GEOLOGY — M.S.

Program director
H. Paul Buchheim

The Department of Earth and Biological Sciences offers the Master of Science degree in geology. Research and course work emphasize field and laboratory studies in sedimentology, paleontology, paleoenvironmental reconstruction, paleoecology, and taphonomy. Areas of curriculum strengths include sedimentary geology and paleontology. Research in paleontology may also be pursued through the M.S. and Ph.D. degree curricula in biology, and through the Ph.D. degree curriculum in earth science.

Program objectives
The Geology Program focuses on field-oriented geology—particularly sedimentology, stratigraphy, and paleontology. The integrated core course sequence provides students with the tools to conduct research in the subdisciplines of sedimentology, paleontology, or environmental geology. Fieldwork is emphasized because it provides a first-hand experience with geological phenomena that cannot be satisfactorily grasped or understood solely from classroom or laboratory study. Throughout the geology curriculum, students are encouraged to develop an open-minded and investigative approach in the application of the scientific method to the resolution of geologic problems. Consideration of multiple working hypotheses is encouraged.

The Geology Program aims to instill in students the values of honesty, scientific integrity, careful research, and independent critical thinking; provide the tools and intellectual environment in which geologists can attain their highest potential in scholarship and research; and challenge graduate students to consider the relationships among science, faith, and societal responsibility.

Learning outcomes
1. Demonstrate advanced breadth and depth of knowledge in earth science.
2. Plan and carry out independent research.
3. Demonstrate written and oral communication skills, and the integration of technology in communication.
4. Demonstrate ability to analyze and synthesize previous knowledge.
5. Demonstrate a professional aptitude and attitude.
6. Demonstrate critical evaluation skills in relation to faith, science, and public interest issues.

Financial aid
Research and teaching assistantships are available at the Department of Earth and Biological Sciences on a competitive basis. Further information can be obtained by contacting the department at <ebs@llu.edu>. Qualified students are also encouraged to seek fellowships and grants from federal and private agencies with the help of their advisors.

Curriculum
Two-year track, for students with an undergraduate degree in geology
A minimum of 56 quarter units, including 44 at or above the 500 level, constitutes the curriculum for the Master of Science degree in geology. In addition to the general requirements of the school in which the program is housed, the following courses are required:

Three-year track, for students without an undergraduate degree in geology
Students with a variety of majors (including science and some nonscience majors) are encouraged to enter the M.S. degree program in geology. The three-year track courses are indicated in the table of course requirements. The total program consists of 78 units, including 22 units of undergraduate geology courses that are not part of the M.S. degree program in geology; and the M.S. degree curriculum in geology with a minimum of 56 quarter units, including 44 at or above the 500 level. Advanced standing may be granted toward cognate requirements.

Other requirements
The remainder of the student’s program will be planned in consultation with the major professor and graduate advisory committee. In addition to course work, students are expected to attend all program seminars while in residence, fulfill research and thesis expectations, and successfully pass a final oral examination.

Seminar attendance requirements
All graduate students in residence must register for and attend seminars (GEOL 607 Seminar in Geology) each quarter at this University.

Registration and tuition after normative time
Students who are past the normative time for completing their degree must register for two units without a tuition waiver each quarter until they earn their degree. After the normative time, students may request a one-year grace period. An extension may be granted contingent upon approval of the department faculty.

Research proposal
Students are urged to select a research project early in their program, in consultation with a faculty member approved by the department. A written research proposal and an oral defense of the student’s proposed research should be completed by the end of the third quarter of study. A comprehensive plan for completion of the degree will be approved at this time.

Advancement to candidacy
Students may apply for advancement to candidacy by completing Form A, which requires:
1. Selecting a research committee.
2. Receiving approval of the written research proposal.
3. Passing the oral defense of the research proposal.
4. Being recommended by the program faculty (should be completed by the end of the third quarter of study).

Thesis
The written thesis must demonstrate the completion of significant, original research and must be written in the format of an appropriate scientific journal.

