earth, including minerals, rocks, and soils. Introductory training in the recognition of minerals, rocks, and soils in the laboratory and the field.

Veblen, Ferry, Jahren 4 credits 3 hours lecture, 3 hours lab

270.224 (N) Oceans and Atmospheres

A broad survey of the oceans and atmospheres, and their role in the environment and climate. Subjects include ocean circulation, weather systems, hurricanes and tornadoes, El Niño, climate change, ozone depletion, and marine ecosystems. For science and engineering students.

Haine, Waugh 3 credits

270.225 (N) Earth System History

Geologic history of Earth and its ecosystems. The evolution and extinction of many forms of life—from bacteria to dinosaurs, flowering plants, and humans—will be reviewed in the context of a changing global environment. Interactions among the upper earth, ocean, atmosphere, and biosphere will be highlighted. Corequisite: 270.226.

Stanley 3 credits

270.226 (N) Earth System History Laboratory

Laboratory exercises employing fossils, rocks, maps, and stratigraphic cross-sections. Corequisite: 270.225.

Stanley 1 credit

270.231 (N) The Ecology of a Changing Planet

Large-scale ecological patterns will be the primary focus of this course. Major transitions for environments late in Earth's history will be discussed as a background for considering present and possible future influences on life of such human activities as deforestation, desertification, overfishing, pollution, emission of greenhouse gases, and introduction of species.

Szlavecz 3 credits spring

270.301 (N) Geochemical Thermodynamics

Principles of chemical thermodynamics. Concept of and criteria for equilibrium. Properties of real fluids and solids. Applications to geologic processes. Prerequisite: 270.222 or 270.341.

Ferry 3 credits 3 hours

270.302 (N) Aqueous Geochemistry

Thermodynamic basis for calculation of equilibria involving minerals and aqueous species at both low and high temperatures and pressures. Theoretical calculation of surface geochemical processes including adsorption and dissolution kinetics. Prerequisite: 270.369.

Sverjensky 4.5 credits 3 hours lecture, 2 hours lab

270.304 (N) Igneous and Metamorphic Petrology

Description and origin of igneous and metamorphic rocks. Classification and occurrence. Application of fundamental principles of physics and chemistry to the study of petrogenesis. The control of plate tectonics on rock-forming processes. Corequisite: 270.306. Prerequisites: 270.341-342.

Ferry 3 credits 3 hours lecture

270.306 (N) Igneous and Metamorphic Petrology Laboratory

Examination of igneous and metamorphic rocks in hand specimen and thin section. Principles and practice in optical mineralogy. Common mineral associations and textures. Rock suites from several classic localities in North America. Corequisite: 270.304.

Ferry 1 credit 3 hours lecture

270.307 (N,Q) Combining Measurements with Models

An introduction to modern ways to interpret observations in the context of a conceptual model. Topics include model building, hypothesis testing, and inverse meth-

ods. Practical examples from geophysics, engineering, and medical physics will be featured.

Haine 4 credits

270.308 (N) Population and Community Ecology

This course explores the distribution and abundance of organisms and their interactions. Topics include dynamics and regulation of populations, population interactions (competition, predation, mutualism, parasitism, herbivory), biodiversity, organization of equilibrium and non-equilibrium communities, energy flow and nutrient cycles in ecosystems. Field trip included.

Szlavecz 3 credits fall

270.311 (N) Geobiology

Dynamic processes that transfer elements across the biosphere/geosphere interface, with special emphasis on terrestrial ecosystems. We focus upon soils as a cycling reservoir of water, nitrogen, carbon, and other important Earth elements; and we focus upon plants as the living link between the terrestrial hydrosphere, geosphere, and the atmosphere. Field trips included.

Jahren 3 credits

270.314/619 (N) Field Course in Soil Formation

This course includes both the basics of the chemistry and physics of soil processes, as well as beginning and advanced practice in soil characterization and field analysis. The field route includes select examples of each of the nine soil orders found in the United States. Each soil sampled along the route will be characterized for texture, structure, color, pH, and horizonation and classified according to standard pedologic procedure. In addition, we will analyze each site extensively in terms of its climatic, geologic, and vegetative context.

