Geology and Geological Engineering

Degrees Offered

- Master of Science (Geology)
- Master of Science (Geological Engineering)
- Doctor of Philosophy (Geology)
- Doctor of Philosophy (Geological Engineering)
- Master of Engineering (Geological Engineer) (Non-Thesis)
- Professional Master Degree (Petroleum Reservoir Systems) (Non-Thesis)
- Professional Master Degree (Mineral Exploration) (Non-Thesis)

Program Description

The Department of Geology and Geological Engineering offers Master of Science and Doctor of Philosophy degrees in Geology; and Master of Engineering, and Master of Science and Doctor of Philosophy degrees in Geological Engineering. Professional Master Degrees are offered in Petroleum Reservoir Systems and Mineral Exploration. Geological Engineering degrees require possession or acquisition of an undergraduate engineering degree or its equivalent.

Graduate students desiring to study ground water, engineering geology/geotechnics, mining engineering geology and some environmental applications are generally expected to pursue the Geological Engineering degree. Students desiring to study petroleum or minerals exploration or development sciences, and/or geology generally pursue Geology degrees. Students are initially admitted to either geoscience or geological engineering degree programs and must receive approval of the GE department Graduate Advisory Committee to switch degree category.

Geoscience students may also choose among several interdisciplinary graduate programs comprised of faculty from several different CSM departments. The most common choices are Geochemistry, Hydrologic Science and Engineering, and Underground Construction and Tunneling. Please see sections in the Catalog for each of these programs.

Program Requirements

Geology Degrees

The Master of Science (Geology) program will require 36 semester hours of course and research credit hours (a maximum of 9 credit hours may be 400-level course work). Twelve of the 36 credit hours must be research credits. To ensure breadth of background, the course of study for the Master of Science (Geology) degree must include at least one graduate course in each of the fields of stratigraphy/sedimentology, structural geology/tectonics, and petrology. At the discretion of the student's Thesis Advisory Committee, an appropriate course may be substituted for one (and only one) of the fields above. All Master of Science (Geology) candidates must also complete an appropriate thesis, based upon original research they have conducted. A thesis proposal and course of study must be approved by the student's Thesis Advisory Committee before the candidate begins substantial work on the thesis research.

The requirement for Doctor of Philosophy (Geology) program will be established individually by a student's Doctoral Thesis Advisory Committee, but must meet the minimum requirements presented below. The Doctor of Philosophy (Geology) academic program requires a minimum of 72 credit hours beyond the Bachelor degree (a maximum of 9 credit hours may be 400-level course work), with a minimum of 36.0 course credit hours.

Students who enter the PhD program with a thesis-based Master's degree may transfer up to 36 semester hours in recognition of the course work and research completed for that degree. At the discretion of the student’s Doctoral Thesis Advisory Committee, up to 24 semester hours of previous graduate-level course work (at CSM or elsewhere) can be applied towards the course requirement of the Doctor of Philosophy (Geology). Students who have previously earned a thesis-based Master's degree will typically take a minimum of 6 course credits and 6 research credits each of the first two semesters of their residence.

Each entering student will select an appropriate Doctoral Thesis Advisory Committee who will decide if any deficiency coursework is necessary and establish the course of study. All Doctor of Philosophy (Geology) students must pass a qualifying examination, which is expected to be conducted immediately following the semester in which the required 36 course credit hours have been completed. The examination will be administered by the student's Thesis Advisory Committee and will consist of a written and an oral part. Depending on the outcome of the qualifying examination, the Doctoral Thesis Advisory Committee can recommend students to take up to 6 additional course credits. In the case of failure of the comprehensive examination, a re-examination may be given upon the recommendation of the Thesis Advisory Committee and the thesis advisor. Students must prepare and defend a thesis proposal that must be approved by the student's Doctoral Thesis Advisory Committee before the student begins substantial work on the thesis research. Students must also complete and defend an appropriate thesis based upon original research they have conducted and are encouraged to have submitted at least two manuscripts based on the dissertation work for publication in peer-reviewed scholarly journals before defending their thesis.

Prospective students should submit the results of the Graduate Record Examination with their application for admission to graduate study. In the event that it is not possible, because of geographic and other restrictions, to take the Graduate Record Examination prior to enrolling at Colorado School of Mines, enrollment may be granted on a provisional basis subject to satisfactory completion of the examination within the first year of residence.

Prerequisites

Geology Program

The candidate for the degree of Master of Science (Geology) or Doctor of Philosophy (Geology) must have completed the following or equivalent subjects, for which credit toward an advanced degree will not be granted.

- General Geology
- Structural Geology
- Field Geology (6 weeks)
- Mineralogy
- Petrology
- Stratigraphy
- Chemistry (3 semesters, including at least 1 semester of physical or organic)
- Mathematics (2 semesters of calculus)
• An additional science course (other than geology) or advanced mathematics
• Physics (2 semesters)

**Professional Master Degree Programs:**
Candidates for the Professional Master Degree must possess an appropriate geosciences undergraduate degree or its equivalent. Prerequisites are the same as those required for the Master of Science (Geology) Degree.

**Engineering Programs**
The candidate for the degree of Master of Engineering (Geological Engineer), Master of Science (Geological Engineering) or Doctor of Philosophy (Geological Engineering) must have completed the following or equivalent subjects. Graduate credit may be granted for courses at or above the 400 level, if approved by the student’s advisory committee.

**Mathematics**
Four semesters including: Calculus (2 semesters) and one semester of any two of: calculus III, differential equations, probability and statistics, numerical analysis, linear algebra, operations research, optimization.

**Basic Science**
• Chemistry (2 semesters)
• Mineralogy and Petrology
• Physics (2 semesters)
• Stratigraphy or Sedimentation
• Physical Geology
• Computer Programming or GIS

**Engineering Science**
• Structural Geology and one semester in four of the following subjects:
  • Physical Chemistry or Thermodynamics
  • Statics
  • Mechanics of Materials
  • Fluid Mechanics
  • Dynamics
  • Soil Mechanics
  • Rock Mechanics

**Engineering Design**
• Field Geology

As part of the graduate program each student must take one semester in two of the following subjects if such courses were not taken for a previous degree:
• Mineral Deposits/Economic Geology
• Hydrogeology
• Engineering Geology

and also as part of the graduate program one semester in three of the following subjects if such courses were not taken for a previous degree:
• Foundation Engineering
• Engineering Hydrology
• Geomorphology
• Airphoto Interpretation, Photogeology, or Remote Sensing
• Petroleum Geology
• Introduction to Mining
• Introductory Geophysics
• Engineering Geology Design
• Mineral Exploration Design
• Groundwater Engineering Design
• Other engineering design courses as approved by the program committee

**Professional Master in Mineral Exploration**
This non-thesis, master degree program is designed for working professionals who want to increase their knowledge and skills, while gaining a thorough up-date of advances across the spectrum of economic geology, mineral exploration techniques, and mining geosciences. Admission to the program is competitive. Preference will be given to applicants with a minimum of two years of industrial or equivalent experience.

The program requires a minimum of 30 credit hours. A minimum of 15 credit hours must be accumulated in five of the following core areas:

• mineral deposits,
• mineral exploration,
• applied geophysics,
• applied geochemistry,
• applied structural geology,
• petrology,
• field geology, and
• economic evaluation.

An additional 15 credit hours may be selected from the course offerings of the Department of Geology and Geological Engineering and allied departments including Mining Engineering, Economics and Business, Geophysics, Chemistry and Geochemistry, Metallurgy and Materials Science, and Environmental Sciences.

Selection of courses will be undertaken in consultation with the academic advisor. Up to 9 credit hours may be at the 400-level. All other credits towards the degree must be 500-level or above. A maximum of 9 credit hours may be independent study focusing on a topic relevant to the mineral exploration and mining industries.

Prerequisites: Admission to the program is generally restricted to individuals holding a four-year undergraduate degree in earth sciences. Candidates for the degree of Professional Master in Mineral Exploration must have completed the following or equivalent subjects, for which credit toward the advanced degree will not be granted. These are general geology, structural geology, field geology, mineralogy, petrology, chemistry (2 semesters), mathematics (2 semesters of calculus), physics (1 semester), and an additional science course other than geology.

