EARTH SCIENCE — PH.D.

Program director
Kevin E. Nick

The Department of Earth and Biological Sciences offers a program leading to the Doctor of Philosophy degree in earth science. Emphasis is on research and coursework in sedimentology, paleontology, igneous petrology, and environmental geology. The student is prepared for understanding

the history of the earth and life, and the scientific approach to deciphering this history. Students are also encouraged to think independently and to consider various approaches to understanding the past. Research in paleontology can also be pursued through the curricula for the Master of Science degree in geology and the Doctor of Philosophy degree in biology.

Objectives

The Earth Science Program strives to:

1. Instill in students the values of scientific integrity, careful research, and both critical and 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 relationships between science, faith, and societal responsibility.

Program learning outcomes

By the end of this program, the graduate should be able to:

1. Pass a standardized national exam in earth science practice;
2. Analyze and synthesize published data and interpretations;
3. Plan and carry out independent research;
4. Apply effective written and oral communication and technological tools to professional practice;
5. Demonstrate a professional aptitude and attitude;
6. Demonstrate critical evaluation skills in relation to philosophy of science and public interest issues.

Student financial aid

Assistantships for research and/or teaching are available at the Department of Earth and Biological Sciences on a competitive basis. Additional 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 with geology backgrounds to finish in four years. In certain circumstances, students may require more time for completion. Students who are past the normative time for completing their degree may risk their departmental assistantship or incur tuition charges.

Seminar attendance requirements

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

Research proposal and comprehensive examination project

Students are urged to select research projects early in their programs, in consultation with a faculty member and approved by the department. Students must complete a comprehensive examination project by the autumn or winter quarter of their second year of residence. A written research proposal and oral defense of the student's proposed research should be completed following the comprehensive examination project. A comprehensive plan for completion of the degree must be approved at this time as required for advancement to candidacy.

Dissertation

The written dissertation must demonstrate the completion of significant, original research and chapters must be written in the style of an appropriate scientific journal where manuscripts are 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 upon consultation with the student's major professor and the course instructor.

Professional development

Ph.D. degree students are expected to publish papers, present at scientific meetings, submit research grant proposals, and be involved with the scientific community.

Admissions

Academic preparation requirements

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:

- Hold an undergraduate or graduate degree from an accredited institution.
- Achieve an acceptable score on the general GRE examination (the subject GRE is not required).
- Demonstrate the minimum required G.P.A. of at least 3.0 in the previous degree program.
- 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> for advice on admission requirements. Advanced standing toward Ph.D. course requirements may be granted based on coursework taken prior to admission and beyond undergraduate degree requirements.

Application time

Students should complete their applications 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)		
GEOL 204	Physical Geology	
GEOL 316	Mineralogy	
GEOL 317	Igneous and Metamorphic Petrology	
GEOL 424	Structural Geology	
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 Ph.D. degree. Advanced standing may be granted toward these requirements.		
GEOL 436	Low Temperature Geochemistry	4
GEOL 443	Historical Geology	4
GEOL 456	Field Methods of Geologic Mapping	4
GEOL 516	Sedimentology and Stratigraphy	6
Core		
GEOL 510	Orientation to Graduate Geology	1
GEOL 556	Paleoenvironments	3
GEOL 557	Paleoenvironments Field Trip	1
GEOL 566	Clastic Sedimentary Geology	4
GEOL 607	Seminar in Geology [1]	--
GEOL 617	Proposal Writing and Grantsmanship	2
GEOL 664	Science Communication Outreach [2]	1
One course required: GEOL 558 required except for students who have taken GEOL 475 or equivalent		4
GEOL 558	Philosophy of Science	
GEOL 559	Philosophy of Science and Origins	
Select one GIS course of the following:		2-3
GEOL 526	Introduction to GIS for the Natural Sciences	
GEOL 535	GIS Spatial Analysis for the Natural Sciences	
HGIS 522	Principles of Geographic Information Systems and Science	
HGIS 524	GIS Software Applications and Methods	
HGIS 535	Integration of Geospatial Data in GIS	
HGIS 536	Spatial Analytic Techniques and GIS	
Select one paleontology course from the following:		4
GEOL 512	Invertebrate Paleontology	
GEOL 513	Vertebrate Paleontology	
GEOL 514	Paleobotany	
GEOL 545	Taphonomy	
Select one course to be approved by PhD committee of the following:		3-4
STAT 509	General Statistics	
STAT___	Statistics course related to dissertation topic and approved by dissertation committee	
Religion		
RELE 5__	Graduate-level Ethics	3
RELR 5__	Graduate-level Relational	3
Select one course with the RELT prefix of the following:		3
RELT 527	The Bible and Ecology	
RELT 558	Old Testament Thought	
RELT 559	New Testament Thought	
RELT 560	Jesus the Revealer: The Message of the Gospel of John	
RELT 564	Apostle of Hope: The Life, Letters, and Legacy of Paul	
RELT 565	Vision of Healing: The Message of the Book of Revelation	
Electives		
Additional courses required by the student's guidance committee to complete total required units. All GEOL graduate level courses not counted towards core requirements may count towards elective credit.		18-69
Research		
4 units minimum; will be graded each quarter and can be repeated for additional credit		
GEOL 699	Dissertation Research (1-8)	4
Total Units		**89**

