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 DETAILS FOR 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. 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 Doctor of Philosophy (Geology) academic program requires a minimum of 72 hours of course and research credit hours (a maximum of 9 credit hours may be 400-level course work). At least 24 of the hours must be research credit hours and at least 36 must be 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 (up to 24 of these semester hours can come from previous graduate-level course work). The specific courses and total number of hours that may transfer are at the discretion of the student's Doctoral Thesis Advisory Committee.

All Doctor of Philosophy (Geology) students must pass a comprehensive examination, which is expected to be conducted immediately following the semester in which the required 36 course credit hours have been completed, and no later than by the end of the second year of their program. 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. 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 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. Students must also complete 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. A thesis proposal and course of study must be approved by the student's Doctoral Thesis Advisory Committee before the student begins substantial work on the thesis research.

Prerequisites for Geology Degrees
No specific pre-requisites are required for admission to the Geology Degree program. However, it is highly recommended that the candidates have the following courses prior to application:

- General Geology
- Field Geology or equivalent (6 weeks)
- Structural Geology
- Petrology
- Mineralogy
- Organic
- 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)

The student's committee will reserve the right to request that students complete additional identified courses prior to granting of a degree of Master of Science (Geology) or Doctor of Philosophy (Geology).

Program Details for Geological Engineering Degrees

The Master of Science (Geological Engineering) program requires 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. The degree includes three areas of specialization: engineering geology/geotechnics, groundwater engineering, and mining geological engineering. All Master of Science (Geological Engineering) 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 Doctor of Philosophy (Geological Engineering) academic program requires a minimum of 72 hours of course and research credit hours (a maximum of 9 credit hours may be 400-level course work). At least 24 of the hours must be research 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 (up to 24 of these semester hours can come from previous graduate-level course work). The specific courses and total number of hours that may transfer are at the discretion of the student’s Doctoral Thesis Advisory Committee.

All Doctor of Philosophy (Geological Engineering) students must pass a comprehensive examination by the end of the second year of their program. 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. Students must also complete appropriate thesis based upon original research they have conducted. A thesis proposal and course of study must be approved by the student's Doctoral Thesis Advisory Committee before the student begins substantial work on the thesis research.

Core Competencies for Geological Engineering Degrees
The candidate for the degree of Master of Science (Geological Engineering) or Doctor of Philosophy (Geological Engineering) must have completed the following or equivalent subjects prior to graduation. These may be satisfied through previous bachelors-level coursework or during the graduate program. Credit will only be granted for 400-level or graduate-level courses that are equivalent to the titles below.

Mathematics
- Calculus (two semesters)
- One semester in two of the following subjects:
  - 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
- Soil Mechanics
- Rock Mechanics
- One semester in two of the following subjects:
  - Physical Chemistry or Thermodynamics
  - Statics
  - Mechanics of Materials
  - Fluid Mechanics
  - Dynamics

Engineering Design
- Field Geology
- Engineering Geology
- Hydrogeology
- One semester in three of the following subjects:
  - Foundation Engineering
  - Engineering Hydrology
  - Geomorphology
  - Remote Sensing or GIS
  - Introductory Geophysics
  - Engineering Geology Design
  - Groundwater Engineering Design
  - Other engineering design courses as approved by the program committee

Program Requirements for Geological Engineering Degrees
In addition to the core competency requirements, the Master of Science or Doctor of Philosophy degrees with specialization in Engineering Geology/Geotechnics require:

