

GEOPHYSICS

Courses offered by the Department of Geophysics are listed under the subject code GEOPHYS on the Stanford Bulletin's ExploreCourses web site.

Geophysics is the branch of Earth science concerned with exploring and analyzing active processes of the 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 Watis 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 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.

Mission of the Undergraduate Program in Geophysics

The mission of the undergraduate program in Geophysics is to expose students to a broad spectrum of geophysics, including resource exploration, environmental geophysics, seismology, and tectonics. Students in the major obtain a solid foundation in the essentials of mathematics, physics, and geology, and build upon that foundation with advanced course work in Geophysics to develop the in-depth knowledge they need to pursue advanced graduate study and professional careers in government or the private sector.

Learning Outcomes (Undergraduate)

The department expects undergraduate majors in the program to be able to demonstrate the following learning outcomes. These learning outcomes are used in evaluating students and the department's undergraduate program. Students are expected to:

1. understand the physics and geology that form the basis for geophysical observation and measurement.
2. understand Earth structure and evolution.
3. identify the physical processes governing the behavior of common geophysical systems.
4. be able to explain the principles of applying geophysical methods to societally relevant problems, including natural hazards, resource exploration and management, and environmental issues.
5. be able to quantitatively describe the behavior of natural systems and the principles of geophysical measurement with physics-based mathematical models.
6. investigate these models by solving the governing equations with a combination of analytical and computational methods.
7. make their own observations with a variety of geophysical instruments, and reduce, model, and interpret their data and uncertainties.

8. effectively communicate their scientific knowledge through written and oral presentations.
9. be able to interpret and evaluate the published literature and oral and poster presentations at national meetings.

Graduate Programs in Geophysics

University requirements for the M.S. and Ph.D. are described in the "Graduate Degrees (<http://www.stanford.edu/dept/registrar/bulletin/4901.htm>)" 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 a letter grade.

Learning Outcomes (Graduate)

The objective of the graduate program in Geophysics is to prepare students to be leaders in the geophysics industry, academia, and research organizations through completion of fundamental courses in the major field and in related sciences, as well as through independent research. Students are expected to:

1. apply skills developed in fundamental courses to geophysical problems.
2. research, analyze, and synthesize solutions to an original and contemporary geophysics problem.
3. work independently and as part of a team to develop and improve geophysics solutions.
4. apply written, visual, and oral presentation skills to communicate scientific knowledge.
5. master's students are expected to develop in-depth technical understanding of geophysics problems at an advanced level.
6. doctoral students are expected to complete a scientific investigation that is significant, challenging and original.

Bachelor of Science in Geophysics

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 and GEOPHYS 199 Senior Seminar: Issues in Earth Sciences in Autumn Quarter of the senior year. Seniors in Geophysics who expect to do graduate work should take the Graduate Record Examination (GRE) early in their final undergraduate year.

Optional Pre-Major Class

		Units
GEOPHYS 90	Earthquakes and Volcanoes	3

Geophysics Core Courses (29-32 units)

Students must take all of the following:

		Units
GEOPHYS 110	Earth on the Edge: Introduction to Geophysics	3
GEOPHYS 120	Ice, Water, Fire	3-5
GEOPHYS 130	Introductory Seismology	3
GEOPHYS 150	Geodynamics: Our Dynamic Earth	3
GEOPHYS 162	Laboratory Methods in Geophysics	2-3
or PHYSICS 67	Introduction to Laboratory Physics	
GEOPHYS 190	Near-Surface Geophysics	3
GEOPHYS 196	Undergraduate Research in Geophysics (or approved research internship)	5
GEOPHYS 197	Senior Thesis in Geophysics	3
or GEOPHYS 198	Honors Program	
GEOPHYS 199	Senior Seminar: Issues in Earth Sciences	3

GEOPHYS 201	Frontiers of Geophysical Research at Stanford: Faculty Lectures	1
Total Units		29-32

Geophysics Breadth Courses (18-29 units)

Choose six upper-level courses, one from each of the following six areas (but an additional Geophysics class may substitute for either the Physics or the Geology breadth areas):

1. Resources, hazards, and the environment

Select one of the following:	3
GEOPHYS 182 Reflection Seismology	
GEOPHYS 183 Reflection Seismology Interpretation	
GEOPHYS 185 Rock Physics for Reservoir Characterization	
ENERGY 120 Fundamentals of Petroleum Engineering	
GES 130	
GES 131	
Total Units	3

2. Whole-Earth Geophysics

Select one of the following:	3
GES 122 (Also GEOPHYS 132)	3-4
GEOPHYS 141 Remote Sensing of the Oceans	3-4
GEOPHYS 184 Journey to the Center of the Earth	
GEOPHYS 186 Tectonophysics (Tectonophysics & Global Tectonics)	3
Total Units	12-14

3. Numerical and computational methods

GEOPHYS 211 Environmental Soundings Image Estimation	3
GEOPHYS 281 Geophysical Inverse Problems	
EARTHSCI 211	
Select one of the following:	3-4
ENERGY 160 Modeling Uncertainty in the Earth Sciences	
EE 102A Signal Processing and Linear Systems I	
CME 108 Introduction to Scientific Computing	
CS 106A Programming Methodology & CS 106B and Programming Abstractions	
PHYSICS 113 Computational Physics	

