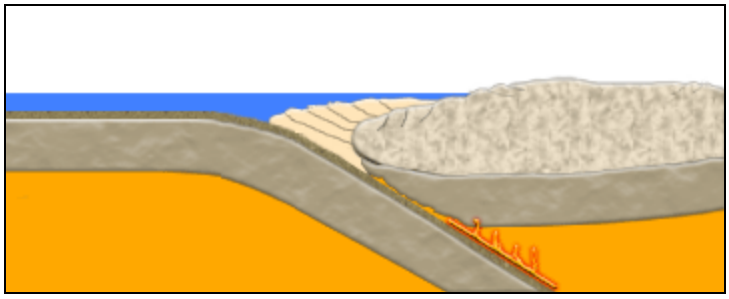
Mountain Building Web Activity -- Predictions (Multiple-Choice)

Instructions: *The following questions are designed to assess students' knowledge of mountain building processes before interacting with a mountain building web activity. Within each set of multiple choice questions, the first part will ask you to choose <u>one</u> answer that best fits your **prediction** about mountain building processes. The second multiple choice question will ask you to choose <u>one</u> statement that best explains your **reasoning** for the prediction you made in the first part.*

Animation #1: How do plate tectonics build mountains?



1.1.a. Which of the following is the <u>most reasonable estimate</u> for how long it will take for a mountain range to form in the continental crust at this new convergent boundary?

- ❍ 700 years
- ❍ 6,000 years
- ❍ 100,000 years
- ❍ 20 million years
- ❍ 2 billion years
- ❍ 4.6 billion years

1.1.b. The reason for my answer is because:

- ❍ mountains formed during the formation of Earth
- ❍ mountains form and change at rates of millimeters per year
- ❍ it takes that long for volcanoes to form the entire mountain chain
- ❍ enough time must pass to allow sediments to accumulate and form a mountain
- ❍ the subducting plate must have sufficient time to push the mountain up through the other plate

1.2.a. What will happen to the elevation of the continental crust <u>above</u> sea level during subduction of the oceanic crust and continental collision?

The elevation of the continental crust will:

- ❍ increase
- ❍ decrease
- ❍ stay the same

1.2.b. The reason for my answer is because:

- ❍ the subducting oceanic crust will push the continental crust upwards
- ❍ the pressure of subduction will pull the continental crust downwards
- ❍ the subducting oceanic plate scrapes off the bottom of the mountain range
- ❍ magma intruding into the crust will add height, but will also increase its density
- ❍ tectonic stresses during subduction and collision will uplift the continental crust

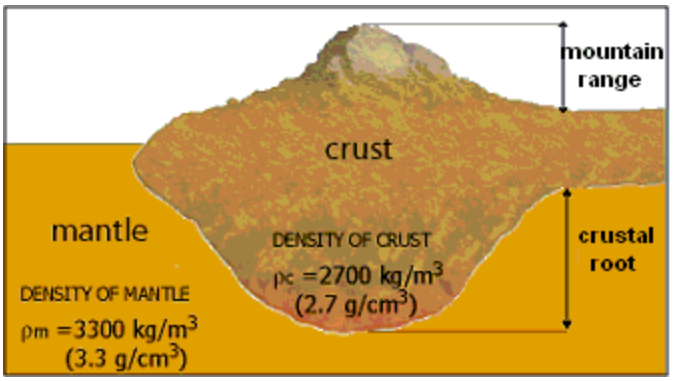
1.3.a. What will happen to the continental crust <u>below</u> a mountain belt during subduction of the oceanic crust and continental collision?

- ❍ The continental crust will become thinner below the surface
- ❍ The continental crust will become thicker below the surface
- ❍ The continental crust below Earth's surface will not be affected

1.3.b. The reason for my answer is because:

- ❍ the base of the continental crust is not related to the mountain belt
- ❍ crust moves up into the mountain belt, leaving less crust below the surface
- ❍ the oceanic plate rubs away the bottom of the mountain range as it subducts
- ❍ continental crust thickens downwards as well as upwards when it is compressed

Animation #2: How are mountain ranges supported from below?



2.1.a. The position of Earth's crust as it floats upon the mantle depends on **isostasy**. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.

Using average density of the crust (2700 kg/m^3) and mantle (3300 kg/m^3) on Earth, what will happen to the crustal root as the mountain range elevation increases?

The crustal root will:

- ❍ move farther down into the mantle
- ❍ move up within the mantle
- ❍ not change size or position

2.1.b. The reason for my answer is because:

- ❍ the crustal root will move up with the mountain since they are connected
- ❍ higher mountains require a thicker crustal root to compensate for the added weight
- ❍ the crustal root is below the surface and is not affected by the mountain range above it
- ❍ the crust will need more support, and the mantle provides better support than the crust

2.2.a. When material is removed from the top of a mountain range by erosion (elevation decreases), what will happen to the position of the crustal root within the mantle?

The crustal root will:

- ❍ move farther down into the mantle
- ❍ move up within the mantle
- ❍ not change size or position

2.2.b. The reason for my answer is because:

- ❍ the mountain range will lose mass and become more buoyant
- ❍ erosion only affects the top of the mountain, not the crustal root
- ❍ the root will not change since the mountain is no longer growing
- ❍ the root must move downward as the mountain elevation decreases
- ❍ the position will not be affected because the density has not changed

2.3.a. On Earth, continental crust has an average density of about 2700 kg/m^3. If the crustal density could hypothetically be increased, what would likely happen to the position of the continental crust within the mantle?

The continental crust would:

- ❍ float higher in the mantle
- ❍ sink lower in the mantle
- ❍ remain in the same position

2.3.b. The reason for my answer is because:

- ❍ the upward buoyancy forces will increase as crustal density increases
- ❍ the downward gravitational forces will increase as crustal density increases
- ❍ buoyancy forces and gravitational forces will become equal when crustal density increases

2.4.a. On Earth, the mantle has an average density of about 3300 kg/m^3. If the mantle density could hypothetically be increased, what would likely happen to the position of the crustal root?

