

# Earth and Environmental Science

The Department of Earth and Environmental Science administers four closely related disciplines in the earth sciences—geology, geophysics, geochemistry, and hydrology—as well as the various options leading to a Bachelor of Science degree in Environmental Science. By its very nature, Environmental Science is an interdisciplinary program, incorporating expertise from biology, chemistry, earth science, physics, and environmental engineering.

## Earth Science

*Professors Aster, Bowman, Campbell (Chair of the Department), Condie, Hendrickx, Kyle, Norman, Phillips, Wilson*  
*Associate Professors Boston, Harrison, Johnson, McIntosh, McPherson, Mozley, Schlue, Tobin*  
*Assistant Professors Bilek, Zhou*  
*Emeritus Professors Balk, Budding, G. Gross, Lattman, Sanford, C. Smith*  
*Adjunct faculty: Austin, Barker, Bauer, Brister, Broadhead, Buckley, S. Cather, Chapin, Connell, Dunbar, Fehler, Fletcher, Glass, Goodwin, Haneberg, Hawley, Heizler, Jaksha, Kelley, D. Love, McCord, McLemore, Ralser, Reiter, Scholle, Small, Stephens, Turin, Ulmer-Scholle, Whitworth*

**Degrees Offered:** *B.S. in Earth Science with options in Geology, Geochemistry, Environmental Geology, and Geophysics; M.S. in Geochemistry, Geology, Geophysics (Solid Earth), and Hydrology; Ph.D. in Earth and Environmental Science with Dissertation in Geochemistry, Geology, Geophysics, or Hydrology*

Undergraduate degrees in earth science require a broad-based background in mathematics, chemistry, and physics, as well as basic training in the earth sciences. The curriculum emphasizes fundamentals and thus provides the background for entry into a number of earth science professions or graduate schools.

The graduate program provides specialized training in theoretical or applied aspects of earth science. Graduate students become actively involved in research projects in ore genesis; the origin of magmas, volcanoes, mountain belts, and continents; the exploration for geothermal sources of energy; the recharge, flow patterns, and water quality in groundwater basins and at hazardous waste sites; modern and ancient depositional processes and environments; landscape and soil evolution; atmospheric and land surface controls on regional energy and water budgets; earthquake seismology; faults and fluid flow; radioactive dating; and regional tectonics. Many staff members of the New Mexico Bureau of Geology and Mineral Resources participate in the graduate program by offering courses and supervising research work for theses and dissertations.

Many students who enter earth science professions will become involved with water resources in the semi-arid and arid regions of the world. An increasing number will seek solutions to such environmental problems as the protection of water quality and the assessment of geologic hazards. Others will find careers working to find new sources of energy and raw materials.

## Undergraduate Program

### Bachelor of Science in Earth Science

*Minimum credit hours required—132*

*Courses taken to fulfill mathematics and basic science requirements of the General Degree Requirements, and courses in Geology, Geochemistry, Geophysics, and Hydrology taken to fulfill departmental requirements must be taken for a letter grade.*

*All degree options in the Bachelor of Science in Earth Science program share the following common core curriculum. Students may therefore immediately begin coursework for the major before choosing a specific option track.*

### Earth Science Core Curriculum

- GEOL 101 (3), 101L (1), 102 (3), 102L (1), 211 (4), 318 (3), 319 (3), 337 (3), 353 (3)
- GEOP 308 (3)

### Bachelor of Science in Earth Science with Geology Option

*Minimum credit hours required—132*

*In addition to the General Degree Requirements (page 48), the following courses are required:*

- GEOL 101 (3), 101L or 103L (1), 102 (3), 102L (1), 211 (4), 306 (3), 318 (3), 319 (3), 337 (3), 341 (3), 353 (3), 468 (3)
- GEOL 480 (6) or (GEOL 481 (3) and 482 (3))
- GEOP 308 (3)
- Mathematics/Computer Science: Six credit hours selected from CS 111 and/or mathematics courses numbered 200 and above.
- Earth Science electives: Minimum of 15 credit hours in courses numbered 400 and above.
- Technical electives: Minimum of 9 credit hours in courses numbered 200 and above selected from the following fields: additional earth and environmental science other than geology, mathematics, biology, computer science, physics, chemistry, and engineering.
- Approved foreign language: six credit hours
- Electives: To complete 132 credit hours

### Sample Curriculum for the Bachelor of Science in Earth Science with Geology Option

#### Semester 1

- 4 CHEM 121 & 121L (general)
- 4 MATH 131 (calculus)
- 3 ENGL 111 (college English)
- 4 GEOL 101 & 101L (earth processes)

15 Total credit hours

#### Semester 2

- 4 CHEM 122 & 122L (general)
- 4 MATH 132 (calculus)
- 3 ENGL 112 (college English)
- 4 GEOL 102 & 102L (earth history)

15 Total credit hours

#### Semester 3

- 4 GEOL 211 (mineralogy)
- 3 GEOL 337 (stratigraphy & paleontology)
- 3 Mathematics/Computer Science
- 5 PHYS 121 & 121L (general)

15 Total credit hours

#### Semester 4

- 3 GEOL 318 (sedimentary rocks)
- 3 Mathematics/Computer Science
- 5 PHYS 122 & 122L (general)
- 3 Social Science
- 3 GEOP 308 (geophysical earth)

17 Total credit hours

*Summer*

3 GEOL 481 (field methods)

*Semester 5*

3 GEOL 319 (igneous &amp; metamorphic petrology)

3 GEOL 341 (environmental)

3 ENGL 341 (technical writing)

3 Humanities

3 Foreign Language

15 Total credit hours

*Semester 6*

3 GEOL 306 (surficial processes)

3 GEOL 353 (structure)

3 Earth Science Elective

3 Technical Elective

3 Social Science

3 Foreign Language

18 Total credit hours

*Summer*

3 or 6 GEOL 482 or GEOL 480 (field methods)

*Semester 7*

6 Earth Science Electives

3 Technical Electives

3 Humanities

3 Social Science

15 Total credit hours

*Semester 8*

3 GEOL 468 (earth evolution)

6 Earth Science Electives

4 Technical/Free Electives

3 Humanities/Social Science

16 Total credit hours

## Bachelor of Science in Earth Science with Environmental Geology Option

Minimum credit hours required—132

In addition to the General Degree Requirements (page 48), the following courses are required:

- GEOL 101 (3), 101L or 103L (1), 102 (3), 102L (1), 211 (4), 306 (3), 318 (3), 319 (3), 337 (3), 341 (3), 353 (3), 403 (3)
- GEOL 480 (6) or (GEOL 481 (3) and 482 (3))
- GEOP 308 (3)
- GEOP 445 (3) or HYD 466 (3)
- GEOC 443 (3)
- HYD 403 (3)
- CHEM 311 (3), 333 (3)
- Mathematics/Computer Science: Six credit hours selected from CS 111 and/or mathematics courses numbered 200 and above.
- Technical Electives: Minimum of 9 credit hours in courses numbered 200 and above selected from the following fields: earth and environmental science, mathematics, biology, computer science, physics, chemistry, and engineering.
- Approved Foreign Language: Six credit hours

### Sample Curriculum for the Bachelor of Science in Earth Science with Environmental Geology Option

*Semester 1*

4 CHEM 121 &amp; 121L (general)

4 MATH 131 (calculus)

3 ENGL 111 (college English)

4 GEOL 101 &amp; 101L (earth processes)

15 Total credit hours

*Semester 2*

4 CHEM 122 &amp; 122L (general)

4 MATH 132 (calculus)

3 ENGL 112 (college English)

4 GEOL 102 &amp; 102L (earth history)

15 Total credit hours

*Semester 3*

4 GEOL 211 (mineralogy)

3 GEOL 337 (stratigraphy &amp; paleontology)

5 PHYS 121 &amp; 121L (general)

3 CHEM 311 (quantitative)

15 Total credit hours

*Semester 4*

3 GEOL 318 (sedimentary rocks)

3 GEOP 308 (geophysical earth)

3 Mathematics/Computer Science

5 PHYS 122 &amp; 122L (general)

3 Social Science

17 Total credit hours

*Summer*

3 GEOL 481 (field methods)

*Semester 5*

3 GEOL 319 (igneous &amp; metamorphic petrology)

3 GEOL 341 (environmental)

3 CHEM 333 (organic)

3 ENGL 341 (technical writing)

3 Foreign Language

15 Total credit hours

*Semester 6*

3 GEOL 306 (surficial processes)

3 GEOL 353 (structure)

3 Humanities

3 Social Science

3 Mathematics/Computer Science

3 Foreign Language

18 Total credit hours

*Summer*

3 or 6 GEOL 482 or GEOL 480 (field methods)

*Semester 7*

3 GEOP 445 (exploration methods)

3 HYD 403 (groundwater)

3 GEOC 443 (principles)

3 GEOL 403 (soils)

3 Humanities/Social Science

15 Total credit hours

*Semester 8*

10 Technical/Free Electives

3 Humanities

3 Social Science

16 Total credit hours

## Bachelor of Science in Earth Science with Geochemistry Option

Minimum credit hours required—132

In addition to the General Degree Requirements (page 48), the following courses are required:

- GEOL 101 (3), 101L or 103L (1), 102 (3), 102L (1), 211 (4), 306 (3), 318 (3), 319 (3), 337 (3), 341 (3), 353 (3), 468 (3)
- GEOL 480 (6) or (GEOL 481 (3) and 482 (3))
- GEOP 308 (3)
- Mathematics/Computer Science: Six credit hours selected from CS 111 and/or mathematics courses numbered 200 and above.
- CHEM 311 (3), 311L (1), 331 (3), 333 (3)
- GEOC 443 (3) and two courses chosen from GEOC 422 (3), 431 (3), 444 (3)
- Technical Electives: Minimum of six credit hours in courses numbered 200 and above selected from the following fields: earth and environmental science, mathematics, biology, computer science, physics, chemistry, and engineering.
- Approved foreign language: Six credit hours

### Sample Curriculum for the Bachelor of Science Degree in Earth Science with Geochemistry Option

#### Semester 1

- 4 CHEM 121 & 121L (general)
  - 4 MATH 131 (calculus)
  - 3 ENGL 111 (college English)
  - 4 GEOL 101 & 101L (earth processes)
- 
- 15 Total credit hours

#### Semester 2

- 4 CHEM 122 & 122L (general)
  - 4 MATH 132 (calculus)
  - 3 ENGL 112 (college English)
  - 4 GEOL 102 & 102L (earth history)
- 
- 15 Total credit hours

#### Semester 3

- 4 GEOL 211 (mineralogy)
  - 3 GEOL 337 (stratigraphy & paleontology)
  - 5 PHYS 121 & 121L (general)
  - 4 CHEM 311 & 311L (quantitative)
- 
- 16 Total credit hours

#### Summer

- 3 GEOL 481 (field methods)

#### Semester 4

- 3 GEOL 318 (sedimentary rocks)
  - 3 GEOP 308 (geophysical earth)
  - 3 Mathematics/Computer Science
  - 5 PHYS 122 & 122L (general)
  - 3 CHEM 331 (physical)
- 
- 17 Total credit hours

#### Semester 5

- 3 GEOL 319 (igneous & metamorphic petrology)
  - 3 GEOL 341 (environmental)
  - 3 CHEM 333 (organic)
  - 3 ENGL 341 (technical writing)
  - 3 Foreign Language
- 
- 15 Total credit hours

#### Semester 6

- 3 GEOL 306 (surficial processes)
  - 3 GEOL 353 (structure)
  - 3 Humanities
  - 3 Social Science
  - 3 Mathematics/Computer Science
  - 3 Foreign Language
- 
- 18 Total credit hours

#### Summer

- 3 or 6 GEOL 482 or GEOL 480 (field methods)

#### Semester 7

- 3 GEOC 431 (exploration & environmental)
  - 3 GEOC 443 (principles)
  - 3 Technical Electives
  - 3 Humanities
  - 3 Social Science
- 
- 15 Total credit hours

#### Semester 8

- 3 GEOC 422 (environmental) or 444 (isotope geochemistry)
  - 3 GEOL 468 (evolution)
  - 3 Technical Electives
  - 3 Social Science
  - 3 Humanities/Social Science
- 
- 15 Total credit hours

## Bachelor of Science in Earth Science with Geophysics Option

Minimum credit hours required—133

- GEOL 101 (3), 101L (1), 102 (3), 102L (1), 211 (4), 318 (3), 319 (3), 337 (3), 353 (3)
- GEOP 308 (3), 445 (3), 446 (3), 448 (3), plus six credit hours chosen from GEOP 325, 342, 370, 420, 466, or any geophysics course numbered 500 and above
- Three credit hours of approved field experience or senior project (GEOP 492)
- PHYS 242 (4), 333 (3)
- MATH 231 (4), 254 (3), 332 (3), 335 (3)
- Earth and Environmental Science Electives: Nine additional credit hours chosen from the upper-division courses offered by the Earth and Environmental Science Department.
- Technical Electives: Six credit hours chosen from any of the upper-division classes offered by the departments of physics, mathematics, computer science, chemistry, and the various engineering curricula.

