Please remember that this is only a guide, and is not meant to be fully comprehensive. However, it should provide a good starting point for your studies. If you have questions, please come see me. My office is PS212g, my office phone is 863.6306, my email is BUNDSMI@UVU.EDU, and the class website can be linked to from HTTP://RESEARCH.UVU.EDU/BUNDS. If you have questions as you prepare for the final and you wish to email me, please include ‘GEOL study guide questions’ on the subject line so that I’ll know your email is important.

ABOUT THE FINAL: Remember that the final exam will be comprehensive. About one half to two thirds of the final exam will test your knowledge on material from the earlier portions of the course and the rest will cover new material – material that we have looked at following midterm three. New material comprises Utah’s earthquake hazards, structures and mountains (Ch. 9), mass wasting (Ch. 13), and glaciers (Ch. 18). You are responsible for the corresponding chapters in your textbook. Remember, there is no formal insurance for the final, but you won’t do well if you don’t do the homework. To prepare for the comprehensive portion of the final, use the study guides and questions for the midterms; use the study questions in this study guide to help prepare for the new material that will be on the exam.

The final will take place in the regular classroom at the official, University – scheduled time, which you can find at www.uvu.edu (follow the links: students/class schedules/final exam schedule). Yes, I want you to look up the exam time on your own; think of it as homework! Don’t be late – the final will end at 3:00 pm or when all the people who arrived on time have finished, whichever comes first.

EARTHQUAKE HAZARD IN UTAH

Steep mountains are an indication of active faulting. Geologists look for fault scarps along the mountain front, and elsewhere. Scarps indicate recent (past 1000’s of years) earthquake activity. We looked at a scarp from the Wasatch fault on a field trip to Rock Canyon. Examples from the mouth of Little Cottonwood Canyon (top), and California are shown on the right.

Trenches are dug through fault scarps to identify ancient, buried soil layers broken by past earthquakes. By dating the broken soil layers, we have identified when large earthquakes have struck in the past 7000 years or so along the Wasatch fault.

Using this information, we can forecast the likelihood of a large earthquake occurring in a future period of time (say the next 25 or 50 years). This is like forecasting the likelihood of a large snow storm in Orem based on how often very large storms have struck Orem in the past, and how large the storms have been.

Several important points:

- A large earthquake may (hopefully) result from a fault breaking and sliding along only one segment of the fault’s entire length. For example, UVU is on the Provo segment (Payson to Pt. of the Mtn.) of the Wasatch fault. SLC is on the Salt Lake Segment (Pt of the Mtn. to about the State Capitol).
- The segments of the Wasatch fault are about 40 km long. The amount of movement that has occurred in past earthquakes on the Wasatch fault, as determined from trenching studies, varies from about 1 to 3 meters. Based on the length of the segments of the Wasatch fault and the amount of slip in past earthquakes, it is estimated that a large earthquake on the Wasatch fault would be magnitude 7 to 7.5. An earthquake on more than one segment at once could be M7.8 or even larger, but this is unlikely to happen.
- Large earthquakes strike somewhere along the Wasatch front about every 350 years. A large earthquake strikes on any given segment of the Wasatch fault about every 1200 to 2600 years. The Salt Lake segment last had an earthquake about 1200 years ago, and has had earthquakes about every 1200 years, so it is due. The Provo segment last had a large earthquake about 650 years ago so it is not ‘due.’ However, there are no guarantees based on our current understanding of earthquakes.

