
Geological Sciences and Environmental Studies

FACULTY

**Year of initial appointment at Binghamton*

Andrus, Richard E., *Associate Professor*, PhD, 1974, SUNY College of Forestry at Syracuse: Bryology, problems of wetlands, environmental studies. (1973)*

Barker, Jeffrey B., *Associate Professor*, PhD, 1984, Pennsylvania State University: Seismology, geophysics, earthquake source mechanisms. (1987)

Beerbower, James R., *Professor Emeritus*, PhD, 1954, University of Chicago: Paleoecology and evolutionary biology, sedimentology. (1969)

Bridge, John S., *Professor*, PhD, 1973, St. Andrews University: Sedimentology, physical processes of sedimentation, rivers and their deposits. (1979)

Demico, Robert V., *Associate Professor*, PhD, 1981, Johns Hopkins University: Sedimentology, carbonate rocks. (1983)

Dickman, Steven R., *Professor and Director of Undergraduate Studies*, PhD, 1977, University of California at Berkeley: Rotation of the Earth, ocean tides, core-mantle coupling, ocean-atmosphere-cryosphere interactions. (1977)

Donnelly, Thomas W., *Bartle Professor*, PhD, 1959, Princeton University: Central American geology, marine geology, chemistry of sediments. (1966)

Graney, Joseph R., *Assistant Professor*, PhD, 1994, University of Michigan: Environmental geochemistry. (1998)

Jenkins, David M., *Professor and Director of Graduate Studies*, PhD, 1980, University of Chicago: Experimental petrology and geochemistry of metamorphic rocks, amphibole stability and crystal chemistry. (1984)

Knuepfer, Peter L. K., *Associate Professor*, PhD, 1984, University of Arizona: Neotectonics, geomorphology. (1986)

Lowenstein, Tim K., *Professor*, PhD, 1983, Johns Hopkins University: Aqueous geochemistry, evaporites, paleoclimatology, continental paleoclimate records, secular variations in seawater chemistry. (1985)

MacDonald, William D., *Professor*, PhD, 1965, Princeton University: Structural geology, tectonics, paleomagnetism, Caribbean, Latin American and Cordilleran regional geology. (1965)

Montz, Burrell E., *Professor*, PhD, 1980, University of Colorado: Natural hazards, environmental studies. (1979)

Naslund, H. Richard, *Professor and Chair*, PhD, 1980, University of Oregon: Igneous petrology, experimental petrology, volcanology, geochemistry. (1987)

Roberson, Herman E., *Professor*, PhD, 1959, University of Illinois: Clay mineralogy, environmental law. (1959)

Salvage, Karen M., *Assistant Professor*, PhD, 1998, Pennsylvania State University: Groundwater hydrology and contamination. (1998)

Sorauf, James E., *Bartle Professor*, PhD, 1962, University of Kansas: Paleontology, stratigraphy, sedimentology. (1962)

Wu, Francis T., *Professor*, PhD, 1966, California Institute of Technology: Seismology, tectonophysics. (1970)

Coates, Donald R., *Professor Emeritus*, PhD, 1956, Columbia University: Environmental geology, geomorphology, glacial geology, hydrogeology. (1954)

Hunter, Hugh E., *Professor Emeritus*, PhD, 1954, University of California at Los Angeles: Petrology. (1961)

UNDERGRADUATE PROGRAMS

The earth sciences embody a wide range of approaches to studying the world around and below us; subdisciplines represented in the Department of Geological Sciences and Environmental Studies include various branches of geology, geochemistry, geophysics and environmental studies. Majors in the department begin with one of several introductory courses, followed by a set of four departmental "core" courses. Cognate requirements and the remaining departmental course requirements depend on whether a BA or BS degree is the goal, and the track selected for the BS degree.

BA Degree in Geological Sciences

The BA degree in geology serves as a liberal arts degree with emphasis on the natural sciences and, with appropriate planning, as a preparatory degree for graduate study and professional employment. The BA degree requires 15 courses,

of which at least eight must be in geology; at least three courses must be from the cognate sciences of biology, chemistry, physics and mathematics, and four courses must be used to fulfill an area of specialization. An important aspect of the program is the flexibility of the four-course specialization, which should be carefully planned with the assistance of the faculty adviser. Final approval of the courses selected for the four-course specialization requirement should be secured from the undergraduate committee no later than the student's sixth semester. These four courses must establish a program with a sound rationale, either in the geological sciences or in related fields.

The BA degree requires 15 courses that include the following:

1. GEOL 111 or 112 or 113 or 114
2. GEOL 211
3. GEOL 212
4. GEOL 213
5. GEOL 214
6. Three courses from GEOL 300 and above, with laboratory
7. CHEM 107 or 111
8. Two courses from BIOL 113, 114, 240, 250 and 360; CHEM 108, 221, 231, 332, 341 and 351; MATH 147, 221, 222, 304 and 323; and PHYS 121, 122, 131, 132 and 227.
9. Four courses in an area of specialization, which must be approved by the department adviser no later than the student's sixth semester.

