Geophysics

Degrees Offered

- Professional Masters in Petroleum Reservoir Systems
- Master of Science (Geophysics)
- Master of Science (Geophysical Engineering)
- Doctor of Philosophy (Geophysics)
- Doctor of Philosophy (Geophysical Engineering)

Program Description

Founded in 1926, the Department of Geophysics at Colorado School of Mines is recognized and respected around the world for its programs in applied geophysical research and education.

Geophysics is an interdisciplinary field – a rich blend of disciplines such as geology, physics, mathematics, computer science, and electrical engineering. Professionals working in the field of geophysics come from programs in these allied disciplines, as well as from formal programs in geophysics.

Geophysicists study and explore the Earth’s interior through physical measurements collected at the Earth’s surface, in boreholes, from aircraft, and from satellites. Using a combination of mathematics, physics, geology, chemistry, hydrology, and computer science, a geophysicist analyzes these measurements to infer properties and processes within the Earth’s complex interior. Noninvasive imaging beneath the surface of Earth and other planets by geophysicists is analogous to noninvasive imaging of the interior of the human body by medical specialists.

The Earth supplies all materials needed by our society, serves as the repository of used products, and provides a home to all its inhabitants. Therefore, geophysics and geophysical engineering have important roles to play in the solution of challenging problems facing the inhabitants of this planet, such as providing fresh water, food, and energy for Earth’s growing population, evaluating sites for underground construction and containment of hazardous waste, monitoring noninvasively the aging infrastructures (natural gas pipelines, water supplies, telecommunication conduits, transportation networks) of developed nations, mitigating the threat of geohazards (earthquakes, volcanoes, landslides, avalanches) to populated areas, contributing to homeland security (including detection and removal of unexploded ordnance and land mines), evaluating changes in climate and managing humankind’s response to them, and exploring other planets.

Energy companies and mining firms employ geophysicists to explore for hidden resources around the world. Engineering firms hire geophysical engineers to assess the Earth’s near-surface properties when sites are chosen for large construction projects and waste-management operations. Environmental organizations use geophysics to conduct groundwater surveys and to track the flow of contaminants. On the global scale, geophysicists employed by universities and government agencies (such as the United States Geological Survey, NASA, and the National Oceanographic and Atmospheric Administration) try to understand such Earth processes as heat flow, gravitational, magnetic, electric, thermal, and stress fields within the Earth’s interior. For the past decade, 100% of CSM’s geophysics graduates have found employment in their chosen field.

With nearly 20 active faculty members and small class sizes, students receive individualized attention in a close-knit environment. Given the interdisciplinary nature of geophysics, the graduate curriculum requires students to become thoroughly familiar with geological, mathematical, and physical theory, in addition to exploring the theoretical and practical aspects of the various geophysical methodologies.

Research Emphasis

The Department conducts research in a wide variety of areas that are mostly related, but not restricted, to applied geophysics. Candidates interested in the research activities of a specific faculty member are encouraged to visit the Department’s website and to contact that faculty member directly. To give prospective candidates an idea of the types of research activities available in geophysics at CSM, a list of the recognized research groups operating within the Department of Geophysics is given below.

The Center for Wave Phenomena (CWP) is a research group with four faculty members from the Department of Geophysics. With research sponsored by some 30 companies worldwide in the petroleum exploration industry, plus U.S. government agencies, CWP emphasizes the development of theoretical and computational methods for imaging of the Earth’s subsurface, primarily through use of the reflection seismic method. Researchers have been involved in forward and inverse problems of wave propagation as well as data processing for data obtained where the subsurface is complex, specifically where it is both heterogeneous and anisotropic. Further information about CWP can be obtained at http://www.cwp.mines.edu.

The Reservoir Characterization Project (RCP) integrates the acquisition and interpretation of 3D multicomponent time-lapse seismic reflection and downhole data with geology and petroleum engineering information of existing oil fields to solve complex reservoir challenges and gain improvements in reservoir performance prediction and development optimization. RCP’s unique research model emphasizes a multidisciplinary, collaborative approach for practical research. It is an industry-funded research consortium with faculty and graduate-level students from Geophysics, Petroleum Engineering, and Geology disciplines. Read more about RCP at http://rcp.mines.edu/.

