GEOPHYSICS

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Courses given in Geophysics have the subject code GEOPHYS. For a complete list of subject codes, see Appendix.

Geophysics is the branch of Earth science concerned with exploring and analyzing active processes of Earth through physical measurement. The undergraduate and graduate programs are designed to provide a background of fundamentals in science, and courses to coordinate these fundamentals with the principles of geophysics. The program leading to the Bachelor of Science (B.S.) in Geophysics permits many electives and a high degree of flexibility for each student. Graduate programs provide specialized training for professional work in resource exploration, research, and education and lead to the degrees of Master of Science and Doctor of Philosophy.

The Department of Geophysics is housed in the Ruth Wattis Mitchell Earth Sciences Building. It has numerous research facilities, among which are a state-of-the-art broadband seismic recording station, high pressure and temperature rock properties and rock deformation laboratories, computers, various instruments for field measurements including seismic recorders, nine dual frequency GPS receivers, and field equipment for measuring in-situ stress at great depth. Current research activities include biogeochemical cycling; crustal deformation; earthquake archaeology; earthquake seismology and earthquake mechanics; reflection, refraction, and tomographic seismology; rock mechanics, rock physics; seismic studies of the continental lithosphere; remote sensing; environmental geophysics; and synthetic aperture radar studies.

UNDERGRADUATE PROGRAMS

BACHELOR OF SCIENCE

Objectives—To provide knowledge about the entire spectrum of geophysics from resource exploration to environmental geophysics to earthquake seismology and plate tectonics, built upon a solid background in the essentials of math, physics, and geology. Students are prepared for either an immediate professional career in the resources and environmental sciences industries or future graduate study.

The following courses are required for the B.S. degree in Geophysics. A written report on original research or an honor's thesis is also required through participation in three quarters of GEOPHYS 185, Research Seminar Series, during the senior year. The departmental program proposal form can be downloaded at http://geo.stanford.edu/GP/undergraduate/major.html. Seniors in Geophysics who expect to do graduate work should take the Graduate Record Examination (GRE) early in their final undergraduate year.

CURRICULUM

FUNDAMENTAL GEOPHYSICS

GEOPHYS 102/EARTHSYS 110. Geosphere
or GES 1. Fundamentals of Geology
GEOPHYS 150. General Geophysics
or GEOPHYS 190. Environmental Geophysics
GEOPHYS 120. Frontiers of Geophysical Research
6 units of GEOPHYS 185. Research Seminar Series (includes WIM requirement)

ADDITIONAL ELECTIVES

3 approved upper-level (100 or higher) Geophysics lecture courses, typically chosen from the following:

GEOPHYS 104. The Water Course
GEOPHYS 106. Planetary Exploration
GEOPHYS 130. Biological Oceanography
GEOPHYS 141. Remote Sensing of the Oceans
GEOPHYS 150. General Geophysics and Physics of the Earth
GEOPHYS 160. Waves
GEOPHYS 182. Reflection Seismology
GEOPHYS 183. Reflection Seismology Interpretation
GEOPHYS 190. Near-Surface Geophysics
GEOPHYS 220. Tectonics
GEOPHYS 262. Rock Physics

3 additional approved upper-level (100 or higher) Earth Sciences lecture courses, typically chosen from the above GEOPHYS electives *or*

GES 102. Earth Materials
GES 110. Structural Geology and Tectonics
GES 111A. Fundamentals of Structural Geology
GES 160. Statistical Methods for Earth and Environmental Sciences
ENERGY 120. Fundamentals of Petroleum Engineering

PREREQUISITE COURSES

MATH 19,20,21. Calculus, or equivalent,
and MATH 53. Ordinary Differential Equations
PHYSICS 41 *and* 110. Mechanics and Intermediate Mechanics
EE 141. Engineering Electromagnetics
or PHYSICS 120. Intermediate Electricity and Magnetism
CHEM 31A. Chemical Principles

RECOMMENDED ELECTIVE

CS 106A. Programming Methodology

MINORS

The Geophysics minor provides students with a general knowledge of geophysics in addition to a background in the related fields of physics, mathematics, and geology. The departmental program proposal form can be downloaded from http://geo.stanford.edu/GP/undergraduate/major.html.

