# GEOPHYSICS

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Courses offered by the Department of Geophysics have the subject code GEOPHYS, and are listed in the "Geophysics (GEOPHYS) Courses" section of this bulletin.

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, 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 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 IN GEOPHYSICS

### BACHELOR OF SCIENCE IN GEOPHYSICS

*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 honors thesis is also required through participation in two or three quarters of GEOPHYS 185, Research Seminar Series, typically 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

GES 1. Fundamentals of Geology
GEOPHYS 150. General Geophysics
*or* GEOPHYS 190. Introduction to Geophysical Field Methods
GEOPHYS 201. Frontiers of Geophysical Research at Stanford

#### ADDITIONAL ELECTIVES

Three approved upper-level (100 or higher) Geophysics lecture courses, typically chosen from the following:
GEOPHYS 107. Journey to the Center of the Earth
GEOPHYS 140. The Earth from Space: Introduction to Remote Sensing
GEOPHYS 150. General Geophysics and Physics of the Earth
GEOPHYS 160. Waves
GEOPHYS 170. Global Tectonics
GEOPHYS 180. Geophysical Inverse Problems
GEOPHYS 190. Introduction to Geophysical Field Methods
GEOPHYS 222. Reflection Seismology
GEOPHYS 262. Rock Physics

1. 6 units of GEOPHYS 185. Research Seminar Series (includes WIM requirement)
2. Three additional approved upper-level (100 or higher) Earth Sciences lecture courses, typically chosen from the above GEOPHYS electives or from the following:

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, or MATH 41,42. Calculus, a score of 4-5 on the Calculus BC AP exam, *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,B. Chemical Principles 1 and 2, or CHEM 31X, Chemical Principles (accelerated), or a score of 4-5 on the Chemistry AP exam

#### RECOMMENDED ELECTIVE

CS 106A. Programming Methodology

### HONORS PROGRAM

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

Select a research project, either theoretical, field, or experimental, that has the approval of an adviser.

3. Submit a proposal to the department, which decides on its suitability as an honors project. Necessary forms are in the department office.
4. Course credit for the project is assigned by the adviser within the framework of GEOPHYS 205.
5. 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.
6. The work done on the honors program cannot be used as a substitute for regularly required courses.

## MINOR IN GEOPHYSICS

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 150. General Geophysics
*or* GEOPHYS 190. Introduction to Geophysical Field Methods
GEOPHYS 201. Frontiers of Geophysical Research at Stanford
Two additional approved upper-level (100 or higher) Geophysics lectures courses, typically chosen from GEOPHYS 107, 140, 150, 160,170, 180, 190, 222, 262.
MATH 19,20,21 *or* 41. Calculus
PHYSICS 41. Mechanics

## COTERMINAL B.S./M.S. PROGRAM IN GEOPHYSICS

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 IN GEOPHYSICS

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 the "Doctor of Philosophy in Geophysics" section of this bulletin). 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 IN GEOPHYSICS

*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:

Complete 15 units of Geophysics lecture courses with at least 9 units numbered 200 or higher.

7. Complete six units numbered 100 or higher and three units of 200-level, non-Geophysics lecture courses in earth sciences.
8. 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.
9. 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.
10. Submit a program proposal for approval by a faculty adviser in the first quarter of enrollment.
11. 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.
12. Students are required to attend department seminars.

## DOCTOR OF PHILOSOPHY IN GEOPHYSICS

*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. Required courses must be taken for a letter grade, if offered. Students are required to attend the department seminars.

ENGR 202W

13. GEOPHYS 201
14. 12 units of Geophysics lecture courses numbered 100 or higher.
15. 12 units of Geophysics lecture courses numbered 200 or higher, taken from at least four faculty members with different research specializations.
16. 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.
17. 9 units of 200-level or higher courses in math, science, engineering, or other quantitative science.
18. 6 units of non-Geophysics lecture courses numbered 100 or higher in Earth or planetary sciences, ecology, hydrology, chemistry, or relevant biology.
19. One 3-unit non-Geophysics lecture course numbered 200 or higher in Earth or planetary science, ecology, hydrology, chemistry, or relevant biology.
20. 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, or equivalent series in other departments with approval of the adviser and graduate coordinator. Students are encouraged to participate in the GEOPHYS 385 series from more than one faculty member or group and relevant equivalent series in other departments.
21. Two quarters of quarter-time teaching assistant experience. For more information, see the *Geophysics Administrative Guide*, section 1.4.1.

