# 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 Engineering) (non-thesis)
- Professional Master's Degree (Mineral Exploration) (non-thesis)
- Graduate Certificate of Economic Geology
- Graduate Certificate of Exploration Methods

## 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 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.

Geoscience students may also choose among several interdisciplinary graduate programs comprised of faculty from several different Mines departments. The most common choices are Geochemistry, Hydrologic Science and Engineering, and Underground Construction and Tunnel Engineering. 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 credits of course and research credits. Twelve of the 36 credits 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 credits. At least 24 of the hours must be research credits and at least 36 must be course credits. Students who enter the PhD program with a thesis-based master's degree may transfer up to 36 credits in recognition of the coursework and research completed for that degree (up to 24 of these credits can come from previous graduate-level coursework). The specific courses and total number of hours that may transfer are at the discretion of the student's doctoral thesis advisory committee. All PhD (Geology) students must pass a comprehensive examination, which is expected to be conducted immediately following the semester in which the required 36 course credits 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.

**Core Competencies for Geology Degrees**

No specific prerequisites are required for admission to the Geology degree program. However, the following courses are identified as Core Competencies that are highly recommended for completion prior to application to the Geology Graduate Program:

- General Geology
- Field methods/ field camp
- Structural Geology
- Mineralogy
- Petrology
- Sedimentology/ Stratigraphy
- Chemistry (three semesters, including at least one semester of physical or organic)
- Mathematics (two semesters of calculus)
- An additional science course (other than geology) or advanced mathematics
- Physics (two semesters)

Generally speaking, if not satisfied through previous bachelor's-level coursework, the Core Competency requirements should be completed during the course of the **Master of Science (Geology) or Doctor of Philosophy (Geology)** program. Specific Core Competency requirements may be waived by the student's thesis committee.

## Program Details for Geological Engineering Degrees

**The Master of Science (Geological Engineering)** program requires 36 credits of course and research credits. 12 of the 36 credits must be research credits, and 24 of the credits must be earned through the completion of coursework. 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 credits. At least 24 of the hours must be research credits, and at least 24 of the hours must be earned through completion of coursework. Students who enter the PhD program with a thesis-based master's degree may transfer up to 36 credits in recognition of the coursework and research

completed for that degree (up to 24 of these credits can come from previous graduate-level coursework). 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 bachelor's-level coursework or during the graduate program. Credit will only be granted for 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:

| | | |
|---|---|---|
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| Candidates must also take at least three of the following: | | |
| GEGN563 | APPLIED NUMERICAL MODELLING FOR GEOMECHANICS | 3.0 |
| GEGN570 | CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY | 3.0 |
| or GEGN673 | ADVANCED GEOLOGICAL ENGINEERING DESIGN | |
| GEGN573 | GEOLOGICAL ENGINEERING SITE INVESTIGATION | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| or GEGN580 | APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES | |
| or GEGN568 | POINT CLOUD DATA ANALYSIS IN EARTH SCIENCE AND ENGINEERING | |
| GEGN671 | LANDSLIDES: INVESTIGATION, ANALYSIS & MITIGATION | 3.0 |

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 Master 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 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 credits. The Master of Engineering (Non-Thesis) Program in Geological Engineering has the same Core Competency requirements as the Geological Engineering Master of Science and Doctor of Philosophy degrees.

## Mines' Combined Undergraduate/Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program may double count up to 6 credits of graduate coursework to fulfill requirements of both their undergraduate and graduate degree programs. These courses must have been passed with B- or better, not be substitutes for required coursework, and meet all other university, department, and program requirements for graduate credit.

Students are advised to consult with their undergraduate and graduate advisors for appropriate courses to double count upon admission to the combined program.

The typical program plan includes 12 course credits in both the fall and the spring terms followed by 6 independent study credits 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.

In consultation with the advisor, the student 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 **Master of Engineering (non-thesis)** requires the following courses in addition to the Core Competencies:

| | | |
|---|---|---|
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN599 | INDEPENDENT STUDY | 6.0 |
| Candidates must also take at least three of the following: | | |
| GEGN563 | APPLIED NUMERICAL MODELLING FOR GEOMECHANICS | 3.0 |
| GEGN570 | CASE HISTORIES IN GEOLOGICAL ENGINEERING AND HYDROGEOLOGY | 3.0 |
| or GEGN673 | ADVANCED GEOLOGICAL ENGINEERING DESIGN | |
| GEGN573 | GEOLOGICAL ENGINEERING SITE INVESTIGATION | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| or GEGN580 | APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES | |
| or GEGN568 | POINT CLOUD DATA ANALYSIS IN EARTH SCIENCE AND ENGINEERING | |
| GEGN671 | LANDSLIDES: INVESTIGATION, ANALYSIS & MITIGATION | 3.0 |

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, groundwater, site characterization, geographical information systems (GIS), project management and geophysics, for example.

## Program Details for Graduate Certificates

## Certificate and Degree Requirements

We offer two graduate certificates and a professional master's degree (non-thesis). The courses taken for certificate degrees can be used toward the professional master's degree.