The Center for Gravity, Electrical & Magnetic Studies (CGEM) is an industry-funded research consortium with faculty and graduate-student participants. Faculty and students from Geophysics, Petroleum Engineering, and Geology disciplines are encouraged to visit the Department’s website and to contact that faculty member directly. CGEM is available on the web at: http://geophysics.mines.edu/cgem/.

The Group for Hydrogeophysics and Porous Media focuses on combining geoelectrical (DC resistivity, complex conductivity, self-potential, and EM) and gravity methods with rock physics models at various scales and for various applications including the study of...
achieve these student outcomes:

The principal objective for students pursuing the PhD degree in Geophysics or Geophysical Engineering is: Geophysics PhD graduates will be regarded by their employers as effective practitioners addressing earth, energy and environmental problems with geophysical techniques. In support of this objective, the PhD programs in the Department of Geophysics are aimed to meet specific career objectives. The program of study is selected by the student, in consultation with an advisor, and with thesis committee approval, according to the student's career needs and interests. Specific degrees have specific requirements as detailed below.

Geophysical Engineering Program Objectives

The principal objective for students pursuing the MS degree in Geophysics or Geophysical Engineering is: Geophysics MS graduates will be regarded by their employers as effective teachers and/or innovative researchers in their early-career peer group. In support of this objective, the MS programs in the Department of Geophysics aim to achieve these student outcomes:

- Graduates will command superior knowledge of Geophysics and fundamental related disciplines.
- Graduates will independently be able to conduct research leading to significant new knowledge and Geophysical techniques.
- Graduates will be able to report their findings orally and in writing.

The chief objective for students pursuing the MS degree in Geophysics or Geophysical Engineering is: Geophysics MS graduates will be regarded by their employers as effective practitioners addressing earth, energy and environmental problems with geophysical techniques. In support of this objective, the MS programs in the Department of Geophysics aim to achieve these student outcomes:

- Graduates will command superior knowledge of Geophysics and fundamental related disciplines.
- Graduates will be able to conduct original research that results in new knowledge and Geophysical techniques.

Program Requirements

The Department offers both traditional, research-oriented graduate programs and a non-thesis professional education program designed to meet specific career objectives. The program of study is selected by the student in consultation with an advisor, and with thesis committee approval, according to the student’s career needs and interests. Specific degrees have specific requirements as detailed below.

Geophysics MS Program Objectives

The Department of Geophysics offers programs in Geophysics and Geophysical Engineering. The chief objective for students pursuing the MS degree in Geophysics is: Geophysics MS graduates will be regarded by their employers as effective practitioners addressing earth, energy and environmental problems with geophysical techniques. In support of this objective, the MS programs in the Department of Geophysics aim to achieve these student outcomes:

- Graduates will be able to conduct research leading to significant new knowledge and Geophysical techniques.
- Graduates will be able to report their findings orally and in writing.

Professional Masters in Petroleum Reservoir Systems

This is a multi-disciplinary, non-thesis master’s degree for students interested in working as geoscience professionals in the petroleum industry. The Departments of Geophysics, Petroleum Engineering, and Geology and Geological Engineering share oversight for the Professional Masters in Petroleum Reservoir Systems program through a committee consisting of one faculty member from each department. Students gain admission to the program by application to any of the three sponsoring departments. Students are administered by that department into which they first matriculate. A minimum of 36 hours of course credit is required to complete the Professional Masters in Petroleum Reservoir Systems program. Up to 9 credits may be earned in 400-level courses. All other credits toward the degree must be 500 level or above. At least 9 hours must consist of:

One course selected from the following:

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<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>PEGN439</td>
<td>WELL LOG ANALYSIS AND FORMATION EVALUATION</td>
<td>3.0</td>
</tr>
<tr>
<td>GPGN439</td>
<td>ADVANCED FORMATION EVALUATION</td>
<td>3.0</td>
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Two courses selected from the following:

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<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>GEGN439</td>
<td>MULTIDISCIPLINARY PETROLEUM DESIGN</td>
<td>3.0</td>
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<tr>
<td>or GPGN439</td>
<td>GEOPHYSICS PROJECT DESIGN / MULTIDISCIPLINARY PETROLEUM DESIGN</td>
<td></td>
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<tr>
<td>or PEGN439</td>
<td>MULTIDISCIPLINARY PETROLEUM DESIGN</td>
<td></td>
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<tr>
<td>GEGN503</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
<td>3.0</td>
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<tr>
<td>or GPGN503</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
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<td>or PEGN503</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
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<tr>
<td>GEGN504</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
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<td>or GPGN504</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
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<tr>
<td>or PEGN504</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
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Also, 9 additional hours must consist of one course, each, from the 3 participating departments. The remaining 18 hours may consist of graduate courses from any of the 3 participating departments, or other courses approved by the committee. Up to 6 hours may consist of independent study, including an industry project.