Jahren 6 credits summer

270.315 (N) Principles of Natural Catastrophes

A survey of naturally occurring catastrophic phenomena, with emphasis on the underlying physical processes. Topics include hurricanes, tornadoes, lightning, earthquakes, tsunamis, landslides, and volcanic eruptions and climate change. Intended for students in science and engineering.

Olson 3 credits

270.316 (N) Invertebrate Fossils and Environments

Marine invertebrate life of the past: functional morphology, sedimentological context of occurrence, and evolution. Special topics will include the history of organic reefs, faunas of anoxic basins, and adaptation to various depositional regimes. Prerequisites: some knowledge of sedimentary geology, permission of instructor. Corequisite: 270.318.

Stanley 3 credits

270.318 (N) Invertebrate Fossils and Environments Laboratory

Corequisite: 270.316.

Stanley 1 credit

270.320 (N,S) Global Change and Human Health

An examination of the links connecting disease and Earth's environment and the implications of those links for human health in a changing global environment. Team-taught by faculty from the schools of Public Health, Arts and Sciences, and Engineering. Enrollment limit: 200.

Staff 3 credits

270.323 (H,N) Darwin and the Origin of Species

After briefly examining organic evolution as it is understood today, this course evaluates Darwin's methodology and impact on science and culture, based on an assessment of *On the Origin of Species* and related writings in the natural and social sciences, humanities, religion, and the visual arts. Limit: 30.

Stanley 3 credits

270.327 (N) Introduction to Seismology

A study of the structure and constitution of Earth's interior using observations of seismic waves. Topics include propagation, reflection, and refraction of elastic waves, ray theory, dispersion of surface waves, seismicity, plate tectonics, Earth structure and composition. Corequisite: 270.329. Prerequisites: calculus and basic physics.

Olson 3 credits

270.329 (N) Introduction to Seismology Laboratory

Laboratory exercises on the interpretation of seismograms. Corequisite: 270.327.

Olson 1 credit one 3-hour lab

270.332 (N) Soil Ecology

This course introduces basic aspects of cycles and flows in the soil ecosystem, and provides students with an overview of the higher groups of soil organisms, focusing on their identification characters and ecological roles. The course is intended for upper level undergraduates or graduate students who are interested in soils and soil ecology. The course provides basic laboratory and field surveying skills in the discipline. Prerequisites: Population and Community Ecology, Geobiology or instructor's permission. Laboratory and field surveying methods are also covered.

Szlavec 3 credits

270.341 (N) Crystallography and the Structure of Inorganic Solids

An introduction to the principles of crystallography, diffraction, and the structures of inorganic crystals. Materials covered include important rock-forming minerals, metals, alloys, semiconductors, superconductors, ceramics, catalysts, and other technologically important materials. Corequisite: 270.343. Prerequisite for Earth science majors: 270.342.

Veblen 3 credits 3 hours lecture

270.342 (N) Mineralogy Laboratory

Exercises in the chemistry and identification of minerals in hand specimen. This laboratory is designed for undergraduate majors in the Earth sciences. Corequisite: 270.341.

Veblen 1 credit 2 hours lab

270.343 (N) Crystallography Laboratory

Exercises in crystallography, crystal chemistry, and X-ray diffraction. Extensive use is made of crystal structure models. This laboratory is designed for students already familiar with minerals in hand specimen or not majoring in Earth sciences. Corequisite: 270.341.

Veblen 1 credit 2 hours lab

270.350 (N) Sedimentary Environments

Introduction to sedimentary processes and petrology of sedimentary rocks. Origin of siliciclastic, carbonate, and chemical deposits with emphasis on depositional models and facies complexes. Weekend field trips. Prerequisite: permission of instructor. Corequisite: 270.351. Minimum enrollment: 5.

Hardie 3 credits spring

270.351 (N) Sedimentary Rocks Laboratory

Laboratory work in petrology of sedimentary rocks. Corequisite: 270.350.

