USESO 2021

Geosphere

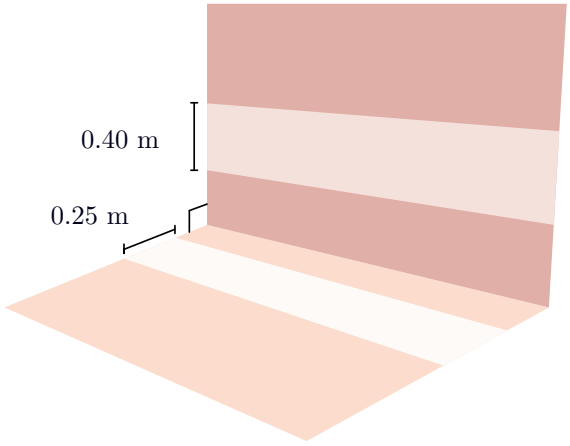
KEY

Instructions:

- Section I consists of 10 multiple choice questions, with each question worth 2 points. There is only one correct option on multiple choice questions
- Section II consists of 2 multipart free response questions
- A non-graphing, non-programmable calculator is allowed; show all work for calculations
- Recommended time management: 30 minutes on each section

Section I

1. (2 points) You discover a planar vein of quartz exposed from a perfectly vertical roadcut on flat ground, as shown in the figure below. The thickness on the ground is 0.25 m, while the thickness on the wall is 0.40 m.



Which of the following is closest to the true thickness, in meters?

A. 0.05 m

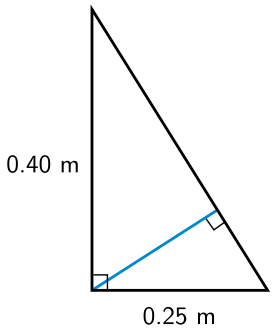
B. 0.10 m

C. 0.15 m

D. 0.20 m

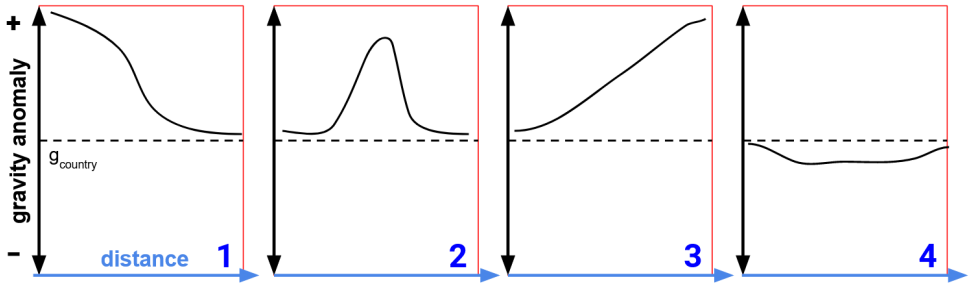
E. 0.25 m

Solution:



The true thickness d is the length highlighted in blue. There are various ways to solve. Here, we use trigonometry. $d = 0.25 \sin(\arctan 0.40/0.25) = 0.21$ m. This is closest to $\boxed{\text{D}}$.

2. (2 points) Bouguer gravity anomaly profiles can be used to study geologic structures by detecting underground density variations. Positive anomalies occur in regions where density is relatively high compared to surrounding country rock, while negative anomalies occur in regions where density is relatively low.



Assuming any hanging walls are **left** of center, match the above Bouguer gravity profiles to their corresponding structure.

A. 1 - normal fault, 2 - mafic dike, 3 - reverse fault, 4 - sedimentary basin

B. 1 - reverse fault, 2 - mafic dike, 3 - normal fault, 4 - sedimentary basin

C. 1 - normal fault, 2 - sedimentary basin, 3 - reverse fault, 4 - mafic dike

D. 1 - reverse fault, 2 - sedimentary basin, 3 - normal fault, 4 - mafic dike

E. 1 - mafic dike, 2 - sedimentary basin, 3 - reverse fault, 4 - normal fault

Solution: 1: Reverse fault, high density of the hanging wall indicates it moves down relative to the footwall. 2: Mafic dike, small region of higher density. 3: Normal fault, high density of the footwall indicates it moves down relative to the hanging wall. 4: Sedimentary basin, sedimentary rocks have lower density relative to igneous country rock.

3. (2 points) Which of the following is consistent with a tectonic environment in which very old oceanic crust subducts under an island arc?