### Sample Curriculum for the Bachelor of Science in Earth Science with Geophysics Option

#### Semester 1

- 4 GEOL 101 & 101L (earth processes)
  - 4 CHEM 121 & 121L (general)
  - 4 MATH 131 (calculus)
  - 3 ENGL 111 (college English)
- 
- 15 Total credit hours

#### Semester 2

- 4 GEOL 102 & 102L (earth history)
  - 4 CHEM 122 & 122L (general)
  - 4 MATH 132 (calculus)
  - 3 ENGL 112 (college English)
- 
- 15 Total credit hours

#### Semester 3

- 4 GEOL 211 (mineralogy)
  - 5 PHYS 121 & 121L (general)
  - 4 MATH 231 (calculus)
  - 3 Social Science
- 
- 16 Total credit hours

#### Semester 4

- 3 GEOL 318 (sedimentary rocks)
  - 3 GEOP 308 (geophysical earth)
  - 5 PHYS 122 & 122L (general)
  - 3 MATH 254 (linear algebra)
  - 3 Humanities
- 
- 17 Total credit hours

**Semester 5**

3	GEOP 325 (shallow methods)
3	GEOL 319 (igneous and metamorphic petrology)
3	GEOL 337 (stratigraphy & paleontology)
3	ENGL 341 (technical writing)
3	Humanities
3	Social Science
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18	Total credit hours

**Semester 6**

3	GEOL 353 (structure)
3	GEOP 445 (exploration geophysics I)
4	PHYS 242 (waves and vibrations)
3	Social Science
3	MATH 332 (vector analysis)
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16	Total credit hours

**Summer**

3	GEOP 492 (senior project or field experience)
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**Semester 7**

3	GEOP 342 (reflection seismology)
3	GEOP 446 (exploration)
3	MATH 335 (applied analysis I)
3	Earth & Environmental Science Elective
3	Technical Elective
3	Humanities/Social Science
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18	Total credit hours

**Semester 8**

3	GEOP 448 (general)
3	PHYS 333 (electricity and magnetism)
6	Earth & Environmental Science Elective
3	Technical Elective
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15	Total credit hours

**Minor in Earth Science**

Minimum credit hours required—18

The following courses are required:

- GEOL 101 & 101L (4)
- GEOL 102 & 102L (4)
- GEOL 211 (4)
- Minimum of six (6) hours chosen from: GEOL 306, 317, 318, 319, 337, 341, 353, 403; GEOC 443, 444; GEOP 308

# Geology

## Five-Year Program: Earth Science with Environmental Geology Option B.S./Geology M.S. Degree Program

The degrees Earth Science with Environmental Geology Option and Geology M.S. are achieved in five years by fulfilling the requirements for a B.S. degree in Earth Science with the Environmental Geology Option in four years and an M.S. degree in Geology the following year. A minimum of 158 credit hours is required to complete both degrees.

Students should apply to the Environmental Geology five-year program at the end of their sophomore year. Admission is contingent upon the acceptability of a proposed course of study, academic performance, and on the number of vacancies in the program. Students who have upper-division standing may also be considered, depending upon prior course work.

Once admitted to the program, every undergraduate student will work with a research group. Required courses include: GEOL 403 or 503, 405 or 505 (may substitute GEOL 430 or 530), 409 or 509, 491 (one credit hour per semester for three semesters), 592 (2 credit hours); GEOP 445 or HYD 466; GEOC 443, 525; HYD 403, 503L; CHEM 311 and 333. Recommended courses include GEOC 422; HYD 412 and 533.

Students in the Environmental Geology five-year program must apply for graduate standing, normally in their seventh semester. Graduate admission will be contingent upon adherence to the approved program of studies, a 3.0 minimum cumulative grade point average, and a 3.0 earned grade point average in mathematics, science, and engineering courses. Graduate status will be granted upon fulfillment of the requirements for the B.S. degree.

## Graduate Program

### Master of Science in Geology

The master's candidate must demonstrate competence in mathematics, chemistry, and physics comparable to the requirements for the Bachelor of Science degree in Geology. The Master of Science degree in Geology may be earned under either of the following plans:

**With Thesis:**

The student's course of study must be approved by the student's advisory committee and must fulfill the general requirements for the master's degree with thesis and must include GEOL 480 or the equivalent, if not previously satisfied, two credits of GEOL 592, at least six credit hours of GEOL 591, and at least four credit hours of GEOL 593, unless the degree is completed in a shorter time. Credits earned in GEOL 592 and 593 may not be applied towards the 30 credits required for the M.S. degree.

**Without Thesis:**

The student's course of study must be approved by the student's advisory committee and must fulfill the general requirements for the master's degree without thesis and must include GEOL 480 or the equivalent, if not previously satisfied, two credits of GEOL 592, at least three credit hours of GEOL 590, and at least four credit hours of GEOL 593, unless the degree is completed in a shorter time. Credits earned in GEOL 592 and 593 may not be applied towards the 30 credits required for the M.S. degree.

### Doctor of Philosophy in Earth and Environmental Science with Dissertation in Geology

Students of exceptional ability, as demonstrated in previous courses or in a master's degree program, may pursue a program leading to the doctoral degree.

The prospective doctoral candidate in earth and environmental science with specialization in geology should develop a good background in geology, chemistry, physics, and mathematics, in addition to achieving a high level of competence in the field of specialization. Ph.D. students must include three credits of GEOL 592 and at least six credit hours of GEOL 593, unless the degree is completed in a shorter time. Additional information is found under the Graduate Program (page 28).

Research fields appropriate for the geology candidate include petrology, volcanology, mineral deposits, geochronology, stable isotopes, environmental geology, coal geology, geohydrology, sedimentation and stratigraphy, regional tectonics, and structural geology. Interdisciplinary programs in the earth science fields are encouraged.

## Geology Courses:

**GEOL 101, Earth Processes, 3 cr, 3 cl hrs**

*Offered fall semester*

A study of the physical processes that operate on and within the Earth and determine its evolution through geologic time. Students are encouraged to enroll concurrently in GEOL 101L or GEOL 103L.

**GEOL 101L, Earth Processes Laboratory, 1 cr, 3 lab hrs**

*Corequisite: GEOL 101*

For students majoring in earth sciences. Identification of rocks and minerals, maps and map reading, and measurement and interpretation of geologic features. Field trips.

**GEOL 102, Earth History, 3 cr, 3 cl hrs***Prerequisite: GEOL 101**Offered spring semester*

Evolution of the lithosphere, hydrosphere, atmosphere, and biosphere in the context of plate tectonic theory. Application of geological/biological processes and products to the formation and evolution of the Earth.

**GEOL 102L, Earth History, 1 cr, 3 lab hrs***Prerequisite: GEOL 101L or 103L**Corequisite: GEOL 102*

Laboratory intended to accompany GEOL 102 for students majoring in the earth sciences and related engineering fields; involves field exercises which illustrate the evolution of the Earth, development of geochronology, geologic mapping, and interpretation of crustal history. Field trips.

**GEOL 103L, Earth Processes Laboratory for Non-Majors, 1 cr, 3 lab hrs***Corequisite: GEOL 101*

Laboratory to accompany GEOL 101 for students not majoring in the earth sciences. Identification of rocks and minerals, maps and map reading, and measurement and interpretation of geologic features.

**GEOL 104L, Earth History Laboratory for Non-Majors, 1 cr, 3 lab hrs***Prerequisite: GEOL 101L or 103L**Corequisite: GEOL 102*

Laboratory intended to accompany GEOL 102 for students not majoring in the earth sciences and related engineering fields; laboratory-oriented course that includes exercises which illustrate geological and paleontological processes, products, and principles involved in the evolution of the Earth. Several short field excursions will occur during laboratory hours.

**GEOL 120, Introductory Oceanography, 3 cr, 3 cl hrs**

An introduction to the oceans, including aspects of physical, geological, and biological oceanography. Focus is on presentation of science in a social context. Topics include: origin and evolution of ocean basins and marine sediments; ocean currents, waves, tides, and sea level; beaches, shorelines, and coastal processes; marine life; climate; marine resources, pollution, and human impacts on the ocean. (Same as GEOP 120)

**GEOL 130, Spaceship Earth, 3cr, 3 cl hrs***Alternate years, spring semester*

Study of Earth as an immense system composed of a gigantic rocky mass, a planet-dominating ocean, an active atmosphere, and an abundance of life. Consideration of subsystems interacting across time and space. Discussion of possible mechanisms that may control this megasystem including controversial topics, e.g. co-evolution, homeostatic feedback mechanisms, and the Gaia Hypothesis.

**GEOL 130L, Spaceship Earth Lab, 1 cr, 3 lab hrs**

Laboratory and field demonstrations of principles of global biogeochemical cycles and the interaction of life with its planetary home.

**GEOL 211, Introduction to Mineralogy, 4 cr, 3 cl hrs, 3 lab hrs***Prerequisite: GEOL 101**Corequisite: CHEM 121**Offered fall semester*

Introduction to crystal structures, crystal chemistry, optical mineralogy, and mineral occurrence. The laboratory teaches mineral identification of major rock-forming and ore minerals based on physical and optical properties.

**GEOL 306, Surficial Processes, 3 cr, 2 cl hrs, 3 lab hrs***Prerequisite: GEOL 102, 102L**Offered spring semester*

Study of the major processes controlling the development of landforms and landscapes. Emphasizes the influence of these processes on our environment. Field trips.

**GEOL 317, Survey of Sedimentary Rocks and Processes, 3 cr, 2 cl hrs, 3 lab hrs***Prerequisite: GEOL 101 or consent of instructor**Offered spring semester*

Study of sedimentary processes, materials, and depositional environments. Field trips. This class is for non-majors only; earth science majors must enroll in GEOL 318.

**GEOL 318, Sedimentary Rocks and Processes, 3 cr, 2 cl hrs, 3 lab hrs***Prerequisites: GEOL 102 and 211 or consent of instructor**Offered spring semester*

Study of sedimentary processes, materials, depositional environments, and the petrography of sedimentary rocks. Field trips. This class is for earth and environmental science majors only.

**GEOL 319, Igneous and Metamorphic Petrology, 3 cr, 2 cl hrs, 3 lab hrs***Prerequisites: GEOL 211 and 318; or consent of instructor**Offered fall semester*

Occurrence, classification, and origin of igneous rocks. Origin of magmas. Principles of metamorphism; classification of metamorphic rocks; metamorphic fabrics, and microstructures; metamorphic facies and interpretation of paleotectonic environments. Field trips.

**GEOL 333, Introductory Stratigraphy, 1 cr, 1 cl hr, 1 lab hr***Prerequisite: GEOL 101**Offered fall semester*

Principles of litho-, bio-, and chronostratigraphy with an emphasis on sequence stratigraphy; and the designation, identification, and correlation of stratigraphic units. Field trip.

**GEOL 337, Stratigraphy and Paleontology, 3 cr, 2 cl hrs, 3 lab hrs***Prerequisite: GEOL 102**Offered fall semester*

Introduction to stratigraphic principles; survey of geologically important invertebrate biota preserved as fossils; their modes of preservation, collection techniques, taxonomy, paleobiology, paleoecology, and biostratigraphic utility. Field trips.