BS Degree in Geological Sciences

The BS degree is intended primarily as training for graduate school and professional employment, with research, teaching and industry careers as the ultimate goals. Seventeen courses are required, including a core sequence of 12 courses and a specialization track (geology, environmental geology or geophysics). No courses for the major may be taken Pass/Fail.

The BS degree requirements include the following:

Cognate Requirements

1. MATH 221 and 222
2. PHYS 121 and 122 *or*
PHYS 121 and GEOL 449
(PHYS 131/132 may be substituted for 121/122)
3. CHEM 107 and 108 *or*
CHEM 107 and GEOL 470
(CHEM 111 may be substituted for 107)

Departmental Requirements

1. GEOL 111 *or* 112 *or* 113 *or* 114
2. GEOL 211
3. GEOL 212
4. GEOL 213

5. GEOL 214
6. GEOL 401 or equivalent (summer field camp)
7. Five additional courses, selected from one of the following tracks:

GEOLOGY TRACK: GEOL 323; 336 or 366; 344; and two GEOL electives above 300 level.

ENVIRONMENTAL GEOLOGY TRACK: GEOL 370, 416, 470 and two GEOL electives above 300 level.

GEOPHYSICS TRACK: GEOL 344, 449, 453 and two electives above the 300 level.

RESTRICTIONS: Regardless of the track selected, GEOL 449 and GEOL 470 cannot be double-counted. (That is, if GEOL 449 or GEOL 470 is used to satisfy a cognate requirement, it cannot also be counted either as one of the specified courses or as one of the electives within a track. If GEOL 470 is used for the cognate requirement, a third geology elective will be required of students if they major in the Environmental Geology track; if GEOL 449 is applied to the cognate requirements, a third elective will be needed for students in the Geophysics track.)

Students are recommended to take the Summer Field Geology course (GEOL 401) following their junior year. In addition, students are encouraged to gain experience with computer languages or programming, word processing and spreadsheets.

Distinguished Independent Work in the Geological Sciences

The award of "Distinguished Independent Work in the Geological Sciences" is granted by the department to those majors who have distinguished themselves in academic endeavor beyond the normal requirements for the bachelor's degree. The requirements for this award include above-average performance in coursework as well as successful completion of an independent research paper under the supervision of a faculty member. Majors are invited to consult with their department advisers about this award before the beginning of the senior year.

Geology Minor

The minor in geology is for students who have a general interest in the earth sciences. Twenty-four credits are required, from courses offered by the Geology Department. No more than 8 credits can be 100-level courses. The department

recommends that at least 8 credits be selected from the geology "core courses": GEOL 211, 212, 213 and 214.

Geophysics Minor

This program is primarily for students with some technical background who wish to gain a fundamental understanding of "pure" geophysics. The 24 credits required are: GEOL 111, 113 or 114; PHYS 331, 341; GEOL 449, 450 and 451.

Applied Geophysics Minor

This program is for geology majors and other science students who want a technical exposure to the concepts and techniques of exploration geophysics. This minor may particularly aid geology students looking for careers in industry because it will strengthen their technical skills. The 32 credits required are: GEOL 111, 113 or 114; PHYS 122; GEOL 449; MATH 304, 323; GEOL 407 and 453 or 450 or 451; and GEOL 408 or 480.

Geochemistry Minor

The minor in geochemistry is for geology majors with a strong interest in geochemistry and for chemistry majors with an interest in earth science. Emphasis is on the application of chemical principles to geologic processes.

The 24 required credits are:

1. GEOL 111 or 113; GEOL 212 and 470.
2. Eight credits from among the following CHEM courses: 221, 351 (one of these is strongly recommended), 231, 332, 341, 422, 452, 482B (Environmental Analysis and Aquatic Systems), 482F (Separation Methods), 482C (Inorganic Phase Equilibria), 484H (Inorganic Solids).
3. Either GEOL 323, 428 or 478.

GRADUATE PROGRAMS

The program enables students to pursue advanced studies in the geological sciences, leading to the degrees of master of arts and doctor of philosophy in the areas of environmental geology, hydrogeology, geomorphology, paleontology, sedimentology, petrology, geochemistry, geophysics, seismology, structural geology and tectonics.

Requirements

For the MA and PhD programs, students with a bachelor's degree in the geological sciences should have completed undergraduate courses in physical geology, mineralogy, structural geology, paleontology, sedimentology and stratigraphy, petrology and field geology or equivalent field experience. In addition, two semesters each of general chemistry, of mathematics (through

integral calculus), and of general physics or general biology are recommended. For students entering with a bachelor's degree in one of the cognate sciences, undergraduate courses in the allied sciences may be accepted in lieu of certain geology requirements. All applicants are required to submit scores for the Graduate Record Examinations.

Graduate students are expected to demonstrate breadth of training by the completion of graduate courses outside their area of specialization. The courses are selected in consultation with the student's adviser and the department's graduate committee.