Rosario Beach Summer courses
In cooperation with the Walla Walla University Marine Station at Anacortes, Washington, facilities are available for marine courses and research by graduate students of this department.
Admissions

In addition to Loma Linda University (http://llucatalog.llu.edu/about-university/admission-policies-information/#admissionrequirementssection) admission requirements, the applicant must also complete the following requirements:

- a bachelor’s degree from an accredited institution
- a G.P.A. of at least 3.0
- achieve an acceptable score on the general GRE examination
- completion of the following courses:
  - General chemistry—full year with laboratory (12 units)
  - Physics—full year with laboratory (12 units)
  - Mathematics, including calculus
  - Statistics
  - Biology—zoology, botany, ecology or general biology (8 units highly recommended, not required)

Some of the above courses may be taken as corequisites during residence at Loma Linda University, with approval of admission committee.

It is highly recommended that the applicant complete the application process by January 31 of the calendar year being considered for admissions, for priority consideration. Review of applications begins in February for Autumn Quarter be submitted by March. Research assistantships are competitively awarded.

It is recommended that applicants contact the department at <ebs@llu.edu>.

Program requirements

3-year Track additional requirements

Corequisites

The following courses are required of all students who have not completed a bachelor’s degree in geology. Courses do not apply toward graduate credit.

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
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<tbody>
<tr>
<td>GEOL 204</td>
<td>Physical Geology</td>
<td>4</td>
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<tr>
<td>GEOL 316</td>
<td>Mineralogy</td>
<td>4</td>
</tr>
<tr>
<td>GEOL 317</td>
<td>Igneous and Metamorphic Petrology</td>
<td>4</td>
</tr>
<tr>
<td>GEOL 416</td>
<td>Sedimentology and Stratigraphy</td>
<td>6</td>
</tr>
<tr>
<td>GEOL 424</td>
<td>Structural Geology</td>
<td>4</td>
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</tbody>
</table>

Total Units 22

M.S. degree requirements for all students—both 2-year and 3-year tracks

Cognates

The following courses are usually taken during the undergraduate program. However, they may be completed during the graduate program and may apply toward the M.S. degree. Advanced standing may be granted toward these requirements.

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
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<tbody>
<tr>
<td>GEOL 431</td>
<td>Geochemistry</td>
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<tr>
<td>GEOL 443</td>
<td>Historical Geology</td>
<td>4</td>
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<tr>
<td>GEOL 456</td>
<td>Field Methods of Geologic Mapping</td>
<td>4</td>
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Core

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<tr>
<th>Course</th>
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<tr>
<td>GEOL 556</td>
<td>Paleoenvironments</td>
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<tr>
<td>GEOL 557</td>
<td>Paleoenvironments Field Trip</td>
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<tr>
<td>GEOL 558</td>
<td>Philosophy of Science</td>
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or GEOL 559 Philosophy of Science and Origins

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<tr>
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<tbody>
<tr>
<td>GEOL 565</td>
<td>Analysis of Sedimentary Rocks</td>
<td>4</td>
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<tr>
<td>GEOL 566</td>
<td>Sedimentary Processes</td>
<td>4</td>
</tr>
<tr>
<td>GEOL 567</td>
<td>Stratigraphy and Basin Analysis</td>
<td>4</td>
</tr>
<tr>
<td>GEOL 607</td>
<td>Seminar in Geology</td>
<td>4</td>
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<tr>
<td>GEOL 617</td>
<td>Proposal Writing and Grantsmanship</td>
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Select two of the following:

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<tr>
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<tbody>
<tr>
<td>GEOL 426</td>
<td>Invertebrate Paleontology</td>
<td>4</td>
</tr>
<tr>
<td>GEOL 427</td>
<td>Vertebrate Paleontology</td>
<td>4</td>
</tr>
<tr>
<td>GEOL 444</td>
<td>Paleobotany</td>
<td>4</td>
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<tr>
<td>GEOL 545</td>
<td>Taphonomy</td>
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Religion

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<tr>
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<tbody>
<tr>
<td>REL 5__</td>
<td>Graduate-level Religion</td>
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Electives

Select the following:

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<thead>
<tr>
<th>Course</th>
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<th>Units</th>
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</thead>
<tbody>
<tr>
<td>BIOL 515</td>
<td>Biogeography</td>
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<tr>
<td>BIOL 566</td>
<td>Multivariate Statistics</td>
<td>4</td>
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<tr>
<td>GEOL 426</td>
<td>Invertebrate Paleontology</td>
<td>4</td>
</tr>
<tr>
<td>GEOL 427</td>
<td>Vertebrate Paleontology</td>
<td>4</td>
</tr>
<tr>
<td>GEOL 444</td>
<td>Paleobotany</td>
<td>4</td>
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<tr>
<td>GEOL 455</td>
<td>Modern Carbonate Depositional Systems</td>
<td>4</td>
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<tr>
<td>GEOL 487</td>
<td>Field Geology Studies</td>
<td>4</td>
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<tr>
<td>GEOL 495</td>
<td>Special Projects in Geology</td>
<td>4</td>
</tr>
<tr>
<td>GEOL 526</td>
<td>Introduction to GIS for the Natural Sciences</td>
<td>4</td>
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<tr>
<td>GEOL 535</td>
<td>GIS Spatial Analysis for the Natural Sciences</td>
<td>4</td>
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<tr>
<td>GEOL 545</td>
<td>Taphonomy</td>
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<tr>
<td>GEOL 554</td>
<td>Limnogeology</td>
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<td>GEOL 555</td>
<td>Carbonate Geology</td>
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<td>GEOL 556</td>
<td>Analysis of Sedimentary Rocks</td>
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<tr>
<td>GEOL 575</td>
<td>Hydrogeology</td>
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<tr>
<td>GEOL 588</td>
<td>Topics in Geology</td>
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<tr>
<td>GEOL 594</td>
<td>Readings in Geology</td>
<td>3</td>
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<tr>
<td>GEOL 595</td>
<td>Readings in Limnogeology</td>
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<td>GEOL 618</td>
<td>Writing for Publication</td>
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<td>GEOL 658</td>
<td>Advanced Philosophy of Science</td>
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<td>GEOL 695</td>
<td>Special Projects in Geology</td>
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<tr>
<td>GEOL 697</td>
<td>Research (This is not for thesis research)</td>
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<td>HGIS 422</td>
<td>Principles of Geographic Information Systems</td>
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<tr>
<td>HGIS 424</td>
<td>Desktop GIS Software Applications</td>
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<tr>
<td>HGIS 434</td>
<td>Advanced GIS Software Applications</td>
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Research

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<th>Units</th>
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<tbody>
<tr>
<td>GEOL 698</td>
<td>Thesis Research</td>
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</table>

Total Units 56

1. One course required: GEOL 588 Topics in Geology required except for students who have taken GEOL 475 Philosophy of Science and Origins or equivalent
2. Registration required for each quarter in residence; maximum counted toward the degree total is 4.5
Noncourse requirements

Defense of thesis
An oral presentation and defense of the thesis is required. This includes final oral examination on student's field of study.

Grade requirement for graduation
An overall G.P.A. of 3.0 is required for graduation.

Normal time to complete the program
27-month track — 2.33 years (7 academic quarters) based on full-time enrollment; part time permitted
36-month track — 3 years (9 academic quarters) based on full-time enrollment; part time permitted

Courses

GEOL 204. Physical Geology. 4 Units.
Introductory geology course that provides the student with a broad picture of geological processes operating on and within the earth. Introduction to minerals, sedimentary and igneous rocks, and fossils. Weathering, earthquakes, volcanism, erosion and sedimentation, and plate tectonics. Three class hours, one three-hour laboratory or field trip per week.

GEOL 316. Mineralogy. 4 Units.
Studies minerals, including: crystallography and crystal chemistry, phase diagrams, and systematic classification. Mineral identification based on hand sample, optical, and other analytical techniques. Three class hours and one three-hour laboratory or field trip per week.

GEOL 317. Igneous and Metamorphic Petrology. 4 Units.
Systematically studies igneous and metamorphic rocks, including: classification by petrography and geochemical methods; application of one-, two-, and three-component phase diagrams; and models of petrogenesis. Three class hours and one three-hour laboratory or field trip per week.