The Graduate Certificate Programs in Economic Geology and Exploration Methods outlined below may be completed by individuals already holding undergraduate or advanced degree in geology or a related field and have at least two to three years of professional experience. The programs are comprised of:

| | |
|---|---|
| Course Work | 12.0 Credits |
| Total Semester Hrs | 12.0 Credits |

**Graduate Certificate of Economic Geology**

Students working toward a Graduate Certificate of Economic Geology are required to take at least 6 credits out of the following courses; courses cannot be used in fulfilling the requirements of other certificates:

**Core courses:**

| | | |
|---|---|---|
| GEOL513 | HYDROTHERMAL GEOCHEMISTRY | 3.0 |
| GEOL521 | FIELD AND ORE DEPOSIT GEOLOGY | 3.0 |
| GEOL524 | ORE DEPOSIT MODELS AND EXPLORATION STRATEGIES | 3.0 |

Students working toward a Graduate Certificate of Economic Geology can choose up to 6 credits out of the following courses' courses cannot be used in fulfilling the requirements of other certificates:

**Electives:**

| | | |
|---|---|---|
| GEOL505 | ADVANCED STRUCTURAL GEOLOGY | 3.0 |
| GEOL520 | NEW DEVELOPMENTS IN THE GEOLOGY AND EXPLORATION OF ORE DEPOSITS | 2.0 |
| GEOL523 | REFLECTED LIGHT AND ELECTRON MICROSCOPY | 2.0 |
| GEOL628 | ADVANCED IGNEOUS PETROLOGY | 3.0 |
| GEOL645 | VOLCANOLOGY | 3.0 |
| CHGC503 | INTRODUCTION TO GEOCHEMISTRY | 3.0 |

## Graduate Certificate of Exploration Methods

Students working toward a Graduate Certificate of Economic Geology are required to take at least 6 credits out of the following courses; courses cannot be used in fulfilling the requirements of other certificates:

**Core courses:**

| | | |
|---|---|---|
| GEGX571 | GEOCHEMICAL EXPLORATION | 3.0 |
| GEOL520 | NEW DEVELOPMENTS IN THE GEOLOGY AND EXPLORATION OF ORE DEPOSITS | 2.0 |
| GEOL523 | REFLECTED LIGHT AND ELECTRON MICROSCOPY | 2.0 |
| GPGN598 | GEOPHYSICS FOR MINERAL EXPLORATION | 3.0 |

Students working toward a Graduate Certificate of Economic Geology can choose up to 6 credits out of the following courses; courses cannot be used in fulfilling the requirements of other certificates:

**Electives:**

| | | |
|---|---|---|
| GEGN501 | MINERAL DEPOSITS | |
| GEGN502 | MINERAL EXPLORATION DESIGN | |
| GEGN532 | GEOLOGICAL DATA ANALYSIS | 3.0 |
| GEGN575 | APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEGN588 | ADVANCED PLANETARY GEOGRAPHIC INFORMATION SYSTEMS | 3.0 |
| GEOL501 | APPLIED STRATIGRAPHY | 4.0 |
| GEOL514 | BUSINESS OF ECONOMIC GEOLOGY | 3.0 |
| GEOL521 | FIELD AND ORE DEPOSIT GEOLOGY | 3.0 |
| GEOL524 | ORE DEPOSIT MODELS AND EXPLORATION STRATEGIES | 3.0 |
| GEOL526 | PLATE TECTONICS | 3.0 |
| GEOL555 | STRUCTURAL FIELD RESEARCH | 4.0 |
| GEOL598 | SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING (Skarns and Related Deposits) | 3.0 |
| GEOL601 | CORE TO OUTCROP STRATIGRAPHY | 2.0 |
| MNGN510 | FUNDAMENTALS OF MINING AND MINERAL RESOURCE DEVELOPMENT | 3.0 |
| MNGN528 | MINING GEOLOGY | 3.0 |
| CHGC504 | METHODS IN GEOCHEMISTRY | 3.0 |

## Mines Combined Undergraduate/Graduate Program

Students enrolled in Mines combined undergraduate/graduate program may double count up to  credits of graduate coursework to fulfill requirements of both their undergraduate and graduate degree programs. These courses must have been passed with B- or better, not be substitutes for required coursework, and meet all other university, department, and program requirements for graduate credit.

Students are advised to consult with their undergraduate and graduate advisors for appropriate courses to double count upon admission to the combined program.

# 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's degree program is designed for working professionals who want to increase their knowledge and skills, while gaining a thorough update 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 credits of coursework, and no research is required. A minimum of 15 credits must be accumulated in five of the following core areas:

- Mineral Deposits,
- Mineral Exploration,
- Applied Geophysics,
- Applied Geochemistry,
- Applied Structural Geology,
- Petrology,
- Field Geology,
- Economic Evaluation.

An additional 15 credits 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. A maximum of 9 credits may be independent study focusing on a topic relevant to the mineral exploration and mining industries.

## Mines Combined Undergraduate/Graduate Program

Students enrolled in Mines combined undergraduate/graduate program may double count up to 6 credits of graduate coursework to fulfill requirements of both their undergraduate and graduate degree programs. These courses must have been passed with B- or better, not be substitutes for required coursework, and meet all other university, department, and program requirements for graduate credit.

Students are advised to consult with their undergraduate and graduate advisors for appropriate courses to double count upon admission to the combined program.

## Courses

**GEGN501. MINERAL DEPOSITS. 4.0 Semester Hrs.**
Introductory presentation of magmatic, hydrothermal, and sedimentary metallic ore deposits. Chemical, petrologic, structural, and sedimentological processes that contribute to ore formation. Description of classic deposits representing individual deposit types. Review of exploration sequences. Laboratory consists of hand specimen study of host rock-ore mineral suites and mineral deposit evaluation problems. Prerequisite: GEGN307, GEGN316.
**Course Learning Outcomes**

- Understand what economic geologists do (exploration and mining geologists).

- Understand the interface between geology and mining engineering, metallurgy, and environmental science).
- Understand the basic types of metallic mineral deposits through lectures, readings, and laboratory examination of samples.
- Enhance student's reading and writing skills.
- Enhance student's ability to solve mineral exploration problems utilizing geologic maps and cross sections.