Master of Arts Program

On matriculation, each student is assigned an adviser. On approval of a thesis topic, the student is assigned a research advisory committee. Programs of study must be approved by the adviser and departmental graduate committee.

Students who satisfy the following departmental requirements are recommended for the degree of master of arts in geological sciences:

1. Complete an approved program of at least six graduate courses (a minimum of 24 credit hours of graduate courses) plus six credit hours of thesis;
2. Submit a thesis proposal with committee endorsement at the commencement of thesis research; and
3. Successfully defend the thesis in an oral examination, and submit an approved final copy.

Doctor of Philosophy Program

Qualified students with either the bachelor's or master's degree, who have demonstrated an understanding of fundamental problems in a broad range of earth-science disciplines, are eligible for admission into the PhD program. Students in this program take courses to strengthen their understanding of the broad principles and practices of the geological sciences as well as to provide training within their chosen specialization. This program can be supported by coursework in appropriate allied sciences, but students are not subject to specific course or credit hour requirements beyond the Graduate School requirements.

Programs of study must be approved by a faculty adviser and the departmental graduate committee. Before undertaking the dissertation, the student is assigned an advisory committee consisting of faculty whose research interests are appropriate to the proposed problem.

Students pursuing the PhD degree must demonstrate an ability to read scientific literature in a language other than English or demonstrate a research skill outside of the geological sciences.

The particular language or research skill and the level of proficiency are determined by the student's supervisory committee.

ADMISSION TO CANDIDACY

Students who satisfy the following departmental requirements are recommended for candidacy for the doctor of philosophy in geological sciences:

1. Complete an approved program of coursework including language or research requirements;
2. Pass the departmental qualifying examination, composed of two parts:
 - (a) passing a general oral examination;
 - (b) oral defense of a proposal for a dissertation that has been approved by the student's advisory committee.

GRANTING OF THE DEGREE

The degree of doctor of philosophy in geological sciences is recommended for candidates who have completed an approved program, received approval of the dissertation by the departmental graduate committee and by the student's advisory committee, passed an oral examination in defense of the dissertation and submitted an approved final copy of the dissertation.

COURSE OFFERINGS/ UNDERGRADUATE

NOTE: Unless otherwise noted, all undergraduate courses carry 4 credits and are offered every year.

GEOL 102. GEOLOGY OF THE SOLAR SYSTEM

Overview of the formation of the Sun, planets and their satellites (moons) within the context of stellar evolution. Examination of the geological processes that have shaped the surfaces and interiors of planets and their satellites. Three hours of lecture and one laboratory each week.

GEOL 111. PLANET EARTH

Application of physical and chemical principles to interpretation of earth processes; nature and origin of earth materials; surface features and internal structure of the earth. May be used to prepare for further work in geology, to supplement a major program in another science or to fulfill the science lab requirement. Three one-hour lectures, one two-hour laboratory per week. Prerequisite: high school chemistry.

GEOL 112. OCEANOGRAPHY

Fundamental concepts and principles of geological, physical and biological systems of oceans and human impact on these systems. Marine exploration, ocean floor structure, ocean sediments and volcanism, ocean circulation, wave and tide dynamics, geochemical evolution, coastal and open-ocean ecosystems, marine resources and pollution problems.

GEOL 113. THE DYNAMIC EARTH

Introductory examination of materials that make up the Earth, the rocks and how they form, as well as the processes that build up or wear down the Earth's landscape. Topics include fossils, geological time and history of life; plate

tectonics; internal structure of the Earth; minerals and rocks; volcanoes and igneous rocks; rock weathering, sediments and sedimentary rocks; landform development, streams and glaciers; ocean basins and continents. Three lectures per week.

GEOL 114. THE EARTH'S DYNAMIC INTERIOR

Introductory examination of the physical processes of the Earth, its origin, composition, structure and properties. Emphasis on dynamic aspects of the Earth's interior, such as its shape and rotation, the geomagnetic field and its origin, radioactive decay and Earth's thermal budget, mantle convection and plate tectonics, earthquakes and volcanoes. Three lectures and one discussion/lab per week. No prerequisites beyond high school science.

GEOL 115. GLOBAL CHANGE: A GEOLOGIC PERSPECTIVE

spring

Examines important, global-scale changes in the atmosphere and hydrosphere from geological and astronomical perspectives. Formation and early state of the solar system; the early greenhouse atmosphere and its tectonic origin; geologic controls on Earth's hothouse and ice house climates; solar and orbital influences on climate; ice ages; the role of the oceans. Study of recent phenomena including ozone depletion, El Niño, acid rain and possible global warming reinforces the modern theme of global human interdependency. The use of unresolved scientific issues in setting public policy is also discussed. Prerequisite: high school chemistry.

GEOL 121 (also ENVI 121). POLLUTION: NATURAL AND UNNATURAL

How pollution affects the daily lives of people on regional and global scales, from physical science and policy perspectives. Topics will include: sources, extent and characteristics of natural and unnatural pollution; processes affecting the fate and transport of contaminants; monitoring and remediation of pollution; and the fundamentals of risk assessment and risk management. Prerequisites: none beyond high school science.