CURRICULUM

GEOPHYS 102. Geosphere *or* GES 1. Fundamentals of Geology
GEOPHYS 120. Frontiers of Geophysical Research
GEOPHYS 150. General Geophysics
or GEOPHYS 190. Environmental Geophysics
Two additional approved upper-level (100 or higher) Geophysics lectures courses, typically chosen from GEOPHYS 104, 106, 130, 141, 150, 160, 182, 183, 190, 220, 262.
MATH 19,20,21 or 41. Calculus
PHYSICS 41. Mechanics

HONORS PROGRAM

The department offers a program leading to the B.S. degree in Geophysics with honors. The guidelines are:

1. Select a research project, either theoretical, field, or experimental, that has the approval of an adviser.
2. Submit a proposal to the department, which will decide on its suitability as an honors project. Necessary forms are in the department office.

3. Course credit for the project is assigned by the adviser within the framework of GEOPHYS 205.
4. The decision whether a given independent study project does or does not merit an award of honors shall be made jointly by the department and the student's adviser. This decision shall be based on the quality of both the honors work and the student's other work in earth sciences.
5. The work done on the honors program should not be used as a substitute for regularly required courses.

COTERMINAL B.S./M.S. PROGRAM

The department offers a coterminal program. Interested individuals should check with a member of the department faculty for details. For University coterminal degree program rules and University application forms, see http://registrar.stanford.edu/shared/publications.htm#Coterm.

GRADUATE PROGRAMS

University requirements for the M.S. and Ph.D. are described in the "Graduate Degrees" section of this bulletin. Lecture course units applied to graduate degree program requirements must be taken for a letter grade if the course is offered for letter grade.

Transfer credit—An incoming student with a relevant Master of Science degree may apply for a departmental waiver of up to 18 units of the 45 units required for the Ph.D. degree (see "Doctor of Philosophy" section below). Students without an M.S. degree may apply for waivers for individual courses taken in post-baccalaureate study at other institutions. Credit for courses generally requires that students identify an equivalent Stanford course and obtain the signature of the Stanford faculty responsible for such a course stating its equivalence.

Waiving of any course requirements or substitution of electives other than those listed below requires the written consent of the student's faculty adviser and the Geophysics graduate coordinator.

MASTER OF SCIENCE

Objectives—To enhance the student's training for professional work in geophysics through the completion of fundamental courses, both in the major fields and in related sciences, and to begin independent work and specialization.

Requirements for the Degree—The candidate must complete 45 units from the following groups of courses:

1. Complete 15 units of Geophysics lecture courses with at least 9 units numbered 200 or higher.
2. Complete six units numbered 100 or higher and three units of 200-level, non-Geophysics lecture courses in earth sciences.
3. Complete one to four electives selected from courses numbered 100 or higher from mathematics, chemistry, engineering, physics, relevant biology, computer science, ecology, hydrology, or earth science. At least one course must be numbered 200 or higher.
4. At least 9, but not more than 18, of the 45 units must be independent work on a research problem resulting in a written report accepted and archived by the candidate's faculty adviser. Normally, this research is undertaken as part of the candidate's participation in multiple quarters of research seminar (GEOPHYS 385 series). A summer internship is encouraged as a venue for research, but no academic credit is given.
5. Submit a program proposal for approval by a faculty adviser in the first quarter of enrollment.
6. Each candidate must present and defend the results of his or her research at a public oral presentation attended by at least two faculty members.

DOCTOR OF PHILOSOPHY

Objectives—The Ph.D. degree is conferred upon evidence of high attainment in Geophysics, and ability to conduct an independent investigation and present the results of such research.

Requirements for the Degree—A minimum of 135 units of graduate study at Stanford must be satisfactorily completed. An acceptable program normally consists of at least 45 lecture units in the areas listed following. Up to 18 lecture units in categories 2, 4, and 6 may be satisfied by courses taken elsewhere if the previous course duplicates an existing Stanford course and the Stanford faculty member responsible for the course concurs.