The crustal root would:

- ❍ move farther down into the mantle
- ❍ move up within the mantle
- ❍ not change size or position

2.4.b. The reason for my answer is because:

- ❍ the buoyancy force pushing up on the crust will increase
- ❍ the root density must increase as the mantle density increases
- ❍ the crust will become less dense as the mantle density increases
- ❍ the mantle is already denser than the crust, so further increases will have no effect

Animation #3: What processes shape and change mountains over time?

3.1.a. How will the **relief** of a region (the difference between the highest and lowest elevations) affect erosion rates?

STEEP RELIEF

GRADUAL RELIEF

- Regions with gradual relief will have faster erosion rates
- Regions with steep relief will have faster erosion rates
- Relief will have no effect on erosion rates

3.1.b. The reason for my answer is because:

- The force of gravity is greater closer to the center of Earth
- Weathering has a greater effect in the plains than in mountainous regions
- Erosion is dependent on temperature and moisture rather than elevation differences
- Water and ice move faster on steeper slopes, increasing its ability to erode and transport sediment

3.2.a. Which climate would you predict will have the <u>lowest</u> erosion rates in regions with steep relief?

GLACIAL

TEMPERATE

TROPICAL

- Glacial (alpine glaciers)
- Temperate (mild climate and moderate precipitation)
- Tropical (warm, humid climate and heavy precipitation)
- Climate will have no effect on erosion rates

3.2.b. The reason for my answer is because:

- ❍ The climate is not cold enough to have high erosion rates
- ❍ Lowest amount of glaciation, landslides and surface runoff
- ❍ Water is frozen in place and cannot erode underlying bedrock
- ❍ All of these regions will erode equally since they have the same relief

3.3.a. Which climate would you predict will have the highest erosion rates in regions with steep relief?

- ❍ Glacial (alpine glaciers)
- ❍ Temperate (mild climate and moderate precipitation)
- ❍ Tropical (warm, humid climate and heavy precipitation)
- ❍ Climate will have no effect on erosion rates

3.3.b. The reason for my answer is because:

- ❍ All of these regions have the same relief
- ❍ Weathering is affected by moisture and temperature
- ❍ Moving ice and water erode and transport sediments
- ❍ The most rainfall is available to contribute to erosion

3.4.a. How will **isostasy** affect the average elevation of mountains over time as mass is removed from the mountain range by erosion?

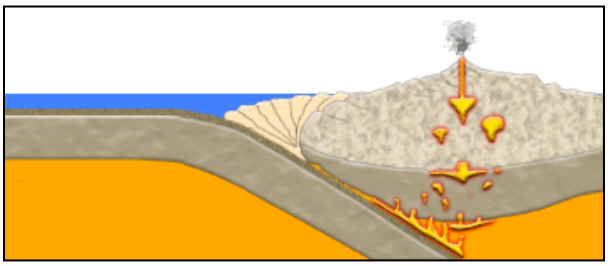
Isostasy will:

- ❍ Not have an effect on average elevation over time
- ❍ Slow the rate at which average elevation decreases over time
- ❍ Speed up the rate at which average elevation decreases over time
- ❍ Increase the average elevation of the mountainous region over time

3.4.b. The reason for my answer is because:

- ❍ The mantle density will increase and push the mountains upward
- ❍ As material is eroded away, the elevation will lower at an increasing rate
- ❍ Movement of the crustal root will uplift the mountain range to greater average elevation
- ❍ As the mountain belt gets smaller, isostasy will push the mountain up to maintain equilibrium

Animation #4: How can rocks formed deep within the crust come to the surface?



4.1.a. Which processes will be responsible for exposing intrusive igneous and metamorphic rocks, which form deep within the crust, at the surface of the mountain range?

Deep crustal rocks will be exposed at the surface by:

- ❍ Melting and cooling of magma
- ❍ Erosion, crustal shortening, and uplift
- ❍ Decrease in density of the rocks after they form
- ❍ Erosion down to the depth where the rocks originated

4.1.b. The reason for my answer is because:

- ❍ Deep crust uplifts as upper crustal layers are removed
- ❍ Rocks can buoyantly rise through the surrounding crust
- ❍ Deep crustal rocks erupt onto the surface through volcanoes
- ❍ Rocks formed in Earth's interior are exposed only in deep canyons

4.2.a. What will happen to the mountain range such as the one shown above as the subduction of the oceanic plate continues?

- ❍ The mountain range will erode down until it reaches the average thickness of the crust
- ❍ Rock material from the deep crust will move up within the mountain range
- ❍ The average elevation of the mountain range will approximately double
- ❍ The mountain range will increase infinitely in elevation

4.2.b. The reason for my answer is because:

- ❍ Convergence of plates will lead to unlimited mountain growth
- ❍ Volcanic eruptions will replace all of the material lost to erosion
- ❍ Subduction can only build mountains for so long before they erode away
- ❍ Crustal shortening will squeeze crust up from below as erosion removes material

4.3.a. What will eventually happen to the mountain range once the subduction zone is no longer active?

- ❍ The mountain range will slowly erode down until it reaches the average thickness of the crust
- ❍ The average elevation of the mountain range will approximately double before growth stops
- ❍ The average elevation of the mountain range will rapidly decrease
- ❍ The mountain range will continually increase in elevation

4.3.b. The reason for my answer is because:

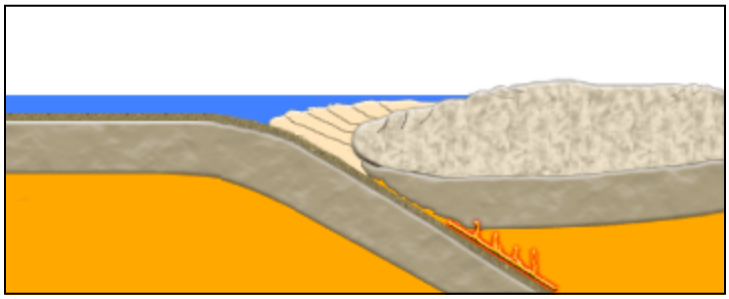
- ❍ When subduction ceases, mountain uplift will stop
- ❍ Erosion rates will exceed isostatic and tectonic uplift rates
- ❍ Once mountain growth ceases, erosion processes will begin
- ❍ Isostatic uplift will completely compensate for loss due to erosion
- ❍ Rock material will stay where it is because of lack of heat and pressure
- ❍ When the subduction zone becomes inactive, elevation will no longer change

OBSERVATIONS POST-TEST IS IDENTICAL TO THE PREDICTIONS PRE-TEST. THE ONLY DIFFERENCE IS THE TENSE USED IN THE QUESTIONS.