GEOL 205. EARTHQUAKES AND VOLCANOES

Earthquakes and volcanic explosions: their effects on human lives; historical descriptions and consequences of major volcanic eruptions; and earthquakes and methods for prediction and hazard reduction. The physical and/or chemical mechanisms of earthquake generation and transport, and volcanic eruption, and their relationship to plate tectonics and the heat engine inside the Earth. Quantitative skills and current research methods applicable to volcanic eruptions and earthquakes. Prerequisites: one of the following: GEOL 111, 112, 113, 114, or consent of instructor.

GEOL 211 (also GEOG 321). EARTH'S SURFACE PROCESSES

Overview of processes acting on the surface of the Earth and how they control the landscape and deposition of sediments. Processes on hill slopes, surface and subsurface hydrology, aeolian and glacial processes, and sedimentary processes on coasts, continental shelves, slopes and the deep ocean. Three hours of lecture and one laboratory or field trip per week. Prerequisites: one of GEOL 111, 112, 113, 114 or GEOG 121, or consent of instructor.

GEOL 212. EARTH MATERIALS

Overview of the principles of crystallography, atomic arrangement, chemistry and physical properties of minerals that make up common Earth materials. Introduction to techniques of optical mineralogy. Classification and gen-

esis of the principal igneous, sedimentary and metamorphic rocks. Three lectures and one laboratory per week. Prerequisites: CHEM 107 (or equivalent) and one of the following: GEOL 111, 112, 113 or 114; or consent of instructor.

GEOL 213. THE ROCK RECORD AND EARTH HISTORY

Overview of the major processes and events that shaped the lithosphere, hydrosphere, and biosphere of Earth. Origin of the Earth, its oceans and atmosphere. Emphasis on origin of life, expansion of the biosphere, and the results of biosphere expansion on the oceans and atmosphere. Periodic collapse of the biosphere during mass extinctions considered in light of geologic and extraterrestrial processes. Types of evidence used by earth scientists to understand these events. Three lectures and one laboratory per week. Prerequisites: one of the following: GEOL 111, 112, 113, 114, or consent of instructor.

GEOL 214. INTERIOR OF THE EARTH

Overview of the geological processes in the interior of the Earth. Mapping and measuring the deformation in the shallow parts of the Earth, plate tectonics, the imaging of the crust, mantle and core, and interpretations of these observations in terms of physical and chemical processes in the Earth that produce these structures. Three hours of lecture and one laboratory per week. Laboratory study and field trips will complement the lectures. Prerequisites: one of the following: GEOL 111, 112, 113, 114, or consent of instructor.

GEOL 226. NONRENEWABLE MINERAL RESOURCES

Natural deposits of both metallic and nonmetallic industrial materials, including energy resources. Varieties of deposits, exploration strategies, and mining and other recovery methods. Evaluation of mineral resources. U.S. national needs and uses of raw materials. U.S. dependence on foreign sources of diverse mineral commodities. Three lectures per week. Prerequisites: an introductory course in geology would be helpful, but is not required.

GEOL 323. IGNEOUS AND METAMORPHIC PETROLOGY

Introduction to the classification, global distribution and origin of igneous and metamorphic rocks in the context of plate tectonics. Identification of pressure, temperature and compositional variables involved in petrogenesis. Examination of mineral textures and rock fabric in hand samples and thin sections. Three one-hour lectures, one three-hour laboratory per week. Prerequisite: GEOL 212.

GEOL 324. GEOLOGICAL HISTORY OF THE EARTH

Introduction to the study of Earth's history utilizing geological principles to interpret evolution of the Earth's lithosphere that produced the land and ocean regions as they are now. Review of 4.5 billion years of evolution of Earth, its oceans, biota and atmosphere. Course develops physical principles of geology and provides introduction to uses of fossils, sediments, plate motions and mountain building to interpret earth history. Three lectures and one discussion per week; field trips. Prerequisites: GEOL 111, 113, or 114.

GEOL 336. SEDIMENTOLOGY AND STRATIGRAPHY

Characteristics and origin of sediment grains; physical, chemical and biological processes of sedimentation; diagenesis and rock classification; definition and spatial correlation of stratigraphic units; sedimentary environments and their deposits. Three hours of lectures and one three-hour laboratory or field trip per week. Prerequisite: GEOL 212.

GEOL 344. STRUCTURAL GEOLOGY

spring

Basic rock structures at all scales: description, analysis, origin, development and interrelationships. Includes rock fabrics, macrofolds, major fault systems. Continental and oceanic structures. Plate tectonics and its relationships to rock structure; other tectonic theories. Field trip(s) for collecting and analyzing structural data. Lectures and laboratory, including some computer exercises. Prerequisite: an introductory course in geology.

GEOL 366 (also BIOL 266). PALEOBIOLOGY

Concepts and methods in paleobiological interpretation of evolution, adaptation and ancient environments. Characteristics of plant and animal groups; fossil representatives. Three one-hour lectures and one laboratory or field trip per week. Prerequisites: one of the following: GEOL 111, 112, 113 or BIOL 114.