**Professional Master in Petroleum Reservoir Systems**
This is a non-thesis, interdisciplinary master degree program jointly administered by the departments of Geology and Geological Engineering, Geophysics, and Petroleum Engineering. This program consists only of coursework in petroleum geoscience and engineering. No research is required.
General Administration

The three participating departments share oversight for this program through a committee consisting of one faculty member from each of the three departments. Students gain admission to the program by application to any of the three sponsoring departments. Students are administered by that department into which they first matriculate.

Requirements

The program requires a minimum of 36 credit hours. Up to 9 credit hours may be at the 400 level. All other credits toward the degree must be 500 level or above.

9-10 hours must consist of:

One course selected from the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN438</td>
<td>PETROLEUM GEOLOGY</td>
<td>4.0</td>
</tr>
<tr>
<td>GPGN419</td>
<td>INTRODUCTION TO FORMATION EVALUATION AND WELL LOGGING</td>
<td>3.0</td>
</tr>
<tr>
<td>or PEGN419</td>
<td>WELL LOG ANALYSIS AND FORMATION EVALUATION</td>
<td></td>
</tr>
</tbody>
</table>

Two courses selected from the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN503</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
<td>3.0</td>
</tr>
<tr>
<td>or GPGN503</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
<td></td>
</tr>
<tr>
<td>or PEGN503</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
<td></td>
</tr>
<tr>
<td>GEGN504</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
<td>3.0</td>
</tr>
<tr>
<td>or GPGN504</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
<td></td>
</tr>
<tr>
<td>or PEGN504</td>
<td>INTEGRATED EXPLORATION AND DEVELOPMENT</td>
<td></td>
</tr>
<tr>
<td>GEOL609</td>
<td>ADVANCED PETROLEUM GEOLOGY</td>
<td>3.0</td>
</tr>
</tbody>
</table>

9 additional hours must consist of one course each from the 3 participating departments.

The remaining 18 hours may consist of graduate courses from any of the 3 participating departments, or other courses approved by the committee. Up to 6 hours may consist of independent study, including an industry project.

Geological Engineering Degrees

The Master of Engineering (Non-Thesis) Program in Geological Engineering outlined below may be completed by individuals already holding undergraduate or advanced degrees or as a combined degree program (see Graduate Degrees and Requirements (catalog.mines.edu/graduate/thegraduateschool) section of this bulletin) by individuals already matriculated as undergraduate students at The Colorado School of Mines. The program is comprised of:

<table>
<thead>
<tr>
<th>Course Code</th>
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<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN438</td>
<td>PETROLEUM GEOLOGY</td>
<td>4.0</td>
</tr>
<tr>
<td>GPGN419</td>
<td>INTRODUCTION TO FORMATION EVALUATION AND WELL LOGGING</td>
<td>3.0</td>
</tr>
<tr>
<td>or PEGN419</td>
<td>WELL LOG ANALYSIS AND FORMATION EVALUATION</td>
<td></td>
</tr>
</tbody>
</table>

The typical program plan includes 15 course credit hours in both the fall and the spring terms followed by 6 independent study credit hours during the summer term. The non-thesis degree includes three areas of specialization (engineering geology/geotechnics, ground-water engineering, and mining geological engineering).

All Master of Engineering (Non-Thesis) program will include the following core requirements:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN532</td>
<td>GEOLOGICAL DATA ANALYSIS</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN599</td>
<td>INDEPENDENT STUDY</td>
<td>6.0</td>
</tr>
</tbody>
</table>

GEGN599 requires a project and report that demonstrate competence in the application of geological engineering principles that merits a grade of B or better. The project topic and content of the report is determined by the student’s advisor, in consultation with the student, and is approved by the Geological Engineering Graduate Program Committee. The format of the report will follow the guidelines for a professional journal paper.

The student, in consultation with the advisor, must prepare a formal program of courses and independent study topic for approval by the Geological Engineering Graduate Program Committee. The program must be submitted to the committee on or before the end of the first week of classes of the first semester.

The most common difficulty in scheduling completion of the degree involves satisfaction of prerequisites. Common deficiency courses are Statics, Mechanics of Materials, and Fluid Mechanics. These are essential to the engineering underpinnings of the degree. An intense program at CSM involving 18 credit hours each semester including Statics in the fall and Fluid Mechanics in the spring and 9 credits in the summer including Mechanics of Materials, allows these classes to be taken along with the standard program. Some students may choose to take these prerequisites elsewhere before arriving on the CSM campus.

Engineering Geology/Geotechnics Specialty (Non-Thesis)

Students working towards a Masters of Engineering (non-thesis) with specialization in Engineering Geology/Geotechnics must meet the prerequisite course requirements listed later in this section. Required courses for the degree are:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN467</td>
<td>GROUNDWATER ENGINEERING</td>
<td>4.0</td>
</tr>
<tr>
<td>GEGN468</td>
<td>ENGINEERING GEOLOGY AND GEOTECHNICS</td>
<td>4.0</td>
</tr>
<tr>
<td>GEGN532</td>
<td>GEOLOGICAL DATA ANALYSIS</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN570</td>
<td>CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY</td>
<td>3.0</td>
</tr>
<tr>
<td>or GEGN571</td>
<td>ADVANCED ENGINEERING GEOLOGY</td>
<td></td>
</tr>
<tr>
<td>GEGN573</td>
<td>GEOLOGICAL ENGINEERING SITE</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN599</td>
<td>INDEPENDENT STUDY</td>
<td>6.0</td>
</tr>
<tr>
<td>GEGN671</td>
<td>LANDSLIDES: INVESTIGATION, ANALYSIS &amp; MITIGATION</td>
<td>3.0</td>
</tr>
<tr>
<td>or GEGN672</td>
<td>ADVANCED GEOTECHNICS</td>
<td></td>
</tr>
<tr>
<td>GE ELECT</td>
<td>Electives</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Total Semester Hrs 36.0
Electives and course substitutions are approved by the Geological Engineering Graduate Program Committee and must be consistent with the program specialization. As part of their elective courses, students are required to have an advanced course in both soil and rock engineering. Possibilities for other electives include graduate-level rock mechanics and rock engineering, soil mechanics and foundations, groundwater, site characterization, geographical information systems (GIS), project management and geophysics, for example.

**Ground Water Engineering/Hydrogeology Specialty (Non-Thesis)**

Students working towards a Masters of Engineering (non-thesis) with specialization in Ground Water Engineering and Hydrogeology must meet the prerequisite course requirements listed later in this section. Required courses for the degree (36 hours) are:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN466</td>
<td>GROUNDWATER ENGINEERING</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN532</td>
<td>GEOLOGICAL DATA ANALYSIS (Fall)</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN681</td>
<td>VADOSE ZONE HYDROLOGY (Fall)</td>
<td>3.0</td>
</tr>
<tr>
<td>or GEGN581</td>
<td>ANALYTICAL HYDROLOGY</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN509</td>
<td>INTRODUCTION TO AQUEOUS GEOCHEMISTRY (Fall or Spring)</td>
<td>3.0</td>
</tr>
<tr>
<td>or CEEN550</td>
<td>PRINCIPLES OF ENVIRONMENTAL CHEMISTRY</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN583</td>
<td>MATHEMATICAL MODELING OF GROUNDWATER SYSTEMS (Spring)</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN470</td>
<td>GROUND-WATER ENGINEERING DESIGN (Spring)</td>
<td>3.0</td>
</tr>
<tr>
<td>or CEEN575</td>
<td>HAZARDOUS WASTE SITE REMEDIATION</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN575</td>
<td>APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (Fall/Spring)</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN599</td>
<td>INDEPENDENT STUDY</td>
<td>6.0</td>
</tr>
<tr>
<td>GE ELECT</td>
<td>Elective</td>
<td>9.0</td>
</tr>
</tbody>
</table>

Total Semester Hrs: 36.0

Electives and course substitutions are approved by the Geological Engineering Graduate Program Committee and must be consistent with the program specialization. Typically, the elective courses are selected from the following topical areas: mineral deposits geology, ore microscopy, applied geophysics, applied geochemistry, remote sensing, engineering geology, environmental geology, engineering economics / management, mineral processing, geostatistics, geographic information systems, environmental or exploration and mining law, and computers sciences.