Mountain Building Web Activity -- Predictions (Essay)

Instructions: *The following questions are designed to assess students' knowledge of mountain building processes before interacting with a mountain building web activity. Please answer each short essay question with your* ***predictions*** *about mountain building processes. To earn maximum points for your answer, please be sure to include each of the bulleted points as part of your answer, and explain your reasoning to the best of your ability. Your goal should be to explain your thoughts as briefly and clearly as possible.*

Animation #1: How do plate tectonics build mountains?

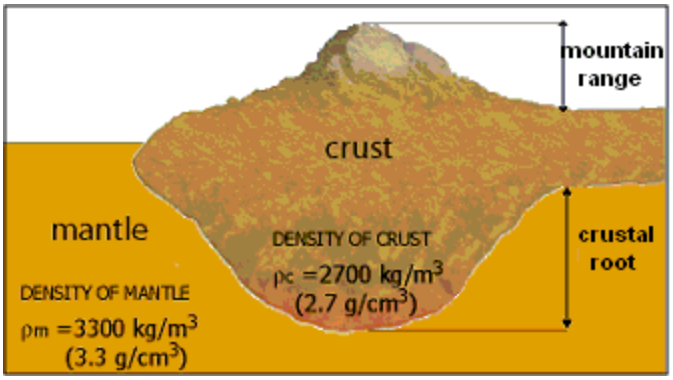


How will the elevation of the crust above sea level and thickness of the crust below the mountain range be affected by continued subduction of the oceanic plate and collision of a second continent?

Be sure to include in your answer:

- Whether the elevation of the crust above sea level will increase, decrease, or stay the same
- Whether the thickness of the crust below the mountain range will become thicker, become thinner, or remain the same
- Your reasoning for **both** of your predictions about the continental crust

Animation #2: How are mountain ranges supported from below?



The position of Earth's crust as it floats upon the mantle depends on **isostasy**. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.

How will the position of Earth's crust floating in the mantle be affected by changes in mountain height or changes in crustal density? Specifically, a) what will happen to the size or position of the crustal root if the height of the mountain range is decreased by erosion?, and b) how would the position of the crust be affected if the crustal density could increase to greater than 2700 kg/m^3?

Be sure to include in your answer:

- Whether the crustal root will move farther down into the mantle, move up within the mantle, or remain the same size/position when the height of the mountain range is decreased by erosion
- Whether the crust would move up, move down or remain in the same position in the mantle if the crustal density increased
- Your reasoning for **both** of your predictions about the continental crust

Animation #3: What processes shape and change mountains over time?

STEEP RELIEF

GRADUAL RELIEF

GLACIAL CLIMATE

(alpine glaciers in the mountains)

TEMPERATE CLIMATE

(mild climate and moderate precipitation)

TROPICAL CLIMATE

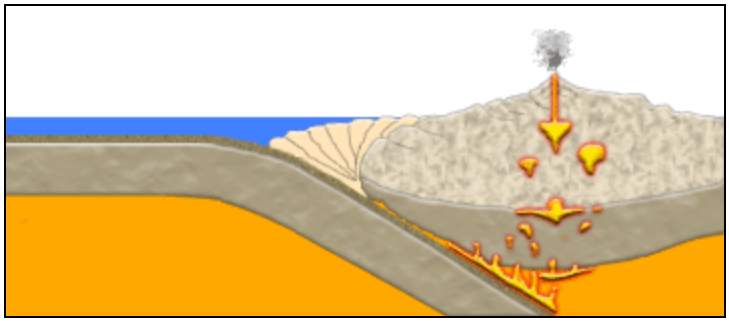
(warm, humid climate

Landforms on Earth are shaped and changed by erosion and other geologic processes. How will **relief** (the difference between the highest and lowest elevations in a region) and **climate** affect average erosion rates in a region?

Be sure to include in your answer:

- Whether faster average erosion rates will occur in regions with steep relief or regions with gradual relief (or whether erosion rates will be unaffected by relief)
- Which of the climates above (glacial, temperate or tropical) will have the fastest average erosion rates (or whether erosion rates will be unaffected by climate)
- Your reasoning for **both** of your predictions about erosion rates

Animation #4: How can rocks formed deep within the crust come to the surface?



Which processes that occur during mountain formation will be responsible for exposing intrusive igneous and metamorphic rocks, which form deep within the crust, at the surface of the mountain range?

Be sure to include in your answer:

- At least **two** processes associated with the formation and evolution of a mountain range that would be involved with exposing deep crustal rocks at the surface of the mountain range
- Your reasoning for **both** of your predictions about how deep rocks can be exposed

OBSERVATIONS POST-TEST IS IDENTICAL TO THE PREDICTIONS PRE-TEST. THE ONLY DIFFERENCE IS THE TENSE USED IN THE QUESTIONS.

