Physical Geology Workbook

Physical Geology Workbook

First USask Edition, December 2019

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SASKATOON, SK

Contents

Introduction

Welcome to the First USask Edition of the Physical Geology Workbook!

This project grew out of a set of study packages I prepared for my first year physical geology students at the University of Saskatchewan. As I learned more about online textbooks through my involvement with textbook and lab manual adaptation projects, I realized that this is a better format to use to deliver this resource to my students. It will also allow me (once the document is ready to release as a first edition) to make these study materials available to other instructors as a complement to our lab manual and textbook resources. I have aligned the content in this workbook to the Physical Geology 1st USask Edition textbook. For each chapter, I've organized the vocab by chapter section. There is also a vocabulary section labelled "other vocabulary" for each chapter; this is for vocab that isn't currently included in the textbook but that I use in my lectures. We will probably incorporate this vocab into the textbook in a future edition.

I hope you find these resources useful, and I welcome feedback or suggestions (or flagged errors – especially flagged errors!). If you would like to collaborate or adapt this workbook please get in touch.

–Joyce McBeth, Assistant Professor, USask Geological Sciences. December 2019.

Cover photos:

Top image: Mt Teide volcano, Tenerife, Canary Islands, Spain. Source: Joyce M. McBeth (2005) CC-BY 4.0. Bottom image: ripples in recently deposited river sediments, Halfway River, BC, Canada. Source: Joyce M. McBeth (2005) CC-BY 4.0.

Acknowledgements

I would not have started this project without Karla Panchuk's leadership, inspiration, and mentorship in undertaking open textbook projects. Many thanks to Tom Ellis, Rainer Dick, Alec Aitken, Tim Prokopiuk, and Michael Cuggy provided helpful brainstorming on background topics to incorporate into the appendices. I am grateful to Kevin Riffel of the Gwenna Moss Centre for Teaching and Learning (GMCTL) at USask for reviewing the content of the topical appendices to check that the content is aligned with material covered in primary and secondary school in Saskatchewan. Thank you to Matt Lindsay for sharing his lecture materials with me back in 2017 when I first got started teaching first year physical geology; your lecture notes gave me the seed of inspiration to start to develop the materials in this workbook and I am grateful for your friendship and collegiality. Thank you to the staff at the GMCTL at USask for creating a fertile, supportive, inspiring, and empowering space to develop my understanding of educational practice. Every time I visit you I get new ideas to push myself further and bring better experiences (I hope!) to my students. I am grateful for your support and friendship. I would particularly like to thank colleagues who reviewed specific parts of the document: Tom Ellis (Chemistry Appendix), and Jim Merriam (Physics Appendix). And Linda Vogt for applying a fine toothed comb to the entire document – I am so grateful for your fresh eyes!

To my students – thank you for demanding I put out the Beta edition of this workbook sooner than I had intended in 2019. Your productive pestering confirmed this resource is desired, needed (right now!!), and that you will make good use of it. I am grateful to all my students, past and future, for their feedback and ideas. Keep sharing the struggles you encounter in your studying, and the things you find difficult. These issues provide me and my colleagues with ideas for developing and improving resources such as this workbook.

-Joyce McBeth, December 2019

Grand Canyon, USA. Source: Joyce M. McBeth (2005) CC BY-SA 4.0

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How to use this workbook

This is an original workbook for first year Physical Geology to accompany the open textbook Physical Geology 1st USask edition by Karla Panchuk. It provides resources to help students study and prepare for exams in courses in introductory physical geology (USask Geol 108 and Geol 121).

The workbook is organized into sections by chapter, each chapter corresponds to a chapter in the Physical Geology 1st USask Edition textbook (or unadapted chapters in Steven Earle's Physical Geology, 2015). There are three parts to each chapter: learning outcomes, vocabulary, and review questions. Corresponding readings from the textbook are provided in the front material for each chapter. Note that your professor may not recommend you read all the textbook sections for each chapter.

Students taking first year physical geology come from a wide range of backgrounds; sometimes they have limited science background and need support reviewing or learning basic concepts in chemistry, physics, math, biology, and geography to prepare for the course. To support these students I've added appendices on these topics to help students identify where they need to focus their review.

I have provided more specific suggestions on how to use the materials in this workbook below. This workbook is still a work in progress, I will add additional review questions and study resources in future editions. If you identify any errors or omissions you would like to flag for me I welcome your feedback!

Good luck with your studies,

-Dr McBeth

Overview of how to use this workbook

1. *start of course*: read through this how-to section
2. *start of course*: read through appendices to review background concepts.
3. *before class*: check recommended readings, if present, in your professor's class slides (these may differ from the corresponding textbook readings shown at the start of each chapter in this workbook – go with the recommendations in the slides). Read through each corresponding vocab section and learn vocab prior to each class. Read or skim recommended readings.
4. *during class (for students in GEOL 108/121 with Dr McBeth)*: participate in class activities using the Top Hat polling system
5. *after class*: review vocabulary and lecture notes, work through review questions, review learning outcomes and assess progress.
6. *after class (for students in GEOL 108/121 with Dr McBeth)*: rewatch or listen to the lecture capture if you missed class or were unclear on the material.

Learning Outcomes

Read through the learning outcomes for each chapter. These describe the facts, concepts, and processes you will (hopefully!) learn in each chapter of the textbook, and corresponding section of the course lectures. As you study, you can use these outcomes to gauge how prepared you are for the exam material on each chapter. The more of these learning outcomes you understand and can explain in detail, the better prepared you will be for your exam.

Vocabulary

The vocabulary sections contain lists of vocabulary words used in each textbook chapter. The vocab words are divided up by chapter sections. If you bring the workbook to class, you can check off the vocabulary that comes up in the lectures, to help you identify which terms you need to know.

Students can use these vocabulary lists to learn the vocabulary and prepare flash cards or definitions lists. They can also review and test themselves and each other using these lists.

If you are a student who struggles with vocabulary, here are some suggestions on how to learn the vocabulary words:

- Before starting to learn vocabulary, familiarize yourself with Appendix VII of this workbook. this appendix contains lists of Latin and Greek suffixes and prefixes that commonly appear in geological vocabulary.
- look up vocab words in textbook(s) or use an online geology dictionary:
  - https://geology.com/geology-dictionary.shtml
  - https://geomaps.wr.usgs.gov/parks/misc/glossarya.html
- find a good image illustrating the vocabulary word (if applicable) in a geological context to help you visualize the meaning of the word.
- Place the vocab word in geological context. for example, in what plate tectonic environment(s) would you find or use this vocabulary word? Where in the world would you find an example of this vocabulary word?
- Write a sentence using the word in a geological context. Try to create your own sentence rather than using one from the web.
- Without looking up the definition for each term, try to define it out loud (it really helps to speak out loud when studying!).
- Next steps: find a friend to study with, and compare your vocabulary words and sentences with theirs.
- If you are uncertain about pronunciation of any words, contact your professor and/or TA to ask for help.

Review questions

The review questions are designed to give you practice in applying the knowledge you are learning in each chapter, and to place this information in the greater context of Earth's geology.

Here are some tips on how to use the review questions:

- Many of the review questions incorporate drawing exercises. Try not to worry too much about making a "perfect" drawing, that is not the point of these exercises. It is more important to use the drawing to communicate (to you, as you review your study notes for exams!) the key features of the geological concept the question is asking you to examine (e.g., the parts of a volcano, stream processes).
- Before working through each review question, read through and check that you are familiar with the vocabulary used in that question (if not, review the vocabulary as described above).
- Self-test yourselves with the review questions before your exams. Try not to look at your answers before you self-test yourself, see if you can answer the question first.
- Teaching and explaining things to someone else is a really effective way to test yourself on material!
- Working with others in study groups can help you identify alternative or more elaborate answers to review questions and help learn the material in more depth.
- These questions are a starting place – use the review questions to help you get ideas to make up your own review

questions.

    - For example, a question that asks "what kind of rock textures would you expect to see in an intrusive igneous rock and why?" This question could be adapted in a few different ways to test yourself. Ask the same question about extrusive igneous rocks. Or what kind of minerals you'd expect to see in each of these rocks. Or you could ask yourself which plate tectonic environments you'd expect to see a particular rock texture or composition.
    - Another example: for the question "What is the aphanitic equivalent of granite?" other questions you might think of like this are "What is the aphanitic equivalent of diorite? Gabbro?" or "Describe the texture of gabbro." "How is the texture of gabbro similar to the texture of granite?"
- Try each question before you hunt for answers. Avoid the temptation to look it up right away, make an attempt to answer it first. It is easy to fool ourselves into thinking we know things in our long term memory right after we read them – but if you do this, it is probably only in your short term memory and will be harder to remember in the exam.

Appendices

Introductory physical geology is a course that requires some high school level background knowledge in chemistry, physics, mathematics, biology, and geography. Before you start working through each chapter of the workbook, please review the materials in the appendices. If the questions worry you, visit your instructor in office hours to let them know and discuss options for moving forward. Note that the purpose of the appendices is not to teach you basic chemistry, physics, math, etc.; it is to provide you with the materials to check you have the background you'll need for this course. If you are missing this background, it may be worth doing some supplementary background readings early on in the course to fill in the gaps and/or taking a high school course by distance education to prepare yourself before taking GEOL 108/121. Chat with your instructor to help determine what a good path forward is for you.

USask Geol 108/121 Course Resources

This section provides information on USask resources that Geol 108/121 students may find useful.

Course Learning Outcomes

Upon completion of this course, you should be able to:

- Describe major geologic processes and their role in the Earth system
- Define the major Earth materials and explain their relation to geologic processes
- Describe relationships between geologic processes and hazards
- Discuss interactions between principal components of the Earth system

Study Resources for Everyone

- USask Library – Student Learning Services (SLS).
    - SLS offer workshops and on-line resources on study skills, peer mentors, and learning communities. http://library.usask.ca/studentlearning/

Study Resources for Aboriginal Students

- First year advisors at the Trish Monture Centre, Arts 248. The first year advisors provide academic advising and coaching, can also advocate with band funders to provide money for tutoring, and connect students with other Aboriginal supports on campus and around town as well (including childcare advocacy). You can make an appointment via the front desk (tmc@artsandscience.usask.ca; (306) 966-2004) to meet with Shanelle or other staff. http://artsandscience.usask.ca/aboriginal/advising.php
- Métis students – the Gabriel Dumont Institute has resources and bursaries available. A Métis local card is not required to apply (you need a parent or grandparent who is Métis). https://gdins.org/s/applications/step_1/
- Gordon Oakes Red Bear Centre offers open tutorial hours for Aboriginal students in chemistry, biology, math and writing. If you would use a geology tutorial, come talk to Dr McBeth. To get a geology tutorial at the centre, an Aboriginal student will need to take the lead to ask for it – I will support you! https://students.usask.ca/aboriginal

Know of other resources that helped you? Let me know so I can share them with other students!

Study Resources for International Students

- International Student and Study Abroad Centre (ISSAC). They offer drop-in advising, workshops, English classes, and bridging classes. https://students.usask.ca/international/issac.php

Know of other resources that helped you? Let me know so I can share them with other students!

Access and Equity Services (AES, formerly DSS)

Every year I meet students who have trouble with exams because of paralyzing anxiety, migraines, gut problems – AES can help with these problems. Exams are not a common “real-world” experience after university, you will rarely have to deal with this kind of pressure and situation again after graduation. So if your performance in university is affected because of problems like this – you can reach out, that’s why we have these resources.
In addition to this, students with challenges relating to disability, religion, family status, or gender identity that interfere with their ability to succeed in the course are encouraged to contact AES to see if they can get accommodation through AES services. This includes students with chronic health problems e.g., migraines, bowel diseases, or eating disorders.

- aes@usask.ca
- 306-966-7273, or 306-966-7276 (for hard of hearing)
- Room E1, Administration Building
- https://students.usask.ca/health/centres/access-equity-services.php

Study Advice

Recommended study plan

- Read the recommended (specified in the lecture slides) textbook readings before lectures. The text is available online. If you prefer to look at a printed copy, it is generally on reserve in the science library along with several other textbooks you may find useful. If it is not on reserve when you check – let your professor know.
- Print and/or download lecture slides, come to lectures, and take notes on the lecture slides during lecture. You can use tools like MS OneNote (allows you to import the slides and annotate them) if you prefer not to print off the slides.
- look through and test yourself using the learning outcomes and questions in the workbook and lecture slides.
- Work through the vocab and study problems in the textbook and workbook.
- Try the review questions at the end of each chapter in the textbook.
- Join (or start) a study group.
- *For students in Dr McBeth's class:*
    - Review the lecture capture (video of lectures up on BBLearn) for lectures you have missed as soon as possible if you are ill or unable to attend lecture.
    - Write down a list of words or concepts you do not understand during the lectures (or the closest approximation of those words you can pronounce), and let me know your problem words/concepts in the Top Hat "Weekly Check-In". You can also try to find the words in the workbook vocab lists and textbook.
    - Review Top Hat questions: I post the Top Hat questions for review, and often include some questions based on the Top Hat questions on the exams.

If these basic study and preparation approaches aren't working for you and you need or want more help:

- Come to your professors office hours (Refer to syllabus for times) and ask questions.
- Would you like to hire a tutor to help you? Contact the instructor for more info. There are geology students and graduates who will tutor by the hour.

Mid-term and other exam preparation: advice on picking your battles

- Start studying now.
- Attend lectures.
- Use the time that is set aside for the course lectures to prepare by listening and/or reviewing course content, whether you are here in person or not (e.g., if you have to stay home due to illness or weather, use the time to prepare if you are well enough).
- One hour seems like it will be easy to make up until you have missed 3, or 6, or more classes. Missed classes add up, this time has value for your studies, you have a choice to throw it away or make best use of it.
- Review your lecture notes.
- Read the assigned textbook readings.
- Read the review questions and vocab in the workbook.
- USask students: check out the rock and mineral displays in GEOL 261. Look at each mineral, igneous rock, and igneous texture and review your notes on these topics.

- Join a study group or find a study buddy if you are struggling, or if you find it helpful and motivating.
- After mid-terms – come to office hours and review the exam if your professor allows it. We can go through the questions you got wrong. Many students find this very helpful to figure out what they need to learn for future exams.
- *For students in Dr McBeth's class:*
    - watch the lectures you missed on BBLearn as soon as possible after you missed them.
    - some students find it useful to rewatch or listen lectures while they are studying, to help pick up on vocab words they have missed or just to reinforce their learning.
    - Fun fact: of my top 10 GEOL 108 students (based on their midterm #1 scores) in the 2019 Winter term, nearly every single one reviewed the lecture capture regularly. Most of these students also attended class in person on a regular basis.

Note-taking approaches

- Some people think hand-writing your notes is better for your learning: https://www.scientificamerican.com/article/a-learning-secret-don-t-take-notes-with-a-laptop/
- A recent study suggests that this may not be the case: https://link.springer.com/article/10.1007%2Fs10648-019-09468-2
- I am unconvinced that hand written notes are the answer for most students. In geology classes, we use a lot of images. It is hard to concentrate on processing and understanding the content if you are scrambling to write everything down. The number of illustrations and that also complicates note-taking.
- It is true though that it can help to take notes in class – students have told me printing off the slides and taking extra notes on the printouts during lectures is a good compromise for them. Some students take notes in word docs, or convert the lecture slides to MS Powerpoint presentations they can take notes in. Some students focus on the lecture in class, then re-watch the lecture on Panopto and write notes.
- Another strategy would be to prepare notes collectively with friends (e.g., on Google Docs).
- Having said all of this – I take notes by hand. Primarily because it keeps me awake and focused! If I type notes I try to write too much, handwritten forces me to be brief.

– *Dr McBeth*

Problematic study approaches

- Reviewing old multiple choice exams
    - Reason 1: Practicing multiple-choice questions can be useful, particularly if you aren't experienced with these kinds of exams. However! Profs each make up our own questions and they are different, and I make up new questions every year. So if you are reviewing multiple-choice questions from other profs' courses, keep in mind that they may have taught the material slightly differently, may have covered other topics that I do not cover, or may focus on different things on their exams than I focus on. The multiple-choice Top Hat review questions provide examples of the kinds of questions I may ask on exams.
    - Reason 2: Learning specific facts and the answers to specific multiple-choice questions is not nearly as effective for learning as digging into the content and knowing your way around it.
    - Every year I get bizarre feedback after midterms asking why the exam didn't have a question on topic "x" – a topic I didn't cover in the course, and have never covered in this course, and isn't in the textbook. This

happens because, presumably, these students studied multiple choice questions from a different course (usually Geol 109/122, a different first year geology course offered in our department).

Forming a study group

Students may want to self- organize to form study group(s), here are suggestions to get started:

- Let your professor know if you are looking to connect for a study group, and they can probably make an announcement in class to help connect you with other students who would like to study together (useful for finding other good times to meet up).
- Meet under the dinosaur skeleton in the natural science museum (outside the science library) at an agreed upon time.
- Hunt down a room to study as a group. I suggest the introductory laboratory, Geology room 261. It should be available after around 6 pm each evening. Geology rooms 269, 255, and 155 are also convenient.
- Things to do:
  - Test each other on vocabulary from the workbook.
  - Work through review questions in the workbook and textbook together, researching answers in the textbook if you don't know them already. Then use the responses you've prepared to test each other.
  - Ask each other questions about things you do not understand. Research answers together and come up with the best answer you can for the question.
  - Make flash cards and use them to test each other. e.g., cards with a vocab word on one side and a definition on the other side.

Workbook updates

The following are updates I'm planning to make to this workbook prior to the 2nd USask Edition release:

- Revising learning outcomes lists for each chapter.
- Adding to flashcard appendix and revising other study resources.
- Adding new review questions to each section, with more illustrations.
- Adding additional review questions to the appendices on math, chem, physics, biology. Checking in with students on whether they were useful and if there are other things that would be helpful in these appendices.
- Fleshing out Appendix VII (Greek and Latin prefixes/suffixes).
- Dr Panchuk and I may also make some edits to the textbook (for the 2nd USask Edition), incorporating some of the other vocabulary that is critical, and perhaps thinning out some of the more complex vocab that is beyond the first-year level.
- Adding worksheets for in-class exercises.
- Adding oceans and shorelines chapters to align with unadapted chapters from the Earle (2015) edition of the textbook.

If you are one of my students, I'm curious how you use this workbook, and if there are things about it that frustrate you or that you'd like me to add. Ideas for additions that would help your learning?

And if you find errors – please let me know!

-Dr McBeth, December 2019.

CHAPTER 1. INTRODUCTION TO GEOLOGY

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 1:

- Section 1.1 What Is geology?
- Section 1.2 Why study Earth?
- Section 1.3 What do geologists do?
- Section 1.4 We study Earth using the scientific method
- Section 1.5 Three big ideas: geological time, uniformitarianism, and plate tectonics

1.1. Introduction to Geology - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Define geology.
- Provide examples of things geologists study.
- List several reasons why geology is a worthy area of study and how it benefits humankind.
- Explain how the scientific method works, and the difference between a hypothesis and a theory.
- List the three “big ideas” in geology. Summarize each theory, and explain how each is important in geology.

1.2. Introduction to Geology - Vocabulary

Section 1.1 What is geology?

- geology
- Earth
- rock
- interior
- exterior
- deep time

Section 1.2 Why study Earth?

- fossil
- climate change
- resource
- volcanic eruption
- slope failure
- earthquake
- metals
- materials
- environment

Section 1.3 What do geologists do?

- sub-surface
- geologic processes
- Earth materials
- field
- lab / laboratory
- geologic hazards

Section 1.4 We study Earth using the scientific method

- scientific method
- deductive Reasoning
- theory
- hypothesis
- upstream

- downstream
- mechanism
- prediction
- test / testable
- realistic
- law
- guess
- phenomenon

Section 1.5 Three big ideas

- Solar System
- geological time
- geological event
- geological record
- geological time scale
- interval
- absolute age
- relative age
- uniformitarianism
- plate tectonics
- boundary
- mountain belt
- volcano
- ocean
- continent

Other useful vocabulary:

- Earth system
- catastrophic event
- gradual process
- mineral resources
- landslide

1.3. Introduction to Geology - Review Questions

- What is geology?
- What is the scientific method?
- What is the difference between a hypothesis and a theory?
- What is the relationship between the scientific method, hypotheses, and theories?
- Describe some of the ways geologists study the Earth.
- Give an example of how geology has impacted each of the following:
  - the rise and fall of nations and empires
  - war
  - migration of people and animals
  - where people build communities
  - technology and innovation
  - fashion
  - health

- Examine the geologic time scale in Figure 1.6 of the textbook.
  - What are the units for measuring time on geological time scales?
  - How is time broken down into parts in the time scale? *[hint: look at the line that begins with the word "age" in the figure]*
  - Look at the scale bar in each age column of the timescale. How does the scale bar differ between the Cenozoic, Mesozoic, Paleozoic, and Precambrian?
- Summarize the theory of uniformitarianism.
- Briefly describe the theory of plate tectonics.

As we move through the course I encourage you to reflect occasionally on how each topic in the course ties into the big ideas of geological time, uniformitarianism, and plate tectonics. The worksheets below (pdf version) can be used to to help you organize your understanding of the geological concepts you are learning, by placing each topic into this larger conceptual framework of the big ideas in geology.

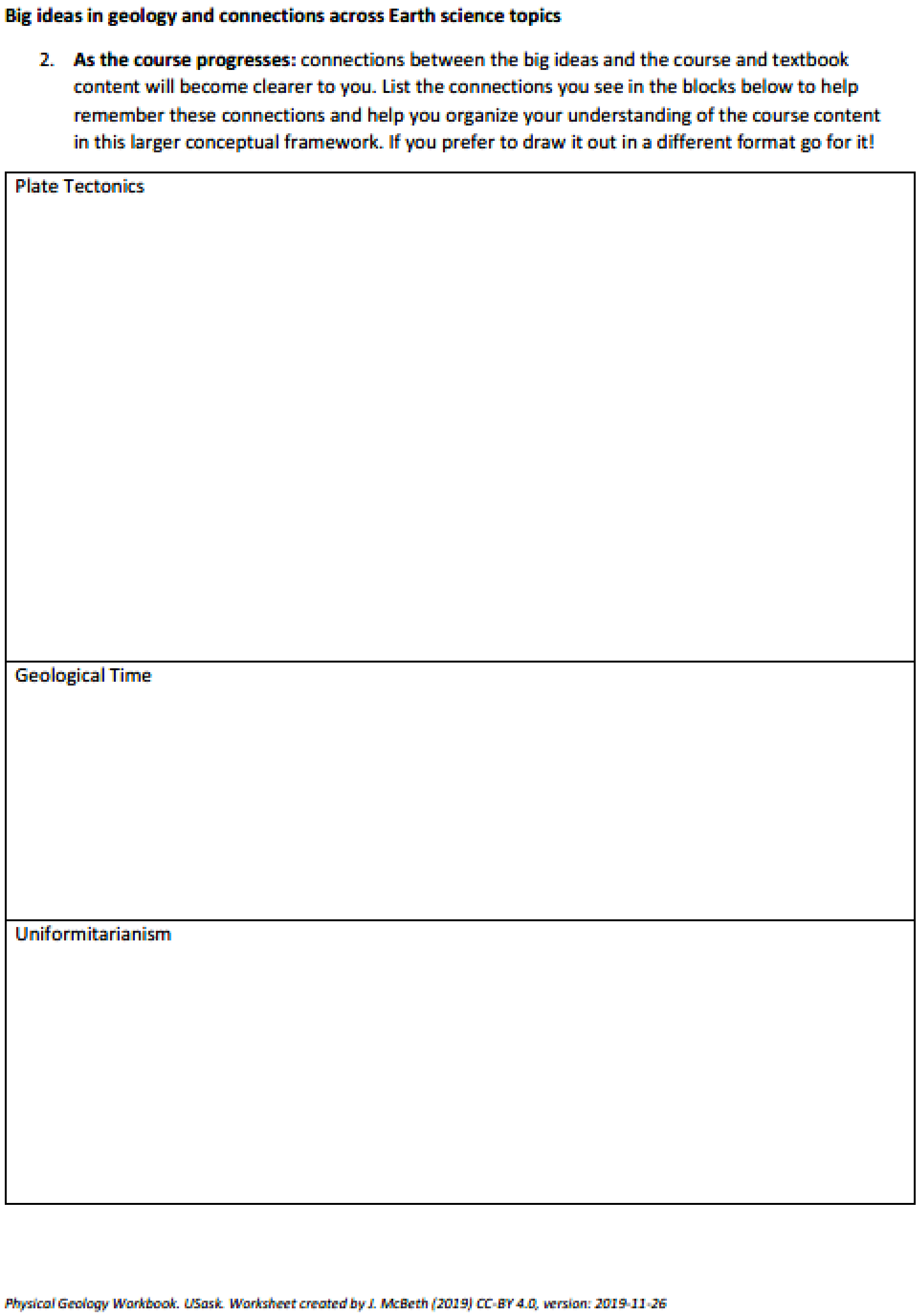
Big ideas in geology and connections across Earth science topics

1. **Start of the course**: briefly read through the syllabus and skim through the chapter descriptions in the textbook. Do you see a connection between each of the topics in the syllabus and chapters of the textbook and the big ideas? Categorize the topics by "big idea" below (some topics may have a connection to more than one big idea).

Plate Tectonics
Geological Time
Uniformitarianism

Physical Geology Workbook. USask. Worksheet created by J. McBeth (2019) CC-BY 4.0, version: 2019-11-26

Figure 1.3.1: Big ideas worksheet – part 1. Source: Joyce McBeth (2019) CC BY-NC-SA 4.0.



Big ideas in geology and connections across Earth science topics

2. **As the course progresses:** connections between the big ideas and the course and textbook content will become clearer to you. List the connections you see in the blocks below to help remember these connections and help you organize your understanding of the course content in this larger conceptual framework. If you prefer to draw it out in a different format go for it!

Plate Tectonics
Geological Time
Uniformitarianism

Physical Geology Workbook. USask. Worksheet created by J. McBeth (2019) CC-BY 4.0, version: 2019-11-26

Figure 1.3.2: Big ideas worksheet – part 2. Source: Joyce McBeth (2019) CC BY-NC-SA 4.0.

CHAPTER 2. THE ORIGIN OF EARTH AND THE SOLAR SYSTEM

Corresponding textbook readings

Physical Geology 1st USask Edition (Panchuk) Chapter 2:

- Section 2.1 Starting with the Big Bang
- Section 2.2 Forming planets from the remnants of exploded stars
- Section 2.3 How to build a solar system
- Section 2.4 Earth's first 2 billion years
- Section 2.5 Are there other Earths?

2.1. The Origin of Earth and the Solar System - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Describe the theory of the big bang.
- Describe in general terms how matter accretes to form stars and planets.
- Describe the formation of the solar system.
- Describe the difference between terrestrial and Jovian planets and the reasons why they differ.
- List the major events that took place in the first 2 billion years of Earth history.

2.2. The Origin of Earth and the Solar System - Vocabulary

Section 2.0 Introduction

- Earth
- Moon
- lunar
- star
- billion

Section 2.1 Starting with the Big Bang

- big bang
- big bang theory
- universe
- energy
- space
- matter
- expand / expansion
- element
- hydrogen
- helium
- light year
- the Sun
- astronomer
- physicist
- cosmic microwave background (CMB)
- galaxy / galaxies
- red-shift
- Doppler effect
- wavelength
- spectrum / spectra
- visual spectrum

Section 2.2 Forming planets from the remnants of exploded stars

- burn
- fuse / fusion
- explode

- supernova / supernovae

Section 2.3 How to build a solar system

- solar system
- nebula / nebulae
- visible light
- infrared light
- gravitational force
- disk
- protoplanetary disk
- rotate
- protoplanet
- orbit
- planet
- terrestrial planet
- Jovian planet
- gas giant
- ice giant
- asteroid belt
- asteroid
- meteroid
- Kuiper belt
- Oort cloud
- frost line
- snow line
- solar wind
- astronomical unit
- accretion
- static electricity
- debris field
- comet

Section 2.4 Earth's first 2 billion years

- Earth
- molten
- atmosphere
- radioactive
- radioactive decay
- thermal energy
- collide / collision
- compression
- differentiation

- impact
- collision
- crater
- coalesce
- giant impact hypothesis
- volcanic eruption
- free oxygen
- chemical reaction
- ultraviolet
- photosynthesis / photosynthetic
- life
- geologic processes
- bar code

Section 2.5 Are there other Earths?

- exoplanet
- extrasolar
- habitable zone

Other related vocabulary:

- nuclear fusion
- impact crater
- ultraviolet light

2.3. The Origin of Earth and the Solar System - Review Questions

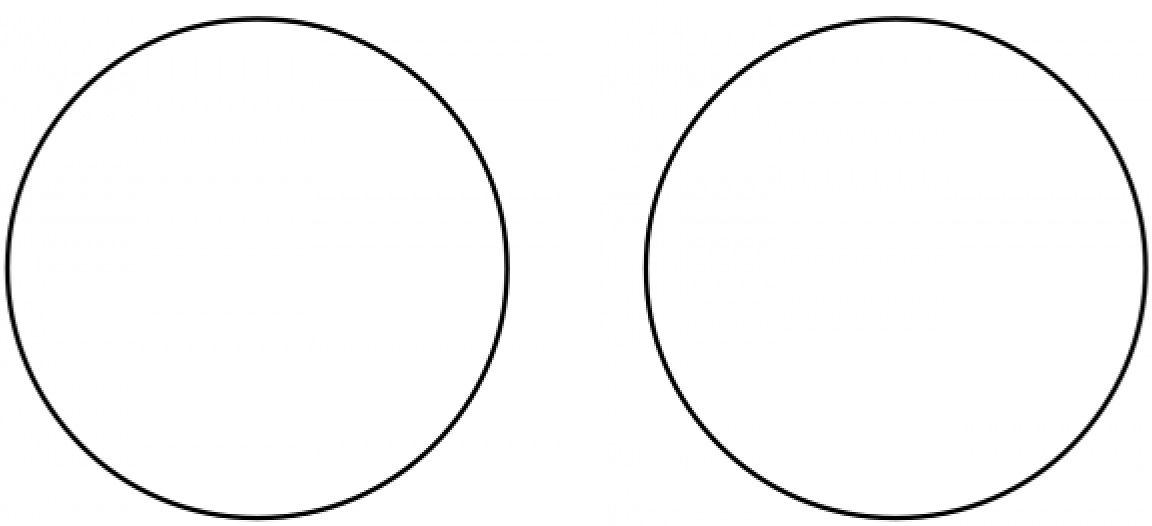
- How was the big bang different from an explosion as we understand explosions today?

- Describe how solar systems are formed.

- Draw a diagram of the solar system. Include the planets and other features such as the asteroid belt.