The Master of Science Degree Program in Geological Engineering requires a minimum of 36 semester hours of course and project/research credit hours (a maximum of 9 credit hours may be 400-level course work), plus a Graduate Thesis. The degree includes three areas of specialization (engineering geology/geotechnics, groundwater engineering, and mining geological engineering) with common requirements as follows:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN532</td>
<td>GEOLOGICAL DATA ANALYSIS</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN707</td>
<td>GRADUATE THESIS/DISSERTATION</td>
<td>12.0</td>
</tr>
<tr>
<td>GEGN</td>
<td>Course work, approved by the thesis committee</td>
<td>24.0</td>
</tr>
</tbody>
</table>

Total Semester Hrs: 39.0

The content of the thesis is to be determined by the student’s advisory committee in consultation with the student. The Masters thesis must demonstrate creative and comprehensive ability in the development or application of geological engineering principles. The format of the thesis will follow the guidelines described under the Thesis Writer’s Guide.

In addition to the common course requirements, the Master of Science degree with specialization in Engineering Geology/Geotechnics requires:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN467</td>
<td>GROUNDWATER ENGINEERING</td>
<td>4.0</td>
</tr>
<tr>
<td>GEGN468</td>
<td>ENGINEERING GEOLOGY AND GEOTECHNICS</td>
<td>4.0</td>
</tr>
<tr>
<td>GEGN570</td>
<td>CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Select at least two of the following: 6.0

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN571</td>
<td>ADVANCED ENGINEERING GEOLOGY</td>
<td></td>
</tr>
<tr>
<td>GEGN573</td>
<td>GEOLOGICAL ENGINEERING SITE INVESTIGATION</td>
<td></td>
</tr>
<tr>
<td>GEGN671</td>
<td>LANDSLIDES: INVESTIGATION, ANALYSIS &amp; MITIGATION</td>
<td></td>
</tr>
<tr>
<td>GEGN672</td>
<td>ADVANCED GEOTECHNICS</td>
<td>17.0</td>
</tr>
</tbody>
</table>

Typically, the additional courses are selected from the following topical areas: engineering geology, groundwater engineering, groundwater modeling, soil mechanics and foundations, rock mechanics, underground
construction, seismic hazards, geomorphology, geographic information systems, construction management, finite element modeling, waste management, environmental engineering, environmental law, engineering management, and computer programming.

In addition to the common course requirements, the Master of Science degree with specialization in Ground Water also requires the following courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN467</td>
<td>GROUNDWATER ENGINEERING</td>
<td>4.0</td>
</tr>
<tr>
<td>GEGN468</td>
<td>ENGINEERING GEOLOGY AND GEOTECHNICS</td>
<td>4.0</td>
</tr>
<tr>
<td>GEGN581</td>
<td>ANALYTICAL HYDROLOGY</td>
<td>3.0</td>
</tr>
</tbody>
</table>

2 Courses Selected as Follows: 6.0

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEEN550</td>
<td>PRINCIPLES OF ENVIRONMENTAL CHEMISTRY</td>
</tr>
<tr>
<td>GEGN580</td>
<td>CHEMICAL FATE AND TRANSPORT IN THE ENVIRONMENT</td>
</tr>
<tr>
<td>GEGN590</td>
<td>INTRODUCTION TO AQUEOUS GEOCHEMISTRY</td>
</tr>
</tbody>
</table>

Total Semester Hrs 17.0

As nearly all ground water software is written in Fortran, if the student does not know Fortran, a Fortran course must be taken before graduation, knowledge of other computer languages is encouraged.

In addition to the common course requirements, the Master of Science degree with specialization in Mining Geology also requires:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNGN523</td>
<td>SELECTED TOPICS (Surface Mine Design or Underground Mine Design)</td>
</tr>
</tbody>
</table>

Total Semester Hrs 15.0

This will include about 5–6 courses (predominantly at 500 and 600 level) selected by the student in conjunction with the Masters program advisory committee. Specialty areas might include: mineral deposits geology, mineral exploration, mining geology, mineral processing, applied geophysics, applied geochemistry, engineering geology, environmental geology, geostatistics, geographic information systems, environmental or exploration and mining law, engineering economics/management, and computer sciences.

The Doctor of Philosophy (Geological Engineering) degree requires a minimum of 72 hours course work and research combined. Requirements include the same courses as for the Master of Science (Geological Engineering) with the additions noted below. After completing all coursework and an admission to candidacy application, the Dissertation is completed under GEGN707 Graduate Research. The content of the dissertation is to be determined by the student's advisory committee in consultation with the student. The dissertation must make a new contribution to the geological engineering profession. The format of the dissertation will follow the guidelines described under the Thesis Writer’s Guide. A minimum of 24 research credits must be taken. Up to 24 course credit hours may be awarded by the candidate's Doctoral Thesis Advisory Committee for completion of a Master of Science degree (at CSM or elsewhere).

In addition to the common course requirements, a PhD specializing in Engineering Geology/Geotechnics requires additional course work tailored to the student’s specific interests and approved by the doctoral program committee. (Typically, the additional courses are selected from the following topical areas: engineering geology, groundwater engineering, groundwater modeling, soil mechanics and foundations, rock mechanics, underground construction, seismic hazards, geomorphology, geographic information systems, construction management, finite element modeling, waste management, environmental engineering, environmental law, engineering management, and computer programming.)

In addition to the common course requirements listed previously, a PhD specializing in Ground Water also requires:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN581</td>
<td>ANALYTICAL HYDROLOGY</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN669</td>
<td>ADVANCED TOPICS IN ENGINEERING HYDROGEOLOGY</td>
<td>1.2</td>
</tr>
<tr>
<td>GEGN681</td>
<td>VADOSE ZONE HYDROLOGY</td>
<td>3.0</td>
</tr>
<tr>
<td>GEGN683</td>
<td>ADVANCED GROUND WATER MODELING</td>
<td>3.0</td>
</tr>
</tbody>
</table>

and additional course work tailored to the student’s specific interests, which are likely to include chemistry, engineering, environmental science, geophysics, math (particularly Partial Differential Equations), microbiology, organic chemistry, contaminant transport, soil physics, optimization, shallow resistivity or seismic methods. The student’s advisory committee has the authority to approve elective courses and any substitutions for required courses.

In addition to the common course requirements, a PhD specializing in Mining Geology also requires:

<table>
<thead>
<tr>
<th>Course Code</th>
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<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEGN468</td>
<td>ENGINEERING GEOLOGY AND GEOTECHNICS</td>
<td>4.0</td>
</tr>
<tr>
<td>or GEGN467</td>
<td>GROUNDWATER ENGINEERING</td>
<td>4.0</td>
</tr>
<tr>
<td>GEOL505</td>
<td>ADVANCED STRUCTURAL GEOLOGY</td>
<td>3.0</td>
</tr>
<tr>
<td>GEOL515</td>
<td>ADVANCED MINERAL DEPOSITS</td>
<td>3.0</td>
</tr>
<tr>
<td>GEOL520</td>
<td>NEW DEVELOPMENTS IN THE GEOLOGY AND EXPLORATION OF ORE DEPOSITS</td>
<td>3.0</td>
</tr>
<tr>
<td>MNGN523</td>
<td>SELECTED TOPICS (Surface Mine Design or Underground Mine Design)</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Total Semester Hrs 15.0

Additional course work suited to the student’s specific interests and approved by the doctoral program committee. (Typically, the additional courses are selected from the following topical areas: mineral deposits geology, mineral exploration, mining geology, mineral processing, applied geophysics, applied geochemistry, engineering geology, environmental geology, geostatistics, geographic information systems, environmental or exploration and mining law, engineering economics/management, and computer sciences).

Geochemistry

The Geochemistry Program is an interdisciplinary graduate program administered by the departments of Geology and Geological Engineering and Chemistry and Geochemistry. The geochemistry faculty from each department are responsible for the operations of the program. Student reside in either Department. Please see the Geochemistry section of the Bulletin for detailed information on this degree program.