**GEOL 341, Environmental Geology, 3 cr, 3 cl hrs***Prerequisites: GEOL 101, CHEM 121**Offered fall semester*

Study of the influence of geologic processes and hazards on human activities. Emphasis will be placed upon topics of interest to students considering careers in environmental science and engineering.

**GEOL 353, Structural Geology, 3 cr, 2 cl hrs, 3 lab hrs***Prerequisites (Earth Science majors): GEOL 102 & 102L; GEOL 317, 318 or 319; PHYS 121 or 131; or consent of instructor**Prerequisites (Mineral Engineering majors): ME 360 & 360L; PHYS 121 or 131; or consent of instructor**Corequisite (Mineral Engineering majors): ME 462**Offered spring semester*

Study and interpretation of geologic structures. Processes of fracturing, faulting, folding, and flow of rocks; stress and strain; and elementary concepts of tectonics. Lab includes solution of map problems and use of stereographic projections. Field trips.

**GEOL 403, Introduction to Soils, 3 cr, 2 cl hrs, 3 lab hrs***Prerequisite: GEOL 102, 102L**Offered fall semester*

Introduction to soil formation, pedogenic processes, and soil description and mapping techniques.

**GEOL 408, Cooperative Education**

On-the-job training to supplement the academic program. Students alternate periods (usually six months long) of full-time semiprofessional employment in their chosen field with periods of full-time academic study.

**GEOL 409, Soil Geomorphology, 3 cr, 2 cl hrs, 3 lab hrs***Prerequisites: GEOL 306 and 403; or consent of instructor**Offered spring semester, alternate years*

Discussion of the use of soils to interpret the rate and timing of geomorphic processes and changing environmental parameters. Field trips.

**GEOL 411, Experimental Mineralogy, 3 cr, 5 lab hrs***Prerequisite: Geology 211**Offered spring semester, alternate years*

Study of the principles of mineralogy through experimentation in the laboratory. Techniques taught include hand sample identification, optical mineralogy, x-ray diffraction, thin section preparation, and mineral synthesis.

**GEOL 420, Paleomagnetism, 3 cr, 2 cl hrs, 3 lab hrs.**

*Prerequisites:* GEOL 101 and PHYS 122 or equivalents; upper-class or graduate standing  
*Offered on demand*

Paleomagnetic theory, methods, and application to geologic problems. Laboratory includes field collection of samples and acquisition, analysis, and interpretation of data. (Same as GEOP 420)

**GEOL 422, Advanced Igneous Petrology, 3 cr, 3 cl hrs**

*Prerequisite:* GEOL 319

*Offered on demand*

Application of phase diagrams, experimental petrology, and field and petrographic relationships to the origin of magmas. Field trips.

**GEOL 424, Sedimentary Petrography, 3 cr, 4 lab hrs**

*Prerequisite:* GEOL 318

*Offered spring semester, alternate years*

Petrographic analysis and interpretation of sedimentary rocks, with emphasis on siliciclastics. Topics include: grain identification and provenance, identification of diagenetic minerals and textures, and interpretation of porosity and permeability characteristics.

**GEOL 430, Active Tectonics, 3 cr hrs**

*Prerequisites:* GEOL 306, 353

*Offered alternate years*

Study of Quaternary faults, including basic field techniques, tectonic geomorphology from fault scarps to mountain fronts, patterns of faulting, structural analysis of faults in alluvium, relation of surface to subsurface structures, paleoseismology, and review of Quaternary dating methods.

**GEOL 432, Interdisciplinary Field Research, 3 cr, 8 lab hrs**

*Prerequisite:* Consent of instructor

*Offered fall semester*

Introduction to field-based research. Activities include proposal writing, data collection, interpretation, and preparation of a written report. Field work is an important part of the course, and hiking is required. The course is team-taught by several instructors.

**GEOL 434, Remote Sensing with Geoscience Applications, 3 cr, 2 cl hrs, 3 lab hrs**

*Prerequisite:* PHYS 122 or 132, or consent of instructor

Emphasis on basic physical principles, imaging principles and systems, image processing, and interpretation of remotely sensed data. Remote sensing applications to atmospheric sciences, hydrology, forestry, agriculture, and mineral and oil exploration, natural hazards monitoring (earthquakes, volcanoes, droughts and floods, landslides, land subsidence, forest fires), and land and resource management. GEOL 434 and 534 lectures shared, but 534 is graded separately and additional graduate-level work is required. (Same as GEOP/HYD 434)

**GEOL 443, Field Sedimentology, 3 cr, 8 lab hrs**

*Prerequisite:* GEOL 318

Description and interpretation of sedimentary rocks in the field. Following several introductory lectures and field trips, students begin work on a cooperative, field-based research project.

**GEOL 445, Volcanology, 3 cr, 2–3 cl hrs, 1–3 lab hrs**

*Prerequisite:* GEOL 319 or consent of instructor

*Offered on demand*

Study of volcanic processes, eruptive products and their mechanism of formation. Volcanic hazards and the environmental impact of volcanism. Field trips to nearby volcanic fields.

**GEOL 450, Cave and Karst Systems, 3 cr, 3 cl hrs**

*Prerequisites:* CHEM 121 & 122; and either GEOL 101 or BIOL 111

*Offered spring semester, even years*

A system-based study of caves and karstic terrains over time including formation mechanisms (speleogenesis), hydrology, geochemistry, mineralogy, and geomicrobiology. Emphasis on caves as interactive microcosms cross-cutting many disciplines. GEOL 450 and 550 lectures shared, but 550 is graded separately and additional graduate-level work is required.

**GEOL 460, Subsurface and Petroleum Geology, 3 cr, 2 cl hrs, 3 lab hrs**

*Prerequisite:* GEOL 317 or 318 or consent of instructor

*Offered spring semester*

Principles and techniques of subsurface geology with emphasis on subsurface mapping, facies analysis, fluid-related rock properties, composition, movement and entrapment of subsurface fluids (oil, natural gases, water), and petroleum source rocks. Laboratory work emphasizes subsurface analysis and mapping with logs, cuttings, and cores. Applications to hydrocarbon exploration and development.

**GEOL 462, Mineral Deposits, 3 cr, 2 cl hrs, 3 lab hrs**

*Prerequisite:* GEOL 211

*Offered spring semester, alternate years*

Geologic and geochemical characteristics of metallic mineral deposits; theories of origin and classification.

**GEOL 463, Geology of the Colorado Plateau, 3 cr, 2 cl hrs, field trips**

*Prerequisites:* GEOL 318; or consent of instructor

*Offered spring semester*

Discussion of geology, archeology, and ecology of the Colorado Plateau, emphasizing the Canyonlands region. Geological topics include geomorphology, sedimentology, tectonics, igneous rocks, and surficial processes. Field trips are an important part of the course, and hiking is required.

**GEOL 466, Geologic River Trip, 1–2 cr, field trip**

*Offered spring semester and summer session*

This course includes one or more whitewater raft trips on rivers in the Southwest with discussions of local geology, archeology, and ecology. During the spring semester, the course also includes weekly seminars. Students may register for the course more than once, but only four (4) credit hours can be applied towards an earth science degree.

**GEOL 468, Evolution of the Earth, 3 cr, 3 cl hrs, field trip**

*Prerequisites:* GEOL 318, 319, 337

*Offered spring semester*

Origin of the solar system and of the earth; the evolution of continents, atmosphere, and oceans; comparative planetary evolution; tectonic regimes in geologic history. Field trip required.

**GEOL 470, Geology of the Cayman Islands and Field Trip, 3 cr**

*Prerequisites:* GEOL 318 and 335 or consent of instructor

*Offered spring semester alternate years*

Investigation of modern and ancient reefs in an easily accessed area, as well as study of the environmental implications of living on an island. Weekly meeting followed by an end-of-semester seven to nine day field trip. Students are expected to complete field exercises, make oral presentations, and write a paper on a topic such as reef ecology through time on the Cayman Islands, the tectonic evolution of the Caribbean and the Caymans, or environmental concerns of island life.

**GEOL 480, Field Methods in Earth Science, 6 cr**

*Prerequisites:* GEOL 318, 319, 337, 353

*Offered summers (6 weeks)*

Collection, processing, and interpretation of field data developed by geologic mapping in sedimentary, igneous, and metamorphic terrane. Presentation of geologic reports involving maps, cross sections, and sample data.

**GEOL 481, Field Methods in Earth Science I, 3 cr**

*Prerequisites:* GEOL 318 and 337

*Offered summers (3 weeks)*

Collection, processing, and interpretation of field data developed by geologic mapping of sediments and sedimentary rocks. Presentation of geologic reports involving maps, cross sections, and sample data. Students should register for this class in the spring semester.

**GEOL 482, Field Methods in Earth Science II, 3 cr**

*Prerequisites:* GEOL 319, 353, and 481

*Offered summers (3 weeks)*

Collection, processing, and interpretation of field data developed by geologic mapping of sedimentary, igneous, and metamorphic terranes. Presentation of geologic reports involving maps, cross sections, and sample data. Students should register for this class in the spring semester.

**GEOL 491, Advanced Problems, hrs and crs to be arranged**

Detailed investigation of a limited area of a problem; presentation of a written report. Work may extend over one or more semesters or a summer session.

**GEOL 492, Senior Thesis, 3 cr**

*Prerequisite: 3.0 GPA in earth science courses and consent of instructor*

Individual research under the direction of a faculty member. Two semesters are usually necessary to complete the research project. Grading will be based on a written report which details the research goals, data collected, interpretation, and conclusions.

**GEOL 500, Directed Research, cr to be arranged**

*This course may not be used to fulfill graduate degree requirements.*

Research under the guidance of a faculty member.

**GEOL 503, Introduction to Soils, 3 cr, 2 cl hrs, 3 lab hrs**

*Prerequisite: GEOL 102*

*Offered fall semester*

Introduction to soil formation, pedogenic processes, and soil description and mapping techniques. Shares lecture/lab with GEOL 403, but is graded separately and additional graduate-level work is required.

**GEOL 507, Ore Deposit Seminar and Field Trip, 1–6 cr**

*Offered spring semester*

Ore deposits and geology of a specific geographic area are studied in a weekly seminar and a one- to two-week field trip. The field trip will generally be international in alternate years. A paper is required. Students may register for the course more than once for a total of six credit hours.

**GEOL 509, Soil Geomorphology, 3 cr, 2 cl hrs, 3 lab hrs**

*Prerequisites: GEOL 306 and 403; or consent of instructor*

*Offered spring semester, alternate years*

Discussion of the use of soils to interpret the rate and timing of geomorphic processes and changing environmental parameters. Field trips. Shares lecture/lab with GEOL 409, but is graded separately and additional graduate-level work is required.

**GEOL 520, Paleomagnetism, 3 cr, 2 cl hrs, 3 lab hrs**

*Prerequisites: GEOL 101 and PHYS 122 or equivalent; upper-class or graduate standing*

*Offered on demand*

Paleomagnetic theory, methods and application to geologic problems. Laboratory includes field collection of samples and acquisition, analysis, and interpretation of data. Shares lecture/lab with GEOL 420, but is graded separately and additional graduate-level work is required.

**GEOL 521, Hydrogeologic Processes, 3 cr, 3 cl hrs**

*Prerequisites: GEOL 102, 102L; HYD 503, 507, 508*

Geologic controls of the occurrence, movement, and quality of groundwater. Hydrologic properties of earth materials. Theory and study of specific hydrogeologic processes including water resource evaluation and well hydraulics, barometric and tidal responses of aquifers, regional groundwater flow, coupled groundwater and heat flow, fracture flow, saturated multiphase flow such as petroleum migration, diagenesis and reactive groundwater flow, coupled groundwater flow and rock deformation, and other issues. (Same as HYD 521)

**GEOL 522, Advanced Igneous Petrology, 3 cr, 3 cl hrs**

*Prerequisites: GEOL 319 and graduate standing; or consent of instructor*  
*Offered on demand*

Applications of phase diagrams, experimental petrology, and field and petrographic relationships to the origin of magmas. Field trips. Shares lecture/lab with GEOL 422, but is graded separately and additional graduate-level work is required.