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.

# GEOPHYSICS (GEOPHYS) COURSES

For information on undergraduate and graduate programs in the Department of Geophysics, see the "Geophysics" section of this bulletin.

## UNDERGRADUATE COURSES IN GEOPHYSICS

**GEOPHYS 20Q. Predicting Volcanic Eruptions**
Stanford Introductory Seminar. 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), alternate years, not given next year*

**GEOPHYS 25. 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 60N. Man versus Nature: Coping with Disasters Using Space Technology**
(Same as EE 60N.) Stanford Introductory Seminar. Preference to freshman. Natural hazards, earthquakes, volcanoes, floods, hurricanes, and fires, and how they affect people and society; great disasters such as asteroid impacts that periodically obliterate many species of life. Scientific issues, political and social consequences, costs of disaster mitigation, and how scientific knowledge affects policy. How spaceborne imaging technology makes it possible to respond quickly and mitigate consequences; how it is applied to natural disasters; and remote sensing data manipulation and analysis. GER:DB-EngrAppSci
*4 units, Aut (Zebker, H)*

**GEOPHYS 100. Directed Reading**
*1-2 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)*

**GEOPHYS 101. Research Preparation**
Structured mentoring of students enrolled in Geophysics Summer Research Program. Development of research proposals and preliminary readings. May be repeated for credit.
*1 unit, Spr (Klemperer, S; Egger, A)*

**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, not given this year*

**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*

**GEOPHYS 107. Journey to the Center of the Earth**
(Same as GES 107, GES 207, GEOPHYS 207.) The interconnected set of dynamic systems that make up the Earth. Focus is on fundamental geophysical observations of the Earth and the laboratory experiments to understand and interpret them. What earthquakes, volcanoes, gravity, magnetic fields, and rocks reveal about the Earth's formation and evolution.
*3 units, Win (Lawrence, J; Mao, W)*

**GEOPHYS 112. Exploring Geosciences with MATLAB**
How to use MATLAB as a tool for research and technical computing, including 2-D and 3-D visualization features, numerical capabilities, and toolboxes. Practical skills in areas such as data analysis, regressions, optimization, spectral analysis, differential equations, image analysis, computational statistics, and Monte Carlo simulations. Emphasis is on scientific and engineering applications.
*1-3 units, Aut (Mukerji, T; Arogunmati, A)*

**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 140. The Earth From Space: Introduction to Remote Sensing**
(Same as EE 140.) 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, not given this year*

**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*

**GEOPHYS 162. Laboratory Methods in Geophysics**
Lab. Types of equipment used in experimental rock physics. Principles and measurements of geophysical properties such as porosity, permeability, acoustic wave velocity, and resistivity through lectures and laboratory experiments. Training in analytical project writing skills and understanding errors for assessing accuracy and variability of measured data. Students may investigate a scientific problem to support their own research.
*2-3 units, Win (Vanorio, T)*

**GEOPHYS 170. Global Tectonics**
(Formerly 220.) 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, not given this year*

**GEOPHYS 171. Tectonics Field Trip**
Long weekend field trip to examine large-scale features in the crust. Destinations may include the San Andreas fault, Mendocino Triple Junction, Sierra Nevada, and western Basin and Range province.
*3 units, Spr (Klemperer, S)*

**GEOPHYS 180. Geophysical Inverse Problems**
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 (Beroza, G; Segall, P), alternate years, not given next year*