4. Geophysical fluid dynamics

Select one of the following:	3-4
GEOPHYS 146 Atmosphere, Ocean, and Climate Dynamics: The Atmospheric Circulation	
GEOPHYS 146 Atmosphere, Ocean, and Climate Dynamics: the Ocean Circulation	
GEOPHYS 181 Fluids and Flow in the Earth: Computational Methods	
ENERGY 121 Fundamentals of Multiphase Flow	
CEE 164 Introduction to Physical Oceanography	
EESS 220	

5. Physics

Select one of the following:	4
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EE 142 Engineering Electromagnetics (formerly EE 141)	3
ME 80 Mechanics of Materials	
PHYSICS 110 Advanced Mechanics	
PHYSICS 120 Intermediate Electricity and Magnetism I	

6. Geology

Select one of the following:	3-5
GES 102	
GES 110	
GES 111	
GES 151	

Units

Units

Supporting Mathematics Courses

Students must take one of the following series (15 or 19 units):

CME 100	Vector Calculus for Engineers	5
CME 102	Ordinary Differential Equations for Engineers	5
CME 104	Linear Algebra and Partial Differential Equations for Engineers	5

Units

Units

(MATH 51 (MATH 51M recommended), MATH 52, and MATH 53 plus either GEOPHYS 112 or CME 192 may substitute for CME series

Supporting Science Courses

Students must take all of the following (8-27 units):

GES 1A		
or GES 1B		
or GES 1C		
CHEM 31A & CHEM 31B	Chemical Principles I and Chemical Principles II	5-10
or CHEM 31X	Chemical Principles Accelerated	
or a score of 5 on the Chemistry AP exam		
PHYSICS 41	Mechanics	4
or PHYSICS 61	Mechanics and Special Relativity	
or a score of 4-5 on the Physics C Mechanics AP exam		
PHYSICS 43	Electricity and Magnetism	4
or PHYSICS 63	Electricity, Magnetism, and Waves	
or a score of 4-5 on the Physics C E & M AP exam		
PHYSICS 45	Light and Heat	4
or PHYSICS 65	Quantum and Thermal Physics	

Optional Field Class

GES 105	3
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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 decides 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 198 Honors Program.

The decision whether a given independent study project does or does not merit an award of honors is made jointly by the department and

Units

the student's adviser. This decision is based on the quality of both the honors work and the student's other work in Earth Sciences.

- 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 minor consists of one required class (3 units), three electives (min. 9 units), and supporting classes in geology, mathematics, and physics.

Curriculum

- Required course:

GEOPHYS 110 Earth on the Edge: Introduction to Geophysics 3

- Plus three additional approved electives, typically chosen from:

Select three of the following: 9

GEOPHYS 120 Ice, Water, Fire

GEOPHYS 130 Introductory Seismology

GEOPHYS 141 Remote Sensing of the Oceans

GEOPHYS 150 Geodynamics: Our Dynamic Earth

GEOPHYS 162 Laboratory Methods in Geophysics

GEOPHYS 184 Journey to the Center of the Earth

GEOPHYS 186 Tectonophysics

GEOPHYS 190 Near-Surface Geophysics

- Supporting Math & Science:

GES 1A 4-5

or GES 1B

or GES 1C

CME 100 Vector Calculus for Engineers 5

or MATH 51 Linear Algebra and Differential Calculus of Several Variables

PHYSICS 21 Mechanics, Fluids, and Heat 3

or PHYSICS 22 Mechanics, Fluids, and Heat Laboratory

or PHYSICS 23 Electricity, Magnetism, and Optics

or PHYSICS 24 Electricity, Magnetism, and Optics Laboratory

or PHYSICS 41 Mechanics

& PHYSICS 43 and Electricity and Magnetism

or PHYSICS 41 Mechanics

& PHYSICS 45 and Light and Heat

or equivalent AP scores

Coterminal Master of Science Program in Geophysics

The department offers a coterminal M.S. degree for students wishing to obtain more specialized training in Geophysics than is normally possible during study for the B.S. degree alone. An M.S. degree should be considered as the professional degree in Geophysics, and is aimed at students wishing to work in a related industry, or students desiring more focused academic study in the field than the B.S. program allows.

The coterminal M.S. degree in Geophysics is offered in conjunction with any relevant undergraduate program at Stanford. Geophysics students often enter the department with degrees in Earth Sciences, Mathematics, Physics, Chemistry, or other natural science or engineering fields. Any of these are suitable for the coterminal Geophysics program,

and interested students are encouraged to discuss their own background with a Geophysics faculty member.

Admission

The requirements for entry into the coterminal M.S. program are submission of a transcript, a statement of purpose, and at least two letters of recommendation. Applications with a letter of recommendation from a Geophysics faculty are generally considered the strongest. Additional letters from other academic or work-related persons also strengthen the application. There are no specific GPA requirements for entry, but the Department looks for proven performance in a rigorous undergraduate curriculum as a prerequisite for admission.