    - Label the Jovian and terrestrial planets.
    - How big is each planet compared to the sun?
    - Label each planet with the major elements that make it up.
    - In the case of planets with atmospheres, label the composition of the atmosphere.
    - Write a few sentences describing the patterns in planetary composition.

- Draw a cross-section of Jupiter, and a cross-section of Earth. How do they differ? How are they similar?



- Do you think there is life on planets outside our solar system? Why or why not?
- What conditions are required on a planet to support life as we know it?

CHAPTER 3. EARTH'S INTERIOR

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 3:

- Section 3.1: Earth's layers: crust, mantle, and core
- Section 3.2. Imaging Earth's interior
- Section 3.3. Earth's interior heat
- Section 3.4. Earth's magnetic field
- Section 3.5. Isostacy

3.1. Earth's Interior - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Name and describe the layers of the Earth.
- Describe how elemental abundances change throughout the Earth's layers.
- Describe how the Earth's crust differs from the Earth's lithosphere.
- Describe and draw the differences between P and S waves and how they move through the different layers of the Earth.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Describe the shape of the Earth.
- Describe how we describe elevations of features on the Earth's surface.

3.2. Earth's Interior - Vocabulary

Section 3.0. Introduction

- The Earth
- composition
- collision
- meteorite
- asteroid
- fragment
- altered / unaltered rock

Section 3.1. Earth's layers: crust, mantle, and core

- layer
- radius
- crust
- mantle
- core
- outer core
- inner core
- physical properties
- density
- continental crust
- oceanic crust
- lithosphere
- asthenosphere
- felsic
- mafic
- ultramafic
- rigid
- D" layer
- abundance
- elements (e.g., iron, silicon, magnesium, aluminum, nickel, sulfur, oxygen)

Section 3.2. Imaging Earth's interior

- seismology / seismologist
- vibration
- P waves
- S waves

- velocity (speed)
- seismic data
- seismic waves
- seismic ray path
- wave front
- reflect
- refract
- rigid
- Moho discontinuity / Mohorovičić discontinuity
- seismic station
- S-wave shadow zone
- P-wave shadow zone
- seismic tomography

Section 3.3. Earth's interior heat

- geothermal gradient
- convection
- buoyancy
- molten
- liquid
- flow
- conduction
- mantle convection
- radioactivity

Section 3.4. Earth's magnetic field

- Earth's magnetic field
- inclination
- equator
- northern hemisphere, southern hemisphere
- compass needle
- North Pole, South Pole
- latitude
- magnetic field reversal / flip
- mathematical model
- rotation axis

Section 3.5. Isostacy

- isostatic

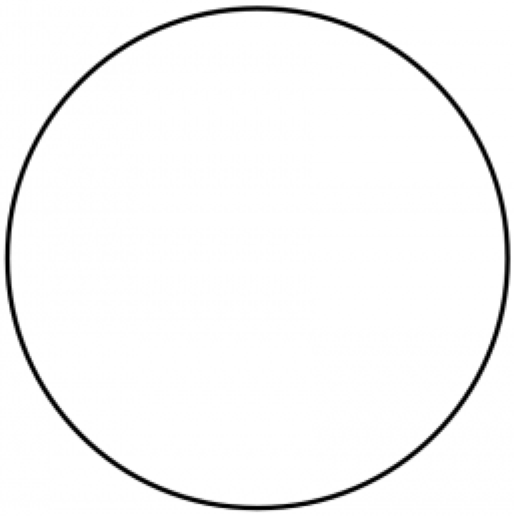
- sea level
- erosion
- float
- rebound
- glacier / glaciation / glacial ice
- subsidence
- solid
- plastic
- viscous
- non-Newtonian fluid
- stress
- deform

Other vocabulary (used in lectures, not in text for this chapter):

- geodesy
- geophysics
- Himalayan Mountains
- Mariana Trench
- Challenger Deep
- Mount Everest
- Mount Chimborazo
- homogeneous
- inhomogeneous
- longitude
- peak
- rotational forces
- spherical
- oblate spheroid
- topography
- mantle plumes
- ductile

3.3. Earth's Interior - Review Questions

- Draw a schematic cross-section diagram through the Earth using the circle below. Label each layer, identify whether it is liquid or solid, and note what elements are most abundant in each layer.



- How do the densities of the materials (in the rocky or liquid layers of the Earth) vary as you move from the surface of the Earth to the centre of the Earth? How does this relate to the composition of each layer and sublayer?

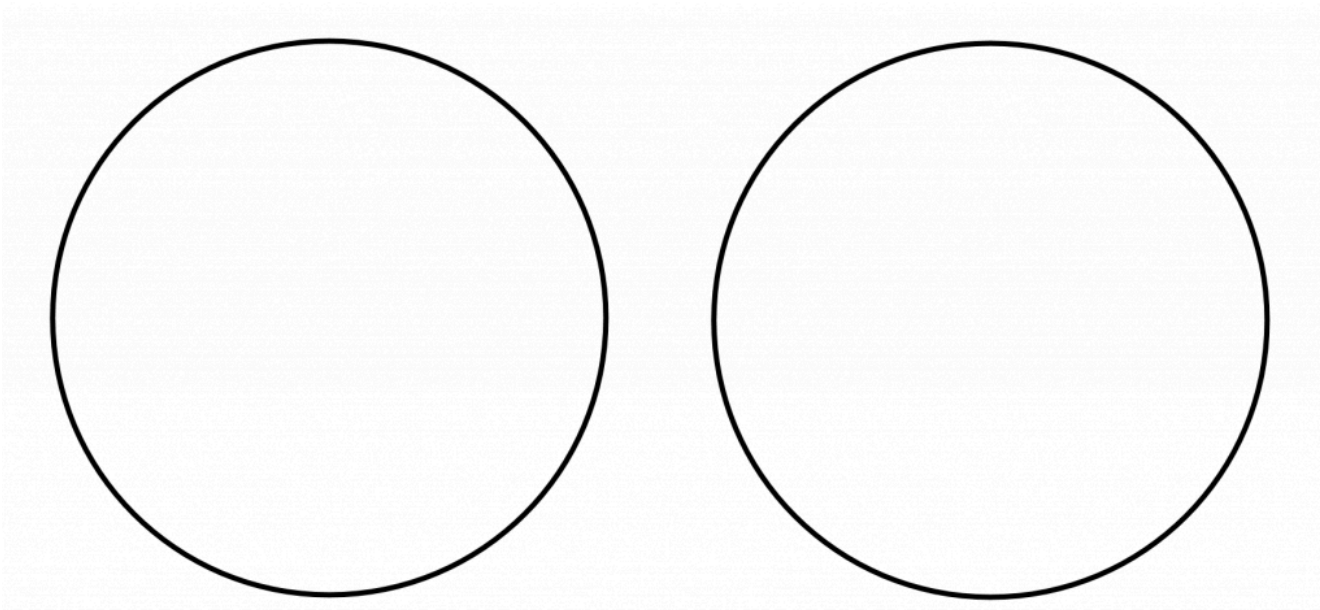
- How homogeneous are the different Earth layers?

- Draw a cross-section through the crust and label the different parts. How does the density of the rock vary across the different kinds of crust (continental and oceanic)?

- How does the depth of the Moho differ between continental and oceanic lithospheric plates?

- Describe the process of isostacy and give examples of locations where isostacy is occurring on Earth today.

- Draw two cross-sections of the Earth including the layers of the Earth, with an earthquake focus near the surface of the Earth.
    - Draw the pattern of P waves that extends from the earthquake focus through the layers of the Earth.
    - Draw the pattern of S waves that extend from the earthquake focus through the layers of the Earth. Label the shadow zones for each.



Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- What shape is the Earth? How does its shape vary on a global scale? If you travelled from one side of Canada to the other, how does the surface of the Earth vary, in terms of topography?

- Where on Earth do we find mantle plume hotspots? Google image search for these places and compare the way the rocks and volcanic eruptions and features look in these places. What similarities do you see?

CHAPTER 4. PLATE TECTONICS

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 4:

- Section 4.1: Alfred Wegener's arguments for plate tectonics
- Section 4.2: Global geological models of the early 20th century
- Section 4.3: Geological renaissance of the mid-20th century
- Section 4.4: Plates, plate motions, and plate-boundary processes
- Section 4.5: Mechanisms for plate motion

4.1. Plate Tectonics - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Describe the difference between the theory of plate tectonics and the continental drift hypothesis, and list scientific evidence supporting each of them.
- Name some of the major tectonic plates and identify their boundaries on a topographic map of the Earth.
- Name the three types of plate boundaries and their characteristics.
- Identify points on a topographic map of the Earth where each type of plate boundary exists.
- Describe one or more of the scientific theories about how plate tectonics works.

4.2. Plate Tectonics - Vocabulary

Section 4.0 Introduction

- spreading center
- Mid-Atlantic Ridge
- plate
- volcano
- crust
- rift zone
- tectonic plate
- margin
- ridge

Section 4.1 Alfred Wegener's arguments for plate tectonics

- Alfred Wegener
- continental drift
- terrestrial
- supercontinent
- Permian
- Pangea / Pangaea
- Gondwana
- Eurasia
- sedimentary strata
- coalfields
- Carboniferous
- glaciation
- Southern Hemisphere
- paleogeographic reconstruction
- iceberg
- Earth's rotation
- ocean crust
- lunar / solar tidal forces

Section 4.2 Global geological models of the early 20th century

- terrestrial species
- fold-belt mountains
- folded mountains
- plate tectonics

- contractionism
- submerge
- permanentism
- geosyncline theory
- fossil distribution patterns
- sediments
- sedimentary layers
- sedimentary rocks
- continental weathering
- compression
- fold
- lateral forces
- intercontinental
- matchup
- land bridge
- climate change
- isostacy
- polar ice cap
- Mesozoic
- continental shelf

Section 4.3 Geological renaissance of the mid-20th century

- plate tectonic theory
- paleomagnetism
- ocean floor
- remnant magnetism
- align
- compass needle
- crystallize
- magma
- basalt
- magnetite
- magnetized
- deposit
- rock layer
- latitude
- magnetic north
- paleomagnetic data
- polar wandering paths
- geographic north pole
- rotational pole
- apparent polar wandering paths
- bathymetry
- weighted line
- acoustic depth sounder

- trans-Atlantic cable
- basin
- bathymetric data
- topography
- Nazca trench
- fracture zone
- ocean trench
- seamount
- seamount chain
- seismic reflection sounding
- geophone
- bedrock topography
- sediment thickness
- rift valley
- vertical exaggeration
- heat flow
- mantle convection
- upward / downward convection
- seismographic station
- earthquake
- mid-ocean ridge
- magnetometer
- magnetic stripes
- magnetic survey
- sea-floor spreading
- mantle material
- landmass
- magnetic field reversal
- anomaly
- mantle plume
- hot spot
- Emperor seamounts
- Hawai'ian mantle plume
- Pacific Plate
- Yellowstone hot spot
- Anahim Volcanic Belt
- oceanic spreading ridges
- fault
- transform fault
- rigid

Section 4.4 Plates, plate motions, and plate-boundary processes

- Eurasian Plate
- Pacific Plate
- Indian Plate

- Australian Plate
- North American Plate
- South American Plate
- African Plate
- Antarctic Plate
- Juan de Fuca Plate
- Nazca Plate
- Scotia Plate
- Philippine Plate
- Caribbean Plate
- Global Positioning System (GPS)
- plate motion
- rate of motion
- plate boundary
- divergent
- convergent
- transform
- crust
- mantle
- lithosphere
- aesthenosphere
- mafic
- San Andreas Fault
- spreading boundary
- partial melting
- pillow lava
- gabbro
- sheeted dykes
- buoyant
- dome
- radial fractures
- three-part rift formation
- Great Rift Valley
- ocean-ocean convergent boundary
- ocean-continent convergent boundary
- continent-continent convergent boundary
- subduct
- subduction
- flux melting
- fluid-induced melting
- pyroxene
- olivine
- serpentine
- island arc
- accretionary wedge
- compression
- thrust fault
- Wilson Cycle

- passive margin
- oceanic lithosphere
- continental lithosphere
- erosion

Section 4.5 Mechanisms for plate motion

- ridge-push
- slab-pull
- convection traction

Other vocabulary

- continental fit
- rock record
- paleoclimate
- glacial striation
- isochron
- magnetic polarity
- matrix
- solid / solidify
- active margin
- seafloor spreading
- heterogeneous
- mid-ocean ridge axis
- random distribution vs non-random distribution
- Ring of Fire
- submarine
- crustal thickening

4.3. Plate Tectonics - Review Questions

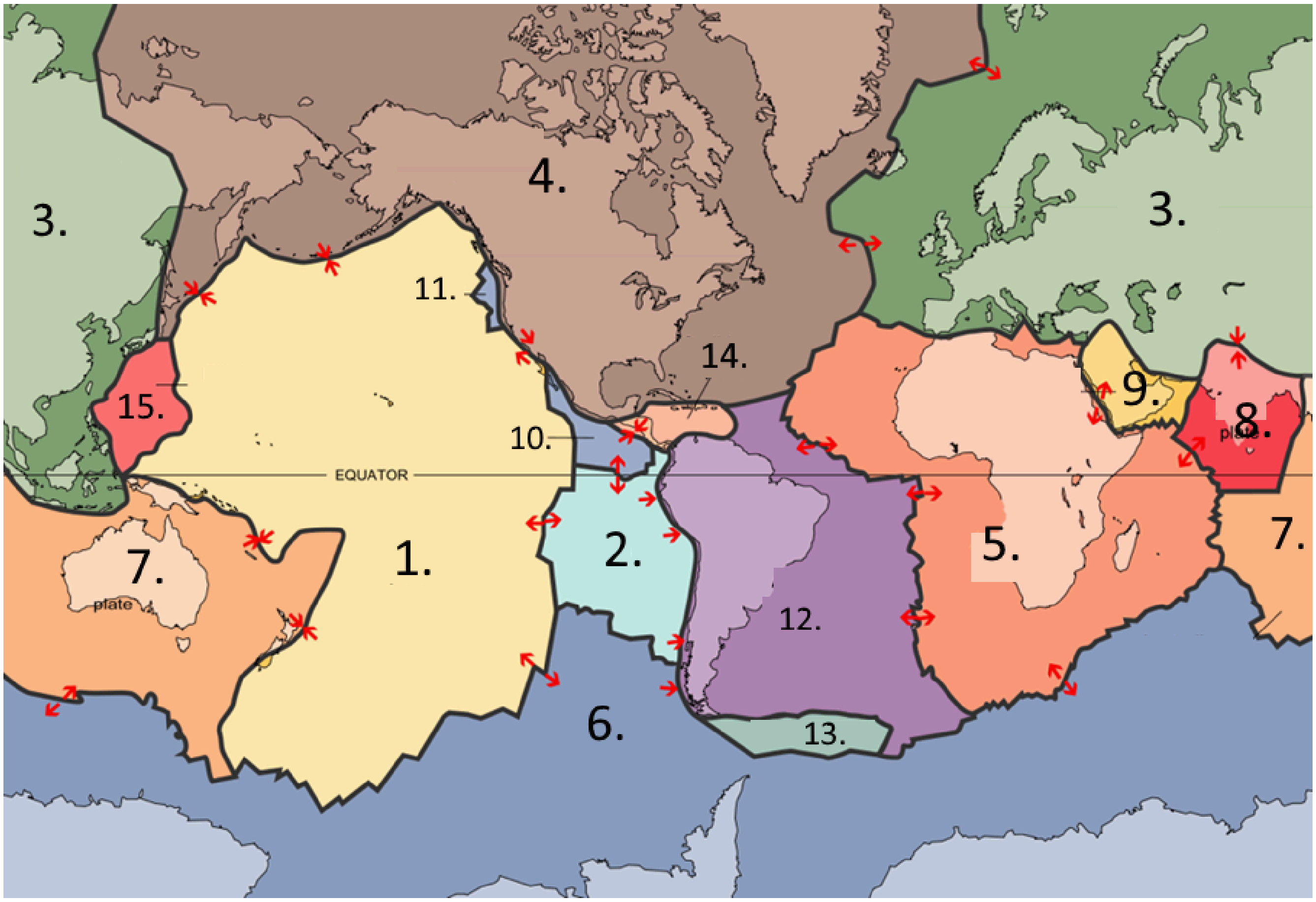


***Figure 4.3.1** | Major tectonic plates of the Earth. Source: Joyce M. McBeth (2018) after USGS (1996) public domain. [View source]*

- Identify and label the tectonic plates (numbered from 1 to 15) on Figure 4.3.1 above.
- Consider the North American Plate (the plate labelled 4 in Figure 4.3.1):
    - What regions of the plate are continental crust?
    - What regions of the plate are oceanic crust?
    - What kinds of plate tectonic boundaries are located at the edges of the North American Plate?
- Consider the Pacific Plate (the plate labelled 1 in Figure 4.3.1):

- What regions of the plate are continental crust?
- What regions of the plate are oceanic crust?
- What kinds of plate tectonic boundaries are located at the edges of the Pacific Plate?

- Consider the South American Plate (the plate labelled 12 in Figure 4.3.1):
  - What regions of the plate are continental crust?
  - What regions of the plate are oceanic crust?
  - What kinds of plate tectonic boundaries are located at the edges of the South American Plate?
- Consider the Antarctic Plate (the plate labelled 6 in Figure 4.3.1):
  - What regions of the plate are continental crust?
  - What regions of the plate are oceanic crust?
  - What kinds of plate tectonic boundaries are located at the edges of the Antarctic Plate?
- Consider the continent of North America (located on the North American Plate): how does the plate tectonic environment of the Pacific coast of North America differ from that of the Atlantic coast of North America?
- What evidence did Wegener use to develop the hypothesis of continental drift?
- Where is the eastern edge of the North American plate? How does the eastern edge of the North American plate differ from the eastern edge of the North American continent?

- List the three types of plate boundary and draw a cross-section of each of them. Find examples of each type of plate boundary on Figure 4.3.1.

- List the three types of convergent plate boundary and draw a cross-section of each of them. Locate an example of each type of plate boundary on Figure 4.3.1.

- At convergent plate boundaries, one of the plates often subducts beneath the other plate. what property determines which plate subducts?

- What does it mean to say that a plate boundary is conservative? Give an example of a conservative plate boundary (location).

- Is the oceanic lithosphere in the centre of the Atlantic Ocean floor younger or older than the oceanic lithosphere in the Atlantic Ocean floor at the coast of the USA?
- Describe how magnetic polarity and magnetic striping in the rock record can be used to determine rates of plate movement.
- Give an example of a hot spot plume located under continental lithosphere, and a hot spot plume located under oceanic lithosphere. What geological evidence is associated with each hot spot location that geologists can use to tell us how they were produced?
- How can we use evidence such as the positions of the islands in the Hawaiian island archipelago to learn about tectonic plate motion?

CHAPTER 5. MINERALS

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 5:

- Introduction
- Section 5.1: Atoms
- Section 5.2: Bonding and lattices
- Section 5.3: Mineral groups
- Section 5.4: Silicate minerals
- Section 5.5: How minerals form
- Section 5.6: Mineral properties

5.1. Minerals - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Define the term mineral and provide examples of several common minerals.
- Name the parts of the atom, draw a diagram of an atom, and label the charges of the particles that make up the atom.
- Name the types of chemical bonds, and give examples of molecules and minerals where they occur.
- Describe several common mineral crystal habits.
- Name the groups/classes of rock forming minerals, give an example of each of them, and an environment where each class of mineral forms.
- Name and sketch the different types of silicate structures and give examples of each.
- Describe the properties we can use to help identify minerals, and give a range of examples of each property.
- Define the term rock.

5.2. Minerals - Vocabulary

Section 5.0 Introduction

- crystal
- mineral
- solid
- liquid
- naturally-occurring
- three-dimensional structure
- anthropogenic
- natural processes
- waxy
- ore
- composition
- variable composition
- solid solution
- substitute / substitution
- chemical formula
- lattice
- internal atomic arrangement
- crystalline
- deposit
- mineraloid

Section 5.1 Atoms

- atom
- element
- proton
- neutron
- electron
- positive charge
- negative charge
- neutral
- nucleus
- isotope
- atomic structure
- atomic number
- mass number
- radioactive
- energy
- decay

- shell
- energy level
- outer shell
- inert
- noble gasses
- compound
- bond
- electron shell configuration
- subshell

Section 5.2 Bonding and lattices

- chemical bond
- transfer electron
- share electron
- ionic bond
- ion
- cation / positive ion
- anion / negative ion
- covalent bond
- charge imbalance
- balance
- Van der Waals forces
- sheet
- layer
- hydrogen bonds
- electrostatically neutral
- asymmetrical
- polar
- metallic bonding
- dissociated electrons
- electrically conductive
- malleable
- deform

Section 5.3 Mineral groups

- anion group
- silicate
- oxide
- carbonate
- sulfate / sulphate
- gemstone
- hydroxide

- hydroxyl ion
- ore
- sulfide / sulphide
- metallic
- sheen
- lustre
- halide
- halogen
- phosphate
- native element

Section 5.4 Silicate minerals

- silicate tetrahedron
- tetrahedra
- building block
- chain
- ring
- framework
- isolated tetrahedra
- Ångstrom
- atomic-scale
- ferric iron
- ferrous iron
- chain silicate
- single-chain silicate
- double-chain silicate
- permissive
- sheet silicate
- framework silicate
- ternary system
- end-member
- polymorph

Section 5.5 How minerals form

- physical conditions
- chemical conditions
- crystallize
- crystal growth
- magma
- fine-grained
- precipitation
- metamorphism

- weathering
- organic (biogenic) mineral formation

Section 5.6 Mineral properties

- colour
- streak
- lustre
- hardness
- habit
- cube
- cubic
- cleavage
- fracture
- density
- texture
- powder
- streak plate
- metallic
- sheen
- non-metallic
- translucent
- transparent
- reflective
- glassy
- earthy
- silky
- pearly
- resinous
- scratch
- Mohs hardness scale
- steel file
- dodecahedron (12 sided)
- bladed
- botryoidal
- dendritic
- drusy
- equant
- fibrous
- platy
- prismatic
- stubby
- crystal shape
- crystal habit
- plane
- basal cleavage

- cleavage planes
- crystal face
- diagnostic
- density
- magnetic
- salty
- bitter
- striations

Other vocabulary

- course-grained
- amorphous
- inorganic
- synthetic
- ceramic
- euhedral
- anhedral
- ductile
- specific gravity
- felsic
- mafic
- geometry
- octahedron (8 sides)
- apex

5.3. Minerals - Review Questions

- What are the three subatomic particles that make up atoms? What are their charges?
- Define the term mineral, and list the 5 characteristics of minerals that distinguish them from other compounds.
- What are the seven major classes of rock forming minerals? What elements are important constituents of each mineral class? Give one or two examples of minerals in each class of mineral.
- Name the seven common rock-forming minerals.
- Name two minerals with cubic crystal habit.
- What are some differences in the properties of diamonds and graphite? Why do they have these different properties?
- What are the seven main physical properties of minerals that we can use to help identify a mineral? What other

properties can also be useful for mineral identification?

- What are the minerals or substances in the Mohs hardness scale? What is their order of hardness?
- Does olivine have a definite or variable composition? Explain.
- What silicate minerals are common in igneous rocks?
- Name three sets of cation pairs that can commonly substitute for one another in mineral structures. *Hint: look at the chemical formulae for the end-members of olivine for one of the cation pairs.*
- Draw a silicon tetrahedron. What are a few examples of different kinds of silicate minerals that contain silicon tetrahedra? For each kind of mineral, are the silica tetrahedral in chains, sheets, a 3-D network, or individual tetrahedral?
- Granite is a common rock type that contains several types of silicate minerals. What are three common minerals with either sheet silicate or 3-D silicate structure that are found in granite?
- Search for examples of the following minerals on google image search: feldspar, pyrite, quartz, gypsum, calcite, mica, fluorite, hematite, native gold. How are the results similar? How are they different?
  Note: *some of the search results will show minerals that are* NOT *the minerals you are searching for, or minerals that have been modified (e.g., dyed or coated quartz is very common). Can you pick out the natural/correctly identified specimens from the fakes?*
- Students often struggle with remember the different types of silicates so this exercise is to help you visualize each

one and self-test yourself on examples. For each of the following:

  - silica tetrahedra (the building blocks of all silicates)
  - sheet silicate
  - three-dimensional (3D) network
  - independent tetrahedra
  - single chain
  - double chain
- Sketch an example of each type of silicate mineral. *Tip: if drawing scares you, try not to get too bogged down in the details, look for the bigger scale patterns in each type of silicate rather than worrying about the precise pattern of the tetrahedra. Are the silica tetrahedra in sheets? Are the sheets continuous or are there gaps? If there are gaps, where are they? Is there anything in them?*

- Write an example or two of each type of silicate mineral.

- How is the structure of each type of silicate reflected in the properties of the minerals that have that structure? E.g., cleavage, compositional variations.

5.4. Lists of Minerals

see Appendix VII for a list of mineral name origins.

Sulfate minerals

- gypsum
- anhydrite
- barite
- celestite

Oxide minerals

- hematite
- magnetite
- corundum
  - ruby
  - sapphire

Hydroxide minerals

- limonite
- bauxite
- ice

Sulfide minerals

- galena
- sphalerite
- chalcopyrite
- molybdenite
- pyrite
- bornite
- arsenopyrite
- stibnite
- cinnabar

Halide minerals

- cryolite
- fluorite
- halite
- sylvite

Carbonate minerals

- calcite
- aragonite
- magnesite
- dolomite
- siderite
- malachite
- azurite

Phosphate minerals

- apatite
- hydroxyapatite
- turquoise

Silicate minerals

- isolated tetrahedra minerals
    - olivine
    - garnet
- chain silicate minerals
    - single-chain silicate
        - pyroxene
    - double-chain silicate
        - amphibole
- sheet silicate
    - mica
        - biotite
        - muscovite
    - clay

        - kaolinite
        - illite
        - smectite
        - talc
- framework silicate
    - feldspar
        - plagioclase feldspar
            - labradorite
            - albite
            - anothite
        - potassium feldspar (K-feldspar)
            - alkali feldspar
                - orthoclase
                - microcline
                - sanidine
    - quartz
        - amethyst
        - smokey quartz
        - citrine
        - rose quartz

Native element minerals

- gold
- copper
- silver
- graphite
- diamond
- sulfur / sulphur
- platinum
- palladium
- mercury

Mineraloids

- opal

Metamorphic minerals

From Chapter 10.

- kyanite
- sillimanite
- andalusite
- garnet
- chlorite
- muscovite
- biotite
- amphibole
- serpentine
- glaucophane

Other minerals (not listed in minerals chapter of textbook at this time)

- forsterite, fayalite (olivine end-members)
- goethite
- spinel
- millerite
- melanterite
- topaz
- beryl
- borax
- sylvite

CHAPTER 6. THE ROCK CYCLE

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 6:

- 6.1: What is a rock?
- 6.2: The rock cycle

6.1. The Rock Cycle - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Define the term rock.
- Name the three main types of rocks.
- Describe what processes act on the three types of rocks to transform them in the rock cycle.
- Draw a rock cycle diagram showing the types of rocks and processes that act on them to change them through time.
- Give examples of plate tectonic environments where each major rock type is formed.
- Name the characteristics we use to identify rocks.

6.2. The Rock Cycle - Vocabulary

Section 6.0 Introduction

- petrified
- ripple / ripples
- sedimentary rock
- metamorphic rock

Section 6.1 What is a rock?

- mineral crystals
- inorganic
- organic
- non-mineral solids
- fossils
- coal
- pegmatite
- igneous rock
- sedimentary rock
- metamorphic rock
- cement
- precipitate
- alter

Section 6.2 The rock cycle

- rock cycle
- force
- hydrological cycle
- magma
- intrusive igneous rocks
- lava
- extrusive igneous rocks
- mountain building
- weathering
- chemical processes
- physical processes
- crack
- exposed
- wedging

- fragments
- erosion / eroded
- transportation / transported
- deposition / deposited
- sediment
- stream channel
- sedimentary structure
- ripple
- burial / buried
- compression / compressed
- particle
- cement / cementation
- cross-section
- sandstone
- squeeze
- transformation
- physical changes
- chemical changes
- react
- limestone
- marble

6.3. The Rock Cycle - Review Questions

- Define the term rock.
- What characteristics (features of the rock) do geologists use to identify rock types?
- What are the three major rock types?
- What rock-forming process(es) form each major rock type?
- Considering the cross-section diagram below (Figure 6.3.1), what are examples of places where each major rock type would form?