**GEOL 524, Sedimentary Petrography, 3 cr, 2 cl hrs, 3 lab hrs**

*Prerequisite: Graduate standing*

*Offered spring semester, alternate years*

Petrographic analysis and interpretation of sedimentary rocks, with emphasis on siliciclastics. Topics include: grain identification and provenance, identification of diagenetic minerals and textures, and interpretation of porosity and permeability characteristics. Shares lecture/lab with GEOL 424, but is graded separately and additional graduate-level work is required.

**GEOL 530, Active Tectonics, 3 cr hrs**

*Prerequisites: GEOL 306, 353, or consent of instructor*

*Offered in alternate years*

Study of Quaternary faults, including basic field techniques, tectonic geomorphology from fault scarps to mountain fronts, patterns of faulting, structural analysis of faults in alluvium, relation of surface to subsurface structures, paleoseismology, and review of Quaternary dating methods. Shares lecture/lab with GEOL 430, but is graded separately and additional graduate-level work is required.

**GEOL 532, Interdisciplinary Field Research, 3 cr, 8 lab hrs**

*Prerequisite: Consent of instructor*

*Offered fall semester*

Introduction to field-based research. Activities include proposal writing, data collection, interpretation, and preparation of a written report. Field work is an important part of the course, and hiking is required. The course is team-taught by several instructors. Shares lecture/lab with GEOL 432, but is graded separately, and additional graduate-level work is required.

**GEOL 535, Crustal and Mantle Evolution, 3 cr, 3 cl hrs**

Origin and evolution of continents and evolution of the mantle.

(Same as GEOC 535)

**GEOL 538, Geographic Information Systems with Geoscience Applications, 3 cr, 2 cl hrs, 3 lab hrs**

*Prerequisite: Consent of instructor*

An introduction to geographic information systems (GIS) with a focus on applications in the geosciences, including geology, hydrology, environmental science and natural resources. Emphasis on theoretical aspects and practical applications of GIS science and technology and its integration with remote sensing data and field measurements. Computing exercises and projects utilizing ArcGIS software. Particular focus on spatial hydrology, terrain analysis, and geologic and vegetation mapping. Discussion of GIS integration with geoscience modeling. Shares lecture with ENV5 438 but is graded separately. (Same as HYD 538)

**GEOL 540, Clastic and Carbonate Diagenesis, 3 cr, 3 cl hrs**

*Prerequisite: Graduate standing or consent of instructor*

*Offered spring semester, alternate years*

Discussion of clastic and carbonate diagenesis. Topics include: mineralogy and chemistry of authigenic minerals, rock-water interaction, mass transfer, influence of bacteria on diagenetic reactions, application of isotopes, diagenetic controls on porosity and permeability, and influence of depositional environment and detrital mineralogy on diagenesis.

**GEOL 543, Field Sedimentology, 3 cr, 8 lab hrs**

*Prerequisite: Graduate standing or consent of instructor*

*Offered fall semester*

Description and interpretation of sedimentary rocks in the field. Following several introductory lectures and field trips, students begin work on a cooperative, field-based research project. Shares lecture/lab with GEOL 443, but is graded separately and additional graduate-level work is required.

**GEOL 546, Advanced Volcanology, 3 cr, 3 cl hrs**

*Prerequisites: GEOL 445; graduate standing or consent of instructor*

*Offered on demand*

Seminar discussions of selected topics in volcanology, such as environmental impact of volcanism, magma chambers, emplacement of ignimbrites, volatiles in magmas, and volcanic processes and products.

**GEOL 547, Depositional Systems and Basin Analysis, 3 cr, 3 cl hrs**

*Prerequisite: Graduate standing or consent of instructor*

*Offered fall semester*

Discussion of the spectrum of modern and ancient depositional environments and their relationships to tectonic settings.

**GEOL 550, Cave and Karst Systems, 3 cr, 3 cl hrs**

*Prerequisites: CHEM 121 & 122; and either GEOL 101 or BIOL 111*

*Offered spring semester, even years*

A system-based study of caves and karstic terrains over time including formation mechanisms (speleogenesis), hydrology, geochemistry, mineralogy, and geomicrobiology. Emphasis on caves as interactive microcosms cross-cutting many disciplines. GEOL 450 and 550 lectures shared, but 550 is graded separately and additional graduate-level work is required.

**GEOL 550L, Cave and Karst Lab, 1 cr, 3 lab hrs***Offered spring semester, even years**Corequisite: GEOL 550*

Survey of techniques applicable to various aspects of speleology and karst studies. Project-based lab, developed for each student in consultation with instructor.

**GEOL 551, Industrial Minerals, 3 cr, 3 cl hrs***Prerequisites: Graduate standing or consent of instructor**Offered alternate years*

Study of basic concepts of production and use of industrial minerals in modern society. Emphasis on complex interactions between economics, geology, processing, marketing, and transportation. Selected industrial minerals studied in detail. Several field trips to operations and occurrences. (Same as ME 551)

**GEOL 556, Fluids in Faults and Shear Zones, 3 cr, 3 cl hrs***Prerequisite: Graduate standing or consent of instructor**Offered fall semester, alternate years*

A seminar class. Processes by which permeability along faults and shear zones is decreased or enhanced, evidence and mechanisms of fluid movement in faults and shear zones, fault valve behavior, water weakening of minerals, and geochemical processes near the surface and at depth. (Same as GEOP 556, HYD 556)

**GEOL 558, Mechanics of Earthquakes and Faulting, 3 cr, 3 cl hrs***Prerequisites: GEOL 353 or equivalent and graduate standing; or consent of instructor**Offered on demand*

Observational and theoretical aspects of brittle failure in the Earth. Fracture mechanics; fault zone geometry and structure; earthquake sources; paleoseismic studies; seismic hazard assessments. (Same as GEOP 558)

**GEOL 561, Ore Genesis, 3 cr, 3 cl hrs***Offered spring semester, alternate years*

Principles of the geochemistry of ore deposits including stable isotopes, lead isotopes, solution geochemistry, and element partitioning. Review of recent tectonic and geochemical generic models of hydrothermal, magmatic, and sedimentary ore deposits. (Same as GEOC 561)

**GEOL 562, Ore Genesis, 3 cr, 3 cl hrs***Offered fall semester, alternate years*

Principles of the geochemistry of ore deposits including stable isotopes, lead isotopes, solution geochemistry, and element partitioning. Review of recent tectonic and geochemical generic models of hydrothermal, magmatic, and sedimentary ore deposits. (Same as GEOC 562)

**GEOL 566, Regional Tectonics, 3 cr, 3 cl hrs***Prerequisite: graduate standing or consent of instructor**Offered on demand*

Study of major orogenic belts and processes of orogeny, with emphasis on the tectonic evolution of western North America. Fundamentals of plate tectonics, relationships between plate tectonics and orogeny.

**GEOL 571, 572, Advanced Topics in Geology, 2–3 cr**

Study of a special topic in geology, normally one related to a field of research at Tech.

**GEOL 581, Directed Study, cr to be arranged**

Study under the guidance of a member of the geology staff. In general, subject matter will supplement that available in the other graduate offerings in geology.

**GEOL 590, Independent Study, cr to be arranged**

In this course, the student must clearly demonstrate the ability to organize and pursue research. A written final report is required. At the discretion of the instructor, other faculty members may be requested to review the final report.

**GEOL 591, Thesis (master's program), cr to be arranged****GEOL 592, Graduate Seminar, 1 cr, 1 cl hr***Prerequisite: Graduate standing**Offered spring semesters*

Seminar presentations by graduate students on their current research topics. M.S. students must present at least one seminar; Ph.D. students must present at least one seminar in each of two different semesters. Graded on S/U basis; credits earned may not be applied towards the 30 credits required for the M.S. degree. (Same as GEOC 592, GEOP 592, HYD 592)

**GEOL 593, Seminar, 1 cr, 1 cl hr***Prerequisite: Graduate standing**Offered fall and spring semesters*

Seminar presentations by faculty, students, and outside speakers. Graded on S/U basis. Satisfactory performance consists of regular attendance at approved seminars. Credit earned may not be applied towards the 30 credits required for the M.S. degree. (Same as GEOC 593, GEOP 593, HYD 593)

**GEOL 595, Dissertation (doctoral degree program), cr to be arranged**

## Geophysics (Solid Earth)

The Geophysics program offers an undergraduate degree in Earth Science with Geophysics option. See page 66.

### Graduate Programs

#### Requirements for the Master of Science in Geophysics (Solid Earth)

The Master of Science degree in Geophysics (Solid Earth) may be earned under either of the plans outlined below:

**With Thesis:**

The student's course of study must be approved by the student's advisory committee and must fulfill the general requirements for the master's degree with thesis and must include (unless taken in undergraduate work): GEOP 445, 446, and 448, or their equivalents; upper-division geology, six credit hours; competence in mathematics corresponding to nine credit hours beyond calculus; at least six credit hours of GEOP 591, two credit hours of GEOP 592, and twelve additional credit hours in graduate geophysics (up to six credit hours of this requirement may be replaced with non-geophysics graduate courses with the advisor's approval).

**Without Thesis:**

Courses approved by the student's advisory committee must fulfill the general requirements for the master's degree without thesis and must include (unless taken in undergraduate work): GEOP 445, 446, and 448, or their equivalents; upper-division geology, six credit hours; competence in mathematics corresponding to nine credit hours beyond calculus; at least three credit hours of GEO 590, two credit hours of GEOP 592, and twelve additional credit hours of graduate courses in geophysics (up to six credit hours of this requirement may be replaced with non-geophysics graduate courses with the advisor's approval).

#### Doctor of Philosophy in Earth and Environmental Science with Dissertation in Geophysics

Students of exceptional ability as demonstrated by previous academic achievement may pursue a program leading to the doctoral degree.

The prospective doctoral candidate in earth and environmental science with specialization in physics of the solid earth should develop a solid background in physics, mathematics, and geology in addition to achieving a high level of competence in the field of geophysics.

With the approval of the advisory committee, the student should select a program including a minimum of nine credit hours in graduate geophysics beyond the M.S. degree, three credit hours of GEOP 592, plus additional courses in related fields.

Research fields appropriate for the geophysics candidate include crustal exploration, earthquake seismology, tectonophysics, environmental, and hydrogeothermal studies. Interdisciplinary programs in the earth science fields are encouraged.

## Geophysics Courses:

### GEOP 120, Introductory Oceanography, 3 cr, 3 cl hrs

An introduction to the oceans, including aspects of physical, geological, and biological oceanography. Focus is on presentation of science in a social context. Topics include: origin and evolution of ocean basins and marine sediments; ocean currents, waves, tides, and sea level; beaches, shorelines, and coastal processes; marine life; climate; marine resources, pollution, and human impacts on the ocean. (Same as GEOL 120)

### GEOP 308, The Geophysical Earth, 3 cr, 2 cl hrs, 3 lab hrs

*Prerequisites:* PHYS 121; GEOL 101

An introductory survey of solid Earth geophysics covering fundamental physical processes shaping the Earth and geophysical techniques used to study Earth structure. Formation and internal structure of the Earth, plate tectonics, gravitational and magnetic fields, heat flow, earthquakes, and seismotectonics.

### GEOP 325, Geophysical Methods of Shallow Exploration, 3 cr, 2 cl hrs, 3 lab hrs

*Prerequisites:* PHYS 121; GEOL 101

Use of standard geophysical methods for exploring the shallow subsurface. Acquisition and common interpretation techniques for seismic, magnetic, and electrical data. Applications to environmental, structural, and exploration problems. Mapping of aquifers, faults, soil profiles, buried stream beds, and other hidden structures.

### GEOP 336, Archeological Geophysics, 3 cr, 1 cl hr, 6 lab hrs

*Prerequisite:* GEOP 325

General archeological background of pre-European civilization in central New Mexico. Class and field instruction in the use of geophysical techniques for non-intrusive archeological exploration of the numerous 800 to 1500 A.D. Native American occupational sites near New Mexico Tech.