1. ENGR 202W.
2. 12 units of Geophysics lecture courses numbered 100 or higher.
3. 12 units of Geophysics lecture courses numbered 200 or higher, taken from at least four faculty members with different research specializations.
4. One 3-unit lecture course numbered 100 or higher in mathematics, science, or engineering covering mathematical methods, continuum or fluid mechanics, or Fourier/spectral analysis.
5. 9 units of 200-level or higher courses in math, science, engineering, or other quantitative science.
6. 6 units of non-Geophysics lecture courses numbered 100 or higher in Earth or planetary sciences, ecology, hydrology, chemistry, or relevant biology.
7. One 3-unit non-Geophysics lecture course numbered 200 or higher in Earth or planetary science, ecology, hydrology, chemistry, or relevant biology.
8. Sufficient units of independent work on a research problem to meet the 135-unit University requirement. 12 units must be met by participation in the GEOPHYS 385 series. Students are encouraged to participate in the GEOPHYS 385 series from more than one faculty member or group.
9. Two quarters of quarter-time teaching experience.

The student's record must indicate outstanding scholarship, and deficiencies in previous training must be removed. Experience as a teaching assistant (quarter-time for at least two academic quarters) is required for the Ph.D. degree. The student must pass the departmental oral examination by presenting and defending a written research paper or proposal by the end of the sixth academic quarter (third academic quarter for students with an M.S. degree); prepare under faculty supervision a dissertation that is a contribution to knowledge and the result of independent work expressed in satisfactory form; and pass the University oral examination. The Ph.D. dissertation must be submitted in its final form within five calendar years from the date of admission to candidacy.

Upon formal acceptance into a research group, the student and faculty adviser form a supervising committee consisting of at least three members who are responsible for overseeing satisfactory progress toward the Ph.D. degree. At least two committee members must be Geophysics faculty members. The committee conducts the department oral examination, and meets thereafter annually with the student to review degree progress. The Geophysics faculty monitors progress of all students who have not yet passed their department oral examination by carrying out an annual performance appraisal at a closed faculty meeting.

COURSES

GEOPHYS 5Q. Earthquakes and Archaeology—Stanford Introductory Seminar. Preference to sophomores. The impact of destructive earthquakes on the abandonment, migration, and settlement of ancient cultures and society. Spring break field trip to archaeological sites in Mexico.

2 units, Win (Kovach, R)

GEOPHYS 20Q. Predicting Volcanic Eruptions—Stanford Introductory Dialogue. Preference to sophomores. The physics and chemistry of volcanic processes and modern methods of volcano monitoring. Volcanoes as manifestations of the Earth's internal energy and hazards to society. How earth scientists better forecast eruptive activity by monitoring seismic activity, bulging of the ground surface, and the discharge of volcanic gases, and by studying deposits from past eruptions. Focus is on the interface between scientists and policy makers and the challenges of decision making with incomplete information. Field trip to Mt. St. Helens, site of the 1980 eruption.

3 units, Spr (Segall, P)

GEOPHYS 25. The First New Science of the Late Renaissance: Hands-on Introduction to Astrobiology—Are human beings alone; are microbes common in the universe? Historical development and modern status of topics such as: the vastness of space and time; star evolution; planetary climate; effects of geological processes and asteroid impacts on life; other habitable places in the solar system with updates on Mars; the Earth as a biological organism; maintenance of society for a geologically long time; and the search for intelligent extraterrestrials. Outdoor lab exercises designed to work in K-12 science classes. Non-science majors welcome.

3 units, Aut (Sleep, N)

GEOPHYS 60Q. Man versus Nature: Coping with Disasters Using Space Technology—(Same as EE 60Q.) Stanford Introductory Seminar. Preference to sophomores. Natural hazards (earthquakes, volcanoes, floods, hurricanes, and fires) affect thousands of people everyday. Disasters such as asteroid impacts periodically obliterate many species of life. Spaceborne imaging technology makes it possible to respond quickly to such threats to mitigate consequences. How these new tools are applied to natural disasters, and how remotely sensed data are manipulated and analyzed. Basic scientific issues, political and social consequences, costs of disaster mitigation, and how scientific knowledge affects policy. GER: DB-EngrAppSci

3 units, Aut (Zebker, H)

GEOPHYS 100. Directed Reading

1-2 units, Aut, Win, Spr, Sum (Staff)

GEOPHYS 101A. Research Preparation—Structured mentoring of students enrolled in Geophysics Summer Research Program. Development of research proposals and preliminary readings.

1 unit, Spr (Klemperer, S)

GEOPHYS 101B. Research Presentation—Student participants from the Geophysics Summer Research Program prepare oral and poster presentations, culminating in formal presentations to the department and community.