GEOL 416. Sedimentology and Stratigraphy. 6 Units.
Interprets the sedimentary rock record through a study of rock types, depositional processes, and models. Studies stratigraphic nomenclature and approaches to correlation on local, regional, and/or global scales. Laboratory analysis of primary and diagenetic mineralogy, textures, and sedimentary structures in clastic and carbonate rocks. Field descriptions of sedimentary rocks, structures, and sequences; and field experience in interpreting depositional processes and stratigraphic relationships.

GEOL 424. Structural Geology. 4 Units.
Theory of stress and strain, and examination of rock deformation in a framework of plate tectonics. Includes problems and applications. Three class hours—with required full-day and half-day field trips—and one three-hour laboratory or field trip per week.

GEOL 426. Invertebrate Paleontology. 4 Units.
Structure, classification, ecology, and distribution of selected fossil invertebrate groups. Principles and methods involved in the study and analysis of invertebrate fossils. Three class hours and one three-hour laboratory per week.

GEOL 427. Vertebrate Paleontology. 4 Units.
Systematics, biology, stratigraphic distribution, and biogeography of fossil vertebrates.

GEOL 431. Geochemistry. 4 Units.
Chemical concepts and their geochemical applications in areas of interest in elementary geology. Prerequisite: College chemistry; or consent of instructor.

GEOL 434. Introduction to GIS for the Natural Sciences (2). 2 Units.
Principles and practice of GIS data acquisition, data editing, map making, and geodatabase management. Recommended for students beginning a research project.

GEOL 435. GIS Spatial Analysis for the Natural Sciences (3). 3 Units.
Advanced analysis of GIS data; statistical analysis, geographic analysis of spatial data, and methods of displaying, editing, and modeling spatial data using ArcGIS and related GIS tools. Recommended for students who have research data in hand to analyze.

GEOL 443. Historical Geology. 4 Units.
Introduces earth history with in-depth examination of the stratigraphic record of rocks and fossils. Three class hours and one three-hour laboratory per week.

GEOL 444. Paleobotany. 4 Units.
Fossil plants; their morphology, paleoecology, taphonomy, classification, and stratigraphic distribution. Analyzes floral trends in the fossil record. Three class hours and one three-hour laboratory or field trip per week.

GEOL 455. Modern Carbonate Depositional Systems. 3 Units.
Examines modern and Pleistocene carbonate systems in the field, using these environments as models for understanding sediment production, facies development, and early diagenesis for many ancient carbonates. Presentations and readings on specific environments combined with field descriptions, mapping, analysis, and reports. Requires rigorous hiking and snorkeling in shallow water.

GEOL 456. Field Methods of Geologic Mapping. 4 Units.
Advanced geologic mapping of complex areas, with interpretation of their history; includes mapping of igneous, metamorphic, and sedimentary rocks. Experience in preparation of geologic reports of each mapped locality.

GEOL 465. Hydrogeology. 4 Units.
Theory and geology of groundwater occurrence and flow, the relation of ground water to surface water, and the potential distribution of ground water by graphical and analytical methods. Three class hours and one three-hour laboratory per week.

GEOL 475. Philosophy of Science and Origins. 4 Units.
Concepts in the history and philosophy of science, and application of these principles in analyzing current scientific trends.

GEOL 484. Readings in Geology. 1-4 Units.
Reviews literature in a specific area of geology. Students make presentations from the literature and submit current papers dealing with the assigned topic.

GEOL 485. Seminar in Geology. 0.5 Units.
Selected topics dealing with recent developments.

GEOL 486. Research and Experimental Design. 2 Units.
Concepts, methods, and tools of research—including experimental design and data analysis.

GEOL 487. Field Geology Studies. 1-6 Units.
Special field study trips lasting one or more weeks. Student involvement required, including field presentations and fieldwork assignments, such as the measurement and analysis of sedimentary sections, facies profiling, paleontologic excavation, mapping, or other geological or paleontology field activity. One unit of credit per week. May be repeated for additional credit.
GEOL 488. Topics in Geology. 1-4 Units.
Reviews current knowledge in specified areas of the earth sciences. Registration should indicate the specific topic to be studied. May be repeated for additional credit. Offered on demand.

GEOL 489. Readings in Paleontology. 1-4 Units.