GEOL 369 (also BIOL 369). HISTORY OF TERRESTRIAL COMMUNITIES

Interpretation of organism-environment relationships. Reconstruction of terrestrial fossil assemblages in light of modern analogues. History of terrestrial communities and dynamics of community evolution. Three lectures, one 3-hour laboratory per week. Prerequisite: one of: BIOL 114, 240, 266 or GEOL 366.

GEOL 370 (also ENVI 370). ENVIRONMENTAL GEOLOGY: THE CHANGING EARTH

Examination of important environmental issues through geochemical investigation of the Earth's atmosphere, hydrosphere and lithosphere. Discussion of past and present controls on the chemical composition of the atmosphere, freshwater, oceans, and groundwaters. Prerequisites: CHEM 107 or consent of instructor, and one of GEOL 111, 112, 113, 114 or ENVI 201.

GEOL 401. FIELD GEOLOGY

6 credits

Field training in stratigraphy, petrologic settings, structural geology, geomorphology, etc.; geologic mapping, use of aerial photographs and topographic maps; geologic field measurements and recordkeeping. Summer course, six-nine weeks long; check with adviser. Offered as transfer credit from other universities.

GEOL 410. RIVERS AND FLOODPLAINS

Overview of the origin, nature and evolution of rivers and floodplains (including alluvial fans and deltas) and their deposits. Also human interaction with rivers and associated environmental and engineering concerns, and economic aspects of fluvial deposits. Prerequisite: GEOL 111 or 113 or consent of instructor.

GEOL 411. ADVANCED GEOMORPHOLOGY

Detailed examination of the processes and landforms developed by water, glaciers and air on the Earth's surface. Interactions of humans with and effects on the landscape. Three hours of lecture and one laboratory or discussion per week. Prerequisite: GEOL 211.

GEOL 413. QUATERNARY GEOLOGY

Overview of geologic processes in the Quaternary. Emphasis on causes of climatic changes in the last two million years and the triggering of the Ice Ages; glacial and cold-climate processes; age-dating of Quaternary deposits; techniques for study of paleoclimates on land and in oceans; Quaternary history of North America and elsewhere. Prerequisite: GEOL 211 or 336 or equivalent.

GEOL 416. HYDROGEOLOGY

Examination of the hydrologic cycle, the physical characteristics of aquifers, fluid flow through porous media, groundwater flow to wells, the geology of groundwater occurrence, groundwater chemistry and contamination. Prerequisites: calculus and introductory geology.

GEOL 424. ADVANCED METAMORPHIC PETROLOGY

In-depth treatment of metamorphic rocks and factors that lead to their formation. Major metamorphic processes, graphical treatment of mineral assemblages, pressure-temperature-composition conditions of metamorphism, and the tectonic setting of metamorphism. Three hours of lecture plus three-hour laboratory per week. Prerequisite: GEOL 323.

GEOL 425. ADVANCED IGNEOUS PETROLOGY

Examination of igneous rocks. Emphasis on classification of igneous rock suites, theories for the origin of magmas, major and trace element trends in igneous suites, experimental studies of nucleation and crystallization in magmas, rheological properties of magmas, computer modeling of igneous differentiation, diffusion and mass transport of magmas. Prerequisite: GEOL 323.

GEOL 428. PRESSURE-TEMPERATURE-COMPOSITION PHASE EQUILIBRIA

Principles underlying construction of phase equilibrium diagrams in pressure-temperature-composition (P-T-X) space as applicable to the geological sciences. Emphasis on developing skills both for interpreting phase diagrams and for constructing diagrams in a qualitative sense. Application to actual geological problems of magma generation, magma crystallization, rock metamorphism, etc. Prerequisites: CHEM 111 and GEOL 212, or consent of instructor.

GEOL 433 (also ENVI 433). CLAYS, SOILS AND SEDIMENTS

Introduction to the role clay minerals play in a wide range of natural settings. Emphasis on how knowledge of clays can be applied to solving environmental problems. Prerequisites: CHEM 107, GEOL 370 or ENVI 270, and one of the following: GEOL 111, 113 or 114, or ENVI 201.

GEOL 441. ADVANCED PRINCIPLES OF TECTONICS

fall, every other year
Plate tectonics, continental drift, ocean-floor spreading, rifting, subduction, crustal formation and deformation. Theory and basis in empirical observations; analytical methods. Lectures, laboratories, computer exercises, discussions. Prerequisite: GEOL 344 or equivalent.

GEOL 442. ADVANCED REGIONAL STRUCTURAL GEOGRAPHY

fall, every other year
Structural investigations of mountain systems, shields, island arcs, continental margins, rift systems, oceanic ridges. Lectures, laboratory, computer exercises, discussions. Prerequisite: GEOL 344 or equivalent.

