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 sciences which explores and analyzes 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 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 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 Geophysics Department expects its undergraduate majors to demonstrate certain learning outcomes. These learning outcomes are used to evaluate students' progress, as well as the undergraduate program itself. 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 their major field and 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

Undergraduates in Geophysics are exposed to a broad spectrum of topics in the Earth sciences that describe and predict our planet's evolution. Majors are built on a solid foundation of mathematics and natural sciences with advanced coursework in geophysics to develop the in-depth knowledge needed to pursue advanced graduate study and professional careers in government or the private sector.

A primary focus of the Geophysics major, both as a primary and secondary major, is the senior research project. Students work closely with a faculty mentor to complete an original research paper that can result in published literature. Students selecting Geophysics as a primary major generally pursue specialized skills in areas such as resource exploration, environmental geophysics, seismology, or tectonics. For students pursuing Geophysics as a secondary major, the department encourages a multidisciplinary approach involving the application of broad knowledge to achieve a better understanding of the Earth and its future.

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.

Geophysics Core Courses

Students must take all of the following:

		Units
GEOPHYS 201	Frontiers of Geophysical Research at Stanford	3
GEOPHYS 110	Introduction to the Foundations of Contemporary Geophysics	3

GEOPHYS 120	Ice, Water, Fire	3
GEOPHYS 162	Laboratory Characterization of Properties of Rocks and Geomaterials	3
Total Units		12

Geophysics Research

		Units
GEOPHYS 199	Senior Seminar: Issues in Earth Sciences	3
GEOPHYS 196	Undergraduate Research in Geophysics	9
Total Units		12

Supporting Mathematics Courses

		Units
CME 100	Vector Calculus for Engineers	5
or MATH 51	Linear Algebra, Multivariable Calculus, and Modern Applications	
or MATH 52	Integral Calculus of Several Variables	
CME 102	Ordinary Differential Equations for Engineers	5
or MATH 53	Ordinary Differential Equations with Linear Algebra	
CME 104	Linear Algebra and Partial Differential Equations for Engineers	5
or MATH 131P	Partial Differential Equations	
Total Units		15

Supporting Physics Courses

		Units
PHYSICS 41	Mechanics	4
or PHYSICS 61	Mechanics and Special Relativity	
PHYSICS 43	Electricity and Magnetism	4
or PHYSICS 63	Electricity, Magnetism, and Waves	
PHYSICS 45	Light and Heat	4
or PHYSICS 65	Quantum and Thermal Physics	
Total Units		12

Supporting Electives (18 units)

18 units of geophysics-relevant upper-level electives to be approved by the Director of Undergraduate Studies and selected from offerings across the across the University including, but not limited to courses in mathematics, Earth and other natural sciences, and engineering.

Substitutions allowed with consent of Director of Undergraduate Studies; classes to be taken for a letter grade if offered, grade 'C' or better.

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.
4. The decision whether a given independent study project does or does not merit an award of honors is made jointly by the department and 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.
5. 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. The minor consists of :

- Four courses in Geophysics numbered 100 or higher
- Supporting math: CME 100 Vector Calculus for Engineers (or MATH 51 Linear Algebra, Multivariable Calculus, and Modern Applications)
- Supporting physics: PHYSICS 21 Mechanics, Fluids, and Heat (or PHYSICS 41 or PHYSICS 61), PHYSICS 23 Electricity, Magnetism, and Optics (or PHYSICS 43 or PHYSICS 63), and PHYSICS 25 Modern Physics (or PHYSICS 45 or PHYSICS 65).