GEOL 495. Special Projects in Geology. 1-4 Units.
Special project in the field, laboratory, museum, or library under the direction of a faculty member. Registration indicates the specific field of the project.

GEOL 497. Undergraduate Research. 1-4 Units.
Original investigation and/or literature study pursued under the direction of a faculty member. May be repeated for additional credit.

GEOL 512. Invertebrate Paleontology. 4 Units.
Structure, classification, ecology, and distribution of selected fossil invertebrate groups. Considers principles and methods involved in the study and analysis of invertebrate fossils. Per week: Class three hours, plus one three-hour laboratory. Additional work required beyond GEOL 426.

GEOL 513. Vertebrate Paleontology. 4 Units.
Fossil vertebrates, with emphasis on the origins of major groups. Systematics, biology, and biogeography of ancient vertebrates. Per week: class three hours, plus one three-hour laboratory. Additional work required beyond GEOL 427.

GEOL 514. Paleobotany. 4 Units.
Fossil plants, their morphology, paleoecology, taphonomy, classification, and stratigraphic distribution. Analyzes floral trends in the fossil record. Per week: three class hours and one three-hour laboratory. Additional work required beyond GEOL 444.

GEOL 516. Sedimentology and Stratigraphy. 6 Units.
Interprets the sedimentary rock record through a study of rock types, depositional processes, and models. Studies stratigraphic nomenclature and approaches to correlation on local, regional, and/or global scales. Laboratory analysis of primary and diageneric mineralogy, textures, and sedimentary structures in clastic and carbonate rocks. Field descriptions of sedimentary rocks, structures, and sequences; and field experience in interpreting depositional processes and stratigraphic relationships. Additional work required beyond GEOL 416.

GEOL 517. Modern Carbonate Depositional Systems. 3 Units.
Examines modern and Pleistocene carbonate systems in the field, using these environments as models for understanding sediment production, facies development, and early diagenesis for many ancient carbonates. Presentations and readings on specific environments combines with field descriptions, mapping, analysis, and reports. Requires rigorous hiking and snorkeling in shallow water. Additional work required beyond GEOL 455.

GEOL 518. Earth Structure, Process, and History. 4 Units.
Study of geological processes and the resulting geological record. Introduces minerals and rocks, sedimentary and igneous processes, fossils, plate tectonics, geological history, and models of earth history. Student prepares a teaching module on the topic. Open only to students in the M.S. degree program in natural sciences. Per week: class three class hours, one three-hour laboratory or field trip.

GEOL 526. Introduction to GIS for the Natural Sciences. 2 Units.
Principles and practice of GIS data acquisition, data editing, map making, and geodatabase management. Recommended for students beginning a research project.

GEOL 535. GIS Spatial Analysis for the Natural Sciences. 3 Units.
Advanced analysis of GIS data; statistical analysis, geographic analysis of spatial data, and methods of displaying, editing, and modeling spatial data using ArcGIS and related GIS tools. Recommended for students who have research data in hand to analyze.

GEOL 545. Taphonomy. 4 Units.
Processes that affect an organism from death until its final burial and fossilization, and utilization of this information in reconstructing ancient assemblages of organisms. Three class hours per week. One laboratory per week to study, describe, and interpret fossil assemblages of vertebrates, invertebrates, and microfossils.

GEOL 554. Limnogeology. 4 Units.
Ancient lake deposits, including their sedimentologic, paleontologic, mineralogic, geochemical, and stratigraphic characteristics. Investigates as analogs the depositional processes occurring in modern lakes. Laboratory and several extended field trips.

GEOL 555. Carbonate Geology. 4 Units.
Advanced look at the geology of carbonate rocks, including petrology; depositional environments; and overview of current topics of research. Laboratory experience in the analysis of carbonate rocks and rock sequences. Field trip to an ancient carbonate sequence.

GEOL 556. Paleoenvironments. 3 Units.
Applies paleontologic, sedimentologic, and geochemical data and methods to interpretation of past sedimentary environments, with emphasis on organism-sediment relationships. Investigates as analogs processes, sediments, and organisms in modern depositional environments.