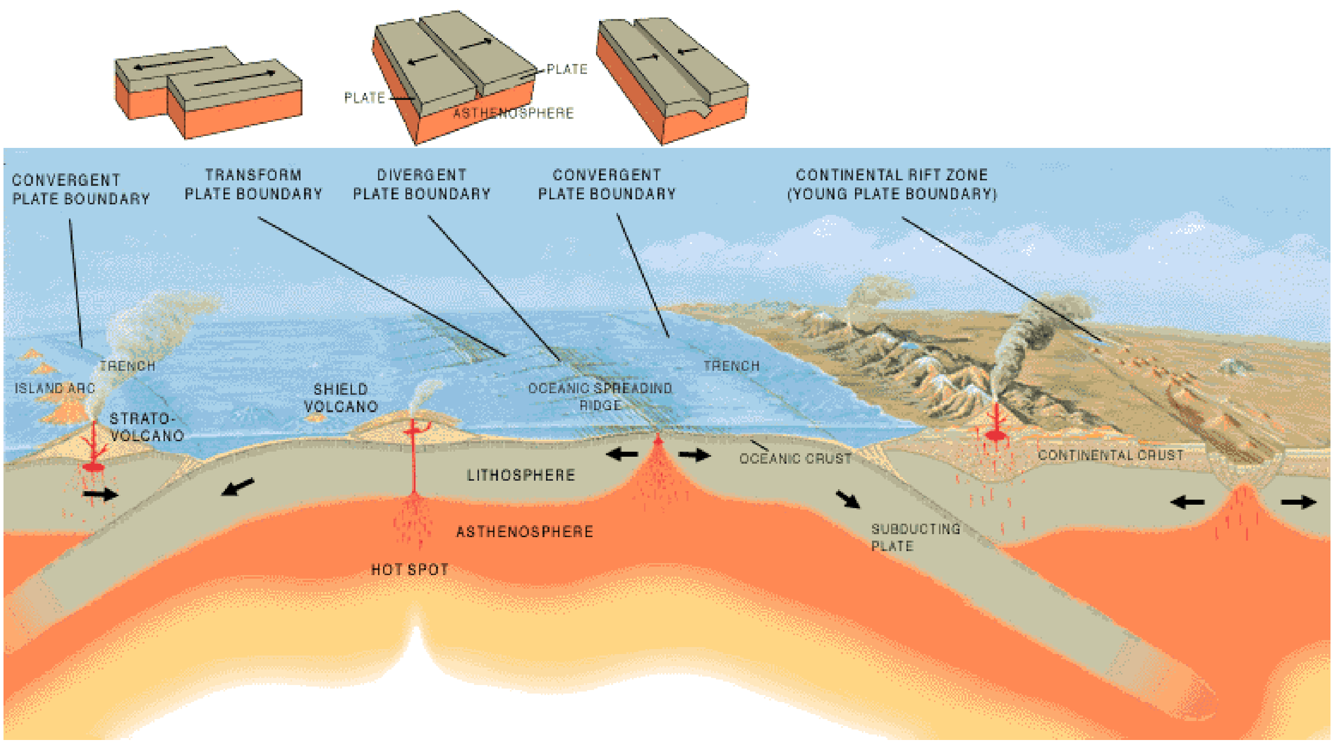


Figure 6.3.1 | *Plate tectonic boundaries and geological settings. Source: José F. Vigil, This Dynamic Planet (1996) USGS, Smithsonian Institute, US NRL, public domain.* [View source]

CHAPTER 7. IGNEOUS ROCKS

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 7:

- Section 7.1: Magma and how it forms
- Section 7.2: Crystallization of magma
- Section 7.3: Classification of igneous rocks
- Section 7.4: Intrusive igneous rocks

7.1. Igneous Rocks - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Explain the properties we use to categorize igneous rocks.
- Describe the four igneous rock textures.
- Discuss the information an igneous rock's texture gives you about the environment where the rock formed.
- Describe how igneous rock composition and mineralogy vary along the spectrum from felsic to ultramafic rocks.
- What are names of intrusive and extrusive rocks that are found in each igneous rock type? Describe each of these types of rock in terms of their composition, mineralogy, and texture.
- How does magma viscosity vary with igneous magma composition? Temperature? Density?
- Describe how the temperature of the lithosphere changes with depth in the following environments: ocean crust, continental crust, mid-ocean ridges, hotspots, and in island arcs
- Explain the concept of partial melting.
- Explain how the composition of magma and the minerals that form can change in a magma chamber as the magma cools.
- Describe how the composition of magma varies by tectonic environment.
- Define plutonic rock.
- Describe the types of igneous intrusions and their features (e.g. dykes).
- Describe features associated with contact metamorphism of country rock by intrusions.
- Classify each type of igneous intrusion as discordant or concordant.
- Describe the process of magmatic stoping.
- Describe the relationship of contact metamorphism to igneous intrusions.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Explain the process of magma differentiation: what factors can affect magma composition?
- Describe how the process of igneous evolution happens.

7.2. Igneous Rocks - Vocabulary

Section 7.1 Magma and how it forms

- magma
- igneous rock
- composition
- crust
- most abundant elements (oxygen, silicon, aluminum, iron, calcium, sodium, magnesium, potassium)
- lighter elements (hydrogen, carbon, sulfur / sulphur)
- water vapour
- carbon dioxide
- hydrogen sulfide / hydrogen sulphide
- sulfur dioxide / sulphur dioxide
- partial melting
- melting temperature
- melt (noun)
- percolate
- pool (verb)
- decompression melting
- flux-induced melting
- volatile compounds
- convection
- plume
- rift zone
- flux (noun)
- subduction zone
- viscous / viscosity
- runny
- thick
- polymerize

Section 7.2 Crystallization of magma

- crystallize
- crystal
- Bowen's reaction series
- continuous branch
- discontinuous branch
- quench
- chemical reaction
- transition
- zone / zoned

- unstable
- react
- silica tetrahedra
- series
- xenolith
- rim
- magma composition
- felsic
- intermediate
- mafic
- ultramafic
- komatiites
- crystal settling
- fractional crystallization
- magma chamber
- settle
- remelt
- country rock

Section 7.3 Classification of igneous rocks

- chemical composition
- felsic
- intermediate
- mafic
- ultramafic
- classification
- intrusive / plutonic
- extrusive / volcanic
- granite
- diorite
- gabbro
- peridotite
- rhyolite
- andesite
- basalt
- komatiite
- grain size
- texture
- phaneritic / course-grained
- aphanitic / fine-grained
- geological setting
- erupt / erupted
- eruption
- porphyritic
- porphyry

- phenocryst
- groundmass / matrix
- ferromagnesian mineral
- light mineral
- dark mineral
- magnification
- glassy
- gas bubble
- vesicle
- vesicular
- amygdule
- cooling rate
- volcanic glass
- obsidian
- scoria
- pumice
- float

Section 7.4 Classification of igneous rocks

- stoping (rhymes with "nope")
- pluton
- stock
- batholith
- dike / dyke
- sill
- laccolith
- pipe
- cylindrical
- conduit
- regular shape
- irregular shape
- coalesce
- igneous intrusion
- tabular intrusion
- concordant
- discordant
- lopolith
- chilled margin

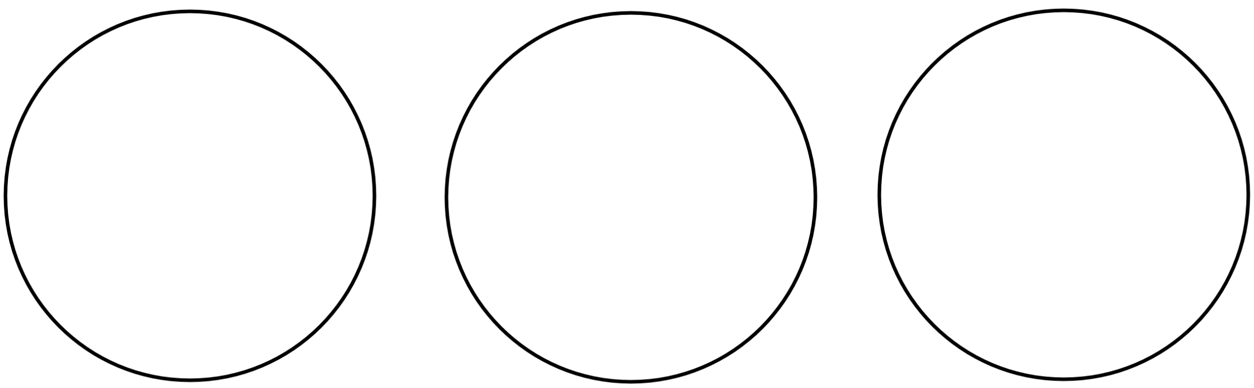
Other vocabulary (not currently in text)

- ropy
- blocky

- magmatic differentiation
- massive
- mineralogy
- pyroclasts
- dyke swarm
- ash
- bombs
- magmatic stoping
- diffuse
- vein
- igneous province
- flood basalt
- pahoehoe
- aa
- geothermal gradient
- solidus
- geotherm
- fluid-induced melting
- residue
- wall-rock assimilation
- magma migration
- magma mixing
- igneous evolution

7.3. Igneous Rocks - Review Questions

- What are igneous rocks? What are the two main kinds of igneous rock?
- What minerals would you expect to see in a granite? In a basalt?
- Describe the common igneous rock textures. Pay particular attention to differences in mineral crystal size in your descriptions.
- What is the difference between phaneritic, aphanitic, and porphyritic textures? Draw examples of each in the circles below, and point out key features of each texture.



- What are the differences between felsic and mafic rocks?
- Name an example a rock type where the colour (dark vs light minerals) of the rock is not representative of the composition (felsic vs mafic) of the rock.
- What are the seven common types of igneous rock? What is their composition and texture? Where do they fit on the igneous classification diagram (Figure 7.13)?

- Assuming constant temperature, how do changes in pressure or water content influence the melting temperature of rock?

- What is the aphanitic equivalent of granite?
- What is the phaneritic equivalent of basalt?
- How does magma (or lava) composition relate to the viscosity of magma (or lava)?

- Describe the process of mineral crystallization in a magma.

- Draw and describe the characteristics of the different types of igneous intrusions.

- Where in the diagram below (Figure 7.3.1) would you expect to find basalt? Gabbro? Diorite? Granite?

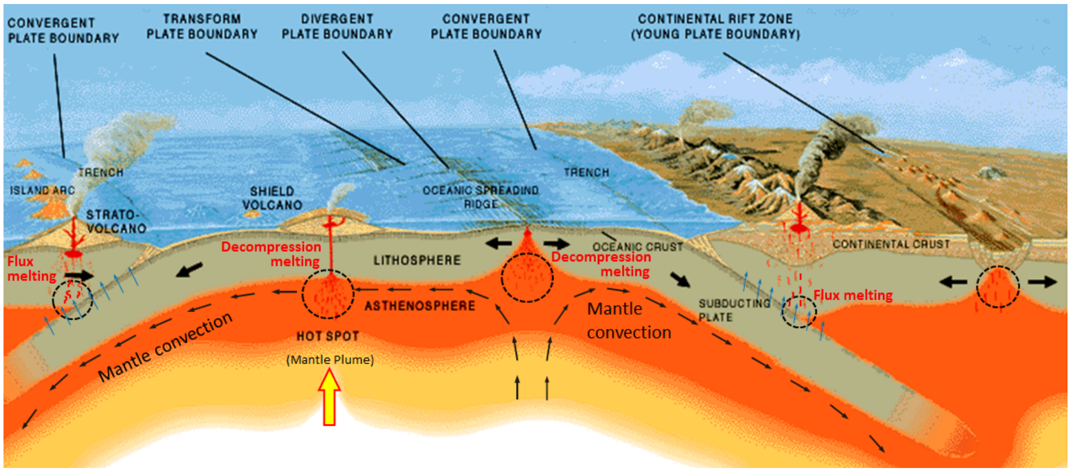


Figure 7.3.1 | *Cross-section through plate tectonic boundaries. Source: Steven Earle (2015) after* USGS, CC BY 4.0. [View source]

- Describe how the composition of magma changes during the process of fractional crystallization. Draw a three panel figure illustrating this process, highlighting (a) which crystals form first as the magma begins to cool, and (b) changes in the composition of the magma before, during, and after the first crystals form and sink to the bottom of the magma chamber (see textbook Figure 7.11 and 7.12 and associated text for guidance).

- Looking at image “a” below:
  - What is the overall texture of this rock?
  - What is the composition of this rock?
- Looking at image “b” below:
    - What is the overall texture of this rock?
    - What is the texture of the matrix?
    - What is the composition of this rock?

***Figure 7.3.2** | Igneous sample “a”. Source: Joyce M. McBeth (2018)* CC-BY 4.0.

***Figure 7.3.3** | Image “b”. Source: Joyce McBeth (2019)* CC BY 4.0.

- Practice filling in the igneous rock classification diagram below (Figure 7.3.4). ***If you understand and memorize this diagram, it will be very useful to you in exams!*** Note: *for the Si (silicon) content, indicate the approximate change in values across the different compositions by drawing a line along the box at the approximate Si % values for each rock type. The overall trend is the most important part of this section of the diagram.*

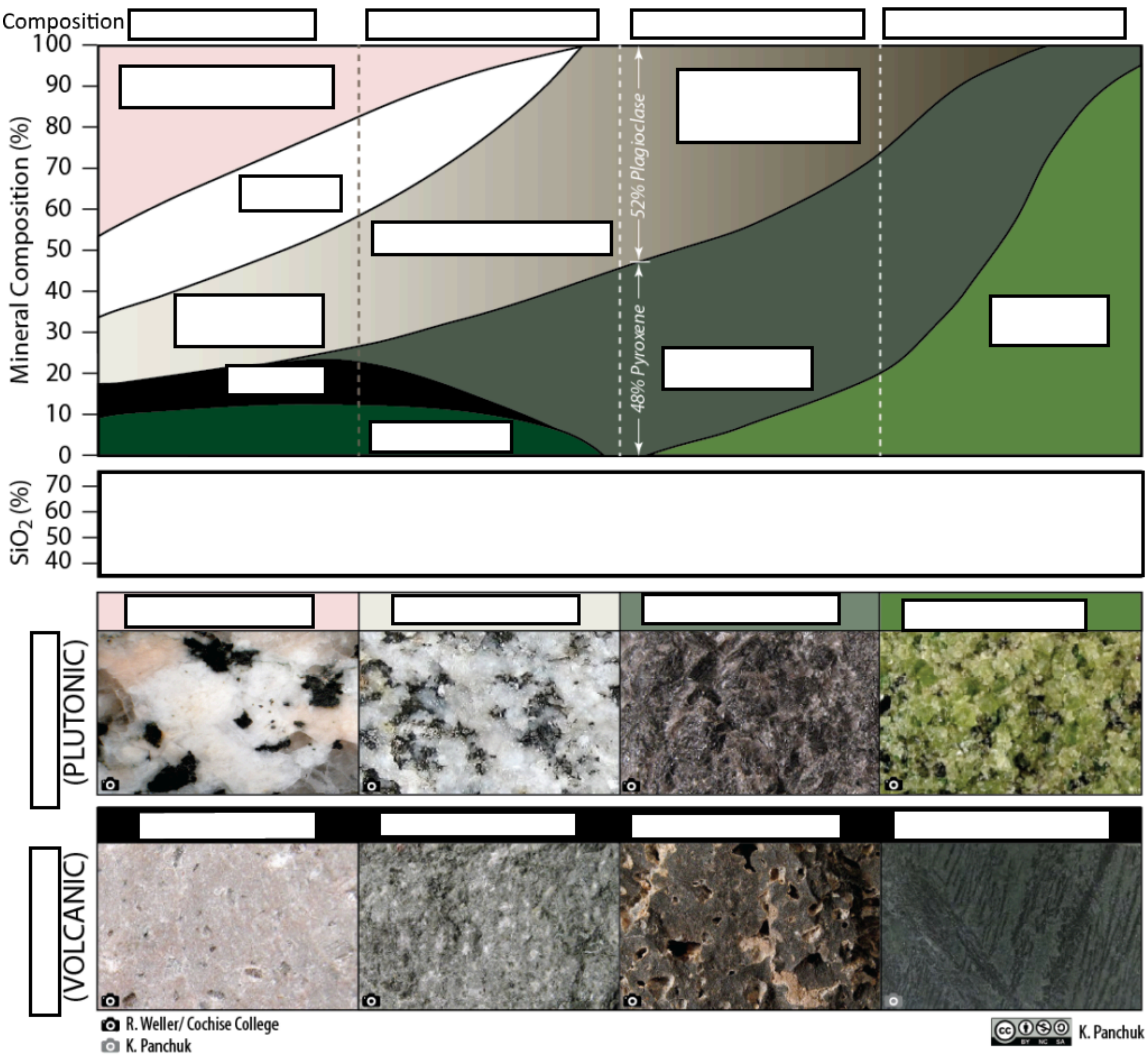


Figure 7.3.4 | *Igneous rocks classification diagram. Joyce McBeth (2018) after Karla Panchuk (2018) CC BY-NC-SA 4.0, modified after Steven Earle (2015) CC BY 4.0.* [View source]

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- Describe the processes that lead to magma differentiation.

CHAPTER 8. WEATHERING, SEDIMENT, AND SOIL

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 8:

- Section 8.1: Mechanical weathering
- Section 8.2: Chemical weathering
- Section 8.3: Controls on weathering processes and rates
- Section 8.4: Weathering and erosion produce sediments
- Section 8.5: Weathering and soil formation
- Section 8.6: Soils of Canada
- Section 8.7: Weathering and climate change

Note to students in Dr McBeth's Geol 108/121 course: we will not be covering Section 8-5 or 8-6 in class or tests.

8.1. Weathering, Sediment, and Soil - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Define weathering.
- Describe the processes that contribute to weathering.
- Give examples of the main types of weathering processes.
- Describe how carbonic acid forms, and detail how it is involved in weathering processes.
- Describe how mine waste weathering can generate acid and metals in mine wastewater.
- Name the mineral(s) that are particularly problematic in mine waste weathering.
- Explain the difference between weathering and erosion.
- Describe the role of oxygen in weathering.
- Order the minerals quartz, halite, olivine, feldspar in terms of their stability to weathering.
- List the components of soils.
- Describe the factors that influence soil formation. Describe how soil composition varies with depth.
- Describe how climate and rock characteristics such as surface area are important in weathering.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Provide examples of physical, chemical, and biological weathering.
- Describe how the size, mineralogy, and angularity of particles change as they are transported downstream in a river.
- Provide examples of environments where only very stable minerals persist over time (due to strong and consistent weathering activity).
- Describe processes that can transport sediment in streams.
- Describe how the energy of stream water influences the size of particles a stream can carry.
- Describe the connection between chemical weathering and the climate system.
- Describe how mineral solubility and dissolution rate relate to weathering.

8.2. Weathering, Sediment, and Soil - Vocabulary

Section 8.0 Introduction

- weathering
- reactive gases
- water
- climate
- mechanical weathering / physical weathering
- chemical weathering
- physical process
- chemical reaction
- fresh surface
- susceptible
- particles
- ions
- soil

Section 8.1 Mechanical weathering

- overlying materials
- outcrop
- expose / exposed / exposure
- expand / expansion
- wedge
- exfoliate / exfoliation
- plane of weakness
- confining pressure
- pressure-release cracking
- frost wedging
- ice wedging
- talus slope
- oscillate
- fan-shaped
- salt wedging
- evaporate
- honeycomb structure / honeycomb weathering
- tafoni
- root wedging
- erosion
- gravity

Section 8.2 Chemical weathering

- dissolution
- alter / altered
- ions
- carbonic acid
- bicarbonate
- organic acid
- percolate
- sinkhole
- hydrolysis
- clay minerals (kaolinite, chlorite, smectite, serpentine)
- weathered
- unweathered
- hydration
- oxidation
- silicic acid
- acid rock drainage
- acid mine drainage
- remediation

Section 8.3 Controls on weathering processes and rates

- climate
- Arctic
- weathering rate
- surface area
- biological processes
- cement / cemented
- differential weathering
- sedimentary bed

Section 8.4 Weathering and erosion produce sediments

- sediment
- erosion
- clast
- particles
- grains
- mineralogy
- texture
- composition
- grain size

- sorting
- rounding
- sphericity
- angular
- rounded
- resistance
- boulder
- cobble
- pebble
- sand
- silt
- clay
- course-grained
- medium-grained
- fine-grained
- micron (μm)
- medium (noun)
- trickle
- stream bed
- well sorted
- moderately sorted
- poorly sorted
- subangular
- subrounded
- sharp edge
- transport / transported
- elongate

Section 8.5 Weathering and soil formation

- soil
- organic matter
- empty space
- soil composition
- soil texture
- climate
- percolate / percolation
- tropical
- leach / leached
- organic / inorganic
- precipitate
- parent material
- parent rock
- loess
- bedrock
- unconsolidated sediment

- residual soil
- transported soil
- glacial deposit
- stream deposit
- fertile soil
- river-flood deposit
- slope
- mass wasting
- landslide
- steep slope
- gentle slope
- humid
- soil horizon
- layers
- temperate climate
- O horizon
- A horizon
- E horizon
- B horizon
- C horizon
- caliche
- arid climate / arid region
- erode /erosion
- disaggregate
- suspension
- tillage
- cultivator
- channelled / unchannelled
- runoff

Section 8.6 Soils of Canada

- forest
- grassland
- glacial
- tundra
- podzolic
- luvisolic
- brunisolic
- chernozemic
- solonetzic
- cryosolic
- vertisolic
- organic
- regosolic
- gleysolic

- soil formation
- podzolization
- poor drainage
- permafrost
- freeze-thaw cycle
- freeze-thaw process

Section 8.7 Weathering and climate change

- carbon cycle
- biological cycle
- geological cycle
- coal
- peat
- organic-rich shale
- carbonate rocks
- carbon dioxide
- permafrost
- marine organisms
- balance
- imbalance

Other vocabulary

- alteration
- weathering rind
- neutral / neutralization
- biological weathering
- freeze-thaw cracking
- abrade / abrasion
- zone of weakness
- universal solvent
- chemical stability
- fracture
- rock joint
- bedding
- ventifact
- solubility
- dissolution rate
- ped
- eolian erosion
- fluvial erosion
- karst topography
- topsoil

- humus
- translocation

8.3. Weathering, Sediment, and Soil - Review Questions

- Define weathering.

- What are the main types of weathering? Describe and give examples of each type of weathering. How do the different types of weathering relate and contribute to each other?

- What are four factors that affect rock weathering rates?

- Describe the relationship between weathered particle size and surface area. Draw pictures to illustrate how weathering of a high surface area particle differs from weathering of a low surface area particle.

- In what ways does water influence chemical weathering? How does the chemistry of water influence weathering?

- How does oxygen influence chemical weathering?

- How does CO_2 influence chemical weathering?

- What acid is produce when CO_2 dissolves in water? How does it change the pH of water? How does it influence chemical weathering?

- How does soil affect weathering of rock?

- Give examples of Fe^{2+}-rich rocks that can be chemically weathered and oxidized.

- Describe how weathering can affect sulfide minerals. What chemical changes happen to sulfide minerals (and water that comes in contact with them) during weathering?

- Which mineral dissolves more readily, feldspar or quartz? Why?

- what are the most common products of mineral weathering?

- What weathering products form from the minerals: feldspars, pyrite, and quartz. What type of weathering process is most important for each mineral transformation?

- Describe how the different minerals in granite weather at different rates? Which minerals alter first? Which mineral in granite is least likely to alter with weathering?

- How resistant are clays to weathering? What types of materials are rich in clays?

- How does rainfall influence weathering rates? How does temperature affect weathering rates?

- Why do we have to worry about weathering when managing mine wastes? What characteristic(s) increase weathering in mine wastes compared to ore rock?

- Point out key feature(s) in the stream shown in Figure 8.3.1 that are evidence that acid mine drainage may be present in this stream.

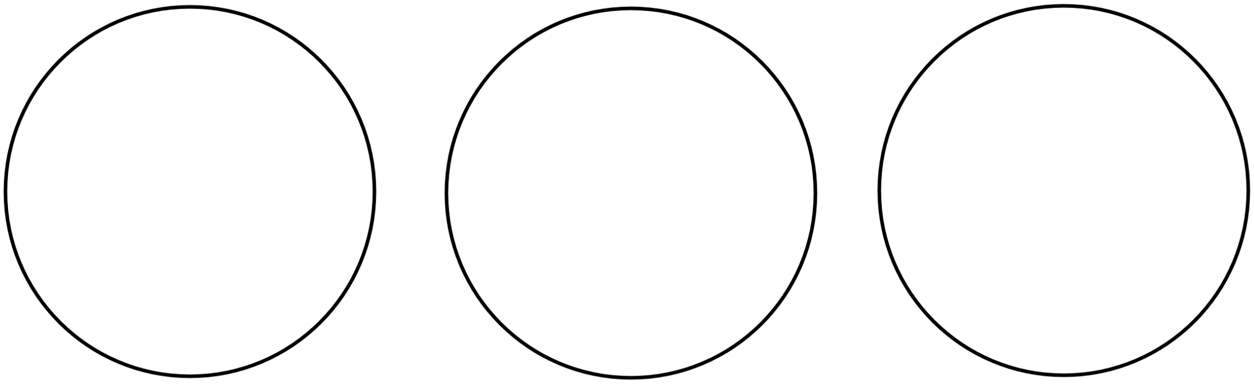
Figure 8.3.1 | *Acid mine drainage in Rio Tinto Spain. Source: Carol Stoker (2002) NASA Ames Research Center, public domain. [View source]*

- Describe the process of erosion. How is erosion different from weathering?

- How do sediments change as they move over the Earths surface? What kinds of surface processes influence sediments as the move through the landscape?

- Describe how sediments are sorted and change as they move down a river that starts in the mountains and ends at a delta where the river waters enter the ocean.

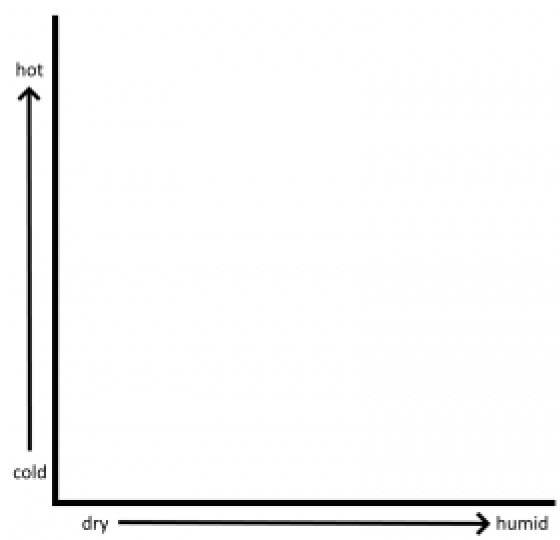
- Describe how particle angularity and size can tell us about how particles have been transported. Draw pictures of particles that are (a) freshly weathered out of a source rock, (b) located in a stream few 100 km downstream from the source rock, (c) located at a beach where the stream enters the ocean.



- What are the major components of soil, in terms of types of materials that compose soil?
- How does climate influence soil formation?
- What factors influence soil formation?
- What is the relationship between soil colour and organic content?
- How do human activities influence soil erosion? Give some examples of where human activities are influencing soil erosion.
- Draw and label a cross-section diagram illustrating a soil profile. Describe in general terms how the soil profile changes with depth.

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- How does karst topography form? What type(s) of weathering is/are responsible for karst topography forming?
- Name some soil inputs, and outputs.
- Describe three ways chemical weathering affects silicate minerals.
- What factors influence mineral solubility?
- Which is more soluble, quartz or halite? If you increased the temperature and pressure, would quartz be more or less soluble?
- What kinds of weathering are common in arid regions? In humid regions? In hot regions? In cold regions? Fill in the diagram below to show how the amount of chemical and physical weathering varies with climate conditions.



- What are the functions of soil?

CHAPTER 9. SEDIMENTARY ROCKS

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 9:

- Section 9.1: Clastic sedimentary rocks
- Section 9.2: Chemical and biochemical sedimentary rocks
- Section 9.3: Organic sedimentary rocks
- Section 9.4: Depositional environments and sedimentary basins
- Section 9.5: Sedimentary structures and fossils
- Section 9.6: Groups, formations, and members

9.1. Sedimentary Rocks - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Provide examples of sedimentary rocks and explain how they form.
- Name the common types of sediments.
- Describe the source materials, how each type of sediment forms, and common minerals in each type of sediment.
- Describe how water, wind, and ice can transport sediments.
- Draw and label a cross-section showing the types of sedimentary basins and describe how each one forms.
- Describe the various terrestrial and marine sediment depositional environments. Describe the processes that transport sediments in each environment. Describe what types of sediments are generally found in each setting.
- Draw and describe how sedimentary structures form.
- Describe how sediments move from their source zone to the place where they are deposited.
- Describe the various processes that transport sediment in streams.
- Describe how the energy of stream water influences the size of particles a stream can carry.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Describe how sedimentary rocks are classified, and describe the common sedimentary rock types.
- Describe the processes of burial, lithification, and diagenesis.
- Describe how the size, mineralogy, and angularity of particles change as they are transported downstream in a river.

9.2. Sedimentary Rocks - Vocabulary

Section 9.0 Introduction

- bed
- contact
- environment
- weathering
- erosion
- transportation
- deposition
- burial
- lithify / lithification
- compact / compaction
- cement / cemented
- clastic sediment
- chemical sediment
- biochemical sediment
- organic sediment
- precipitate / precipitated / precipitation

Section 9.1 Clastic sedimentary rocks

- lithification
- compaction
- sediment
- deposit / deposited
- pore space
- cementation
- pore space
- precipitate
- cement
- clastic
- clast
- fragment
- grain size
- grain shape
- grain sorting
- conglomerate
- breccia
- sandstone
- arenite
- quartz arenite

- quartz sandstone
- feldspathic arenite
- arkose sandstone
- wacke
- shale
- mudstone
- fissile
- well-rounded
- angular
- lithic arenite
- lithic sandstone
- matrix
- greywacke
- siltstone
- claystone
- sediment maturity
- sedimentary rock
- immature sedimentary rock
- mature sedimentary rock

Section 9.2 Chemical and biochemical sedimentary rocks

- inorganic process
- organically-mediated process
- carbonate rock
- carbonate ion
- limestone
- marine
- freshwater
- aquatic
- reef
- shells
- tests
- tropical region
- nutrient-rich
- upwelling current
- offshore
- fore-reef area
- inshore
- back-reef area
- lagoon
- mollusc shell
- foraminifera test
- ooid
- tufa
- travertine

- speleothem
- stalactite
- stalagmite
- dolostone
- dolomite
- dolomitization
- chert
- silica
- cryptocrystalline
- nodule
- lens / lenses
- diatom
- radiolarian / radiolaria
- banded iron formation (BIF)
- ferrous iron
- cyanobacteria
- ferric iron
- oxygenation
- free oxygen
- evaporite
- arid region
- evaporate / evaporation
- concentrate / concentration
- dissolved salts
- saturate / saturation
- crystallize
- salt deposit
- inland sea

Section 9.3 Organic sedimentary rocks

- organic sedimentary rock
- organic molecule
- soft tissues
- coal
- stagnant
- oxidation
- oxygen-poor water
- decay
- peat
- lignite coal
- plant fossils
- coalification
- bituminous coal
- anthracite coal

Section 9.4 Depositional environments and sedimentary basins

- depositional environment
- sedimentary basin
- glacial
- alluvial
- aeolian
- lagoonal
- lacustrine
- evaporite
- deltaic
- fluvial
- tidal
- beach
- reef
- shallow water marine
- submarine fan
- shallow water marine
- deep water marine
- terrestrial depositional environment
- marine depositional environment
- transport process
- basin
- trench basin
- forearc basin
- foreland basin
- rift basin
- subside / subsidence

Section 9.5 Sedimentary structures and fossils

- geological principles
- principle of original horizontality
- principle of superposition
- principle of inclusions
- principle of faunal succession
- sedimentary structure
- bed / bedding
- parting
- cross-bedding
- ripple
- current flow
- graded bedding
- imbricate / imbricated
- mud cracks

Section 9.6 Groups, formations, and members

- unit
- stratigraphic unit
- formation
- group
- member
- lithology
- rock type
- bed
- turbidite

Other vocabulary

- sedimentation
- diagenesis
- biomineralization
- abrasion
- scouring
- turbulent
- saltation
- passive-margin basin
- foreland (flexural) basin
- flex / flexure / flexural
- terrigenous
- continental environment
- shoreline environment
- siliceous environment
- stratification
- paleodepositional environments
- bioturbation
- bedding sequence
- inclined beds
- bioturbation structures
- interstitial water
- massive
- phosphorite

9.3. Sedimentary Rocks - Review Questions

- What are the four types of sedimentary rock?
- What are the steps in forming a sedimentary rock?
- Describe the relationship between plate tectonics and sedimentary basins.
- Describe sedimentary depositional environments you would find in Canada. What are key characteristics of depositional environments?
- Describe the differences and similarities between the various types of clastic sedimentary rocks, in terms of formation environment, particle size, mineral composition, and other features.
- Draw and label a cross-section diagram illustrating the various basin environments generated through tectonic processes. What are the sources of sediments that accumulate in each basin?