Hydrologic Science and Engineering

The Hydrologic Science and Engineering (HSE) Program is an interdisciplinary graduate program comprised of faculty from several different CSM departments. Please see the Hydrologic Science and Engineering section of the Bulletin for detailed information on this degree program.
Qualifying Examination

Ph.D. students in Geology, Geological Engineering, Geochemistry, and Hydrologic Science and Engineering must pass a qualifying examination by the end of the second year of their programs. This timing may be adjusted for part-time students. This examination will be administered by the student's Doctoral committee and will consist of an oral and a written examination, administered in a format to be determined by the Doctoral Committee. Two negative votes in the Doctoral Committee constitute failure of the examination. In case of failure of the qualifying examination, a re-examination may be given upon the recommendation of the Doctoral Committee and approval of the Graduate Dean. Only one re-examination may be given.

Professor and Department Head

M. Stephen Enders

Professors

David A. Benson
Wendy J. Harrison
Reed M. Maxwell
Alexei Milkov
Paul M. Santi
Kamini Singha, Associate Department Head
Stephen A. Sonnenberg, Charles Boettcher Distinguished Chair in Petroleum Geology
Richard F. Wendlandt
Lesli J. Wood, Weimer Distinguished Chair and Professor, Geology

Associate Professors

Yvette Kuiper
Thomas Monecke
Piret Plink-Bjorklund
Bruce Trudgill
Wendy Zhou

Assistant Professors

Alexander Gysi
Richard M. Palin
Alexis Sitchler
Gabriel Walton

Teaching Professor

Christian V. Shorey

Research Professors

Marsha French
Richard Goldfarb

Zane Jobe
David Leach
J. Frederick (Rick) Sarg

Research Assistant Professors

Mary Carr
Katharina Pfaff

Professor Emerita

Eileen P. Poeter

Professors Emeriti

John B. Curtis
Thomas L.T. Grose
John D. Haun
Jerry D. Higgins
Murray W. Hitzman
Neil F. Hurley
Keenan Lee
Samuel B. Romberger
A. Keith Turner
John E. Warme
Robert J. Weimer

Associate Professors Emeriti

L. Graham Closs
Timothy A. Cross
Gregory S. Holden

Courses

GEGN503. 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.
GEGN504. 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.

GEGN509. INTRODUCTION TO AQUEOUS GEOCHEMISTRY. 3.0 Semester Hrs.
(I) Analytical, graphical and interpretive methods applied to aqueous systems. Thermodynamic properties of water and aqueous solutions. Calculations and graphical expression of acid-base, redox and solution-mineral equilibria. Effect of temperature and kinetics on natural aqueous systems. Adsorption and ion exchange equilibria between clays and oxide phases. Behavior of trace elements and complexation in aqueous systems. Application of organic geochemistry to natural aqueous systems. Light stable and unstable isotopic studies applied to aqueous systems. Prerequisite: DCGN209 or equivalent. 3 hours lecture; 3 semester hours.

GEGN520. INDUSTRIAL MINERALS AND ROCKS. 3.0 Semester Hrs.
Introduction to the Industrial Minerals industry via appreciation of geologic occurrence, physical and chemical material properties, mining and processing considerations, and marketing of various commodities. Development of skills in preparation of commodity surveys, reserves and resources classifications, and project appraisals. Required field trips to operational sites and trip reports. Mid-term and final exams. Individual student commodity term project and presentation. Prerequisite: Senior or graduate status in earth resources field. 3 hours lecture/seminar; 3 semester hours. Offered alternate years when student demand is sufficient.

GEGN527. ORGANIC GEOCHEMISTRY OF FOSSIL FUELS AND ORE DEPOSITS. 3.0 Semester Hrs.
(II) A study of organic carbonaceous materials in relation to the genesis and modification of fossil fuel and ore deposits. The biological origin of the organic matter will be discussed with emphasis on contributions of microorganisms to the nature of these deposits. Biochemical and thermal changes which convert the organic compounds into petroleum, oil shale, tar sand, coal, and other carbonaceous matter will be studied. Principal analytical techniques used for the characterization of organic matter in the geosphere and for evaluation of oil and gas source potential will be discussed. Laboratory exercises will emphasize source rock evaluation, and oil-source rock and oil-oil correlation methods. Prerequisite: CHGN221, GEGN438. 2 hours lecture; 3 hours lab; 3 semester hours. Offered alternate years.

GEGN530. CLAY CHARACTERIZATION. 2.0 Semester Hrs.
Equivalent with GEOL530.
(I) Clay mineral structure, chemistry and classification, physical properties (flocculation and swelling, cation exchange capacity, surface area and charge), geological occurrence, controls on their stabilities. Principles of X-ray diffraction, including sample preparation techniques, data collection and interpretation, and clay separation and treatment methods. The use of scanning electron microscopy to investigate clay distribution and morphology. Methods of measuring cation exchange capacity and surface area. Prerequisites: GEGN206. 1 hour lecture, 3 hours lab; 2 semester hours.

GEGN532. GEOLOGICAL DATA ANALYSIS. 3.0 Semester Hrs.
(II) Techniques and strategy of data analysis in geology and geological engineering: basic statistics review, analysis of data sequences, mapping, sampling and sample representativity, univariate and multivariate statistics, geostatistics, and geographic information systems (GIS). Practical experience with geological applications via supplied software and data sets from case histories. Prerequisite: MATH323 or MATH530. 3 hours lecture; 3 semester hours.

GEGN561. UNDERGROUND CONSTRUCTION ENGINEERING LABORATORY 1. 0.5 Semester Hrs.
(I) This course provides students with hands-on experience with tools and skills which are commonly used in the underground construction industry. Bi-weekly labs integrate with other courses in the field of Underground Construction and Tunnel Engineering. Co-requisites: CEEN513. 1.5 hours lab; 0.5 semester hours.

GEGN562. UNDERGROUND CONSTRUCTION ENGINEERING LABORATORY 2. 0.5 Semester Hrs.
(II) This course provides students with hands-on experience with tools and skills which are commonly used in the underground construction industry. Bi-weekly labs integrate with other courses in the field of Underground Construction and Tunnel Engineering. Co-requisites: MNGN504 or CEEN523. 1.5 hours lab; 0.5 hours.

GEGN563. APPLIED NUMERICAL MODELLING FOR GEOMECHANICS. 3.0 Semester Hrs.
(I) Course focuses on a comprehensive suite of numerical analysis techniques suited to geotechnical design with a focus on excavations in rock/soil and landslides. Finite element, finite difference, discrete/continuum plasticity, brittle fracture and discontinuum deformation are explored in detail. Projects involving real case histories are undertaken to highlight the application of and engineering judgment associated with numerical analysis for problems involving rockmasses. Prerequisites: GEGN468, MNGN321 or CEEN312. 3 hours lecture; 3 semester hours.

GEGN570. CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY. 3.0 Semester Hrs.
(I) Case histories in geological and geotechnical engineering, ground water, and waste management problems. Students are assigned problems and must recommend solutions and/or prepare defendable work plans. Discussions center on the role of the geological engineer in working with government regulators, private-sector clients, other consultants, and other special interest groups. Prerequisite: GEGN467, GEGN468, GEGN469, GEGN470. 3 hours lecture; 3 semester hours.

GEGN571. ADVANCED ENGINEERING GEOLOGY. 3.0 Semester Hrs.
(I) Emphasis will be on engineering geology mapping methods, and geologic hazards assessment applied to site selection and site assessment for a variety of human activities. Prerequisite: GEGN468 or equivalent. 2 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years.
GEGN573. GEOLOGICAL ENGINEERING SITE INVESTIGATION. 3.0 Semester Hrs.
(I) Methods of field investigation, testing, and monitoring for geotechnical and hazardous waste sites, including: drilling and sampling methods, sample logging, field testing methods, instrumentation, trench logging, foundation inspection, engineering stratigraphic column and engineering soils map construction. Projects will include technical writing for investigations (reports, memos, proposals, workplans). Class will culminate in practice conducting simulated investigations (using a computer simulator). 3 hours lecture; 3 semester hours.