1 unit, Aut (Klemperer, S)

GEOPHYS 102. Geosphere—(Same as EARTHSYS 110.) Large-scale natural systems of the solid earth, oceans, and atmosphere, their variation through space and time, and the implications of how these systems impact and are being impacted by humankind. Topics include plate tectonics and its relationship to natural hazards and climate, large-scale ocean and atmospheric systems, energy systems, and the linkages among these topics. Prerequisites: EARTHSYS 10, GES 1. GER:DB-NatSci

3 units, Aut (Zoback, M; Tabazadeh, A)

GEOPHYS 104. The Water Course—(Same as EARTHSYS 104.) The pathway that water takes from rainfall to the tap using student home towns as an example. How the geological environment controls the quantity and quality of water; taste tests of water from around the world. Current U.S. and world water supply issues. GER:DB-NatSci

3 units, not given this year (Knight, R)

GEOPHYS 112. Exploring Geosciences with MATLAB—Introduction to efficient use of Matlab as a tool for research in Engineering and Earth Sciences. Hands-on, computer-based exercises explore the 2-D and 3-D visualization features, numerical capabilities, and various Matlab toolboxes, addressing simple problems in widely applicable areas such as data analysis, statistics, regressions, least-squares, Fourier transforms and filtering in 1- and 2-D, simple spectral analysis, differential equations, and simulations.

1-3 units, Aut (Mukerji, T)

GEOPHYS 113. Earthquakes and Volcanoes—(Same as EARTHSYS 113.) Earthquake location, magnitude and intensity scales, seismic waves, styles of eruptions and volcanic hazards, tsunami waves, types and global distribution of volcanoes, volcano forecasting. Plate tectonics as a framework for understanding earthquake and volcanic processes. Forecasting; earthquake resistant design; building codes; and probabilistic hazard assessment. For non-majors and potential earth scientists. GER: DB-EngrAppSci

3 units, Spr (Beroza, G; Segall, P)

GEOPHYS 117. Biology and Global Change—(Same as BIOSCI 117, EARTHSYS 111.) The biological causes and consequences of anthropogenic and natural changes in the atmosphere, oceans, and terrestrial and freshwater ecosystems. Topics: glacial cycles and marine circulation, greenhouse gases and climate change, tropical deforestation and species extinctions, and human population growth and resource use. Prerequisite: Biological Sciences or Human Biology core or graduate standing. GER: DB-NatSci

3 units, Win (Vitousek, P; Arrigo, K)

GEOPHYS 120. Frontiers of Geophysical Research at Stanford: Faculty Lectures—Required for new students entering the department. Second-year and other graduate students may attend either for credit or as auditors. Department and senior research staff lectures introduce the frontiers of research problems and the methods being employed or developed in the department and unique to department faculty and students: what the current research is, why the research is important, what methodologies and technologies are being used, and what the potential impact of the results might be.

1 unit, Aut (Segall, P)

GEOPHYS 130/231. Biological Oceanography—(Graduate students register for 231; same as EARTHSYS 130/230.) Required for Earth Systems students in the oceans track. Interdisciplinary look at how oceanic environments control the form and function of marine life. Topics: distributions of planktonic production and abundance, nutrient cycling, the role of ocean biology in the climate system, expected effects of climate changes on ocean biology. Possible local field trips on weekends. Prerequisites: BIOSCI 43 and GES 8 or equivalent. Corequisite: GES 159/259.

2-4 units, Spr (Arrigo, K)

GEOPHYS 136/236. Physical Chemistry of Atmospheric Particles—(Graduate students register for 236; same as CEE 161T/261T.) Thermodynamic principles and their application to approximate the phase behavior and surface properties of multi-component solution droplets in the atmosphere. Topics: water and its phase transformations; equilibrium models of electrolyte solutions; aerosol water uptake; relative humidity conditions for particle efflorescence (crystallization) and deliquescence; mechanisms of colloid formation and organic matter precipitation in aqueous particles; aerosol and cloud surface characterization using bulk composition and adsorption isotherms; and the role of aerosol surface tension in cloud activation.

3 units, Spr (Tabazadeh, A)

GEOPHYS 137/237. Fundamentals of Ecological Modeling—(Graduate students register for 237.) The dynamics of complex systems through quantitative models that synthesize knowledge and forecast system behavior. Principles of ecological modeling including model conceptualization, construction, analysis, use, and abuse. Modeling exercises that culminate in the design, implementation, and evaluation of a process-based simulation model.

