Geophysics

Degrees Offered

- Professional Masters in Petroleum Reservoir Systems
- Master of Science (Geophysics) (Non-Thesis)
- Master of Science (Geophysical Engineering) (Non-Thesis)
- 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 that blends disciplines such as geology, physics, mathematics, computer science, and electrical engineering. Professionals working in geophysics often come from programs in these allied disciplines, as well as from formal programs in geophysics.

Geophysicists study and explore Earth’s interior through physical measurements collected at Earth’s surface, in boreholes, from aircraft, and from satellites. Using a combination of mathematics, physics, geology, computer science, hydrology, and chemistry, a geophysicist analyzes these measurements to infer properties and processes within 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.

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 Earth and 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 and NASA), try to understand Earth processes such as heat flow, gravitational, magnetic, electric, thermal, and stress fields within Earth’s interior. For the past decade, 95% of CSM’s geophysics graduates have found employment in their chosen field.

With 12 full-time 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 current research activities of specific faculty members 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, and information about other research strengths in the Department, is given below.

The Center for Wave Phenomena (CWP) in the Department of Geophysics is a research group led by four faculty members, which is supported by the petroleum exploration industry and U.S. government agencies. CWP is focused on the development of advanced seismic modeling, imaging, and inversion methods for realistic heterogeneous, anisotropic media. Among the current CWP research topics are wave field imaging and tomography, wave inversion of reflection and microseismic data, seismic interferometry and Marchenko imaging, quantification of uncertainty in seismic inversion, seismic fracture characterization, and data acquisition using robotics and distributed acoustic sensing (DAS). CWP faculty and students actively work on large-scale cluster and GPU computing. Further information about CWP can be obtained at https://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 to gain improvements in reservoir performance prediction and development optimization. RCP’s unique research model emphasizes a multidisciplinary, collaborative approach for practical research. RCP also focuses on specific research areas such as fiber optics, machine learning, compressive sensing and EOR in unconventional. 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) in the Department of Geophysics is an academic research center that focuses on the quantitative interpretation of gravity, magnetic, electrical and electromagnetic, and surface nuclear magnetic resonance (NMR) data in applied geophysics. The Center brings together the diverse expertise of faculty and students in these different geophysical methods and works towards advancing the state of art in geophysical data interpretation for real-world problems. The emphases of CGEM research are processing and inversion of applied geophysical data. The primary areas of application include petroleum exploration and production, mineral exploration, geothermal, and geotechnical and engineering problems. In addition, environmental problems, infrastructure mapping, archaeology, hydrogeophysics, and crustal studies are also research areas within the Center. There are currently five major focus areas of
research within CGEM: Gravity and Magnetics Research Consortium (GMRC), mineral exploration, geothermal exploration, surface NMR, and hydrogeophysics. Research funding is provided by petroleum and mining industries, ERDC, SERDP, DOE, and other agencies. More information about CGEM is available on the web: http://cgem.mines.edu.

The Electromagnetic Resource Exploration Group (EMREX) at the Colorado School of Mines focuses on may aspects of applied electromagnetic methods in geophysics. Projects in which we are currently involved include the effects of steel oil & gas infrastructure (such as casing and pipelines) on controlled-source electromagnetic (CSEM) surveys, marine mineral exploration, powerline contamination of airborne electromagnetic data magnetic storm hazard assessment for electrical power grids, and look-ahead geophysical methods during underground tunneling & construction.

Global seismology research investigates using 3D numerical seismic wave simulations to improve our understanding of Earth’s interior, by linking observed data to advances in theory and numerical methods in wave propagation and optimization techniques.

Hydrogeophysics and porous media research focuses on combining ground-penetrating radar, electrical, and seismic measurements with rock physics models at various scales and for various applications including the study of contaminant plumes, geothermal systems, leakage in earth dams and embankments, and active volcanoes.

Another research strength of the Department is in Rock Physics, which focuses on rock and fluid properties for basic science as well as for exploration and industrial applications. The primary goal of exploration and production geophysics is to identify fluids, specifically hydrocarbons, in rocks. These applications are successful only with a fundamental understanding of the physical phenomena of transport and storage properties as well as the interactions between fluids and rocks.

Rock physics and geomechanics projects center on fluid storage, fluid distributions and storage in rocks and how these distributions affect characteristics such as wave attenuation, velocity dispersion and seismic signatures. The research also explores geohazards associated with earthquakes and landslides.