- Test yourself on depositional environments by filling in the following tables.

Terrestrial Depositional Environments (After Table 9.1, Physical Geology 3rd Adapted Edition)			
Environment	**Key Transport Processes**	**Depositional Settings**	**Typical Sediments**
glacial			
alluvial			
fluvial			
aeolian			
lacustrine			
evaporite			
Source: Karla Panchuk (2018) CC BY 4.0, modified after Steven Earle (2015) CC BY 4.0 view source.			

Marine Depositional Environments (After Table 9.2, Physical Geology 3rd Adapted Edition)			
Environment	**Key Transport Processes**	**Depositional Settings**	**Typical Sediments**
deltaic			
beach			
tidal			
reef			
shallow marine			
lagoonal			
submarine fan			
deep water			
Source: Karla Panchuk (2018) CC BY 4.0, modified after Steven Earle (2015) CC BY 4.0 view source.			

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- How are sedimentary rocks used by people:
  - in buildings
  - when building roads
  - for other purposes

- Draw and label cross-sectional diagrams illustrating the following sedimentary structures. What environments do each of the structures form in? What do they look like in the rock record? bioturbation structures, cross-bedding, graded bedding, bedding, symmetrical ripples, bedding sequence from a river, asymmetrical ripples.

CHAPTER 10. METAMORPHISM AND METAMORPHIC ROCKS

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 10:

- Section 10.1: Controls on metamorphic processes
- Section 10.2: Foliation and rock cleavage
- Section 10.3: Classification of metamorphic rocks
- Section 10.4: Types of metamorphism and where they occur
- Section 10.5: Metamorphic facies and index minerals
- Section 10.6: Metamorphic hydrothermal processes and metasomatism

10.1. Metamorphism and Metamorphic Rocks - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Define the terms metamorphic rock and protolith.
- List the principle factors driving metamorphism. Describe the role of each factor, and how variations in each factor influence metamorphism.
- Describe the types of metamorphism and the environments where you find them. Give examples of types of metamorphic rocks found in each environment.
- Describe the tectonic environments where you find each type of metamorphism, and features associated with metamorphism in these environments.
- Define the term index mineral.
- Describe how metamorphic grades vary with pressure and temperature.
- Provide examples of silicate minerals that are only found in metamorphic rocks.
- Provide examples of silicate minerals that are found both in metamorphic rocks and in igneous or sedimentary rocks.
- Describe the metamorphic textures and how they form.
- Describe how metamorphic textures vary with metamorphic grade.
- Describe what metamorphic rocks are formed by each type of metamorphism when you start with different protolith rocks.
- Define metamorphic facies.
- Describe the metamorphic facies diagram. Explain the pressure and temperature conditions and metamorphic facies and grades rocks would pass through during:
    - (1) accretionary prism subduction in a subduction zone, and
    - (2) shallow contact metamorphism.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Provide examples of index minerals that are characteristic of low, medium, and high grade metamorphism.
- Explain the difference between cleavage, schistosity, and banding.

10.2. Metamorphism and Metamorphic Rocks - Vocabulary

Section 10.0 Introduction

- metamorphic rock
- metamorphism
- parent rock
- protolith
- diagenesis
- mineral assemblage

Section 10.1 Controls on metamorphic processes

- mineral composition
- temperature
- metamorphic reaction
- mineral stability
- polymorph
- pressure
- directed pressure
- directed stress
- shear stress
- align / aligned / alignment
- fabric
- foliation
- parallel
- elongate
- fluid
- hydrothermal
- time
- reaction rate
- metamorphic process

Section 10.2 Foliation and rock cleavage

- foliation
- metaconglomerate
- rock cleavage
- shear stress

- perpendicular
- aligned crystals
- deform
- platy crystal habit
- band
- blocky
- lens
- recrystallization
- shadows
- wings
- plane of weakness
- rock cleavage
- slate
- slaty cleavage
- metaconglomerate

Section 10.3 Classification of metamorphic rocks

- foliated
- non-foliated
- metamorphic grade
- slate
- phyllite
- schist
- gneiss
- low-grade metamorphism
- satin texture
- crystal face
- medium-grade metamorphic rock
- high-grade metamorphic rock
- bands
- continuous
- lenses
- mudrock protolith
- amphibolite
- contact metamorphism
- marble
- quartzite
- hornfels
- recrystallize
- impurities
- align / alignment
- randomly oriented
- stable
- migmatite
- partial melting

- ptygmatic folding

Section 10.4 Types of metamorphism and where they occur

- burial metamorphism
- commercial rock name
- regional metamorphism
- large-scale metamorphism
- geothermal gradient
- compressing force
- seafloor (hydrothermal) metamorphism
- convection / convective
- hydrated minerals
- low-grade metamorphism
- greenstone
- subduction zone metamorphism
- lithostatic pressure
- isotherm
- blueschist metamorphism
- eclogite
- contact metamorphism
- confining pressure
- metamorphic aureole
- country rock
- intruding body
- volatile compounds
- thermal energy
- exsolve
- “wet” intrusion
- shock metamorphism
- shocked quartz
- shatter cone
- shock wave
- dynamic metamorphism
- fault zone
- cataclastic rock
- fault breccia
- mylonite
- protomylonite

Section 10.5 Metamorphic facies and index minerals

- metamorphic facies
- index mineral

- geothermal gradient
- amphibolite facies
- greenschist facies
- blueschist facies
- eclogite facies
- hornfels facies
- zeolite facies
- granulite facies
- parent rock
- metamorphic zone
- high-grade metamorphism
- high-grade metamorphic rocks
- low-grade metamorphism
- low-grade metamorphic rocks
- Barrovian metamorphism

Section 10.6 Metamorphic hydrothermal processes and metasomatism

- hydrothermal
- metasomatism
- dissolved ions / minerals
- precipitate
- fractures
- veins
- magmatic water
- alter / alteration
- thermal metamorphism
- hydrothermal alteration
- skarn
- epidote

Other vocabulary

- solid-state re-crystallization
- geothermometer
- discrete zone
- reoriented
- parallel alignment
- preferred orientation
- hydrothermally-altered rock
- hydrothermal fluids
- high-pressure metamorphism
- geobarometer
- geothermometer

- staurolite
- granoblastic rocks
- porphyroblasts
- schistosity
- schistose
- banding
- equi-dimensional crystals
- zoned recrystallization

10.3. Metamorphism and Metamorphic Rocks - Review Questions

- What are the principle agents of metamorphism in rocks?
- Marble is a metamorphic rock that forms when limestone is metamorphosed. What do marble and limestone have in common? What is different? Go through the other metamorphic rocks described in the lectures and textbook and describe the similarities and differences these rocks have from their protoliths. Note: *some metamorphic rocks have more than one possible protolith.*
- How does the depth of the 300°C isotherm in the crust vary across the various kinds of tectonic margins?
- Describe how fluids are involved in metamorphism. What are the two fluids that are most important in metamorphism?
- What is the temperature range over which metamorphism normally occurs? Why doesn't metamorphism generally occur at even higher temperatures?
- Describe how heat and pressure are important in metamorphism.
- What changes can occur in minerals due to metamorphism?

- What are the possible sources of fluids in metamorphic rocks?
- What common minerals found in metamorphic rocks are not useful as index minerals? Why not?
- List examples of minerals only formed by metamorphic processes, and describe each mineral.
- As metamorphic grade increases, what do we generally observe in terms of the degree of foliation in rocks? Why?
- How are foliated rocks classified? Give examples of foliated rocks, describe what minerals they contain, and draw their textures.
- What is the difference between foliation and cleavage?
- Would you expect to find foliated and/or non-foliated metamorphic rocks in each type of metamorphic environment listed in this chapter?
- How can we use the metamorphic facies of a metamorphic rock to understand the pressure and temperature history of the rock?

- What facies would you expect to see in:
    - contact metamorphosed rocks?
    - a volcanic arc?
    - mountains generated by a continent-continent plate boundary?

- Draw and describe confining (lithostatic) pressure, directed pressure, and differential stress. What metamorphic textures are associated with each?

- Draw and label the following metamorphic environments. Describe features associated with metamorphism in each environment. How will the amount and type of metamorphism vary as you move across each environment?
    - contact metamorphism
    - high-pressure metamorphism
    - seafloor hydrothermal metamorphism
    - burial metamorphism

- Draw and label a diagram illustrating regional metamorphism. Describe features associated with metamorphism in this environment. How will the amount and type of metamorphism vary as you move across the environment?

- Draw and label features of the following metamorphic rock textures. Under what conditions do you expect each to form? What metamorphic environments? List a specific location in the world where you would you expect to find each type of metamorphic rock.
    - banded gneiss
    - schistose
    - slaty rock cleavage

- Fill in the metamorphic rocks corresponding to each protolith in the following table.

Table 10.1 A Rough Guide to the Effect of Metamorphism on Different Protoliths

Protolith	Very Low Grade 150-300°C	Low Grade 300-450°C	Medium Grade 450-550°C	High Grade Above 550°C
Mudrock				
Granite				
Basalt				
Sandstone				
Limestone				

Note: Temperature ranges are approximate

Source: Joyce M. McBeth (2018) after Karla Panchuk (2018) CC-BY 4.0. [*View source*]

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- What four factors drive metamorphism? How do these factors differ across an area affected by regional metamorphism (e.g., a continent-continent plate boundary)

- List and describe examples of index minerals for low, medium, and high grade metamorphism.

- What are the defining features of metamorphic textures? Describe the three general classes of metamorphic textures, draw them, and give examples of each.

- Draw and label the following textures for practice. What environments do each texture form in? Would you expect to find each texture in an igneous rock or a metamorphic rock?
  - aphanitic
  - phaneritic
  - porphyritic
  - porphyroblastic
  - granoblastic

CHAPTER 11. VOLCANISM

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 11:

- Section 11.1: What is a volcano?
- Section 11.2: Materials produced by volcanic eruptions
- Section 11.3: Types of volcanoes
- Section 11.4: Types of volcanic eruptions
- Section 11.5: Plate tectonics and volcanism
- Section 11.6: Volcanic hazards
- Section 11.7: Monitoring volcanoes and predicting eruptions
- Section 11.8: Volcanoes in Canada

11.1. Volcanism - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Define volcanism.
- Describe the key characteristics of a volcano.
- Explain how the viscosity of lava changes with magma composition and why.
- Explain how the shapes of volcanos and the types of volcanic materials that make them up vary with magma composition.
- Describe the different types of volcanic eruption and name volcanoes where these eruptions have occurred.
- Describe the different kinds of tephra and volcanic textures and how they form.
- Describe the hazards associated with volcanoes.
- Describe the relationship between volcano type, composition, and tectonic environment.
- Describe how volcanoes interact with the atmosphere and the hydrosphere.
- Describe where we find volcanoes in Canada. Provide examples of these volcanoes and describe the plate tectonic environments where they form.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Describe the difference between a central vent volcano and a large-scale volcanic terrain.
- Name the major types of volcano. Describe each type of volcano.
- Provide an example of a place in the world where you find each type of volcano.

11.2. Volcanism - Vocabulary

Section 11.0 Introduction

- volcano / volcanoes
- erupt / eruption
- lava flow
- explosion
- hazards

Section 11.1 What is a volcano?

- volcano
- volcanism
- erupt
- magma
- lava
- fissure eruption
- magma chamber
- vent
- conduit
- crater
- flank eruption
- lava flow
- central vent
- volcanic debris
- caldera
- collapse

Section 11.2 Materials produced by volcanic eruptions

- tephra
- volcanic gas
- dissolved
- bubbles
- carbon dioxide (CO_2)
- water vapour (H_2O)
- sulfur dioxide (SO_2)
- hydrogen sulfide (H_2S)
- fumerole
- polymerization

- low viscosity
- high viscosity
- frothy
- lava dome
- rhyolitic lava
- basaltic lava
- andesitic lava
- lava tube
- solidify / solidified
- skylight
- lava levee
- pahoehoe
- ropy lava
- vesicles
- a'a / aa
- blocky lava
- lava flow toe
- pillow lava
- outcrop
- joints
- columnar joints
- pyroclastic material
- tephra
- pyroclast
- pyroclastic debris
- volcanic ash
- lapilli
- Pele's tears
- Pele's hair
- block
- bomb
- vesicular
- pumice
- scoria
- reticulite

Section 11.3 Types of volcanoes

- cinder cone / splatter cone
- composite volcano / stratovolcano
- shield volcano
- accumulation

Section 11.4 Types of volcanic eruptions

- eruption column
- explosiveness
- Hawai'ian eruption
- Strombolian eruption
- Vulcanian eruption
- Plinian eruption
- hydrovolcanic (phreatic) eruption
- explosive eruption
- effusive
- effusive eruption
- fissure eruption
- explosive
- pyroclastic flow
- lava dome
- nuee ardente
- eruptive column
- lahar
- volcanic lightning

Section 11.5 Plate tectonics and volcanism

- decompression melting
- mantle plume
- flux-melting
- hot spot
- ocean spreading ridge
- convection
- partial melting
- pillow lava
- lava flow
- continental rift zone
- fractional crystallization
- subduction zone
- slab
- hotspot volcano
- large igneous province (LIP)
- columnar basalt
- Columbia River Basalt Group
- Siberian Traps
- kimberlite
- kimberlite pipe

Section 11.6 Volcanic hazards

- volcanic gas
- tephra
- hydrofluoric acid (HF)
- aerosol
- pyroclastic flow
- flank
- tsunami
- lahar
- mud flow
- debris flow
- sector collapse / flank collapse
- earthquake

Section 11.7 Monitoring volcanoes and predicting eruptions

- sign
- imminent eruption
- gas leak
- bulge / bulging
- seismicity
- seismicity ceases
- big bump
- steam
- seismometer
- ground deformation
- tiltmeter
- Global Positioning System (GPS)

Section 11.8 Volcanoes in Canada

- British Columbia
- Yukon Territory
- subduction zone
- mantle plume
- continental rift zone
- Wrangell Volcanic Belt
- Garibaldi Volcanic Belt
- transform fault
- Stikine Volcanic Belt
- Anahim Volcanic Belt
- Wells Gray-Clearwater Volcanic Field

- Cascade Volcanic Arc
- Juan de Fuca Plate
- volcanic centre
- tuya
- North America Plate
- Rainbow Range

Other vocabulary

- landform
- constructive geological process
- glassy
- obsidian
- welded tuff
- central vent volcano
- summit crater
- large scale volcanic terrains
- volcanic dome
- rhyolite caldera complexes
- diatreme
- xenolith
- monogenetic field
- maar vent
- basalt plateau
- flood basalts
- intraplate volcanism
- hydrosphere
- volatiles
- geysers
- hydrothermal activity
- caldera collapse
- mount / mt

List of some well known volcanoes

- Mt Garibaldi / Nch'ḵay̓ (BC, Canada)
- Mt Meager (BC, Canada)
- Kilauea (Hawai'i, USA)
- Mauna Loa (Hawai'i, USA)
- Yellowstone Caldera (USA)
- Mt Edziza (BC, Canada)
- Nazka cone (BC, Canada)
- Mauna Loa (Hawai'i, USA)
- Mt Edziza (BC, Canada)

- Mt St Helens (USA)
- Popocatépetl (Mexico)
- Pacaya Volcano (Guatamala)
- Cotopaxi (Equador)
- Chimborazo (Equador)
- Eyjafjallajökull (Iceland)
- Mt Vesuvius (Italy)
- Santorini (Italy)
- Mt Stromboli (Italy)
- Mt Etna (Italy)
- Mt Teide (Tenerife, Spain)
- Mt Kilimanjaro (Tanzania)
- Mt Fuji (Japan)
- Sierra Negra (Galapagos Islands)
- Mt Pinatubo (Philippines)
- Krakatoa (Indonesia)
- Mt Tambora (Indonesia)
- Mt Merapi (Indonesia)
- Rotorua Caldera (New Zealand)
- Lake Taupo / Taupo Volcano (New Zealand)

11.3. Volcanism - Review Questions

- Name places where you would expect to find each of the following lavas. Describe the composition of each type of lava. Describe the viscosity of each lava type.
    - Basaltic
    - Andesitic
    - Rhyolitic

- Which kind of lava is associated with explosive eruptions? Which kind of lava is associated with effusive eruptions?

- Give an example of a location on earth where you find rocks formed from each of the following types of lava: basaltic, andesitic, and rhyolitic.

- Describe textures that are common in volcanic rocks.

- What are the three major types of volcanoes? Describe and draw the shape, size, and origin of each, the tectonic setting where each occurs, and provide an example of each.

- Describe and draw the major features of volcanoes.

- List and describe several volcanic hazards.

- Where do we find volcanoes in Canada? What kinds of volcanoes are they? What kinds of hazards are associated with these volcanoes?

- What are the most abundant volcanic gasses? Which ones are toxic? If you look up the composition of air, how does it's composition differ from the list of abundant volcanic gasses?

- Search for "volcanic" on google. Test yourself by describing the photos with as much detail as possible. Try to use words describing the lava and its properties and the rocks and pyroclastic materials that are shown in the images, and see if you can guess more than you see (e.g., if it looks like a basaltic lava flow, what texture and minerals would you expect to see in the rocks?). Can you see evidence to suggest what the tectonic setting is where the photos were taken?

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- Lava can produce different kinds of landforms. What are the three main factors influencing the type of landform lava produces?

- What are the six major types of volcanoes? Describe and draw the shape, size, and origin of each, the tectonic setting where each occurs, and provide an example of each.

- Using the list of famous volcanoes in section 11.2 of this workbook, label the locations of these volcanoes on the map of the world below (Figure 11.3.1).

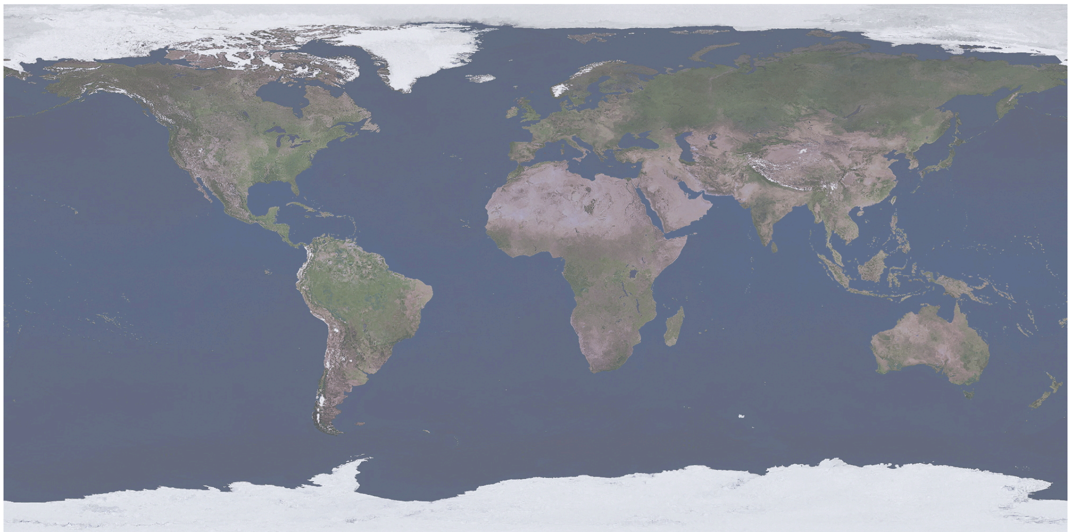


***Figure 11.3.1** | Image of Earth from space. Source:* NASA, *public domain.* [*view source*]

- Compare the positions of the volcanoes you have placed on the map with the figure in section 4.3 (Figure 4.3.1). Which volcanoes are associated with plate boundaries? Which volcanoes are not associated with plate boundaries? What is the source of the magma that generates the volcanoes that are not at plate boundaries?

CHAPTER 12. EARTHQUAKES

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 12:

- Section 12.1: What is an earthquake?
- Section 12.2: Measuring earthquakes
- Section 12.3: Earthquakes and plate tectonics
- Section 12.4: The impacts of earthquakes
- Section 12.5: Forecasting earthquakes and minimizing impacts

12.1. Earthquakes - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Define the terms earthquake and fault.
- Describe the processes that can cause earthquakes.
- Draw and describe the different types of faults.
- Define elastic rebound theory and describe how strain build up can lead to earthquakes.
- Draw a diagram showing an earthquake including the epicentre, focus, and fault.
- Draw and describe the types of seismic waves.
- Describe how seismographs work and how we can use seismic information to locate the epicentre of an earthquake.
- Describe the different methods we use to describe earthquake magnitude and intensity, and name the ones we use most commonly today.
- Define seismology and describe how it is used to study the Earth.
- Describe and compare and contrast the earthquakes we observe at transform, convergent, and divergent plate tectonic boundaries and in intraplate environments.
- Describe primary and secondary hazards associated with earthquakes and provide examples of location(s) where each type of hazard could occur.
- Describe earthquake activity in Canada: distribution, sources, approximate magnitudes.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Describe patterns of earthquake foreshocks and aftershocks in terms of magnitude and spatial distribution after a major earthquake.

12.2. Earthquakes - Vocabulary

Section 12.0 Introduction

- earthquake
- magnitude
- shaking
- seismograph
- seismologist

Section 12.1 What is an earthquake?

- rupture
- displacement
- deform / deformation
- reversible
- elastic deformation
- vibrate / vibration
- shaking
- elastic rebound
- rupture surface
- fault plane
- asperities
- displacement
- fault
- hypocentre
- focus
- epicentre
- failure
- mainshock
- foreshock
- aftershock
- episodic tremor and slip (ETS)
- seismic tremor
- locked zone
- continuous slip zone
- ETS zone

Section 12.2 Measuring earthquakes

- seismic wave

- magnitude
- body waves
- P-wave / primary wave
- compression wave
- S-waves / secondary wave
- shear wave
- surface waves
- Rayleigh wave / R-wave
- Love wave / L-wave
- ground motion
- seismometer
- seismograph
- seismogram
- seismic station
- magnitude
- intensity
- energy release
- amplitude
- baseline
- Richter magnitude
- local magnitude
- moment magnitude
- seismic moment
- logarithmic scale
- modified Mercalli intensity scale

Section 12.3 Earthquakes and plate tectonics

- megathrust earthquake
- discontinuity
- intraplate earthquake
- induced seismicity
- hydraulic fracturing
- seismic zone

Section 12.4 The impacts of earthquakes

- direct impact / primary impact
- shaking
- structural damage
- secondary impact
- landslide
- fire
- tsunami

- frequency / frequencies
- vibration
- high frequency
- low frequency
- building code
- liquifaction
- subside / subsidence
- water-saturated
- sand volcano
- slope failure
- gas line rupture
- electrical line damage
- ocean wave height

Section 12.5 Forecasting earthquakes and minimizing impacts

- forecast
- predict
- creep
- magnetic field
- earthquake probability
- seismic upgrade
- preparedness
- emergency plan
- emergency supplies

Additional vocabulary not currently used in this chapter:

- Wadati-Benioff zone
- strain buildup and release
- elastic rebound theory
- fracture
- fault zone
- fault scarp
- focus / foci
- earthquake clusters
- S-P time interval
- triangulation
- ground acceleration
- wave refraction
- wave reflection
- slow earthquakes
- silent earthquakes
- low-frequency earthquakes

- slow-slip events
- nuclear test monitoring
- primary hazards
- secondary hazards
- earthquake retrofitting

12.3. Earthquakes - Review Questions

- How does energy that builds up in the Earth's crust relate to earthquakes?
- If a magnitude 4.0 earthquake occurred directly under Saskatoon due to a collapse of a potash mining tunnel, where would you locate seismometers to use to pinpoint the epicentre? *Note: there are many answers you could give for this question.* What is the minimum number of seismometers you would need to pinpoint the epicentre?
- How do P waves differ from S waves? Which one moves the fastest through rock? If you are located a few hundred kilometers from an earthquake epicenter, which seismic waves arrive last in a seismogram?
- How do the magnitudes and depths of earthquakes tend to vary with tectonic environments?
- What causes intraplate earthquakes? Give a few examples of places where intraplate earthquakes occur.
- Name some primary and secondary hazards of earthquakes. Describe each.
- Describe the process that generates a tsunami.
- Draw and describe a cross-section of an earthquake on a fault, labelling the key descriptive features of the earthquake (e.g., epicentre, focus). To test yourself you can draw versions for different kinds of faults and earthquake environments (e.g., subduction zone, transform fault).

- Draw and describe the different kinds of seismic waves.

- Draw picture(s) to help show how the size of the tsunami wave varies between the source of the tsunami and when it hits land. Label the drawings.

- Highlight areas on the map of the lower mainland of BC below (Figure 12.3.1) that are at high risk if a megathrust earthquake occurs along the subduction zone below the coast of BC.

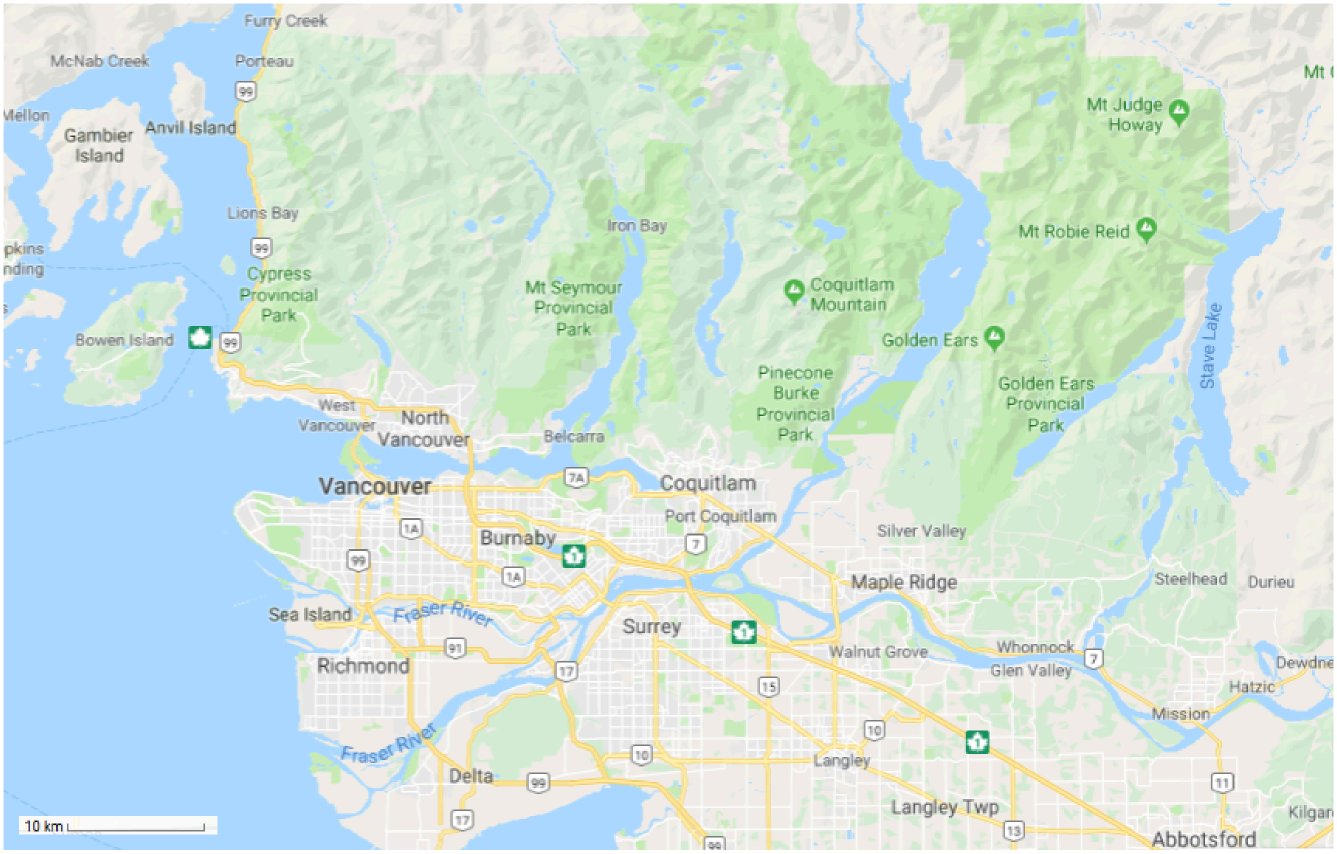


Figure 12.3.1 | *Map of the BC Lower Mainland. Source: Google Maps (2018, map data (c) 2018 Google.*

- Label and annotate the diagram to indicate why these areas are at higher risk than others. Where would you chose to buy a house and why? Note: *some people choose to live in riskier areas because they sometimes have a better view, or are prettier – it's up to you!*

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- How do we use seismic waves to monitor nuclear testing?

- The 2010 Haiti earthquake resulted in far more deaths and infrastructure damage than the 2001 Seattle earthquake. Discuss why this was the case. Consider differences in tectonic environment, geology, the earthquake magnitudes, and human considerations such as population density and building codes.

- In which tectonic environment would you find a Wadati-Benioff zone? Where are some specific locations around the globe where you would expect to find this pattern of earthquakes?

- Examine Figure 12.3.2 (below) showing the Wadati-Benioff zone under the Andes Mountains in South America.

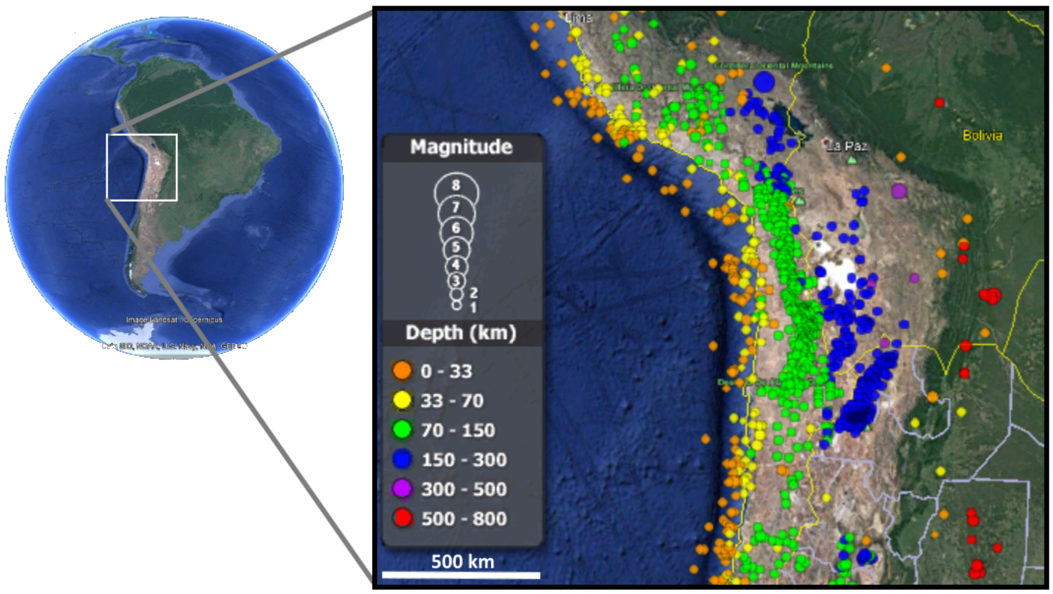


Figure 12.3.2 | *Wadati-Benioff Zone, Andes Mountains. Source: Joyce M. McBeth (2019) CC-BY-SA 4.0. Image sources: Google Earth (2019), earthquake data USGS (2019), image Landsat/Copernicus, data SIO, NOAA, U.S. Navy, NGA, GEBCO, 2018.*

- Sketch a cross-section across the map area represented in Figure 12.3.2 from west to east in the box below. Plot the earthquakes (and their depths) on the cross-section. Using this information, reconstruct the position of the subduction zone under the Andes Mountains. Which direction is the subduction zone dipping in?