Threats posed by earthquakes
ground shaking, liquefaction, landslides, fire and even disease

And don’t forget:
- Most Earthquakes happen at plate boundaries
- Largest are at convergent
- Medium at transform
- Smallest at divergent (normal faults)

**Deformation of the Crust (Structures and Mountains)**

a. Structural geology is the study of deformation of rocks and the Earth, especially the crust
b. Geologic structures are features formed when rocks get deformed (squished, broken).
c. Deformation is the change in shape, rotation or displacement of objects (i.e., rocks, the crust). Most deformation happens at or near plate boundaries.
  i. Extensional deformation occurs when the crust is stretched in a horizontal direction
  ii. Compressional deformation refers to the crust being shortened in a horizontal direction.
  iii. Note that if the crust is extended horizontally, it is shortened (i.e., thinned) vertically; note also that the reverse is true for compressional deformation of the crust.
  iv. Shear deformation (technically ‘simple shear’) refers to shearing like in a deck of cards, or when a square is changed into a parallelogram. Shear deformation is common in and near faults.
d. Brittle vs ductile deformation (we will talk about these ideas in conjunction with earthquakes – its very important with regard to structures and mountain building as well)
  i. Brittle involves breaking – cracks, sliding of pieces past each other. Peanut brittle. Brittle deformation often involves a sudden loss of strength upon breaking.
  ii. Ductile – squishing, smearing, flowing (but as a solid). Silly putty.
  iii. Brittle is promoted by low temperature, rapid deformation. Cold (-196°F) play dough deforms brittlely!
  iv. Ductile is promoted by higher temperature, slow deformation. Room temperature play dough.
  v. Therefore brittle generally happens in upper part of Earth’s crust – down to about 12 to 20 km in most parts of N. America; deformation is generally ductile below that, where temps are >300°c. This is important because earthquakes result from brittle deformation. In some places the crust is cool enough that brittle deformation happens at greater depths, for example at subduction zones.
e. Types of Structures. Geologic structures are shapes and features in rocks formed by deformation. The 3 main types of structures that we discussed are folds, faults and foliations.
  i. Folds
    1) Anticlines - upward arch, oldest rocks in center when eroded; can trap oil
    2) Synclines – downward arch, youngest rocks in center when eroded.
  ii. Faults
    1) Hanging wall vs footwall. In a tunnel dug along an inclined (non-vertical) fault, you stand on the footwall, hang your lantern on the hanging wall.
    2) Normal fault – hanging wall down. The Wasatch fault is an active normal fault. From in response to horizontal extension or stretching of the Earth’s crust, and are most common at divergent plate boundaries.
    3) Thrust or Reverse faults – hanging wall up; most slope or dip shallowly and are called thrust faults. Form in response to horizontal shortening or compression of the Earth’s crust and are most common at convergent plate boundaries.
    4) Strike slip faults – are right-lateral or left-lateral. The San Andreas is _____ - lateral. Most common at transform plate boundaries.
  iii. Foliations – we talked about these in conjunction with metamorphism. Note that foliations reflect ductile deformation, as you should expect in a rock undergoing metamorphism due to heat.

. Mountains

The crust floats (in a vertical sense) on the mantle. This concept is known as isostacy. Major mountains occur where the crust is thicker (or lighter) than in most places. The highest mountains and thickest crust in the world are both at the Himalaya, where India is colliding with Asia.

Mountain remnants (i.e., erosional remnant mountains) are left after extensive erosion of thick crust. As tops of mountains are eroded, floating crust rises, just as ice does in water, or a raft when weight is removed. This is an important point, partly because it is a major reason that rocks that formed deep in the crust (e.g., plutons and metamorphic rocks) are exhumed to the surface where we can see them

There are two true major mountain belts in the world, they lie at convergent plate boundaries where continental crust is involved:

1) West coast of the Americas, from Alaska to Tierra del Fuego (the tip of S. America)
2) Alps (Europe) through Himalayas, China.

Mountains (including smaller ranges) can be divided into three categories, compressional, extensional and erosional remnant. We discussed these three types, including examples of each in class.
**Basin and Range** mountain ranges – know about it: where it is; it results from crustal extension; horsts and grabens; normal faults, Wasatch Mtns., etc.

**Oceans** exist over ocean crust, which is more dense than continental crust and consequently floats ‘lower.’ Mid-ocean ridges exist because younger oceanic crust is relatively young and warm, which causes it to be less dense and float better. Know this.