Master of Science Degrees: Geophysics and Geophysical Engineering

Students may obtain a Master of Science Degree in either Geophysics or Geophysical Engineering, pursuant to the general and individual program requirements outlined below.

For either Master of Science degree, the minimum credits required include:

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<th>Course Code</th>
<th>Credits</th>
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<tr>
<td>Course credits</td>
<td>26.0</td>
</tr>
<tr>
<td>Graduate research</td>
<td>12.0</td>
</tr>
<tr>
<td>Total Semester Hrs</td>
<td>38.0</td>
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</tbody>
</table>
While individual courses constituting the degree are determined by the student, and approved by the advisor and thesis committee, courses applied to all MS degrees must satisfy the following specific criteria:

- All course, research, transfer, residence, and thesis requirements are as described in Registration and Tuition Classification and Graduate Degrees and Requirements sections of the Bulletin.
- Up to 9 credits may be satisfied through 400 (senior) level coursework. All remaining course credits applied to the degree must be at the 500 level or above.
- Students must include the following courses in their Master degree program:

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<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>LICM501</td>
<td>PROFESSIONAL ORAL COMMUNICATION</td>
<td>1.0</td>
</tr>
<tr>
<td>GPGN581</td>
<td>GRADUATE SEMINAR</td>
<td>1.0</td>
</tr>
<tr>
<td>GPGN707</td>
<td>GRADUATE RESEARCH CREDIT beyond the required 26.0 course credits</td>
<td>12.0</td>
</tr>
</tbody>
</table>

- Additional courses may also be required by the student's advisor and committee to fulfill background requirements as described below.

Students are admitted into the Master of Science in Geophysics program. If a student would like to obtain the Master of Science in Geophysical Engineering, the student must submit a request to the Department to change to the Master of Science in Geophysical Engineering. The coursework and thesis topic must meet the following specific requirements. Note that these requirements are in addition to those associated with the Master of Science in Geophysics.

- Students must complete, either prior to their arrival at CSM or while at CSM, no fewer than 16 credits of engineering coursework. What constitutes coursework considered as engineering is determined by the Geophysics faculty.
- In the opinion of the Geophysics faculty, the student's dissertation topic must be appropriate for inclusion as part of an Engineering degree.

As described in the Master of Science, Thesis and Thesis Defense section of this Bulletin, all MS candidates must successfully defend their MS thesis in an open oral Thesis Defense. The guidelines for the Thesis Defense enforced by the Department of Geophysics generally follow those outlined in the Graduate Departments and Programs section of the Bulletin, with one exception. The Department of Geophysics requires students submit the final draft of their written thesis to their thesis committee no later than three weeks prior to the thesis defense date.

**Doctor of Philosophy Degrees: Geophysics and Geophysical Engineering**

We invite applications to our PhD program not only from those individuals with a background in geophysics, but also from those whose background is in allied disciplines such as geology, physics, mathematics, computer science, and electrical engineering.

Students may obtain a Doctor of Philosophy Degree in either Geophysics or Geophysical Engineering, pursuant to the general and individual program requirements outlined below.

For either PhD degree, at least 72 credits beyond the Bachelors Degree are required. Of that total, at least 24 research credits are required. At least 12 course credits must be completed in a minor program of study, approved by the candidate's PhD thesis committee. Up to 36 course credits may be awarded by the candidate's committee for completion of a thesis-based Master's Degree.

While individual courses constituting the degree are determined by the student and approved by the student's advisor and committee, courses applied to all PhD degrees must satisfy the following criteria:

- All course, research, minor degree programs, transfer, residence, and thesis requirements are as described in Registration and Tuition Classification and Graduate Degrees and Requirements sections of the Bulletin.
- Up to 9 credits may be satisfied through 400 (senior) level coursework. All remaining course credits applied to the degree must be at the 500 level or above.
- Students must include the following courses in their PhD program:

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<thead>
<tr>
<th>Course Code</th>
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<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>LICM501</td>
<td>PROFESSIONAL ORAL COMMUNICATION</td>
<td>1.0</td>
</tr>
<tr>
<td>SYGN502</td>
<td>INTRODUCTION TO RESEARCH ETHICS</td>
<td>1.0</td>
</tr>
<tr>
<td>GPGN681</td>
<td>GRADUATE SEMINAR ? PHD</td>
<td>1.0</td>
</tr>
<tr>
<td>GPGN707</td>
<td>GRADUATE THESIS / DISSERTATION RESEARCH CREDIT</td>
<td>24.0</td>
</tr>
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</table>

Choose two of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
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<tbody>
<tr>
<td>SYGN501</td>
<td>THE ART OF SCIENCE</td>
<td>1.0</td>
</tr>
<tr>
<td>SYGN600</td>
<td>COLLEGE TEACHING</td>
<td>2.0</td>
</tr>
<tr>
<td>LAIS601</td>
<td>ACADEMIC PUBLISHING</td>
<td>2.0</td>
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<td>3.0</td>
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</tbody>
</table>

- Additional courses may also be required by the student's advisor and committee to fulfill background requirements described below.

Students are admitted into the PhD in Geophysics program. If a student would like to obtain the PhD in Geophysical Engineering, the student must submit a request to the Department to change to the Doctor of Philosophy in Geophysical Engineering. The coursework and thesis topic must meet the following additional requirements:

- Students must complete, either prior to their arrival at CSM or while at CSM, no fewer than 16 credits of engineering coursework. What constitutes coursework considered as engineering is determined by the Geophysics faculty.
- In the opinion of the Geophysics faculty, the student’s dissertation topic must be appropriate for inclusion as part of an Engineering degree.

Students in both PhD programs are also required to participate in a practical teaching experience. This must take place within a single semester and include:

- Planning and delivery of a minimum of 6 lecture hours, or 4 lecture hours and 2 labs;
- Creating and evaluating students' homework and laboratory reports, if appropriate; and
- Holding office hours if necessary.

In both PhD programs, students must demonstrate the potential for successful completion of independent research and enhance the breadth of their expertise by completing a Doctoral Research Qualifying Examination no later than two years from the date of enrollment in the program. An extension of one additional year may be petitioned by students through their thesis committees. In the Department of Geophysics, the Doctoral Research Qualifying Examination consists of
the preparation, presentation, and defense of one research project and a thesis proposal. The research project and thesis proposal used in this process must conform to the standards posted on the Department of Geophysics website. As described in the Doctor of Philosophy Thesis Defense section of this bulletin, all PhD candidates must successfully defend their PhD thesis in an open oral Thesis Defense. The guidelines for the Thesis Defense enforced by the Department of Geophysics follow those outlined in the Graduate Departments and Programs section of the Bulletin, with one exception. The Department of Geophysics requires students submit the final draft of their written thesis to their thesis committee not later than three weeks prior to the thesis defense date.

Acceptable Thesis Formats
In addition to traditional dissertations, the Department of Geophysics also accepts dissertations that are compendia of papers published or submitted to peer-reviewed journals. The following guidelines are applied by the Department in determining the suitability of a thesis submitted as a series of written papers.

- All papers included in the dissertation must have a common theme, as approved by a student’s thesis committee.
- Papers should be submitted for inclusion in a dissertation in a uniform format and typeset.
- In addition to the individual papers, students must prepare abstract, introduction, discussion, and conclusions sections of the thesis that tie together the individual papers into a unified dissertation.
- A student’s thesis committee might also require the preparation and inclusion of various appendices with the dissertation in support of the papers prepared explicitly for publication.

Graduate Program Background Requirements
All graduate programs in Geophysics require that applicants have a background that includes the equivalent of adequate undergraduate preparation in the following areas:

- Mathematics – Linear Algebra or Linear Systems, Differential Equations, and Computer Programming
- Physics – Classical Physics
- Geology – Structural Geology and Stratigraphy
- Geophysics – Courses that include theory and application in three of the following areas: gravity/magnetics, seismic, electrical/electromagnetics, borehole geophysics, remote sensing, and physics of the Earth
- Field experience in the hands-on application of several geophysical methods
- In addition, candidates in the Doctoral program are required to have no less than one year of college-level or two years of high-school-level courses in a single foreign language, or be able to demonstrate proficiency in at least one language other than English.