Hardie 1.5 credits 3 hours lab

270.355 Introductory Atmospheric Science

An introduction to all aspects of atmospheric science. The course will include discussions of observations together with theories and simple models of the key dynamical, radiative, and chemical processes. Topics covered include global atmospheric circulation, air pollution, and climate change. This course is especially for third- and fourth-year undergraduates and graduate students in science and engineering. Prerequisites: 030.101, 110.108-109, 171.101-102.

Waugh 3 credits fall/odd years

270.369 (N) Geochemistry of the Earth & Environment

An introduction to all aspects of geochemistry: theoretical, experimental, and observational, including the application of geochemistry to issues such as the migration of toxic metals and nuclear waste.

Sverjensky 3 credits 1 hour lab

270.375 (E,N) Groundwater

Introduction to theory of groundwater flow in the saturated and unsaturated zones; hydrology of aquifers; flow nets; well hydraulics; groundwater engineering. Applications to watershed hydrology, groundwater resource evaluation, groundwater contamination, geotechnical problems, and geologic processes.

Garven 3 credits 1 field trip fall

270.377 Climates of the Past

An overview of Earth's climatic components, global climate regimes, climate variability, the climate-sensitive Earth archives, paleoclimate through geologic time, episodes of extremes, and models of paleoclimate change. For upper-level and beginning graduate students. Prerequisite: 270.115 or 270.120 or instructors permission.

Hinnov 3 credits

270.378 (N) Present and Future Climate

This course is intended for science majors who are interested in the science that underlies the current debate on global warming. In applying basic laws of physics,

the emphasis will be on the results of such application, observations, and what one can glean from model simulations. For a more advanced course, delving further into theory, and including analysis methods and model development, see 270.410 (Global Climate Change). Although not requisite, 270.224 (Oceans and Atmospheres) and 270.377 (Climates of the Past) would provide a useful background. Prerequisites: 110.108-109 (Calculus I and II) and 171.101-102 (General Physics).

Arking 3 credits

270.394 (N) Global Geochemical Cycles and Climate Change

This course offers an integrated examination of (1) the global-scale geochemical cycles operating in the atmosphere, the hydrosphere, the lithosphere, and interior of the Earth, and their role in the evolution of the Earth System, (2) the Earth's present and past climate system and the origin and evolution of the chemistry of the atmosphere, the oceans, and the solid Earth. Emphasis will be on the coupling between the different components that make up the Earth System (e.g., atmosphere-ocean interactions; hydrosphere-lithosphere interactions). Prerequisites: 030.105-106, 171.101-102.

Hardie, Waugh 3 credits fall

270.395 (N) Planetary Physics and Chemistry

The fundamental principles governing the dynamic processes within and around the planets are treated in some detail. Core equations are developed and used to analyze nebula condensation, planetary accretion, convection in mantles and atmospheres, radiative and conductive heat transport, seismic waves, hurricanes, volcanism, and meteorite impacts, among others. Emphasis is on fundamentals and problem solving. Prerequisites: Calculus II, 030.101, 171.101-102 or 103-104 or 105-106.

Marsh, Strobel 3 credits

270.400 Intersession Independent Study

An independent course of study may be pursued under the direction of an adviser on those topics not specifically listed in the form of regular courses.

270.401 (N) Introduction to Physical Oceanography

This course is designed for first year graduate students in oceanography, graduate students in engineering disciplines that will involve ocean processes (Civil, Environmental and Mechanical Engineering departments), and advanced undergraduates that want to understand the application of their knowledge of physics and mathematics to the ocean. This first semester of the sequence is an introduction to a wide range of oceanic phenomena. Prerequisites: Students are to be knowledgeable about partial differential equations.

Haine/Osborn 3 credits

270.402 (N) Introduction to Dynamical Oceanography

This course is designed for first year graduate students in oceanography, graduate students in engineering disciplines that will involve ocean processes (Civil, Environmental and Mechanical Engineering departments), and

advanced undergraduates that want to understand the application of their knowledge of physics and mathematics to the ocean. This second semester is designed to cover the dynamics of the processes that are relevant for coastal and open ocean dynamics. Prerequisites: 270.401.