GEGN575. APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS. 3.0 Semester Hrs.
(II) An introduction to Geographic Information Systems (GIS) and their applications to all areas of geology and geological engineering. Lecture topics include: principles of GIS, data structures, digital elevation models, data input and verification, data analysis and spatial modeling, data quality and error propagation, methods of GIS evaluation and selection. Laboratories will use Macintosh and DOS-based personal computer systems for GIS projects, as well as video-presentations. Visits to local GIS laboratories, and field studies will be required. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN578. GIS PROJECT DESIGN. 1-3 Semester Hr.
(I, II) Project implementation of GIS analysis. Projects may be undertaken by individual students, or small student teams. Documentation of all project design stages, including user needs assessment, implementation procedures, hardware and software selection, data sources and acquisition, and project success assessment. Various GIS software may be used; projects may involve 2-dimensional GIS, 3-dimensional subsurface models, or multi-dimensional time-series analysis. Prerequisite: none. Variable credit, 1-3 semester hours, depending on project. Offered on demand.

GEGN580. APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES. 3.0 Semester Hrs.
(I) This course offers an introduction to remote sensing in general and radar remote sensing and optical remote sensing in specific as well as their applications to all areas of geotechnical engineering and geosciences. Lecture topics include: principles SAR (Synthetic Aperture Radar) and InSAR (Interferometry of Synthetic Aperture Radar) and their applications, as well as basic concepts of optical remote sensing and its application in geoengineering and geosciences. Topics include various sensors and platforms of SAR data acquisition, SAR data access, SAR data processing, data acquisition and processing of optical remote sensing images. Prerequisites: Graduate standing. 2 hours lecture, 3 hours lab, 3 semester hours.

GEGN581. ANALYTICAL HYDROLOGY. 3.0 Semester Hrs.
Equivalent with GEGN481.
(I) Introduction to the theory, and hydrological application of, probability, statistics, linear algebra, differential equations, numerical analysis, and integral transforms. The course will require more challenging assignments and exams commensurate with graduate credit. Prerequisites: GEGN467. 3 hours lecture; 3 semester hours.

GEGN582. INTEGRATED SURFACE WATER HYDROLOGY. 3.0 Semester Hrs.
Equivalent with ESGN582.
(I) This course provides a quantitative, integrated view of the hydrologic cycle. The movement and behavior of water in the atmosphere (including boundary layer dynamics and precipitation mechanisms), fluxes of water between the atmosphere and land surface (including evaporation, transpiration, precipitation, interception and throughfall) and connections between the water and energy balances (including radiation and temperature) are discussed at a range of spatial and temporal scales. Additionally, movement of water along the land surface (overland flow and snow dynamics) and in the subsurface (saturated and unsaturated flow) as well as surface-subsurface exchanges and runoff generation are also covered. Finally, integration and connections within the hydrologic cycle and scaling of river systems are discussed. Prerequisites: Groundwater Engineering (GEGN466/GEGN467), Fluid Mechanics (GEGN351/EGGN351), math up to differential equations, or equivalent classes. 3 hours lecture; 3 semester hours.

GEGN583. MATHEMATICAL MODELING OF GROUNDWATER SYSTEMS. 3.0 Semester Hrs.
(II) Lectures, assigned readings, and direct computer experience concerning the fundamentals and applications of finite-difference and finite-element numerical methods and analytical solutions to ground water flow and mass transport problems. Prerequisite: A knowledge of FORTRAN programming, mathematics through differential and integral calculus, and GEGN467. 3 hours lecture; 3 semester hours.

GEGN584. FIELD METHODS IN HYDROLOGY. 3.0 Semester Hrs.
(I) Design and implementation of tests that characterize surface and subsurface hydrologic systems, including data logger programming, sensor calibration, pumping tests, slug tests, infiltration tests, stream gauging and dilution measurements, and geophysical (EM, resistivity, and/or SP) surveys. Prerequisites: Groundwater Engineering (GEGN466/GEGN467), Surface Water Hydrology (ESGN582) or equivalent classes. 2 hours lecture; 5 hours lab and field exercises one day of the week. Days TBD by instructor; 3 semester hours.

GEGN585. FLUID MECHANICS FOR HYDROLOGY. 2.0 Semester Hrs.
(I) This class focuses on the fundamental concepts of engineering fluid mechanics as they relate to the study of hydrology. Topics include fluid statics, dynamics, continuity, energy and momentum, dimensional analysis and open channel flow. 2 hours lecture; 2 semester hours.

GEGN586. NUMERICAL MODELING OF GEOCHEMICAL SYSTEMS. 3.0 Semester Hrs.
(II) This course provides quantitative methods for evaluating the geochemical characteristics of geological systems. The course is project based with lectures to provide information about the topic and use of geochemical modeling software. Student projects consist of chemical speciation of waters, activity diagrams, reaction progress models, water-rock interactions, sorption and surface complexation, and kinetic mineral reactions. Students complete an individual project on the geochemical system of their choice and present it to the class. Prerequisite: CEEN550 or CHGC509. 3 hours lecture, 3 semester hours. Offered spring semester, odd years.

GEGN598. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING. 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.
GEGN599. INDEPENDENT STUDY IN ENGINEERING GEOLOGY OR ENGINEERING HYDROGEOLOGY. 0.5-6 Semester Hrs.
(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.

GEGN669. ADVANCED TOPICS IN ENGINEERING GEOLOGY. 1-2 Semester Hr.
(I, II) Review of current literature and research regarding selected topics in engineering geology. Group discussion and individual participation. Guest speakers and field trips may be incorporated into the course. Prerequisite: none. 1 to 2 semester hours; may be repeated for credit.

GEGN670. ADVANCED TOPICS IN GEOLOGICAL ENGINEERING. 3.0 Semester Hrs.
(I, II) Review of current literature and research regarding selected topics in engineering geology. Group discussion and individual participation. Guest speakers and field trips may be incorporated into the course. Prerequisite: none. 3 hours lecture; 3 semester hours. Repeatable for credit under different topics.

GEGN671. LANDSLIDES: INVESTIGATION, ANALYSIS & MITIGATION. 3.0 Semester Hrs.
(I) Geological investigation, analysis, and design of natural rock and soil slopes and mitigation of unstable slopes. Topics include landslide types and processes, triggering mechanisms, mechanics of movements, landslide investigation and characterization, monitoring and instrumentation, soil slope stability analysis, rock slope stability analysis, rock fall analysis, stabilization and risk reduction measures. Prerequisites: GEGN468, EGGN361, MNGN321, (or equivalents). 3 hours lecture; 3 semester hours.

GEGN672. ADVANCED GEOTECHNICS. 3.0 Semester Hrs.
Practical analysis and application of techniques in weak rock engineering, ground-water control in construction, fluvial stabilization and control, earthquake hazard assessment, engineering geology in construction, engineering geology in dam investigation, and other current topics in geotechnics practice. Prerequisite: GEGN468, CEEEN312, CEEEN312L and MNGN321. 3 hours lecture; 3 semester hours. Offered alternate years.

GEGN673. ADVANCED GEOLOGICAL ENGINEERING DESIGN. 3.0 Semester Hrs.
(II) Application of geological principles and analytical techniques to solve complex engineering problems related to geology, such as mitigation of natural hazards, stabilization of earth materials, and optimization of construction options. Design tools to be covered will include problem solving techniques, optimization, reliability, maintainability, and economic analysis. Students will complete independent and group design projects, as well as a case analysis of a design failure. 3 hours lecture; 3 semester hours. Offered alternate years.

GEGN681. VADOSE ZONE HYDROLOGY. 3.0 Semester Hrs.
(II) Study of the physics of unsaturated groundwater flow and contaminant transport. Fundamental processes and data collection methods will be presented. The emphasis will be on analytic solutions to the unsaturated flow equations and analysis of field data. Application to non-miscible fluids, such as gasoline, will be made. The fate of leaks from underground tanks will be analyzed. Prerequisites: GEGN467 or equivalent; Math through Differential Equations. 3 hours lecture; 3 semester hours.

GEGN682. FLOW AND TRANSPORT IN FRACTURED ROCK. 3.0 Semester Hrs.
(I) Explores the application of hydrologic and engineering principles to flow and transport in fractured rock. Emphasis is on analysis of field data and the differences between flow and transport in porous media and fractured rock. Teams work together throughout the semester to solve problems using field data, collect and analyze field data, and do independent research in flow and transport in fractured rock. Prerequisites: GEGN581. 3 hours lecture; 3 credit hours. Offered alternate years.