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<tbody>
<tr>
<td>GEGN532</td>
<td>GEOLOGICAL DATA ANALYSIS</td>
<td>3.0</td>
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<tr>
<td>GEGN563</td>
<td>APPLIED NUMERICAL MODELLING FOR GEOMECHANICS</td>
<td>3.0</td>
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<tr>
<td>GEGN570</td>
<td>CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY</td>
<td>3.0</td>
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<tr>
<td>or GEGN573</td>
<td>ADVANCED GEOLOGICAL ENGINEERING DESIGN</td>
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<tr>
<td>GEGN573</td>
<td>GEOLOGICAL ENGINEERING SITE INVESTIGATION</td>
<td>3.0</td>
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<tr>
<td>GEGN575</td>
<td>APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS</td>
<td>3.0</td>
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<tr>
<td>or GEGN580</td>
<td>APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEO SCIENCES</td>
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<tr>
<td>GEGN671</td>
<td>LANDSLIDES: INVESTIGATION, ANALYSIS &amp; MITIGATION</td>
<td>3.0</td>
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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.

Program Details for Non-Thesis Masters of 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
undergraduate/graduate degree program by individuals already matriculated as undergraduate students at The Colorado School of Mines. The program is comprised of 24 hours of coursework and 6 hours of independent study (non-thesis project) for a total of 30 semester hours. Prerequisite requirements are the same as those listed for Geological Engineering degrees.

**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 Master of Engineering (Non-Thesis) Program in Geological Engineering. Courses that count towards the graduate degree requirements are defined below and may be used for the purposes of double counting at the discretion of the advisor (ME Non-Thesis). These courses must have been passed with a “B-” or better and meet all other University, Department, Division, and Program requirements for graduate credit.

Up to nine credit hours can be at the 400 level and the remainder will be 500 or 600 level. For the combined degree program, courses recommended as appropriate for double counting may be chosen from:

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<tr>
<td>GEGN403</td>
<td>MINERAL EXPLORATION DESIGN</td>
<td>3.0</td>
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<tr>
<td>GEGN439</td>
<td>MULTIDISCIPLINARY PETROLEUM DESIGN</td>
<td>3.0</td>
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<tr>
<td>GEGN469</td>
<td>ENGINEERING GEOLOGY DESIGN</td>
<td>3.0</td>
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<tr>
<td>GEGN470</td>
<td>GROUND-WATER ENGINEERING DESIGN</td>
<td>3.0</td>
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The typical program plan includes 12 course credit hours in both the fall and the spring terms followed by 6 independent study credit hours during the summer term.

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. 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. Some students may choose to take these prerequisites elsewhere before arriving on the Mines campus.

The Masters of Engineering (non-thesis) requires the following courses in addition to the prerequisites:

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<tr>
<td>GEGN532</td>
<td>GEOLOGICAL DATA ANALYSIS</td>
<td>3.0</td>
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<tr>
<td>GEGN599</td>
<td>INDEPENDENT STUDY</td>
<td>6.0</td>
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Candidates must also take at least three of the following:

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<tbody>
<tr>
<td>GEGN563</td>
<td>APPLIED NUMERICAL MODELLING FOR GEOMECHANICS</td>
<td>3.0</td>
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Electives and course substitutions are approved by the advisor. Possibilities for other electives include graduate-level rock mechanics and rock engineering, soil mechanics and foundations, ground water, site characterization, geographical information systems (GIS), project management and geophysics, for example.

**Program Details for Professional Master Degrees**

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.

**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 of coursework, and no research is required. 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.

**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.

**Professor and Department Head**  
Wendy Bohrson

**Professors**  
David A. Benson  
Zhaoshan Chang, Charles F. Fogarty Endowed Chair  
Wendy J. Harrison  
Reed M. Maxwell, Rowlinson Professor of Hydrology  
Alexei Milkov, Director of Potential Gas Agency  
Paul M. Santi  
Kamini Singha, Associate Department Head  
Stephen A. Sonnenberg, Charles Boettcher Distinguished Chair in Petroleum Geology  
Lesli J. Wood, Weimer Distinguished Chair

**Associate Professors**  
Yvette Kuiper  
Thomas Monecke, Co-Director of CMRS  
Alexis Navarre-Sitchler  
Piret Plink-Bjorklund  
Bruce Trudgill  
Wendy Zhou