1. Registration is required for each quarter in residence, maximum units counted toward the degree total is 5
2. Fulfills service learning requirement

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. Departmental approval of a research advisor and committee.
2. Showing progress in the program while maintaining a satisfactory GPA.
3. Research committee approval of the comprehensive examination requirement as stated in the department student handbook.

4. Research committee approval of the written research proposal, budget, and oral defense of proposed research.
5. Being recommended by the program faculty.

Research Presentation

Presentation of research findings at a scientific meeting is required.

Dissertation and defense

The research committee will be presented with the student's written dissertation. An oral presentation and defense of the dissertation, including final oral examination on the student's field of study, are required. Approval of the dissertation and its defense is by the research committee which recommends it to the department and the faculty of graduate studies. This defense is required to complete Form D.

Normal time to complete the program

Five (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.
Study minerals and their occurrences 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.
Introduction to classification and origin of igneous and metamorphic rocks.Study phase diagrams and processes controlling magma crystallization. Examine relationship of plate tectonics to the genesis and distribution of igneous and metamorphic rocks. Three class hours and one three-hour laboratory or field trip per week.

GEOL 416. Sedimentology and Stratigraphy. 6 Units.
Focus on the sedimentary rock record through a study of rock types, depositional processes, and models. Stratigraphic nomenclature and approaches to correlation on local, regional, and 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. Examples presented in field settings.

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, and biogeography of ancient fossil vertebrates, with emphasis on the origins of major groups.

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 436. Low Temperature Geochemistry. 4 Units.
Principles of the chemistry of systems that pertain to surface geological and environmental settings. Major topics include: water quality, mineral solubility, natural systems represented by chemical equations, carbonate equilibrium systems, mineral stability plots, and oxidation-reduction systems. Prerequisite: College chemistry; consent of instructor.

GEOL 443. Historical Geology. 4 Units.
Overview of salient geological and paleontological features in the geological record, explaining the way they are interpreted in the formulation of models of Earth's history.

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 464. Science Communication Outreach. 1 Unit.
Guided immersion into science communication outreach. Presentation of principles of communication outreach and small group work. Student teams participate in project that interacts with a specific, identified community. Undergraduate students will work with graduate students in small teams and engage collaborative planning to address a community need, then present, evaluate, and reflect on the experience. Cross-listing: ENVS 464.

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 485. Seminar in Geology. 0.5 Units.
Presentations and discussion of selected topics featuring recent developments. Members of all geology meet together.

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.
A didactic course in a specified area of earth science to cover time-sensitive subjects or topics on demand. Requires an independent study title request form that describes the specific area covered in the class and course requirements.

GEOL 489. Readings in Geology and Paleontology. 1-4 Units.
Focused readings and discussion of literature with course instructor in a seminar setting. Requires an independent study title request form that describes the specific area covered in the class and course requirements.

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.
Credit for supervised research activities, including activities related to completion of the senior thesis. Requires an independent study title request form that explains the research and evaluation criteria.