DELAYED POST-TEST: Caucasus Mountains (Multiple-Choice)

Satellite image courtesy of:
visibleearth.nasa.gov

The Caucasus Mountains are located between the Black Sea and Caspian Sea, separating Europe from Asia. This 550-mile long mountain range lies between Russia to the north and the countries of Georgia, Azerbajian and Armenia to the south. With an average elevation of 6000-9000 feet (~1800-2700 meters), the Caucasus Mountains contain several 4000 meter (13,000 feet) peaks, including Mt. Elbrus at 5642 m (18,481 feet) in height. The western Caucasus Mountains, because of its proximity to the Black Sea, have a warm, humid and rainy climate with thick conifer and deciduous forests. The Central Caucasus Mountains are glaciated at high elevations with high, jagged peaks and 30 small glaciers. At lower elevations, the Central Caucasus consists of alpine meadows and pine forests in the valleys. The Eastern Caucasus has a drier, semi-desert climate and contains barren foothills with isolated peaks.

Instructions: *Answer the following questions about the Caucasus Mountains based on the brief information given above and your knowledge of mountain building processes. YOU WILL NOT NEED ANY OTHER REFERENCES TO COMPLETE THIS ASSESSMENT. For each multiple choice question, please choose the <u>one</u> answer that best reflects how a geologist would answer. In the space provided below each multiple choice question, please provide a brief, but clear. The second multiple choice question in each set will ask you to explain your reasoning for your choice to the previous question.*

1. Which of the following is the <u>most reasonable estimate</u> for the age of the Caucasus Mountain range?
   - 800 years
   - 6,000 years
   - 100,000 years
   - 3 million years
   - 700 million years
   - 4.6 billion years

2. The reason for my answer to Question 1 is because:

- mountains formed during the formation of Earth
- mountains form and change at rates of millimeters per year
- it takes that long for volcanoes to form the entire mountain chain
- enough time must pass to allow sediments to accumulate and form a mountain
- the subducting plate must have sufficient time to push the mountain up through the other plate

3. Which of the following processes is primarily responsible for the formation of the Caucasus Mountains?
- volcanic eruptions extending between the Black and Caspian Seas
- the separation of the Eurasian continent from Pangaea
- sea level decreasing in the Black and Caspian Seas
- the collision of the Eurasian and Arabian plates

4. The reason for my answer to Question 3 is because:

- linear mountain ranges form at the edge of rifting continents
- the subducting oceanic crust pushed the continental crust upwards
- the entire mountain chain is formed of volcanic peaks and fissures
- the mountain range has been gradually exposed as the ocean recedes
- tectonic stresses during subduction and collision uplift the continental crust

5. The position of Earth's crust as it floats upon the mantle depends on **isostasy**. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.

What is likely happening to the position of the crustal root below the Caucasus Mountains as the average elevation of the range above sea level is increasing?

The crustal root:
- moves farther down into the mantle
- moves up within the mantle
- does not change size or position

6. The reason for my answer to Question 5 is because:

- the crustal root moves up with the mountain since they are connected
- higher mountains require a thicker crustal root to compensate for the added weight
- the crustal root is below the surface and is not affected by the mountain range above it
- the crust needs more support, and the mantle provides better support than the crust

7. How does the crustal root below the Caucasus Mountains likely respond when erosion removes material from the top of the mountain range?

The crustal root:
- moves farther down into the mantle
- moves up within the mantle
- does not change size or position

8. The reason for my answer to Question 7 is because:

- the mountain range loses mass and becomes more buoyant
- erosion only affects the top of the mountain, not the crustal root
- the root must move downward as the mountain elevation decreases
- the position is not affected because the density has not changed
- the root does not change since the mountain is no longer growing

9. The presence of volcanic rocks such as tuff and andesite in addition to exposed granite and granodiorite plutons in the Caucasus Mountains are evidence that magma has intruded into the continental crust from the underlying mantle. How has the input of lower-density molten magma most likely affected the continental crust forming the Caucasus Mountains?

The intrusion of liquid magma has caused the crust to:

- remain in the same position relative to the mantle
- float higher in the mantle
- sink lower in the mantle

10. The reason for my answer to Question 9 is because:

- the continental crust has become more bouyant
- added material of any kind will cause the crust to sink
- the mantle density changes in proportion to the crust density
- the crust is already less dense than the mantle, so there will be no effect

11. Based on the relationship between relief and erosion, which of the following places of the Caucasus Mountains is likely to experience the highest erosion rate?

- areas of steep relief with high peaks and deep valleys
- areas of moderate relief such as foothills
- areas of gradual relief such as plains
- all areas should have the same erosion rate

12. The reason for my answer to Question 11 is because:

- the force of gravity is greater closer to the center of Earth
- weathering has a greater effect in the plains than in mountainous regions
- erosion is dependent on temperature and moisture rather than elevation differences
- water and ice move faster on steeper slopes, increasing its ability to erode and transport sediment

13. According the climate information provided in the introductory paragraph, which of the following regions of the Caucasus Mountains is likely to experience the lowest erosion rate?

- Western (warm, humid, rainy, temperate forested)
- Central (glacial in mountain regions, temperate forests at lower elevations)
- Eastern (drier, semi-arid climate)
- all regions should have the same erosion rate

14. The reason for my answer to Question 13 is because:

- cold, dry climates allow little weathering
- less water is available to contribute to erosion
- more glaciers and jagged peaks slow erosion rates
- all regions will erode equally because of similar relief

15. How does **isostasy** affect the average elevation of the Caucasus Mountains over time as mass is removed from the mountain range by erosion?

Isostasy:

- does not have an effect on average elevation over time
- slows the rate at which average elevation decreases over time
- speeds up the rate at which average elevation decreases over time
- increases the average elevation of the mountainous region over time

16. The reason for my answer to Question 15 is because:

- the mantle density increases and pushes the mountains upward
- as material is eroded away, the elevation decreases at an faster rate
- movement of the crustal root uplifts the mountain range to greater average elevation
- as the mountain belt gets smaller, isostasy pushes the mountain up to maintain equilibrium

17. High grade metamorphic rocks and intrusive igneous rocks are exposed and visible at the surface of the Caucasus Mountains. How can metamorphic and igneous rocks formed deep in the crust eventually be found at the surface?