**GLACIERS AND GLACIATION**

1. **What** – glacial ice, recrystallized snow, flowing under their own weight
2. 2.15% of Earth’s surface water
4. **When** – Multiple episodes of widespread glaciation during Pleistocene time (the past 1.6 million years or so) also periods of glaciation through much of Earth’s history. Last ice age peaked about 20,000 to 30,000 years ago and ended about 10,000 to 12,000 years ago. But Earth has been non-glaciated for most of its history.
5. **How**: Glacial budget, zones of accumulation and wastage (melting), and flow from accumulation zone to wastage zone. Accumulation leads to thickness, weight, recrystallization into glacial ice, and flow.

6. **Types**:
   a. **Valley/Alpine**. In mountain valleys, flow downhill. Up to 100 km long, kilometers wide, couple-100 meters thick. Think of the slides.
   b. **Continental (also known as ice sheets)**: much bigger, hundreds, thousands of square miles/kilometers, 100’s of meters, even kilometers (miles) thick/deep. Thickest at zones of accumulation, slowly flow outwards to zones of wastage under their own weight, just as some thick, whipped honey will slowly spread across a plate.

7. **Movement**: Glaciers move downhill (Alpine glaciers) by sliding and flow; Continental glaciers spread outwards due to their weight. Valley glaciers move inches to 10’s of yards per day. Can surge and move even faster – A huge valley glacier in Alaska, the Bering Glacier, moved 1 mile in 3 weeks! Glaciers retreat by melting, not flowing uphill.

8. Glaciers create erosional and depositional **landforms** because they erode and deposit large amounts of material. They carry rocks in their base and sides, thus are like giant sandpaper and can do lots of erosion.

9. **Erosional landforms created by Alpine/Valley glaciers**: cirques, arêtes, horns, U shaped valleys, hanging valleys. Can also polish rock surfaces and leave grooves that show the movement direction. Material is super poorly sorted, from house-sized to flour-sized particles. Glaciers make **U-shaped valleys** (Big Cottonwood is classically V-shaped at bottom, U-shaped above Mill-D and Reynolds Flat). Know this stuff.

10. **Depositional landforms created by glaciers**. Glaciers deposit **glacial till in moraines**. Moraines are the eroded material under, in and along a glacier, both while in transport (active glacier) and when left behind after glacier melts. **Basal, lateral, medial, terminal, recessional**. Sediment in a moraine is called **till**. Know this stuff.

11. Causes of glaciation: Glaciation has 3 time periods to it. Over Earth history, there have been several periods millions or so years long during which glaciers came and went repeatedly (i.e., multiple ice ages). During these periods, it looks like there were 100,000 year time spans when glaciers were more abundant, but during those periods glaciers came and went also. So glaciation has a millions of years cycle to it, a 100,000 year cycle to it, and probably a thousands or 20,000 year cycle to it.
   a. **Long term**, millions of years (to 100’s of millions of years): Probably caused by plate tectonics. Different groupings of the plates create different ocean circulation patterns, which may alter climate. And when a continent is near a pole, it is more likely to be glaciated.
   b. **Intermediate term**, 100,000 years: Milankovich Cycle. Variations in the Earth’s orbit (tilt of the Earth’s axis, orbital eccentricity, and equinox precession) conspire every ~100,000 years to make the seasons significantly more pronounced.
c. **Short term**, thousands of years: unclear. Possibly volcanoes or perhaps changes in Sun activity. Volcanoes release CO₂ gas, which is a greenhouse gas and can make the Earth warmer, but they also can release a lot of ash/dust into the upper atmosphere, which blocks the Sun and can cause cooling. Humans are putting approximately 7 billion tons of CO₂ into the atmosphere each year, and have raised its concentration in the atmosphere to much higher levels than existed at the ends of at least the last 4 ice ages, and are on track to raise the level to higher than its been in the past 60 million years.

12. Some specifics: Last ice age peaked about 20,000 to 30,000 years ago and ended about 10,000 to 12,000 years ago. During this last ice age there were large lakes in the Basin and Range – Lake Lahontan in Nevada and Lake Bonneville in Utah. Alpine glaciers were present in the high Wasatch mountains and reached the valleys at least at the mouth of Little Cottonwood canyon.