### GEOP 370, Formation Evaluation, 3 cr, 2 cl hrs, 3 lab hrs

*Prerequisite:* PHYS 122

*Corequisite:* GEOL 353

The qualitative and quantitative interpretation of electric, sonic, and radioactive well logs. Physical and electrical properties of saturated rock. Formation testing and analysis. Laboratory exercises in log reading and interpretation. Preparation of subsurface maps for estimation of reserves. (Same as PETR 370)

### GEOP 420, Paleomagnetism, 3 cr, 2 cl hrs, 3 lab hrs

*Prerequisites:* GEOL 101 and PHYS 122 or equivalents; upper-class or graduate standing

*Offered on demand*

Paleomagnetic theory, methods, and application to geologic problems. Lab includes field collection of samples and acquisition, analysis, and interpretation of data. (Same as GEOL 420)

### GEOP 434, Remote Sensing with Geoscience Applications, 3 cr, 2 cl hrs, 3 lab hrs

*Prerequisite:* PHYS 122 or 132, or consent of instructor

Emphasis on basic physical principles, imaging principles and systems, image processing, and interpretation of remotely sensed data. Remote sensing applications to atmospheric sciences, hydrology, forestry, agriculture, and mineral and oil exploration, natural hazards monitoring (earthquakes, volcanoes, droughts and floods, landslides, land subsidence, forest fires), and land and resource management. GEOP 434 and 534 lectures shared, but 534 is graded separately and additional graduate-level work is required. (Same as GEOL/HYD 434)

### GEOP 445, Exploration Geophysics I, 3 cr, 2 cl hrs, 3 lab hrs

*Prerequisites:* PHYS 121 or equivalent; GEOL 101; upper-class standing

An introductory course on seismic refraction and reflection imaging of the subsurface, including methods of data acquisition, processing, and interpretation in two and three dimensions. Designed for students with a range of earth science and engineering backgrounds.

### GEOP 446, Exploration Geophysics II, 3 cr, 2 cl hrs, 3 lab hrs

*Prerequisites:* PHYS 122 or equivalent; GEOL 101; upper-class standing

Introduction to gravity, magnetic, electrical and electromagnetic methods of geophysical exploration. Surface and subsurface methods. Physical principles, applications, inversion methods.

### GEOP 448, General Geophysics, 3 cr, 3 cl hrs

*Prerequisites:* PHYS 122 or equivalent; GEOL 101; upper-class standing

An introduction to the general field of solid earth geophysics. Subjects covered are the origin of the earth; structure and internal properties of the earth; gravity, magnetic, and temperature fields of the earth; origin of the earth's atmosphere, hydrosphere, and surface features.

### GEOP 491, Advanced Problems, hrs and crs to be arranged

### GEOP 492, Senior Field Experience, hrs and crs to be arranged

*Prerequisite:* GEOP 325 or 445 or 446; or consent of instructor

Individual field-based research planned and carried out by the student under the direction of a geophysics program faculty member. Work will be evaluated based on a written report documenting the research goals, field methods used, and data analysis and interpretation. Alternatively, this requirement may be satisfied by successful completion of a summer geophysical field course approved by the faculty.

### GEOP 500, Directed Research, cr to be arranged

*This course may not be used to fulfill graduate degree requirements.*

Research under the guidance of a faculty member.

### GEOP 505, Analysis of Time Series and Spatial Data, 3 cr, 3 cl hrs

*Offered in alternate years*

An introductory overview of methods for analyzing temporal and spatial series with an emphasis on scientific applications. Linear systems in continuous and discrete time, Fourier analysis, spectral estimation, convolution and deconvolution, filtering, the z and Laplace transforms, stationary and nonstationary time series, ARIMA modeling, forecasting, and generalizations to multidimensional and multichannel applications. (Same as MATH 587 and HYD 587)

### GEOP 523, Theoretical Seismology, 3 cr, 3 cl hrs

*Offered in alternate years*

Linear elastic wave theory including reflection and refraction of elastic waves, propagation of body and surface waves, free oscillations of an elastic sphere, seismic rays in a spherically-stratified earth, and earthquake mechanisms.

### GEOP 524, Observational Seismology, 3 cr, 3 cl hrs

*Offered in alternate years*

Techniques and methods in earthquake seismology including seismometry and seismic networks, earthquake location, earthquake statistics, strong-motion seismology, and seismic source parameters.

### GEOP 525, Tectonophysics, 3 cr, 3 cl hrs

*Offered on demand*

An analytical study of the problems of earthquake generation, faulting, mountain building, and volcanism. Emphasis is placed upon the formulation of mathematical models which explain the physical observations.

### GEOP 529, Geophysical Inverse Methods, 3 cr, 3 cl hrs

*Offered in alternate years*

Theory and practice of the various techniques of inverting geophysical data to obtain models. Primary emphasis is on the understanding and use of linear inverse techniques. (Same as MATH 519)

**GEOP 534, Remote Sensing with Geoscience Applications, 3 cr, 2 cl hrs, 3 lab hrs**

*Prerequisite:* PHYS 122 or 132, or consent of instructor

Emphasis on basic physical principles, imaging principles and systems, image processing, and interpretation of remotely sensed data. Remote sensing applications to atmospheric sciences, hydrology, forestry, agriculture, and mineral and oil exploration, natural hazards monitoring (earthquakes, volcanoes, droughts and floods, landslides, land subsidence, forest fires), and land and resource management. GEOP 434 and 534 lectures shared, but 534 is graded separately and additional graduate-level work is required. (Same as GEOL/HYD 534)

**GEOP 543, 544, 545, Geodynamics, 3 cr, 3 cl hrs each course**

*Offered on demand*

Applications of continuum physics to geologic problems. Topics include plate tectonics, stress and strain, elasticity and flexure, heat transfer, gravity, fluid mechanics, rock rheology, thermal subsidence of sedimentary basins, faulting, and flow in porous media.

**GEOP 556, Fluids in Faults and Shear Zones, 3 cr, 3 cl hrs**

*Prerequisite:* Graduate standing or consent of instructor

*Offered on demand*

A seminar class. Processes by which permeability along faults and shear zones is decreased or enhanced, evidence of and mechanisms of fluid movement in faults and shear zones, fault valve behavior, water weakening of minerals, and geochemical processes near the surface and at depth. (Same as GEOL 556, HYD 556)

**GEOP 558, Mechanics of Earthquakes and Faulting, 3 cr, 3 cl hrs**

*Prerequisites:* GEOL 353 or equivalent and graduate standing; or consent of instructor

*Offered on demand*

Observational and theoretical aspects of brittle failure in the Earth. Fracture mechanics; fault zone geometry and structure; earthquake sources; paleoseismic studies; seismic hazard assessments. (Same as GEOL 558)

**GEOP 570, Current Topics in Earthquake Seismology, 3 cr, 3 cl hrs**

*Prerequisite:* consent of instructor

*Offered in alternate years*

A seminar of current research topics in earthquake seismology with an emphasis on the critical review of recently published papers and preprints.

**GEOP 571, 572, Advanced Topics in Geophysics, 2–3 cr each semester**

*Offered on demand*

Study of advanced topics in geophysics.

**GEOP 581, Directed Study, cr to be arranged**

Study under the guidance of a member of the graduate faculty. In general, subject matter will supplement that available in the other graduate course offerings.

**GEOP 590, Independent Study, cr to be arranged**

In this course, the student must clearly demonstrate the ability to organize and pursue research. A written final report is required. At the discretion of the instructor, other faculty members may be requested to review the final report.

**GEOP 591, Thesis (master's program), cr to be arranged****GEOP 592, Graduate Seminar, 1 cr, 1 cl hr**

*Prerequisite:* Graduate standing

*Offered spring semesters*

Seminar presentations by graduate students on their current research topics. M.S. students must present at least one seminar; Ph.D. students must present at least one seminar in each of two different semesters. Graded on S/U basis; credits earned may not be applied towards the 30 credits required for the M.S. degree (same as GEOL 592, GEOC 592, HYD 592)

**GEOP 593, Seminar, 1 cr, 1 cl hr**

*Prerequisite:* Graduate standing

*Offered fall and spring semesters*

Seminar presentations by faculty, students, and outside speakers. Graded on S/U basis. Satisfactory performance consists of regular attendance at approved seminars. Credit earned may not be applied towards the 30 credits required for the M.S. degree. (Same as GEOC 593, GEOL 593, HYD 593)

**GEOP 595, Dissertation (doctoral degree program), cr to be arranged**

# Geochemistry

The Geochemistry program offers an undergraduate degree in Earth Science with Geochemistry Option. See page 66.

## Master of Science in Geochemistry

The Master of Science degree in Geochemistry may be earned either with thesis or without thesis in accordance with the general requirements of the Graduate Program.

The master's candidate must demonstrate competence in chemistry, geology, mathematics, and physics comparable to the requirements for the Bachelor of Science degree in either chemistry, one of the engineering sciences, or one of the geological sciences.

A program of study for the master's degree must be approved by the student's advisory committee and must satisfy the general requirements for the degree, including Geochemistry 590 (at least three credit hours) or GEOC 591 (at least six credit hours). Students must complete two credit hours of GEOC 592, at least four credit hours of GEOC 593 (unless the degree is completed in a shorter time), 12 credit hours in geochemistry, and six credit hours in upper-division or graduate chemistry courses. As part of the degree requirements, students must have completed CHEM 331; GEOC 443, 444; GEOL 211; or their equivalents.

## Doctor of Philosophy in Earth and Environmental Science with Dissertation in Geochemistry

Students of exceptional ability as demonstrated in previous courses or in a master's degree program may pursue a program leading to the doctoral degree.

The prospective doctoral candidate in earth and environmental science with specialization in geochemistry should develop a good background in chemistry, geology, mathematics, and physics in addition to achieving a high level of competence in the field of specialization. Ph.D. students must include three credit hours of GEOC 592 and at least six credit hours of GEOC 593, unless the degree is completed in a shorter time. Additional information is found under the Graduate Program (page 28).

Fields of doctoral dissertation research include geochemistry of ore deposits, trace element and isotope geochemistry of igneous and metamorphic systems, fluid-inclusion geochemistry, geochronology, hydrogeochemistry, stable isotope geochemistry, and environmental geochemistry. Interdisciplinary programs in the earth science fields are encouraged.

## Geochemistry Courses:

**GEOC 408, Cooperative Education**

On-the-job training to supplement the academic program. Students alternate periods (usually six months long) of full-time semiprofessional employment in their chosen field with periods of full-time academic study. See page 36 for more information about this program.

**GEOC 422, Environmental Geochemistry, 3 cr, 3 cl hrs**

*Prerequisites:* Any two of the following: CHEM 311, 331, or 333

*Offered in alternate years*

Application of chemical principles to the study of the environment. Includes natural processes and pollution problems related to water, air, and soil. (Same as CHEM 422)

**GEOC 431, Exploration and Environmental Trace Element Geochemistry, 3 cr, 2 cl hrs, 3 lab hrs**

*Prerequisites:* GEOL 102, 211; CHEM 122

*Offered fall semester, alternate years*

Distribution of trace elements in surficial and deep-seated environments. Processes of trace element dispersion and mobility of trace elements in surficial environments. Trace element anomalies as guides to mineral deposits. A field project will be a required part of the course work. Field trips.

**GEOC 443, Principles of Geochemistry, 3 cr, 3 cl hrs***Prerequisites: CHEM 122; GEOL 211**Offered spring semester, even-numbered years*

Application of chemical principles to geologic processes.

**GEOC 444, Principles of Isotope Geochemistry, 3 cr, 3 cl hrs***Prerequisites: CHEM 122; GEOL 211**Offered fall semester, odd-numbered years*

Principles of radiogenic isotope geochemistry and applications to geologic dating and to the petrogenesis of rock suites.

**GEOC 491, Advanced Problems, hrs and cr to be arranged**

Detailed investigation of a limited area of a problem; presentation of a written report. Work may extend over one or more semesters or a summer session.

**GEOC 492, Senior Thesis, 3 cr***Prerequisite: 3.0 GPA in earth science courses and consent of instructor*

Individual research under the direction of a faculty member. Two semesters are usually necessary to complete the research project. Grading will be based on a written report which details the research goals, data collected, interpretation, and conclusions.

**GEOC 500, Directed Research, cr to be arranged***This course may not be used to fulfill graduate degree requirements.*

Research under the guidance of a faculty member.