GEGN683. ADVANCED GROUND WATER MODELING. 3.0 Semester Hrs.
(II) Flow and solute transport modeling including: 1) advanced analytical modeling methods; 2) finite elements, random-walk, and method of characteristics numerical methods; 3) discussion of alternative computer codes for modeling and presentation of the essential features of a number of codes; 4) study of selection of appropriate computer codes for specific modeling problems; 5) application of models to ground water problems; and 6) study of completed modeling projects through literature review, reading and discussion. Prerequisite: GEGN509/CHGC509 or GEGN583. 2 hours lecture, 3 hours lab; 3 semester hours.

GEGN698. 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.

GEGN699. INDEPENDENT STUDY IN ENGINEERING GEOLOGY OR ENGINEERING HYDROGEOLOGY. 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.

GEGN707. 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.

GEGX571. GEOCHEMICAL EXPLORATION. 3.0 Semester Hrs.
(I) Dispersion of trace metals from mineral deposits and their discovery. Laboratory consists of analysis and statistical interpretation of data of soils, stream sediments, vegetation, and rock in connection with field problems. Term report required. Prerequisite: none. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL501. APPLIED STRATIGRAPHY. 4.0 Semester Hrs.
(I) Review of basic concepts in siliciclastic and carbonate sedimentology and stratigraphy. Introduction to advanced concepts and their application to exploration and development of fossil fuels and stratiform mineral deposits. Modern facies models and sequence-stratigraphic concepts applied to solving stratigraphic problems in field and subsurface settings. Prerequisites: GEOL314 or equivalent. 3 hours lecture, 4 hours lab; 4 semester hours.
GEOL502. STRUCTURAL METHODS FOR SEISMIC INTERPRETATION. 3.0 Semester Hrs.
(I) A practical course that covers the wide variety of structural methods and techniques that are essential to produce a valid and coherent interpretation of 2D and 3D seismic reflection data in structurally complex areas. Topics covered include: Extensional tectonics, fold and thrust belts, salt tectonics, inversion tectonics and strike-slip fault systems. Laboratory exercises are based on seismic datasets from a wide variety of structural regimes from across the globe. The course includes a 4 day field trip to SE Utah. Prerequisite: GEOL309 and GEOL314 or GEOL315, or equivalents. 3 hours lecture/lab; 3 semester hours.

GEOL503. INTEGRATED GEOLOGICAL INTERPRETATION OF 3D SEismic DATA. 3.0 Semester Hrs.
(II) INTEGRATED GEOLOGICAL INTERPRETATION OF 3D SEISMIC DATA: A PRACTICAL COURSE IN SEISMIC INTERPRETATION OF GLOBAL DATASETS. A practical course in workstation based, integrated geological interpretation of 3D seismic reflection data. Course builds directly on the seismic interpretation skills learnt in the prerequisite GEOL502 Structural Methods for Seismic Interpretation. Key concepts developed in this course are: making internally consistent interpretations of complex 3D datasets and developing integrated geological (structural and stratigraphic) interpretations of 3D seismic data. Prerequisite: GEOL502. 3 hours lecture/lab; 3 semester hours.

GEOL505. ADVANCED STRUCTURAL GEOLOGY. 3.0 Semester Hrs.
(I) Advanced Structural Geology builds on basic undergraduate Structural Geology. Structures such as folds, faults, foliations, lineations and shear zones will be considered in detail. The course focuses on microstructures, complex geometries and multiple generations of deformation. The laboratory consists of microscopy, in-class problems, and some field-based problems. Prerequisites: GEGN307, GEOL309, GEOL316, GEOL321, or equivalents. 2 hours lecture, 2 hours lab, and field exercise; 3 semester hours.

GEOL512. MINERALOGY AND CRYSTAL CHEMISTRY. 3.0 Semester Hrs.
(I) Relationships among mineral chemistry, structure, crystallography, and physical properties. Systematic treatments of structural representation, defects, mineral stability and phase transitions, solid solutions, substitution mechanisms, and advanced methods of mineral identification and characterization. Applications of principles using petrological and environmental examples. Prerequisites: GEOL321, DCGN209 or equivalent. 2 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years.

GEOL513. HYDROTHERMAL GEOCHEMISTRY. 3.0 Semester Hrs.
Equivalent with CHGC513. (II) Geochemistry of high-temperature aqueous systems. Examines fundamental phase relationships in model systems at elevated temperatures and pressures. Major and trace element behavior during fluid-rock interaction. Theory and application of stable isotopes as applied to hydrothermal mineral deposits. Review of the origin of hydrothermal fluids and mechanisms of transport and deposition of ore minerals. Includes the study of the geochemistry of magmatic aqueous systems, geothermal systems, and submarine hydrothermal vents. Prerequisites: GEGN401. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOL514. BUSINESS OF ECONOMIC GEOLOGY. 3.0 Semester Hrs.
Examines the business side of mineral exploration including company structure, fundraising, stock market rules and regulations, and legal environment. Reviews the types of minerals exploration companies, differences between mineral sectors, rules and practices of listing a minerals company on a stock exchange, and legal requirements of listing and presenting data to stockholders. The course is centered on lectures by industry representatives from the Denver area. Includes participation in a technical conference in Vancouver or Toronto and meetings with lawyers, stockbrokers, and geoscientists working in the mineral industry. Prerequisites: GEGN401. 3 hours lecture and seminar; 3 semester hours. Offered alternate years when student demand is sufficient.

GEOL515. ADVANCED MINERAL DEPOSITS. 3.0 Semester Hrs.
(I) Geology of mineral systems at a deposit, district, and regional scale formed by magmatic-hydrothermal, sedimentary/basinal, and metamorphic processes. Emphasis will be placed on a systems approach to evaluating metal and sulfur sources, transportation paths, and traps. Systems examined will vary by year and interest of the class. Involves a team-oriented research project that includes review of current literature and laboratory research. Prerequisites: GEGN401. 1 hour lecture, 5 hours lab; 3 semester hours. Repeatable for credit.

GEOL517. FIELD METHODS FOR ECONOMIC GEOLOGY. 3.0 Semester Hrs.
(I) Methods of field practices related to mineral exploration and mining. Lithology, structural geology, alteration, and mineralization vein-type precious metal deposits. Mapping is conducted both underground at the Edgar Test Mine and above ground in the Idaho Springs area. Drill core and rock chips from different deposit types are utilized. Technical reports are prepared for each of four projects. Class is run on Saturday (9 am-4 pm) throughout the semester. Prerequisites: GEGN401. 6 hours lab and seminar; 3 semester hours. Offered alternate years when student demand is sufficient.

GEOL518. MINERAL EXPLORATION. 3.0 Semester Hrs.
(II) Mineral industry overview, deposit economics, target selection, deposit modeling, exploration technology, international exploration, environmental issues, program planning, proposal development. Team development and presentation of an exploration proposal. Prerequisite: GEOL515, GEOL520, or equivalent. 2 hours lecture/seminar, 3 hours lab; 3 semester hours. Offered when student demand is sufficient.

GEOL519. ABIṬĪBI GEOLOGY AND EXPLORATION FIELD SCHOOL. 3.0 Semester Hrs.
(II, S) Methods of field practices related to mineral exploration and mining. Regional and deposit-scale geology of Archean mineral deposits, including lode gold deposits and volcanic-hosted massive sulfide deposits. Includes mineral prospect evaluation, structural geology, geophysical volcanology, deposit definition, alteration mapping, mining methods, ore processing, and metallurgy. Core logging, underground stope mapping, open pit mapping, lithogeochemical sampling, and field-analytical techniques. Course involves a seminar in the spring semester that focuses on the geology and deposit types in the area to be visited. An intense 14-day field trip is run in the summer semester. Each day includes up to 4 hours of instruction in the field and 4 hours of team-oriented field exercises. Prerequisites: none. 6 hours lab and seminar; 2 semester hours in spring, 1 semester hour in summer. Offered alternate years when student demand is sufficient.
GEOL520. NEW DEVELOPMENTS IN THE GEOLOGY AND EXPLORATION OF ORE DEPOSITS. 3.0 Semester Hrs.
(I, II) Each topic unique and focused on a specific mineral deposit type or timely aspects of economic geology. Review of the geological and geographic setting of a specific magmatic, hydrothermal, or sedimentary mineral deposit type. Detailed study of the physical and chemical characteristics of selected deposits and mining districts. Theory and application of geological field methods and geochemical investigations. Includes a discussion of genetic models, exploration strategies, and mining methods. Prerequisites: GEGN401. 2 hours lecture; 2 semester hours. Repeatable for credit.