**Assistant Professors**  
Alexander Gysi  
Richard M. Palin  
Danica Roth  
Gabriel Walton

**Teaching Professor**  
Christian V. Shorey

**Research Professors**  
Marsha French  
Richard Goldfarb  
Zane Jobe, Director of the Chevron Center of Research Excellence

David Leach  
J. Frederick (Rick) Sarg

**Research Assistant Professors**  
Mary Carr  
Nigel Kelly  
Katharina Pfaff  
Theresa Schwartz

**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  
Keith A. Turner  
John E. Warme  
Robert J. Weimer  
Richard F. Wendlandt

**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 alternate 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 geological and geotechnical engineering: basic statistics review, mapping, sampling and sample representativity, univariate and multivariate statistics, regression, hypothesis testing, cluster and discriminant analysis, principal component analysis, geostatistics. Practical experience in learning to write code in Matlab and use of data sets from case histories. Prerequisite: MATH323 or MATH350. 3 hours lecture; 3 semester hours.

GEGN542. ADVANCED ENGINEERING GEOMORPHOLOGY. 3.0 Semester Hrs.
(I, II, S) Application of Geomorphic principles to solve geological and geotechnical engineering problems, with an emphasis on incorporating GIS and remote sensing tools. Course will present in-depth analysis of specific landform classes and geologic processes, followed by application exercises. Topics will include analysis and hazard studies of erosion, landslides, neotectonics (recent faulting), stream restoration, rock weathering, dam removal, wildfire, and coastal issues. Prerequisite: GEGN203 and GEGN205, or equivalent introductory geomorphology course, or undergraduate degree in geoscience, GEGN468, GEGN475. 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 semester 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/solid and landslides. Finite element, finite difference, discrete/distinct element and boundary element methods are all discussed with hands-on application workshops using state-of-the-art geomechanics software. Analytical models and pre- and post-processing techniques suited to typical rock engineering problems are developed through assignments. Strength criteria and non-linear inelastic constitutive models for 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 simulations for 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.

GEGN579. PYTHON SCRIPTING FOR GEOGRAPHIC INFORMATION SYSTEMS. 3.0 Semester Hrs.
(I) Students will learn to use Python scripting with ArcGIS to perform common GIS tasks and to develop their own standalone Python scripts for GIS-based problem solving, automating repetitive or complex geoprocessing work flows, and preparing GIS-based maps. Specific topics include: (1) using Python for basic GIS tasks including field manipulation (e.g., adding, deleting, joining, or calculating fields), file manipulation (e.g., creating, deleting, moving, renaming files), and performing basic spatial analyses; (2) creating stand-alone Python scripts and tools; (3) Using the Python mapping module to control map elements in map layouts; and (4) problem solving to explore more advanced features of Python with ArcGIS. Prerequisite: EDNS264. 2 hours lecture, 3 hours lab; 3 semester hours.

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 geoenigineering 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 through fall) 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.

GEGN587. HYDROGEOCHEMICAL PROCESSES. 3.0 Semester Hrs.
(II) Analysis of the chemistry of natural waters in the context of hydrologic systems. The course focuses on sources and dynamic behavior of common natural and anthropogenically introduced solutes of interest, their interactions with minerals, and fate and transport in subsurface and surface environments. 3 hours lecture; 3 semester hours.

GEGN588. ADVANCED GEOGRAPHIC INFORMATION SYSTEMS. 3.0 Semester Hrs.
(I, II, S) This course offers spatial statistical methods in modeling and understanding the processes operating in spatial and temporal domains. The visualization (2D and 3D), exploration and modeling for discrete and continuous point data and aerial data are covered. Uni-variate and multivariate geospatial data analyses techniques are explained with their implementation for the selected case studies. Prerequisite: ENDS264 and GEGN432. 3 hours lecture; 3 semester hours.

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 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.