Haine/Osborn 3 credits

270.404 (N,W) Environmental Seminar

A seminar for seniors enrolled in one of the Environmental Science programs; requires preparation of a term paper focusing on the interplay between the policy and scientific aspects of environmental issues. Team-taught by faculty from science and policy-oriented departments.

Fisher 3 credits

270.410 (N) Global Climate Change: Introduction

An introduction to the basic principles of atmospheric structure and its response to natural and anthropogenic perturbations. It includes the role of the sun, atmospheric constituents, and Earth's surface in determining Earth's climate and its sensitivity to change. Prerequisites: Calculus I-II and General Physics I-II, or permission of instructor. Recommended: Calculus III.

Arking 3 credits alternate falls

270.416 (N) Geochemistry of Natural Waters

This course explores how important types of natural waters such as seawater, rainwater, river waters, groundwaters, basinal brines, and hydrothermal brines originated and evolved over geologic time.

Hardie 3 credits

270.421 (N) Marine Ecosystem Dynamics

This course will cover fisheries and fisheries management concepts, harmful algal blooms, population dynamics of marine species, and other topics selected by the participants.

Osborn 3 credits

270.422 (N) Geochemistry of Ore Deposits

This course explores the geologic processes and economic factors that result in the development of commercial concentrations of non-energy mineral resources. The course will discuss a broad spectrum of ore deposits, ranging from the formation of placer-type Au deposits at Rand, society's largest source of Au, to the genetic link between subduction zone dehydration, porphyry-type Cu, Au, Mo, W, Bi, Sn deposits and shallow-level epithermal Au, Ag deposits. Emphasis will be placed on the physicochemical differences between deposit types and the geochemical causes of ore deposit diversity. The course will examine the relationship between element suites (e.g., Platinum group elements: copper, silver, gold), their position in the periodic table and the reasons they are found together in nature. Related topics to be discussed include importance of mineral resources to the global economy, mineral exploration and evaluation, and mineral extraction and processing. Reading material for the course will be selected from academic journals.

Staff 3 credits

270.475 (E,N) Groundwater Contamination

Principles of groundwater chemistry; sources of contamination; theory for solute transport in porous media; mapping contaminant plumes; monitoring; site remediation; pollution case studies.

Garven 4 credits 1 field trip, lab project spring

270.495-496 (W) Senior Thesis

Preparation of a substantial thesis based upon independent student research, supervised by at least one faculty member in Earth and Planetary Sciences. Open to senior departmental majors only. Required for departmental honors.

Staff 4 credits per semester

270.501-502 Independent Study

An independent course of study may be pursued under the direction of an adviser on those topics not specifically listed in the form of regular courses.

270.507-508 Internship**Cross-Listed****570.429 (E,N) Surface Effects in Technological Processes and Materials**

Mechanical properties and stability of disperse systems and materials are considered in dependence on real microheterogeneous structure and physical/chemical surface phenomena determining particles cohesion. Concepts of modern physical/chemical mechanics are applied to achieve two cardinal goals: high stability and durability of materials including natural and living tissues, and low resistance during deformation and treatment, independence upon surrounding media and other environmental conditions. Prerequisites: 570.444 or general physics and chemistry.

Shchukin 3 credits fall

Graduate Courses**270.601 Fluids Seminar**

Graduate discussion group ranging over all aspects of fluids in Earth and planetary sciences.

Haine 1 hour

270.603 Geochemistry Seminar

A variety of topics of current interest involving mineral-fluid interactions will be reviewed. Prerequisite: permission of instructor.

Sverjensky 2 hours

270.604 Geophysical Petrology Seminar

Discussion of present research topics in geophysics and igneous petrology. With consent of instructor.

Marsh 1 hour

270.605-606 Journal Club

Review and discussion of new geologic literature and current research. All earth and planetary sciences graduate students participate and deliver at least one paper a year.