**GEGN502. MINERAL EXPLORATION DESIGN. 3.0 Semester Hrs.**
Exploration project design: commodity selection, target selection, genetic models, alternative exploration approaches and associated costs, exploration models, property acquisition, and preliminary economic evaluation. Lectures and laboratory exercises to simulate the entire exploration sequence from inception and planning through implementation to discovery, with initial ore reserve calculations and preliminary economic evaluation. Prerequisite: GEGN501, GEGN475 (or concurrent enrollment).
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**GEGN508. ADVANCED ROCK MECHANICS. 3.0 Semester Hrs.**
Equivalent with MNGN418, Analytical and numerical modeling analysis of stresses and displacements induced around engineering excavations in rock. Insitu stress. Rock failure criteria. Complete load deformation behavior of rocks. Measurement and monitoring techniques in rock mechanics. Principles of design of excavation in rocks. Analytical, numerical modeling and empirical design methods. Probabilistic and deterministic approaches to rock engineering designs. Excavation design examples for shafts, tunnels, large chambers and mine pillars. Seismic loading of structures in rock. Phenomenon of rock burst and its alleviation. Prerequisite: MNGN321.
**Course Learning Outcomes**

- Identical to MNGN508 ADVANCED ROCK MECHANICS course

**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

- No change

**GEGN532. GEOLOGICAL DATA ANALYSIS. 3.0 Semester Hrs.**
(II) Techniques and strategy of data analysis in geology and geological 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. 3 hours lecture; 3 semester hours. Prerequisite: MATH201 or MATH530 and MATH 332 or equivalent.
**Course Learning Outcomes**

- 1) Demonstration of exemplary disciplinary expertise. 2) Demonstration of a set of professional skills necessary to succeed in a student's chosen career path.

**GEGN542. ADVANCED DIGITAL TERRAIN ANALYSIS. 3.0 Semester Hrs.**
Application of GIS and Remote Sensing principles to solve geoscience and geological engineering problems, with an emphasis on modeling and visualizing the surface of the Earth, performing analysis and support decision making for a variety of applications. Course will present in-depth analysis of specific digital terrain analysis techniques, followed by application exercises. Topics will include analysis and hazard studies of erosion, landslides, stream restoration, wildfire, and environmental issues.
**Course Learning Outcomes**

- Identification dominant geologic processes operating on an area and estimate the process rate, maturity of the resulting landscape, and the associated hazards and other impacts to infrastructure and natural resources
- Selection and application of analytical tools to interpret geomorphological data to provide quantitative assessment of processes, predict future landscape response, and assess hazard and risk
- Use GIS tools and remote sensing data to analyze landscape features and quantify hazards.

**GEGN561. UNDERGROUND CONSTRUCTION ENGINEERING LABORATORY. 1.0 Semester Hr.**
This course provides students with hands-on experience with tools and skills which are commonly used in the underground construction industry. Weekly labs integrate with other courses in the field of Underground Construction and Tunnel Engineering. Pre-requisites: Graduate standing in Underground Construction and Tunnel Engineering, Civil engineering, Mining engineering, or Geological Engineering.
**Course Learning Outcomes**

- Reinforce concepts learned in lecture courses
- Provide students with hands-on experience with common tools in the UC industry

**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/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.
**Course Learning Outcomes**

- Understand the fundamentals of various computation techniques
- Utilize numerical modelling software to solve geomechanics design problems
- Think critically about the practical strengths and limitations of different modelling approaches

**GEGN566. GROUNDWATER ENGINEERING. 3.0 Semester Hrs.**
(I) Theory of groundwater occurrence and flow. Relation of groundwater to surface water; hydraulic head distribution and flow; theory of aquifer tests; water chemistry, water quality, and contaminant transport. 3 hours lecture, 3 semester hours. Prerequisite: Calc III (MATH213 or MATH223) and DiffEQ (MATH225 or MATH235) and GEGN351 or MEGN351.
**Course Learning Outcomes**

- No changes to current class outcomes.

**GEGN568. POINT CLOUD DATA ANALYSIS IN EARTH SCIENCE AND ENGINEERING. 3.0 Semester Hrs.**
This course is intended to expose students to the fundamentals of point cloud data collection, processing and analysis. In-class exercises, homework assignments and readings will expose students to a broad array of earth science and geological engineering applications and provide hands-on experience with current academic/government/industry standard software. In consultation with the instructors, each student will design and implement a unique term project using point cloud data to advance their own research interests and goals.
**Course Learning Outcomes**

- 1)
- 2)
- 3)
- 4)

**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.
**Course Learning Outcomes**

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**GEGN571. ADVANCED ENGINEERING GEOLOGY. 3.0 Semester Hrs.**
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.
**Course Learning Outcomes**

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**GEGN572. ENGINEERING GEOLOGY AND GEOTECHNICS. 4.0 Semester Hrs.**
(I) Application of geology to evaluation of construction, mining, and environmental projects such as dams, water ways, tunnels, highways, bridges, buildings, mine design, and land-based waste disposal facilities. Design projects including field, laboratory, and computer analysis are an important part of the course. 3 hours lecture, 3 hours lab, 4 semester hours. Prerequisite: MNGN321, CEEN312, CEEN312L.
**Course Learning Outcomes**

- Describe key engineering properties and behaviors of commonly encountered geomaterials
- Recognize the key geological factors relevant to dam siting, foundation stability, earthquake hazards, tunnel design, and slope stability
- Identify which earth material behaviors and hazards are relevant to a given engineering geology design problem
- Assess the adequacy of different material characterization and technical analysis tools for investigation of a given engineering geology problem
- Analyze engineering geology problems using methods and tools commonly applied in industry
- Design solutions to mitigate geological risks associated with natural and man-made slopes and underground excavations in rock
- Concisely communicate data collection, data analysis, and design processes and results to a technical audience in written and oral formats using appropriate technical vocabulary and graphical aids

**GEGN573. GEOLOGICAL ENGINEERING SITE INVESTIGATION. 3.0 Semester Hrs.**
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).
**Course Learning Outcomes**

- No change

**GEGN575. APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS. 0-3 Semester Hr.**
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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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. 2 hours lecture, 3 hours lab; 3 semester hours.
**Course Learning Outcomes**

- See GEGN579_Syllabus_2019.