- erosion removes overlying material as rocks within the crust are uplifted
- the crust is eroded away down to the mantle, exposing igneous rocks
- the rocks decrease in density once cooled and rise to the surface
- a drastic decrease in sea level exposed the rocks at the surface

18. The reason for my answer to Question 17 is because:

- the rocks are uncovered as the water level decreases
- rocks can buoyantly rise through the surrounding crust
- deep crustal rocks erupt onto the surface through volcanoes
- mass removal from the mountain allows the crust to move up

19. Marine sedimentary rocks containing fossils 10 million years in age have been found at elevations of 3500 m (11,500 feet) in the Caucasus Mountains. Which of the following is the most likely explanation for ocean sediments to be found at this elevation?

- marine organisms have evolved to live in mountainous regions
- sea level has dropped 4 kilometers in the last 10 million years
- the crust where the sediment was deposited has been uplifted
- dense ocean basins have sunk to a deeper elevation over time

20. The reason for my answer to Question 19 is because:

- marine sediments are left on land as the ocean floor sinks lower
- volcanism has uplifted the sedimentary rocks to high elevations
- the sedimentary rocks are uncovered as the water level decreases
- the seafloor sediment is pushed upwards as the continents collide

21. The Caucasus Mountains are one of Earth's most rapidly growing mountain ranges. What does this imply about the relationship between erosion rates and uplift rates in this region?

- uplift rates and erosion rates are approximately equal
- uplift rates are greater than erosion rates
- uplift rates are less than erosion rates

22. The reason for my answer to Question 21 is because:

- erosion processes are very slow until after the mountain range reaches its maximum height
- though erosion is ongoing, tectonic and isostatic forces combine to cause uplift
- erosion does not begin until plate convergence ceases
- isostasy prevents erosion from occurring

DELAYED POST-TEST: Caucasus Mountains (Essay)

Satellite image courtesy of:
visibleearth.nasa.gov

The Caucasus Mountains are located between the Black Sea and Caspian Sea, separating Europe from Asia. This 550-mile long mountain range lies between Russia to the north and the countries of Georgia, Azerbajian and Armenia to the south. With an average elevation of 6000-9000 feet (~1800-2700 meters), the Caucasus Mountains contain several 4000 meter (13,000 feet) peaks, including Mt. Elbrus at 5642 m (18,481 feet) in height. The western Caucasus Mountains, because of its proximity to the Black Sea, have a warm, humid and rainy climate with thick conifer and deciduous forests. The Central Caucasus Mountains are glaciated at high elevations with high, jagged peaks and 30 small glaciers. At lower elevations, the Central Caucasus consists of alpine meadows and pine forests in the valleys. The Eastern Caucasus has a drier, semi-desert climate and contains barren foothills with isolated peaks.

Instructions: *Answer the following questions about the Caucasus Mountains based on the brief information given above and your knowledge of mountain building processes. YOU WILL NOT NEED ANY OTHER REFERENCES TO COMPLETE THIS ASSESSMENT. To earn maximum points for each short essay answer, please be sure to include each of the bulleted points as part of your answer, and explain your reasoning to the best of your ability. Your goal should be to explain your thoughts as briefly and clearly as possible.*

Question 1:
How has the elevation of the Caucasus Mountains above sea level and thickness of the crust below the mountain range been affected by the convergence of the Eurasian and Arabian plates?

Be sure to include in your answer:

- Whether the elevation of the crust above sea level has increased, decreased, or remained the same as before the plates began to converge
- Whether the thickness of the crust below the mountain range has become thicker, become thinner, or remained the same
- Your reasoning for **both** of your observations about the continental crust

Question 2:
The position of Earth's crust as it floats upon the mantle depends on **isostasy**. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.

How is the position of Earth's crust floating in the mantle affected by changes in mountain height or changes in crustal density? Specifically, a) how does the crustal root below the Caucasus Mountains most likely react to the loss of material at the top due to erosion?, and b) how does the position of the crust likely react to the intrusion of low-density molten magma that has formed granite plutons in the Caucasus Mountains?

Be sure to include in your answer:

- Whether the crustal root moves farther down into the mantle, moves up within the mantle, or remains the same size/position as material erodes from the Caucasus Mountain range?
- Whether the crust moves up, moves down or remains in the same position in the mantle as low-density magma intrudes into the crust
- Your reasoning for **both** of your observations about the continental crust

Question 3:
The Caucasus Mountain range contains regions with varied topographic relief, as well as a variety of climates. The mountain range has steep relief in areas of high peaks and deep valleys, moderate relief in the foothills, and gradual relief in the plains and plateaus. As is detailed in the introductory paragraph, the climate in the western portion of the range is warm, humid and rainy. In the central Caucasus, a glacial climate exists in higher elevations with temperate forests at lower elevations. The Eastern portion, furthest inland, is drier and semi-arid. Which climate and which degree of relief (steep, moderate or gradual) likely results in the lowest erosion rates in the Caucasus Mountains?

Be sure to include in your answer:

- Whether slower average erosion rates occur in regions with steep relief or regions with gradual relief (or whether erosion rates are unaffected by relief)
- Which of the climate regions above (western, central or eastern Caucasus) has the slowest average erosion rates (or whether erosion rates are unaffected by climate)
- Your reasoning for **both** of your observations about erosion rates

Question 4:

High grade metamorphic rocks and intrusive igneous rocks (granite and granodiorite plutons) are exposed and visible at the surface of the Caucasus Mountains. How can metamorphic and igneous rocks formed deep in the crust eventually be found at the surface?

Be sure to include in your answer:

- At least **two** processes associated with the formation and evolution of the Caucasus Mountains that are involved with exposing deep crustal rocks at the surface of the mountain range
- Your reasoning for **both** of the processes you observed that contributed to exposing deep crustal rocks

Rubrics for Essay Responses

Pre-test and Post-test questions were identical except that the Post-Test are in present rather than future (predictive) tense.

Predictions (Pre-Test) and Observations (Post-Test)
How will the elevation of the crust above sea level and thickness of the crust below the mountain range be affected by continued subduction of the oceanic plate and collision of a second continent?