Staff 1 hour

270.608 Seminar in Atmospheric Sciences

Discussion of current research topics in atmospheric science.

Waugh 1 hour

270.609-610 Special Topics in Earth and Planetary Sciences

Reading courses on particular topics in this area can be arranged after consultation with an individual faculty member.

Staff

270.613 Metamorphic Petrology Seminar

Discussion of recent research topics in metamorphic petrology and geochemistry.

Ferry 1 hour

270.614 Atmospheric and Oceanic Vortices

The fundamental dynamics of vortices in rapidly rotating, stratified fluids is discussed and used to examine the structure and dynamics of vortices occurring in the Earth's atmosphere and oceans and in the atmospheres of the outer planets.

Waugh 2 hours alternate springs

270.621 Transmission Electron Microscopy: Practice and Applications

A lab and lecture course covering the practical aspects of transmission electron microscopy. Electron diffraction, image formation, and analytical techniques are explained, and students are given an opportunity to gain hands-on microscopy experience. The detailed theory for these experiments is developed in 270.622.

Hemker, Veblen 1 hour lecture, 4 hours lab

270.622 Transmission Electron Microscopy: Theory and Understanding

This course, which follows and complements 270.621, introduces the student to more detailed aspects of kinematical and dynamical theories of electron diffraction. Theory of conventional TEM imaging, phase-contrast imaging (high-resolution electron microscopy), X-ray and energy-loss analytical TEM, and computer-based image simulation are included.

Veblen, Hemker 3 hours lecture, occasional lab work

270.623 Planetary Atmospheres

Fundamental concepts and basic principles of chemistry and physics applied to the study of planetary atmospheres. Vertical structure of planetary atmospheres. Atmospheric radiation, thermodynamics and transport. Principles of photochemistry. Planetary spectroscopy and remote sensing. Upper atmospheres and ionospheres. Evolution and stability of planetary atmospheres. Prerequisite: permission of instructor.

Strobel 3 hours

270.624 Seminar in Stable Isotope Techniques

This laboratory course will compare the new automated preparation systems attached to the Isoprime mass spectrometer with more traditional off-line vacuum apparatus, on the basis of ease/rapidity of analysis, sensitivity, preci-

sion, and flexibility. We will focus on the stable isotopes of C in organic matter (modern and fossil) and D/H and O in water.

Jahren 2 hours

270.625 Groundwater and Geologic Processes

Introduction to the role of groundwater flow in geologic processes. Topics include the theory of fluid flow, heat transport, and chemical mass transport in hydrothermal systems; laboratory and field techniques for rock permeability measurement; hydrogeology of diagenesis; fluid flow in sedimentary basins; thermally-driven flows around cooling plutons; and the coupling between fluid flow and rock deformation in the Earth's crust.

Garven 3 hours alternate years

270.627 Invertebrate Paleobiology Seminar

Functional morphology, paleoecology, and general systematics of major taxonomic groups of fossilized invertebrates.

Stanley 3 hours

270.629 Carbonate Rock Environments

Reconstruction of depositional environments of ancient carbonate rocks by the method of detailed comparison with modern active carbonate sediment environments. Several weekend field trips. Corequisite: 270.630.

Hardie 4 hours alternate falls

270.630 Carbonate Rock Environments Laboratory

Corequisite: 270.629.

Hardie 3 hours

270.631 (N) Carbonates and Evaporites

The origin of carbonate and evaporite sedimentary deposits and their geological significance. Several field trips. Prerequisites: Consent of Instructor. Co-requisite: 270.632.

Hardie 3 hours

270.632 (N) Carbonates and Evaporites Laboratory

The origin of carbonate and evaporite sedimentary deposits and their geological significance. Co-requisite: 270.631.

Hardie 2 lab hours

270.634 Macroevolution

Rates, trends, and patterns of evolution as seen through the application of biological principles to the fossil record. Prerequisite: permission of instructor.

Stanley 3 hours

270.635 Crystal Chemistry and Behavior of Rock-Forming Minerals

A detailed exploration of the crystal structures and subsolidus behavior of the major rock-forming mineral groups. Prerequisite: a basic understanding of crystallography and diffraction.