3 units, Aut (Arrigo, K)

GEOPHYS 140. Introduction to Remote Sensing—Global change science as viewed using space remote sensing technology. Global warming, ozone depletion, the hydrologic and carbon cycles, topographic mapping, and surface deformation. Physical concepts in remote sensing. EM waves and geophysical information. Sensors studied: optical, near and thermal IR, active and passive microwave. GER:DB-EngrAppSci

3 units, Aut (Zebker, H)

GEOPHYS 141/241. Remote Sensing of the Oceans—(Graduate students register for 241; same as EARTHSYS 141/241.) How to observe and interpret physical and biological changes in the oceans using satellite technologies. Topics: principles of satellite remote sensing, classes of satellite remote sensors, converting radiometric data into biological and physical quantities, sensor calibration and validation, interpreting large-scale oceanographic features. GER:DB-NatSci

4 units, alternate years, not given this year (Arrigo, K)

GEOPHYS 150. General Geophysics and Physics of the Earth—Elementary study of gravitational, magnetic, seismic, and thermal properties of the Earth. Earth's crust, mantle, core. Plate tectonics and mantle convection. Probing Earth structure with seismic waves. Measurements, interpretation, and applications to Earth structure and exploration. Prerequisites: calculus, first-year college physics. GER:DB-NatSci

3 units, Win (Klemperer, S; Sleep, N)

GEOPHYS 160. Waves—Topics: derivations of wave equations and their solutions in 1-D, 2-D, and 3-D; amplitude, polarization, phase and group velocities, attenuation, and dispersion; reflection and transmission at single and multiple interfaces; ray theory. Applications from acoustics, elastodynamics, and electromagnetics. Prerequisites: differential/integral calculus and complex functions. GER:DB-NatSci

3 units, not given this year (Harris, J; Clearbout, J; Beroza,G)

GEOPHYS 162. Laboratory Methods in Geophysics—Lectures, laboratory experiments, and demonstrations explore principles and measurements of geophysical properties such as velocity, attenuation, porosity, permeability, electrical resistivity, and magnetic susceptibility. A foundation for conducting experiments and for assessing accuracy and variability in reported experimental data. No previous laboratory experience required.

1-3 units, Spr (Staff)

GEOPHYS 180. Geophysical Inverse Problems—Fundamental concepts of inverse theory, with application to geophysics. Inverses with discrete and continuous models, generalized matrix inverses, resolving kernels, regularization, use of prior information, singular value decomposition, nonlinear inverse problems, back-projection techniques, and linear programming. Application to seismic tomography, earthquake location, migration, and fault-slip estimation. Prerequisite: MATH 103. GER:DB-Math

3 units, Aut (Segall, P; Beroza, G)

GEOPHYS 182. Reflection Seismology—The principles of seismic reflection profiling, focusing on methods of seismic data acquisition and seismic data processing for hydrocarbon exploration. GER:DB-NatSci

3 units, Aut (Klemperer, S)

GEOPHYS 183. Reflection Seismology Interpretation—The structural and stratigraphic interpretation of seismic reflection data, emphasizing hydrocarbon traps in two and three dimensions on industry data, including workstation-based interpretation. Lectures only, 1 unit. Prerequisite: 182, or consent of instructor.

1-4 units, alternate years, not given this year (Klemperer, S; Graham, S)

GEOPHYS 184. Seismic Reflection Processing—Workshop in computer processing of seismic reflection data. Students individually process a commercial seismic reflection profile from field tapes to migrated stack, using interactive software on a workstation. Prerequisite: consent of instructor.

3 units, alternate years, not given this year (Klemperer, S)

GEOPHYS 185. Research Seminar Series—(Graduate students register for 385 series.) Limited to Geophysics undergraduates and coterminal master's candidates. Undergraduates participate directly in an ongoing research project: experimental and computational work, joining in reading and study groups, giving seminar papers, and doing original research for the undergraduate thesis. Prerequisite: consent of instructor.

GEOPHYS 185A. Reflection Seismology—(Graduate students register for 385A.) Research in reflection seismology and petroleum prospecting. May be repeated for credit. WIM at 3-unit level.

1-3 units, Aut, Win, Spr, Sum (Biondi, B; Clearbout, J)

GEOPHYS 185B. Environmental Geophysics—(Graduate students register for 385B.) Research on the use of geophysical methods for near-surface environmental problems. May be repeated for credit.