**GEOPHYS 185A. Reflection Seismology**
(Same as GEOPHYS 385A.) Research in reflection seismology and petroleum prospecting. May be repeated for credit. WIM at 3-unit level.
*1-3 units, Aut (Biondi, B; Clapp, R), Win (Biondi, B; Clapp, R), Spr (Biondi, B; Clapp, R), Sum (Staff)*

**GEOPHYS 185B. Environmental Geophysics**
(Same as GEOPHYS 385B.) Research on the use of geophysical methods for near-surface environmental problems. May be repeated for credit. WIM at 3-unit level.
*1-3 units, Aut (Knight, R), Win (Knight, R), Spr (Knight, R), Sum (Staff)*

**GEOPHYS 185E. Tectonics**
(Same as GEOPHYS 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. WIM at 3-unit level.
*1-3 units, Aut (Klemperer, S; Sleep, N; Thompson, G), Win (Klemperer, S; Sleep, N; Thompson, G), Spr (Klemperer, S; Sleep, N; Thompson, G), Sum (Staff)*

**GEOPHYS 185J. Global Seismic Techniques, Theory, and Application**
(Same as GEOPHYS 385J.) Topics chosen from surface wave dispersion measurement, 1D inversion techniques, regional tomographic inversion, receiver functions, ray theory in spherical geometry, seismic attenuation, seismic anisotropy, seismic focusing, reflected phases, stacking, and interpretations of seismic results in light of other geophysical constraints. May be repeated for credit.
*1-3 units, Aut (Lawrence, J), Win (Lawrence, J), Spr (Lawrence, J), Sum (Lawrence, J)*

**GEOPHYS 185K. Crustal Mechanics**
(Same as GEOPHYS 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. WIM at 3-unit level.
*1-3 units, Aut (Zoback, M), Win (Zoback, M), Spr (Zoback, M)*

**GEOPHYS 185L. Earthquake Seismology, Deformation, and Stress**
(Same as GEOPHYS 385L.) Research on seismic source processes, crustal stress, and deformation associated with faulting and volcanism. May be repeated for credit. WIM at 3-unit level.
*1-3 units, Aut (Zoback, M; Segall, P; Beroza, G), Win (Beroza, G; Segall, P; Zoback, M), Spr (Segall, P; Beroza, G; Zoback, M)*

**GEOPHYS 185S. Wave Physics**
(Same as GEOPHYS 385S.) Theory, numerical simulation, and experiments on seismic and electromagnetic waves in complex porous media. Applications from Earth imaging and in situ characterization of Earth properties, including subsurface monitoring. Presentations by faculty, research staff, students, and visitors. May be repeated for credit. WIM at 3-unit level.
*1-3 units, Aut (Harris, J), Win (Harris, J), Spr (Harris, J)*

**GEOPHYS 185V. Poroelasticity**
(Same as GEOPHYS 385V.) Research on the mechanical properties of porous rocks: dynamic problems of seismic velocity, dispersion, and attenuation; 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. WIM at 3-unit level.
*1-3 units, Aut (Mavko, G), Win (Mavko, G), Spr (Mavko, G)*

**GEOPHYS 185Z. Radio Remote Sensing**
(Same as GEOPHYS 385Z.) Research applications, especially crustal deformation measurements. Recent instrumentation and system advancements. May be repeated for credit. WIM at 3-unit level.
*1-3 units, Aut (Zebker, H), Win (Zebker, H), Spr (Zebker, H)*

**GEOPHYS 190. Introduction to Geophysical Field Methods**
Applications of geophysical methods for imaging and characterizing the top 500 meters of the Earth. Field-based equipment demonstrations and data acquisition practices; underlying theories; and modeling and interpreting the data. Techniques include electrical resistivity, ground penetrating radar, gravity, magnetics, electromagnetic and seismic methods focusing on applications in hydrology, engineering, and archaeology. GER:DB-EngrAppSci
*3 units, Spr (Crook, N)*

## GRADUATE COURSES IN GEOPHYSICS

Primarily for graduate students; undergraduates may enroll with consent of instructor.