Undergraduates with at least junior-level standing may apply, and applications should be submitted by the Autumn Quarter of the senior

year.

The graduation requirements to obtain the degree are identical to those for the regular Geophysics master's degree.

University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the "Coterminal Master's Program (<http://exploreddegrees.stanford.edu/cotermdegrees>)" section. University requirements for the master's degree are described in the "Graduate Degrees (<http://exploreddegrees.stanford.edu/graduatedegrees/#mastertext>)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken during or after the first quarter of the sophomore year are eligible for consideration for transfer to the graduate career; the timing of the first graduate quarter is not a factor. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate adviser be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

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.

Degree Requirements

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.
- 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. Enroll for at least three quarters of research seminar (GEOPHYS 385 series).
5. At least 6, but not more than 15, of the 45 units must be earned by enrollment in GEOPHYS 400 Research in Geophysics for independent work on a research problem resulting in a written report accepted and archived by the candidate's faculty. A summer internship is encouraged as venue for research, but no academic credit is given.
6. Submit a program proposal for approval by a faculty adviser in the first quarter of enrollment.
7. 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; and turn in a thesis/report to adviser.
8. 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.

Transfer Credit

An incoming student with a relevant master of science degree may apply for a departmental waiver of up to 12 units of the 30 lecture units required for the Ph.D. degree, for certain courses as approved by the departmental graduate faculty adviser. Credit for courses generally requires that students identify an equivalent Stanford course and obtain the signature of the Stanford faculty responsible for that course, stating its equivalence.

Requirements for the Degree

A minimum of 135 units of graduate study at Stanford must be satisfactorily completed. Required courses must be taken for a letter grade, if offered. Students are required to attend the department seminars, and to complete 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. Students with a Master's degree may waive up to 12 units for approved courses.

ENGR 202W Technical Writing, is recommended but not required.

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. For more information, see the Geophysics Administrative Guide, section 1.4.1.

The student must pass the departmental oral examination 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.

Course requirements

1. *Geophysics*: 12 units, lecture courses numbered 200 and above, from 4 different Geophysics faculty with different research specializations. These units cannot be waived.
2. *Additional Geophysics*: 3 units, lecture courses numbered 150 and above
3. *School of Earth Sciences (non-Geophysics)*: 3 units, lecture courses numbered 100 or above
4. *Mathematics (numbered 100 or above), Science, and Engineering (non-School of Earth Sciences)*: 6 units, lecture courses numbered 200 or above
5. *Any of the above categories*: 6 units, lecture courses numbered 200 or above
6. *Total required units*: 30 units.

Ph.D. Department Examination Requirement

1. One research proposal (10-20 pages) with a completed component that outlines a plan of research for 2-3 years
2. Second scientific proposal or paper (4-10 pages) with a professor in another area
3. An oral presentation with the student's advising committee on both the research proposal (~30-40 min) and the second proposal/paper (~10 min), with questions by the committee constituting the qualifying exam.

Second Project

The purpose of the second research project is to add breadth to Ph.D. study and give the student the opportunity, ability and confidence to carry out research in multiple areas.

Description/Scope:

The second project should stand alone as a separate piece of work from the primary research project.

- The second project must be in Geophysics or a closely related discipline
- The topic must be substantially different from the topic of the Ph.D. thesis; i.e., it should not be the same method applied to a different problem, or a different method applied to the same problem.
- The second project should be supervised by a Stanford Geophysics faculty member (Academic Council or research faculty) who does not serve as the primary research adviser, and who must be in a separate research group. Exceptions allowing for second project advisers who are not Stanford Geophysics faculty must be approved by both the research adviser and the Director of Graduate Studies.
- Completion of the second project ideally results in a publication in the refereed literature, or a presentation at a scientific conference.
- Most students are expected to complete the second research project as part of their Ph.D. studies. However, the department allows an option of meeting academic breadth requirements through additional focused course work; see the Geophysics (<https://pangea.stanford.edu/departments/geophysics/academics/graduate-program/graduation-requirements>) web site for further information on program requirements and the coursework breadth option.

Chair: Howard Zebker

Associate Chair: Biondo Biondi

Professors: Greg Beroza, Biondo Biondi, Jerry M. Harris, Simon Klemperer, Rosemary J. Knight, Paul Segall, Norman H. Sleep, Howard Zebker,* Mark D. Zoback

Associate Professor: Eric Dunham

Assistant Professors: Tiziana Vanorio, Jenny Suckale

Professor (Research): Gerald M. Mavko

Associate Professor (Research): Tapan Mukerji***

Emeriti: Jon Claerbout, Antony Fraser-Smith,* Robert Kovach, Amos Nur, Joan Roughgarden,** George A. Thompson

Courtesy Professors: Stephan A. Graham, Wendy Mao, David D. Pollard

* Joint appointment with Electrical Engineering

** Joint appointment with Biological Sciences

*** Joint appointment with Energy Resources Engineering