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

Admission

To apply for admission to the Geophysics coterminal M.S. program, students must submit the Coterminal Online Application (https://applyweb.com/stanterm), including 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://exploredegrees.stanford.edu/cotermdegrees)" section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" 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:

1. Complete 15 units of Geophysics lecture courses with at least 9 units numbered 200 or higher.
2. Complete 9 units of non-Geophysics lecture courses in the School of Earth, Energy, and Environmental Sciences, with at least 3 units numbered 200 level or higher.
3. Complete 1-4 electives selected from courses numbered 100 or higher from mathematics, chemistry, engineering, physics, relevant biology, computer science, ecology, hydrology, or within the School of Earth, Energy, and Environmental Sciences. At least one course must be numbered 200 or higher. (GEOPHYS 201 excluded.)
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 used to fulfill requirements for the Ph.D. in Geophysics must be lecture courses (component LEC) taken for a letter grade (unless S/NC is the only option offered). Geophysics courses used to fulfill requirements for the Ph.D. must be taught by Geophysics faculty (or senior academic staff if supervised by a faculty member). Lecture courses on geophysical topics taught by visiting faculty can only be counted as fulfilling a Geophysics requirement if approved in advance by the department Chair and the Director of Graduate Studies. 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.

ENGR 202W Technical Communication, 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 120 and above
3. *School of Earth, Energy & Environmental Sciences (non-Geophysics):* 3 units, lecture courses numbered 100 or above
4. *Mathematics (numbered 100 or above), Science, and Engineering (non-School of Earth, Energy & Environmental 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.

Requirements

- The student must discuss potential second project topics and advisers with the committee at the first annual review (fourth academic quarter).
- The Ph.D. qualifying exam includes 10-15 minutes of presentation time related to the second project. Unless the project has been completed, a proposal (~5 pages) for the second project must be presented at the time of the qualifying exam, including a plan for completion by the end of the third year. Lack of this constitutes failure of the qualifying exam.
- If the project has been completed (or is close to completion), evidence of this must be given at the time of the qualifying exam; e.g., a copy of the paper, the poster, or the submitted conference abstract.
- Students register for 15 graded research units with their second project adviser, or with the Director of Graduate Studies if the adviser is outside Stanford. The final grade will be submitted on completion of a written report documenting the project.
- The completion of the Second Project form and signature of the second-project adviser is a graduation requirement.
- Students cannot be advanced to TGR status or receive the Ph.D. degree before completion of the second project.

The Course Work Breadth/Multiple Area Option

The department expects most students to demonstrate academic breadth and ability in multiple areas by completing a second research project as described above. However, in some cases the department allows an alternative path consisting of focused coursework. A student selecting this option must complete the Coursework Breadth Option Petition which must be approved by the adviser and Director of Graduate Studies. Requirements for this option are:

- The option must include 15 units of graded (or Instructor-mandated S/NC) lecture courses at the 200 level or higher.
- The courses chosen must be relevant to study in Geophysics, and be approved as such by the adviser and Director of Graduate Studies.
- At least 6 units must be from the Department of Geophysics. The remaining courses may chosen from any department.
- The Coursework Breadth Option Petition must state the classes to be taken, and explain how these classes provide breadth or a second focus area to the student's course of study and how they are important to the student's career goals.
- The courses cannot be used to meet any other degree requirements at Stanford.
- No transfer credit may be used to meet this requirement.
- The proposed set of anticipated courses must be evaluated by the student's committee at the first annual review, and approved again at the time of the qualifying exam.
- Students cannot be advanced to TGR status or receive the Ph.D. degree until completion of the 15 additional units.

Exceptions

Any exceptions to the above rules must be approved and signed by the student's adviser, by all members of the student's academic committee, by the Director of Graduate Studies and Chair.

Graduate Advising Expectations

The Department of Geophysics is committed to providing academic advising in support of graduate student scholarly and professional development. When most effective, this advising relationship entails collaborative and sustained engagement by both the adviser and the advisee. As a best practice, advising expectations should be periodically discussed and reviewed to ensure mutual understanding. Both the adviser and the advisee are expected to maintain professionalism and integrity.

Faculty advisers guide students in key areas such as selecting courses, designing and conducting research, developing of teaching pedagogy, navigating policies and degree requirements, and exploring academic opportunities and professional pathways.

Graduate students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.

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, Dustin Schroeder

Professor (Research): Gerald M. Mavko, William Ellsworth

Emeriti: Jon Claerbout, Robert Kovach, Amos Nur,

Courtesy Professors: Stephan A. Graham, Wendy Mao, Tapan Mukerji, Alexandra Konings

* Joint appointment with Electrical Engineering