**GEOC 507, Hydrogeochemistry, 3 cr, 3 cl hrs***Prerequisite: CHEM 122**Pre- or Corequisite: HYD 403 or 503*

The thermodynamics and aqueous chemistry of natural waters, with emphasis on groundwater. Chemical equilibrium concepts, surface chemistry, redox reactions, and biochemistry. The interaction of water with the atmosphere and geologic materials. Basic concepts applied to problems of groundwater quality evolution, water use, and groundwater contamination. (Same as HYD 507)

**GEOC 516, <sup>40</sup>Ar/<sup>39</sup>Ar Geochronology, 4 cr, 3 cl hrs, 3 lab hrs***Prerequisite: Geochemistry 444**Offered spring semester, alternate years*Principles and applications of <sup>40</sup>Ar/<sup>39</sup>Ar geochronology and thermochronology, including field and laboratory methods.**GEOC 517, Advanced <sup>40</sup>Ar/<sup>39</sup>Ar Geochronology, 3 cr, 3 cl hrs**Advanced topics, specialized applications, and current research in <sup>40</sup>Ar/<sup>39</sup>Ar geochronology.**GEOC 535, Crustal and Mantle Evolution, 3 cr, 3 cl hrs**

Origin and evolution of continents and evolution of the mantle. (Same as GEOL 535)

**GEOC 543, Mineral Equilibria, 3 cr, 2 cl hrs, 3 lab hrs***Offered spring semester, alternate years*

Application of chemical thermodynamics to mineral stabilities in aqueous systems.

**GEOC 552, X-ray Fluorescence Spectrometry, 1–2 cr, 3 lab hrs***Offered on demand*

Theory and application of x-ray fluorescence to the analysis of geologic materials.

**GEOC 554, Fluid Inclusions, 1–2 cr, 6 lab hrs***Offered on demand*

Theory and application of thermometric analysis to fluid inclusions.

**GEOC 558, Environmental Tracers in Hydrology, 3 cr, 3 cl hrs***Prerequisites: HYD 403 or 503; HYD 507**Offered in alternate years*Atomic structure and abundances of environmental isotopes. Stable isotope fractionation. Mass spectrometry. Applications of the stable isotopes of hydrogen, oxygen, and carbon to meteorology and hydrology. Radioactive decay and radionuclide production. Applications of tritium, <sup>3</sup>He, <sup>14</sup>C, <sup>36</sup>Cl, and other radionuclides. Application of CL, Br, chlorofluorocarbons and other environmental tracers to hydrologic problems. (Same as HYD 558)**GEOC 561, Ore Genesis, 3 cr, 3 cl hrs***Offered spring semester, alternate years*

Principles of the geochemistry of ore deposits including stable isotopes, lead isotopes, solution geochemistry, and element partitioning. Review of recent tectonic and geochemical generic models of hydrothermal, magmatic, and sedimentary ore deposits. (Same as GEOL 561)

**GEOC 562, Ore Genesis, 3 cr, 3 cl hrs***Offered fall semester, alternate years*

Principles of the geochemistry of ore deposits including stable isotopes, solution geochemistry, and element partitioning. Review of recent tectonic and geochemical generic models of hydrothermal, magmatic, and sedimentary ore deposits. (Same as GEOL 562)

**GEOC 565, Stable Isotope Geochemistry, 3 cr, 3 cl hrs***Offered spring semester*

Principles of stable isotope geochemistry with applications to geologic systems.

**GEOC 566, Practical Aspects of Mass Spectrometry, 3 cr, 1 cl hr, 6 lab hrs***Prerequisites: GEOC 565; consent of instructor**Offered fall semester*

Theory and application of stable isotope mass spectrometry. Through lectures, problem sets, and laboratory exercises, students learn how to analyze geologic samples to determine stable isotope composition.

**GEOC 571, 572, Advanced Topics in Geochemistry, 2 or 3 cr**

Study of a special topic in geochemistry, normally one related to a field of research at Tech.

**GEOC 575, Theory and Practice of Electron Microprobe Analysis, 1 cr***Prerequisites: GEOL 211; GEOL 318 or 319; consent of instructor*

Principles, techniques and applications of electron microprobe analysis: X-ray theory, sample preparation techniques, hands-on analysis using the electron microprobe, techniques of instrument calibration and data reduction. Emphasis on analysis of geological samples. Class participation is required for students who plan to use the electron microprobe as part of their thesis research. Class time will be divided between lecture and hands-on sample preparation and analysis.

**GEOC 581, Directed Study, cr to be arranged**

Study under the guidance of a member of the geochemistry staff. In general, subject matter will supplement that available in the other graduate offerings in geochemistry.

**GEOC 590, Independent Study, cr to be arranged**

In this course, the student must clearly demonstrate the ability to organize and pursue research. A written final report is required. At the discretion of the instructor, other faculty members may be requested to review the final report.

**GEOC 591, Thesis (master's program), cr to be arranged****GEOC 592, Graduate Seminar, 1 cr, 1 cl hr***Prerequisite: Graduate standing**Offered spring semesters*

Seminar presentations by graduate students on their current research topics. M.S. students must present at least one seminar; Ph.D. students must present at least one seminar in each of two different semesters. Graded on S/U basis; credits earned may not be applied towards the 30 credits required for the M.S. degree (same as GEOL 592, GEOP 592, HYD 592)

**GEOC 593, Seminar, 1 cr, 1 cl hr***Prerequisite: Graduate standing**Offered fall and spring semesters*

Seminar presentations by faculty, students, and outside speakers. Graded on S/U basis. Satisfactory performance consists of regular attendance at approved seminars. Credit earned may not be applied towards the 30 credits required for the M.S. degree. (Same as GEOL 593, GEOP 593, HYD 593)

**GEOC 595, Dissertation (doctoral degree program), cr to be arranged**

# Hydrology

## Five-Year Program: Science or Engineering B.S./Hydrology M.S. Degree

The five-year B.S./Hydrology M.S. degrees are achieved by fulfilling the separate requirements of both an undergraduate degree in a science or engineering field and a graduate degree in hydrology in a five-year period. A minimum of 158 total credit hours is required to complete both degrees.

Students should apply to the program at the end of their sophomore year. Admission is contingent upon the acceptability of a proposed course of study, academic performance, and on the number of vacancies in the program. Students having upper-division standing may also be considered, depending upon prior course work.

Once admitted to the program, every undergraduate student will work with a research group. Required courses include:

- HYD 491 (one credit hour per semester for three semesters)
- HYD 503, 503L, 507, 508, 512, 512L, 517, 521, 533
- HYD 591 (at least six credit hours)
- HYD 592 (two credit hours)
- GEOL 102
- MATH 335 and 335L and either MATH 283 or 382

During the senior year, the student in this program must select a graduate advisory committee and formalize his or her graduate research topic.

Students in the Hydrology five-year program must normally apply for graduate standing at the end of their seventh semester. Graduate admission will be contingent upon adherence to the approved program of studies, a 3.0 cumulative grade point average, and a 3.0 earned grade point average in mathematics, science, and engineering courses. Graduate status will be granted upon fulfillment of the requirements for the B.S. degree.

## Graduate Program

### Master of Science in Hydrology

The Master of Science degree in Hydrology requires completion of a thesis according to the general requirements of the Graduate Program.

The student's course of study must be approved by the student's advisory committee and must fulfill the general requirement for the master's degree and must include:

- HYD 503, 503L, 507, 508, 512, 512L, 517, 521, and 533
- HYD 591 (at least six credit hours)
- HYD 592 (two credit hours).
- GEOL 102 or equivalent
- MATH 335 and 335L and either MATH 283 or 382 or equivalents

Examples of courses other than hydrology which are appropriate for graduate programs in hydrology include, but are not limited to: BIOL 343, 442, 446; CHEM 331, 332, 333, 334; GEOC 443, 444, 543; GEOL 353, 403, 409, 460, 503, 509, 526; GEOP 370, 445, 446, 448, 505, 529; MATH 332, 382, 384, 410, 411, 415, 433, 434, 435, 436, 438, 483, 486, 488, 511, 512, 533, 534, 586, 587; PETR 445, 523, 526, 544, 546, 564; PHYS 421, 526.

### Doctor of Philosophy in Earth and Environmental Science with Dissertation in Hydrology

Students of exceptional ability as demonstrated in previous courses or in a master's degree program may pursue a program leading to the doctoral degree.

The prospective doctoral candidate in earth and environmental science with specialization in hydrology should develop a good background in physics, mathematics, chemistry, and geology in addition to achieving a high level of competence in the field of specialization.

With approval of the advisory committee, the student should select a program including a minimum of nine credits in graduate hydrology beyond the M.S. degree, three credits of HYD 592, plus additional courses in related fields. Some appropriate courses are given under the Master of Science degree requirements.

Research fields appropriate for the doctoral candidate are regional hydrology, groundwater recharge, vadose zone hydrology, stochastic subsurface hydrology, hydrogeochemistry, isotope hydrology, hydroclimatology, pollutant transport, aquifer restoration, multi-phase flow of immiscible fluids, deterministic and stochastic numerical aquifer simulation, finite difference and finite element numerical methods, and field instrumentation. Interdisciplinary programs in the earth science fields are encouraged.

## Hydrology Courses:

### HYD 403, Groundwater Hydrology, 3 cr, 3 cl hrs

*Prerequisite: MATH 231 or consent of instructor; upper-class standing*

Fundamentals of groundwater hydrology. The hydrologic cycle, Darcy's law, aquifer parameters, steady and transient flow equations, well hydraulics, elementary multi-phase flow, groundwater recharge, watershed hydrology, geological controls on groundwater flow, well construction, and groundwater chemistry and pollution. Shares lecture with HYD 503 but is graded separately.

### HYD 412, Surface Water Hydrology, 3 cr, 3 cl hrs

*Prerequisites: PHYS 121; MATH 132; upper-class standing*

Theory, observations and modeling of the physical processes in the land-phase of the hydrologic cycle. Processes considered include atmospheric radiation, surface energy balance, precipitation, infiltration, runoff generation, streamflow and open channel hydraulics, evapotranspiration, rainfall interception, snow melt and shallow subsurface flow. Catchment hydrologic processes illustrated through case study in the Rio Grande and its subbasins. Remote sensing, geographical information systems (GIS) and hydrologic model applications to surface hydrology. Shares lectures with HYD 512 but is graded separately.

### HYD 434, Remote Sensing with Geoscience Applications, 3 cr, 2 cl hrs, 3 lab hrs

*Prerequisite: PHYS 122 or 132, or consent of instructor*

Emphasis on basic physical principles, imaging principles and systems, image processing, and interpretation of remotely sensed data. Remote sensing applications to atmospheric sciences, hydrology, forestry, agriculture, and mineral and oil exploration, natural hazards monitoring (earthquakes, volcanoes, droughts and floods, landslides, land subsidence, forest fires), and land and resource management. HYD 434 and 534 lectures shared, but 534 is graded separately and additional graduate-level work is required. (Same as GEOL/GEOP 434)

### HYD 491, Special Problems, 1–5 cr

An introduction to methods of research. Problems are chosen from the field of hydrology and may be small independent investigations or a part of a research program being directed by the instructor.

### HYD 500, Directed Research, cr to be arranged

*This course may not be used to fulfill graduate degree requirements.*

Research under the guidance of a faculty member.

### HYD 503, Groundwater Hydrology, 3 cr, 3 cl hrs

*Prerequisite: Math 231 or consent of instructor*

Fundamentals of groundwater hydrology. The hydrologic cycle, Darcy's law, aquifer parameters, steady and transient flow equations, well hydraulics, elementary multi-phase flow, groundwater recharge, watershed hydrology, geological controls on groundwater flow, well construction, and groundwater chemistry and pollution. Shares lecture with HYD 403 but is graded separately.

### HYD 503L, Groundwater Hydrology Laboratory, 1 cr, 3 lab hrs

*Pre- or corequisite: HYD 403 or 503*

A series of experiments and problems illustrating flow and transport in porous media, together with applied problems.