- Mark locations where Earthquakes commonly occur on the map below with asterisks. *Tip: if you aren't sure where earthquakes commonly occur, you can look at the* USGS Earthquakes website *for a real-time map of earthquakes that have happened recently.*

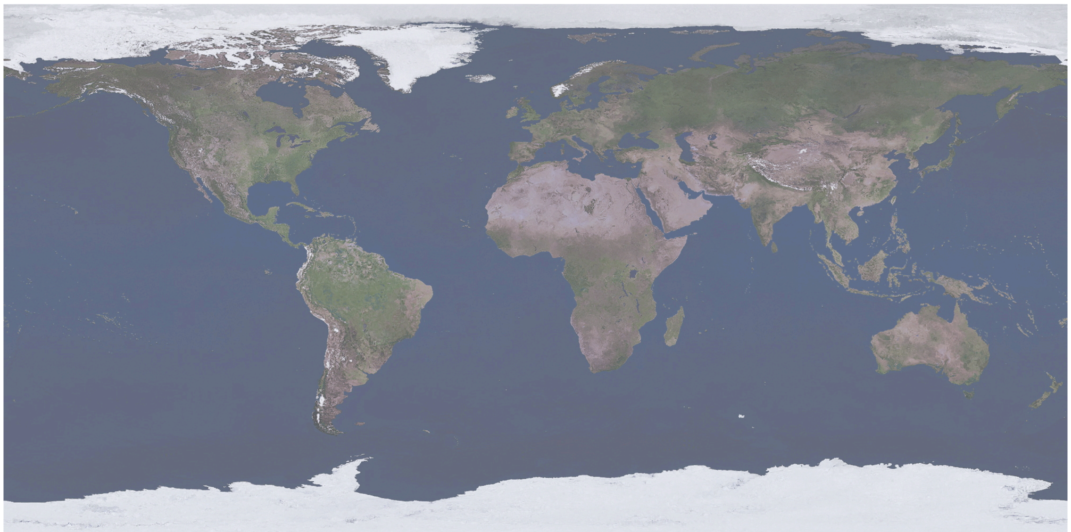
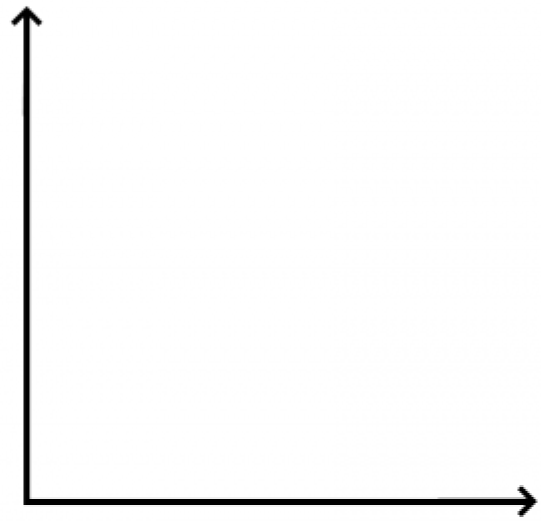


Figure 12.3.1 | *Image of Earth from space. Source: NASA, public domain. [view source]*

- describe how earthquakes are distributed over the surface of the Earth.

- Draw and describe how earthquake clusters occur around a major earthquake event (before, during, after, using the boxes below. How do the locations of the clusters differ before and after an earthquake?

- Draw a graph showing the distribution of cluster earthquakes through time and how their magnitudes vary over time using the x-y diagram below (don't forget to label your axes!).



- Draw a cross-section diagram of the Earth's crust with a low density rock layer overlying a high density rock layer.

- Label the layers.
- Draw an earthquake focus and epicentre on your diagram in the low density upper layer.
- If a P wave moves from the focus of the earthquake through the low density rock layer and into the high density rock layer, how does the direction of the P wave change? What is this phenomenon called?

CHAPTER 13. GEOLOGICAL STRUCTURES AND MOUNTAIN BUILDING

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 13:

- Section 13.1: Stress and strain
- Section 13.2: Folds
- Section 13.3: Fractures, faults, and joints
- Section 13.4: Mountain building
- Section 13.5: Measuring geological structures

13.1. Geological Structures and Mountain Building - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Define deformation.
- Describe the differential stresses that can lead to deformation.
- Describe the three stages of strain that occur as stress is applied to a rock.
- Define and describe the three types of deformation strain: elastic, ductile, and brittle deformation.
- Describe the factors that control which kind of deformation occurs in a particular geological environment.
- Describe the geologic features that are formed by strain, and the environments where each feature may form.
- Describe and draw the different kinds of faults, and describe which environments they form in.
- Describe and draw the different kinds of folds.
- Describe the processes that can lead to mountain building, the different types of mountain settings, and how each relates to plate tectonics.
- Define and draw examples of the terms strike and dip and describe how these measurements are used to describe geological structures.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Describe the characteristics of a geological map, and the kinds of field data geologists collect to prepare geological maps.

13.2. Geological Structures and Mountain Building - Vocabulary

Section 13.0 Introduction

- fold
- mountain belt
- flex
- bend
- geological structure

Section 13.1 Stress and strain

- stress
- strain
- force
- deform / deformed / deformation
- normal stress
- shear stress
- shear / shearing
- compression
- tension
- strain
- elastic strain
- reversible
- elastic rebound
- plastic strain
- permanent deformation
- ductile deformation
- brittle deformation
- composition
- elastic deformation
- boudinage structures
- boudin
- confining pressure
- hydrostatic pressure
- lithostatic pressure
- brittle-ductile transition zone
- strain rate
- pore space
- pore pressure
- fracture / fracturing

- tilt / tilting
- stretch / stretching
- fault / faulting

Section 13.2 Folds

- fold / folding
- limbs
- hinge zone
- axis
- axial surface
- axial trace
- syncline
- anticline
- fold train
- symmetrical fold
- asymmetrical fold
- overturned fold
- isoclinal fold
- recumbent fold
- plunge
- plunging fold
- V-shaped pattern
- plunge angle
- landform
- ridge
- valley
- erode
- resistant layer
- geologic cross-section
- trace

Section 13.3 Fractures, faults, and joints

- tectonic forces
- fracture
- fault
- joint
- joint set
- stress regime
- exfoliation joints
- offset
- relative motion
- dip-slip fault

- dipping fault plane
- hanging wall / head wall
- foot wall
- normal fault
- extension
- reverse fault
- compression
- strike-slip fault
- shear stress
- dextral / right-handed / right lateral
- sinistral / left-handed / left lateral
- extentional tectonics
- horst and graben structures
- horst
- graben
- Basin and Range
- thrust fault

Section 13.4 Mountain building

- orogeny
- orogen
- forearc basin
- accretionary wedge
- suture zone
- reactivate / reactivated
- fault-block mountain

Section 13.5 Measuring geological structures

- orientation
- attitude of bedding
- strike
- strike direction
- dip
- dip angle
- compass orientation / compass direction
- perpendicular
- horizontal line
- dip direction
- align
- geological compass
- clinometer
- planar feature

Other vocabulary:

- geometry
- left lateral
- right lateral
- monocline
- concave
- convex
- differential stress
- compressional stress
- tensional stress
- confining stress
- Hooke's law
- non-permanent strain
- permanent strain
- rate of strain
- thermal contraction
- geologic map
- lithostratigraphy
- outcrop
- Brunton compass
- displacement
- oblique-slip fault
- simple folds
- complex folds
- basin
- dome
- outcrop pattern
- strike-and-dip notation
- tensional tectonics
- crustal extension
- basin and range province
- fold and thrust belts

13.3. Geological Structures and Mountain Building - Review Questions

- What types of stress are present in the Earth's crust? What are the sources of these stress? What deformation structures are generated in rocks by these stresses?
- Explain the differences between elastic, ductile, and brittle deformation.
- Where in the Earth's crust would you expect to find brittle deformation occurring? Why? Where would you expect to find ductile deformation occurring? Why?
- Draw and label simple diagrams to illustrate the three principal stresses that drive deformation.

- Draw and label diagrams to show large scale (e.g., outcrop to regional scale) geologic features that are associate with each type of stress. Think about what small scale (rock sized to microscopic) features would be associated with each type of stress.

- Draw and label structures that result from elastic, ductile, and brittle deformation.

- List the factors that influence deformation in strained rock. Explain how each can vary and what the effect is on rock deformation.

- What are the similarities and differences between the deformation processes that produce faults and folds?
- How do the types of deformation processes that occur change with depth in the lithosphere and rock strength?
- Draw cross-section diagrams of strike-slip, normal, reverse, and thrust faults. Label the strike, dip, and direction of movement for each fault type. In which tectonic environment(s) would you expect to find each type of fault?

- Draw and label cross-sections of folds including symmetrical, asymmetrical and overturned folds. Label the strike, dip, and dip direction for each limb. Label the anticlines, synclines, and other features of the folds. *If you want to really challenge yourself: If you cut a cross-section through the folds from a different angles, what would the maps look like (including strike and dip symbols)?*

- Describe the three broad types of mountain building processes. How do these processes related to plate tectonic activity? Describe the folding and faulting features associated with each type of process (where applicable).

- Describe the features of fold and thrust belts and give examples of two locations where we see fold and thrust belt mountains on Earth today.

- Google "rock deformation" and look at the image results. Describe a few of the photo results as best you can, using the terms you have learned for describing deformation processes, fold structures, etc.

- Google “fault” and look at the image results. Try to identify the strike, dip, and dip direction for folds and faults in the images (for many of the images you will need to draw or imagine the rocks in 3-D).

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- What are the parts of a geologic map? What kinds of information about rocks do geologists include on a geologic map?

CHAPTER 14. STREAMS AND FLOODS

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 14:

- Section 14.1: The hydrological cycle
- Section 14.2: Drainage basins
- Section 14.3: Stream erosion and deposition
- Section 14.4: Stream types
- Section 14.5: Flooding

14.1. Streams and Floods - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Describe the different major reservoirs of water on Earth, and their residence time.
- Define the term drainage basin, and give examples of how drainage basins influence surface water movement.
- Describe the different ways that sediments are transported in streams.
- Describe the different types of stream channels and the parts of streams.
- Describe how streams mature through time.
- Explain the concept of base level, and describe how base level can change due to natural and engineered processes.
- Describe how sediments are transported and deposited during flood events, and some of the evidence that is left behind by floods.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Explain how individual water use is related to water stress and scarcity, and provide examples of placers in the world where there is water stress and scarcity.
- Explain how human activities influence water quality and movement.
- Describe the pattern of water runoff over North America.
- Describe the concepts of stream and watershed order and provide examples of each.
- Describe the patterns of sediment deposition in flood plains, deltas, graded streams, and alluvial fans.

14.2. Streams and Floods - Vocabulary

Section 14.0 Introduction

- stream
- waterfall
- canyon
- erosion
- transportation
- sediment
- Earth's surface
- topography
- storm
- snowmelt
- torrent / torrential
- spill
- bank
- flood
- infrastructure
- population
- natural disaster

Section 14.1 The hydrological cycle

- hydrology
- hydrologic cycle
- evaporate
- transpiration
- solar energy
- gas / gaseous
- water droplet
- ice crystal
- lake
- ocean
- groundwater
- infiltrate
- pore
- crack
- groundwater flow path
- intersect
- precipitation
- condensation
- runoff

- storage
- groundwater discharge
- reservoir
- salty
- saltwater
- freshwater
- ice
- glacial ice
- water supply
- atmosphere
- water vapour
- stream flow
- surface water
- ocean water
- residence time

Section 14.2 Drainage basins

- drainage basin
- watershed
- groundwater flow
- gradient
- rate of change
- elevation
- steep gradient
- shallow gradient
- valley
- erosion
- mass wasting
- tectonic uplift
- glacial erosion
- post-glacial
- base level
- inundate / inundation
- drainage basin divide
- boundary
- ridge
- tributary / tributaries
- underlying rock
- structures
- fold
- fault
- fracture
- tilt / tilted
- dendritic drainage
- trellis drainage

- rectangular
- deranged drainage
- lake
- wetland
- radial drainage
- radiate
- downcutting
- graded stream
- headwaters
- mouth
- ungraded stream
- rapids
- topographic profile
- upstream
- downstream
- ungraded
- base level change
- river channel
- flood plain
- terrace
- cycle of erosion
- immature
- V-shaped valley
- straight path
- mature / maturity
- meander / meandering
- channel wall
- Davis cycle
- stream evolution
- isostatic rebound
- glaciation
- dam reservoir

Section 14.3 Stream erosion and deposition

- sediment transport
- stream velocity
- flow / flowing
- geometry
- stream channel
- flow velocity
- friction
- stream bed
- curve / curved
- discharge
- cross-sectional area

- turbulence / turbulent
- medium
- chaotic
- muddy
- laminar flow
- bedload
- saltation
- collide / colliding
- traction
- suspend / suspension
- suspended load
- dissolve / dissolved
- dissolved load
- solubility
- ions
- mass
- grain
- deposit / deposited / deposition
- erode / erosion
- transport / transportation
- Hjulström-Sundborg Diagram
- stationary
- levee
- natural levee
- bank-full stage
- elevated
- flood control measure
- engineered solution

Section 14.4 Stream types

- stream channel
- straight
- curved
- deep
- shallow
- youthful stream
- course sediment
- downcutting
- ungraded
- step-pool
- morphology
- V-shaped valley
- canyon
- mountainous terrain
- U-shaped valley

- braided stream
- gravel bar
- current
- sinuous
- flow pattern
- point bar
- meander / meandering
- migrate / migration
- oxbow lake
- neck
- bend
- delta
- stream velocity

Section 14.5 Flooding

- discharge level
- variable / variability / variations
- water level
- stage
- flood stage
- snow pack
- rainfall
- dyke / dike
- breach
- inundate / inundated
- maximum stage
- discharge
- economic toll
- floodway
- emergency plan
- annual discharge
- peak
- peak flow

Other Vocabulary

- hydrosphere
- drainage system
- graded profile
- straight channel
- artificial levee
- stream order
- first-order basin

- continental watershed
- solution load
- desalination
- sustainable
- unsustainable
- industrial use
- domestic use
- irrigation
- contamination
- recharge
- water stress
- water scarcity
- water use
- water demand
- water quality
- eutrophication
- flux
- groundwater table
- evapotranspiration
- impervious
- humidity
- orographic precipitation
- rain shadow
- drought
- arid region
- urbanization
- thalweg
- undercut bank
- Island
- normal discharge
- flood stage
- alluvium
- dynamic equilibrium
- fluvial
- stream piracy / stream capture
- headward erosion
- dredging
- hydroelectric dam
- incised channel
- alluvial terrace
- alluvial fan
- progradation
- bottomset beds
- foreset beds
- topset beds
- delta plain
- avulsion

14.3. Streams and Floods - Review Questions

- What are the major reservoirs for water on Earth? Give examples of both saltwater and freshwater reservoirs.
- Describe the hydrologic cycle. How does temperature influence the movement of water between difference reservoirs in the hydrosphere?
- Describe how the residence time varies between different water types of water reservoirs on Earth. Why are there such big differences in residence time between some of these reservoirs?
- What factors influence the amount of runoff that occurs in a given environment?
- What is the difference between turbulent and laminar flow?
- Describe how meanders form in a stream, how meandering streams move across the landscape through time, and what kinds of features they leave behind.
- Describe the differences you would expect to see between a stream in a mountainous region of BC and the streams you see in Saskatchewan.
- Describe how levees form.
- Describe how landscape changes such as hydroelectric dams can alter stream behaviour and properties through time.
- Go to Google Earth or Google Maps and look for examples of meandering streams in southern and central Saskatchewan. Draw two or three examples of the paths these streams take across the landscape (in plan view, i.e., from above).

- Draw a cross-section through a river that has flooded numerous times. What are the important features of rivers that flood?

- Describe and draw a cross-section through a river and its banks, showing the level of the water at normal river flow. Then draw a cross-section through the river at bankful and flood stage. Compare the level of the water in the river at each stage.

- Give an example of a flood that happened in Canada at some point in the past. What kind of damage did it do? Did anyone die? Did the province and/or municipality do anything before or after the flood to try to alleviate the risk of flooding?

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- What are some of the ways we use freshwater? How do these uses influence the quality of freshwater resources?
- Describe water use in Canada, in terms of the proportion used for different industries and purposes.
- Where does the water from each of Canada's major river systems in Canada end up?
- What is water stress and water scarcity? Name some countries that are affected by water stress and water scarcity. Is Canada affected by water stress or scarcity? Should we be concerned about it?
- Describe how infiltration and runoff vary between an urban and rural environment in Saskatchewan. How can this influence water quality? What other factors will influence the water quality in these environments?
- How do changes in relative humidity and temperature as air flows over mountains interact to form orographic precipitation?
- What are some of the consequences of drought?
- Describe and draw how drainage systems are organized into watersheds. How does stream order relate to drainage basins?
- How does water discharge vary with stream order?

- What is a graded stream, and what is dynamic equilibrium.

- Consider how sediments are deposited and eroded within a graded stream: if you followed the path of a stone down a graded stream, what kinds of process would it be influenced by? How might it weather as it moves downstream?

- Draw cross-sections through the different types of streams, and label where the thalweg position is in each, and the profile for water velocities across the stream. Consider how this influences sediment transport in the stream.

- Describe how a fluvial landscape changes through time.

- Describe how river deltas form and change through time. What features are associate with river deltas? Why are they important?

- Go hunting on Google Earth and/or Google Maps for some of the features described in this chapter: river deltas, alluvial fans, rain shadows, alluvial terraces, streams and tributaries. There is so much interesting geology we can explore from looking at the landscape from above! Draw some examples of the features you find, in plan view, in the boxes below.

- Describe how alluvial terraces form. Draw cross-sections through time showing how alluvial terraces form in a river valley.

CHAPTER 15. MASS WASTING

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 15:

- Section 15.1: Factors that control slope stability
- Section 15.2: Classification of mass wasting
- Section 15.3: Preventing, delaying, monitoring, and mitigating mass wasting

15.1. Mass Wasting - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Describe the differences between weathering, erosion, and mass wasting.
- Describe the factors that drive mass wasting and how variations in these factors can influence slope stability.
- Give examples of natural and anthropogenic causes of mass wasting.
- Describe the three factors used to classify mass wasting events.
- Draw and describe the different kinds of mass wasting events.
- Describe which regions of Canada have the most mass wasting events and why.
- Describe some of the measures we can take to prevent or lessen the mass wasting events.

15.2. Mass Wasting - Vocabulary

Section 15.0 Introduction

- weather / weathering
- erode / eroded / erosion
- mass wasting
- landslide
- slope failure
- gravity
- mass movement
- downslope
- Earth materials
- unconsolidated
- consolidated
- foliation plane
- snow avalanche
- material failure

- ## Section 15.1 Factors that control slope stability

- gravitational force
- vertical
- horizontal
- block
- shear force
- perpendicular
- normal force
- friction
- shear strength
- steep / steepness
- stable / stability
- unstable
- strength
- weak
- strong
- planes of weakness
- orientation
- weak layer
- cement / cemented
- binding
- cohesion
- glacial till

- talus
- cone
- water content / moisture content
- pore space
- porosity
- dry
- moist
- saturated
- saturated materials
- unsaturated materials
- grain boundary / grain boundaries
- surface tension
- grain contact
- fracture
- bedding plane
- clay-bearing zone
- saturated conditions
- water pressure
- hydrostatic pressure
- water table
- road cut
- spring
- absorb
- swell
- slippery
- trigger
- water flow pattern
- dam / dammed
- runoff
- slope drainage
- rainy period

Section 15.2 Classification of mass wasting

- criterion / criteria
- material
- motion
- fall
- slide
- flow
- coherent
- incoherent
- internal motion
- rupture surface
- curve / curved
- rotational slope failure

- planar
- translational slope failure
- rock fall
- debris fall
- rock fragment
- talus slope
- scree slope
- angle of repose
- rock slide
- parallel
- sackung
- catastrophic failure
- scarp
- head scarp
- side scarp
- drain
- drainage hole
- rock bolt
- steel mesh curtain
- rock avalanche
- fluid movement
- cushion of air
- creep
- solifluction
- loose material
- lean / leaning
- pistol butt tree
- terracettes
- slump / slumping
- downward motion
- outward motion
- snowmelt runoff
- toe
- basal material
- seasonal stream
- coulee
- mud flow
- debris flow
- lahar
- collapse
- stream bank
- temporary dam
- dam burst

Section 15.3 Preventing, delaying, monitoring, and mitigating mass wasting

- mitigate / mitigation
- delay
- damaging effects
- infrastructure
- rock bolts
- drill holes
- drainage holes
- retaining wall
- highway roadcut
- degradation
- corrode
- plug / plugged
- slope monitoring
- geological engineer
- geotechnical engineer
- preventative measures
- road surface
- fill
- filled slope
- cut slope
- natural drainage feature
- runoff water
- oversaturation
- excavation
- drainage changes
- lawn irrigation
- septic system
- rapid failure
- monitor / monitoring
- warning system
- inclinometer
- bore-hole motion sensor
- GPS survey instrument
- acoustic monitor
- safe ground
- avalanche shelter
- defensive structure
- drainage basin
- concrete-lined channel
- constructed basin

Other vocabulary

- slope steepening
- frost wedging
- liquifaction
- lubricant
- regolith
- permafrost
- deforestation
- debris slide
- tension crevasse
- joint plane
- water permeable
- water impermeable
- soil saturation
- re-grade slope
- undercutting
- rock netting

15.3. Mass Wasting - Review Questions

- What are the three major factors influencing mass wasting? How can each factor vary to influence mass wasting?
- Describe the different kinds of materials that can make up a slope.
- What are examples of unconsolidated materials? Consolidated materials? What kinds of mass wasting events are associate with each type of material?
- How does water content influence slope stability? Why?
- Of dry, wet, and damp sand, which is the most cohesive? Why? Which is the least cohesive? Why?
- Draw a cross-section through a pile of wet sand vs a pile of dry sand. How do they differ in terms of their angle of repose?
- How does slope steepness influence the likelihood of mass movements? Is a steep slope more or less stable than a shallow slope?
- What are some natural processes that can increase mass wasting? Anthropogenic (human) causes? Why does each process increase the likelihood of mass wasting?

- How are mass movements classified (three main characteristics)? Give examples of how each characteristic influences the type of mass wasting event that can occur.

- Draw examples of the different mass wasting events described in this chapter, and the features associated with them.

- How could you try to prevent each type of mass wasting event from happening?

- What is soil creep? What kinds of evidence would we expect to see on a slope affected by creep? Draw examples of these features (in plan view or cross-section).

- What kinds of events can trigger a rock slide? Rock fall? Mud flow?

- Name some major mass wasting events that have occurred in Canada. What caused each event?

- What are some measures that can be used to mitigate mass wasting events?

- Go to Google Images and search for "mass wasting". How would you try to mitigate or prevent the various mass wasting events that appear in the images? If you can't think of ways to mitigate the mass wasting events, what are other ways people could avoid endangering themselves?

- Draw a picture of a soil slump, in cross-section. What kind of faulting is similar to soil slumping?

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- Describe circumstances where liquefaction can occur. What kinds of materials are subject to liquefaction?

- What regions of Canada have the highest risk of landslides? Why are these regions more prone to mass wasting?

- How does a slope's angle of repose vary with the size and angularity of the particles in the slope?

CHAPTER 16. EARTH-SYSTEM CHANGE

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 16:

- Section 16.1: What is the Earth system?
- Section 16.2: Causes of climate change
- Section 16.3: Methods for studying past climate
- Section 16.4: Computer models of the Earth system
- Section 16.5: Humans in the Earth system
- Section 16.6: Welcome to the Anthropocene

16.1. Earth-System Change - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Explain the difference between weather and climate.
- List and describe aspects of each component of the climate system that can influence and change climate patterns.
- Describe examples of positive and negative climate feedback.
- Describe how carbon dioxide concentrations have changed over the past 200 years, sources of CO_2, and the potential impacts on climate and life on Earth.
- Give examples of how scientists study past climate using proxy data.
- Describe important considerations for preparing climate models that can be used in predicting future climate behaviour.
- Describe some of the consequences of anthropogenic climate change.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Describe the Earth's atmosphere, hydrosphere, cryosphere, lithosphere and biosphere.
- Describe the relationships between the Earth's atmosphere, hydrosphere, cryosphere, biosphere, and lithosphere and how these relationships can influence climate.

16.2. Earth-System Change - Vocabulary

Section 16.0 Introduction

- Earth system
- glaciation
- climate system
- global temperature
- mean global temperature
- temperature fluctuation
- Snowball Earth
- climate change
- anthropogenic

Section 16.1 What is the Earth system

- atmosphere
- hydrosphere
- biosphere
- lithosphere
- water cycle
- carbon cycle
- Earth-system
- ice cap
- albedo
- habitat
- precipitation
- transpiration
- rainfall pattern
- ocean circulation
- feedback
- positive feedback
- negative feedback
- albedo feedback
- plant growth feedback
- ice albedo feedback
- amplify
- reduce
- instability
- permafrost
- accelerate
- initial conditions

Section 16.2 Causes of climate change

- weather
- climate
- forcing
- climate-forcing mechanism
- insolation
- incoming solar radiation
- star
- solar life history
- orbital cycles
- cyclical
- Earth's orbit
- Earth's rotation
- eccentricity
- elliptical
- circular
- orbit
- obliquity
- Earth's axis of rotation
- seasonal difference
- precession
- glacial cycles
- Milankovic cycles / Milankovitch cycles
- northern hemisphere
- oxygen isotope record
- ice core
- microfossils
- particles
- sunspot cycle
- sunspot
- plasma
- magnetic field lines
- solar energy
- solar energy output
- average
- global average temperature
- global average temperature anomaly
- climate forcing
- absorb / absorption
- heat transport
- current
- ocean current
- surface current
- deep current
- density
- thermohaline circulation

- Gulf Stream current
- downwelling
- upwelling
- North Atlantic Deep Water (NADW)
- Antarctic Bottom Water (AABW)
- circulation
- intermediate water
- deep water
- Atlantic meridional overturning circulation (AMOC)
- decadal cycles
- model simulation
- ice albedo feedback effect
- El Niño Southern Oscillation (ENSO)
- La Niña
- global scale
- reflect / reflected / reflectivity
- evaporative cooling
- greenhouse gases (GHGs)
- GHG emissions
- infrared (IR) radiation
- greenhouse effect

Section 16.3 Methods for studying past climate

- paleoclimate / palaeoclimate
- direct data
- proxy data
- instrumental data
- instrumental records
- meteorological station network
- climate variation
- glacier
- ice sheet
- sea ice
- climate anomaly / anomalies
- tree growth rings
- drought
- dendroclimatology
- isotope
- stable isotopes
- radioactive isotopes
- fingerprint
- reconstruct
- water vapour
- methane
- carbon dioxide

- climate zone
- subtropical climate zone
- temperate climate zone
- palynology
- varves

Section 16.4 Computer models of the Earth system

- Earth-system computer models
- global warming
- datum / data
- variable
- results
- computer model
- grid cells
- calculate / calculation
- predict / prediction
- uncertainty
- global change

Section 16.5 Humans in the Earth system

- anthropogenic
- Agricultural Revolution
- Industrial Revolution
- fossil fuels
- photosynthesis
- stable carbon isotopes
- parts per thousand / per mil / ‰
- Anthropocene Epoch
- half-life
- “hockey-stick” diagram
- sea level change

Section 16.6 Welcome to the Anthropocene

- Intergovernmental Panel on Climate Change (IPCC)
- World Meteorological Organization (WMO)
- extreme climate-system events
- extreme weather
- sea-level rise
- tropical storm

- evaporation
- permafrost

Other vocabulary

- environmental processes
- solar forcing
- diurnal
- seasonal temperatures
- cryosphere
- troposphere
- aerosols
- convection
- friction
- boundary layer
- trade winds
- troposphere cells
- stratosphere
- altitude
- ozone
- radiation
- ultraviolet (UV) radiation / UV light
- turbulence
- major gases
- minor gases
- trace gases
- continental water
- groundwater
- saltwater
- freshwater
- infiltration
- surface flow
- sublimation
- condensation
- vertical convection
- horizontal movement
- salinity gradient
- temperature gradient
- hydrous mineral
- polar oceans
- land surface
- radiate
- topography
- orographic precipitation
- rain shadow
- ash particles

- depletion
- ubiquitous
- biomass
- visible light
- electromagnetic spectrum
- photon
- global heat budget
- long wave radiation
- short wave radiation
- CFCs
- radiative damping
- water vapour feedback
- climate models
- short-term variations
- long-term variation
- interglacial period
- glacial period
- minimum
- maximum
- glacial maximum / maxima
- climate record
- anomalous
- deforestation
- biomass burning
- cement
- ocean warming
- ocean acidification
- weather disaster
- eustacy
- isostacy

16.3. Earth-System Change - Review Questions

- What are the main “spheres” of the climate system? Describe each, and how they interact with one another.

- Draw a diagram to illustrate the spheres (geosphere, biosphere, hydrosphere/cryosphere, lithosphere) and how they interact with one another.

- What are greenhouse gases and what influence do they have on climate? What are the most important greenhouse gases?
- What is the greenhouse effect?
- What is albedo? How does it differ between ice and rocky surfaces on the crust? How does that affect climate?
- How can volcanoes influence climate?
- How does the biosphere influence climate?
- How does the level of CO_2 in the atmosphere currently compare to the levels of CO_2 over the past 400,000 years?
- What are some examples of forms of carbon found in the atmosphere, hydrosphere, lithosphere, biosphere?
- What are two examples of positive and negative climate feedback, and give examples of each.
- Why are climate models challenging to create? What are some limitations of climate models? What have climate models told us about what is coming in terms of climate change in the future?
- What are some examples of short-term climate changes? Long-term climate changes? Describe the changes in the various climate system "spheres" that occur in association with these changes.
- What are some major sources of CO_2 emissions? Think about all the things you see and do in a day; what things emit, or have emitted, CO_2 that you interact with daily. What things could you do to decrease your CO_2 emissions?

