

Geomicrobiology

GEOB 515, GEOL 415, GEOC 515, HYD 515, BIOT-515
Fall, 2022

Lectures

M/W/F 1:00-1:50 PM,
MSEC Room 103

Instructor

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Office hours: TBA or by appointment.

Virtual office hours (via Zoom): TBA, or by appointment

Course overview: Welcome to Geomicrobiology! Microorganisms play an enormous role in the geological and geochemical processes that shape our planet's surface. Because of their ubiquity and metabolic diversity, microbes control crucial chemical transformations in the modern world, and their evolution over the past 3.5 billion years has forever altered Earth's landscape. In this course, we will start by exploring the basis for those interactions, including redox geochemistry, microbial metabolism, the diversity of microbial lifestyles, and microbe-mineral interactions. Later in the course we will consider the consequences of microbial processes for global biogeochemical cycling and for the co-evolution of life and the Earth. Other topics will include molecular and phylogenetic methods for exploring the microbial world, pollutant biodegradation, microbial paleobiology, and astrobiology.

Place in Curriculum: This course is an elective for most undergraduate and graduate degrees offered in the Earth and Environmental Science Department, and is required for the PhD in Earth and Environmental Science with Dissertation in Geobiology.

Course Learning Outcomes: By the end of this course, students will have developed an appreciation for the diversity of life on our planet, and be able to:

- Explain how microorganisms impact geochemical processes in diverse natural and engineered systems
- Apply principles of thermodynamics to predict energetically-favorable metabolisms in a given environmental context
- Describe how microbial activity is used in engineering processes such as pollutant biodegradation and metal mining
- Explain how microbial evolution has impacted Earth's biosphere and geosphere through time
- Recognize evidence for early life in the rock record.
- Demonstrate that they are able to integrate and synthesize material from the primary literature during class discussions and writing assignments.

Program Learning Outcomes: Learning outcomes for undergraduate and graduate degrees in Earth and Environmental Science: <https://nmt.edu/academics/ees/Outcomes.php>

Prerequisites: Previous college coursework in biology, chemistry, and geology is a prerequisite for this course. If you have a limited biology or geology background and have arranged with me to take the course anyway, you should expect to work harder than usual to catch up on material that would have been covered in the prerequisite course. You may find it useful to develop working collaborations with students who have complementary biology or geology expertise to help you get up to speed.

Mode of instruction: In-person (and remote synchronous or asynchronous for DE students, via Zoom). Depending on the state of the pandemic, we may change the mode of instruction for some or all lectures to remote synchronous delivery, and lectures will be recorded to accommodate students that are unable to attend in person for COVID-19-related issues, such as during quarantine periods or out of concern of exposure.

Field trip: There will be one weekend field trip during the course. Attendance and participation is required, and in the event of a schedule conflict, we will find alternative activities. Details will be provided in lecture. Students taking the Distance Education (DE) section of this course will have the option of an alternative activity (Winogradsky columns) in place of the field trip.

Attendance: Attendance at lecture is required and expected. Please make every effort to attend and participate in class. We will make reasonable accommodations for medical absences and for students that contact us in advance about unavoidable absences, including for students that are unable to attend for COVID-19-related reasons. Please do not come to class if you are feeling ill, and follow any quarantine guidelines that are given in the event of exposure to COVID-19. Please consult NMT's COVID-19 information page (<https://www.nmt.edu/covid19/>) for up-to-date guidelines, and contact your instructor if you miss class, in advance if possible.

Course website: Canvas course website, <http://learn.nmt.edu>

Readings:

Required text: *Brock Biology of Microorganisms (15th ed.)*, by Madigan et al. Brock Biology is an excellent reference and is the microbiology text of choice for many physical scientists interested in microorganisms. If you don't want to purchase it, a copy is placed on reserve at the Skeen Library and used copies of earlier editions are also available. If you choose to use an earlier edition, you will need to translate the page number for reading assignments.