**Hydrology 507, Hydrogeochemistry, 3 cr, 3 cl hrs***Prerequisite:* CHEM 122*Pre- or Corequisite:* HYD 403 or 503

The thermodynamics and aqueous chemistry of natural waters, with emphasis on groundwater. Chemical equilibrium concepts, surface chemistry, redox reactions, and biochemistry. The interaction of water with the atmosphere and geologic materials. Basic concepts applied to problems of groundwater quality evolution, water use, and groundwater contamination. (Same as GEOC 507)

**HYD 508, Flow and Transport in Hydrologic Systems, 3 cr, 3 cl hrs***Prerequisites:* HYD 403 or 503; MATH 335 or HYD 533

Principles of flow and transport in groundwater aquifers, the vadose zone, and surface water bodies. Mass, momentum and energy conservation. Storage, compressibility, capillarity, and Darcy's law in porous media. Single phase, two phase and Richard's equations approaches to flow in porous media. Flow in fractures and streams. Transport of non-reactive chemical species by advection, diffusion and dispersion in porous and fractured media, and surface water bodies.

**HYD 512, Surface Water Hydrology, 3 cr, 3 cl hrs***Pre- or Corequisites:* MATH 335 or HYD 533; HYD 403 or 503

Theory, observations and modeling of the physical processes in the land-phase of the hydrologic cycle. Processes considered include atmospheric radiation, surface energy balance, precipitation, infiltration, runoff generation, streamflow and open channel hydraulics, evapotranspiration, rainfall interception, snow melt and shallow subsurface flow. Catchment hydrologic processes illustrated through case study in the Rio Grande and its subbasins. Remote sensing, geographical information systems (GIS) and hydrologic model applications to surface hydrology. Shares lectures with HYD 412 but is graded separately.

**HYD 512L, Surface Water Hydrology Laboratory, 1 cr, 3 lab hrs***Pre- or Corequisite:* HYD 412 or 512, or consent of instructor

Practical problems in surface water hydrology, including computer exercises in catchment hydrologic processes with data analysis, geographic information systems (GIS), remote sensing data and hydrologic models.

**HYD 513, Hydrometeorology, 3 cr, 3 cl hrs***Prerequisites:* HYD 503, 508, 512

Theory and observations of hydrologic processes in land-surface and atmosphere. Exchange of mass, heat, and momentum between the soil, vegetation, or water surface and the overlying atmosphere. Precipitation processes, radiation and clouds, atmospheric boundary layer dynamics, coupled balance of moisture and energy, soil moisture and climate feedback, hydroclimatology, monsoonal flow and thunderstorms. Emphasis on recent research and modern methods for data analysis and modeling.

**HYD 517, Vadose Zone Hydrology, 3 cr, 3 cl hrs***Prerequisite:* HYD 508; or consent of instructor.

Physical processes governing fluid, vapor, heat, and solute movement between the land surface and the ground water table. Determination of soil physical properties in the laboratory and field. Application of the model HYDRUS1D for evaluation of water flow and contaminant movement in the vadose zone.

**HYD 521, Hydrogeologic Processes, 3 cr, 3 cl hrs***Prerequisites:* GEOL 102, 102L; HYD 507, 508

Geologic controls of the occurrence, movement, and quality of groundwater. Hydrologic properties of earth materials. Theory and study of specific hydrogeologic processes including water resource evaluation and well hydraulics, barometric and tidal responses of aquifers, regional groundwater flow, coupled groundwater and heat flow, fracture flow, saturated multiphase flow such as petroleum migration, diagenesis and reactive groundwater flow, coupled groundwater flow and rock deformation, and other issues. (Same as GEOL 521)

**HYD 522, Advanced Hydrogeologic Processes, 3 cr, 3 cl hrs***Prerequisite:* HYD 521*Offered on demand*

Advanced study of the effect of groundwater flow on geologic processes and vice-versa. Roles of groundwater within sedimentary basins, mountain massifs, the seafloor, faults, fractures, and other structures. Hydrothermal flow and its effect on petroleum generation and migration, ore formation. Fault and fracture formation, earthquakes and associated hydrogeologic processes. Emphasis on case studies, including recent research and modern methods of analysis.

**HYD 532, Groundwater Modelling, 3 cr, 3 cl hrs***Prerequisites:* HYD 508*Offered on demand*

Analysis and synthesis of hydrology problems. Conceptual modelling process: parameter estimation, model validation, and model prediction. Mathematical models for steady and transient flow and pollutant transport. Applications to well hydraulics, water supply, regional flow, recharge and infiltration, subsidence, sea water intrusion, surface water/groundwater interaction, groundwater pollution, and geotechnical problems. Case studies.

**HYD 533, Practicum in Quantitative Methods, 1 cr, 3 lab hrs***Corequisite:* HYD 403 or 503

Instruction and practice in computational methods used to solve hydrological problems. Introduction to spreadsheets, graphics programs, and statistical packages. Vector and matrix operations and finite difference programming using mathematical packages. Introduction to structured programming and subroutine libraries. Graded on S/U basis; credits earned may not be used to apply to the 30 credit hours required for the M.S. degree.

**HYD 534, Remote Sensing with Geoscience Applications, 3 cr, 2 cl hrs, 3 lab hrs***Prerequisite:* PHYS 122 or 132, or consent of instructor

Emphasis on basic physical principles, imaging principles and systems, image processing, and interpretation of remotely sensed data. Remote sensing applications to atmospheric sciences, hydrology, forestry, agriculture, and mineral and oil exploration, natural hazards monitoring (earthquakes, volcanoes, droughts and floods, landslides, land subsidence, forest fires), and land and resource management. HYD 434 and 534 lectures shared, but 534 is graded separately and additional graduate-level work is required. (Same as GEOL/GEOP 534)

**HYD 538, Geographic Information Systems with Geoscience Applications, 3 cr, 2 cl hrs, 3 lab hrs***Prerequisite:* Consent of instructor

An introduction to geographic information systems (GIS) with a focus on applications in the geosciences, including geology, hydrology, environmental science and natural resources. Emphasis on theoretical aspects and practical applications of GIS science and technology and its integration with remote sensing data and field measurements. Computing exercises and projects utilizing ArcGIS software. Particular focus on spatial hydrology, terrain analysis, and geologic and vegetation mapping. Discussion of GIS integration with geoscience modeling. Shares lecture with ENV5 438 but is graded separately. (Same as GEOL 538)

**HYD 542, Numerical Simulation of Groundwater Hydrology, 4 cr, 3 cl hrs, 3 lab hrs***Prerequisites:* MATH 335; CS 410 or MATH 410; HYD 508; or consent of instructor*Offered in alternate years*

An introductory course in finite difference methods and finite element methods for solving flow and transport problems in groundwater hydrology and petroleum engineering. Differential equations, finite difference approximations, finite element concepts. Applications to saturated, unsaturated, and multiphase flow, and to miscible displacement and pollutant transport.

**HYD 543, Advanced Numerical Simulation Methods, 3 cr, 3 cl hrs**

*Prerequisites:* HYD 542 or PETR 523; MATH 511; and consent of instructor  
*Offered on demand*

Focuses on selected topics (examples given below) from recent research on numerical simulation methods with applications to fluid flow and miscible displacement in groundwater and petroleum reservoirs. Equation solvers, including conjugate gradient, multi-grid, and adaptive grid methods; domain decomposition; sensitivity and uncertainty analysis; higher order finite differences and finite elements; mixed finite element methods; front tracking and backward method of characteristics.

**HYD 545, Stochastic Methods in Groundwater Hydrology, 3 cr, 3 cl hrs**

*Prerequisites:* HYD 508; MATH 382, 586

*Offered in alternate years*

Selected topics from the theory of stochastic processes and random fields with applications to natural variability in groundwater hydrology; stochastic differential equations, spectral representation, perturbation methods, Monte Carlo simulation, Kalman filtering, kriging, Bayesian estimation, conditional simulation and related topics. Applications include estimation of aquifer parameters, effective properties of heterogeneous media, macroscopic dispersion, and monitoring network design.

**HYD 546, Contaminant Hydrology, 3 cr, 3 cl hrs**

*Prerequisites:* HYD 403 or 503; HYD 507

*Pre- or Corequisite:* HYD 508

The physics, chemistry, and biology of inorganic, organic, and microbial contaminants in groundwater and surface water systems. Mechanisms by which contaminants are introduced. Transport and transformations of contaminants in surface waters, the vadose zone, and the saturated zones. Movement, capillary trapping, and solubility of relatively immiscible organic liquids. Contaminant isolation and remediation techniques.

**HYD 548, Laboratory and Field Methods in Hydrology, 3 cr, 1 cl hr, 6 lab hrs**

*Prerequisite:* HYD 403 or 503; HYD 503L and 507

*Offered on demand*

Instrumentation and methodologies used in hydrological investigations, with an emphasis on contaminant hydrology. Experiments include sorption isotherms, miscible displacement, well installation, sample collection and storage, aquifer characterization, tracer tests, and physical and chemical characterization of sediments, soils, and aquifer materials.

**HYD 552, Fluid/Surface Interactions, 3 cr, 3 cl hrs**

*Prerequisite:* Consent of instructor

*Offered in alternate years*

The physics and chemistry of interfaces, focusing on the behavior of multifluid systems both in the presence and absence of solids. How basic interactions among microscopic particles can explain macroscopic phenomena. Application-oriented, focusing on interactions important in hydrology, petroleum engineering, and environmental engineering. (Same as PETR 552)

**HYD 554, Environmental Physics for Evapotranspiration, 3 cr, 3 cl hrs**

*Prerequisites:* HYD 512, 517; or consent of instructor.

The first part of the course includes elements of environmental physics: radiation balance of the earth's surface; transfer of momentum, heat, and mass; and crop micrometeorology. The second part focuses on vegetation water use and evapotranspiration: measurement methods; evaluation from meteorological observations; and prediction of spatial and temporal distribution of regional evapotranspiration using remote sensing.

**HYD 556, Fluids in Faults and Shear Zones, 3 cr, 3 cl hrs**

*Prerequisite:* Graduate standing or consent of instructor

*Offered alternate years*

A seminar class. Processes by which permeability along faults and shear zones is decreased or enhanced, evidence of and mechanisms of fluid movement in faults and shear zones, fault valve behavior, water weakening of minerals, and geochemical processes near the surface and at depth. (Same as GEOL 556, GEOP 556)

**HYD 558, Environmental Tracers in Hydrology, 3 cr, 3 cl hrs**

*Prerequisites:* HYD 403 or 503; HYD 507

*Offered in alternate years*

Atomic structure and abundances of environmental isotopes. Stable isotope fractionation. Mass spectrometry. Applications of the stable isotopes of hydrogen, oxygen, and carbon to meteorology and hydrology. Radioactive decay and radionuclide production. Applications of tritium,  $^3\text{He}$ ,  $^{14}\text{C}$ ,  $^{36}\text{Cl}$ , and other radionuclides. Application of Cl, Br, chlorofluorocarbons and other environmental tracers to hydrologic problems. (Same as GEOC 558)

**HYD 560, Applied Groundwater Hydrology, 3 cr, 2 cl hrs, 3 lab hrs**

*Prerequisites:* HYD 508

*Offered on demand*

Topics for in-depth investigation may include well design, aquifer pumping test design and interpretation, groundwater flow simulation, and aquifer contamination. Field experiments, field trips, lab analysis, computer work, technical report preparation, and oral presentations.

**HYD 564, Advanced Well Hydraulics, 3 cr, 3 cl hrs**

*Prerequisites:* HYD 508 or PETR 445

*Offered on demand*

Discussion of well hydraulics theories for confined, unconfined, leaky, and fractured aquifers. Use of well hydraulics solutions to characterize aquifer hydrogeological features (formation evaluation) and to estimate important model parameters. Similarity overlays in various well hydraulics theories developed in hydrogeology and petroleum reservoir engineering.

**HYD 567, Advances in Flow and Transport, 3 cr, 3 cl hrs**

*Prerequisite:* HYD 508

*Offered on demand*

Review of fundamental fluid mechanics: continuity, Euler, Bernoulli, potential flow, and Navier-Stokes equations; related applications. Ensemble averaging of flow and transport in fractures and porous media: tortuosity, effective properties, Darcy's law, dispersion, multi-phase behavior, capillary percolation.

**HYD 570, Seminar in Hydrology, 2 cr, 2 cl hrs**

Review and discussion of papers relating to hydrology.

**HYD 571, 572, Advanced Topics in Hydrology, 2–3 cr each semester**

*Offered on demand*

Study of special topics in hydrology.

**HYD 581, Directed Study, cr to be arranged**

Study under the guidance of a member of the graduate faculty. In general, subject matter will supplement that available in the other graduate course offerings.