Veblen 3 hours

270.636 Stable Isotope Biogeochemistry

Theory and measurement of stable isotopes are discussed, with relevant emphasis on instrumentation. The record

of stable isotope measurements of carbon, oxygen, and hydrogen are examined in detail, with special emphasis upon the breadth of applications across geology, biology, archaeology, biogeochemical cycling, and global climate reconstruction.

Jahren 3 hours

270.641 Inorganic Solids: Structure, Properties, Chemistry, Applications, and Crystallography

An exploration of the structures of inorganic solids, including the chemical elements, minerals, alloys, ceramics, catalysts, and other important materials. A brief but rigorous introduction to crystallography. Laboratory exercises include extensive work with structure models, symmetry, and one field trip.

Veblen 3 hours class, 3 hours lab

270.642 Surface Geochemistry

An overview of theoretical models of adsorption at the solid-aqueous solution interface. Surface chemistry of oxides and silicates in electrolyte solutions. Surface complexation of metals. Prediction of adsorption on surfaces.

Sverjensky 3 hours

270.643 Oceanic Turbulence and Mixing

An in-depth review of the present state of knowledge on small scale turbulence in the ocean. Topics include ocean thermocline, bottom boundary layer, diffusion, dissipation, measurement techniques, and unsolved problems.

Osborn 3 hours

270.644 Physics of Climate Variability

This course is an advanced-level review of the key dynamic and thermodynamic processes causing climate fluctuations on timescales of seasons to decades. The focus is on phenomena that involve the ocean and topics will cover, depending on the class' interest, ocean circulation theories, large-scale ocean waves and eddies, thermohaline circulation, air/sea interaction, and modes of climate variability. Geophysical understanding and the links to fundamental mechanisms are emphasized.

Haine 2 hours

270.646 Fluid Dynamics of the Earth and Planets I

A first course in the mechanics of Earth and planets fluids systems. The focus is on fundamental fluid processes and their applications to phenomena occurring in the atmosphere, oceans, and interior of Earth and other planets.

Olson, Waugh 3 hours fall

270.647 Mechanics of the Earths Interior

Mechanical processes in Earths core and mantle with applications to plate tectonics, the thermal and chemical evolution of Earth, and generation of Earths magnetic field. Topics vary yearly.

Olson 3 hours

270.651 Planetary Geophysics

The application of continuum physics to the large-scale processes governing the evolution of Earths crust and mantle. Topics include elasticity and flexure, creep deformation,

conductive and convective heat transfer, fault mechanics and flow in porous media. Prerequisite: 270.321.

Olson 3 hours

270.652 Physics of Magma

The principles of viscous fluid flow, heat conduction and convection are treated in reference to all aspects of the mechanics of magma. Emphasis is placed on understanding petrologic processes as observed in rocks and rock sequences.

Marsh 3 hours

270.653 Fluid Dynamics of the Earth and Planets II

A sequel to 270.646 concentrating on planetary-scale atmospheric and oceanic circulation. Physical understanding of the underlying fluid dynamics will be emphasized.

Haine, Waugh 3 hours spring

270.657 Flow in Porous Media

Dynamics of fluids in permeable media: theory for groundwater flow; potential fields and inhomogeneous fluids; multiphase flow; chemical transport and reactive flows; heat transport and coupled processes; flow with rock deformation.

Garven 3 hours alternate falls

270.659 Seminar in Oceanography I

Osborn 2 hours fall

270.660 Seminar in Oceanography II

Osborn 2 hours spring

270.661 Planetary Fluid Dynamics

This is a self-contained one-semester course in the applications of basic fluid dynamics concepts to the study of planetary atmospheres. Topics include equations of motion on a rotating planet, the Boussinesq approximation, conservation properties, hydrodynamic instability, convection, turbulence and planetary boundary layers, quasi-geostrophic theory, baroclinic instability, general circulation, and linear wave propagation. Prerequisite: 270.646 or equivalent highly desirable.