Other required readings: Additional readings will be taken from the scientific literature, and are listed in the course schedule. Electronic versions will be made available through the course webpage.

Skeen library reserve: The following references are placed on reserve at the Skeen library

- *Brock Biology of Microorganisms* by Madigan et al. A copy of both the 15th and 12th editions are on reserve.
- *Introduction to Geomicrobiology* by Konhauser (2007). This text is another good geomicrobiology reference, and you might find it useful both for reinforcing course

concepts as well as when researching for your review paper or proposal.

- *Ehrlich's Geomicrobiology* by Ehrlich, Newman, and Kappler (2015). This text is a more advanced geomicrobiology reference. A copy of the 6th edition is on reserve.
- *Fundamentals of Geobiology* by Knoll (2012). This is an excellent geobiology reference, and is especially relevant for global biogeochemistry and deep time topics.

Writing: Effective communication to both a broad audience and to your scientific peers is paramount for a successful career. Students will be asked to write a term paper for this course, either a review paper or a proposal. A more detailed description of the writing assignment is given below, and additional details will be provided in class. I will also assign additional writing as part of the homework.

Grade basis:

Homework	10%
Proposal or review paper	25%
Topic statement, outline, drafts (5%)	
Final paper (20%)	
Midterm exams	30%
Final exam	10%
Class participation	10%
Presentations	10%
Field trip participation	5%

Exams: We will have two midterms and a final exam that will cover lecture and reading material.

Homework: During the term, homework assignments will be posted online. Assignments will be made available after class, and will generally be due in class the following week. Homework will take the form of problem sets (for example, balancing redox reactions and calculating free energy) as well as critical analysis of primary literature.

Class participation: We will have periodic class discussions of primary literature throughout the term. Primary literature refers to articles from peer-reviewed journals that present results of original research, and are the main mechanism by which scientific results are communicated. The purpose of these discussions is to critically evaluate the assumptions, results, and implications of different studies that represent significant milestones in geomicrobiology. Part of your grade will be based on participation in group discussions, which includes the following:

- Before each discussion, all members of the class are expected to contribute a question or comment to facilitate discussion of the assigned article (via an online forum), and in some cases, fill out a “figure facts” worksheet or answer pre-class questions about the assigned reading.
- Active participation during the in-class discussion, which includes reading the assigned article, and asking questions and responding to prompts by discussion leaders.
- Leading in-class discussions: each student will be designated to lead or co-lead a discussion one or more times during the semester. Discussion leaders will present the

paper, and then informally facilitate a class discussion. Discussion leaders should do the following:

- Prepare a ~10 minute presentation (could be by Powerpoint/Google Slides, or a chalk talk with handouts) to introduce the paper, put it in context, describe major results and discussion points, and add a few comments of your own about what you thought was interesting, what could have been done better/differently, etc.
- Expect the class to ask questions during your presentation, and at the end of your talk, prompt the class for questions and comments, and lead a discussion.
- Use the questions/comments posted by the class to facilitate discussion, either as discussion prompts and/or as inspiration to target your discussion
- You are strongly encouraged to meet with your instructor to discuss the article beforehand.

Presentations: You will give two or more short “lightening talks” during the term, one or more “microbe of the week” presentations and a lightening talk about your proposal or review paper. Presentations will last five minutes or less, and details will be discussed in class. Breaking down a complex topic into a brief presentation that is appropriate and easily digestible for your target audience is a tall order, but one that is important for your success as a scientist, whether you are talking to a scientific peer, neighbor, state senator, or funding agency representative.

Proposal or Review Paper: The final paper for the class will be a proposal or a review paper on a topic of your choice, due on the last day of class. Graduate students are required to write a proposal, and undergraduates can choose between a proposal and a review paper.

Proposal: For the proposal, you will identify a compelling research avenue in the field of geomicrobiology, and propose questions, hypotheses, and methods to address the issue in an original way. The proposal should be 8-10 pages (12 point Time New Roman font or 11 point Arial font, 1 inch margins, single-spaced), including figures but not references, and should be formatted as an NSF-style proposal. You are encouraged to incorporate original figures that you have drafted yourself. No budget is needed, nor is a realistic budget a requirement. (Within reason! No sample return trips to Europa!)