A. A relatively narrow forearc basin and a steeply-dipping Wadati-Benioff seismic zone

B. A relatively narrow forearc basin and an abundance of granulite facies

C. A relatively wide forearc basin and back-arc compression

D. A shallow-dipping Wadati-Benioff seismic zone and an abundance of granulite facies

E. A shallow-dipping Wadati-Benioff seismic zone and back-arc extension

F. A steeply-dipping Wadati-Benioff seismic zone and back-arc compression

Solution: Very old oceanic crust is very dense, so it will subduct at a high angle relative to the surface and create a steeply-dipping Wadati-Benioff seismic zone. Thus, the magmatic arc will form closer to the trench, leaving a narrow forearc basin. Steep subduction is associated with back arc extension, while shallow subduction causes compressional stresses on the back arc region. Metamorphism in subduction zones is characterized by high pressure/low temperature facies such as blueschist and eclogite; granulite forms at generally higher temperatures.

4. (2 points) Geosphere dynamics may affect climate in interesting ways. Which of the following is **not** true about the interaction of the geosphere with the global climate?

I) Greenhouse climates tend to be associated with faster mid-ocean ridge spreading rates than icehouse climates

II) The eruption of supervolcanoes like Yellowstone initially cools the planet

III) The weathering of silicates is a net carbon sink

A. I only

B. II only

C. III only

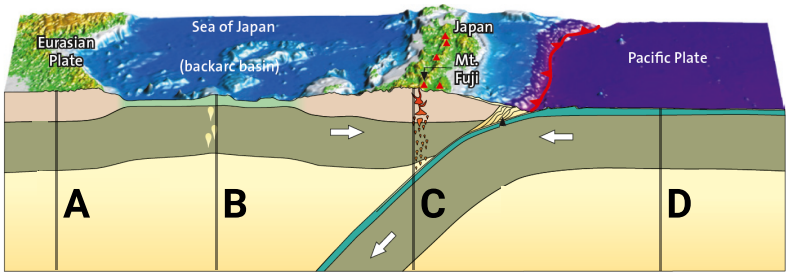
D. II and III

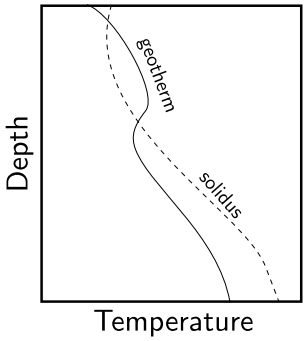
E. I, II, and III

F. None

Solution: Faster mid-ocean ridge spreading is associated with more prolific volcanism and outgassing of GHGs - I is true. Supervolcano eruptions release both GHGs and aerosols into the atmosphere, but aerosols dominate the short term climate response and reflect shortwave radiation, thereby cooling the planet - II is true. Silicate weathering consumes more CO_2 than is released during ocean carbonate formation (see carbonate-silicate cycle) - III is true. Thus, the answer is $\boxed{\text{F}}$.

5. (2 points) Which of the following tectonic environments is most likely depicted by the geotherm and solidus curves shown below?





A. A

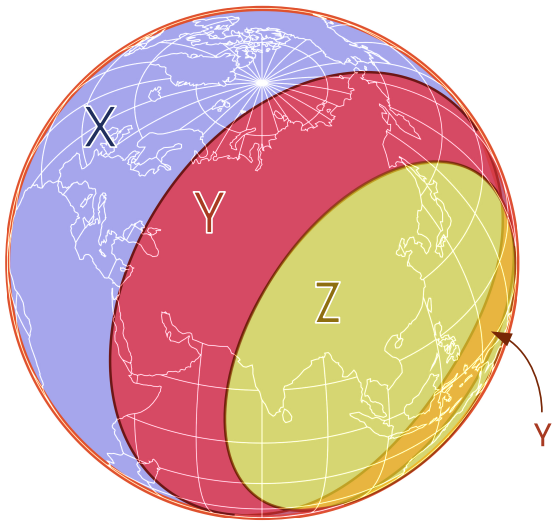
B. B

C. C

D. D

Solution: First, notice that the geotherm dips at depth, suggesting that there is an anomalously cold region. Next, the solidus curve also dips, suggesting that there is some process that is lowering the melting point of mantle rock. Both of these clues point towards the presence of a subducting slab, which introduces water into the mantle, lowering the solidus via flux melting. Thus, the answer is $\boxed{\text{C}}$.