**GEGN580. APPLIED REMOTE SENSING FOR GEOENGINEERING AND GEOSCIENCES. 0-3 Semester Hr.**
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 geoengineering 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.
**Course Learning Outcomes**

- 1. Learn basic concepts and principals of SAR and InSAR through classroom lectures and lab exercises. These skills will be of importance in most geosciences and geoengineering careers that you will follow. 2. Learn basic optical remote sensing concepts and principals through classroom lectures and lab exercises. These skills will also be of importance in most geosciences and geoengineering careers that you will follow. 3. Learn and use many skills necessary for project design and planning, as well as ideas and means of facilitating problem solving in science/engineering projects.

**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.
**Course Learning Outcomes**

- To introduce the student to the analysis of many types of hydrologic data using the tools from several mathematics courses, including basic probability and statistics, linear algebra, differential equations, and numerical. The course is also designed to develop the analytic skills necessary to understand and quantify hydrologic processes and problems.
- The class is designed to meet the Hydrologic Science and Engineering admission prerequisite of one semester each of Differential Equations and Probability/Statistics.

**GEGN582. INTEGRATED SURFACE WATER HYDROLOGY. 3.0 Semester Hrs.**
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. 3 hours lecture; 3 semester hours.
**Course Learning Outcomes**

- .No change

**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.
**Course Learning Outcomes**

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**GEGN584. FIELD METHODS IN HYDROLOGY. 3.0 Semester Hrs.**
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, Integrated Surface Water Hydrology (GEGN582) or equivalent classes. 2 hours lecture; 5 hours lab and field exercises one day of the week. Days TBD by instructor; 3 semester hours.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

- 1. Students will solve problems on fundamental fluid mechanics concepts including hydrostatics, momentum, pressure and flow and energy systems.
- 2. Students will conduct simple dimensional analysis and explain its application to hydrologic research.
- 3. . Students will solve problems related to flow measurement, fluid properties, and fluid statics.
- 4. Students will solve problems related to energy, impulse, and momentum equations.
- 5. Students will solve problems related to pipe and other internal flow.
- 6. Student will explain (or demonstrate or predict or describe or evaluate) how fluid mechanics relates to hydrological systems.

**GEGN585L. INTRODUCTION TO COMPUTATIONAL METHODS IN HYDROLOGY. 1.0 Semester Hr.**
This 1-cr class is a computational lab for the lecture course GEGN/CEEN 585 (Fluid Mechanics for Hydrology). The lab may be taken alone if a Fluid Mechanics lecture course has already been taken. The lab introduces the student to computational platforms and concepts germane to Fluid Mechanics and many other sciences. We use Matlab, Python, and various parallel programming environments to solve problems that use numerical integration, finite-difference solutions of first- and second-order ODEs, random walks to solve advection/diffusion problems, and various statistical concepts. Applications include calculating pressure on a submerged surface, bacterial growth/decay, laminar flow and solute transport between plates, and gradually-varying flow in open channels. Prerequisite: Fluid Mechanics. Co-requisites: GEGN/CEEN 585 Fluid Mechanics for Hydrology.
**Course Learning Outcomes**

- • Design algorithms that can be implemented in modern programming environments including matlab, python, and fortran/openmp • Code useful programs for many different scientific applications, most notably surface water/groundwater hydrology. • Understand and apply concepts needed for parallel computing. • Present code that is readable and editable by others.

**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.
**Course Learning Outcomes**

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**GEGN587. HYDROCHEMICAL AND TRANSPORT 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.
**Course Learning Outcomes**

- 1. Evaluate the chemistry of groundwater and surface water samples
- 2. Understand the sources and behavior of common solute of interest in natural systems
- 3. Apply chemical reaction kinetic equations to evaluate the dynamic behavior of common solutes of interest in natural systems
- 4. Evaluate fate and transport of contaminants in surface water and groundwater systems.

**GEGN588. ADVANCED PLANETARY GEOGRAPHIC INFORMATION SYSTEMS. 3.0 Semester Hrs.**
(I, II, S) This course offers a unique opportunity to expand your knowledge and skills in the new and emerging field of planetary mapping and analysis. Upon completing this course, students will possess the knowledge and skills necessary to perform independent planetary GIS tasks, contributing to the advancement of planetary science and space exploration in the student's area of expertise. Throughout the course, we will learn about planetary GIS fundamentals, an overview of historical and contemporary remote sensing space missions, locating open source planetary GIS datasets, organizing GIS data, planetary mapping, geospatial analyses, and digital terrain modeling. We will explore these topics through class discussions, lab exercises, and peer reviews, culminating in an individual planetary GIS project that allows students to investigate a matter of their choosing in-depth. After completing this course, students can locate and integrate planetary GIS datasets for planetary mapping and space resource characterization. Prerequisite: GEGN575, GEGN542, or equivalent. Asynchronous online, 3.0 semester hours. Prerequisite: GEGN575, GEGN432, or equivalent.
**Course Learning Outcomes**

- See GEGN588_Syllabus_9_4_2018.docx

**GEGN590. GIS-BASED REAL WORLD LEARNING PROJECT I - FUNDAMENTALS. 1-6 Semester Hr.**
This course requires a GIS-based project and report that demonstrate competence in the application of GIS to real word 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. 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.
**Course Learning Outcomes**

- see SYGN588_Syllabus_8_30_2018.docx

**GEGN592. GIS-BASED REAL WORLD LEARNING PROJECT II - ADVANCED APPLICATIONS. 1-6 Semester Hr.**
This course requires a GIS-based project and report that demonstrate competence in the application of GIS to real word 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. 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.
**Course Learning Outcomes**

- see SYGN588_Syllabus-8_30_2018.docx

**GEGN598. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING. 0-6 Semester Hr.**
(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.