Professors
Terence K. Young, Professor and Department Head
Thomas L. Davis
Roelof K. Snieder, Keck Foundation Professor of Basic Exploration Science
Ilya D. Tsvankin

Associate Professors
Jeffrey Andrews-Hanna
Thomas M. Boyd, Associate Provost and Dean of Graduate Studies
Yaoguo Li
Andre Revil
Paul C. Sava, C.H. Green Chair of Exploration Geophysics

Assistant Professors
Edwin Nissen
Andrei Swidinsky
Whitney Trainor-Guitton

Professors Emeriti
Frank A. Hadsell
Alexander A. Kaufman
Gary R. Olhoeft
Phillip R. Romig, Jr.

Research Professors
Norman Bleistein, University Emeritus Professor
Dave Hale
Kenneth L. Larner, University Emeritus Professor

Research Associate Professor
Robert D. Benson

Research Assistant Professor
Richard Krahenbuhl

Adjunct Faculty
Timothy Collett
Gavin P. Hayes
Stephen J. Hill
Walter S. Lynn
Charles P. Oden
Bruce VerWest
David J. Wald

Distinguished Senior Scientists
Warren B. Hamilton
Misac N. Nabighian

Research Associate
John W. Stockwell, Jr.
Courses

GPGN503. INTEGRATED EXPLORATION AND DEVELOPMENT. 3.0 Semester Hrs.
(I) Students work alone and in teams to study reservoirs from fluvial-deltaic and valley fill depositional environments. This is a multidisciplinary course that shows students how to characterize and model subsurface reservoir performance by integrating data, methods and concepts from geology, geophysics and petroleum engineering. Activities include field trips, computer modeling, written exercises and oral team presentations. Prerequisite: none. 2 hours lecture, 3 hours lab; 3 semester hours. Offered fall semester, odd years.

GPGN504. INTEGRATED EXPLORATION AND DEVELOPMENT. 3.0 Semester Hrs.
(I) Students work in multidisciplinary teams to study practical problems and case studies in integrated subsurface exploration and development. The course addresses emerging technologies and timely topics with a general focus on carbonate reservoirs. Activities include field trips, 3D computer modeling, written exercises and oral team presentation. Prerequisite: none. 3 hours lecture and seminar; 3 semester hours. Offered fall semester, even years.

GPGN507. NEAR-SURFACE FIELD METHODS. 3.0 Semester Hrs.
(I) Students design and implement data acquisition programs for all forms of near-surface geophysical surveys. The result of each survey is then modeled and discussed in the context of field design methods. Prerequisite: none. 2 hours lecture, 3 hours lab; 3 semester hours. Offered fall semester, even years.

GPGN509. PHYSICAL AND CHEMICAL PROPERTIES AND PROCESSES IN ROCK, SOILS, AND FLUIDS. 3.0 Semester Hrs.
(I) Physical and chemical properties and processes that are measurable with geophysical instruments are studied, including methods of measurement, interrelationships between properties, coupled processes, and processes which modify properties in pure phase minerals and fluids, and in mineral mixtures (rocks and soils). Investigation of implications for petroleum development, minerals extraction, groundwater exploration, and environmental remediation. Prerequisite: none. 3 hours lecture, 3 semester hours.

GPGN511. ADVANCED GRAVITY AND MAGNETIC EXPLORATION. 4.0 Semester Hrs.
(I) Field or laboratory projects of interest to class members; topics for lecture and laboratory selected from the following: new methods for acquiring, processing and interpreting electrical and electromagnetic data, methods for the solution of two- and three-dimensional EM problems, physical modeling, integrated inversions. Prerequisite: GPGN420 or GPGN520. 3 hours lecture, 3 hours lab; 4 semester hours. Offered spring semester, even years.

GPGN520. ELECTRICAL AND ELECTROMAGNETIC EXPLORATION. 4.0 Semester Hrs.
(I) Electromagnetic theory. Instrumentation. Survey planning. Processing of data. Geologic interpretations. Methods and limitations of interpretation. Prerequisite: GPGN302 and GPGN303. 3 hours lecture, 3 hours lab; 4 semester hours. Offered fall semester, odd years.

GPGN521. ADVANCED ELECTRICAL AND ELECTROMAGNETIC EXPLORATION. 4.0 Semester Hrs.
(II) Field or laboratory projects of interest to class members; topics for lecture and laboratory selected from the following: new methods for acquiring, processing and interpreting electrical and electromagnetic data, methods for the solution of two- and three-dimensional EM problems, physical modeling, integrated inversions. Prerequisite: GPGN420 or GPGN520. 3 hours lecture, 3 hours lab; 4 semester hours. Offered spring semester, even years.