Review paper: For the review paper, you will review a geomicrobiological process or group of geobiologically-important organisms. The review should be 8-10 pages (12 point Time New Roman font or 11 point Arial font, 1 inch margins, single-spaced), including figures but not references, and you are encouraged to incorporate original figures that you have drafted yourself. You should expect to cite a minimum of 20 articles from the peer-reviewed literature.

Please note the due dates for the paper/proposal topic, abstract/summary, outline and bibliography, and partial draft on the class schedule. **You are also welcome to turn in a draft to me at any point up until ~2 weeks before the final paper is due.** If you choose to do this (and I highly recommend it!), do not expect to receive immediate feedback from me, but within three days is reasonable. Drafts may be rough, but should be reasonably well written and not contain egregious spelling errors and typos. (The last date to turn in a draft for feedback is 11/19.)

You are encouraged to take advantage of the resources available at the Writing and Communication Lab, which offers qualified tutors for graduate and undergraduate students to improve writing skills (<https://www.nmt.edu/academics/class/center.php>).

Examples of potential paper topics:

(but, you are encouraged to come up with your own idea!)

- The deep marine biosphere
- Microbial formation of phosphatic mineral deposits
- Bioremediation of acidic mine drainage
- Chemosynthetic communities at whale falls
- Cave geomicrobiology
- Adaptations to microbial life at extremely acidic pH or at extremely high temperatures
- Animal-bacterial symbioses at hydrothermal vents or cold seeps
- Microbiology of mercury methylation
- Bacterial photosynthesis in the ocean
- Evolution of photosynthesis
- Nitrogen fixation
- Microbial role in granite weathering
- Carbonate formation at methane seeps
- Perchlorate-reducing bacteria
- Trichloroethylene (TCE) biodegradation
- Ammonia oxidation in wastewater
- Extracellular polymeric substances in microbial mats
- Arsenate respiration
- Microbial chromium transformation
- Carbonate precipitation in stromatolites

And many others... you are *strongly* encouraged to discuss your idea with me before you start (especially if you decide on a paper topic that is not on this list)

Late work and extra credit policy: Homework assignments may be turned in up to 5 days late at a 25% penalty. No credit will be given for homework assignments turned in more than 5 days late, in part because I will need to post the answer key for other students in the class. Writing assignments will be penalized 10% each day they are late. In other words, if you turn in your final review paper or proposal two days late, the maximum score you can expect to receive is 80%. I can nearly always be flexible with accepting late assignments without penalty as long as you talk to me *in advance*.

No extra credit is available. I will look over any exam or homework questions you think are not graded correctly and adjust your score as appropriate, but I will not negotiate your final grade for even a fraction of a point. If you are having trouble in class for academic or any other reasons and are concerned about your grade, please see me early on so we can discuss how you can improve your understanding and performance.

Academic Honesty: New Mexico Tech's Academic Honesty Policy for undergraduate and graduate students is found in the catalog, which can be found at: <https://www.nmt.edu/registrar/catalogs.php/>. Further information about academic honesty can be found on the Associate Vice President for Academic Affairs website:

https://www.nmt.edu/academicaffairs/avpaa/academic_honesty.php. You are responsible for knowing, understanding, and following this policy.

Reasonable Accommodations: New Mexico Tech is committed to protecting the rights of individuals with disabilities and providing access and full participation in the educational experience. Students with disabilities who require reasonable accommodations are invited to make their needs known to the Office for Student Access Services (SAS) as soon as possible. Accommodations are not retroactive and may take some time to implement. The process for requesting accommodations can be found at their website <https://www.nmt.edu/ds/academicaccommodations.php>.

You can contact SAS in person at the Fidel Center Room 245, call 575-835-6209, email access@nmt.edu or book through the link on our [website](#).