**GEGN598. SPECIAL TOPICS. 0-6 Semester Hr.**

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**GEGN598. SPECIAL TOPICS. 0-6 Semester Hr.**

**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.

**GEGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**

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**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.
**Course Learning Outcomes**

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**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. 3 hours lecture; 3 semester hours. Prerequisite: GEGN468, EGGN361, MNGN321, (or equivalents).
**Course Learning Outcomes**

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**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 MNGN321. 3 hours lecture; 3 semester hours. Offered alternate years.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**GEGN698. SPECIAL TOPICS. 0-6 Semester Hr.**
(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.
**Course Learning Outcomes**

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**GEGX571. GEOCHEMICAL EXPLORATION. 3.0 Semester Hrs.**
(II) 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. 2 hours lecture, 3 hours lab; 3 semester hours. Prerequisite: none.
**Course Learning Outcomes**

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**GEOL501. APPLIED STRATIGRAPHY. 0-4 Semester Hr.**
(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.
**Course Learning Outcomes**

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**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.

**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**GEOL504. UNCERTAINTY IN GEOSCIENCES. 3.0 Semester Hrs.**
In this fully online course you will learn to identify, assess and communicate uncertainty and bias in geosciences. This course provides pragmatic skills for uncertainty assessment and communication in industry and academia, with the aim to improve resource industry effectiveness and academic advancement of knowledge. The course includes video presentations from industry professionals and academics across the geological disciplines and industries. Learning methods are focused on projects, discussions and reflection.
**Course Learning Outcomes**

- After the successful completion of this course students will be able to: 1. identify and accept sources of uncertainty in geoscience 2. Synthesize the sources and types of uncertainties as linked to data collection, analyses and interpretation in different geoscience disciplines 3. Assess the effects of uncertainty in academic and industry settings, including the effects of uncertainty on the advancement of knowledge and the effectiveness of resource industry 4. Critique uncertainty assessment, or the lack thereof, in industry and academic applications 5. Apprise solutions for reducing uncertainty as related to uncertainty types and sources 6. Design uncertainty assessment and reduction strategies that are relevant for your professional or academic discipline 7. Communicate uncertainty to a wide range of audiences clearly and effectively

**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, GEGN316, GEOL321, or equivalents. 2 hours lecture, 2 hours lab, and field exercise; 3 semester hours.
**Course Learning Outcomes**

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**GEOL508. SKARNS AND RELATED DEPOSITS. 3.0 Semester Hrs.**
Skarn deposits are one of the most common deposit types in the world. They are the largest source of W and Sn, and also a significant source of Au, Ag, B, Cu, Fe, Mo, Pb, Zn, Pb, Mo, plus U, REE and other rare metals. This course will introduce to students all aspects of skarns and skarn deposits, including the geological features (e.g., geological context, host rock packages, alteration assemblages, mineralization styles, paragenesis and zonations), formation processes and evolution (e.g., magma fertility, magma-hydrothermal transition, fluid composition, fluid-rock reactions, plus metal sources, transportation, deposition and enrichment), investigation and research methods, the relationship between skarns and other types of deposits (porphyry, epithermal, carbonate replacement, Carlin type, SEDEX, MVT, VHMS, orogenic, and IOCG deposits), and exploration methods. The course has a significant lab/field skill component with representative skarn samples from all over the world and intensive hands-on training on skarn alteration-mineralization and texture recognization and interpretation, plus a field trip to one of the skarns in Colorado or nearby states. Prerequisites: GEGN307, GEGN316, GEGN401 and GEOL321.
**Course Learning Outcomes**

- Capacity to make accurate, efficient, and critical geological observations and document the observations into maps, cross-sections, and reports/publications. Be familiar with various field and laboratory tools and methods, and know what methods to use for what purposes. The objects of observation and documentation includes igneous rocks, wallrocks, alteration and mineralization mineralogy, texture, paragenesis, spatial zonation, ages of events, rock and mineral compositions (major + trace elements), isotopic features, spectral feature, and fluid properties. Be able to make sampling strategies and take samples for laboratory analyses and studies.
- Capacity to infer formation conditions based on the observations, including the temperature, pressure, redox state, pH, fluid source, fluid compositions, rock mechanical properties (brittle vs. ductile), conditions for fluid flow (e.g., rock permeability, potential fluid channel), and fluid-rock reactions.
- Capability of critical thinking to, based on the observations and inferred conditions, predict the architecture of the skarn system and estimate the position of orebodies, to reconstruct the formation processes, and/or to make hypotheses and design tests/further investigation to verify or reject the hypotheses.
- The course contributes to the program goals in enriching students with mineral deposit knowledge and understanding, and enhancing students' skills and capacities in mineral exploration, because skarn deposits are one of the most common and important deposit types in the world.

**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.
**Course Learning Outcomes**

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**GEOL513. HYDROTHERMAL GEOCHEMISTRY. 3.0 Semester Hrs.**
Equivalent with CHGC513,
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 or GEOL524.

**Course Learning Outcomes**

- No changes

**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.

**Course Learning Outcomes**

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**GEOL515. ADVANCED MINERAL DEPOSITS. 2.0 Semester Hrs.**
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 sources, transportation paths, and traps. The system examined will vary by year. Repeatable for credit.

**Course Learning Outcomes**

**GEOL517. DRILL CORE LOGGING FOR ECONOMIC GEOLOGY. 2.0 Semester Hrs.**
(I, II) Methods of diamond drill core logging related to mineral exploration. Documentation of lithology, alteration, structural geology, and mineralization. Drill core from different deposit types is utilized. Sampling strategies for geochemical analysis and rock quality designation are discussed. Participants prepare technical reports for each drill hole logged. 2 semester hours.

**Course Learning Outcomes**

- Methods of drill core logging related to mineral exploration.