GEOL 449 (also PHYS 449). INTRODUCTION TO GLOBAL GEOPHYSICS

Application of physical concepts to understanding the solid earth. Topics: origin of the earth; gravitational and geomagnetic fields and effects; earthquakes and seismic waves; composition and structure of earth's interior; radioactivity and its geothermal consequences; fluid flow; principles of geophysical exploration for natural resources. Applications to moon, sun and planets as appropriate. Three lectures, one 2-hour laboratory per week. Prerequisite:

sites: PHYS 121, MATH 221 and one of the following: GEOL 111, 112, 113 or 114.

GEOL 450 (also PHYS 450). GEOPHYSICS I

Foundations of seismology. Elasticity theory; wave equation; body and surface waves. Inferences concerning earth's interior. Seismographs; field seismology; data processing. Earthquake occurrence. Three one-hour lectures, one-hour laboratory per week (concurrently with GEOL 550). Prerequisites: MATH 371, PHYS 331 and 341.

GEOL 451 (also PHYS 451). GEOPHYSICS II

Fundamental nonseismic aspects of solid earth geophysics: gravity, rotational dynamics, tides; equations of state of the interior; geothermal heat flow, earth's thermal history; geomagnetic field. Observations and theory emphasized. Three one-hour lectures, one-hour laboratory per week. Prerequisites: MATH 371, PHYS 331 and 341.

GEOL 453. ENVIRONMENTAL GEOPHYSICS

Application of geophysical principles and techniques to exploration of interior of the earth, its crust and upper mantle. Seismological, gravity, magnetic and electrical methods introduced; main results discussed. Interactive microcomputer-based teaching programs in laboratory sessions illustrate theory and provide hands-on experience in data interpretation. Prerequisites: introductory courses in geological sciences and physics, or consent of instructor.

GEOL 465. ENVIRONMENTAL MEASUREMENTS

Sampling methods, analysis and interpretation of results acquired from collection of environmental samples. Focus will be on tracing inorganic pollutants in the atmosphere and hydrosphere. Integrated lecture and laboratory involving applied geochemistry principles and design, development and implementation of research projects. Prerequisites: CHEM 107 or 111 and GEOL 370/ENVI 270, or consent of instructor.

GEOL 470. GEOCHEMISTRY

Chemical thermodynamics, mineral equilibria, stable isotopes, radioactive dating methods, aqueous geochemistry, reaction kinetics as applied to geological systems; principles governing distribution and transport of elements in earth system. Three one-hour classes per week. Prerequisites: GEOL 112, CHEM 111 and MATH 221, or consent of instructor.

GEOL 478. CHEMICAL SEDIMENTS

every other year
Examines major types of chemically precipitated sediments. Modern environments in which chemical sediments form and phase equilibria in aqueous solutions guide interpretation of chemical and depositional settings of ancient deposits. Labs and field trips. Prerequisites: CHEM 107, GEOL 336 or equivalent, and consent of instructor.

GEOL 480. GEOTECHNIQUES

Specialized techniques useful in study of certain geological and geophysical problems, including X-ray diffraction powder methods, microprobe analysis, resistivity.

GEOL 497. INDEPENDENT WORK

Independent research under supervision of faculty member. Prior to registration, student must consult instructor and receive approval of problem to be investigated and amount of credit to be received. Prerequisite: consent of department.

COURSE OFFERINGS/ GRADUATE

GEOL 510. RIVERS AND FLOODPLAINS

Overview of the origin, nature and evolution of rivers and floodplains (including alluvial fans and deltas) and their deposits. Also human interaction with rivers and associated environmental and engineering concerns, and economic aspects of fluvial deposits. Prerequisite: GEOL 111 or 113, or consent of instructor.

GEOL 511 (also GEOG 511). ADVANCED GEOMORPHOLOGY I—FLUVIAL *every other fall*

Detailed examination of the processes and landforms developed by water, glaciers and air on the Earth's surface. Interactions of humans with and effects on the landscape. Three hours of lecture and one laboratory or discussion per week. Prerequisite: introductory geomorphology.

GEOL 513. QUATERNARY GEOLOGY *every other spring*

Overview of geologic processes in Quaternary, including climate changes, glacial and periglacial, and nonglacial processes, techniques for Quaternary dating, and pollen studies. Three lectures, one laboratory per week. Prerequisite: geomorphology, sedimentology or consent of instructor.

GEOL 516 (also GEOG 516). HYDROGEOLOGY *fall*

Examination of the hydrologic cycle, the physical characteristics of aquifers, fluid flow through porous media, groundwater flow to wells, the geology of groundwater occurrence, groundwater chemistry and contamination. Prerequisites: calculus and introductory geology.

GEOL 520. CLAY MINERALOGY/PETROLOGY *every other fall*

Fundamental properties of clay minerals as mineral entities and as rock forming materials. Origin, alteration, distribution of clay minerals. Diverse set of topics offered to students with interests in sedimentology, geomorphology, rock mechanics. Prerequisite: consent of instructor.