Counseling Services: New Mexico Tech offers individual and couples counseling, safety assessments, crisis intervention, outreach and consultations through the Counseling Center. These confidential services are provided free of charge by licensed professionals. Please note that delivery of counseling services will be in transition for Fall 2022. For more information on how to access services, please call 835-6619, email counseling@nmt.edu or check out our website at <https://www.nmt.edu/cds/>.

Respect Statement: New Mexico Tech supports freedom of expression within the parameters of a respectful learning environment. As stated in the New Mexico Tech Guide to Conduct and Citizenship: “New Mexico Tech’s primary purpose is education, which includes teaching, research, discussion, learning, and service. An atmosphere of free and open inquiry is essential to the pursuit of education. Tech seeks to protect academic freedom and build on individual responsibility to create and maintain an academic atmosphere that is a purposeful, just, open, disciplined, and caring community.”

COVID-19 Safety Issues for Face-to-Face Instruction: Please note: provisions on masks, vaccines or other possible COVID-related requirements are subject to change as the situation evolves, based on guidance from the Centers for Disease Control, the State of New Mexico, and university officials (i.e., the President and the Board of Regents). For the most up-to-date guidelines, please consult NMT’s COVID-19 information page: <https://www.nmt.edu/covid19/>.

As of the beginning of Fall semester, NMT classes are under the following constraints, which may change as COVID conditions and/or New Mexico Governor’s orders change:

- 1) Students are required to officially go through the **Fall 2022 Check-in** process and obtain a **Designated Campus Access Lanyard (DCAL)** before entering Tech-owned buildings and attending face-to-face (F2F) classes and labs.
- 2) Students should not come to class if they are feeling ill and should follow any quarantine guidelines that they are given in the event of exposure to COVID-19. If you do miss class, please contact the instructor for missed assignments, contact the Student Health Center, and consider getting tested for COVID-19. Please note the Student Health Center does not provide Sick Notes to students who are not seen by them.

Title IX Reporting: Sexual misconduct, sexual violence and other forms of sexual misconduct and gender-based discrimination are contrary to the University’s mission and core values, violate university policies, and may also violate state and federal law (Title IX). Faculty members are considered “Responsible Employees” and are required to report incidents of these prohibited behaviors. Any such reports should be directed to Tech’s Title IX Coordinator (Dr. Peter Phaiiah, 122 West Hall, 575-835-5953 (O), 575-322-0001 (C), titleixcoordinator@nmt.edu) or reports can be filed online to [Tech’s Title IX & Sexual Misconduct Report](#). Please visit Tech’s Title IX Website (www.nmt.edu/titleix) for additional information and resources.

Student Success: New Mexico Tech offers numerous peer tutoring services for students who are struggling in their courses, or who just wish to receive friendly advice, including the Office of Student Learning (Skeen Library, <https://www.nmt.edu/osl/>), the Writing and Communication Lab (Skeen Library, <https://www.nmt.edu/academics/class/center.php>), and numerous department-run centers. These services are free of charge to students!

To read about the services a student will need to be successful visit MyNMT:
<https://www.nmt.edu/mynmt.php>

Land Acknowledgement: We acknowledge that the New Mexico Institute of Mining and Technology campus stands on the unceded ancestral lands of the Pueblo and Mescalero Apache peoples. These lands were taken by Congress in the Indian land Cession 689 on October 1, 1886, and the people forcibly moved to reservations. These injustices were accomplished under false white-supremacist ideologies such as manifest destiny and the doctrine of discovery. As visitors to these lands we appreciate their millennia of stewardship to the land, water, animals and plants, and the opportunity to live and learn here. Please visit <https://indianpueblo.org/new-mexicos-19-pueblos/> to learn more about these Native nations, their cultures, and sovereignty.

