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 the interior of the Earth (as well as of other planetary bodies) through physical measurements collected at its 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 much like the 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 challenges 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 and mining companies 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), work 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 geology, physics, mathematics and computer science, 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 (https://geophysics.mines.edu/) and to contact that faculty member directly. To give prospective candidates an idea of the types of research activities available in geophysics at MINES, 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 wavefield imaging and tomography, waveform inversion of reflection and microseismic data, seismic interferometry and Marchenko imaging, quantification of uncertainty in seismic inversion, seismic fracture characterization, data acquisition using robotics and distributed acoustic sensing (DAS) and applications of geophysical technology to space exploration. 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 natural 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,
The Center for Rock Abuse at the Colorado School of Mines focuses on fluid distributions in rocks and how these distributions affect characteristics such as wave attenuation, velocity dispersion, and seismic signature. The Center uses a range of instrumentation through the Rock Lab in the Green Center, including low-frequency devices, laser optics equipment, and x-ray computed tomography equipment. The Center manages two major research consortia. For more information, visit https://crusher.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.

The Global and Computational Seismology Group at the Colorado School of Mines focuses on investigating Earth’s interior and other planetary bodies using passive seismic sources, such as quakes and ambient noise. Harnessing the opportunities provided by high-performance computing, ever-increasing seismic data, the group analyzes seismic wiggles and construct high-resolution CAT scan images of Earth’s interior to interpret the composition & inner dynamics of our planet, and relate them to surface processes to understand the origin of and the driving forces behind tectonic activities. These studies also have strong societal impact including assessment and mitigation of natural hazards related to seismic activity and tsunamis in earthquake-prone regions. The experience gained from our planet is also used to inspect the composition and dynamics of Mars and Moon. Research interests of the group include (numerical) simulations of seismic wave propagation & full-waveform inversion (FWI) from regional to global scales; seismic tomography with emerging data sets (i.e., from floating robots and distributed acoustic sensors, environmental noise, etc.); multi-scale structure, anisotropy, and anelasticity of Earth’s mantle, D” region and core; seismic hazard analysis; planetary seismology.

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.

Cryosphere Geophysics aims to understand physical processes of glaciers, ice sheets, snow, permafrost, and sea ice on Earth and other planetary bodies, using ground-, air-, and space-based geophysical methods. Cryospheric geophysical research at Colorado School of Mines particularly tries to understand how these frozen bodies interact with other physical systems, such as oceans, atmosphere, and groundwater on Earth or past climate on Mars.

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.
- 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.
- 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 Title</th>
<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>GPGN530</td>
<td>APPLIED GEOPHYSICS</td>
<td>3.0</td>
</tr>
<tr>
<td>GPGN536</td>
<td>ADVANCED GEOPHYSICAL COMPUTING I</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>GPGNX00</td>
<td>Additional Course credits</td>
<td>18.0</td>
</tr>
<tr>
<td>Total Semester Hrs</td>
<td></td>
<td>30.0</td>
</tr>
</tbody>
</table>
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</th>
<th>Credits</th>
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<tbody>
<tr>
<td>GPGNXXXX Required Courses</td>
<td>12.0</td>
</tr>
<tr>
<td>GPGNXXXX GPN Elective Courses (500+ level)</td>
<td>6.0</td>
</tr>
<tr>
<td>CSMXXXX CSM Approved Elective Courses (500+ level)</td>
<td>12.0</td>
</tr>
<tr>
<td>Total Semester Hrs</td>
<td>30.0</td>
</tr>
</tbody>
</table>

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

- GPGN530 **APPLIED GEOPHYSICS** 3.0
- GPGN536 **ADVANCED GEOPHYSICAL COMPUTING I** 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
- GPGN537 **ADVANCED GEOPHYSICAL COMPUTING II** 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

### 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>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>LICM501 <strong>PROFESSIONAL ORAL COMMUNICATION</strong></td>
<td>1.0</td>
</tr>
<tr>
<td>GPGN530 <strong>APPLIED GEOPHYSICS</strong></td>
<td>3.0</td>
</tr>
<tr>
<td>GPGN536 <strong>ADVANCED GEOPHYSICAL COMPUTING I</strong></td>
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<tr>
<td>GPGN581 <strong>GRADUATE SEMINAR</strong></td>
<td>1.0</td>
</tr>
<tr>
<td>GPGN5XX <strong>Readings (research) Seminar</strong></td>
<td>1.0</td>
</tr>
<tr>
<td>GPGN605 <strong>INVERSION THEORY</strong></td>
<td>3.0</td>
</tr>
<tr>
<td>GPGN5XX <strong>Additional Course credits</strong></td>
<td>12.0</td>
</tr>
<tr>
<td>GPGN707 <strong>GRADUATE THESIS / DISSERTATION RESEARCH CREDIT</strong></td>
<td>6.0</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, 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.