Be sure to include in your answer:

- Whether the elevation of the crust above sea level will increase, decrease, or stay the same
- Whether the thickness of the crust below the mountain range will become thicker, become thinner, or remain the same
- Your reasoning for **both** of your predictions about the continental crust

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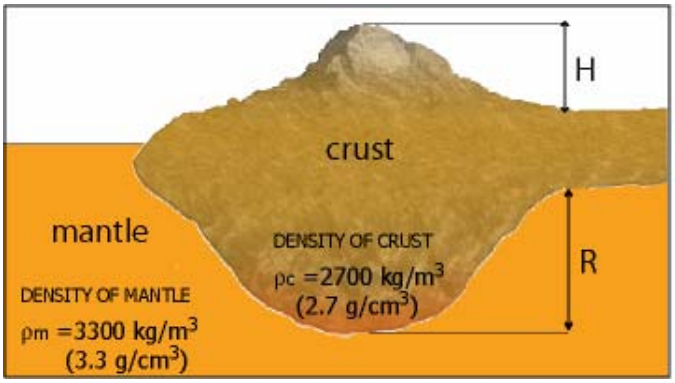
RUBRIC for Question #1 (pre, post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

Criterion	Points Earned
Correctly states that the elevation of the crust above sea level will INCREASE	/1 pt
Includes reasoning for increase in elevation, which could include: • Upward movement of magma/mantle during subduction (resulting in thickening or volcanism) • Addition of new material to the crust (accretionary wedge) • Shortening/thickening due to compression or plate convergence • Other scientifically accurate reasoning that is directly applicable to the question **Uplift due to subducting plate pushing up continental plate is NOT acceptable	/1 pt
Correctly states that the thickness of the continental crust below the mountain range will INCREASE	/1pt
Includes reasoning for thickening of crust, which could include: • Upward movement of magma/mantle during subduction • Addition of new material to the crust (accretionary wedge) • Shortening/thickening due to compression or plate convergence • Thickening occurs above and below surface to maintain balance • Other scientifically accurate reasoning that is directly applicable to the question.	/1 pt
TOTAL SCORE for Question #1	/4 pts

Notes:

- The elevation and thickness could potentially STAY THE SAME if student's reasoning includes an explanation such as: If all factors (tectonic uplift, volcanism, erosion, etc.) are in balance, elevation maintains equilibrium
- Some responses show student confusion about the "crust below the mountain range". Responses discuss the subducting oceanic crust will receive no credit for that portion of the response because the question asks for predictions or observations about the continental crust. Responses that refer to the continental crust as a whole, w/o making reference to "below the mountain range" are acceptable if they are scientifically correct.



Predictions (Pre-Test) and Observations (Post-Test)
The position of Earth's crust as it floats upon the mantle depends on **isostasy**. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.
How will the position of Earth's crust floating in the mantle be affected by changes in mountain height or changes in crustal density? Specifically, a) what will happen to the size or position of the crustal root if the height of the mountain range is decreased by erosion?, and b) how would the position of the crust be affected if the crustal density could increase to greater than 2700 kg/m^3?

Be sure to include in your answer:

- Whether the crustal root will move farther down into the mantle, move up within the mantle, or remain the same size/position when the height of the mountain range is decreased by erosion
- Whether the crust would move up, move down or remain in the same position in the mantle if the crustal density increased
- Your reasoning for **both** of your predictions about the continental crust

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RUBRIC for Question #2 (pre, post)
This question is graded on a 0-4 point scale. Each point can be earned as follows:

Criterion	Points Earned
Correctly states that the crustal root will MOVE UP within the mantle when mountain height decreases due to erosion	/1 pt
Includes reasoning for upward movement of root, which could include: • Decreased downward force (crust is lighter) • Less crustal root is necessary to compensate for weight of mt. range • The crustal root responds by thinning to maintain isostatic equilibrium • Other scientifically accurate reasoning that is directly applicable to the question.	/1 pt
Correctly states that the crust will MOVE DOWN or SINK INTO the mantle when crustal density increases	/1pt
Includes reasoning for downward movement of crust, which could include: • Increased downward force (crust is heavier, more affected by gravity) • Decreased buoyancy • Crust responds to maintain isostatic equilibrium • Other scientifically accurate reasoning that is directly applicable to the question. **Crust completely sinking into mantle is not acceptable unless crust density > mantle density. "Heavy things sink" is not acceptable (e.g. battleships are heavy, but buoyant).	/1 pt
TOTAL SCORE for Question #2	/4 pts

TEST QUESTION INCLUDES VISUALS OF CLIMATE AND RELIEF CONTRASTS

Predictions (Pre-Test) and Observations (Post-Test)
Landforms on Earth are shaped and changed by erosion and other geologic processes. How will **relief** (the difference between the highest and lowest elevations in a region) and **climate** affect average erosion rates in a region?

Be sure to include in your answer:

- Whether faster average erosion rates will occur in regions with steep relief or regions with gradual relief (or whether erosion rates will be unaffected by relief)
- Which of the climates above (glacial, temperate or tropical) will have the fastest average erosion rates (or whether erosion rates will be unaffected by climate)
- Your reasoning for **both** of your predictions about erosion rates

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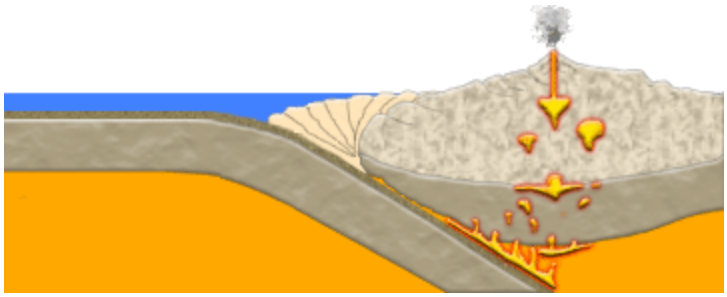
RUBRIC for Question #3 (pre, post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