1-3 units, Aut, Win, Spr, Sum (Knight, R)

GEOPHYS 185C. Topics in Biological Oceanography—(Graduate students register for 385C.) Research on biological processes of the world's oceans. May be repeated for credit.

1-3 units, Aut, Win, Spr, Sum (Arrigo, K)

GEOPHYS 185E. Tectonics—(Graduate students register for 385E.) Research on the origin, major structures, and tectonic processes of the Earth's crust. Emphasis is on use of deep seismic reflection and refraction data. May be repeated for credit.

1-3 units, Aut, Win, Spr, Sum (Klemperer, S; Sleep, N; Thompson, G)

GEOPHYS 185K. Crustal Mechanics—(Graduate students register for 385K.) Research in areas of petrophysics, seismology, in situ stress, and subjects related to characterization of the physical properties of rock in situ. May be repeated for credit.

1-3 units, Aut, Win, Spr (Zoback, M)

GEOPHYS 185L. Earthquake Seismology, Deformation, and Stress—(Graduate students register for 385L.) Research on seismic source processes, crustal stress, and deformation associated with faulting and volcanism. May be repeated for credit.

1-2 units, Aut, Win, Spr (Zoback, M; Segall, P; Beroza, G)

GEOPHYS 185S. Seismic Tomography—(Graduate students register for 385S.) Research in transmission and reflection tomography, including topics on forward modeling, inversion, and data acquisition. May be repeated for credit.

1-3 units, Aut, Win, Spr (Harris, J)

GEOPHYS 185V. Poroelasticity—(Graduate students register for 385V.) Research on the mechanical properties of porous rocks: dynamic problems of seismic velocity, dispersion, and attentuation; and quasi-static problems of faulting, fluid transport, crustal deformation, and loss of porosity. Participants define, investigate, and present an original problem of their own. May be repeated for credit.

1-3 units, Aut, Win, Spr (Mavko, G)

GEOPHYS 185Z. Radio Remote Sensing—(Graduate students register for 385Z.) Research applications, especially crustal deformation measurements. Recent instrumentation and system advancements. May be repeated for credit.

1-3 units, Aut, Win, Spr (Zebker, H)

GEOPHYS 190. Near-Surface Geophysics—Applications of geophysical methods for imaging and characterizing the top 100 meters of the Earth. Focus is on the use of electrical and seismic methods for environmental and engineering applications. Introduction to the link between electrical and elastic properties of rocks, soils, and sediments, and their physical, chemical, and biological properties. Surface and borehole methods used for data acquisition. GER:DB-EngrAppSci

3 units, Aut (Knight, R)

GEOPHYS 200A. Oil and War: Oil Peaks and Oil Panics—For upper-division undergraduates and graduate students. Links between oil and future international conflicts. Guest speakers.

2-3 units, Spr (Nur, A)

GEOPHYS 202. Reservoir Geomechanics—Basic principles of rock mechanics and the state of stress and pore pressure in sedimentary basins related to exploitation of hydrocarbon and geothermal reservoirs. Mechanisms of hydrocarbon migration, exploitation of fractured reservoirs, reservoir compaction and subsidence, hydraulic fracturing, utilization of directional and horizontal drilling to optimize well stability.

3 units, alternate years, not given this year (Zoback, M)

GEOPHYS 205. Honors Program—Experimental, observational, or theoretical honors project and thesis in geophysics under supervision of a faculty member. Students who elect to do an honors thesis should begin planning it no later than Winter Quarter of the junior year. Prerequisites: department approval.

1-3 units, Aut, Win, Spr, Sum (Staff)

GEOPHYS 210. Basic Earth Imaging—Echo seismogram recording geometry, head waves, moveout, velocity estimation, making images of complex shaped reflectors, migration by Fourier and integral methods. Anti-aliasing. Dip moveout. Computer labs. See http://sep.stanford.edu/sep/prof/.

3-4 units, Aut (Claerbout, J; Clapp, R)

GEOPHYS 211. Environmental Soundings Image Estimation—Imaging principles exemplified by means of imaging geophysical data of various uncomplicated types (bathymetry, altimetry, velocity, reflectivity). Adjoints, back projection, conjugate-gradient inversion, preconditioning, multidimensional autoregression and spectral factorization, the helical coordinate, and object-based programming. Common recurring issues such as limited aperture, missing data, signal/noise segregation, and nonstationary spectra. See http://sep.stanford.edu/sep/prof/.