- Which industrial sectors are the largest sources of greenhouse gas emissions? How could we decrease the amount of greenhouse gases emitted by these sectors?

- How has the amount of sea ice changed over the past 40 years? How does the amount of sea ice relate to changes in ocean water temperature?

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- What are some examples of gradients that are important in climate systems? In the ocean? In the atmosphere?

- Describe the two layers of the atmosphere that are nearest the surface of the Earth (it may help to draw a cross-section diagram). What gases are found in these layers? What kinds of air patterns are observed in these layers?

- Why is the sky blue?

- Draw a diagram showing the hydrosphere, with arrows to show the movement of water through the hydrosphere.

- Describe several reservoirs where freshwater and saline water are found in the Earth's climate system.

- Describe seasonal interactions that occur between the cryosphere and the hydrosphere.

- Describe how topography, specifically mountains, can influence climate systems?
- What is the difference between isostacy and eustacy?
- Describe how global annual average temperatures have changed over the past 150 years using the “hockey stick” diagram. Draw a sketch of the diagram (don’t forget to label the x and y axes!).
- How is the pattern in the hockey stick diagram over the past 150 years different than other times with high global annual average temperatures over the course of the Holocene epoch?
- Over the past 10 years, which countries/regions have had the largest CO_2 emissions?
- How are increasing CO_2 concentrations in the atmosphere influencing ocean pH?
- What are some of the potential implications for life in the ocean if the CO_2 concentration continues to rise?

CHAPTER 17. GLACIATION

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 17:

- Section 17.1: Types of glaciers
- Section 17.2: Glacial erosion
- Section 17.3: Glacial deposits
- Section 17.4: Glaciations over Earth's history

17.1. Glaciation - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Define the term glacier and describe where glaciers are found on Earth.
- Describe the features of glaciers and how they grow, shrink, and move.
- Describe the different kinds of glaciers, and the erosional features they leave on the Earth's surface.
- Describe how changes to thermohaline circulation could change temperatures around the world.
- Describe how Milankovich cycles influence climate.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Describe how geologists use oxygen isotopes in ice to determine paleotemperatures on Earth.

17.2. Glaciation - Vocabulary

Section 17.0 Introduction

- glacier
- ice
- glacial ice
- climate
- glaciated
- meltwater

Section 17.1 Types of Glaciers

- continental ice sheet
- alpine glacier
- latitude
- topography
- polar region
- snow
- ice sheet
- sea level
- Antarctic Ice Sheet
- Greenland Ice Sheet
- vertical
- horizontal
- ice shelf / ice shelves
- valley glacier
- zone of ablation
- zone of accumulation
- equilibrium line
- temperate region
- tropical region
- slope
- ice surface
- snowfall
- firn
- compress / compressed
- compact / compacted / compaction
- snowflake
- granule
- weld / welded
- percolation
- stress

- brittle
- low pressure
- high pressure
- shallow
- deep
- deform / deformed / deformation
- landform
- ductile deformation
- plastic deformation
- rigid
- kilopascals (kPa)
- flow
- irregularities
- crevasse
- terrain
- velocity
- tension
- basal sliding
- sliding
- freezing point
- internal flow
- basal flow
- friction
- rainwater
- meltwater
- geothermal heat
- insulator
- thrust fault
- sediment
- terminate
- calve / calving
- iceberg
- stationary
- retreat
- melting
- evaporation
- sublimation
- advance

Section 17.2 Glacial erosion

- erosion
- base
- rock fragment
- gouge
- grind

- erosional features
- glacial erosion
- drumlin
- esker
- moraine
- terminal moraine
- floodplain
- kettle lake
- kame
- ground moraine
- Laurentide Ice Sheet
- glacial meltwater
- Glacial Lake Missoula
- outflow
- catastrophe / catastrophic
- valley
- U-shaped valley
- V-shaped valley
- fjord
- tributary valley
- arête
- col
- horn
- ridge
- saddle
- cirque
- tarn
- basin
- hanging valley
- truncated spur
- cliff
- glacial maximum
- nunatak
- roche moutonnée
- outcrop
- low angle slope
- steep slope
- glacial groove
- glacial striation / glacial striae
- glacial polish
- moraine lake
- end moraine
- dam
- glacial till
- rock basin lake
- paternoster lake
- finger lake

Section 17.3 Glacial deposits

- aggregate
- unconsolidated
- transport
- deposit
- icefield
- debris
- supraglacial
- unsorted
- englacial
- end moraine
- terminal moraine
- medial moraine
- subglacial sediment
- lodgement till
- abrasion
- well-compacted sediment
- poorly sorted
- freeze-thaw eroded material
- lateral moraine
- outwash
- outwash sediments
- proglacial region
- fluvial environment
- lacustrine environment
- marine environment
- glaciofluvial sediments
- glacially-derived sediments
- sandur
- outwash plain
- kettle
- pothole lake
- prairie pothole
- subglacial stream
- channel
- drumlin field
- long axis
- proglacial lake
- glaciolacustrine
- glaciomarine
- varve
- laminated
- melt discharge
- drop stone

Section 17.4 Glaciations over Earth's history

- glacial period
- glaciation
- ice age
- Huronian Glaciation
- Cryogenian Period
- Snowball Earth
- Andean / Saharan Glaciation
- Karoo Glaciation
- Cenozoic Glaciation
- Antarctic Circumpolar Current
- oxygen isotopes
- Earth's orbit
- Milankovitch Cycles
- orbit
- tilt
- wobble
- cyclical change
- Wisconsinan Glaciation
- Laurentide Ice Sheet
- Cordilleran Ice Sheet
- northern hemisphere
- southern hemisphere
- interglacial ice
- interglacial period
- climate feedback

Other vocabulary

- neve
- recrystallized
- snowline
- high elevation
- low elevation
- high latitude
- low latitude
- glacial plucking
- rock flour
- temperate glacier
- polar glacier
- subpolar glacier
- icecap
- outlet glacier
- mass balance

- terminus
- zone of wastage
- sea ice
- post-glacial sea level rise
- last glacial maximum
- unstratified
- erratic
- glacial retreat
- paleoclimatology / palaeoclimatology
- isotopic fractionation
- atmospheric moisture
- mid-latitudes
- depleted
- condense
- ice core
- geochemical proxy
- Fennoscandian ice sheet
- deglaciation
- bedrock isostatic rebound
- Earth's axis
- eccentricity
- obliquity
- precession
- Younger Dryas
- orbital forcing
- paleoclimate / palaeoclimate
- thermohaline circulation

17.3. Glaciation - Review Questions

- Describe how snow deposited on top of a glacier becomes glacial ice. What is the difference between snow and glacial ice?
- What is the difference between an alpine and a continental glacier?
- How do glaciers move?
- How are sediments generated and moved around by glaciers?
- Draw a cross-section through a glacier, from the zone of accumulation to the terminus and outwash plain. Label important features.
- Where does ductile deformation occur in a glacier? Where does plastic deformation occur in a glacier?

- Draw examples of glacial erosional features. Describe how each feature is formed.

- What is the difference between a glacial till and a river deposited conglomerate, in terms of (a) formation processes and (b) characteristics of the particles in the sediments/rock?

- Go to Google Maps or Google Earth. Zoomed out (and viewing in Earth mode for Google Maps):
    - Find examples of glaciation on Earth today. Note down the locations (continent, mountain chain) for a few of these examples.
        - Where in Canada do you find alpine glaciers? Where in Europe? Asia? The southern hemisphere?
        - Find examples of ice sheets, and ice shelves.
    - Let's search for evidence of past glaciation.
        - Continental glaciation features are very common in Saskatchewan! In some locations, we can clearly see them from above. Cut and paste the following coordinates into Google Maps or Google Earth, and draw and describe the glacial feature located at each set of coordinates. See if you can find other examples of the same kinds of features in nearby areas.
            - (a) 57°59'1.37″N 107°26'58.99″W
            - (b) 57°53'12.04″N 109°25'19.19″W
            - (c) 52° 2'3.60″N 106°32'3.13″W
    - Search for "Columbia Icefield Discovery Centre" on Google Maps, and take 5-10 minutes to explore this area in plan view and in street view. What glacial erosional and depositional features can you see? Sketch a few of them. Think about the processes that form each of these features.

- Moving back to plan view in the Columbia Icefields area, look for lakes near this location. What colour are they? Why do you think they are this colour?

- What are Milankovitch cycles? Draw the three Milankovitch cycles below. How does the Earth's orbit and the angle of its axis change through time? How do they influence the Earth's climate?

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- Describe the relationships between elevation, latitude, and occurrence of glaciers.

- What is the difference between a temperate and a polar glacier?

- How does the amount of glaciation influence sea level? How has glaciation varied through time, over the Pleistocene period in Earth history?

- What evidence is preserved in glacial ice that tells us about previous climate conditions, including temperature conditions?

- Which ice sheet covered Saskatchewan during the last glacial maximum? Which one covered Europe? Newfoundland?

- When did the last ice sheet finish retreating from the North American continent?

CHAPTER 18. GEOLOGICAL RESOURCES

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 18:

- Section 18.1: If you can't grow it, you have to mine it
- Section 18.2: Metal deposits
- Section 18.3: Industrial minerals
- Section 18.4: Fossil fuels
- Section 18.5: Diamonds

18.1. Geological Resources - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Name examples of ores that are sources of elements used in industry, including: iron, aluminum, uranium, zinc.
- Describe some of the geological processes that lead to ore formation, and the kinds of ores that form from these processes.
- Name several mines in Canada and the kind of ore that is produced in each.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- List several types of renewable energy, including energies driven by solar, geothermal, and tidal sources.
- Describe the sources of energy that we use in Canada, and how these sources vary by province.

18.2. Geological Resources - Vocabulary

Section 18.1: If you can't grow it, you have to mine it

- mine
- extract
- resource
- energy resource
- uranium
- fossil fuel
- gas
- petroleum
- gold
- copper
- silver
- nickel
- nickel-metal-hydride (NiMH)
- fibreglass
- steel
- quarry
- oil or gas well

Section 18.2: Metal deposits

- mine / mining
- mining district
- mining deposit
- supplier
- extraction
- resource
- mining sector
- revenue
- petroleum sector
- metal deposit
- ore minerals
- economy / economic / economical / economically
- background level
- ore grade
- economic grade
- viable deposit
- parts per million (ppm)
- concentration factor
- mineable deposit

- host rock
- ore-forming processes
- mineral deposit
- magmatic nickel deposit
- gravity segregation
- crystal settling
- smelter / smelting
- sphalerite
- chalcopyrite
- volcanogenic massive sulfide (VSM) deposit
- submarine volcanism
- hydrothermal vent
- black smoker
- massive sulfide deposit
- precipitate / precipitation
- ore body
- porphyry deposit
- commodity
- metal enrichment
- metal-rich water
- vein-type gold deposit
- epithermal deposit
- bornite
- molybdenite
- banded iron formation (BIF)
- hematite
- chert
- magnetite
- unconformity-type uranium deposit
- uraninite
- mineral processing
- open-pit mine
- underground mine
- waste rock
- mine shaft
- decline
- level
- tunnel
- pillar
- headframe
- ventilation shaft
- crusher
- exploratory drill holes
- concentrate
- tailings
- tailings pond
- settling pond
- concentrator

- embankment
- acid rock drainage (ARD)
- acidic water
- neutral water
- tailings dam breach
- metal refinement

Section 18.3: Industrial minerals

- industrial mineral
- aggregate
- quarry / quarried
- concrete
- calcite
- limestone
- sylvite
- rock salt
- gypsum
- drywall
- building facade

Section 18.4: Fossil fuels

- fossil fuel
- coal
- oil
- gas
- organic matter
- lignite
- bituminous coal
- anthacite
- low grade
- high grade
- coal deposit
- electricity generation
- biogenic gas
- thermogenic gas
- methane
- oil window
- source rock
- reservoir rock
- migration
- permeable
- petroleum field / oil field

- impermeable cap rock
- anticline trap
- oil and gas migration
- seismic section
- migration path
- petroleum geologist
- reserve
- conventional reserve
- unconventional oil and gas
- oil sands
- hydrocarbon
- environmental cost
- strip-mining
- shale gas
- hydraulic fracturing
- fracking
- induced seismicity
- directional drilling
- fracking chemicals
- gas-bearing formation
- coal-bed methane

Section 18.5: Diamonds

- kimberlite
- diamond-bearing rock
- craton

Summary

- geologic resources

Other Vocabulary

- bauxite
- galena
- native copper
- cobaltite
- ilmenite
- rutile
- non-renewable resources
- renewable resources

- non-metallic mineral resources
- agricultural minerals
- construction minerals
- gangue
- gossan
- immiscible melt
- cumulate
- hydrothermal veins
- metasomatism
- residual mineral deposits
- secondary enrichment zone
- leached zone
- sedimentary mineral deposits
- placer deposits
- magmatic segregation deposits
- solar energy
- geothermal energy
- tidal energy
- electromagnetic radiation
- hydro / hydroelectric power
- source bed
- reservoir bed
- oil trap
- peat
- particulates
- wind power
- bioenergy
- ocean energy
- geogenic

18.3. Geological Resources - Review Questions

- What metals and other ores do we mine in Saskatchewan? What do we use them for?
- List some common metal ore types. Which metal is extracted from each kind of ore?
- Describe black smokers. What kind of minerals and ores are associated with them? How do they form?
- What kinds of ores and metals do you find associated with hydrothermal deposits?
- If you have folds of sedimentary rock (capped with shale) in a reservoir, where do you think the oil is most likely to be?
- Where are the top three biggest oil reserves in the world?
- Where are Canada's coal reserves located?
- What are the types of coal? What do each of them look like? Describe each type of coal, including the environment where they form.
- Draw and label some of the key features of oil reservoirs. Describe briefly the processes that lead to oil formation.

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- Name the 10 common metal ores. What metals do we get from these ores? How do we use these metals? What are some major sources (i.e., countries) where metal ores are found?
- What metals do we mine in Canada? Where?
- What are some examples of non-renewable resources we use to generate energy in Canada?
- What are some examples of renewable resources we use to generate energy in Canada?
- Give examples of industrial minerals, agricultural minerals, and construction minerals.
- What metals are abundant (globally) in ores? What metals are more scarce?
- Discuss how hydrothermal fluids generate metasomatism. How can this effect ore formation?
- Give examples of metals and minerals that are found in placer deposits. Where do you find them in the environment?
- What are three fundamental energy sources?
- Describe energy sources used in Canada, and the relative importance of each of them. How do the sources of energy differ across the country?

- Where are the world's largest coal reserves?

- What chemical compounds and elements are released by burning coal?

- Describe the various sources of renewable energy.

- Draw and label the following kinds of ore deposits, and describe briefly how each one forms: magmatic segragation deposit – immiscible melt, hydrothermal deposit, bauxite, placer gold.

- Draw a diagram showing oil consumption and discovery vs. time. What are the implications of this diagram, in terms of energy use in the future? *There are lots of directions you can go with this question, e.g., how might this influence our energy use in the future?*

CHAPTER 19. MEASURING GEOLOGICAL TIME

Corresponding textbook readings

From Physical Geology 1st USask Edition (Panchuk) Chapter 19:

- Section 19.1: The geologic time scale
- Section 19.2: Relative dating methods
- Section 19.3: Dating rocks using fossils
- Section 19.4: Isotopic dating methods
- Section 19.5: Other dating methods
- Section 19.6: Understanding geological time

19.1. Measuring Geological Time - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Describe the difference between absolute and relative dating. Describe approaches used for each dating approach.
- Name the principles of stratigraphy and explain each one.
- Explain how radioactive decay of isotopes is used to date rocks.
- Give examples of radioactive isotopes that are useful for dating rocks.
- Describe how dendrochronology and magnetic reversals are used in dating rocks.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Describe the types of geological events used to determine relative ages.
- Define isotope and describe how the isotopes of an element differ from one another.

19.2. Measuring Geological Time - Vocabulary

Section 19.0 Introduction

- time
- dimension
- geological time
- vast
- geological processes
- relative age
- spatial relationship
- fossils
- evolution
- isotopic techniques
- absolute age

Section 19.1 The geologic time scale

- geological time scale
- James Hutton
- observations
- rock record
- principle of uniformitarianism
- historic time
- correlate / correlation
- William Smith
- strata
- principle of faunal succession
- time interval
- geological map
- cross-section
- sequence
- principle of superposition
- Nicholas Steno
- sedimentary rocks
- stratigraphic colulmn
- geological time period
- eon
- Hadean eon
- Archean eon
- Proterozoic eon
- Phanerozoic eon
- era

- period
- Palaeozoic era
- Mesozoic era
- Cenozoic era
- Paleogene period
- Neogene period
- Quaternary period
- Pleistocene epoch
- Holocene epoch
- extinction

Section 19.2 Relative dating methods

- relative dating principles
- principle of superposition
- principle of original horizontality
- principle of lateral continuity
- principle of inclusions
- principle of cross-cutting relationships
- principle of baked contacts
- principle of chilled margins
- delta foreset bed
- ripple
- cross-bedding
- depositional basin
- unconformity
- river delta
- xenolith
- clast
- dyke
- fault
- metamorphose / metamorphosis
- erode / eroded / erosion
- angular unconformity
- nonconformity
- disconformity
- paraconformity
- block diagram

Section 19.3 Dating rocks using fossils

- paleontology
- fossil / fossiliferous
- fossil assemblages

- Cambrian
- Carboniferous
- Triassic
- Devonian
- Ordivician
- Permian
- dinosaur
- mammal
- reptile
- birds
- plants
- insects
- amphibians
- extinction
- Cretaceous-Paleogene (K-Pg) boundary / Cretaceous-Tertiary (K-T) extinction
- asteroid impact
- Deccan Traps
- shark
- index fossil
- biozone
- ammonite
- suture line
- septae
- foraminifera
- correlate / correlation
- rock type
- lithology
- lithostratigraphic correlation
- biostratigraphic correlation
- chronostratigraphic correlation
- diachronous
- Walther's Law
- marker bed
- ash layer

Section 19.4 Isotopic dating methods

- isotopic dating method
- atom
- isotope pair
- absolute age
- isotopic dating technique
- decay
- Potassium-Argon (K-Ar) dating
- radioactive isotope
- radioactive decay

- billion years (Ga)
- million years (Ba)
- parent isotope
- daughter isotope
- mass spectrometer
- Uranium-Lead (U-Pb) dating
- Rubidium-Strontium (Rb-Sr) dating
- Carbon-Nitrogen (C-N) dating
- half-life
- error
- feldspar
- zircon
- radiometric date
- age date
- Curie point
- isotopic clock
- reset
- geological history
- sequence
- clastic sedimentary rock
- maximum age
- radiocarbon (^{14}C) dating
- organic material

Section 19.5 Other dating methods

- dendrochronology / tree-ring dating
- tsunami
- coastal swamp
- inundate / inundated
- magnetic chronology
- magnetic field reversal
- reversed polarity
- normal magnetism
- reversed magnetic polarity
- magnet / magnetized
- oceanic crust
- sea-floor spreading
- magnetic chronology
- magnetometer

Section 19.6 Understanding geological time

- year

- decade

Other vocabulary

- relative dating technique
- deep time
- radiometric dating
- absolute dating
- stratigraphic record
- fossil record
- chronological age
- geologic events
- principles of stratigraphy
- continuous strata
- eroded strata
- erosional features
- inclusions
- stratigraphic sequence
- the Burgess shale formation
- mass extinction events
- unstable nucleus
- particle
- electromagnetic radiation
- emit
- parent nucleus
- daughter nucleus
- alpha particle
- beta particle
- electron capture
- accuracy
- uncertainty
- Acasta gneiss
- Nuvvuagittuq Greenstone Belt

19.3. Measuring Geological Time - Review Questions

Relative dating

- Describe each of the principles of stratigraphy.

- Draw, describe, and label examples of each principle of stratigraphy.
  - principle of superposition
  - principle of cross-cutting relationships
  - principle of original horizontality
  - principle of lateral continuity
  - principle of inclusions
  - principle of unconformities
  - principle of fossil succession
  - principle of baked contacts
  - principle of chilled margins

- Draw examples of the four kinds of unconformities. Label the key features of each type of unconformity.
    - disconformity
    - nonconformity
    - paraconformity
    - angular unconformity

- Search for “relative dating cross-section” on Google Images.
    - Test yourself on determining relative stratigraphic ages using the images that come up from this search.
    - Name the types of unconformities that you see in the cross-sections.
    - Come up with a hypothesis about the geological history of each cross-section you describe (e.g., sedimentary deposit, followed by uplift and folding, erosion, deposition of additional strata, tectonic compression, etc.).

- Draw a cross-section through a section of Earth’s crust in the box below, similar to the ones you found on Google Images in the previous exercise. This time, create your own unique cross-section! Include different kinds of unconformities, layers of sedimentary rock, faults that offset the strata, and cross cutting igneous intrusions such as dikes and sills. Consider how fossils in the sedimentary rocks could help you date the rocks.

- Determine the relative ages of the strata and features in your cross-section, and provide a description of the geological history of the cross-section area. *If you want to, you can show your cross-section to your professor or a TA and see if it makes sense geologically. Then you could show your cross-section to a friend/colleague in the class, and they can use the principles of superposition to determine the relative ages of the strata.*

- Scale is important when assessing relative ages of strata; if we look at strata at a single outcrop or part of an outcrop, sometimes we will get a different answer about relative ages than we would if we looked at the same strata at numerous outcrops. Draw a few examples of scenarios where looking at a rock outcrop might give you a different answer for the relative ages of strata than if you looked at the same strata at a series of outcrops at a regional scale.

- You are mapping the geology of a rock outcrop, and you think you may have identified a paraconformity. What kinds of information or data would you need to get to assess whether a paraconformity is present or not?

- Describe how you can use fossils to determine the relative ages of rock strata.

- What kinds of geologic features can cross-cut strata?

- What are the basic types of divisions of the geologic time scale?

- What important event happened at the boundary between the Paleozoic and Mesozoic Eras?

- What do scientists believe happened to cause this event?

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- There are five geologic events that can give us information that we can use to determine relative ages of rocks: intrusion, erosion, deposition, faulting, and rock deformation. Draw pictures of each type of geologic event.

- Describe how human understanding of the age of the Earth has changed as we have learned how to “read the rocks” over the past few hundred years.

- What is the Burgess shale known for? Where is it located?

Absolute dating

- What is the difference between relative and absolute dating? What tools do geologists use to determine ages of rocks for each approach?
- What is a half-life?
- What is uranium-lead dating useful for? What mineral is commonly used for this kind of dating?
- Refer to table 19.2 in the textbook. What radioisotopes could you use to date a rock that you expect is on the order of 1 Ga old? 500 Ma?
- Is carbon-nitrogen dating useful for dating rocks? Why or why not?

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- What is an isotope? What is the difference between different isotopes of an atom?
- Describe how radioactive decay works. What are three types of radioactive decay?
- Where are the oldest rocks on Earth (that we have identified so far) located? How old are they?
- What radioisotopes were used to date the oldest rocks on Earth? Which minerals do we analyse to examine these radioisotopes?
- Name the four Eons of the geologic time scale, and describe event(s) that occurred in each one. What did the Earth's surface look like in each of the Eons?

- Using your arm as a representation of the age of the Earth, practice pointing and naming the positions of the Eons along your arm. Point to a few positions where major life forms evolved: the earliest life, the first multicellular life, the first land plants, vertebrates, and humans. Where is 4.6 Ga on your arm? Where is 2.6 Ga? Where is 542 Ma? 2 Ma?

CHAPTER 14 (EARLE, 2015). GROUNDWATER

Corresponding textbook readings

From Steven Earle (2015) Physical Geology Chapter 14:

- Section 14.1: Groundwater and aquifers
- Section 14.2: Groundwater flow
- Section 14.3: Groundwater extraction
- Section 14.4: Groundwater quality

14.1. Groundwater - Learning Outcomes

After reading this chapter of the textbook, learning the vocabulary, and working through the review questions, students should be able to:

- Draw a rough cross-section drawing through a typical aquifer and describe the features of an aquifer system.
- Describe the difference between the saturated and unsaturated zones of an aquifer.
- Describe how the water table can vary seasonally and/or due to changes in climate conditions.
- Describe how porosity varies between unconsolidated sediments, sedimentary rocks, and igneous and metamorphic rocks. Draw examples of the different kinds of pore spaces.
- Describe how permeability can vary depending on porosity and interconnectedness of pores.
- Give examples of types of groundwater contamination and their sources.

Learning outcomes not covered in the textbook chapter in detail, but we may discuss them in class (depending on your professor):

- Describe the difference between a losing stream and a gaining stream.
- Describe how groundwater resources can be depleted by over-use of groundwater wells, and how in coastal areas this can lead to saltwater inundation.

14.2. Groundwater - Vocabulary

Section 14.0: Introduction

- spring
- fresh water
- glacial ice
- groundwater
- surface water
- contaminated
- sustainable / sustainably / sustainability

Section 14.1: Groundwater and aquifers

- aquifer
- municipal
- agricultural
- industrial
- pore / porous / porosity
- primary porosity
- secondary porosity
- fracture / fractured
- unconsolidated sediment
- cement / cementation
- fine-grained
- course-grained
- consolidation
- interlocking crystals
- cavern / cavernous
- dissolution
- permeable / permeability
- interconnected
- friction
- variable
- extract
- hydraulic conductivity (K)
- solutional openings
- polar molecule
- aquitard
- relative
- absolute
- unconfined aquifer
- confined aquifer

- confining layer
- cross-section
- seep / seepage

Section 14.2: Groundwater flow

- groundwater flow
- saturated
- unsaturated
- unsaturated zone
- saturated zone
- water table
- precipitation
- rain
- hail
- fog
- runoff
- infiltrate / infiltration
- transpiration
- evaporate / evaporation
- root zone
- recharge
- topographic relief
- water well
- pump
- recharge area
- discharge area
- viscosity
- gravitational potential energy
- potentiometric surface
- potential energy
- artesian well
- flowing artesian well
- perched aquifer
- perched water table
- hydraulic gradient
- hydraulic conductivity
- Darcy's equation
- hydrogeologist
- velocity
- underground storage tank (UST)
- contamination
- karst
- cave
- hydraulic head
- equipotential

- flow path
- pressure gradient
- right angle
- hydraulic potential
- Darcy's law

Section 14.3: Groundwater extraction

- groundwater extraction
- spring
- drill
- well
- water-well drilling rig
- casing
- well screen
- submersible pump
- municipal water supply well
- irrigation
- water level
- cone of depression
- dry well
- rate
- sustainable
- unsustainable
- observation well
- automatic recorder
- water level
- fluctuation
- groundwater chemistry
- groundwater quality
- private well
- short term variation
- store / storage
- long-term fluctuation
- variable / variation
- extract / extraction
- overextraction
- license / licensing
- surface water stream
- ecosystem
- streamflow
- base flow
- watershed
- water-dependent
- declining water level
- drought

- groundwater regulation
- water usage
- water table decline
- impermeable surface
- deplete / depleted / depletion
- overuse
- stress
- drainage system
- storm sewer
- surface water infiltration
- wetland
- constructed wetland
- decontaminate
- infiltrate

Section 14.4: Groundwater quality

- groundwater quality
- surface water
- naturally contaminated
- inert
- dissolve
- consumption
- agricultural use
- level
- exposure
- toxic
- bacterial contamination
- groundwater supply
- World Health Organization (WHO)
- oxidation potential
- anoxic conditions
- anthropogenic contamination
- pollution
- vulnerable / vulnerability
- landfill
- animal waste
- leaking storage tank
- septic system
- road runoff
- golf course
- agricultural contamination
- landfill leachate
- regulation
- engineered landfill
- impermeable liner

- drain / draining / drainage
- landfill gas
- leak / leakage
- aquatic habitat
- recycle
- industrial pollution
- contaminated site
- contaminated groundwater
- environmental damage
- acid rock drainage (ARD)
- abandoned mine
- operating mine
- gas station
- petroleum fuel
- volatile component
- solubility
- petroleum vapour
- septic tank
- drainage field
- anaerobic
- sludge
- aerobic
- effluent
- percolate
- pathogenic bacteria
- prevention
- mitigation
- tailings impoundment
- remediation
- pump and treat

Other vocabulary

- seasonal fluctuation
- groundwater discharge
- groundwater recharge
- groundwater withdrawal
- impermeable layer
- stream bed
- losing stream
- gaining stream
- hydraulic pressure
- intergranular
- aquiclude
- artesian aquifer
- saltwater intrusion

- naturally-occurring
- subsidence
- water pressure
- groundwater flow
- karst topography
- sinkhole
- stalactite
- stalagmite

14.3. Groundwater - Review Questions

- What is the difference between a confined and unconfined aquifer?
- Consider how water moves into and out of an unconfined aquifer. How does the level of water in an unconfined aquifer vary seasonally?
- What makes a good aquifer (i.e., an aquifer that can hold lots of water that will flow readily to a well in that aquifer)?
- How does groundwater recharge?
- How is groundwater connected with surface water?
- Draw a cross-section through an aquifer and label all the parts.
- Describe how the level of the water table can change around a groundwater well when water is removed. What controls changes in the water table level? What happens if the discharge is higher than the recharge for extended periods of time?
- Describe some examples of groundwater pollution. What kinds of contaminants can create problems in groundwater? What are some sources for each type of contaminant?

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- What proportion of municipal water used in Saskatchewan is sourced from groundwater?

- Draw and describe the differences between a gaining and a losing stream.

- What are the three principle types of pores found in aquifer materials? Draw examples of each.

- What leads to saltwater intrusion?

CHAPTER 21 (EARLE, 2015). GEOLOGICAL HISTORY OF WESTERN CANADA

Corresponding textbook readings

From Steven Earle (2015) Physical Geology Chapter 21:

- Section 21.1: Geological history of Canada
- Section 21.2: Western Canada during the Precambrian
- Section 21.3: Western Canada during the Paleozoic
- Section 21.4: Western Canada during the Mesozoic
- Section 21.5: Western Canada during the Cenozoic

21.1. Geological History of Western Canada - Learning Outcomes

Note to students in Dr McBeth's course section: Much of this textbook chapter is far beyond the scope of what I would expect a first year student to know. Use the learning outcomes, the [chapter 1 overview](https://openpress.usask.ca/geolmanual/chapter/overview-of-canadian-geology/) from the lab manual, and my lecture slides to guide your studies of this chapter. I do <u>not</u> expect you to know much of the detail in this chapter, e.g., the names of the various cratons within the Canadian Shield, or the names of the various groups of rocks in BC. I still include the vocabulary from this chapter in the vocab section since this is part of a larger project for the textbook, but I will only expect you to know vocab I cover in lecture for this section. The review questions I have provided are all appropriate for you to use in your studying and will give you a realistic idea of the level of detail you need to know for exams. – Dr McBeth

A link to the Chapter 1 overview in the lab manual:

https://openpress.usask.ca/geolmanual/chapter/overview-of-canadian-geology/

After attending the lecture and reading this chapter of the textbook and in the lab manual, learning the vocabulary, and working through the review questions, students should be able to:

- Name the 6 geologic provinces of Canada, and describe features of each of them.
- Label the positions of the geologic provinces of Canada on a map.