GEGN669. ADVANCED TOPICS IN ENGINEERING HYDROGEOLOGY. 1-2 Semester Hr.
(I, II) Review of current literature and research regarding selected topics in hydrogeology. 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.
(II) 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. 3 hours lecture; 3 semester hours. Prerequisite: GEGN468, EGGE561, MGNN321, (or equivalents).

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, CEEN312, CEEN312L and MGNN321. 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. 3 hours lecture; 3 credit hours. Prerequisite: GEGN581.

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.
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: GEOL307, GEOL309, GEOL316, GEOL321, or equivalents. 2 hours lecture, 2 hours lab, and field exercise; 3 semester hours.

GEOLS12. 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.

GEOLS13. 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: GEOL401. 2 hours lecture, 3 hours lab; 3 semester hours.

GEOLS14. 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.

GEOLS15. 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. 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.

GEGN98. 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.

GEGN99. 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.

GEGN07. 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 of and statistical interpretation of data of soils, stream sediments, vegetation, and rock in connection with field problems. Term report required. 2 hours lecture, 3 hours lab; 3 semester hours. Prerequisite: none.

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 laboratory consists of microscopy, in-class problems, and some field-based problems. Prerequisites: GEOL307, 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) 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. 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.

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: GEOL401. 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: GEOL401. 1 hour lecture, 5 hours lab; 3 semester hours. Repeatable for credit.

GEOL516. ADVANCED MINERAL DEPOSITS II. 3.0 Semester Hrs.
(S) Advanced Mineral Deposits II is a continuation of GEOL515. Emphasis will be placed on regional-scale geological studies of mineral deposits and potential mineral deposit types. Prerequisites: GEOL515. 3 hours lecture/lab; 3 semester hours.
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. 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 development, 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; 2 semester hours.

GEOL519. ABITIBI 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, physical 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. Prerequisite: 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. 2.0 Semester Hrs.
(I, II, S) 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. Prerequisite: GEGN401. 2 hours lecture; 2 semester hours.

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. Emphasis 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.

GEOL524. ECONOMIC GEOLOGY. 3.0 Semester Hrs.
(I) Provides an up-to-date synopsis of the geological settings and characteristics of the major types of magmatic, hydrothermal, and sedimentary metallic ore deposits. Emphasis is placed on the discussion of the source of metals, their transport, and the physical and chemical factors controlling the deposition of metallic ores in different geological environments. Exploration strategies are discussed for each deposit type. Laboratory consists of hand specimen study of host rock and ore mineral suites, optical microscopy, interpretation of phase diagrams, drill core logging, and open pit and underground field investigations. Lectures and laboratories are accompanied by assigned reading. 2 hours lecture; 3 hours lab; 3 semester hours. Prerequisite: Students attending should have a solid understanding of geology and must have received undergraduate training in mineralogy, petrology, and geochemistry. Familiarity with basic concepts of plate tectonics is required. Students also must have attended a field camp or must have equivalent field experience. Mineral identification skills in hand specimens are desirable.
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 geochemistry, 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 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) Lithogeochemistry 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 hydrothermal 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-ore geochronology and mineral paragenesis. Includes a mine visit if available. Prerequisites: GEOL321, GEGN401. 2 hours lecture; 3 hours lab, 3 semester hours.

GEOL540. ISOTOPIC 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, digitizing 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.
(II) 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.
(II) 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 orientated 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.
(II) The course is designed for geoscience students to evaluate as a team a geophysical and geological dataset. The date 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.
(II) 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, S) 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 geohazards, 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, 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.

GEOL599. 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.

GEOL601. CORE TO OUTCROP STRATIGRAPHY. 2.0 Semester Hrs.
(II) 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.
(I) Subjects to be covered involve 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. 3 hours lecture; 3 semester hours. Prerequisite: GEGN438.

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?s 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. 3 hours lecture and seminar; 3 semester hours.

GEOL613. GEOLOGIC RESERVOIR CHARACTERIZATION. 3.0 Semester Hrs.
(I) 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. 3 hours lecture; 3 semester hours. Prerequisite: GEGN438, GEOL501, GEOL505 or equivalents.