**MASS WASTING**

**Definition** – downward movement (erosion) of large volumes of rock/sediment at once. ‘Landslides.’

**Basic underlying ideas.** Plate tectonics, which fundamentally is driven by the Earth’s internal heat, causes the land surface to go up in places (i.e., mountain building). Erosion and mass wasting inexorably tear down the mountains and hills.

**Expensive and dangerous.** $1.5 billion, 25 – 50 human deaths each year in U.S. alone. Most problematic in West (because it’s mountainous here).

A. Slide Types; classified primarily based on speed of movement, and also based on how intact the material is.
   1. Creep – slow downslope movement of regolith and soil. Potentially expensive but easy to get out of the way of.
   2. Slumps. curved base, fairly intact, common moderate sized slides etc
   3. Flows. rock liquefies, pours down, often down canyons. can travel far and fast (debris flows, lahars and mudflows all fall in this category)
   4. Falls and rock avalanches. just what it says. rock falls. it hurts if it hits you. happens all the time under cliffs

B. Controlling Factors
   - driving forces: gravity (weight), slope angle
   - resisting forces: rock strength, toe, vegetation (indirectly)
   - a landslide can result from a change the balance between these forces.
     - Addition of water, usually from precipitation or snow melt, but occasionally from irrigation.
     - Removal of the toe - key to many small human-caused slides.
     - Strength of ground is crucial - weak rocks and soils just can’t make steep slopes; this is the underlying problem in Sherwood Hills and Pleasant Grove, where the clay rich, very weak Manning Canyon shale underlies some houses. *Clays are weak!* However, strong rocks – such as crystalline rocks like granite – can support steep slopes, even cliffs (think of Yosemite, Zion).
     - Fire – forest fires can greatly increase the risk of debris flows because they change the soil so water can’t soak in easily (so flash floods and debris flows result instead) and they kill plants that normally help hold soil and sediment in place.

C. Mitigation (i.e., prevention, risk reduction)
   1. Build Caison pilings – reinforced concrete pillars set into hopefully solid material beneath the glide plane of a slump, hopefully hold the slump in place. Only has a chance of working on small slumps.
   2. Keep water off of potential slump.
   3. Steel walls held in place by cables inserted into holes drilled into hillside and bolted to hopefully solid rock. Marginally effective.
   4. Vegetation – maintaining existing plants and seeding/planting new ones can be helpful.

D. Snow avalanches
   1. Slab avalanches are basically just block slides
      - Stability vs. occurrence of avalanches in cold conditions is the constant competition between addition of weight from snow added by storms (which can cause avalanches) and metamorphism from underlying layers of snow (e.g., layers left by earlier storms), which strengthens the snowpack and inhibits avalanches. When weight is added faster than the snow underneath can get stronger, avalanches occur. This is why most slab avalanches occur during or within a few days of large storms. However, snow is light weight, so adding body weight can make the difference and cause a slide. More rarely, metamorphism can weaken underlying snow.
      - Slab avalanches commonly travel at 60 to 80 mph; can obtain 100 – 200 mph speeds!
   2. Wet snow slides are basically just flows. They happen when a thick snowpack starts to melt. Common in the spring.
   3. Approximately 10,000 avalanches occur each year in the Wasatch Mtns. About 100 are
Study questions. Note that ‘insurance’ is not available for the final. However, if you don’t do well on the final but you do these questions (on a separate sheet of paper), plus the questions from the book and web (listed on course syllabus) and turn them into me, I will take your work into account when determining your grade.