3 units, Win (Claerbout, J)

GEOPHYS 220. Tectonics—The architecture of the Earth's crust; regional assembling of structural or deformational features and their relationship, origin and evolution. The plate-tectonic cycle: rifting, passive margins, sea-floor spreading, subduction zones, and collisions. Case studies.

3 units, alternate years, not given this year (Klemperer, S.)

GEOPHYS 230. Advanced Topics in Well Logging—(Same as ENERGY 230.) State of the art tools and analyses; the technology, rock physical basis, and applications of each measurement. Hands-on computer-based analyses illustrate instructional material. Guest speakers on formation evaluation topics. Prerequisites: 130 or equivalent; basic well logging; and standard practice and application of electric well logs.

3 units, Spr (Lindblom, R)

GEOPHYS 241A. Practice of Geostatistics and Seismic Data Integration—(Same as ENERGY 241.) Students build a synthetic 3D fluvial channel reservoir model with layer depths, channel geometry, and facies-specific petrophysic and seismic properties, stressing the physical significance of geophysical data. Reference data set is sparsely sampled, providing the sample data typically available for an actual reservoir assessment. Geostatistical reservoir modeling uses well and seismic data, with results checked against the reference database. Software provided (GSLIB and SRBtools). Prerequisite: ENERGY 240. Recommended: experience with Unix, Matlab/C++/Fortran programming.

3-4 units, Spr (Caers, J; Mukerji, T)

GEOPHYS 255. Report on Energy Industry Training—On-the-job-training for master's and doctoral degree students under the guidance of on-site supervisors. Required report detailing work activities, problems, assignment, and key results. Prerequisite: written consent of adviser.

1-3 units, Aut, Win, Spr, Sum (Staff)

GEOPHYS 260. Rock Physics for Reservoir Characterization—How to integrate well log and laboratory data to determine and theoretically generalize rock physics transforms between sediment wave properties (acoustic and elastic impendence), bulk properties (porosity, lithology, texture, permeability), and pore fluid conditions (pore fluid and pore pressure). These transforms are used in seismic interpretation for reservoir properties, and seismic forward modeling in what-if scenarios.

3 units, alternate years, not given this year (Dvorkin, J)

GEOPHYS 262. Rock Physics—Properties of and processes in rocks as related to geophysical exploration, crustal studies, and tectonic processes. Emphasis is on wave velocities and attenuation, hydraulic permeability, and electrical resistivity in rocks. Application to in situ problems, using lab data and theoretical results.

3 units, Aut (Mavko, G)

GEOPHYS 265. Imaging Radar and Applications—(Same as EE 355.) Topics include radar system elements, the radar equation and signal to noise ratio, signal and image processing, range/Doppler algorithms, interferometric measurements. Applications to crustal deformation, topographic mapping, velocities of ice sheets and glaciers, polarimetry and terrain analysis. Computational labs give hands-on-experience with real data.

3 units, Win (Zebker, H)

GEOPHYS 270. Electromagnetic Properties of Geological Materials—Laboratory observations and theoretical modeling of electromagnetic properties and nuclear magnetic resonance response of geological materials. Relationships between these properties and water-saturated materials properties such as composition, water content, surface area, and permeability.

2 units, not given this year (Knight, R)

GEOPHYS 280. 3-D Seismic Imaging—The principles of imaging complex structures in the Earth subsurface using 3-D reflection seismology. Emphasis is on processing methodologies and algorithms, with examples of applications to field data. Topics: acquisition geometrics of land and marine 3-D seismic surveys, time vs. depth imaging, migration by Kirchhoff methods and by wave-equation methods, migration velocity analysis, velocity model building, imaging irregularly sampled and aliased data. Computational labs involve some programming. Lab for 3 units.

2-3 units, Spr (Biondi, B)

GEOPHYS 287. Earthquake Seismology—Theorems in elastodynamics, Green's functions, attenuation, wave propagation in layered media, ray theory, seismic moment tensors, finite-source effects, kinematics and dynamics of earthquakes, and engineering aspects of seismology.