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 and Geophysical Engineering Program Objectives
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 educators and/or innovative researchers in their early-career peer group. In support of this objective, the PhD programs in the Department of Geophysics are aimed at achieving 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.

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.
- Graduates will be able to report their findings orally and in writing.

Master of Science Degrees (Non-Thesis): Geophysics and Geophysical Engineering
Students may obtain a Master of Science (MS) Degree (Non-Thesis) in either Geophysics or Geophysical Engineering, pursuant to the general and individual program requirements outlined below.

For either Master of Science (Non-Thesis) degree, the minimum credits required include:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>LICM501</td>
<td>PROFESSIONAL ORAL COMMUNICATION</td>
<td>1.0</td>
</tr>
<tr>
<td>GPGN530</td>
<td>APPLIED GEOPHYSICS</td>
<td>3.0</td>
</tr>
<tr>
<td>GPGN535</td>
<td>GEOPHYSICAL COMPUTING</td>
<td>3.0</td>
</tr>
<tr>
<td>GPGN581</td>
<td>GRADUATE SEMINAR</td>
<td>1.0</td>
</tr>
<tr>
<td>GPGN5XX</td>
<td>Readings (research) Seminar</td>
<td>1.0</td>
</tr>
<tr>
<td>GPGN605</td>
<td>INVERSION THEORY</td>
<td>3.0</td>
</tr>
<tr>
<td>GPGNXXX</td>
<td>Additional Course credits</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Total Semester Hrs: 30.0

The student and advisor determine individual courses constituting the degree. The courses applied to all MS degrees must satisfy the following specific criteria:

- All course, transfer, residence, and thesis requirements are as described in Registration and Tuition Classification and Graduate Degrees and Requirements sections of the Catalog.
- Up to 6 credits of 400 or 500 level work may be double counted in the undergraduate and graduate degree for students enrolled in the Combined Degree.
- 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.
- Additional courses may also be required by the student’s advisor and committee to fulfill background requirements.
- Students must complete, either prior to their arrival at Mines or while at Mines, no fewer than 16 credits of engineering coursework. What constitutes coursework considered as engineering is determined by the Geophysics faculty.

Computational Geophysics Track
Students in the Geophysics Non-Thesis Master’s Degree program, Computational Geophysics Track, will be expected to complete the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
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<tbody>
<tr>
<td>GPGNXXXXX</td>
<td>Required Courses</td>
<td>12.0</td>
</tr>
<tr>
<td>GPGNXXXXX</td>
<td>GPGN Approved Elective Courses (500+ level)</td>
<td>6.0</td>
</tr>
<tr>
<td>CSMXXXXX</td>
<td>CSM Approved Elective Courses (500+ level)</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td><strong>Total Semester Hrs</strong></td>
<td><strong>30.0</strong></td>
</tr>
</tbody>
</table>

The **Required Courses** for the program are:

- GPGN530  APPLIED GEOPHYSICS  3.0
- GPGN535  GEOPHYSICAL COMPUTING  3.0
- GPGN605  INVERSION THEORY  3.0
- LICM501  PROFESSIONAL ORAL COMMUNICATION  1.0
- GPGN581  GRADUATE SEMINAR  1.0
- GPGN5XX  Readings (research) Seminar  1.0

The **Approved GPGN Electives** with a significant computational component are:

- GPGN533  GEOPHYSICAL DATA INTEGRATION & GEOSTATISTICS  3.0
- GPGN555  EARTHQUAKE SEISMOLOGY  3.0
- GPGN570  APPLICATIONS OF SATELLITE REMOTE SENSING  3.0
- GPGN658  SEISMIC WAVEFIELD IMAGING  3.0

The **Approved CSM Electives** are:

- MATH540  PARALLEL SCIENTIFIC COMPUTING  3.0
- MATH550  NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS  3.0
- MATH551  COMPUTATIONAL LINEAR ALGEBRA  3.0
- CSCI403  DATA BASE MANAGEMENT  3.0
- CSCI470  INTRODUCTION TO MACHINE LEARNING  3.0
- or CSCI575  MACHINE LEARNING  3.0
- CSCI542  SIMULATION  3.0
- CSCI568  DATA MINING  3.0
- CSCI580  ADVANCED HIGH PERFORMANCE COMPUTING  3.0
- EENG509  SPARSE SIGNAL PROCESSING  3.0
- EENG511  CONVEX OPTIMIZATION AND ITS ENGINEERING APPLICATIONS  3.0
- EENG515  MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS  3.0