**HYD 587, Analysis of Time Series and Spatial Data, 3 cr, 3 cl hrs**

*Offered in alternate years*

An introductory overview of methods for analyzing temporal and spatial series with an emphasis on scientific applications. Linear systems in continuous and discrete time, Fourier analysis, spectral estimation, convolution and deconvolution, filtering, the  $z$  and Laplace transforms, stationary and nonstationary time series, ARIMA modeling, forecasting, and generalizations to multidimensional and multichannel applications. (Same as MATH 587 and GEOP 505)

**HYD 591, Thesis (master's program), cr to be arranged****HYD 592, Graduate Seminar, 1 cr, 1 cl hr**

*Prerequisite:* Graduate standing

*Offered spring semesters*

Seminar presentations by graduate students on their current research topics. M.S. students must present at least one seminar; Ph.D. students must present at least one seminar in each of two different semesters. Graded on S/U basis; credits earned may not be applied towards the 30 credits required for the M.S. degree (same as GEOL 592, GEOC 592, GEOP 592)

**HYD 593, Seminar, 1 cr, 1 cl hr**

*Prerequisite:* Graduate standing

*Offered fall and spring semesters*

Seminar presentations by faculty, students, and outside speakers. Graded on S/U basis. Satisfactory performance consists of regular attendance at approved seminars. Credit earned may not be applied towards the 30 credits required for the M.S. degree. (Same as GEOC 593, GEOL 593, GEOP 593)

**HYD 595, Dissertation (doctoral degree program), cr to be arranged**

## Faculty Research Interests

Aster—Earthquake and Volcanic Seismology, Seismic Tomography, Network Seismology  
 Bilek—Earthquake Rupture Processes, Stresses and Structure of Fault Zones, Shallow Subduction Zone Processes, Tsunami  
 Boston—Caves, Karst Systems, Geomicrobiology, Extremophile Organisms, Geobiochemical Cycling, Astrobiology, Robotic and Human Exploration of Other Planets, Comparative Planetology, Evolutionary Implications of Conjoined Organic/Cybernetic Devices  
 Bowman—Surface Chemistry, Solute Transport, Groundwater Contamination  
 A. R. Campbell—Metallic Ore Deposits, Stable Isotope Geochemistry  
 Condie—Trace Element and Isotope Geochemistry, Precambrian Studies  
 Harrison—Soil Properties, Recurrence Intervals of Earthquakes, Soil Salinization in Arid Environments, Soil Stability  
 Hendrickx—Soil-water Physics, Vadose Zone Hydrology, Soil Contamination  
 Johnson—Biostratigraphy, Paleozoic Depositional Environments  
 Kyle—Igneous Geochemistry, Antarctic Geology, Volcanology  
 McIntosh—Cenozoic Volcanism, Paleomagnetism, Antarctic Studies, Argon Dating  
 McPherson—Basin-scale Modeling, Physical Properties of Aquifer Materials, Simulation Modeling  
 Mozley—Environmental Geology, Sedimentary Petrology, Low-Temperature Geochemistry  
 Norman—Metallic Ore Deposits, Geochemistry of Ore Deposits, Fluid Inclusion Studies  
 Phillips—Groundwater Chemistry, Isotope Hydrology, Groundwater Dating, Quaternary Studies  
 Schlue—Seismology, Surface Waves, Crustal and Upper Mantle Structure, Rift Studies, Inverse Methods  
 Tobin—Physical Properties of Sediments and Fault Zones, Geophysical Detection of Fluids and Faults, Reflection Seismology, Subduction Zone Tectonics  
 Wilson—Groundwater Hydrology, Numerical and Analytical Modelling, Stochastic Hydrology, Colloid and Bacteria Transport

## Adjunct Faculty Research Interests

Austin—Clay Mineralogy, Industrial Minerals  
 Barker—Industrial Minerals, Mineral Economics, Economic Geology  
 Bauer—Structural Geology and Tectonics, Precambrian Geology  
 Brister—Petroleum Geology, Stratigraphy, Depositional Environments  
 Broadhead—Petroleum Geology, Stratigraphy  
 Buckley—Fluid Interactions in Porous Media  
 S. Cather—Clastic and Volcaniclastic Sedimentology, Basin Analysis, Regional Tectonics  
 Chapin—Volcanology, Tectonics, Economic Geology  
 Connell—Neogene and Quaternary Geology and Stratigraphy, Geomorphology  
 Dunbar—Igneous Petrology, Volcanology, Trace Element Behavior in High- and Low-Temperature Aqueous Systems, Microbial Geochemical Analysis  
 Fehler—Wave Propagation in the Heterogeneous Earth; Scattering, Imaging, and Development of Novel Methods for Modeling Wave Propagation in the Earth  
 Fletcher—Geomechanics, Structural Geology  
 Glass—Subsurface Flow and Transport  
 Goodwin—Spatial and Temporal Evolution of Faults and Shear Zones  
 Haneberg—Geomechanics, Engineering Geology, Structural Geology, Hydrogeology  
 Hawley—Geomorphology, Quaternary Stratigraphy, Environmental Geology, Hydrogeology

Heizler—<sup>40</sup>Ar/<sup>39</sup>Ar Thermochronology  
 Jaksha—Seismology  
 Kelley—Fission-Trace Thermochronology, Tectonics, Thermal Studies  
 D. Love—Environmental Geology, Quaternary Geology, Sedimentology  
 McCord—Vadose Zone Hydrology, Numerical Modeling, Stochastic Hydrology  
 McLemore—Economic Geology  
 Ralser—Structural Geology, Tectonics, GIS, Precambrian Geology  
 Reiter—Geothermics, Hydrogeothermics, Crustal Geodynamics  
 Scholle—Carbonate Sedimentology and Petroleum Geology; Controls on Diagenesis and Porosity in Chalks; Paleozoic Carbonates of New Mexico  
 Small—Hydroclimatology, Regional Climate Change, Geomorphology  
 Stephens—Hydrogeology, Unsaturated Flow, Groundwater Flow Modelling  
 Ulmer-Scholle—Carbonate Sedimentology, Diagenesis and Petrography  
 Whitworth—Hydrogeology, Hydrogeochemistry  
 Zhou—Remote Sensing

## Emeritus Faculty Research Interests

Balk—Cambrian-Ordovician Trilobites, Shallow Marine Carbonates, Paleozoic Stratigraphy  
 Budding—Metamorphic Petrology, Geotectonics  
 G. Gross—Electrical and Electrochemical Properties of Ice, Isotope Hydrology, Geophysics, Desert Geomorphology  
 Lattman—Geomorphology, Remote Sensing  
 Sanford—Earthquake Seismology, Crustal Exploration, Tectonophysics, Geophysical Methods for Shallow Exploration

## Environmental Science

*Environmental Science Advisory Committee:*

*Dr. Carl Popp, Chemistry*

*Dr. Bruce Harrison, Earth and Environmental Science*

*Dr. Rebecca Reiss, Biology*

*Dr. David Norman, Earth and Environmental Science*

*Dr. Clint Richardson, Environmental Engineering*

*Most faculty at New Mexico Tech have an interest in the application of their research to environmental problems. Their research interests are listed in the appropriate departmental section of the catalog.*

**Degrees Offered: B.S. in Environmental Science with Options in Biology, Chemistry, Geology, Hydrology, and Instrumentation and Measurements**

The Bachelor of Science degree in Environmental Science draws upon courses from biology, chemistry, earth science, physics, and environmental engineering. Students must be aware of the complexity of environmental problems, yet have a rigorous enough background to address specific aspects of those problems. To ensure that graduates are competitive in the marketplace, Environmental Science students take classes in all of the disciplines listed above. They also select a specialization in biology, chemistry, geology, hydrology, or instrumentation and measurements. Each option is sufficiently in-depth to allow students to continue their education in a traditional graduate program in that discipline, should they choose.

An advisory committee, composed of faculty from the specific disciplines, is available to help students plan their programs.

## Undergraduate Program

### Core Requirements for the Bachelor of Science Degree in Environmental Science

In addition to the General Degree Requirements (page 48), the following core program is required of all Environmental Science students:

- BIOL 331 (3), 343 & 343L (4)
- CHEM 311 & 311L (4), 333 & 333L (4), 422 & 422L (4)
- GEOL 102 & 102L (4), 341 (3)
- HYD 403 (3)
- ENVE 201 (3), 302 (2)
- CS 111 (4)
- MATH 231 (4), 283 (3)
- ENVS 472 (1)
- All students in the Environmental Science program are required to attend the Environmental Science Senior Seminar (ENVS 472) for four years or, if transfer students, for the duration of their enrollment in the Environmental Science program. In the first three years, students need only audit the seminar, but in their senior year, they are required to present at the seminar and take the class for a grade.
- Three credit hours of courses numbered 491 and 492 taken in the appropriate department in the subject area of environmental science. These credit hours shall comprise a supervised research project, supervised scholarship project, or a supervised internship, and must result in a written paper or senior thesis. Prior to beginning the research project or internship, the student must prepare a short proposal of the activity. This proposal must be approved by the student's advisor and two faculty from the Environmental Science Advisory Committee. Following completion of the project, all three faculty must sign off on the resulting research paper.

### Bachelor of Science in Environmental Science with Biology Option

Minimum credit hours required—135

In addition to the General Degree Requirements (page 48), and the core Environmental Science Requirements (above), the following courses are required:

- BIOL 112 & 112L (4), 211 & 211L (4), 333 & 333L (4)
- Technical Electives (12)—Chosen from BIOL 341 & 341L (4), 344 & 344L (4), 447 & 447L (4)

### Bachelor of Science in Environmental Science with Chemistry Option

Minimum credit hours required—135

In addition to the General Degree Requirements (page 48), and the core Environmental Science Requirements (above), the following courses are required:

- CHEM 331 & 331L (4), 334 & 334L (4), 411 & 411L (4)
- Technical Electives (14)—Recommended technical electives, which must be approved by the advisory committee, include CHEM 332, 441, 442

### Bachelor of Science in Environmental Science with Geology Option

Minimum credit hours required—135

In addition to the General Degree Requirements (page 48), and the core Environmental Science Requirements (above), the following courses are required:

- GEOL 211 (4), 306 (3), 318 (3), 319 (3), 353 (3), 403 (3), 480 (6)
- Electives to meet minimum credit hours required.

### Bachelor of Science in Environmental Science with Hydrology Option

Minimum credit hours required—135

In addition to the General Degree Requirements (page 48), and the core Environmental Science Requirements (above), the following courses are required:

- HYD 403 (3), 412 (3), 466 (3), 503L (1)
- GEOL 306 (3), 317 (3), 353 (3)
- GEOP 370 (3)
- MATH 335 (3)
- Electives to meet minimum credit hours required.

### Bachelor of Science in Environmental Science with Instrumentation and Measurements Option

Minimum credit hours required—135

In addition to the General Degree Requirements (page 48), and the core Environmental Science Requirements (above), a minimum of 25 credit hours from the following (at least 17 credit hours must be numbered 300 or above) are required:

- ES 332 (3)
- EE 211 (3), 212 & 212L (4), 231 & 231L (4), 308 & 308L (4), 321 & 321L (4)
- CHEM 331 & 331L (4), 411 & 411L (4)
- GEOL 353 (3)
- GEOP 370 (3)
- PHYS 434 (3), 493 (3)
- Electives to complete 135 credit hours

## Environmental Science Courses:

### ENVS 438, Geographic Information Systems with Geoscience Applications, 3 cr, 2 cl hrs, 3 lab hrs

Prerequisite: Consent of instructor

An introduction to geographic information systems (GIS) with a focus on applications in the geosciences, including geology, hydrology, environmental science and natural resources. Emphasis on theoretical aspects and practical applications of GIS science and technology and its integration with remote sensing data and field measurements. Computing exercises and projects utilizing ArcGIS software. Particular focus on spatial hydrology, terrain analysis, and geologic and vegetation mapping. Discussion of GIS integration with geoscience modeling. Shares lecture with HYD/GEOL 538 but is graded separately.

### ENVS 472, Senior Seminar, 1 cr, 1 cl hrs

Offered in spring semester

Undergraduate students in Environmental Science are required to give one seminar on research resulting from the paper written for 491 or 492.