GEOL 557. Paleoenvironments Field Trip. 1 Unit.
Field experience intended as a follow up to GEOL 556 Paleoenvironments. Consists a ten-day field trip to selected locations representing a broad spectrum of sedimentary environments.

GEOL 558. Philosophy of Science. 4 Units.
Selected topics in the history and philosophy of science, and application of these principles in analyzing contemporary scientific trends.

GEOL 559. Philosophy of Science and Origins. 1 Unit.
Studies selected topics in the history and philosophy of science, and applies these principles in analyzing current scientific trends. Provides an advanced update in the topic for students who have had a similar course at the undergraduate level.

GEOL 565. Analysis of Sedimentary Rocks. 4 Units.
Provides exposure to a range of analytical tools used to answer questions in sedimentary geology. Emphasizes three instruments—optical microscope, x-ray diffractometer, and scanning electron microscope—and introduces other analytical approaches. Participants will use case studies to develop skills in project design, collection of quantitative data, and evaluating existing datasets.

GEOL 566. Sedimentary Processes. 4 Units.
Advanced methods and principles of sedimentology, with emphasis on analysis and interpretation of sedimentary structures and the processes that produced them. Discusses in detail sedimentary facies, depositional environments, chemogenic and biogenic sedimentation, and postdepositional diagenetic processes. Research or project paper required. Three class hours and one three-hour laboratory or field trip per week, and several extended field trips.
GEOL 567. Stratigraphy and Basin Analysis. 4 Units.
Advanced methods of stratigraphy and basin analysis, including facies analysis, depositional systems, sequence stratigraphy, paleogeography, and basin modeling. Research or project paper required. Three class hours and one laboratory or field trip per week, and two extended field trips.

GEOL 575. Hydrogeology. 4 Units.
Theory and geology of groundwater occurrence and flow, the relation of groundwater to surface water, and the potential distribution of groundwater by graphical and analytical methods. Three class hours and one three-hour laboratory per week.

GEOL 588. Topics in Geology. 1-4 Units.
Reviews current knowledge in specified areas of the earth sciences. When registering, the student must indicate specific topic to be studied. May be repeated for additional credit. Offered on demand.

GEOL 594. Readings in Geology. 1-4 Units.
Reviews the literature in a specific area of geology. Students make presentations from the literature and submit current papers dealing with the assigned topic.

GEOL 595. Readings in Limnogeology. 1 Unit.
Readings and analysis of current and classic scientific literature dealing with modern and ancient lake environments—including geochemistry, sedimentology, biology and paleontology, and related subjects. Activities include student presentations of papers, discussion, and research proposals and reports. One extended, multiday field trip required.

GEOL 607. Seminar in Geology. 0.5 Units.
Selected topics dealing with recent developments.

GEOL 616. Research and Experimental Design. 2 Units.
Concepts, methods, and tools of research—including experimental design and data analysis.

GEOL 617. Proposal Writing and Grantsmanship. 2 Units.
Skills and practice of effective proposal writing, and strategies for locating and obtaining research grants.

GEOL 618. Writing for Publication. 1 Unit.
Explores the mechanics and processes of preparing, submitting, revising, and resubmitting a manuscript for publication in a peer-reviewed journal. Designed for students who are well along in the process of writing their first manuscript for publication. Prepares students to handle the manuscript revision process when the manuscript is returned from reviewers, as well as the final stage of resubmission to the journal.

GEOL 658. Advanced Philosophy of Science readings (2). 2 Units.
Reading and discussion of selected references in the philosophy of science, and the application of these concepts in the practice of scientific research and interpretation, including their influence on scientific study of origins. Best taken near the end of a student's graduate program. Two-hour class session per week.

GEOL 695. Special Projects in Geology. 1-4 Units.
Special project in the field, laboratory, museum, or library under the direction of a faculty member. Registration indicates the specific field of the project.

GEOL 697. Research. 1-8 Units.

GEOL 698. Thesis Research. 1-8 Units.
Credit for research and for writing the master's thesis. Grade received does not indicate whether thesis is completed and approved.

GEOL 699. Dissertation Research. 1-8 Units.
Credit for research and for writing the doctoral dissertation. Grade received does not indicate whether dissertation is completed and approved.