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 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>
</tr>
</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</td>
<td>24.0</td>
</tr>
<tr>
<td></td>
<td>Research Credit</td>
<td></td>
</tr>
</tbody>
</table>

Choose two of the following:

<table>
<thead>
<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.

Courses
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.

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.
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.

GPGN519. ADVANCED FORMATION EVALUATION. 3.0 Semester Hrs.
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.

GPGN520. ELECTRICAL AND ELECTROMAGNETIC EXPLORATION. 3.0 Semester Hrs.
(I) Electromagnetic theory, Instrumentation, Survey planning, Processing of data, Geologic interpretations. Methods and limitations of interpretation. Offered Spring semester in conjunction with GPGN420. Prerequisite: GPGN314. 3 hours lecture; 3 semester hours.

GPGN530. APPLIED GEOPHYSICS. 3.0 Semester Hrs.
(I) 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.

GPGN536. ADVANCED GEOPHYSICAL COMPUTING I. 3.0 Semester Hrs.
This course extends the principles of geophysical computing in the context of simulating and validating numerical solutions to geophysical data processing challenges and 2D/3D partial differential equations commonly found in geophysical investigations. Students develop 2D and 3D numerical solutions to geophysical problems through prototyping and validating code in both high- (e.g., Python) and low-level (e.g., C/C++/F90) languages. Offered in conjunction with GPGN435. Prerequisite: CSCI250 or instructor consent.

GPGN537. ADVANCED GEOPHYSICAL COMPUTING II. 3.0 Semester Hrs.
A survey of computer programming skills most relevant to geophysical modeling, data processing, visualization, and analysis. Skills enhanced include effective use of multiple programming languages, multicore systems, computer memory hierarchies, GPUs, and parallel computing strategies. Problems addressed include multidimensional geophysical partial differential equations, geophysical image processing, regularization of geophysical data acquired at scattered locations, and other geophysical computing problems encountered in research by students. Prerequisite: GPGN536 or instructor consent.

GPGN547. PHYSICS, MECHANICS, AND PETROPHYSICS OF ROCKS. 3.0 Semester Hrs.
This course will discuss topics in rock physics, rock mechanics and petrophysics as outlined below. The class is a combination of lectures, practical sessions, and critical reading and discussion of papers. Topics addressed: Segment in Rock physics: stress, strain, stiffness, modulus, attenuation and dispersion, Segment in Petrophysics: seismic & log expression of various formations, wettability, shale analysis, diagenesis, formation evaluation.

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 AND QUANTITATIVE ANALYSIS. 3.0 Semester Hrs.
This course gives participants an understanding of how to model, understand, interpret and analyze seismic data in a quantitative manner on several worldwide projects. When you look at seismic data, how does it relate to the rock properties, what do the amplitudes mean, what is tuning, what is a wavelet, how does the seismic relate to structure, and what are seismic attributes and inversion products? How do you use this information in exploration, production and basic volumetric and economics calculations? The course will go over these topics. Students will work in teams on several modeling and seismic field data exercises around the world in most widely used software platforms (Ikon-RokDoc, Schlumberger-Petrel, GEOX, CGG-HampsonRussell). The course aims to give participants knowledge and information to assist in professional and career development and to be operationally prepared for the work environment.
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 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 GEOSCIENCE. 3.0 Semester Hrs.
This interdisciplinary course introduces the concepts and practice of geoscientific investigations in humanitarian projects. Students will evaluate humanitarian geoscience 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 and 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 Mines Engineering Design and Society Division and other participating departments. Prerequisite: GPGN 486 Field Camp; CEEN 330 Engineering Field Session, Environmental; or equivalent accredited field session or applicable field experience as approved course instructor.

GPGN581. GRADUATE SEMINAR. 1-1 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.
(I) 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 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) 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, 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.

SYGN501. RESEARCH SKILLS FOR GRADUATE STUDENTS. 1.0 Semester Hr.
(I, II) 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.

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

Associate Professors
Brandon Dugan, Associate Department Head, Baker Hughes Chair of Petrophysics and Borehole Geophysics
Jeffrey C. Shragge
Andrei Swidinsky

Assistant Professors
Ebru Bozdag
Ge Jin
Matthew Siegfried

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

Associate professor emeritus
Thomas M. Boyd

Research Professor
Jeffrey Lee

Research Associate Professor
James L. Simmons

Research Assistant Professors
Jyoti Behura
Richard Krahenbuhl
Mathias Pohl
Whitney Trainor-Guitton
Adjunct Faculty

Timothy Collett, Senior Scientist, US Geological Survey
Gavin P. Hayes, NEIC Research Seismologist, US Geological Survey
Morgan Moschetti, Research Geophysicist, US Geological Survey
Ryan North, Principal Geophysicist, Olson Engineering
Nathaniel Putzig, Senior Scientist, Planetary Science Institute
Andreas Rueger, Chief Geophysicist, Digital Geo Specialists