**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.

**Course Learning Outcomes**

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**GEOL519. ORE DEPOSITS OF THE WESTERN US. 2.0 Semester Hrs.**
(I, II, S) Methods of field practices related to mineral exploration and mining. Regional and deposit-scale geology, including epithermal deposits and porphyry deposits. Includes mineral prospect evaluation, structural geology, physical volcanology, deposit definition, alteration mapping, mining methods, and ore processing. Core logging, mapping, lithogeochemical sampling, and mine visits. Course involves a seminar that focuses on the geology and deposit types in the area to be visited and an intense multi-day field trip. Each day in the field includes up to 4 hours of instruction and 4 hours of team-oriented field exercises. 2 semester hours.

**Course Learning Outcomes**

- Methods of field practices related to mineral exploration. Mineral prospect evaluation, structural geology, physical volcanology, deposit definition, alteration mapping, mining methods, and ore processing.

**GEOL520. NEW DEVELOPMENTS IN THE GEOLOGY AND EXPLORATION OF ORE DEPOSITS. 2.0 Semester Hrs.**
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.

**Course Learning Outcomes**

- Apply knowledge of geological field methods and investigations.

**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.

**Course Learning Outcomes**

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**GEOL522. TECTONICS AND SEDIMENTATION. 3.0 Semester Hrs.**
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.

**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

- n/a

**GEOL524. ORE DEPOSIT MODELS AND EXPLORATION STRATEGIES. 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.
**Course Learning Outcomes**

- 1. Have an understanding of fundamental principles of ore deposit genesis; 2. Will understand ore deposit classification; 3. Will understand which commodities are mined from which deposit types; 4. Will understand ore deposit models for the most important deposit types; 5. Will understand key phase diagrams required to explain the mineralogy of ore deposits and alteration halos; 6. Will have gained experience in drill core logging and underground mapping; 7. Will have better writing skills; 8. Will have been exposed to principles of ore deposit research; 9. Will understand the publication process and; 10. Will have gained insights into the exploration and mining industry.

**GEOL525. PRINCIPLES OF METAMORPHIC GEOLOGY. 3.0 Semester Hrs.**
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.
**Course Learning Outcomes**

- 1) Demonstration of exemplary disciplinary expertise. 2) Demonstration of a set of professional skills necessary to succeed in a student's chosen career path.

**GEOL526. PLATE TECTONICS. 3.0 Semester Hrs.**
Introduction to the theory of plate tectonics as a first-order framework with which the evolution of the Earth’s lithosphere in space and time may be described and understood. Key topics include plate boundaries, the mechanisms of mountain building, crustal growth and destruction, volcanism and seismicity in intraplate and plate-margin settings, and secular changes in plate tectonic processes and products over geological time. Formation of all rocks types (igneous, sedimentary, metamorphic) will be discussed in the context of plate tectonics. Other planets and planetary processes will be discussed and compared to Earth. Prerequisite: Basic geology knowledge; Consent from instructor.
**Course Learning Outcomes**

- Students will: 1. Explore geophysical techniques, to learn about the layers of the earth 2. Be able to reconstruct plate motions based on paleomagnetic data 3. Predict plate motions and tectonic processes based on current or given pate boundaries and their orientations, and plate velocities and directions 4. Interpret and predict processes at convergent, divergent and transform plate boundaries 5. Use seismic data to interpret fault motions during earthquakes 6. Debate when plate tectonics started on Earth 7. Explore other planets and interpret geologic processes from available imagery 8. Interpret and predict the relationship between plate tectonics, and earth resources, climate, life on earth and other relevant processes

**GEOL527. SWIR (SHORT WAVELENGTH INFRA-RED) SPECTRAL ANALYSIS. 1.0 Semester Hr.**
SWIR (Short Wavelength Infra-Red) spectral analysis is an efficient way to clay minerals and other minerals containing H2O, OH-, CO32-, and ammonia. The numerical spectral values are useful in inferring mineral compositions and formation conditions, plus revealing spatial trends, which helps to understand mineral deposits and facilitate mineral exploration. This course will train to students on how to use portable SWIR instruments to make measurements, then how to interpret the spectra to identify clay and other minerals containing H2O, OH-, CO32-, and ammonia, and to extract numerical values of spectral features, plus the geological implications of these values, and how to reveal spatial trends in those values. 0.7 hours lecture, 0.9 hours lab; 1 semester hour. Prerequisite: GEOL 321 Mineralogy and mineral characterization, GEGN401 Mineral Deposits. Co-requisite: NA.
**Course Learning Outcomes**

- Capacity to take measurements using SWIR instruments.
- Capacity to identify clay and other hydrous minerals and to extract numerical values of spectral features from SWIR spectra.
- Capacity to infer the geological implications (e.g., compositions and formation temperatures of certain minerals) and to reveal spatial trends.
- Graduate Profile

**GEOL528. MINING GEOLOGY. 3.0 Semester Hrs.**
Role of geology and the geologist in the development and production stages of a mining operation. Topics addressed: mining operation sequence, mine mapping, drilling, sampling, reserve estimation, economic evaluation, permitting, support functions. Field trips, mine mapping, data evaluation, exercises and term project. 2 hours lecture/seminar, 3 hours laboratory: 3 semester hours. Offered in even years.