Strobel 3 hours

270.662 Seminar in Planetary Science

Major problems of current interest in planetary science are critically discussed in depth. Prerequisite: permission of instructor.

Strobel 1-3 hours

270.664 Seminar in Fluid Mechanics

A seminar course on the interaction of particles in turbulent flow.

Osborn 2 hours

270.673 (N) Time Series and Data Analysis

Spectral analysis, digital filtering, convolutions, and other techniques for processing data will be covered.

Osborn 3 hours

270.676 Numerical Methods in Hydrogeology

Numerical analysis of steady and transient groundwater flow, heat transport, mass transport, and geochemical

mass transfer. Finite-difference, finite-element, integrated finite-difference, method of characteristics, collocation, and random-walk modeling of transport processes. Applications to modeling regional flow, infiltration, aquifer systems, see page through earth dams, geothermal systems, ground-water contamination, and water-rock reactions. Prerequisite: permission of instructor.

Garven 4 hours alternate springs

270.678 Seminar in Advanced Hydrogeology

Current research topics are examined on various aspects of groundwater flow and geologic processes with emphasis on quantitative analysis.

Garven 2 hours fall

270.681 Advanced Metamorphic Petrology

The interpretation of metamorphic processes based on mineral assemblages, mineral chemistry, chemical thermodynamics, transport theory, experimental petrology, and field studies. Geothermometry and geobarometry; mineral reactions and reaction mechanisms; heat transfer and fluid transfer; element and isotope mobility; thermal models for orogenic belts. Prerequisites: 270.301 and 270.304 or equivalents. Corequisite: 270.682.

Ferry 3 hours

270.682 Advanced Metamorphic Petrology Laboratory

Laboratory studies of metamorphic rocks in thin section. Application of theory and experiment to individual rock samples. Prerequisites: 270.301 and 270.304 or equivalents. Corequisite: 270.681.

Ferry 3 hours

270.690 Igneous Petrology

Properties, occurrence, and origin of the major types of igneous rock. Generation, emplacement, and crystallization of magmas. Prerequisite: 270.306 or permission of instructor. Corequisite: 270.692.

Marsh 3 hours

270.692 Igneous Petrology Laboratory

Experimental crystallization of rocks; fluid mechanical experiments, and computer simulation of movement and crystallization magma. Corequisite: 270.690.

Marsh 3 hours

270.807-808 Research

Independent research for the Ph.D. dissertation. Staff

Courses by Category

Introductory

- 270.101 Exploring Earth's History Through Fossils
- 270.102 Freshman Seminar: Conversation with the Earth
- 270.103 Earth's Environments
- 270.109 Exploring Earth's History Through Fossils
- 270.114 A Guided Tour of the Planets
- 270.120 The Extinction of the Dinosaurs
- 270.201 Sustainability: Scientific and Religious Perspectives
- 270.231 Ecology of a Changing Planet

Core

- 270.220 The Dynamic Earth: An Introduction to Geology
- 270.221 The Dynamic Earth Laboratory
- 270.222 Earth Materials
- 270.224 Oceans and Atmospheres
- 270.225 Earth System History
- 270.226 Earth System History Laboratory

General

- 270.307 Combining Measurements with Models
- 270.308 Population and Community Ecology
- 270.315 Principles of Natural Catastrophes
- 270.320 Global Change and Human Health
- 270.323 Darwin and the Origin of Species
- 270.394 Global Geochemical Cycles and Climate Change
- 270.400 Intersession Independent Study
- 270.404 Environmental Seminar
- 270.495-496 Senior Thesis
- 270.507-508 Independent Study
- 270.601 Fluids Seminar
- 270.605-606 Journal Club
- 270.609-610 Special Topics in Earth and Planetary Sciences
- 270.673 Time Series and Data Analysis
- 270.807-808 Research

Solid Earth Geophysics

- 270.327 Introduction to Seismology
- 270.329 Introduction to Seismology Laboratory
- 270.395 Planetary Physics & Chemistry
- 270.604 Geophysical Petrology Seminar
- 270.646 Fluid Dynamics of the Earth and Planets I
- 270.647 Mechanics of the Earth's Interior
- 270.651 Planetary Geophysics
- 270.652 Physics of Magma
- 270.653 Fluid Dynamics of Earth and Planets II