*Language on New Mexico Tech policies from <https://www.nmt.edu/academicaffairs/policies.php>
Land acknowledgement text courtesy of Anne Gray, Chris ChoGlueck, Michael Schaefer and the EES Diversity, Equity, and Inclusion (DEI) committee.*

Class schedule: Geomicrobiology (GEOB 515/GEOL-415/GEOC-515/HYD-515/BIOT-515)

Be aware that both lecture materials and readings may be subject to change as the semester progresses

Week 1		Course introduction and tree of life	
M	8/15	Course overview and introduction to geomicrobiology <i>Reading: Brock Ch. 1</i>	
W	8/17	The universal tree of life <i>Reading: Brock Ch. 1 part IV; Pace (2006); Spang and Ettema (2016)</i>	
F	8/19	Overview of the Bacteria, Archaea, and Eukarya <i>Reading: Brock Ch. 2</i>	
Week 2		Chemical energy and redox	
M	8/22	Oxidation reduction reactions and chemical energy <i>Reading: Brock Ch. 3 p. 78-85 and handouts</i>	HW #1 assigned, redox reactions, free energy
W	8/24	Chemical energy continued <i>Reading: Brock Ch. 3; Amend and LaRowe (2019)</i>	
F	8/26	Chemical energy continued; microbial energy generation <i>Reading: Brock Ch. 3; Amend and LaRowe (2019)</i>	
S	8/27	Field trip: Valles Caldera and Jemez Springs, depart from MSEC at 8:00 am	
Week 3		Microbial energy generation	
M	8/29	Microbial diversity in sulfur springs and other extreme environments of the Valles Caldera area - microscopy activity (meet in Jones Annex) <i>Reading: Brock Ch. 1 p. 11-17; Szykiewicz et al. (2012)</i>	
		If you are unable to attend class this day, please arrange to make up the microscopy activity	
W	8/31	Field trip recap; Winogradsky column presentations and predictions <i>Reading: Szykiewicz et al. (2012); Brock Ch. 3</i>	
F	9/2	Continue microbial energy generation <i>Reading: Amend et al. (2020); come prepared to discuss this article in class</i>	Due in class: HW #1; HW #2 assigned, sulfur spring metabolic diversity Literature discussion: Amend et al. (2020)
Week 4		Microbial energy generation	
M	9/5	No class - Labor Day	
W	9/7	Chemosynthesis and autotrophy <i>Reading: relevant sections of Brock Ch. 14 and 15 - try not to get bogged down in the details of these chapters, focus on getting an overview of microbial energy sources and modes of energy generation</i>	
F	9/9	Chemosynthesis and autotrophy <i>Reading: Yu and Leadbetter (2020); come prepared to discuss this article in class</i>	Literature discussion: Yu and Leadbetter (2020)
Week 5		Microbial energy generation	
M	9/12	Anaerobic respiration and fermentation <i>Reading: relevant sections of Brock Ch. 14 and 15</i>	Due in class: HW #2
W	9/14	Photosynthesis and phototrophy <i>Reading: relevant sections of Brock Ch. 14 and 15</i>	
F	9/16	Phototrophy and Photoheterotrophy <i>Reading: relevant sections of Brock Ch. 14 and 15</i>	