**Master of Science Degrees: Geophysics and Geophysical Engineering**

Students may obtain a Master of Science (MS) 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:

<table>
<thead>
<tr>
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<th>Credits</th>
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<tr>
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<tr>
<td>GPGN530</td>
<td>APPLIED GEOPHYSICS</td>
<td>3.0</td>
</tr>
<tr>
<td>GPGN535</td>
<td>GEOPHYSICAL COMPUTING</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td><strong>Total Semester Hrs</strong></td>
<td><strong>6.0</strong></td>
</tr>
</tbody>
</table>

The student and advisor, with approval from the thesis committee, determines individual courses constituting the degree. The courses applied to all MS degrees must satisfy the following specific criteria:

- All course, research, transfer, and thesis requirements are as described in Registration and Tuition Classification and Graduate Degrees and Requirements sections of the Catalog.
- Up to 6 credits of 400 or 500 level work may be double counted in the undergraduate and graduate degree for students enrolled in the Combined Degree.
- 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.
- Additional courses may also be required by the student’s advisor and committee to fulfill background requirements.

The coursework and thesis topic for the degree Master of Science, Geophysical Engineering, 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 Mines or while at Mines, no fewer than 16 credits of engineering coursework. What constitutes coursework considered as engineering is determined by the Geophysics faculty.
- The student’s dissertation topic must be appropriate for inclusion as part of an Engineering degree, as determined by the Geophysics faculty.

As described in the Master of Science, Thesis and Thesis Defense section of this Catalog, all MS candidates must successfully defend their MS thesis in a public oral Thesis Defense. The guidelines for the Thesis Defense enforced by the Department of Geophysics generally follow those outlined in in the Graduate Departments and Programs section of the Catalog, with one exception. The Department of Geophysics requires students submit the final draft of their written thesis to their thesis committee a minimum of three weeks prior to the thesis defense date.

**Professional Masters in Petroleum Reservoir Systems**

The Professional Masters in Petroleum Reservoir Systems (PMPRS) degree is designed for individuals who have petroleum industry experience and are interested in increasing their knowledge across the disciplines of geology, geophysics, and petroleum engineering. This is an interdisciplinary, non-thesis master’s degree for students interested in working as geoscience professionals in the petroleum industry. Details including program requirements and description can be found on the Interdisciplinary section of the catalog or by searching for Petroleum Reservoir Systems.

**Mines’ Combined Undergraduate/Graduate Degree Program**

Students enrolled in Mines’ combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines
graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any courses that count towards the graduate degree requirements as either “Required Coursework” or “Elective Coursework”, as defined below, may be used for the purposes of double counting at the discretion of the advisor (MS Non-Thesis) or thesis committee (MS Thesis or PhD). These courses must have been passed with a “B-” or better and meet all other University, Department, Division, and Program requirements for graduate credit.

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

We invite applications to our Doctor of Philosophy (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, or electrical engineering.

Students may obtain a PhD 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 Catalog.
- 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:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<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</td>
<td>24.0</td>
</tr>
<tr>
<td></td>
<td>RESEARCH CREDIT</td>
<td></td>
</tr>
</tbody>
</table>

  Choose two of the following:

<table>
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<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYGN501</td>
<td>RESEARCH SKILLS FOR GRADUATE STUDENTS</td>
<td>1.0</td>
</tr>
<tr>
<td>SYGN600</td>
<td>COLLEGE TEACHING</td>
<td>2.0</td>
</tr>
<tr>
<td>HASS601</td>
<td>ACADEMIC PUBLISHING</td>
<td>2.3</td>
</tr>
</tbody>
</table>

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

The coursework and thesis topic for the degree Doctor of Philosophy, Geophysical Engineering, must meet the following additional requirements:

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

Students in both PhD programs are also required to participate in a practical teaching experience. This requirement must be fulfilled, within a single semester and course, under observation and evaluation by the course instructor of record, 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 not 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 catalog, 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 Catalog, with one exception. The Department of Geophysics requires students submit the final draft of their written thesis to their thesis committee a minimum of 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. Dissertations submitted in the latter format must adhere to the following guidelines.