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.
GEOL621. PETROLOGY OF DETRITAL ROCKS. 3.0 Semester Hrs.
(I, II) Compositions and textures of sandstones, siltstones, and mudrocks. Relationship of compositions and textures of provenance, environment of deposition, and burial history. Development of porosity and permeability. Laboratory exercises emphasize use of petrographic thin sections, x-ray diffraction analysis, and scanning electron microscopy to examine detrital rocks. A term project is required, involving petrographic analysis of samples selected by student. Prerequisite: GEOL321 or equivalent. 2 hours lecture and seminar, 3 hours lab; 3 semester hours. Offered on demand.

GEOL624. CARBONATE SEDIMENTOLOGY AND PETROLOGY. 3.0 Semester Hrs.
(I) Processes involved in the deposition of carbonate sediments with an emphasis on Recent environments as analogs for ancient carbonate sequences. Carbonate facies recognition through bio- and lithofacies analysis, three-dimensional geometries, sedimentary dynamics, sedimentary structures, and facies associations. Laboratory stresses identification of Recent carbonate sediments and thin section analysis of carbonate classification, textures, non-skeletal and biogenic constituents, diagenesis, and porosity evolution. 2 hours lecture/seminar, 2 hours lab; 3 semester hours. Prerequisite: GEOL321 and GEOL314.

GEOL628. ADVANCED IGNEOUS PETROLOGY. 3.0 Semester Hrs.
(I) Igneous processes and concepts, emphasizing the genesis, evolution, and emplacement of tectonically and geochemically diverse volcanic and plutonic occurrences. Tectonic controls on igneous activity and petrochemistry. Petrographic study of igneous suites, mineralized and non-mineralized, from diverse tectonic settings. Prerequisites: GEOL321, GEGN206. 2 hours lecture, 3 hours lab; 3 semester hours. Offered alternate years.

GEOL642. FIELD GEOLOGY. 1-3 Semester Hr.
(S) Field program operated concurrently with GEGN316 field camp to familiarize the student with basic field technique, geologic principles, and regional geology of Rocky Mountains. Prerequisite: Undergraduate degree in geology and GEGN316 or equivalent. During summer field session; 1 to 3 semester hours.

GEOL643. GRADUATE FIELD SEMINARS. 1-3 Semester Hr.
(I, II, S) Special advanced field programs emphasizing detailed study of some aspects of geology. Normally conducted away from the Golden campus. Prerequisite: Restricted to Ph.D. or advanced M.S. candidates. Usually taken after at least one year of graduate residence. Background requirements vary according to nature of field study. Fees are assessed for field and living expenses and transportation. 1 to 3 semester hours; may be repeated for credit.

GEOL645. VOLCANOLOGY. 3.0 Semester Hrs.
(I, II, S) Assigned readings and seminar discussions on volcanic processes and products. Principal topics include pyroclastic rocks, craters and calderas, caldron subsidence, diatremes, volcanic domes, origin and evolution of volcanic magmas, and relation of volcanism to alteration and mineralization. Petrographic study of selected suites of lava and pyroclastic rocks in the laboratory. 1 hour seminar, 6 hours lab; 3 semester hours. Prerequisite: none.

GEOL653. CARBONATE DIAGENESIS AND GEOCHEMISTRY. 3.0 Semester Hrs.
(I) 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) 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) 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) 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.

SYGN588. GIS-BASED REAL WORLD LEARNING PROJECT. 1-6 Semester Hr.
(I, II) This course requires a GIS-based project and report that demonstrate competence in the application of GIS to real world problems. The project topic and content of the report is determined by the course instructor, in consultation with the student. The format of the report will follow the guidelines for a professional journal paper. Prerequisite: ENDS264 or equivalent. Variable credit: 1 to 6 credit hours. Repeatable for credit under different topics/experience and the cumulative maximum is 6 credit hours and 3 repeats total.