Week 6		Contaminants and bioremediation	
M	9/19	Sulfide mineral oxidation and acid mine drainage <i>Reading: Brock Ch. 22</i>	
W	9/21	Sulfide mineral oxidation and acid mine drainage <i>Reading: Brock Ch. 22</i>	
F	9/23	Midterm exam 1 (covers material from weeks 1-5)	
Week 7		Bioremediation and microbe-mineral interactions continued	
M	9/26	Finish acid mine drainage and bioremediation <i>Reading: Brock Ch. 22</i>	HW #3 assigned, primary literature review
W	9/28	Microbial mercury cycling and methylmercury <i>Reading: Brock Ch.21 part III; Perspective by Poulain and Barkay (2013)</i>	
*Topic for final proposal/paper due (in class, 9/28)			
F	9/30	Selenium and fungi <i>Reading: Rosenfeld et al. (2017); come prepared to discuss this article in class</i>	Literature discussion: Rosenfeld et al. (2017)
Week 8		Microbe-mineral interactions continued	
M	10/3	Respiration of minerals <i>Optional reading: Gralnick and Newman (2007)</i>	
W	10/5	Finish mineral respiration; biomineralization <i>Optional reading: Brock Ch. 2.8; Schulz and Schulz (2005)</i>	
F	10/7	Sulfur bacteria and microbial sulfur cycling <i>Reading: Pfeffer et al. (2012); News and Views by Reguera; Come prepared to discuss these articles in class</i>	Literature discussion: Pfeffer et al. (2012)
Week 9		The tree of life	
M	10/10	No class - GSA week	
W	10/12	Horizontal gene transfer and the tree of life <i>Reading: Brock Ch. 13 section III; Optional readings by Doolittle (1999); Reviews/News and Views by Attar (2016), McNerney and O'Connell (2017)</i>	Due in class: HW #3
F	10/14	Viruses in the environment <i>Reading: Philippe et al. (2013); News and Views by Pennisi (2013). Come prepared to discuss these articles in class</i>	Literature discussion: Philippe et al. (2013)
Week 10		Selected topics and case studies: TBA (based on student interest)	
M	10/17	TBA (student interest) <i>Reading: TBA</i>	
*Outline and draft summary/abstract of proposal/review paper due (at the start of class, 10/17)			
W	10/19	TBA (student interest) <i>Reading: TBA</i>	
F	10/21	TBA (student interest) <i>Reading: TBA</i>	
Week 11		Selected topics and case studies	
M	10/24	Midterm exam 2 (covers material from weeks 6-10)	
W	10/26	TBA (student interest) <i>Reading: TBA</i>	
F	10/28	TBA (student interest) <i>Reading: TBA</i>	

Week 12		Early life and evolution of the biosphere	
M	10/31	Early evidence for life <i>Optional reading: Brock Ch. 13, section I</i>	Due in class: HW #4
*First 3 pages of proposal/review paper due (in class 10/31)			
W	11/2	Early evidence for life continued <i>Reading: TBA</i>	
F	11/4	Stromatolites and microbial mats <i>Reading: Reid et al. (2000); Come prepared to discuss this article in class. Additional readings TBA</i>	Literature discussion: Reid et al. (2000)
Week 13		Early life and evolution of the biosphere	
M	11/7	Microfossils and microbial paleobiology <i>Reading: Schopf et al. (2002), Brasier et al. (2002), Schopf et al. (2018); Come prepared to discuss these articles in class.</i>	Literature discussion: Schopf and Brasier
W	11/9	Rise of oxygen 1 <i>Reading: Kump (2008)</i>	
F	11/11	Rise of oxygen 2 <i>Reading: Konhauser et al. (2002); Come prepared to discuss this article in class.</i>	Literature discussion: Konhauser et al. (2002)
Week 14		Early life and evolution of the biosphere	
M	11/14	Finish rise of oxygen; Origin of life <i>Reading: excerpts from Lane (2009) and Hazen (2005)</i>	
W	11/16	Origin of life continued <i>Reading: excerpts from Lane (2009) and Hazen (2005)</i>	
F	11/18	Asgard Archaea; class presentations <i>Reading: Imachi et al. (2020); Come prepared to discuss this article in class.</i>	Literature discussion: Imachi et al. (2020)
*Optional: last day to turn in proposals/review paper drafts for feedback (in class, 11/19/2019)			
Week 15		Thanksgiving break	
----- Thanksgiving break, Nov 21 to Nov 25 -----			
Week 16		Astrobiology	
M	11/28	Class presentations; astrobiology and life elsewhere <i>Reading: TBA</i>	
W	11/30	Class presentations; astrobiology and life elsewhere <i>Reading: TBA</i>	
F	12/2	Astrobiology and life elsewhere *Proposal/review paper due (in class 12/2)	
Final exam (will be scheduled between 12/3 - 12/9)			