3 units, Win (Beroza, G) alternate years, not given next year

GEOPHYS 288A. Crustal Deformation—Earthquake and volcanic deformation, emphasizing analytical models that can be compared to data from GPS, InSAR, and strain meters. Deformation, stress, and conservation laws. Dislocation models of strike slip and dip slip faults, in 2 and 3 dimensions. Crack models, including boundary element methods. Dislocations in layered and elastically heterogeneous earth models. Models of volcano deformation, including sills, dikes, and magma chambers.

3-5 units, not given this year (Segall, P)

GEOPHYS 288B. Crustal Deformation—Earthquake and volcanic deformation, emphasizing analytical models that can be compared to data from GPS, InSAR, and strain meters. Viscoelasticity, post-seismic rebound, and viscoelastic magma chambers. Effects of surface topography and earth curvature on surface deformation. Gravity changes induced by deformation and elastogravitational coupling. Poro-elasticity, coupled fluid flow and deformation. Earthquake nucleation and rate-state friction. Models of earthquake cycle at plate boundaries.

3-5 units, not given this year (Segall, P)

GEOPHYS 289. Global Positioning System in Earth Sciences—The basics of GPS, emphasizing monitoring crustal deformation with a precision of millimeters over baselines tens to thousands of kilometers long. Applications: mapping with GIS systems, airborne gravity and magnetic surveys, marine seismic and geophysical studies, mapping atmospheric temperature and water content, measuring contemporary plate motions, and deformation associated with active faulting and volcanism.

3-5 units, Win (Segall, P) alternate years, not given next year

GEOPHYS 290. Tectonophysics—The physics of faulting and plate tectonics. Topics: plate driving forces, lithospheric rheology, crustal faulting, and the state of stress in the lithosphere.

3 units, Win (Zoback, M) alternate years, not given next year

GEOPHYS 300. Earth Sciences Seminar—(Same as EARTHSYS 300, GES 300, IPER 300, ENERGY 300.) Required for incoming graduate students except coterms. Research questions, tools, and approaches of faculty members from all departments in the School of Earth Sciences. Goals are: to inform new graduate students about the school's range of scientific interests and expertise; and introduce them to each other across departments and research groups. Two faculty members present work at each meeting. May be repeated for credit.

1 unit, Aut (Matson, P; Graham, S)

SCHOOL OF EARTH SCIENCES

GEOPHYS 327. The Glacial World—(Same as GES 327.) The environmental changes that took place on Earth between the last glacial maximum (LGM) and the present. Focus is on the cause of the low atmospheric CO_2 concentrations characteristic of the LGM and what conditions explain these reduced CO_2 levels. How changes in sea level, marine primary production, ocean circulation, and elemental cycling may have contributed to past global changes.

2-3 units, not given this year

GEOPHYS 385. Research Seminar Series—See 185 series for offerings and descriptions. Opportunity for advanced graduate students to frame and pursue research or thesis research in the context of an ongoing research project in the department, and present thesis research progress reports before a critical audience. Prerequisite: consent of instructor.

GEOPHYS 399. Teaching Experience in Geophysics—On-the-job training in the teaching of geophysics. An opportunity to develop problem sets and lab exercises, grade papers, and give occasional lectures under the supervision of the regular instructor of a geophysics course. Regular conferences with instructor and with students in the class provide the student teacher with feedback about effectiveness in teaching.

2-4 units, Aut, Win, Spr, Sum (Staff)

GEOPHYS 400. Research in Geophysics

1-15 units, Aut, Win, Spr, Sum (Staff)

COGNATE COURSES

See respective department listings for course descriptions and General Education Requirements (GER) information. See degree requirements above or the program's student services office for applicability of these courses to a major or minor program.

AA 272C. Global Positioning Systems

3 units, Win (Enge, P)

EE 106. Planetary Exploration

3 units, Spr (Fraser-Smith, A)

EEES 257. Introduction to Computational Earth Sciences

2-4 units, Spr (Clapp, R; Harris, J)

GES 144. Fundamentals of Geographic Information Science (GIS)

4 units, Win (Seto, K)

GES 215A,B. Structural Geology and Rock Mechanics—(Same as CEE 297G,H.)

3-5 units, **A:** *Aut,* **B:** *Win (Pollard, D)*

GES 222. Planetary Systems: Dynamics and Origins

3-4 units, Aut (Staff)

GES 223. Planetary Systems: Atmospheres, Surfaces, and Interiors

3 units, Win (Staff)