**Course Learning Outcomes**

- No changes

**GEOL535. LITHO ORE FORMING PROCESSES. 1.0 Semester Hr.**
Lithogeochemistry is the study of fluid-rock interaction in hydrothermal systems from a mineralogical perspective. Practical 1 credit seminar course were we review mechanisms of metal complexation, transport and mineralization processes in hydrothermal fluids and how they are connected to mineral alteration textures, mineral/rock geochemistry and mineral paragenesis. Students will combine observations of mineral assemblages in rocks and thin sections, and geochemical data to link this knowledge to field observations. The tools provided by this course will enable students to recognize alteration types, establish a mineral paragenesis, and connect alteration features with geochemical changes in bulk rock and mineral chemistry in ore deposits. An extra day will be spent in the field to visit a historic mining district in Colorado. The seminar course comprise also discussions and readings of recent articles and a brief review of hydrothermal-(magmatic) ore deposits (e.g. Greisen alteration, epithermal and porphyry systems, REE and critical metal deposits in (per)alkaline systems, Pb-Zn MVT type deposits). Prerequisite: GEOL321, GEGN401.
**Course Learning Outcomes**

- Present and critically examine research articles.
- Predict mineral stabilities and metal transport in hydrothermal fluids using the program GEM-Selektor.
- Recognize rock alteration types and establish a mineral paragenesis for different ore deposits.
- Interpret geochemical changes in bulk rock and mineral chemistry.
- Analyze results from mineral and bulk rock chemical data.
- Write reports and critically evaluate results from numerical modeling.

**GEOL540. ISOTOPE 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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**GEOL551. APPLIED PETROLEUM GEOLOGY. 3.0 Semester Hrs.**
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.
**Course Learning Outcomes**

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**GEOL552. UNCONVENTIONAL PETROLEUM SYSTEMS. 3.0 Semester Hrs.**
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.
**Course Learning Outcomes**

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**GEOL553. GEOLOGY AND SEISMIC SIGNATURES OF RESERVOIR SYSTEMS. 3.0 Semester Hrs.**
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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**GEOL556. VIRTUAL STRUCTURAL FIELD MAPPING. 1.0 Semester Hr.**
This exercise takes students to Rhoscolyn, Anglesey, NW Wales, virtually. Students acquire some of the interpretative and associated technique-oriented skills involved via a 'virtual approach' that exploits traditional photography and modern computer ('gaming') opportunities, linked to the provision of relevant field data. This course gives a unique opportunity to visit Rhoscolyn in Wales, to map and analyze structures, including folds and bedding/cleavage relationships that will be useful to those working in mining, petroleum, or academia. Prerequisite: Structural geology knowledge; Consent from instructor .
**Course Learning Outcomes**

- At the completion of this course, students will be able to: • Apply field-based skills such as (1) map construction from field data including boundary projection techniques, (2) true-profile cross-section construction, (3) stereographic projection, (4) keeping accurate field notes and sketches. • Interpret progressive and polyphase deformation in the field area based on mapping and structural analysis • Write a detailed outline of the progressive and/or polyphase geological evolution of the field area, with statements of your field observations that support each event, with reference to appropriate geologic map, cross section, stereographic projection, etc.

**GEOL557. EARTH RESOURCE DATA SCIENCE 1: FUNDAMENTALS. 3.0 Semester Hrs.**
A hands-on course intended to introduce basic concepts of data science as it pertains to managing surface and subsurface Earth resources, and give examples that can be used in daily geoscience workflows.
**Course Learning Outcomes**

- A hands-on course intended to introduce basic concepts of data science as it pertains to managing surface and subsurface Earth resources, and give examples that can be used in daily geoscience workflows.

**GEOL558. EARTH RESOURCE DATA SCIENCE 2: APPLICATIONS AND MACHINE-LEARNING. 3.0 Semester Hrs.**
Introduction to specific applications (use cases) for Earth resource data science, with examples from the petroleum and minerals industries as well as water resource monitoring and remote-sensing of Earth change. Students are encouraged to provide their own datasets to enable real-world application of the concepts discussed. Prerequisites: GEOL557.
**Course Learning Outcomes**

- Introduction to specific applications (use cases) for Earth resource data science, with examples from the petroleum and minerals industries as well as water resource monitoring and remote-sensing of Earth change. Students are encouraged to provide their own datasets to enable real-world application of the concepts discussed.

**GEOL559. APPLIED STRUCTURAL FIELD MAPPING. 2.0 Semester Hrs.**
Students will take their knowledge and skills from Virtual Structural Field Mapping, or equivalent, to the field, map an area, and receive feedback on deliverables from other students and the instructor along the way through two rounds of submission and peer review. Students will get to know each other and will build a network for the future that will be an invaluable resource to find and provide help beyond this course. Prerequisite: GEOL556. Co-requisite: GEOL556.
**Course Learning Outcomes**

- This course will consist of the following components, where students will not only learn to map independently, but also to incorporate comments by their peers and instructors, and to provide valuable constructive feedback to their peers. 1. Design a semester plan for structural mapping and analysis 2. Construct a map and cross section and use stereographic projection 3. Interpret the structural history of the map area and its implications 4. Provide critical and constructive evaluations of structural maps and analyses provided by others To accomplish the above outcomes, you will: 1. students make a plan for what they want to map and at what scale 2. map for ~30 hours over five weeks and submit a (preliminary) map, cross section, structural analysis and report 3. do a peer review of two others in the course, where students will see how others are doing what they are doing, learn about each other's areas, see what works and what doesn't, provide feedback, discuss, and (perhaps most importantly) create community between mappers so they can help each other in the future. 4. the instructor gives them individual feedback, and students and instructor meet as a group to discuss what was learned. 5. second round of mapping for ~30 hours over five weeks and submit a final map, cross section, and structural analysis, plus a writeup of the geological history and potential controls on mineral deposits and locations thereof in their area. 6. second round of peer review (students will give feedback of two different class mates in the course than before) 7. the instructor gives them individual feedback, and students and instructor meet as a group to discuss what was learned.

**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.
**Course Learning Outcomes**

- Evaluate as a team a geophyiscal and geological dataset (seismic, well data, geochemical information, and geophysical logs).
- The class provides students with an insight into the hydrocarbon exploration business.

**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.
**Course Learning Outcomes**

- 1. Estimate geological risks for conventional and unconventional exploration prospects.
- 2. Calculate deterministic volumes of petroleum in exploration prospects.
- 3. Assess the range of input parameters for volumetric calculations.
- 4. Calculate probabilistic volumes of petroleum in exploration prospects.