21.2. Geological History of Western Canada - Vocabulary

Section 21.0 Introduction

- geological history
- geological features
- Laurentia
- Archaean
- Holocene

Section 21.1 Geological history of Canada

- geologic provinces
- craton
- stable
- supercontinent
- Pangea / Pangaea
- uplift
- burial
- plate tectonics
- Acasta Gneiss
- Nuvvuagittuq greenstone belt
- greenstone belt
- Billion years ago (Ga)
- Million years ago (Ma)
- Appalachian fold belt
- Innuitian fold belt
- Cordilleran fold belt
- Canadian shield
- Rodinia
- Ordivician period
- Silurian period
- Devonian period
- marine sediments
- Gondwana
- Appalachian Mountains
- Himalaya Mountains
- Pearya
- Rocky Mountains
- collide / collision
- lithology / lithologies / lithological

Section 21.2 Western Canada during the Precambrian

- Precambrian
- orogen
- Superior Province
- metamorphose / metamorphosed
- greenstone belt
- volcanogenic massive sulphide deposit / VMS deposit
- Trans-Hudson Orogen (THO)
- Churchill Craton
- Wyoming Craton
- Hearne Craton
- Rae Cratons
- Athabasca Basin
- Thelon Basin
- undeformed
- unconformity-type uranium deposit
- extraterrestrial impact
- Carswell Crater
- Taltson Magmatic Zone (TMZ)
- Slave Craton
- Acasta Gneiss
- Wopmay Orogen
- continent-continent collision
- Muskox Intrusion
- Ultramafic intrusion
- Monashee Complex
- supergroup
- Purcell Supergroup / Belt Supergroup
- supercontinent Columbia
- Windermere Group
- clastic sedimentary rock
- deposition
- Snowball Earth glaciation
- continental slope
- Toby Formation
- glacial dropstone

Section 21.3 Western Canada during the Paleozoic

- Paleozoic Eon
- passive margin
- Cambrian Era
- Burgess Shale
- Stephen Formation

- fossil bed
- inland sea
- Western Canada Sedimentary Basin (WCSB)
- Prairie Evaporite Formation
- terrane
- Panthalassic Ocean
- Wrangellia Terrane

Section 21.4: Western Canada during the Mesozoic

- Mesozoic Era
- accretion
- terrane accretion
- Quesnel Terrane
- Cache Creek Terrane
- Stikine Terrane
- Intermontane Superterrane
- BC Interior Plateau
- Insular Superterrane
- Alexander Terrane
- outboard terranes
- Coast Plutonic Complex (CPC)
- thrust
- plate convergence
- uplift
- foreland basin
- terrestrial sediment
- marine sediment
- Dinosaur Park Formation
- Scollard Formation
- Horseshoe Canyon Formation
- Hilda Bone Bed
- depositional basin
- Nanaimo Basin
- Bowser Basin

Section 21.5 Western Canada during the Cenozoic

- Cenezoic Era
- Pacific Rim Terrane
- Crescent Terrane
- subduction
- Juan de Fuca Plate
- igneous complex

- sedimentation
- Paskapoo Formation
- Ravenscrag Formation
- Turtle Hills Formation
- strata
- terrestrial fluvial environment
- deltaic environment
- Kamloops Group
- Tranquille Formation
- lacustrine sediment
- Dewdrop Flats Formation
- McAbee Beds
- Pleistocene glaciation
- Cordilleran Ice Sheet
- Laurentide Ice Sheet
- glacier / glaciation
- glacial erosion features
- glacial sediment
- glacial depositional features
- drumlin field
- esker

Other vocabulary

- ice sheet
- interior platform
- basement rocks
- thermal subsidence
- buoyant uplift
- domes
- the Canadian Prairies
- intracratonic basins
- Western Interior Seaway
- Laramide orogeny
- Taconic orogeny
- Acadian orogeny
- Appalachian orogeny
- Appalachian orogen
- Innuitian orogen
- Ellesmerian orogeny
- Eurekan orogeny
- Axel Heiberg Island
- Cordilleran orogen
- Coast Range
- cordillera
- Pacific Cordillera / Canadian Cordillera

- continental shelf and slope
- Atlantic continental shelf
- thrust fault

21.3. Geological History of Western Canada - Review Questions

For these questions, students in Dr McBeth's GEOL 108/121 class should refer to the [Chapter 1](https://openpress.usask.ca/geolmanual/chapter/overview-of-canadian-geology/) overview section of the lab manual for GEOL 121 and the lecture slides. Reading through this chapter of the textbook will also be useful but there is far more information in the textbook than you will need to know for exams – so it is best to focus your studying by working through these review questions.

https://openpress.usask.ca/geolmanual/chapter/overview-of-canadian-geology/

- What are the six geologic provinces of Canada?

- Draw a rough outline of Canada (The northern half of the North American Continent). Draw lines (approximate) and label the geologic provinces on your drawing.

- Which geologic province does Saskatoon fall within? What other geologic province is partly in Saskatchewan?

- Describe the features and characteristics of each of the geologic provinces of Canada.

- What are the ages (in terms of eons and eras) of the different geologic provinces of Canada?

- Which provinces are known for holding valuable mineral and energy deposits? What kinds of mineral and energy deposits?

- If you could make a movie highlighting the most important events affecting each of the geologic provinces of Canada across geological history, what events would you show?

Extra review questions that may be covered in lecture (depending on your professor) that are not completely covered in the the textbook readings:

- Draw a cross-section of the continental shelf and slope, including the rocks beneath the shelf sedimentary deposits.

Appendix I. Chemistry

It is helpful to review some key concepts from high school chemistry to prepare for this course. These are concepts that are generally covered in schools in Saskatchewan in Grade 10 science class (or earlier). This appendix contains outcomes, vocabulary, and review questions in chemistry.

Note that this appendix is not intended to re-teach you high school chemistry; it provides guidance on aspects of high school chemistry that will be useful as background for this introductory physical geology course. If you are struggling with these concepts please approach your instructor to chat about other resources to help you.

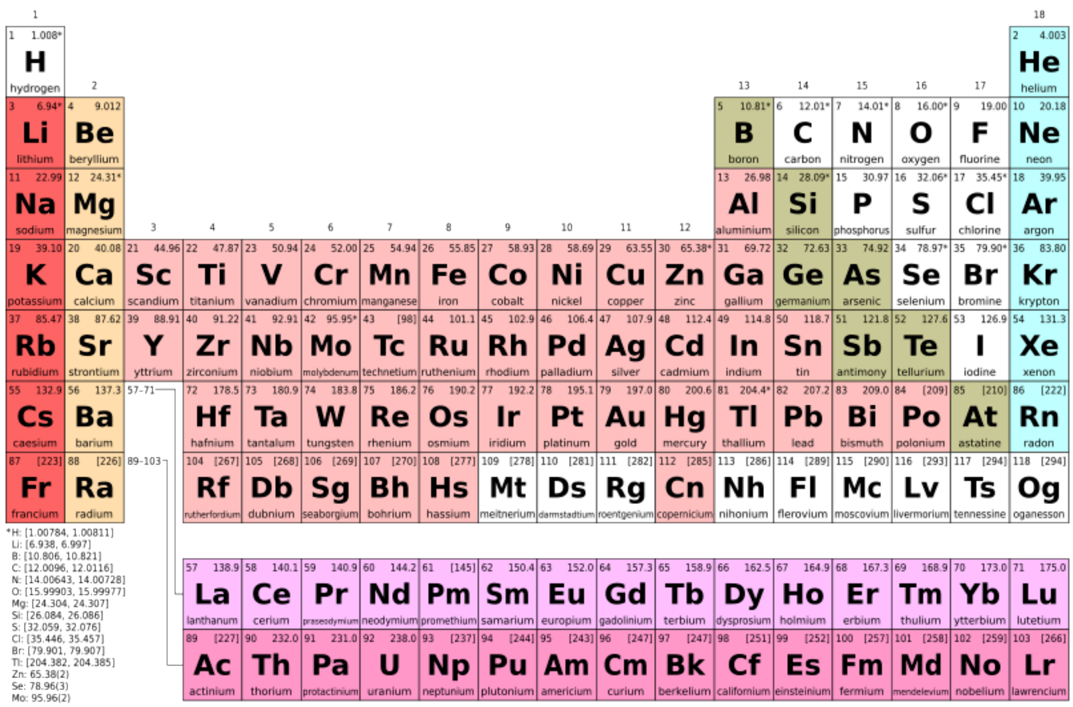


***Figure AI-1** | Periodic table of the elements. Source: Wikimedia user "László Németh", 2013, public domain. [View Source]*

AI-1. Outcomes

After reviewing this appendix the learner should be:

- familiar with the structure and content of the periodic table,
- able to write the one or two letter codes for key elements such as iron and oxygen,
- familiar with key vocabulary for physical and chemical processes, and be able to use these words in sentences and provide examples of their importance in their everyday life,
- be prepared to give examples of common items that have acid, neutral, and basic pH.

AI-2. Vocabulary

Review this list of vocabulary. Try to define each one out loud, and create a sentence using each word in context. You can look them up on Wikipedia if you need help remembering their meaning.

- periodic table
- element
- atomic weight
- atomic mass
- atomic number
- atom
- matter
- molecule
- solid
- liquid
- gas
- conditions
- acid
- base
- react
- charge
- gain
- lose
- repel
- attract
- pH
- heat
- cold
- melt
- boil
- freeze
- melting point
- boiling point
- freezing point
- solidify
- metal
- noble gas
- halide
- alkali metal
- transition element
- chemical bond
- inert
- density
- mass
- heavy
- light
- variations

- chemical reaction
- chemical properties
- chemical formula
- composition
- increase
- decrease
- water
- ice
- seawater
- salt
- substance
- freshwater
- dissolve
- solute
- solvent
- dilute
- concentrate
- evaporate
- condense
- precipitate / precipitation
- component
- mixture
- transformation
- stable
- unstable

AI-3. Review Questions

Work your way through the following review questions. If you are not able to answer the questions on your own, look the terms in the question up on Wikipedia to get more background information to help you answer the question.

- Describe the differences between a solid, a liquid, and a gas. Give an example of each from your daily life.

- What happens to liquid water if you cool it to below 0˚C? Note: *this depends on atmospheric pressure, but for the purposes of this question you can consider what would happen if you did this in Saskatoon.*

- What happens to liquid water if you heat it to greater than 100˚C? Note: *this depends on atmospheric pressure, but for the purposes of this question you can consider what would happen if you did this in Saskatoon.*

- What happens if water vapour (e.g., from a boiling kettle) hits a cold mirror?

- What is a neutral pH? What is an acidic pH? What is a basic pH?

- Give examples of food or household items that are acids and bases (you can search on google if you don't know any off the top of your head, or refer to figure AI-2 below).

- When you put an egg into a cola drink, the shell will dissolve (you can try it if you haven't before!). Is the cola and acid or a base?

- What is the difference between an atom and a molecule?

- Is water an atom or a molecule?

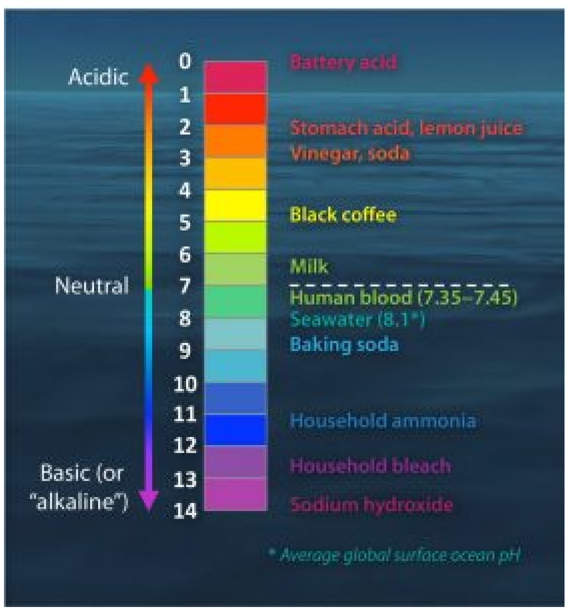


***Figure AI-2** |pH scale and placement of common items on the scale. Source: PMEL Program NOAA (2018) Public Domain.* [*View source*]

Exploring the periodic table

- Examine the periodic table in figure AI-1 (located at the start of this appendix) and note the following:

- Each box in the table represent one of the elements.
- Each element has a set of one or two letters that are used as a code to represent that element. For example, the element gold is represented by the letters “Au”.
- Some of the letter codes for elements do not seem intuitive, but there is a reason for each one. The letter abbreviations are often from the Latin names for the elements. For example, gold in Latin is **Au**rum.
- What defines an element is the number of protons that element contains. Each element has a specific number of protons. The number of neutrons in each atom of an element can vary, but the number of protons stays the same (or if a proton is lost, the atom becomes a different element).
- The number in the top left corner of each element box is the atomic number for that element – the number of protons in an atom of that element.
- The atomic mass is the sum of the protons plus neutrons for an element. It will vary with different isotopes of the element, since the number of neutrons will vary between isotopes (but not the number of protons, because then they would be different elements!). The units of atomic mass are atomic mass units.
- The number in the top right corner of each element box is the average atomic mass. This is the average mass of an atom of that element. There are different isotopes for most elements and the atomic weight is the weighted average (by abundance) of the masses of these isotopes.
- Note the numbers along the top of the periodic table; these are called groups. The elements in each group generally behave similarly when they bind to other elements.
- The horizontal rows of the periodic table are called periods.
- The colours of the boxes correspond to groups or periods of elements that are grouped by common properties (e.g., the light blue elements are noble gases)
- The video introduction to the periodic table by CrashCourse may also be helpful as you review the periodic table.

- What are some properties that are similar between the elements in each set of boxes with the same colour?

- Figure AI.3 is a periodic table that is missing the names of the elements, but still has the one or two letter codes for each element. Find the following elements in this table. These are elements that will come up in introductory physical geology, so it will help to be familiar with them. You may need to refer to Figure AI-1 to find the elements; if that is the case, review this exercise again until you know the code for that element and can find it without checking the other table.
    - iron
    - sodium
    - magnesium
    - chlorine
    - aluminum
    - hydrogen
    - helium
    - oxygen
    - sulfur / sulphur
    - zinc
    - lead
    - gold
    - silver
    - uranium
    - potassium

- argon

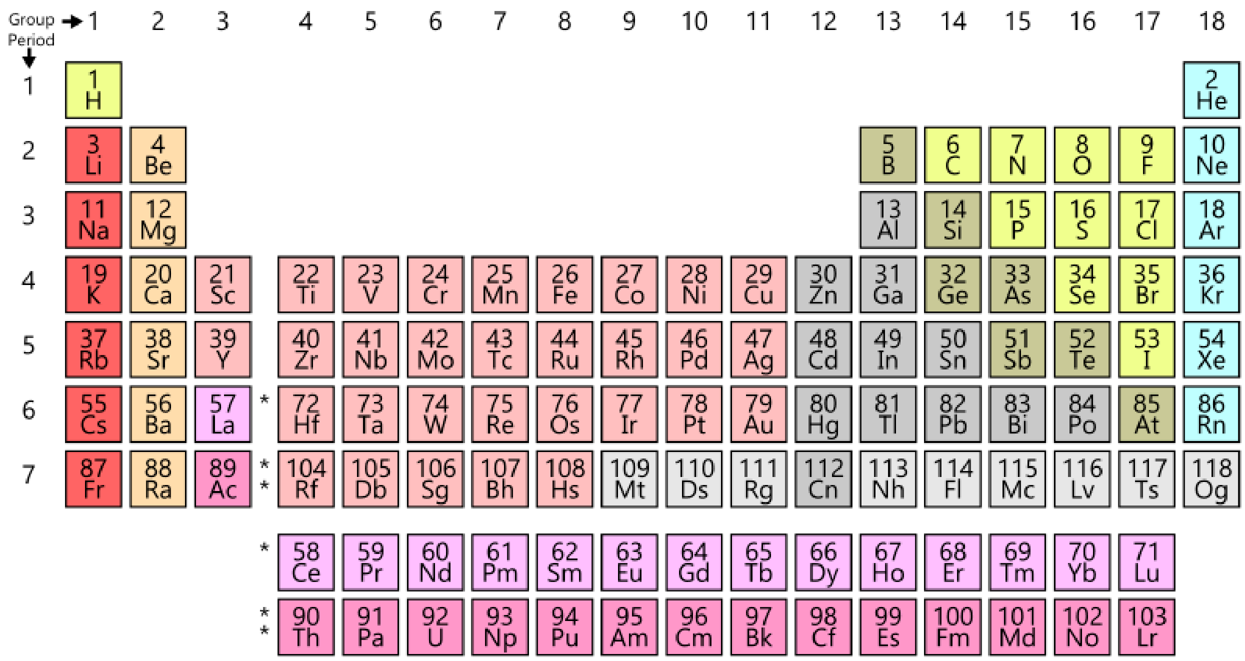


***Figure AI-3** | Periodic table of the elements. The number above each element's code is the atomic number. Source: Wikimedia user "Offnfopt", 2017, Public Domain. [View Source]*

- Look up each element listed in the previous question on Wikipedia.
  - How common is each element in nature?
  - Is the element generally found as a gas, solid, or liquid?
  - Do you encounter each element in the list each day? If you do, where? In what form (e.g., what elements are found in air, water, steel, and jewellery)?

Note the change in atomic weight as you move across the periodic table, and down the periodic table. The density of the elements (g/cm^3, mass divided by volume) is related to the atomic weight of the element but also the volume of space the atoms take up. Gases are less dense than solids or liquids, even if the atomic weight of the element is higher.

- Referring to the density version of the interactive periodic table on [RSC.org]:
  - How does the density of lead compare to the density of carbon?
  - How does the density of iron compare to the density of mercury? Gold?

Appendix II. Physics

It is helpful to review some key concepts from high school physics to prepare for this course. These are concepts that are generally covered in schools in Saskatchewan in Grade 10 science class (or earlier). This appendix contains outcomes, vocabulary, and review questions in physics.

Note that this appendix is not intended to re-teach you high school physics; it provides guidance on aspects of high school physics that will be useful as background for this introductory physical geology course. If you are struggling with these concepts please approach your instructor to chat about other resources to help you.

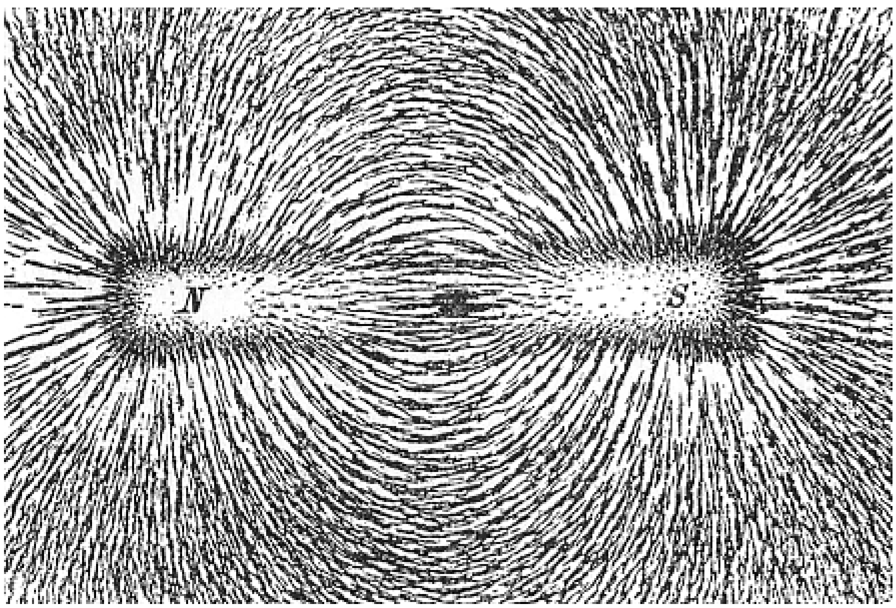


Figure AII-1 | *Iron filings illustrating magnetic field lines around a dipole magnet. Source: Newton Henry Black, Harvey N. Davis (1913) Practical Physics, The MacMillan Co., USA, p. 242, fig. 200. Public Domain (out of copyright).* [View source]

AII-1. Outcomes

After reviewing this appendix the learner should be:

- familiar with key physics vocabulary, and be able to use these words in sentences and provide examples of their importance in their everyday life.

AII-2. Vocabulary

Review this list of vocabulary. Try to define each on out loud, and create a sentence using each word in context. You can them up on Wikipedia if you need help remembering their meaning.

- matter
- atom
- proton
- neutron
- electron
- nucleus
- orbit
- solid
- liquid
- gas
- fluid
- steam
- positive charge
- negative charge
- neutral
- radioactive decay
- energy
- power
- electricity
- static electricity
- conductor / conductive
- insulator
- force
- mass
- velocity
- stationary
- acceleration
- rate
- pressure
- magnetic field
- repel
- attract
- physical properties
- temperature
- reflect
- refract
- prism
- concave
- convex
- units
- acoustic
- emit
- detect
- sound
- high-energy
- echo
- crystallize
- compression

- wave
- instrument
- evidence
- soft
- hard
- friction
- smooth
- rough
- clear
- opaque
- transparent
- translucent
- naked eye
- magnify / magnification

AII-3. Review Questions

- Test yourself: draw an atom. label the parts of the atom, the types of particles (protons, neutrons, and electrons), and the charges of the different particles.

- What is acceleration? how does it differ from force? How does it differ from velocity?

- Imagine yourself starting a car and increasing the speed from 0 km/hr to 100 km/hr, then driving down the highway with the cruise control set to 100 km/hr for 5 min. Then you slow the vehicle down from 100 km/hr to 30 km/hr to turn onto a country road. As soon as you turn onto the country road, you park the car so you can get out and admire the beautiful Saskatchewan sunset!
  - During which part(s) of the drive is the car accelerating?
  - During which part of the drive does the car have a constant velocity, or speed?
  - what is the difference between acceleration and constant velocity?

- If you are holding an apple then drop it, what force is acting on the apple that causes it to drop and hit the ground?

- Is the force of gravity (gravitational acceleration) on Earth higher or lower than the force of gravity (gravitational acceleration) on the moon? Why?

- What is the difference between mass and weight?

- What is the equation that is used to calculate the weight of the apple (hint: Newton's second law of motion)?
- If you were on the moon, how would the weight of the apple be different from the weight of the apple on Earth?
- What is an example of a magnetic field you encounter in everyday life?
- What happens when you put an object made of iron in a magnetic field? Why?
- What are some examples of metric units? Imperial units?
- What units are used to describe:
    - the velocity of a car driving down the highway?
    - the mass of an object?
    - the speed of light?
    - The area of a room (in metric units)?

Appendix III. Mathematics

It is helpful to review some key concepts from high school mathematics to prepare for this course. These are concepts that are generally covered in schools in Saskatchewan in Grade 10 science class (or earlier). This appendix contains outcomes, vocabulary, and review questions in mathematics.

Note that this appendix is not intended to re-teach you high school math; it provides guidance on aspects of high school math that will be useful as background for this introductory physical geology course. If you are struggling with these concepts please approach your instructor to chat about other resources to help you.

AIII-1. Outcomes

After reviewing this appendix the learner should be:

- familiar with key mathematics vocabulary and be able to use these words in sentences.
- able to draw acute, right, and obtuse angles, and know the difference between parallel and perpendicular lines.

AIII-2. Vocabulary

Review this list of vocabulary. Try to define each on out loud, and create a sentence using each word in context. You may look them up on Wikipedia if you need help remembering their meaning.

- perpendicular
- angle
- acute angle (low angle)
- right angle
- left
- right
- parallel
- geometry
- greater than
- less than
- equal to
- plus
- minus
- formula
- notation
- unit
- vertical
- horizontal
- scale
- continuous
- discontinuous

- order of magnitude
- linear
- symmetrical
- asymmetrical
- straight
- curved
- thin
- thick
- radius /radii
- diameter
- subscript
- superscript
- symbol
- size
- shape
- circle / circular
- ellipse / elliptical
- cylinder / cylindrical
- sphere
- square
- cube
- rectangle
- triangle
- pyramid
- prism
- range
- 90 degrees (90˚)
- two dimensional (2-D)
- three dimensional (3-D)
- one dimensional (1-D)
- times (e.g., 10,000 times, or 10,000 x)
- scientific notation (e.g., 3 cm = 3 x 10^-2 m or 3 x 10^{-2} m)
- dimensions (length, width, height)
- adjacent
- orientation
- interior
- exterior
- proportion
- bisect
- graph
- horizontal axis
- vertical axis
- graph scale
- average / mean
- center / centre
- logarithmic scale

AIII-3. Review Questions

Geometry

- What is the word and symbol used to describe an angle (if you are writing the value for an angle in a sentence)? E.g., a 90 ______ angle.
- What is the symbol for angle if you are drawing an angle?
- What is the angle between two perpendicular lines?
- What is a right angle?
- Draw a right angle triangle.
- What is the symbol for an angle that is perpendicular?
- What is the angle between two parallel lines?
- What are some examples of surfaces that are parallel that you interact with in your daily life?
- What are some examples of surfaces that are perpendicular that you interact with in your daily life?
- Label the following objects as two-dimensional (2-D) or three-dimensional (3-D). Draw an example of each of these objects.
    - rectangle
    - square
    - sphere
    - circle

- triangle
- pyramid

Units and conversations

- What is the mathematical symbol for:
  - greater than
  - less than
  - equal to

- What is the abbreviation for millimeter? centimeter? kilometer?

- Pick a unit scale that would be appropriate for measuring each of the following (mm, cm, m, or km). Estimate (roughly) the width of each.
  - your foot
  - the building you live in
  - the city of Saskatoon
  - your thumbnail
  - the width of an eyelash
  - the diameter of grains of sand

- What is the scientific notation in metres (m) for each of the following:
  - 10,000 cm
  - 100 m
  - 0.0001 km
  - 3,300 mm
  - 0.00051 cm

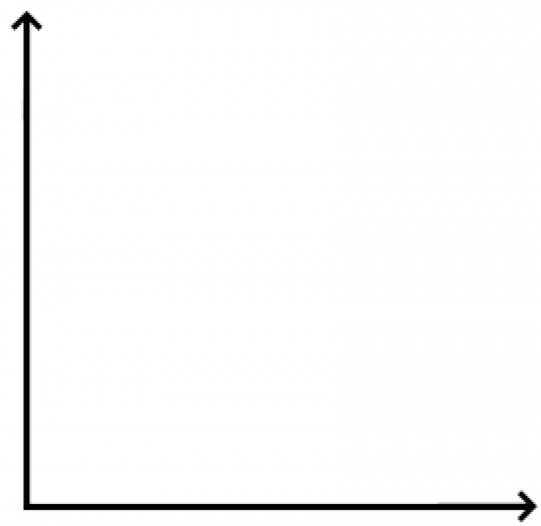
- convert each of the following into metres (m):
  - 10 km
  - 1000 cm

- 1 mm

Graphing and graph interpretation practice

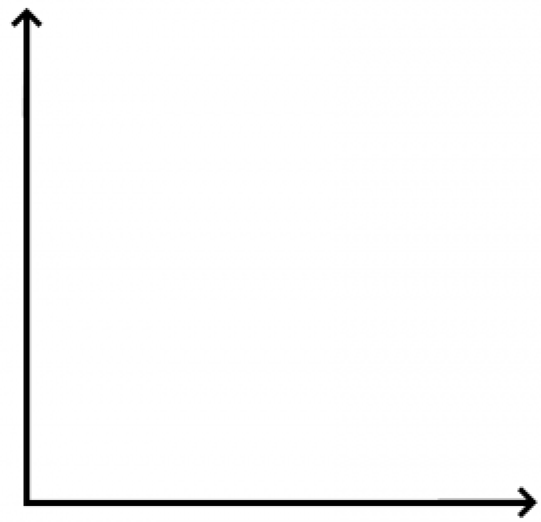
- Calculate the average (mean) of the following numbers:
  - 2, 10, 5, 6

- Draw a graph showing the months of the year on the x axis, and the average number of steps per day you walk per day in each month on the y axis (you can get steps data directly from your cell phone health application). Alternatively, you could estimate your average steps per day for each month at three levels: high, medium, and low. Don't forget to add a legend and labels for your axes, and units for the y axis. Note: *If you aren't sure which axis is the x-axis, and which is the y-axis, check on Wikipedia.*



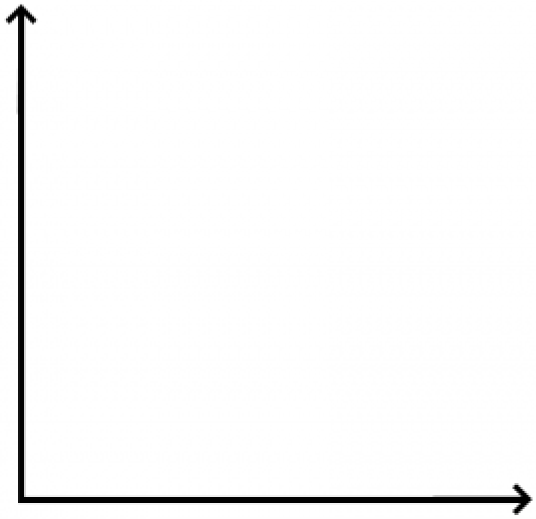
  - What does the graph tell you about your walking patterns seasonally?

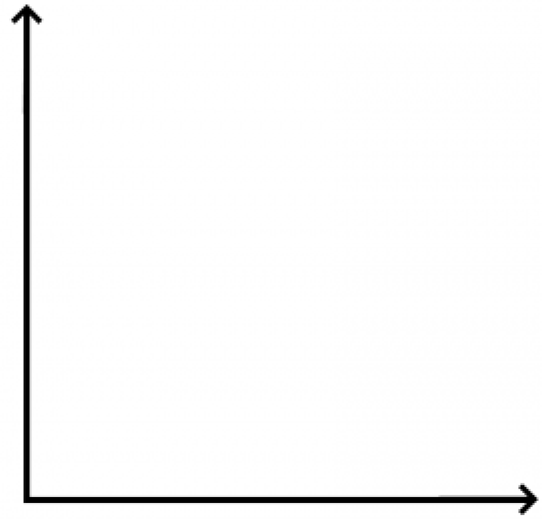
- Look up the average monthly temperature data for Saskatoon on Wikipedia, Graph the average monthly temperature (y-axis) against the month.