GEOL 524. ADVANCED METAMORPHIC PETROLOGY *every other spring*

Metamorphic rocks, their petrogenesis. Graphical treatment of mineral assemblages and textures. Equilibrium, nonequilibrium in metamorphic systems. Three lectures, one three-hour laboratory per week. Prerequisite: introductory petrology or consent of instructor.

GEOL 525. ADVANCED IGNEOUS PETROLOGY *every other spring*

Occurrence, origin and chemical evolution of selected igneous rock groups. Experimental studies of igneous systems and other related topics. Computer modeling of igneous processes. Prerequisites: introductory petrology and physical chemistry, or consent of instructor.

GEOL 528. PRESSURE-TEMPERATURE-COMPOSITION PHASE EQUILIBRIA *every other spring*

Principles governing construction and interpretation of phase diagrams pertinent to geology. Emphasis on understanding geometric aspects of phase equilibria in P-T-X space. Prerequisites: introductory chemistry and mineralogy, or consent of instructor.

GEOL 535. SEDIMENTARY ENVIRONMENTS AND FACIES *every other spring*

Introduction to analysis of sedimentary environments and facies. Facies of rivers, deserts, lakes, shorelines, shelf seas, oceans. Three lectures per week, field interpretation of ancient sedimentary environments.

GEOL 537. PHYSICAL PROCESSES OF SEDIMENTATION *every other fall*

Fundamentals of fluid flow, sediment transport and deposition by unidirectional water and air flows, waves, tides, turbidity currents and other sediment gravity flows. Three hours of lecture and one three-hour laboratory or field trip per week.

GEOL 539. ADVANCED TOPICS IN SEDIMENTOLOGY *every other fall*

Detailed examination of currently important topics in sedimentology which are controversial and problematic. Introductory lectures and one or two seminars per week.

GEOL 541. ADVANCED PRINCIPLES OF TECTONICS *every other fall*

Plate tectonics, continental drift, ocean-floor spreading, rifting, subduction, crustal formation and deformation. Theory and basis in empirical observations; analytical methods. Lectures, laboratory, computer exercises, discussions; independent project. Prerequisite: introductory course in structural geology or permission of instructor.

GEOL 542. ADVANCED REGIONAL STRUCTURAL GEOLOGY *every other fall*

Structural investigations of mountain systems, shields, island arcs, continental margins, rift systems, oceanic ridges. Lectures, laboratory, computer exercises, discussions; independent project. Prerequisite: introductory course in structural geology or permission of instructor.

GEOL 545. NEOTECTONICS *every other spring*

Study of active tectonic structures, including kinematics and tectonic setting, geologic and geomorphic study techniques. Studies of paleoseismology, geodetic studies of active earth deformation. Overview of mountain-building and geodynamics. Three lectures, one laboratory per week.

GEOL 549. INTRODUCTION TO GLOBAL GEOPHYSICS *spring*

Application of physical concepts to understanding the solid earth. Topics: origin of the earth; gravitational and geomagnetic fields and effects; earthquakes and seismic waves; composition and structure of earth's interior; radioactivity and its geothermal consequences; fluid flow; principles of geophysical exploration for natural resources. Applications to moon, sun and planets as appropriate. Three lectures, one 2-hour laboratory per week. Prerequisites: one semester of physics, calculus and geology; or consent of instructor.

GEOL 550 (also PHYS 550). GEOPHYSICS I *fall*

Fundamental aspects of solid earth geophysics, emphasis on seismology. Basic differential equations and solutions discussed; features of earth deduced or explained, data acquisition and analysis examined. Prerequisites: one semester each of mathematical methods, analytical mechanics, electricity and magnetism.

GEOL 551 (also PHYS 551). GEOPHYSICS II *fall*
Fundamental nonseismic aspects of solid earth geophysics: gravity, rotational dynamics, tides; equations of state of interior; geothermal heat flow, earth's thermal history; geomagnetic field. Observations and theory emphasized. Prerequisites: one semester each of analytic mechanics, E & M, math methods.

GEOL 552. THEORETICAL SEISMOLOGY *fall*
Theoretical development of computational methods in seismology: representation theorem, body-force equivalents, seismic moment tensor, Cagniard-deHoop method, propagator matrix method, anelastic attenuation, scattering, instrumentation. Prerequisites: GEOL 550, complex variables and partial differential equations, or consent of instructor.

GEOL 553. ENVIRONMENTAL GEOPHYSICS *fall*
Comprehensive introduction to methods and interpretation in applied geophysics. Gravity, magnetics, electrical, electromagnetic, seismic methods. Computer data analysis and interpretation. Use of exploration instruments. Prerequisites: introductory geology and physics.

GEOL 565. ENVIRONMENTAL MEASUREMENTS
Sampling methods, analysis and interpretation of results acquired from collection of environmental samples. Focus will be on tracing inorganic pollutants in the atmosphere and hydrosphere. Integrated lecture and laboratory involving applied geochemistry principles and design, development and implementation of research projects. Prerequisites: GEOL 470/570 or equivalent strongly recommended.