- 5. Use industry-standard software (REP, GeoX, or both) to run Monte-Carlo simulations to estimate risks and volumes for exploration segments, prospects and wells.
- 6. Use dependencies between segments to estimate risked prospect volumes.
- 7. Aggregate prospects into exploration portfolio.

**GEOL570. APPLICATIONS OF SATELLITE REMOTE SENSING. 3.0 Semester Hrs.**
(II) An introduction to geoscience applications of satellite remote sensing of the Earth and planets. The lectures provide background on satellites, sensors, methodology, and diverse applications. Topics include visible, near infrared, and thermal infrared passive sensing, active microwave and radio sensing, and geodetic remote sensing. Lectures and labs involve use of data from a variety of instruments, as several applications to problems in the Earth and planetary sciences are presented. Students will complete independent term projects that are presented both written and orally at the end of the term. Prerequisites: PHGN200 and MATH225. 2 hours lecture, 2 hours lab; 3 semester hours.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

- 1) Demonstration of exemplary disciplinary expertise. 2) Demonstration of a set of professional skills necessary to succeed in a student's chosen career path.

**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.
**Course Learning Outcomes**

- This course will review both qualitative and quantitative approaches to interpreting and applying seismic geomorphologic observations in basin exploration and development.
- Introductory look at the tool of seismic geomorphology suitable for any geoscientist or engineer looking to enhance understanding of ancient depositional systems imaged in seismic data.

**GEOL597. SPECIAL SUMMER COURSE. 0-15 Semester Hr.**

**GEOL597. SPECIAL SUMMER COURSE. 0-15 Semester Hr.**

**GEOL598. SEMINAR IN GEOLOGY OR GEOLOGICAL ENGINEERING. 0-3 Semester Hr.**
(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.

**GEOL598. SPECIAL TOPICS. 0-6 Semester Hr.**

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**GEOL598LA. SPECIAL TOPICS LAB. 0-6 Semester Hr.**

**GEOL598LB. SPECIAL TOPICS LAB. 0-6 Semester Hr.**

**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.

**GEOL599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**

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**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.
**Course Learning Outcomes**

- 1) Demonstration of exemplary disciplinary expertise. 2) Demonstration of a set of professional skills necessary to succeed in a student's chosen career path.

**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.
**Course Learning Outcomes**

- No change

**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.
**Course Learning Outcomes**

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**GEOL610. ADVANCED SEDIMENTOLOGY. 3.0 Semester Hrs.**
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.
**Course Learning Outcomes**

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**GEOL611. SEQUENCE STRATIGRAPHY IN SEISMIC, WELL LOGS, AND OUTCROP. 3.0 Semester Hrs.**
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.
**Course Learning Outcomes**

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**GEOL613. GEOLOGIC RESERVOIR CHARACTERIZATION. 3.0 Semester Hrs.**
(I) Principles and practice of characterizing petro leum 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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**GEOL621. PETROLOGY OF DETRITAL ROCKS. 3.0 Semester Hrs.**
(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. Pre-requisites: GEGN206 , GEOL321 or equivalent. 2 hours lecture and seminar, 3 hours lab; 3 semester hours. Offered on demand.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

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**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.
**Course Learning Outcomes**

- Recognize petrologic, geochemical, and isotopic approaches to the study of diagenetic changes in carbonate sediments and rocks.

**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.
**Course Learning Outcomes**

- See course objectives.

**GEOL698. SPECIAL TOPICS. 0-6 Semester Hr.**
(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.

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**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.
**Course Learning Outcomes**

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**SYGN588. GIS-BASED REAL WORLD LEARNING PROJECT I - FUNDAMENTALS. 1-6 Semester Hr.**
This course requires a GIS-based project and report that demonstrate competence in the application of GIS to real word 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. 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.

## Professor and Department Head

Alexis Navarre-Sitchler

## Professors

David A. Benson

Wendy A. Bohrson

Zhaoshan Chang, Charles F. Fogarty Endowed Chair

Thomas Monecke, Director of Center for Advanced Subsurface Earth Resource Models and Co-Director of Center for Mineral Resources Science

Alexis Navarre-Sitchler, Joint Faculty Appointee, Energy and Natural Resources Security Group Los Alamos National Laboratory

Piret Plink-Bjorklund

Eric Roberts, Director, Potential Gas Agency

Paul M. Santi, Director of the Institute for Initiatives in Latin America

Kamini Singha, Associate Dean of Earth and Society Programs

Stephen A. Sonnenberg, Charles Boettcher Distinguished Chair in Petroleum Geology

Lesli J. Wood, Robert Weimer Distinguished Chair

Wendy Zhou

## Associate Professors

Mathias Burisch

Yvette Kuiper

Gabriel Walton

## Assistant Professors

Adrienne Marshall

Ryan Venturelli

## Research Professors

Marsha French

Richard Goldfarb

Zane Jobe, Director of the Chevron Center of Research Excellence

David Leach

J. Frederick Sarg

Richard Wanty

## Research Associate Professor

Katharina Pfaff

## Research Assistant Professors

Kevin Cannon

Mary Carr

Ben Frieman

Shiqiang Huang

Arnoud Slootman

## Teaching Professor

Christian V. Shorey

## Teaching Assistant Professor

Brendan Hanger

## Professor Emerita

Wendy Harrison

Eileen P. Poeter

## Professors Emeriti

John B. Curtis

Jerry D. Higgins

Murray W. Hitzman

Neil F. Hurley

Keenan Lee

Samuel B. Romberger

John E. Warme

Richard F. Wendlandt

## Associate Professors Emeriti

L. Graham Closs

Timothy A. Cross

Gregory S. Holden

Bruce Trudgill