EARTH SCIENCE — PH.D.

Program director
H. Paul Buchheim

The Department of Earth and Biological Sciences offers the program leading to a Doctor of Philosophy degree in earth science. Emphasis is on research and courses in sedimentology, paleontology, and paleobiology that prepare the student to understand the history of the earth and life, its geological context, and the science involved in deciphering this history. Students are encouraged to think independently and to consider various approaches to understanding earth history. Areas of curricular strength and research emphases include sedimentology, limnogeology, paleontology, paleoenvironments, paleoecology, taphonomy, and microbial carbonates. Research in paleontology can also be pursued through the Master of Science degree in geology curriculum and the Doctor of Philosophy degree in biology curriculum.

The specific research and academic interests and strengths of the faculty are in:
- vertebrate paleontology, taphonomy, philosophy of science
- limnogeology, sedimentology, paleoenvironments
- biostratigraphy, terrestrial paleoecology
- tropical marine and intertidal ecology and marine invertebrate ecophysiology, comparative physiology
- animal behavior and distribution
- paleomagnetics and sedimentology geographic information analysis and technology
- igneous petrology, nuclear physics, and geophysics
- vertebrate paleontology and biogeography
- microbial carbonates

Objectives
The Earth Science Program strives to:

1. instill in students the values of honesty, scientific integrity, careful research, and critical, independent thinking.
2. provide the tools and intellectual environment that will facilitate the earth scientist’s attainment of the highest potential in scholarship, research, and teaching.
3. challenge graduate students to consider the relationship among science, faith, and societal responsibility.

Learning outcomes
1. Demonstrate advanced breadth and depth of knowledge in earth science.
2. Demonstrate the ability to plan and carry out independent research.
3. Demonstrate written and oral communication skills, as well as the integration of technology in communication.
4. Demonstrate ability to analyze and synthesize previous knowledge.
5. Demonstrate a professional aptitude and attitude.

Student financial aid
Assistantships for research and/or teaching 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 from federal and private agencies with the help of their advisor.

General requirements
For information about requirements and practices to which all graduate students are subject, the student should consult relevant sections of this CATALOG, as well as general information pertinent to the school in which this program is housed.

Registration and tuition after normative time
The program design is for Ph.D. degree students to finish in the normative time of four years. In certain circumstances, students may require more time for completion. Students who are past the normative time for completing their degree must register for two units each quarter without a tuition waiver until they complete their degree. After their normative time, students may request a one-year grace period that must be approved by the department faculty.

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

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 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.

Comprehensive examination
Students must complete a comprehensive examination during Fall or Winter quarter of their second year of residence. The examination includes presentation of the results of a project approved by their advisement committee (usually part of their research proposal). A publishable style paper detailing the results of the research project is required at the time of the examination.

Dissertation
The written thesis must demonstrate the completion of significant, original research and must be written in the format of an appropriate scientific journal where the manuscript is likely to be submitted for publication. At least one manuscript from the dissertation must be submitted for publication before the Ph.D. degree will be granted.

Teaching experience
Teaching is recommended during at least one quarter. This experience may be obtained through laboratory teaching or it may include presenting several lectures for a course, in consultation with the student’s major professor and the course instructor.

Professional development
Ph.D. degree students are expected to publish papers, present papers at scientific meetings, and submit research grant proposals.
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 students of this program.

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

- achieve an acceptable score on the general GRE examination (the subject GRE is not required).
- minimum required G.P.A. in a previous M.S. degree program is at least 3.0.
- Expected undergraduate preparation includes:
  - two quarters of college mathematics (including calculus)
  - general physics with laboratory (one year)
  - general chemistry with laboratory (one year)
  - statistics (one course)
  - undergraduate geology courses (see corequisites listed below)

Some of these courses may be taken during residence at Loma Linda University, with approval of the admissions committee.

Students may also contact the department at <ebs@llu.edu>.

Application time
It is highly recommended that student complete the application process by January 31 of the year being considered for admission, for priority consideration. Review of applications begins in February for Autumn Quarter admission. Research assistantships are competitively awarded.

Program requirements
A minimum of 72 quarter units of academic credit for courses, seminars, and research beyond the master’s degree is required (including at least 55 at or above the 500 level); that is, a minimum of 120 units beyond the baccalaureate degree, including the following required courses:

(Advanced standing may be granted toward these requirements)

Corequisites
May be taken during the program in addition to the units required for the degree (advanced standing may be granted for equivalent courses)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEOL 204</td>
<td>Physical Geology</td>
<td>3</td>
</tr>
<tr>
<td>GEOL 316</td>
<td>Mineralogy</td>
<td>3</td>
</tr>
<tr>
<td>GEOL 317</td>
<td>Igneous and Metamorphic Petrology</td>
<td>3</td>
</tr>
<tr>
<td>GEOL 416</td>
<td>Sedimentology and Stratigraphy</td>
<td>4</td>
</tr>
<tr>
<td>GEOL 424</td>
<td>Structural Geology</td>
<td>4</td>
</tr>
<tr>
<td>GEOL 431</td>
<td>Geochemistry</td>
<td>3</td>
</tr>
<tr>
<td>GEOL 443</td>
<td>Historical Geology</td>
<td>3</td>
</tr>
<tr>
<td>GEOL 456</td>
<td>Field Methods of Geologic Mapping</td>
<td>4</td>
</tr>
</tbody>
</table>