- 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 Mechanics, and Electromagnetism
• 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 geodynamics.
• 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 fluency in at least one language other than English.

Professors
John H. Bradford, Vice Provost of Global Initiatives and Dean of Earth Resources and Environmental Programs
Yaoguo Li
Paul C. Sava, C.H. Green Chair of Exploration Geophysics and Interim Department Head
Roelof K. Snieder, W.M. Keck Distinguished Professor of Professional Development Education
Ilya D. Tsvankin
Ali Tura

Associate Professors
Thomas M. Boyd
Brandon Dugan, Baker Hughes Chair of Petrophysics and Borehole Geophysics
Jeffrey C. Shragge

Assistant Professors
Ebru Bozdag
Ge Jin
Matthew Siegfried
Andrei Swidinsky
Whitney Trainor-Guitton

Professors Emeriti
Norman Bleistein
Thomas L. Davis
Dave Hale
Alexander A. Kaufman
Kenneth L. Larner
Gary R. Olhoeft
Phillip R. Romig, Jr.
Terence K. Young

Research Associate Professor
James L. Simmons

Research Assistant Professors
Jyoti Behura
Antoine Guitton
Richard Krahenbuhl

Adjunct Faculty
Timothy Collett
Gavin P. Hayes
Morgan Moschetti
Nathaniel Putzig
Bruce VerWest

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, computer modeling, written exercises and oral team presentations. Prerequisite: none. 3 hours lecture and seminar; 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 METHODS. 3.0 Semester Hrs.
(I) This course presents the theory and methods for processing and interpreting gravity and magnetic data acquired in geoscience applications. The course covers four major topic areas in the gravity and magnetic methods: (1) the data quantities measured in field surveys; (2) the methods for modeling, processing, and analyzing gravity, gravity gradient, and magnetic data; (3) 3D inversion of gravity and magnetic data; and (4) integrated interpretation of gravity and magnetic data through inversion and geology differentiation for extracting geology information. Prerequisites: GPGN314, GPGN328. 3 hours lecture, 3 semester hours.

GPGN519. ADVANCED FORMULATION EVALUATION. 3.0 Semester Hrs.
(II) A detailed review of well logging and other formation evaluation methods will be presented, with the emphasis on the imaging and characterization of hydrocarbon reservoirs. Advanced logging tools such as array induction, dipole sonic, and imaging tools will be discussed. The second half of the course will offer in parallel sessions: for geologists and petroleum engineers on subjects such as pulsed neutron logging, nuclear magnetic resonance, production logging, and formation testing; for geophysicists on vertical seismic profiling, cross well acoustics and electro-magnetic surveys. Prerequisite: GPGN419/PEGN419. 3 hours lecture; 3 semester hours.

GPGN520. ELECTRICAL AND ELECTROMAGNETIC EXPLORATION. 3.0 Semester Hrs.

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.

GPGN533. GEOPHYSICAL DATA INTEGRATION & GEOSTATISTICS. 3.0 Semester Hrs.
(I) Students will learn the fundamentals of and explore opportunities for further development of geostatistical data integration techniques for subsurface earth modeling. The class will build on probability theory, spatial correlations and geostatistics algorithms for combing data of diverse support and resolution into subsurface models. The emphasis of the material will be on stochastic methods for combining quantitative and qualitative data into many equi-probable realizations. Activities include computer modeling, written exercises, oral team presentations, and a semester project with opportunity to enhance student's respective research projects. Also, we will read, discuss and implement current research articles the in literature to encourage implementation of state-of-the-art practices and/or highlighting current opportunities for research. 3 hours lecture; 3 semester hours.

GPGN535. GEOPHYSICAL COMPUTING. 3.0 Semester Hrs.
(I) 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 addressed 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.