GPGN530. APPLIED GEOPHYSICS. 3.0 Semester Hrs.
(II) Introduction to geophysical techniques used in a variety of industries (mining, petroleum, environmental and engineering) in exploring for new deposits, site design, etc. The methods studied include gravity, magnetic, electrical, seismic, radiometric and borehole techniques. Emphasis on techniques and their applications are tailored to student interests. The course, intended for non-geophysics students, will emphasize the theoretical basis for each technique, the instrumentation used and data collection, processing and interpretation procedures specific to each technique so that non-specialists can more effectively evaluate the results of geophysical investigations. Prerequisites: PHGN100, PHGN200, MATH111, GEGN401. 3 hours lecture; 3 semester hours.

GPGN535. GEOPHYSICAL COMPUTING. 3.0 Semester Hrs.
(II) A survey of computer programming skills most relevant to geophysical data processing, visualization and analysis. Skills enhanced include effective use of multiple programming languages, data structures, multicore systems, and computer memory hierarchies. Problems discussed include multidimensional geophysical image processing, geophysical data acquired at scattered locations, finite-difference approximations to partial differential equations, and other computational problems encountered in research by students. Prerequisites: Experience programming in Java, C, C++ or Fortran. 3 hours lecture, 3 credit hours.

GPGN540. MINING GEOPHYSICS. 3.0 Semester Hrs.
(I) Introduction to gravity, magnetic, electric, radiometric and borehole techniques used primarily by the mining industry in exploring for new deposits but also applied extensively to petroleum, environmental and engineering problems. The course, intended for graduate geophysics students, will emphasize the theoretical basis for each technique, the instrumentation used and data collection, processing and interpretation procedures specific to each technique. Prerequisites: GPGN221, GPGN322, MATH111, MATH112, MATH213. 3 hours lecture; 3 semester hours.

GPGN551. WAVE PHENOMENA SEMINAR. 1.0 Semester Hr.
(I, II) Students will probe a range of current methodologies and issues in seismic data processing, and discuss their ongoing and planned research projects. Topic areas include: Statics estimation and compensation, deconvolution, multiple suppression, wavelet estimation, imaging and inversion, anisotropic velocity and amplitude analysis, seismic interferometry, attenuation and dispersion, extraction of stratigraphic and lithologic information, and correlation of surface and borehole seismic data with well log data. Every student registers for GPGN551 in only the first semester in residence and receives a grade of PRG. The grade is changed to a letter grade after the student's presentation of thesis research. Prerequisite: none. 1 hour seminar; 1 semester hour.
GPGN552. INTRODUCTION TO SEISMOLOGY. 3.0 Semester Hrs.
(I) Introduction to basic principles of elasticity including Hooke's law, equation of motion, representation theorems, and reciprocity. Representation of seismic sources, seismic moment tensor, radiation from point sources in homogeneous isotropic media. Boundary conditions, reflection/transmission coefficients of plane waves, plane-wave propagation in stratified media. Basics of wave propagation in attenuative media, brief description of seismic modeling methods. Prerequisite: GPGN461. 3 hours lecture; 3 semester hours.

GPGN553. INTRODUCTION TO SEISMOLOGY. 3.0 Semester Hrs.
(II) This course is focused on the physics of wave phenomena and the importance of wave-theory results in exploration and earthquake seismology. Includes reflection and transmission problems for spherical waves, methods of steepest descent and stationary phase, point-source radiation in layered isotropic media, surface and non-geometrical waves. Discussion of seismic modeling methods, fundamentals of wave propagation in anisotropic and attenuative media. Prerequisite: GPGN552. 3 hours lecture; 3 semester hours. Offered spring semester, even years.

GPGN555. INTRODUCTION TO EARTHQUAKE SEISMOLOGY. 3.0 Semester Hrs.
(II) Introductory course in observational, engineering, and theoretical earthquake seismology. Topics include: seismogram interpretation, elastic plane waves and surface waves, source kinematics and constraints from seismograms, seismicity and earthquake location, magnitude and intensity estimates, seismic hazard analysis, and earthquake induced ground motions. Students interpret digital data from globally distributed seismic stations. Prerequisite: GPGN461. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GPGN558. SEISMIC DATA INTERPRETATION. 3.0 Semester Hrs.
(II) Practical interpretation of seismic data used in exploration for hydrocarbons. Integration with other sources of geological and geophysical information. Prerequisite: GPGN461, GEOL501 or equivalent. 2 hours lecture, 3 hours lab; 3 semester hours.