Select two paleontology courses of the following: 7-8

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 426</td>
<td>Invertebrate Paleontology</td>
<td>3</td>
</tr>
<tr>
<td>BIOL 427</td>
<td>Vertebrate Paleontology</td>
<td>3</td>
</tr>
<tr>
<td>BIOL 444</td>
<td>Paleobotany</td>
<td>3</td>
</tr>
<tr>
<td>GEOL 545</td>
<td>Taphonomy</td>
<td>3</td>
</tr>
</tbody>
</table>

Select one GIS course of the following: 2-3

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>HGIS 521</td>
<td>Cartography and Map Design</td>
<td>3</td>
</tr>
<tr>
<td>HGIS 522</td>
<td>Principles of Geographic Information Systems and Science</td>
<td>3</td>
</tr>
<tr>
<td>HGIS 524</td>
<td>GIS Software Applications and Methods</td>
<td>3</td>
</tr>
<tr>
<td>HGIS 535</td>
<td>Integration of Geospatial Data in GIS</td>
<td>3</td>
</tr>
<tr>
<td>HGIS 536</td>
<td>Spatial Analytic Techniques and GIS</td>
<td>3</td>
</tr>
</tbody>
</table>

Select one course to be approved by PhD committee of the following: 3-4

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 509</td>
<td>General Statistics</td>
<td>3</td>
</tr>
<tr>
<td>STAT 525</td>
<td>Applied Multivariate Analysis</td>
<td>3</td>
</tr>
</tbody>
</table>

Religion

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>RELE_5__</td>
<td>Graduate-level Ethics</td>
<td>3</td>
</tr>
<tr>
<td>RELR_5__</td>
<td>Graduate-level Relational</td>
<td>3</td>
</tr>
</tbody>
</table>

Select one course with the RELT prefix of the following: 3

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>RELT 527</td>
<td>The Bible and Ecology</td>
<td>3</td>
</tr>
<tr>
<td>RELT 558</td>
<td>Old Testament Thought</td>
<td>3</td>
</tr>
<tr>
<td>RELT 559</td>
<td>New Testament Thought</td>
<td>3</td>
</tr>
<tr>
<td>RELT 560</td>
<td>Jesus the Revealer: The Message of the Gospel of John</td>
<td>3</td>
</tr>
<tr>
<td>RELT 564</td>
<td>Apostle of Hope: The Life, Letters, and Legacy of Paul</td>
<td>3</td>
</tr>
<tr>
<td>RELT 565</td>
<td>Vision of Healing: The Message of the Book of Revelation</td>
<td>3</td>
</tr>
</tbody>
</table>

Electives
Additional courses required by the student’s guidance committee to complete total required units

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEOL 699</td>
<td>Dissertation Research (4 minimum)</td>
<td>4</td>
</tr>
</tbody>
</table>

Total Units 76

Research
4 units minimum; will be graded each quarter and can be repeated for additional credit

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEOL 699</td>
<td>Dissertation Research (4 minimum)</td>
<td>4</td>
</tr>
</tbody>
</table>

1 Registration is required for each quarter in residence, maximum units counted toward the degree total is 5

Varied course offerings
In addition to the primary offerings of the department, the student, with committee approval, may take courses in other departments as part of the graduate work--according to special interests and needs.
Non-course requirements

Grade requirement for graduation
All courses applied toward the Ph.D. must receive a grade of at least a B.

Advancement to candidacy
Students may apply for advancement to candidacy by completing Form A, which requires:

1. Completing all deficiencies and corequisites.
2. Selecting a research committee.
3. Completing an approved written research proposal and budget.
4. Passing the oral defense of the research proposal.
5. Passing the oral comprehensive exam.
6. Being recommended by the program faculty (should be completed by the end of the third quarter of study).

Comprehensive examination
An oral comprehensive examination is given in connection with a written and oral presentation of an initial research project, approved by the student's guidance committee. The written portion is in the form of a "publishable" paper in a specific journal style.

The purpose is to measure the student's knowledge of his/her field of study and his/her ability to find, understand, and synthesize the research literature on a topic and to conduct original research. The oral examination covers the student's field of study, as well as defense of the research.

Defense of dissertation
An oral presentation and defense of the dissertation, including final oral examination on the student's field of study, are required.

Normal time to complete the program
5 years 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.
Interpret 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 445. 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 455. Field Methods of Geologic Mapping. 4 Units.
Advanced field methods of geologic mapping. 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.
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.
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 514. Paleobotany. 4 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 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 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.
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.

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.