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. EARTHQUAKE SEISMOLOGY. 3.0 Semester Hrs.
Equivalent with GPGN455.
(I) Earthquakes are amongst the most significant natural hazards faced by mankind, with millions of fatalities forecast this century. They are also our most accessible source of information on Earth's structure, rheology and tectonics, which are what ultimately govern the distribution of its natural resources. This course provides an overview of how earthquake seismology, complemented by geodesy and tectonic geomorphology, can be used to determine Earth structure, earthquake locations, depths and mechanisms; understand Earth's tectonics and rheology; establish long-term earthquake histories and forecast future recurrence; and mitigate against seismic hazards. GPGN555 differs from GPGN455 in that the assignments are approximately 20% longer and encompass more challenging questions. GPGN555 is the appropriate course for graduate students and for undergraduates who expect to go on to study earthquake seismology at graduate school. 3 hours lecture; 3 semester hours. Prerequisite: GPGN320.
GPGN558. SEISMIC DATA INTERPRETATION. 3.0 Semester Hrs.
(II) Earth resource industries are increasingly being called on to contribute to sustainable development in the communities and regions in which they take place. In this graduate level course, students will develop an understanding and appreciation of the ways in which resource extraction projects can contribute to sustainable development. The course will be framed around the UN Sustainable Development Goals and will include the following elements: 1) examination of sustainable development principles relevant to mining and energy projects and current best practices and continuing challenges; 2) critical assessment of necessary elements of corporate social responsibility policies and practices; 3) evaluation of stakeholder roles and specify strategies for effective stakeholder engagement; 4) identification of criteria for engineering and management that contribute to sustainable development; and 5) evaluation of real cases that demonstrate where social license to operate was either gained/maintained or not granted/withdrawn. 2 hours lecture; 3 hours lab; 3 hours total.

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 onedimensional and 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.

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. ADVANCED HYDROGEOPHYSICS. 3.0 Semester Hrs.
(I) Application of geophysical methods to problems in hydrology. Effects of water saturation on the physical properties of rocks. Use of geophysical methods in the exploration, development and production of groundwater, groundwater surface water interaction, snow and ice as a water resource, delineation of groundwater contamination, and mapping of saltwater intrusion. Introduction to the equations governing groundwater flow. Application of inversion to geophysical data to estimate hydrologic parameters. Prerequisite: GPGN 409. 3 hours lecture; 3 semester hours.

GPGN577. HUMANITARIAN GEOPHYSICS. 3.0 Semester Hrs.
(I) This course introduces the concepts and practice of applying geophysical investigations in humanitarian projects. Students will evaluate humanitarian geophysics case studies, devise the characteristics of successful projects, and identify how these best practices could improve previous case studies. This knowledge will be applied towards a group project. Students will split into groups pair up with a faculty advisor and a local organization (e.g., NGO or community group) to design, execute and assess the impact of their project. A key emphasis in all aspects of the course will be on community engagement. This course is taught in collaboration with the CSM Engineering Design and Society Division. Prerequisite: GPGN486. 2 hours lecture; 3 hours lab; 3 semester hours.

GPGN581. GRADUATE SEMINAR. 1.0 Semester Hr.
(I, II) Attendance at scheduled weekly Heiland Distinguished Lectures during each semester of enrollment. Students must complete one individual presentation during the graduate program, at an approved public venue, before degree is granted. Every thesis-based MS student in Geophysics and Geophysical Engineering registers each semester in residence in the program and receive 0.0 credit hours until the last semester in residence. For the last semester, 1.0 credit hours and a grade of PRG are awarded with satisfactory attendance and successful completion of individual presentation requirement. 1 hour seminar; 0 or 1 semester hours.

GPGN590. INSTRUMENTAL DESIGN IN APPLIED GEOPHYSICS. 3.0 Semester Hrs.
(II) A hands-on course on instrumental design in applied geophysics. The first half of the course consists of basic electronic concepts to familiarize students with the skills needed to build instruments (such as DC circuits, AC circuits, amplifiers and digital electronics). The second half of the course consists of a project (or projects) of the students choosing, where they build simple geophysical instruments such as a fluxgate magnetometer or a resistivity system. Prerequisite: None, although Applied Geophysics is recommended. 2.5 hours lecture; 1.5 hours lab; 3 semester hours.

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.

GPGN681. GRADUATE SEMINAR - PHD. 1.0 Semester Hr.
(I, II) Attendance at scheduled weekly Heiland Distinguished Lectures during each semester of enrollment. Students must complete one individual presentation at an approved, off-campus conference before degree is granted. Every PhD student in Geophysics and Geophysical Engineering registers each semester in residence in the program and receive 0.0 credit hours until the last semester in residence. For the last semester, 1.0 credit hours and a grade of PRG are awarded with satisfactory attendance and successful completion of individual presentation requirement. 1 hour seminar; 0 or 1 semester hours.

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, 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.

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.