**GEOPHYS 200. Fluids and Flow in the Earth: Computational Methods**
Interdisciplinary problems involving the state and movement of fluids in crustal systems, and computational methods to model these processes. Examples of processes include: nonlinear, time-dependent flow in porous rocks; coupling in porous rocks between fluid flow, stress, deformation, and heat and chemical transport; percolation of partial melt; diagenetic processes; pressure solution and the formation of stylolites; and transient pore pressure in fault zones. MATLAB, Lattice-Boltzmann, and COMSOL Multiphysics. Term project. No experience with COMSOL Multiphysics required.
*3 units, Win (Staff)*

**GEOPHYS 201. 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 faculty and senior research staff introduce the frontiers of research problems and 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 (Beroza, G)*

**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*

**GEOPHYS 203. Professional Development in Geoscience Education**
(Same as EESS 200, GES 200.) May be repeated for credit.
*1 unit, Aut (Payne, J), Spr (Payne, J)*

**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 (Staff), Win (Staff), Spr (Staff), Sum (Staff)*

**GEOPHYS 207. Journey to the Center of the Earth**
(Same as GES 107, GES 207, GEOPHYS 107.) The interconnected set of dynamic systems that make up the Earth. Focus is on fundamental geophysical observations of the Earth and the laboratory experiments to understand and interpret them. What earthquakes, volcanoes, gravity, magnetic fields, and rocks reveal about the Earth's formation and evolution.
*3 units, Win (Lawrence, J; Mao, W)*

**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; Cardoso, C)*

**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; Ayeni, G)*

**GEOPHYS 222. Reflection Seismology**
(Formerly 182.) The principles of seismic reflection profiling, focusing on methods of seismic data acquisition and seismic data processing for hydrocarbon exploration.
*3 units, alternate years, not given next year*

**GEOPHYS 223. Reflection Seismology Interpretation**
(Formerly 183.) The structural and stratigraphic interpretation of seismic reflection data, emphasizing hydrocarbon traps in two and three dimensions on industry data, including workstation-based interpretation. Prerequisite: 222, or consent of instructor.
*1-4 units, alternate years, not given this year*

**GEOPHYS 224. Seismic Reflection Processing**
(Formerly 184.) 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*

**GEOPHYS 240. Crosswell Seismic Profiling**
Seismic imaging between boreholes for applications to subsurface characterization, reservoir imaging, and reservoir monitoring. Topics include data acquisition, data analysis, data processing and imaging. Inversion models for transmitted, reflected, and diffracted waves for imaging velocity, attenuation, and anisotropy in heterogeneous media. Use of field datasets and field applications. Prerequisites: 160 or equivalent; familiarity with Matlab or other programming language.
*3 units, Win (Harris, J)*

**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 (Mukerji, T; Caers, J)*

**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. Students submit a report detailing work activities, problems, assignment, and key results. May be repeated for credit. Prerequisite: written consent of adviser.
*1-3 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)*

**GEOPHYS 257. Introduction to Computational Earth Sciences**
Techniques for mapping numerically intensive algorithms to modern high performance computers such as the Center for Computational Earth and Environmental Science's (CEES) high productivity technical computing (HPTC). Topics include: debugging, performance analysis, and concepts of parallel programming; efficient serial and parallel programs; OpenMP; and MPI. Exercises using SMP and cluster computers. See http://pangea.stanford.edu/research/cees/. Recommended: familiarity with MATLAB, C, or Fortran. May be repeated for credit.
*2-4 units, Spr (Clapp, R; Harris, J)*

**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, Win (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.) Radar remote sensing, radar image characteristics, viewing geometry, range coding, synthetic aperture processing, correlation, range migration, range/Doppler algorithms, wave domain algorithms, polar algorithm, polarimetric processing, interferometric measurements. Applications: polarimetry and target discrimination, topographic mapping surface displacements, velocities of ice fields.
*3 units, Win (Zebker, H)*