GEOL521. FIELD AND ORE DEPOSIT GEOLOGY. 3.0 Semester Hrs.
(I, S) Field study of major mineral deposit districts inside and outside of the USA. Examines regional and deposit-scale geology. Underground and open pit mine visits and regional traverses. Topics addressed include deposit definition, structural geology, alteration mapping, mining methods, and ore processing. Course involves a seminar in the spring semester that focuses on the geology and deposit types in the area to be visited. An intense 10-14 day field trip is run in the summer semester. Prerequisites: none. 6 hours lab and seminar; 2 semester hours in spring, 1 semester hour in summer. Offered alternate years when student demand is sufficient. Repeatable for credit.

GEOL522. TECTONICS AND SEDIMENTATION. 3.0 Semester Hrs.
(II) Application and integration of advanced sedimentologic and stratigraphic concepts to understand crustal deformation at a wide range of spatial- and time-scales. Key concepts include: growth-strata analysis, interpretation of detrital composition (conglomerate unroofing sequences and sandstone provenance trends), paleocurrent deflection and thinning trends, tectonic control on facies distribution and basic detrital zircon and fission track analysis. Students will read a wide range of literature to explore the utility and limitation of traditional "tectonic signatures" in stratigraphy, and will work on outcrop and subsurface datasets to master these concepts. Special attention is paid to fold-thrust belt, extensional and salt-related deformation. The course has important applications in Petroleum Geology, Geologic Hazards, and Hydrogeology. Required: 2-3 fieldtrips, class presentations, and a final paper that is written in a peer-reviewed journal format. Prerequisites: GEOL314 or equivalent, and GEOL309 or equivalent. 3 hours lecture and seminar; 3 semester hours. Offered even years.

GEOL523. REFLECTED LIGHT AND ELECTRON MICROSCOPY. 2.0 Semester Hrs.
(I) Theoretical and practical aspects of reflected light and electron microscopy. Microscopy will be placed on applications to ore deposit exploration and research. Lecture and discussion topics will highlight both standard and new techniques and instrumentation including SEM and QEMSCAN, as well as key questions in mineral deposit genesis which can be addressed using reflected light and electron microscopy. Includes detailed study of a selected suite of samples, with emphasis on mineral identification, textural relationships, paragenetic sequences, and mineral chemistry. Course culminates in a project. Prerequisites: GEGN401. 1 hour lecture; 3 hours lab; 2 semester hours.

GEOL525. PRINCIPLES OF METAMORPHIC GEOLOGY. 3.0 Semester Hrs.
(I) Study of metamorphic processes and products that occur on Earth at the micro- to the macro-scale. Areas of focus include (a) the nature of metamorphism in subduction zones and continental interiors, (b) the mechanisms and physico-chemical effects of fluid-rock and melt-rock interactions, (c) links between metamorphism and ore-forming processes, and (d) combining metamorphism with geochemistry, isotope geochronology, and structural geology to quantify the tectonothermal evolution of the lithosphere throughout space and time. Laboratory exercises emphasize the examination, identification, and interpretation of metamorphic minerals and microstructures in hand sample and down the microscope, and the calculation and application of thermodynamically constrained phase equilibria to describe and predict the pressure-temperature evolution of rocks and terranes. Short field excursions to local sites of metamorphic interest. Offered every other year. Prerequisites: GEOL321 and GEGN307. 2 hours lecture; 3 hours lab; 3 semester hours.

GEOL535. LITHO ORE FORMING PROCESSES. 3.0 Semester Hrs.
(I, II, S) Lithochemistry is the study of fluid-rock interaction in hydrothermal systems from a mineralogical perspective. Practical course on numerical modeling of fluid-rock interaction combined with observations of mineral assemblages in rocks and thin sections taking hydothermal ore deposits as test examples including pegmatites and veins, greisen alteration, porphyry systems and REE deposits. Mechanisms of metal complexation, transport and mineralization processes in hydrothermal fluids are connected to mineral alteration textures, mineral/rock geochemistry and mineral paragenesis. Includes a mine visit if available. Prerequisites: GEOL321, GEGN401. 2 hours lecture; 3 hours lab, 3 semester hours.

GEOL540. ISOPTOE GEOCHEMISTRY AND GEOCHRONOLOGY. 3.0 Semester Hrs.
(II) A study of the principles of geochronology and stable isotope distributions with an emphasis on the application of these principles to important case studies in igneous petrology and the formation of ore deposits. U, Th, and Pb isotopes, K-Ar, Rb-Sr, oxygen isotopes, hydrogen isotopes, and carbon isotopes included. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered alternate years.

GEOL550. INTEGRATED BASIN MODELING. 3.0 Semester Hrs.
(I) This course introduces students to principal methods in computer-based basin modeling: structural modeling and tectonic restoration; thermal modeling and hydrocarbon generation; and stratigraphic modeling. Students apply techniques to real data set that includes seismic and well data and learn to integrate results from multiple approaches in interpreting a basin's history. The course is primarily a lab course. Prerequisite: none. A course background in structural geology, sedimentology/stratigraphy or organic geochemistry will be helpful. 1 hour lecture, 5 hours labs; 3 semester hours.

GEOL551. APPLIED PETROLEUM GEOLOGY. 3.0 Semester Hrs.
(II) Subjects to be covered include computer subsurface mapping and cross sections, petrophysical analysis of well data, digitalizing well logs, analyzing production decline curves, creating hydrocarbon-porosity-thickness maps, volumetric calculations, seismic structural and stratigraphic mapping techniques, and basin modeling of hydrocarbon generation. Students are exposed to three software packages used extensively by the oil and gas industry. Prerequisite: GEGN438 or GEOL609. 3 hours lecture; 3 semester hours.
GEOL552. UNCONVENTIONAL PETROLEUM SYSTEMS. 3.0 Semester Hrs.
(I) Unconventional petroleum systems have emerged as a critical and
indispensable part of current US production and potential future reserves.
Each of the 5 unconventional oil and 4 unconventional gas systems will
be discussed: what are they, world wide examples, required technology
to evaluate and produce, environmental issues, and production/resource
numbers. The oil part of the course will be followed by looking at cores
from these systems. The gas part of the course will include a field
trip to the Denver, Eagle, and Piceance Basins in Colorado to see
outstanding outcrops of actual producing units. Prerequisites: GEGN438
or GEOL609, GEGN527. 3 hours lecture; 3 semester hours. Offered
alternate years.

GEOL553. GEOLOGY AND SEISMIC SIGNATURES OF RESERVOIR
SYSTEMS. 3.0 Semester Hrs.
(I) This course is a comprehensive look at the depositional models,
log signatures, characteristics, and seismic signatures for all the main
reservoirs we explore for and produce from in the subsurface. The first
half is devoted to the clastic reservoirs (12 in all); the second part to
the carbonate reservoirs (7 total). The course will utilize many hands-
on exercises using actual seismic lines for the various reservoir types.
Prerequisites: GEOL501 or GEOL314. 3 hours lecture; 3 semester hours.
Offered alternate years.

GEOL555. STRUCTURAL FIELD RESEARCH. 4.0 Semester Hrs.
(I) This course focuses on geological field work along the Colorado Front
Range through inquiry-based research and hypothesis-testing. The type
of problems students will work on will vary from more applied problems
(e.g. centered around the Edgar mine) or more academic/scientific
oriented problems, depending on the student’s interest. The class will
be split up in groups of students with similar interests. In the first part of
the course, we take an introductory two-day field trip, and students will
review existing literature and maps and write a brief research proposal
including hypotheses, tests and a work plan for the remainder of
the course. The second part of the course will focus on field work. During
the last part of the course, students prepare a geological map and
appropriate cross sections, and a report presenting rock descriptions,
structural analysis, a geological history, and interpretation of results in
the context of the hypotheses posed. Prerequisites: (need previous field
experience such as a field course, and a course in structural geology and
one in earth materials). 2 hours lecture, 6 hours lab; 4 semester hours.