Groundwater Hydrology

- 270.375 Groundwater
- 270.475 Groundwater Contamination
- 270.625 Groundwater and Geologic Processes
- 270.657 Flow in Porous Media

- 270.676 Numerical Methods in Hydrogeology
- 270.678 Seminar in Advanced Hydrogeology

Mineralogy, Petrology, and Geochemistry

- 270.301 Geochemical Thermodynamics
- 270.302 Aqueous Geochemistry
- 270.304 Igneous and Metamorphic Petrology
- 270.305 Geophysical Petrology Seminar
- 270.306 Igneous and Metamorphic Petrology Laboratory
- 270.341 Crystallography and the Structure of Inorganic Solids
- 270.342 Mineralogy Laboratory
- 270.343 Crystallography Laboratory
- 270.369 Geochemistry of the Earth & Environment
- 270.416 Geochemistry of Natural Waters
- 270.422 Geochemistry of Ore Deposits
- 270.603 Geochemistry Seminar
- 270.613 Metamorphic Petrology Seminar
- 270.621 Transmission Electron Microscopy: Practice and Applications
- 270.622 Transmission Electron Microscopy: Theory and Understanding
- 270.635 Crystal Chemistry and Behavior of Rock Forming Minerals
- 270.636 Stable Isotope Biogeochemistry
- 270.641 Inorganic Solids: Structure, Properties, Chemistry, Applications, and Crystallography
- 270.642 Surface Geochemistry
- 270.681 Advanced Metamorphic Petrology
- 270.682 Advanced Metamorphic Petrology Laboratory
- 270.690 Igneous Petrology
- 270.692 Igneous Petrology Laboratory

Oceans and Atmospheres

- 270.307 Combining Measurements with Models
- 270.401 Introduction to Physical Oceanography
- 270.402 Introduction to Dynamical Oceanography
- 270.410 Global Climate Change: Introduction
- 270.421 Marine Ecosystem Dynamics
- 270.601 Fluids Seminar
- 270.614 Atmospheric and Ocean Vortices
- 270.643 Oceanic Turbulence and Mixing
- 270.644 Physics of Climate Variability
- 270.646 Fluid Dynamics of the Earth and Planets I
- 270.647 Mechanics of the Earth's Interior
- 270.652 Physics of Magma
- 270.653 Fluid Dynamics of Earth and Planets II
- 270.659 Seminar in Oceanography I
- 270.660 Seminar in Oceanography II
- 270.661 Planetary Fluid Dynamics
- 270.664 Seminar in Fluid Mechanics

Paleobiology, Paleoclimatology, Ecology

- 270.308 Population and Community Ecology
- 270.311 Geobiology
- 270.314/619 Field Course in Soil Formation
- 270.316 Invertebrate Fossils and Environments

270.318 Invertebrate Fossils and Environments

Laboratory

270.332 Soil Ecology

270.377 Climates of the Past

270.378 Present and Future Climate

270.607 Invertebrate Paleobiology Seminar

270.624 Seminar in Stable Isotope Techniques

270.634 Macroevolution

270.636 Stable Isotope Biogeochemistry

Earth and Planetary Atmospheres

270.355 Introductory Atmospheric Science

270.608 Seminar in Atmospheric Sciences

270.614 Atmospheric and Oceanic Vortices

270.623 Planetary Atmospheres

270.661 Planetary Fluid Dynamics

270.662 Seminar in Planetary Science

Sedimentology

270.350 Sedimentary Environments

270.351 Sedimentary Rocks Laboratory

270.629 Carbonate Rock Environments

270.630 Carbonate Rock Environments Laboratory

270.631 Carbonates and Evaporites

270.632 Carbonates and Evaporites Lab

Geomorphology and Surficial Geology

Students interested in this general area should consult the courses listed in the Department of Geography and Environmental Engineering (see page 446).