**GEOPHYS 270. Electromagnetic Properties of Geological Materials**
Laboratory observations and theoretical modeling of the electromagnetic properties and nuclear magnetic resonance response of geological material. Relationships between these properties and water-saturated materials properties such as composition, water content, surface area, and permeability.
*2-3 units, not given this year*

**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)*

**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, alternate years, not given this year*

**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, alternate years, not given this year*

**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. Exercises: lithospheric temperature and strength profiles, calculation of seismic strain from summation of earthquake moment tensors, slip on faults in 3D, and stress triggering and inversion of stress from earthquake focal mechanisms.
*3 units, Win (Zoback, M)*

**GEOPHYS 300. Earth Sciences Seminar**
(Crosslisted in each department in the School of Earth Sciences.) 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 (Harris, J)*

**GEOPHYS 385A. Reflection Seismology**
(Same as GEOPHYS 185A.) Research in reflection seismology and petroleum prospecting. May be repeated for credit. WIM at 3-unit level.
*1-3 units, Aut (Biondi, B; Clapp, R), Win (Biondi, B; Clapp, R), Spr (Biondi, B; Clapp, R), Sum (Staff)*

**GEOPHYS 385B. Environmental Geophysics**
(Same as GEOPHYS 185B.) Research on the use of geophysical methods for near-surface environmental problems. May be repeated for credit. WIM at 3-unit level.
*1-3 units, Aut (Knight, R), Win (Knight, R), Spr (Knight, R), Sum (Staff)*

**GEOPHYS 385E. Tectonics**
(Same as GEOPHYS 185E.) 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. WIM at 3-unit level.
*1-3 units, Aut, Win, Spr (Klemperer, S; Sleep, N; Thompson, G), Sum (Staff)*

**GEOPHYS 385J. Global Seismic Techniques, Theory, and Application**
(Same as GEOPHYS 185J.) Topics chosen from surface wave dispersion measurement, 1D inversion techniques, regional tomographic inversion, receiver functions, ray theory in spherical geometry, seismic attenuation, seismic anisotropy, seismic focusing, reflected phases, stacking, and interpretations of seismic results in light of other geophysical constraints. May be repeated for credit.
*1-3 units, Aut, Win, Spr, Sum (Lawrence, J)*

**GEOPHYS 385K. Crustal Mechanics**
(Same as GEOPHYS 185K.) 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. WIM at 3-unit level.
*1-3 units, Aut (Zoback, M), Win (Zoback, M), Spr (Zoback, M)*

**GEOPHYS 385L. Earthquake Seismology, Deformation, and Stress**
(Same as GEOPHYS 185L.) Research on seismic source processes, crustal stress, and deformation associated with faulting and volcanism. May be repeated for credit. WIM at 3-unit level.
*1-3 units, Aut (Zoback, M; Segall, P; Beroza, G), Win (Beroza, G; Segall, P; Zoback, M), Spr (Segall, P; Beroza, G; Zoback, M)*

**GEOPHYS 385S. Wave Physics**
(Same as GEOPHYS 185S.) Theory, numerical simulation, and experiments on seismic and electromagnetic waves in complex porous media. Applications from Earth imaging and in situ characterization of Earth properties, including subsurface monitoring. Presentations by faculty, research staff, students, and visitors. May be repeated for credit. WIM at 3-unit level.
*1-3 units, Aut (Harris, J), Win (Harris, J), Spr (Harris, J)*

**GEOPHYS 385V. Poroelasticity**
(Same as GEOPHYS 185V.) 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. WIM at 3-unit level.
*1-3 units, Aut (Mavko, G), Win (Mavko, G), Spr (Mavko, G)*

**GEOPHYS 385Z. Radio Remote Sensing**
(Same as GEOPHYS 185Z.) Research applications, especially crustal deformation measurements. Recent instrumentation and system advancements. May be repeated for credit. WIM at 3-unit level.
*1-3 units, Aut (Zebker, H), Win (Zebker, H), Spr (Zebker, H)*

**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 (Staff), Win (Staff), Spr (Staff), Sum (Staff)*

**GEOPHYS 400. Research in Geophysics**
*1-15 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)*