GEOL560. IMPERIAL BARREL AAPG COMPETITION CLASS. 3.0
Semester Hrs.
(I) The course is designed for geoscience students to evaluate as a
team a geophysical and geological dataset. The data set consists of
seismic, well data, geochemical information, and geophysical logs. The
class provides students with an insight into the hydrocarbon exploration
business. A petroleum geology background is useful but not required.
A team will compete at the Rocky Mountain Section competition and go
onto the Annual American Association of Petroleum Geologist (AAPG)
meeting competition if they win the section competition. The class is
intended for graduate students only. 3 hours lecture; 3 semester hours.

GEOL565. RISKS AND VOLUMES ASSESSMENT FOR
CONVENTIONAL AND UNCONVENTIONAL PROSPECTS AND
PLAYS. 3.0 Semester Hrs.
(I) Students learn to translate geological knowledge into sound and
realistic numbers and ranges for consistent risk and volume assessment
of exploration prospects. Prerequisite: GEGN438. 3 hours lecture; 3
semester hours.

GEOL570. APPLICATIONS OF SATELLITE REMOTE SENSING. 3.0
Semester Hrs.
(I) 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.

GEOL575. PETROLEUM SYSTEMS ANALYSIS. 3.0 Semester Hrs.
(I, II) The goal is to learn how to analyze petroleum systems and use
tools of petroleum geochemistry and basin modeling to find, appraise
and produce oil and gas. Prerequisites: GEGN438. 3 hours lecture; 3
semester hours.

GEOL585. APPLICATION OF SEISMIC GEOMORPHOLOGY. 3.0
Semester Hrs.
(I) Seismic Geomorphology is the study of landforms imaged in 3-D
seismic data, for the purpose of understanding the history, processes
and fill architecture of a basin. This course will review both qualitative
and quantitative approaches to interpreting and applying seismic
geomorphologic observations in basin exploration and development.
Examples from Gulf of Mexico, Indonesia, Trinidad, Morocco, New
Zealand and other basins of the world will be used to illustrate the
techniques for interpreting the depositional elements of fluvial, deltaic,
shoreline, shelf, deep water clastic systems, as well as delineating
géohazards, and for quantifying and using those data to predict
reservoir distribution and architecture, body geometries, planning field
developments and assessing uncertainty. This introductory look at
the tool of seismic geomorphology is suitable for any geoscientists or
engineers looking to enhance their understanding of ancient depositional
systems imaged in seismic data. 3 hours lecture; 3 semester hours.

GEOL598. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING.
3.0 Semester Hrs.
(I, II) 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.

GEOL599. INDEPENDENT STUDY IN GEOLOGY. 0.5-6 Semester Hr.
(I, II) Individual research or special problem projects supervised
by a faculty member, also, when a student and instructor agree on a
subject matter, content, and credit hours. Prerequisite: ?Independent
Study? form must be completed and submitted to the Registrar. Variable
credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/
experience and maximums vary by department. Contact the Department
for credit limits toward the degree.

GEOL601. CORE TO OUTCROP STRATIGRAPHY. 2.0 Semester Hrs.
(I) A seminar series integrating core and outcrop observations with
class discussions. Topics range from global to regional scale tectono-
stratigraphy to process sedimentology. Discussions are based on reading
journal papers combined with core observations. Field trip encompasses
a series of outcrop-based projects/exercises. Prerequisite: GEOL501. 2
hours seminar; 2 semester hours.
GEOL608. HISTORY OF GEOLOGICAL CONCEPTS. 3.0 Semester Hrs.
(I) Lectures and seminars concerning the history and philosophy of the science of geology; emphasis on the historical development of basic geologic concepts. Course is an elective for doctoral candidates in department. 3 hours lecture; 3 semester hours.

GEOL609. ADVANCED PETROLEUM GEOLOGY. 3.0 Semester Hrs.
(II) Subjects to be covered include consideration of basic chemical, physical, biological and geological processes and their relation to modern concepts of oil/gas generation (including source rock deposition and maturation), and migration/accumulation (including that occurring under hydrodynamic conditions). Concepts will be applied to the historic and predictive occurrence of oil/gas to specific Rocky Mountain areas. In addition to lecture attendance, course work involves review of topical papers and solution of typical problems. Prerequisite: GEGN438. 3 hours lecture; 3 semester hours.

GEOL610. ADVANCED SEDIMENTOLOGY. 3.0 Semester Hrs.
(I) Keynote lectures, mixed with discussions, in-class exercises, core and field observations in a seminar series on sedimentology. Introduction to current hot topics in sedimentology, and discussions on fundamental principles. Specific topics vary yearly depending on most recent advancements and course participant? interests. Quantitative sedimentology. Applications of sedimentology. All seminars are based on reading and discussing journal papers. Field trip to a modern environment. Essays and presentations required. Prerequisite: GEOL501. Acceptable to take GEOL610 at the same time, as GEOL501. 3 hours lecture and seminar; 3 semester hours. Offered alternate years.

GEOL611. SEQUENCE STRATIGRAPHY IN SEISMIC, WELL LOGS, AND OUTCROP. 3.0 Semester Hrs.
(I) Keynote lectures and a seminar series on the sequence stratigraphy of depositional systems, including both siliciclastics and carbonates and how they behave in changing sea-level, tectonic subsidence, and sediment supply conditions. Application of sequence stratigraphy concepts to reflection seismic, well-log, and outcrop datasets. Field trip and report required. Prerequisite: GEOL501. Acceptable to take GEOL610 at the same time, as GEOL501. 3 hours lecture and seminar; 3 semester hours. Offered alternate years.

GEOL613. GEOLOGIC RESERVOIR CHARACTERIZATION. 3.0 Semester Hrs.
(I, II) Principles and practice of characterizing petroleum reservoirs using geologic and engineering data, including well logs, sample descriptions, routine and special core analysis and well tests. Emphasis is placed on practical analysis of such data sets from a variety of clastic petroleum reservoirs worldwide. These data sets are integrated into detailed characterizations, which then are used to solve practical oil and gas field problems. Prerequisites: GEGN438, GEOL501, GEOL505 or equivalents. 3 hours lecture; 3 semester hours.

GEOL617. THERMODYNAMICS AND MINERAL PHASE EQUILIBRIA. 3.0 Semester Hrs.
(I) Basic thermodynamics applied to natural geologic systems. Evaluation of mineral-vapor mineral solution, mineral-melt, and solid solution equilibria with special emphasis on oxide, sulfide, and silicate systems. Experimental and theoretical derivation, use, and application of phase diagrams relevant to natural rock systems. An emphasis will be placed on problem solving rather than basic theory. Prerequisite: DCGN209 or equivalent. 3 hours lecture; 3 semester hours. Offered alternate years.
GEOL653. CARBONATE DIAGENESIS AND GEOCHEMISTRY. 3.0 Semester Hrs.
(II) Petrologic, geochemical, and isotopic approaches to the study of
diagenetic changes in carbonate sediments and rocks. Topics covered
include major near-surface diagenetic environments, subaerial exposure,
dolomitization, burial diagenesis, carbonate aqueous equilibria, and
the carbonate geochemistry of trace elements and stable isotopes.
Laboratory stresses thin section recognition of diagenetic textures
and fabrics, x-ray diffraction, and geochemical/isotopic approaches to
diagenetic problems. Prerequisites: GEOL624. 2 hours lecture; 3 hours
lab; 3 semester hours.

GEOL660. CARBONATE RESERVOIRS - EXPLORATION TO
PRODUCTION ENGINEERING. 3.0 Semester Hrs.
Equivalent with PEGN660,
(II) An introduction to the reservoir characterization of carbonate rocks,
including geologic description, petrophysics, and production engineering.
Develops an understanding of the integration of geology, rock physics,
and engineering to improve reservoir performance. Application of
reservoir concepts in hands-on exercises that include reflection seismic,
well-log, and core data. 3 hours lecture; 3 semester hours.

GEOL698. 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.

GEOL699. INDEPENDENT STUDY IN GEOLOGY. 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.

GEOL707. 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.