GEOL 570. GEOCHEMISTRY *fall*
Chemical thermodynamics, mineral equilibria, stable isotopes, radioactive dating methods, aqueous geochemistry, reaction kinetics as applied to geological systems; principles governing distribution and transport of elements in earth system. Three one-hour lectures, one laboratory per week. Prerequisite: consent of instructor.

GEOL 583. SCANNING ELECTRON MICROSCOPE/MICROPROBE TECHNIQUES *2 credits*
Overview of the theory and operation of the electron microprobe and scanning electron microscope. Intended to develop skills in the usage of these instruments for imaging and chemically analyzing geological materials. One lecture and laboratory session per week. Prerequisite: consent of instructor.

GEOL 597. INDEPENDENT RESEARCH *1-4 credits/semester*
Research on special problems not related to thesis or dissertation research, subject to approval and supervision by faculty member. Work may be pursued individually or jointly with other students. May be repeated for credit with consent of department.

GEOL 599. RESEARCH (THESIS) *1-9 credits/semester*
Number of credit hours determined by consultation with departmental adviser. Graded on S/U basis only.

GEOL 609. SPECIAL TOPICS *1-4 credits/semester*
Subject and credit announced in advance. May be repeated for credit with consent of department.

GEOL 609A. COMPUTER MODELING OF GROUND-WATER FLOW AND CONTAMINANT TRANSPORT *spring*

Examines how the physical and geochemical phenomena affecting groundwater flow and subsurface contaminant transport are incorporated into computer models. Theory, mathematical representation, numerical methods and practical applications are investigated; extensive, hands-on experience emphasized. Prerequisites: GEOL 416/516 or equivalent.

GEOL 614. SEMINAR IN GEOMORPHOLOGY *2 credits/semester*
Selected topics in geomorphology, Pleistocene geology. May be repeated for credit with consent of department.

GEOL 629. TOPICS IN PETROLOGY *1-4 credits*
Advanced course dealing with current topics and newly emerging areas of igneous and metamorphic petrology not usually covered in other petrology courses. Credit and subject(s) announced in advance. Prerequisite: consent of instructor.

GEOL 641. SEMINAR IN PHYSICAL GEOLOGY *2 credits/semester*
Plate tectonics, geophysics, physical aspects of structural geology and tectonophysics. May be repeated for credit with consent of department.

GEOL 643. SEMINAR IN PALEOMAGNETISM *2-4 credits*
Paleomagnetism theory, methods, equipment and results. Application to structure, tectonics, stratigraphic correlation and other fields of geoscience. Interactions of the geomagnetic field with iron-bearing minerals. Research projects possible with consent of instructor.

GEOL 658. SEMINAR IN GEOPHYSICS *2-4 credits*
Selected topics in geophysics, such as mechanics of failure, earthquake prediction, mantle rheology, tides, satellite geodesy, time series analysis. Participants will discuss their own research, or present a summary and critique of papers. Prerequisites: GEOL 550 and 551, or consent of instructor.

GEOL 659. CURRENT TOPICS IN SEISMOLOGICAL RESEARCH *2-4 credits*
Topics in seismology including: seismic source characteristics; propagation of elastic waves; crust, mantle and core structures; generation and propagation of strong ground motions; synthetic seismograms; and discrimination between humanmade and natural seismic signals. Prerequisites: simultaneous or prior coursework in seismology.

GEOL 677. FLUID INCLUSION GEOCHEMISTRY *every other spring*
Principles of phase equilibria involved in fluid inclusion research and applications to geological problems. Operation of the fluid inclusion heating-freezing stage. Individual projects. Prerequisites: geochemistry and consent of instructor.

GEOL 678. CHEMICAL SEDIMENTS *every other spring*
Examination of major types of chemically precipitated sediments: alkaline earth carbonates, evaporites, iron deposits, phosphates, cherts, clays and zeolites. Modern environments in which chemical sediments form, and phase equilibria in aqueous solutions, serve as guides for interpreting chemical and depositional settings.

GEOL 679. DIAGENESIS *every other spring*
Diagenesis of sediments, including shales, sandstones, carbonates and evaporites, emphasizing mineralogical-textural changes, chemistry of sediment-water and rock-water interaction, and possible driving forces for diagenetic processes. Case studies. Prerequisites: chemistry and sedimentology.

GEOL 698. PREDISERTATION RESEARCH *1-9 credits/semester*
Independent reading and/or research in preparation for comprehensive examinations for admission to PhD candidacy, and/or preparation of dissertation prospectus. Graded on S/U basis only.

GEOL 699. DISSERTATION *1-9 credits/semester*
Research for and preparation of dissertation. Graded on S/U basis only.

GEOL 700. CONTINUOUS REGISTRATION *1 credit/semester*
Required for maintenance of matriculated status in graduate program. No credit toward graduate degree requirements.

GEOL 707. RESEARCH SKILLS *1-4 credits*
Development of research skills required within graduate programs. May not be applied toward course credits for any graduate degree. Prerequisite: approval of relevant graduate program directors or department chairs.