1. Draw a left-lateral strike-slip fault offsetting a road, and label it with motion arrows.
2. At what type of plate boundary are strike-slip faults common? Why? Give an example of a well-known strike-slip fault.
3. Draw and label a normal fault.
4. At what type of plate boundary are normal faults common? Why? Give an example of a well-known normal fault.
5. Draw and label a thrust fault.
6. Do faults form as a result of brittle or ductile deformation?
7. What kind of fold can trap oil?
8. Is the crust under the Himalaya mountains thicker than the crust under Florida? What is the rational for your answer?
9. If a 5 mile thick layer of rock were placed over the entire state of Florida, what would happen to the level of the current ground surface of Florida over time (i.e., would it perhaps rise or sink)?
10. Why is the ocean shallower over mid-ocean ridges compared to most of the rest of the oceans (i.e., why are there ridges at divergent plate boundaries/sea-floor spreading centers)?
11. Where is the Basin and Range?
12. What type of faults are present in the Basin and Range and are responsible for its landscape?
13. What direction is Sacramento California slowly moving relative to Park City as a result of the ongoing deformation in the Basin and Range (note that the San Andreas fault is west of Sacramento)?
14. Draw a side-view picture of the Wasatch Mtns, Utah Valley and the Lake Mountains, which are the mountains on the west side of Utah Valley and the upper crust under them. Show how faulting has formed the two mountains ranges and the valley. Label the hanging and foot walls as well as the movement on the faults on the picture.
15. What is liquifaction, what characteristics of the ground make it likely to happen, and where are these characteristics prevalent in Utah Valley and/or the Salt Lake Valley?
16. What information do geologists use to estimate the possible magnitude of future large earthquakes on the Wasatch fault?
17. Draw and label an active normal fault.
18. What information do geologists use to estimate the likelihood of a future earthquake on the Wasatch fault?
19. How do geologists obtain information on past earthquakes on hazardous faults in Utah?
20. What are the four crucial factors that combine to control how much damage occurs to a building as a result of an earthquake?
21. What kind of plate boundary produces the largest earthquakes?
22. What is the largest magnitude earthquake likely to occur at a transform plate boundary?
23. What is the largest magnitude earthquake likely to occur at a divergent plate boundary?
24. When the ‘big one’ strikes Utah, what magnitude will it probably be? On what basis is the estimate of the magnitude of a big one on the Wasatch fault made?
25. What is the difference between a glacier and a snowfield?
26. Why do glaciers flow?
27. Explain how ice flow, the zone of accumulation and the zone of wastage interact in a mountain glacier.
28. How is it that glaciers retreat? Do they flow back up their valleys?
29. How do medial moraines form?
30. The next time you drive up Big Cottonwood canyon, what two things can you look for to be able to tell how far down the canyon the glacier moved in the last ice age? (Hints: how do glacially carved valleys typically differ from river-cut valleys? And what do glaciers leave behind at their point of farthest advance?)
31. What might cause the climate, and thus the amount of glaciation on Earth, to vary every 100,000 years? (the answer to this is in the study guide above and in the text)
32. Explain how in the geologic past there could have been glaciers in tropical India at the same time parts of Africa at the same latitude (north-south position) were a desert?
33. When was the peak of the last ice age?
34. Approximately when did the last ice age end in Utah?
35. Be sure that you are familiar with erosional and depositional landforms created by glaciers.
36. What major feature (not a glacier) that is not here today was present in Utah Valley during the last ice age?
37. When was Lake Bonneville present in Utah?
38. What are the four main types of mass wasting?
39. What forces resist mass wasting?
40. What forces cause mass wasting?
41. How do humans often affect mass wasting (be specific)?
42. How do forest fires contribute to mass wasting, and which type of mass wasting commonly results after forest fires?
43. Using a sketch and words, explain what a slump is.
44. What types of mass wasting move quickly enough to easily be a threat to people’s lives and health?
45. Sketch a slump.
46. Describe a debris flow. Where did very powerful and damaging debris flow(s) occur recently?
47. Explain how a landslide that fills canyon can create a major flood hazard. Note that such a problem occurred in Spanish Fark Canyon in 1983.
48. Draw a side view sketch of the ground beneath your house that shows the unsaturated zone, water table, and saturated zone. Label the features and assume that the water table is at a depth of 10 meters (11 yards in old money).
49. What benefit(s) (i.e., resource) can an aquifer provide to people, and at a minimum, what physical properties should a good aquifer possess?