Criterion	Points Earned
Correctly states that erosion rates are higher in regions with STEEP relief	/1 pt
Includes reasoning for high erosion rates with steep relief, which could include: • Less slope stability (weathered material removed more easily) • More exposure to erosive agents • Stream velocities greater/greater driving forces • Other scientifically accurate reasoning that is directly applicable to the question.	/1 pt
Correctly states that erosion rates are highest in GLACIAL climates	/1pt
Includes reasoning for high erosion rates in glacial climates, which could include: • Movement of heavy/massive glaciers is a strong erosive force • Combination of several erosive forces (water, ice, rockfall, etc.) • Other scientifically accurate reasoning that is directly applicable to the question. ** if glacier is frozen to bedrock, erosion will be minimal, but not all glaciers are frozen to the bedrock, so overall, glacial climates still have fastest erosion	/1 pt
TOTAL SCORE for Question #3	/4 pts

Notes:

- High erosion rates in TROPICAL climates are also acceptable, if sufficient explanation is included. Simple statements about climate such as high precipitation or high humidity and temperature are not acceptable without an explanation of WHY those climate conditions produce high weathering or erosion rates. The distinction between weathering rates and erosion rates is too subtle to be penalized at the Geology 101 level. "Heavy precipitation" or "more water" is not acceptable without references to water velocity or relief. More water does not necessarily = faster erosion rates.



Predictions (Pre-Test) and Observations (Post-Test)
Which processes that occur during mountain formation will be responsible for exposing intrusive igneous and metamorphic rocks, which form deep within the crust, at the surface of the mountain range?

Be sure to include in your answer:

- At least **two** processes associated with the formation and evolution of a mountain range that would be involved with exposing deep crustal rocks at the surface of the mountain range
- Your reasoning for **both** of your predictions about how deep rocks can be exposed

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RUBRIC for Question #4 (pre, post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

Criterion	Points Earned
One process related to mountain building that could expose deep rocks at the surface is identified, which could include: • Erosion • Isostatic Uplift (upward movement of crust or crustal root) • Crustal shortening/thickening (tectonic uplift due to convergence) • Faulting/earthquakes • Caldera formation (**volcanism in itself is not sufficient, unless xenoliths are specified**) • Weathering (only if erosion is also included in answer) • Folding/overturning (in association with erosion)	/1 pt
Reasoning consistent with the process listed above is included, which must be a "Scientifically Accurate" statement (an explanation of WHY or HOW the above process contributes to the exposure of deep rocks must be included in order to receive this point)	/1 pt
A second process related to mountain building that could expose deep rocks at the surface is identified, which could include: • Erosion • Isostatic Uplift (upward movement of crust or crustal root) • Crustal shortening/thickening (tectonic uplift due to convergence) • Faulting/earthquakes • Caldera formation (**volcanism in itself is not sufficient, unless xenoliths are specified**) • Weathering (only if erosion is also included in answer) • Folding/overturning (in association with erosion)	/1pt
Reasoning consistent with the process listed above is included, which must be a "Scientifically Accurate" statement (an explanation of WHY or HOW the above process contributes to the exposure of deep rocks must be included in order to receive this point)	/1 pt
TOTAL SCORE for Question #4	/4 pts

****In order to receive full credit, one of the identified processes MUST be EROSION****

Delayed Post-Test

The Caucasus Mountains are located between the Black Sea and Caspian Sea, separating Europe from Asia. This 550-mile long mountain range lies between Russia to the north and the countries of Georgia, Azerbajian and Armenia to the south. With an average elevation of 6000-9000 feet (~1800-2700 meters), the Caucasus Mountains contain several 4000 meter (13,000 feet) peaks, including Mt. Elbrus at 5642 m (18,481 feet) in height. The western Caucasus Mountains, because of its proximity to the Black Sea, have a warm, humid and rainy climate with thick conifer and deciduous forests. The Central Caucasus Mountains are glaciated at high elevations with high, jagged peaks and 30 small glaciers. At lower elevations, the Central Caucasus consists of alpine meadows and pine forests in the valleys. The Eastern Caucasus has a drier, semi-desert climate and contains barren foothills with isolated peaks.

TEST QUESTION INCLUDES SATELLITE IMAGE OF CAUCASUS MOUNTAINs

How has the elevation of the Caucasus Mountains above sea level and thickness of the crust below the mountain range been affected by the convergence of the Eurasian and Arabian plates?

Be sure to include in your answer:

- Whether the elevation of the crust above sea level has increased, decreased, or remained the same as before the plates began to converge
- Whether the thickness of the crust below the mountain range has become thicker, become thinner, or remained the same
- Your reasoning for **both** of your observations about the continental crust

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RUBRIC for Question #1 (delayed post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

Criterion	Points Earned
Correctly states that the elevation of the crust above sea level will INCREASE	/1 pt
Includes reasoning for increase in elevation, which could include: • Upward movement of magma/mantle during subduction (resulting in thickening or volcanism) • Addition of new material to the crust (accretionary wedge) • Shortening/thickening due to compression or plate convergence • Other scientifically accurate reasoning that is directly applicable to the question. **Uplift due to subducting plate pushing up continental plate is NOT acceptable	/1 pt
Correctly states that the thickness of the crust below the mountain range will INCREASE	/1pt
Includes reasoning for thickening of crust, which could include: • Upward movement of magma/mantle during subduction • Addition of new material to the crust (accretionary wedge) • Shortening/thickening due to compression or plate convergence • Thickening occurs above and below surface to maintain balance • Other scientifically accurate reasoning that is directly applicable to the question.	/1 pt
TOTAL SCORE for Question #1	/4 pts

Notes: The elevation and thickness could potentially STAY THE SAME if student's reasoning includes an explanation such as: If all factors (tectonic uplift, volcanism, erosion, etc.) are in balance, elevation maintains equilibrium

Delayed Post-Test

The position of Earth's crust as it floats upon the mantle depends on **isostasy**. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.