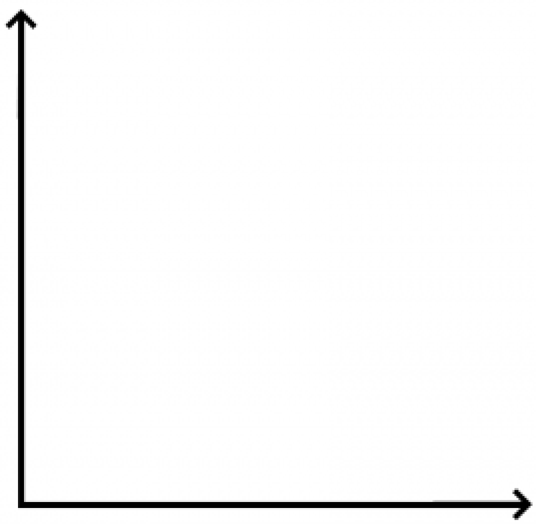


    - What is the pattern of this graph? Is there a relationship between this and your walking patterns over the course of a year?

- Have a look at this [illustration comparing energy use] in households across Canada. Create an x-y graph representing the data in the illustration. Note: *there are a few different ways you could plot this data, I have provided three x-y graphs so you can try plotting the data in different ways*. How does the plot you make influence how you interpret the data in your graph?







Appendix IV. Geography

It is helpful to review some key concepts from high school geography to prepare for this course. These are concepts that are generally covered in schools in Saskatchewan in Grade 10 science class (or earlier). This appendix contains learning outcomes, vocabulary, and review questions in geography.

Note that this appendix is not intended to re-teach you high school geography; it provides guidance on aspects of high school geography that will be useful as background for this introductory physical geology course. If you are struggling with these concepts please approach your instructor to chat about other resources to help you.

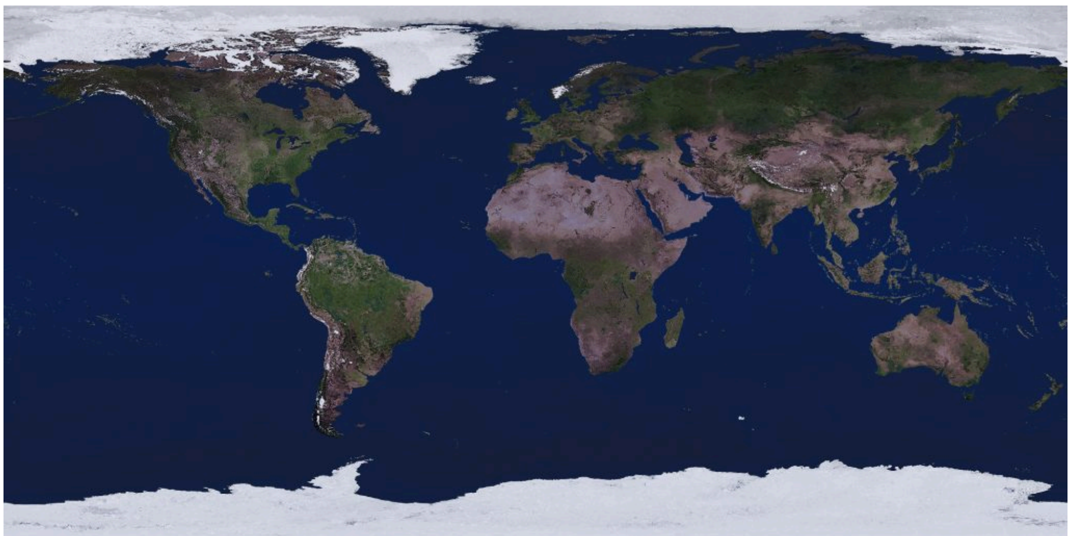


***Figure AIV-1** | Image of Earth from space.* Source: NASA, *public domain.* *view source*

AIV-1. Outcomes

After reviewing this appendix the learner should be able to:

- Define selected key geographic terms (provided in the vocabulary list)
- find the locations of the following on a map and on an image of the Earth:
    - the continents
    - notable countries (listed below)
    - the Canadian provinces and territories
    - notable US states (listed below)
    - notable water bodies (listed below)
    - notable mountain chains (listed below)

AIV-2. Vocabulary

Review this list of vocabulary. Try to define each on out loud, and create a sentence using each word in context. You may look them up on Wikipedia if you need help remembering or defining these terms.

- continent
- country
- border
- city
- province
- state
- region
- map
- latitude
- longitude
- cosmopolitan
- mountain chain
- river
- stream
- current
- wave
- glacier
- ocean
- sea
- bay
- lake
- cloud
- atmosphere
- altitude
- rainbow
- rain
- raindrop
- valley
- hill
- cave
- cavern
- island
- shore
- desert
- slope
- topography
- depth
- shallow
- deep
- elevation
- plain
- political map

- equator
- globe
- inland
- location
- Eastern
- Western
- Northern
- Southern
- pole
- North Pole
- South Pole
- Polar ice cap
- tide
- The Sun
- The Moon
- Mars
- star
- planet
- solar
- lunar
- wind

AIV-3. Review Questions

1a. Using a political map of the world, learn or review the locations of the countries and/or regions in the list below.

- India
- Iceland
- China
- Canada
- USA
- Mexico
- Japan
- Indonesia
- Nepal
- New Zealand
- Australia
- Equador
- Peru
- Belize
- Chile
- Brazil
- Ireland
- Iran
- Norway
- Sweden

- England
- Scotland
- Spain
- the Democratic Republic of Congo
- Kenya
- South Africa
- Egypt
- Caribbean
- Greenland
- Britain
- Europe
- Asia
- North America
- South America
- Africa
- Scandinavia
- Galapagos Islands
- Bering Strait

1b. Once you have found each country, test yourself by finding the location of each country again on an image of the Earth without border and country labels (Figure AIV-1).

2a. Using a political map of the USA, learn the locations of the US states and regions in the list below.

- Hawaii
- Alaska
- California
- Oregon
- Washington
- Wyoming
- Idaho
- Nevada
- Arizona
- Florida
- Baja California (Mexico)
- Hawaiian island chain
- Aleutian islands

2b. Once you have found each state, test yourself by finding the location of each state again on an image of the Earth without border and country labels (Figure AIV-1).

Figure AIV-2 *| Political Map of Canada. Source: Wikimedia users "E Pluribus Anthony, AThing, Heqs, Cogito ergo sumo" (2006) Public Domain, based on basemap from Atlas of Canada.* view source.

3a. Using a political map of Canada (Figure AIV-2) learn the locations of the 10 Canadian provinces (BC, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick, Nova Scotia, Newfoundland and Labrador, and PEI) and 3 territories (Yukon Territory, Northwest Territories, Nunavut Territory).

3b. Once you have found each province, test yourself by finding the location of each province again on an image of the Earth without border and country labels (Figure AIV-1).

3c. Locate the following regions/places on a map of Canada. Use Google Maps or Google Earth to locate the places if you cannot find them on Figure AIV-2.

- Queen Charlotte Islands
- Vancouver Island
- The maritimes (the maritime provinces – Nova Scotia, Newfoundland, PEI, New Brunswick)
- The prairie provinces (Alberta, Saskatchewan, Manitoba)
- Canadian Arctic Islands
- Vancouver
- Edmonton
- Calgary
- Saskatoon
- Regina
- Winnipeg

- Flin Flon
- Thunder Bay
- Fort McMurray
- Sudbury

4. Using google maps, search for and learn the locations of the following oceans and water bodies:

- Atlantic Ocean
- Pacific Ocean
- Arctic Ocean
- Indian Ocean
- Antarctic Ocean
- Gulf of Mexico
- Mediterranean
- North Sea
- Hudson Bay
- Red Sea
- Mississippi River (USA)
- Fraser River (Canada)
- Saint Lawrence River (Canada)
- The Great Lakes
- The Nile River, Nile Delta (Egypt)
- The Amazon River (Brazil)
- Red Sea
- Gulf of Aden
- Gulf of California

5a. Using google maps, search for and learn the locations of the following mountain chains:

- The Himalayas
- The Andes
- The Rocky Mountains
- The Pyrenees
- The Ural Mountains
- Cascade Mountain Range
- The Appalachian Mountains
- The Teton Mountains
- Zagros Mountains
- The Alps

5b. In which country (or countries) is/are each mountain chain located?

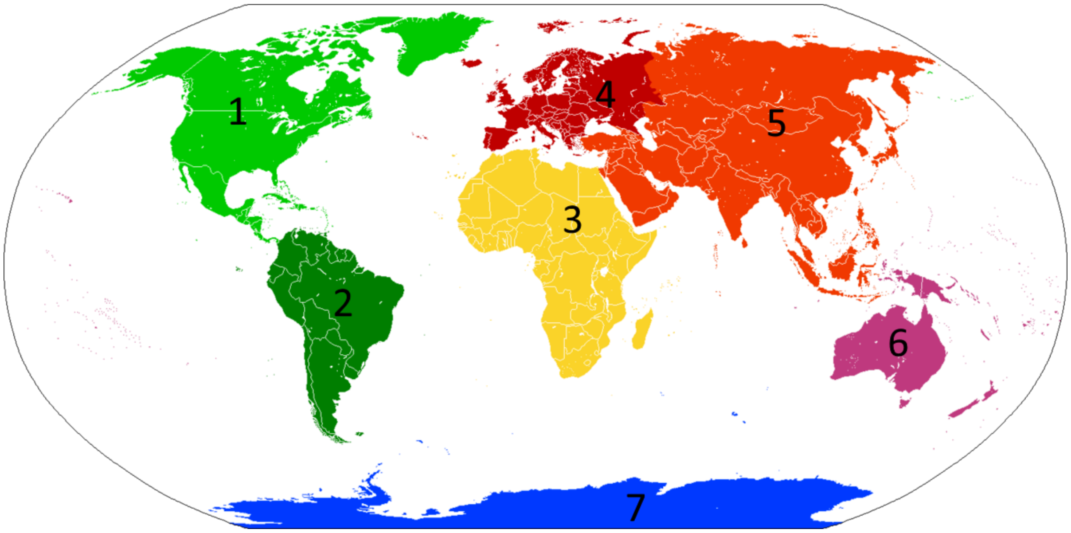


***Figure AIV-3** | The Continents. Source: Joyce McBeth (2019) CC BY-SA 4.0, using basemap Wikimedia "Cogito ergo sumo" (2016) CC BY-SA 3.0. [view source]*

6. Figure AIV-3 shows the continents of the world. Name the continents that correspond to each numbered region on the figure.

Appendix V. Biology

It is helpful to review some key concepts from high school biology to prepare for this course. These are concepts that are generally covered in schools in Saskatchewan in Grade 10 science class (or earlier). This appendix contains outcomes, vocabulary, and review questions in biology.

Note that this appendix is not intended to re-teach you high school biology; it provides guidance on aspects of high school biology that will be useful as background for this introductory physical geology course. If you are struggling with these concepts please approach your instructor to chat about other resources to help you.

AV-1. Outcomes

After reviewing this appendix the learner should be:

- familiar with key vocabulary for biological processes, and be able to use these words in sentences and provide examples of their importance in their everyday life.

AV-2. Vocabulary

Review this list of vocabulary. Try to define each on out loud, and create a sentence using each word in context. You may look these terms up on Wikipedia if you need help remembering the definitions or are not sure what the words mean.

- plant
- animal
- Bacteria
- Archaea
- organism
- organic
- inorganic
- nutrient
- vegetation
- photosynthesis
- biosphere
- virus
- life cycle
- evolution
- endangered
- extinct
- genetics
- DNA
- mutation
- natural selection
- nature

- migrate
- grow / growth
- decay
- toxic
- decompose
- coral
- reef
- swamp
- algae
- mushroom
- forestry
- prairie
- agriculture
- rain forest
- root

AV-3. Review Questions

Work your way through the following review questions. If you are not able to answer the questions on your own, you can look the terms in the question up on Wikipedia to get more background information to help you answer the question.

- What is life? What is the difference between a virus and a living organism?

- What is the biosphere? What kinds of life are found in the biosphere?

- What foods that come from living things do you eat each day?

- How does life affect the environment around it? What are some ways that you affect the environment around you? What are some ways animals and plants affect the world around them?

- What is the course of the oxygen in the Earth's atmosphere?

- How do the kinds of plants you observe in the environment vary over the surface of the Earth? E.g., in the Arctic vs Saskatchewan vs California vs Costa Rica vs Sub-Saharan Africa?

- What is the difference between an endangered and an extinct animal?

Appendix VI. List of Earth Science Careers

The following is a list of Earth science careers. It is not a complete list – if you spot a gap please let me know!

- geologist
  - mineralogist
  - structural geologist
  - geochemist
    - aqueous geochemist
    - low-temperature aqueous geochemist
    - biogeochemist
    - isotope geochemist
    - organic geochemist
  - petroleum geologist
  - geochronologist
  - geomicrobiologist
  - geobiologist
  - palaeontologist
    - palaeobiologist
    - ichnologist
  - hydrogeologist
  - petrologist
    - igneous petrologist
    - metamorphic petrologist
    - sedimentary petrologist
  - sedimentologist
  - volcanologist
  - economic geologist
  - limnologist
- geophysicist
  - tectonophysicist
  - seismologist
- glaciologist
- meteorologist
- hydrologist
- atmospheric chemist
- oceanographer
- geological engineer
  - rock mechanics engineer
  - geotechnical engineer
- environmental engineer

Appendix VII. Vocabulary word origins and mineral names

Many scientific and technical terms we use in the textbook come from Greek or Latin terms. Often these prefixes (which appear at the start of words) or suffixes (which appear at the end of words) are not very intuitive to learn. If you learn some of these terms, you may find it easier to learn scientific vocabulary. Even if you don't know some vocabulary words on an exam, if you notice that the word contains a prefix you know, maybe you can work out its meaning or at least take a better guess at the answer to the question! I've provided examples for each Greek or Latin prefix and suffix in the tables below.

In addition to the prefixes and suffixes in the tables, there are other chemical prefixes and suffixes that may help you when learning mineral names. Note that not all minerals are named for their chemistry, many are named for famous people and mineralogists or for the places where they were first identified (localities). Students often ask me for an easy and consistent way to remember mineral names – sorry, there is no easy answer to that question! I have provided a list of mineral names and their name origins in this appendix.

Greek prefixes and suffixes

Common prefixes are indicated by a "-" following the Greek term, and suffixes are indicated with a "-" preceding the term. Some terms can appear as either prefixes or suffixes in scientific words, this is indicated with a "-" on either side of the term.

prefix or suffix	meaning	examples
an-, a-	not	anhedral, aphanitic, anion
poly-	much/many	polyhedral, polymorph
eu-	good, well	euhedral
-morph-	shape	polymorph, morphological
-hedral, -hedron	having a number of sides	polyhedral, dodecahedron
phaner-	visible	phaneritic
geo-	related to the Earth	geology, geocentric
-lith-	stone	lithology, lithosphere, batholith, megalith
-logy	study of, science of	geology
iso-	equal	isotope, isostatic
pan-	all	Pangaea, panorama
meso-	middle	Mesozoic
palaeo-, paleo-	old, ancient	Palaeozoic, Palaeontology, paleomagnetism
anthro-	human	Anthropocene, anthropogenic
-oid	like, resembling	mineraloid
hydro-	of water	hydrogen, hydrology, hydroxide, hydroxyl
-ox-	sharp, containing oxygen	oxygen, oxide, hydroxyl
chalc-	containing copper	chalcopyrite
Sources: compiled by Joyce M. McBeth (2019) CC-BY 4.0. Etymology – mindat.org, wiktionary.org, and www.lexico.com.		

Latin prefixes and suffixes

prefix or suffix	meaning	examples
ex-	out of, from, beyond	exogenous, example, expert, expand, exoplanet
re-	again, back	redo, reflect
homo-	the same	homogeneous
hetero-	different	heterogeneous
terr-	earth, land	terrestrial, territory
strat-	cover, level	stratigraphy, strata, stratosphere
sub-	under, below, beneath	subduct, submarine, substitute
cat-	down, against, back	cation, catalogue
de-	remove, separate	deform, deconstruct
sulf-, sulph-	containing sulfur	sulfate, sulfide
Sources: compiled by Joyce M. McBeth (2019) CC-BY 4.0. Etymology – mindat.org, wiktionary.org, and www.lexico.com.		

Other prefixes and suffixes

The following prefixes and suffixes are not derived from Latin or Greek roots, and are also found in scientific terminology.

prefix or suffix	meaning	examples
neu-	un-, non-, dis-	neutron, neutral
Sources: compiled by Joyce M. McBeth (2019) CC-BY 4.0. Etymology – mindat.org, wiktionary.org, and www.lexico.com.		

Mineral name origins

Here are some links to webpages that may help you with learning mineral names:

- Wikibooks.org General Chemistry/Naming Substances, and
- the mindat.org database contains stunning photos of minerals and information on how they were named.

The table below presents name origin information for minerals mentioned in the textbook, and a few additional interesting minerals. I have added in a few mnemonics/characteristics to help you remember the minerals and their names. If you think of more mnemonics, or better ones – let me know and I will add them to the table (and give you credit!)

Mineral	Name origin (language)	meaning	Mnemonic/facts
Sulfate minerals			
gypsum	gypsos (Greek)	plaster	gyprock (plasterboard) is made of gypsum
anhydrite	anhydros (Greek)	without water	like gypsum, but it isn't hydrated like gypsum
barite	barus (Greek)	heavy	barium is heavy. It is used in the oilfield to make drilling fluid heavier, and in medicine for gut imaging procedures.
celestite	cœlestis (Greek)	celestial	
Oxide minerals			
hematite	aematitis lithos (Greek)	blood stone	colour is a reddish brown, like dried blood (heme)
magnetite	Magnesia, Greece	named for mineral locality	Magnetite is magnetic
corundum	kuruvinda (Sanskrit)	ruby	
Hydroxide minerals			
limonite	leimṓn (Greek)	meadow	it is a yellowy-brown colour, sort of like rotton lemons
bauxite	Baux (or Beaux) (France)	named for a locality	
Sulfide minerals			
galena	galene (Greek)	lead ore	heavy because it contains lead, and generally forms many shiny, metallic cubes
sphalerite	sphaleros (Greek)	treacherous	sphalerite as a resinous luster, somewhat like amber, it is also often sub-metallic (and often in the same specimen)
chalcopyrite	chalkos, pyrites (Greek)	copper, strike fire	
molybdenite	mólubdos (Greek)	lead (note: molybdenite doesn't contain lead!)	moly lubricant is made from molybdenum, and molybdenite is also soft
pyrite	pyr (Greek)	fire	gold in colour, like a yellow fire
bornite	Ignaz von Born (German)	named for a person	iridescent blue, like it is "born again"
arsenopyrite	arsenikón, pyrites (Greek)	pyrite containing arsenic	
stibnite	stibi (Greek)	antimony	
cinnabar	zinjifrah (Persian)	lost	cinnamon candies are red like cinnabar
Halide minerals			
cryolite	krúos, líthos (Greek)	ice-stone	
fluorite	fluere (Latin)	to flow	the colour of fluorite is often green, like a mountain stream, flowing, fluo
halite	háls (Greek)	sea	the sea is salty, halite forms when you dry out seawater
sylvite	sal digestibus Sylvii, François Sylvius de le Boe (Nederlands)	salts of Sylvius, named for a person	Sylvia Fedoruk was from Saskatchewan, and sylvite is our provincial mineral
Carbonate minerals			

calcite	calx (Latin)	lime	
aragonite	Molina de Aragón (Spain)	named for locality	
magnesite	Magnesia (Greek)	contains magnesium (which is named for a locality)	
dolomite	Déodat (Dieudonné) Guy Silvain Tancrède Gratet de Dolomieu (French)	named for person	
siderite	sideros (Greek)	iron	brownish colour like many iron minerals
malachite	molochitus (Greek)	mallows	brilliant green colour, like a copper roof that has tarnished
azurite	lazhward (Persian)	blue	azure, like a dark blue sky
Phosphate minerals			
apatite	apatáō (Greek)	deceptive	
hydroxyapatite	apatao, hydro- (Greek)	deceptive, water-rich	our teeth are made of this mineral
turquoise	turques (French)	turkish	bright blue with black veins running through it, used in jewellery
Silicate minerals			
isolated tetrahedra minerals			
olivine	ŏlīva (greek)	olive fruit	it is an olive-green colour, and the gem version is called peridotite
garnet	granatum (Latin)	pomegranate	colour is reminiscent of pomegranate, and garnet sounds like pomegranate.
chain silicate minerals			
single-chain silicate			
pyroxene	pyr, xénos (Greek)	fire, stranger	difficult to identify! A dark mineral, found in mafic rocks
double-chain silicate			
amphibole	amphibolos (Greek)	ambiguous	hornblende is a common amphibole mineral, amphiboles are dark minerals
sheet silicate			
mica	micare (Latin)	to flash, or glisten	
biotite	Jean-Baptiste Biot (France)	named for a person	brown, forms large and very flat crystals
muscovite	Muscovia (Latin)	Moscow	clear, forms large and very flat crystals, almost like a window (and it was used that way historically)
kaolinite	Kaoling (Gaoling) (China)	named for a locality	
illite	Illinois (French, from Miami-Illinois Indigenous language)	named for locality	

smectite	smēktis (Greek)	fuller earth	smectite clays swell (hence "fuller earth")
talc	talq (Arabic)	pure	talc is a pure white colour
framework silicate			
feldspar	Feldspat (German)	field spar	
plagioclase	plágios, klásis (Greek)	oblique, breaking fracture	
labradorite	Labrador (Canada)	named for locality	irridescent blue feldspar crystals in a darker background, often used in jewellery, countertops, or building facades
albite	albus (Latin)	white	Albus Dumbledore from Harry Potter has white hair
anothite	an, orthos (Greek)	not right angle, oblique	
orthoclase	orthos (Greek)	right	
microcline	mīkrós, klínein (Greek)	little, incline	
sanidine	sanis, idos (Greek)	little plate, to see	
quartz	querz (German; the etymology is complicated!)	quartz	clear quartz is very common, often a main mineral in sand because it is very hard
amethyst	a-methystos (Greek)	not drunk	forms purple crystals, often found in geodes
citrine	citrina (Latin)	colour as yellow as citron	yellow like a lemon
Native element minerals			
gold	gold (Old English)	yellow	commonly used for wedding rings and other jewellery
copper	kyprios (Greek)	of Cyprus	commonly used in electrical wiring, and in some jewellery
silver	seolfor (Old English)	[meaning unknown/ lost]	commonly used in earrings, rings, and other jewellery, a shiny grey colour.
graphite	graphein (Greek)	to write	pencil leads contain graphite, and you can make graphs with them
diamond	adamas (Greek)	invincible	very hard (but brittle!), used in jewellery especially diamond engagement rings
sulfur / sulphur	sulpur (Latin)	sulfur	yellow, often powdery
platinum	platina (Spanish)	silver (diminutive)	
palladium	Pallas (Latin)	named for an asteroid	
mercury	Mercurius (Latin)	Roman messenger to the gods	liquid metal at room temperatures, used to be used commonly in thermometers
Mineraloids			
opal	possibly upala (Sanskrit); or opalus (Latin)	stone, precious stone; opal	gem quality opal has shiny irridescence in a white or black matrix
Metamorphic minerals			
kyanite	kyanos (Greek)	blue	long blue crystals

sillimanite	Benjamin Silliman, Sr. (USA)	named for person	fine grained white granualar
andalusite	Andalusia region (Spain)	named for locality	
garnet	granatum (Latin)	pomegranate	colour is reminiscent of pomegranate, and garnet sounds like pomegranate.
chlorite	khlōritis (Greek)	green precious stone	chlorine gas is yellow-green, chlorite is a yellow-green mica
amphibole	amphibolos (Greek)	ambiguous	
serpentine	serpens (Latin)	snake	serpentine is a mottled green colour like a snake
biotite	Jean-Baptiste Biot (France)	named for a person	brown, forms large and very flat crystals
muscovite	Muscovia (Latin)	Moscow	clear, forms large and very flat crystals, almost like a window (and it was used that way historically)
glaucophane	glaukos, phainestai (Greek)	sky-blue, to appear	a blue mica
Other minerals (not presently in minerals chapter of textbook)			
forsterite	Adolarius Jacob Forster (German)	named for person	dark green, like a forest
fayalite	Faial Island (Fayal Island) (Portuguese)	named for locality	
goethite	Johann Wolfgang von Goethe (German)	named for person	iron oxide mineral, colour variable, often black, brown, reddish.
spinel	spinella (Latin)	little thorn	
millerite	William Hallowes Miller (Wales)	named for person	forms needle-like crystals
melanterite	melantria (Greek)	ferrous sulfate	
topaz	Topasos Island (Egypt)	named for a locality	
beryl	beryllos (Greek, possibly)	blue-green stone	
borax	bauraq (Arabic)	white	

Sources: compiled by Joyce M. McBeth (2019) CC-BY 4.0. Etymology – mindat.org, wiktionary.org, and www.lexico.com.

Appendix VIII. Flash cards

Flash cards are a popular tool for studying, particularly in vocabulary intensive courses such as geology. Students in introductory geology don't always have experience using flash cards to study. The purpose of this appendix is to offer those students support, to help them find a place to start if they want to use flash cards as a study tool.

This appendix contains examples of flash cards and similar study resources. It also contains examples of ways students use flash cards to study. This appendix is a work in progress!

I am grateful to students in Geology 108/121 Winter Semester 2019 for sharing examples with me of the ways they use flash cards in their studies, and for exploring flash card ideas with me during office hours. Your input and participate are very helpful in helping me to generate this resource to help all my students with their studying.

-Dr McBeth

What you need to prepare flash cards

There are two options for flash cards: paper flash cards or digital flash cards.

Paper:

- Paper flash cards are the classic way to prepare flash cards. They are portable and very versatile.
- Some ideas for how to use paper flash cards: you can use them to test yourself or a friend, you can shuffle your flash card deck and play word association games with them.
- You can either print out flash cards on cardstock or paper using a printer, or purchase index cards and write on them yourself. You'll probably want to get some elastic bands to hold your flash card decks together.
- For printable flash cards – here is a website where you can prepare printable pdf versions of flashcards to print double-sided, or to prepare foldable flashcards: http://www.kitzkikz.com/flashcards/
- If you want to write out your own flash cards, index cards are available from most office supply stores and are cheap ($5 or less for 100 cards) (e.g., the USask Bookstore, Wal-Mart, Amazon, Superstore, Staples, Dollorama). Index cards are made of thicker paper than printer paper so they withstand more aggressive study use!

Digital:

- Quizlet is a popular on-line tool for preparing flash cards and other study materials, they have both webpage and app interfaces for using their tools. https://quizlet.com
    - The materials students prepare on quizlet can be shared with others, made publicly available, or kept private if you prefer not to share them with others.
    - Previous geology 121 students have created numerous decks of flash cards on quizlet that you can check out.
    - This resource is free, it has ads but students can pay for an ad-free version if they want to.
    - Note that I have not vetted any of the slide card decks on Quizlet, and some of these decks were generated for sections where other profs taught the course. It is up to you to determine that the information in the decks is correct and relevant to the course you are taking.
- There are other options that are similar to Quizlet, however some of these charge for access to resources that have questionable value to your learning in this course. Check with me if you think you've found something that may be valuable.

Types of flash cards and ways to use them

Simple vocabulary flash cards

- one side of the flash card has a word, the other side has the definition.
  - you can test yourself using either the definition or the vocab word, for example for a flash card with quartz on one side and 3-D framework silicate on the other:
    - What type of mineral is quartz? It is a 3-D framework silicate mineral.
    - Give an example of a 3-D framework silicate mineral? quartz.
- Example of simple vocabulary flash cards: Flashcards – Common Minerals.
  - This is a link to a pdf example of some vocab flash cards that you can use to study for this course.
  - These cards each have a common mineral on one side, and its corresponding mineral class on the other side.
  - Print this pdf double-sided, then cut them into individual cards.
  - Check that the correct mineral and mineral class/type are matched up for each card after you've cut and printed the flash cards.
- You can also use either side of simple vocabulary flash cards as a seed for ideas for connecting ideas together and discussing a variety of course topics.
  - E.g., using the word quartz as a seed for discussion:
    - What kind of mineral is quartz? What does its crystal structure look like? what are its properties?
    - What are examples of some kinds of rocks that contain quartz? what other minerals do we find in these rocks?
    - What environments do we find quartz in?
    - What happens to quartz when you weather it?
    - Describe the journey of a grain of quartz from its source rock to deposition in the ocean.

Vocabulary flash cards incorporating images

- One side of the flash card has a vocabulary word, the other side has an image illustrating that vocab word.
  - Here is an example of flash cards incorporating images (for these flash cards, you type in your guess for the answer): Igneous Rock Texture Flash Cards
- Students can use the vocab word as a seed idea to draw related images and diagrams to practice the concept and visualize the concept in association with the word.
- Students could use the image side of the card as a seed to discuss related concepts.
- Examples of vocab flash cards with images that students have used in this course:
  - photo of mineral on one side of flash card, name and properties (lustre, cleavage, hardness, etc.) on the other.

Word association using flash cards

- prepare a deck of flash cards with various vocabulary words on them, and nothing on the other side. Mix them upside down on a table, then pick out a few cards at random. Try to create a sentence that makes a connection (or explains the differences) between the words. For example if the words you select include igneous, quartz, and tephra you could make up a sentence such as:

  - Felsic igneous rocks contain the mineral quartz, and when felsic lava is erupted it generates tephra including ash.

Other advice on preparing flash cards

- when practising remembering definitions for vocab words, try to word the definitions in your own words. This helps you to test that what you are practising is connecting the vocab word to its meaning, rather than a memorized definition (that you may not truly understand).
- Try to link definitions to an image in your mind, e.g., vocab word: mafic, definition: igneous rock composition rich in iron and magnesium rich silicate minerals such as pyroxene and olivine, images: pahoehoe, black lava rock.
- you can use coloured pens to highlight different kinds of information on the flash cards, with this approach you can test many different things at once. For example, on your mineral index cards you could add lustre in a different colour, formation environment in another colour, etc.

Flash card ideas from GEOL 108/121 students

- lecture cue words on one side, used for reviewing the topic at a glance.
- use the lecture slides like flash cards, review the slide, then test yourself on what you have retained.
- Use the visual on the slide to help you remember the concepts and link them to Earth's examples. e.g., draw a picture of a stratovolcano on one side of the flash card, then have words associated with stratovolcanoes on the other side.
- something similar to flash cards: a list of terms on a piece of paper, with definitions beside them, with the definitions in a different pen colour from the vocab words. This allows you to selectively not look at the ink colour of the definitions when you look at the vocab word (or vice versa) and then you can test yourself on the definition/vocab word combination.