GPGN561. SEISMIC DATA PROCESSING I. 3.0 Semester Hrs.
(I) Introduction to basic principles underlying the processing of seismic data for suppression of various types of noise. Includes the rationale for and methods for implementing different forms of gain to data, and the use of various forms of stacking for noise suppression, such as diversity stacking of Vibroseis data, normal-moveout correction and common-midpoint stacking, optimum-weight stacking, beam steering and the stack array. Also discussed are continuous and discrete oneand two-dimensional data filtering, including Vibroseis correlation, spectral whitening, moveout filtering, data interpolation, slant stacking, and the continuous and discrete Radon transform for enhancing data resolution and suppression of multiples and other forms of coherent noise. Prerequisite: GPGN461. 3 hours lecture; 3 semester hours.

GPGN562. SEISMIC DATA PROCESSING II. 3.0 Semester Hrs.
(II) The student will gain understanding of applications of deterministic and statistical deconvolution for wavelet shaping, wavelet compression, and multiple suppression. Both reflection-based and refraction-based statistics estimation and correction for 2-D and 3-D seismic data will be covered, with some attention to problems where subsurface structure is complex. Also for areas of complex subsurface structure, students will be introduced to analytic and interactive methods of velocity estimation. Where the near-surface is complex, poststack and prestack imaging methods, such as layer replacement are introduced to derive dynamic corrections to reflection data. Also discussed are special problems related to the processing of multi-component seismic data for enhancement of shearwave information, and those related to processing of vertical seismic profile data for separation of upgoing and downgoing P- and S-wave arrivals. Prerequisite: GPGN461 and GPGN561. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GPGN570. APPLICATIONS OF SATELLITE REMOTE SENSING. 3.0 Semester Hrs.
(II) An introduction to geoscience applications of satellite remote sensing of the Earth and planets. The lectures provide background on satellites, sensors, methodology, and diverse applications. Topics include visible, near infrared, and thermal infrared passive sensing, active microwave and radio sensing, and geodetic remote sensing. Lectures and labs involve use of data from a variety of instruments, as several applications to problems in the Earth and planetary sciences are presented. Students will complete independent term projects that are presented both written and orally at the end of the term. Prerequisites: PHGN200 and MATH225. 2 hours lecture, 2 hours lab; 3 semester hours.

GPGN574. GROUNDWATER GEOPHYSICS. 4.0 Semester Hrs.
(II) Description of world groundwater aquifers. Effects of water saturation on the physical properties of rocks. Use of geophysical methods in the exploration, development and production of groundwater. Field demonstrations of the application of the geophysical methods in the solution of some groundwater problems. Prerequisite: none. 3 hours lecture, 3 hours lab; 4 semester hours.

GPGN575. PLANETARY GEOPHYSICS. 3.0 Semester Hrs.
Equivalent with GPGN475, (I) Of the solid planets and moons in our Solar System, no two bodies are exactly alike. This class will provide an overview of the observed properties of the planets and moons, cover the basic physical processes that govern their evolution, and then investigate how the planets differ and why. The overarching goals are to develop a quantitative understanding of the processes that drive the evolution of planetary surfaces and interiors, and to develop a deeper understanding of the Earth by placing it in the broader context of the Solar System. Prerequisites: Graduate standing. 3 hours lecture; 3 semester hours.

GPGN576. SPECIAL TOPICS IN THE PLANETARY SCIENCES. 1.0 Semester Hr.
(I, II) Students will read and discuss papers on a particular topic in the planetary sciences. The choice of topic will change each semester. The emphasis is on key topics related to the current state and evolution of the solid planets and moons in our solar system. Readings will include both seminal papers and current research on the topic. Students will take turns presenting summaries of the papers and leading the ensuing discussion. Prerequisites: Graduate standing, or senior standing. 1 hour lecture; 1 semester hour. Repeatable for credit.
GPGN581. GRADUATE SEMINAR. 1.0 Semester Hr.
(I, II) Presentation describing results of MS thesis research. All students must present their research at an approved public venue before the degree is granted. Every MS student registers for GPGN581 only in his/her first semester in residence and receives a grade of PRG. Thereafter, students must attend the weekly Heiland Distinguished Lecture every semester in residence. The grade of PRG is changed to a letter grade after the student's public research presentation and thesis defense are both complete. 1 hour seminar, 1 semester hour.