GEOL 510. Orientation to Graduate Geology. 1 Unit.
Provides a platform for introducing students to skills and strategies for successfully navigating through their graduate degree and for pllanning their future professional career development.

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. 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 or field trip. Additional work required beyond GEOL 444.

GEOL 516. Sedimentology and Stratigraphy. 6 Units.
Rock types, depositional processes, and models. Stratigraphic nomenclature and approaches to correlation on local, regional, and 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. Requires additional laboratory and field activities over 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 and Evaporite Geology. 4 Units.
Advanced course on the geology of carbonate and evaporite rocks, including: petrography, depositional systems, diagenesis, and overview of current topics of research. Includes weekly laboratory experience in the analysis of carbonate and evaporite samples and a field trip to ancient carbonate sequences.

GEOL 556. Paleoenvironments. 3 Units.
Venue to learn skills to distinguish and reconstruct ancient depositional environments. Applies paleontologic, sedimentologic, and geochemical data and methods to interpretation of paleoenvironments, 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-based geology that integrates with GEOL 556, Paleoenvironments. Ten days spent visiting a variety of ancient and modern depositional environments. Published observations reviewed and relived to develop a regional context and collect primary field data.

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 range of analytical tools used for assessment in sedimentary geology. Tools covered include: saws and grinders, photography through microscope, point counting with optical microscope, x-ray diffraction of bulk and clays, scanning electron microscopy with EDS, magnetic susceptibility, grain size analysis, acid insoluble residues, making thin sections, MP-AES, GPS, image analysis, and error analysis. Participants will use case studies to develop skill in project design.

GEOL 566. Clastic Sedimentary Geology. 4 Units.
Advanced course on the geology of clastic sedimentary rocks--including: petrography, depositional systems, diagenesis, and overview of current topics of research. Includes weekly laboratory experience in the analysis and description of clastic rock samples and a field trip to ancient clastic sequences.

GEOL 567. Stratigraphy and Basin Analysis. 4 Units.
Addresses vertical and lateral relationships of sedimentary units and facies in the context of the development and filling of sedimentary basins within a chronostratigraphic framework. Emphasis on the impact of tectonics, sea level variations, and autogenic processes and their expression as sequences with specific stratal geometries in different basin types. Both surface (field outcrop studies) and subsurface (well logs and seismic stratigraphy) approaches to basin analysis will be covered.

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.
A didactic course in a specified area of earth science to cover time-sensitive subjects or topics on demand. Requires an independent study title request form that describes the specific area covered in the class and course requirements.

GEOL 594. Readings in Geology and Paleontology. 1,2 Unit.
Focused readings and discussion of the literature with the course instructor in a seminar setting. Requires an independent study title request form that describes the specific area covered in the class and course requirements.

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.
Presentations and discussion of selected topics featuring recent developments. Members of all geology programs meet together.

GEOL 616. Research and Experimental Design. 2 Units.
Concepts, methods, and tools of research, including experimental design and data analysis. Cross-listing: BIOL 616.

GEOL 617. Proposal Writing and Grantsmanship. 2 Units.
Develops skills in writing proposals and in acquiring funding for research. Increases understanding of the culture of research. Reviews the infrastructure of science funding and identifies individualized sources of potential funding. Presents successful proposal-writing strategies for both governmental and nongovernmental sources of funding. Emphasizes development of effective writing skills during preparation of the student's thesis or dissertation proposal.

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 664. Science Communication Outreach. 1 Unit.
Guided immersion into science communication outreach. Principles of communication outreach and small group work presented. Student teams devise project that engages a specific, identified community. Small teams collaboratively interact with community to address a need, present findings, evaluate impact, and reflect on experience. Cross-listing: BIOL 664.

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.
Credit for supervised research activities. Requires an independent study title request form that explains the research and evaluation criteria.

GEOL 698. Thesis Research. 1-8 Units.
Credit for supervised research activities and for writing of the master's thesis. Requires an independent study title request form that explains the research and evaluation criteria. Grade received does not indicate whether thesis is completed and approved.

GEOL 699. Dissertation Research. 1-8 Units.
Credit for supervised research activities and for writing the doctoral dissertation. Requires an independent study title request form that explains the research and evaluation criteria. Grade received does not indicate whether dissertation is completed and approved.