How is the position of Earth's crust floating in the mantle affected by changes in mountain height or changes in crustal density? Specifically, a) how does the crustal root below the Caucasus Mountains most likely react to the loss of material at the top due to erosion?, and b) how does the position of the crust likely react to the intrusion of low-density molten magma that has formed granite plutons in the Caucasus Mountains?

Be sure to include in your answer:

- Whether the crustal root moves farther down into the mantle, moves up within the mantle, or remains the same size/position as material erodes from the Caucasus Mountain range?
- Whether the crust moves up, moves down or remains in the same position in the mantle as low-density magma intrudes into the crust
- **Your reasoning for** both **of your observations about the continental crust**

RUBRIC for Question #2 (delayed post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

Criterion	Points Earned
Correctly states that the crustal root will MOVE UP within the mantle when mountain height decreases due to erosion	/1 pt
Includes reasoning for upward movement of root, which could include: • Decreased downward force (crust is lighter) • Less crustal root is necessary to compensate for weight of mt. range • The crustal root responds by thinning to maintain isostatic equilibrium • Other scientifically accurate reasoning that is directly applicable to the question.	/1 pt
Correctly states that crust will MOVE UP, STAY THE SAME, or MOVE DOWN when low-density magma intrudes into crust	/1pt
Includes reasoning for movement of crust, which could include: • Increased buoyancy with the addition of low-density material (which increases volume more than it increases mass) • Addition of molten magma decreases overall density of crust • Addition of new material increases thickness (increases elevation) • Other scientifically accurate reasoning that is directly applicable to the question. **Does not move downward due to increased weight or increased mass because overall density decreases ****Because of the complexity of this part of the question, accept any response that is internally consistent and scientifically reasonable****	/1 pt
TOTAL SCORE for Question #2	/4 pts

Notes:

- The intruding magma could have no measurable effect on the crust because the amount of magma is very little compared to the size of the mountain (amount of magma isn't specified in the question – so this is a good point)
- With a reasonable (scientifically accurate) explanation, the position of the crust could STAY THE SAME (ie. erosion and uplift rates are in balance)
- Accept the crustal ROOT moving downward when low-density magma intrudes (due to increased volume, crustal thickening)

Delayed Post-Test

The Caucasus Mountain range contains regions with varied topographic relief, as well as a variety of climates. The mountain range has steep relief in areas of high peaks and deep valleys, moderate relief in the foothills, and gradual relief in the plains and plateaus. As is detailed in the introductory paragraph, the climate in the western portion of the range is warm, humid and rainy. In the central Caucasus, a glacial climate exists in higher elevations with temperate forests at lower elevations. The Eastern portion, furthest inland, is drier and semi-arid. Which climate and which degree of relief (steep, moderate or gradual) likely results in the lowest erosion rates in the Caucasus Mountains?

Be sure to include in your answer:

- Whether slower average erosion rates occur in regions with steep relief or regions with gradual relief (or whether erosion rates are unaffected by relief)
- Which of the climate regions above (western, central or eastern Caucasus) has the slowest average erosion rates (or whether erosion rates are unaffected by climate)
- Your reasoning for **both** of your observations about erosion rates

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RUBRIC for Question #3 (delayed post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

Criterion	Points Earned
Correctly states that erosion rates are higher in regions with STEEP relief	/1 pt
Includes reasoning for high erosion rates with steep relief, which could include: • Less slope stability • More exposure to erosive agents • Stream velocities greater/greater driving forces • Other scientifically accurate reasoning that is directly applicable to the question.	/1 pt
Correctly states that erosion rates will be slowest in the EASTERN Caucasus region	/1pt
Includes reasoning for slow erosion rates in Eastern Caucasus, which could include: • dry climate (dry = less moving water, less precipitation, no glaciation) **no credit for just stating it is a dry climate w/o further explanation**	/1 pt
TOTAL SCORE for Question #3	/4 pts

Notes:

- The CENTRAL Caucasus region could also be acceptable because they are temperate forests if heavy vegetation is mentioned.

Delayed Post-Test

High grade metamorphic rocks and intrusive igneous rocks (granite and granodiorite plutons) are exposed and visible at the surface of the Caucasus Mountains. How can metamorphic and igneous rocks formed deep in the crust eventually be found at the surface?

Be sure to include in your answer:

- At least **two** processes associated with the formation and evolution of the Caucasus Mountains that are involved with exposing deep crustal rocks at the surface of the mountain range
- Your reasoning for **both** of the processes you observed that contributed to exposing deep crustal rocks

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RUBRIC for Question #4 (delayed post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

Criterion	Points Earned
One process related to mountain building that could expose deep rocks at the surface is identified, which could include: • Erosion • Isostatic Uplift (upward movement of crust or crustal root) • Crustal shortening/thickening (tectonic uplift due to convergence) • Faulting/earthquakes • Caldera formation (**volcanism in itself is not sufficient, unless xenoliths are specified**) • Weathering (only if erosion is also included in answer) • Folding/overturning (in association with erosion)	/1 pt
Reasoning consistent with the process listed above is included, which must be a "Scientifically Accurate" statement (an explanation of WHY or HOW the above process contributes to the exposure of deep rocks must be included in order to receive this point)	/1 pt
A second process related to mountain building that could expose deep rocks at the surface is identified, which could include: • Erosion • Isostatic Uplift (upward movement of crust or crustal root) • Crustal shortening/thickening (tectonic uplift due to convergence) • Faulting/earthquakes • Caldera formation (**volcanism in itself is not sufficient, unless xenoliths are specified**) • Weathering (only if erosion is also included in answer) • Folding/overturning (in association with erosion)	/1pt
Reasoning consistent with the process listed above is included, which must be a "Scientifically Accurate" statement (an explanation of WHY or HOW the above process contributes to the exposure of deep rocks must be included in order to receive this point)	/1 pt
TOTAL SCORE for Question #4	/4 pts

****In order to receive full credit, one of the identified processes MUST be EROSION****