GPGN597. SUMMER PROGRAMS. 12.0 Semester Hrs.
GPGN598. SPECIAL TOPICS IN GEOPHYSICS. 6.0 Semester Hrs.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

GPGN599. GEOPHYSICAL INVESTIGATIONS MS. 0.5-6 Semester Hr.
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

GPGN605. INVERSION THEORY. 3.0 Semester Hrs.
(II) Introductory course in inverting geophysical observations for inferring earth structure and processes. Techniques discussed include: Monte-Carlo procedures, Marquardt-Levenburg optimization, and generalized linear inversion. In addition, aspects of probability theory, data and model resolution, uniqueness considerations, and the use of a priori constraints are presented. Students are required to apply the inversion methods described to a problem of their choice and present the results as an oral and written report. Prerequisite: MATH225 and knowledge of a scientific programming language. 3 hours lecture; 3 semester hours.

GPGN651. ADVANCED SEISMOLOGY. 3.0 Semester Hrs.
(I) In-depth discussion of wave propagation and seismic processing for anisotropic, heterogeneous media. Topics include influence of anisotropy on plane-wave velocities and polarizations, traveltime analysis for transversely isotropic models, anisotropic velocity-analysis and imaging methods, point-source radiation and Green's function in anisotropic media, inversion and processing of multicomponent seismic data, shear-wave splitting, and basics of seismic fracture characterization. Prerequisites: GPGN552 and GPGN553. 3 hours lecture; 3 semester hours.

GPGN658. SEISMIC WAVEFIELD IMAGING. 3.0 Semester Hrs.
(I) Seismic imaging is the process that converts seismograms, each recorded as a function of time, to an image of the earth's subsurface, which is a function of depth below the surface. The course emphasizes imaging applications developed from first principles (elastodynamics relations) to practical methods applicable to seismic wavefield data. Techniques discussed include reverse-time migration and migration by wavefield extrapolation, angle-domain imaging, migration velocity analysis and analysis of angle-dependent reflectivity. Students do independent term projects presented at the end of the term, under the supervision of a faculty member or guest lecturer. Prerequisite: none. 3 hours lecture; 3 semester hours.

GPGN660. MATHEMATICS OF SEISMIC IMAGING AND MIGRATION. 3.0 Semester Hrs.
(II) During the past 40 years geophysicists have developed many techniques (known collectively as ?migration?) for imaging geologic structures deep within the Earth's subsurface. Beyond merely imaging strata, migration can provide information about important physical properties of rocks, necessary for the subsequent drilling and development of oil- and gas-bearing formations within the Earth. In this course the student will be introduced to the mathematical theory underlying seismic migration, in the context of ?inverse scattering imaging theory. The course is heavily oriented toward problem solving. 3 hours lecture; 3 semester hours. Offered spring semester, odd years.

GPGN681. GRADUATE SEMINAR ? PHD. 1.0 Semester Hr.
(I, II) Presentation describing results of PhD thesis research. All students must present their research at an approved public venue before the degree is granted. Every PhD student registers for GPGN681 only in his/her first semester in residence and receives a grade of PRG. Thereafter, students must attend the weekly Heiland Distinguished Lecture every semester in residence. The grade of PRG is changed to a letter grade after the student's public research presentation and thesis defense are both complete. 1 hour seminar, 1 semester hour.

GPGN698. SPECIAL TOPICS. 6.0 Semester Hrs.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

GPGN699. GEOPHYSICAL INVESTIGATION-PHD. 0.5-6 Semester Hr.
(I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

GPGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

SYGN501. THE ART OF SCIENCE. 1.0 Semester Hr.
This course consists of class sessions and practical exercises. The content of the course is aimed at helping students acquire the skills needed for a career in research. The class sessions cover topics such as the choice of a research topic, making a work plan and executing that plan effectively, what to do when you are stuck, how to write a publication and choose a journal for publication, how to write proposals, the ethics of research, the academic career versus a career in industry, time-management, and a variety of other topics. The course is open to students with very different backgrounds; this ensures a rich and diverse intellectual environment. Prerequisite: none. 1 hour lecture; 1 semester hour.