Refer to the figure below for questions 6 and 7. The figure below divides Earth's surface into three regions according to the seismic waves (or lack thereof) that are observed in each after an earthquake. Note: the arrow points to a portion of region Y seen on the other side of the globe.



6. (2 points) Where, approximately, did this earthquake most likely occur?

   A. Southeast Asia

   B. Off the coast of South America

   C. Near the Mediterranean

   D. The North Pole

   E. The South Pole

Solution: Notice that X shows where both P- and S-waves occur, Y represents the P-wave shadow zone, and Y and Z comprise the S-wave shadow zone. One may see that the earthquake occurred in the center of X. The only plausible answer is $\boxed{\text{B}}$ (not shown in the figure).

7. (2 points) Consider if the radius of the outer core was increased. Which of the following would be true?

I) Only P-waves would be observed in Y

II) Y would move towards X

III) Surface waves would be observed in Z

IV) Z would expand

A. I only

B. II only

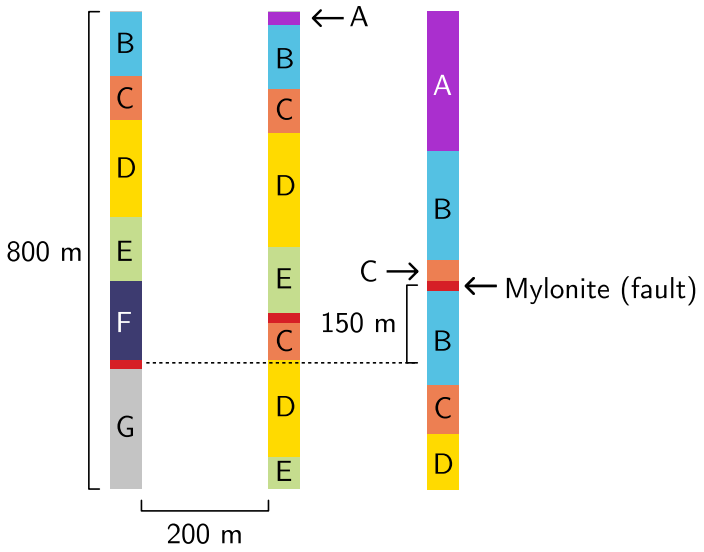
C. I and III

D. II and IV

E. II, III, and IV

Solution: Like in the previous question, this answer is most clear using a two-dimensional view of seismic wave rays. I is false because both P- and S-waves are refracted back to the surface unobstructed. Meanwhile, the hypothetically larger outer core does obstruct their path such that the boundary between regions X and Y moves towards the center of X; II is true. III is false — surface waves would not reach the other side of the globe. Finally, IV is true because a larger core would create a larger area where core-refracted P-waves reach the surface.

8. (2 points) Three drill cores, each of 800 m depth, are drilled in a line, each spaced 200 meters apart. The width of each core can be neglected. Let δ represent the true dip. Assume no overturning unless otherwise stated.



Different geologic beds are denoted as different colors and are labeled A-G.

(a) Which of the following best describes the structure immediately surrounding the fault?

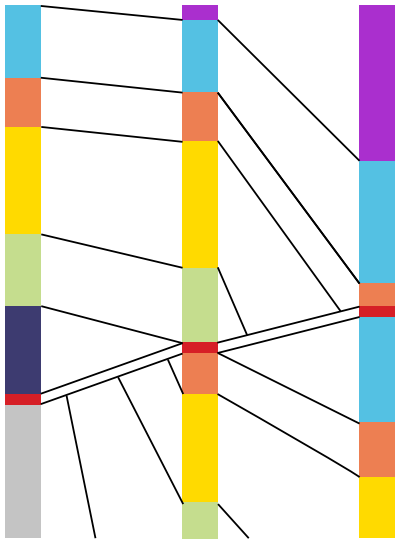
A. Rightward dipping planar beds

B. A syncline above the fault plane with an anticline below the fault plane

C. A single syncline split by the fault

D. An anticline above the fault plane with a syncline below the fault plane

Solution: The most direct approach is to interpolate the strata between the three drill cores, because they are drilled in a line.



This best fits description D.

(b) Which of the following most accurately describes the fault?

A. A normal fault with $\delta \geq 69.4$ degrees

B. A normal fault with $\delta \leq 20.6$ degrees

C. A normal fault with $\delta = 20.6$ degrees

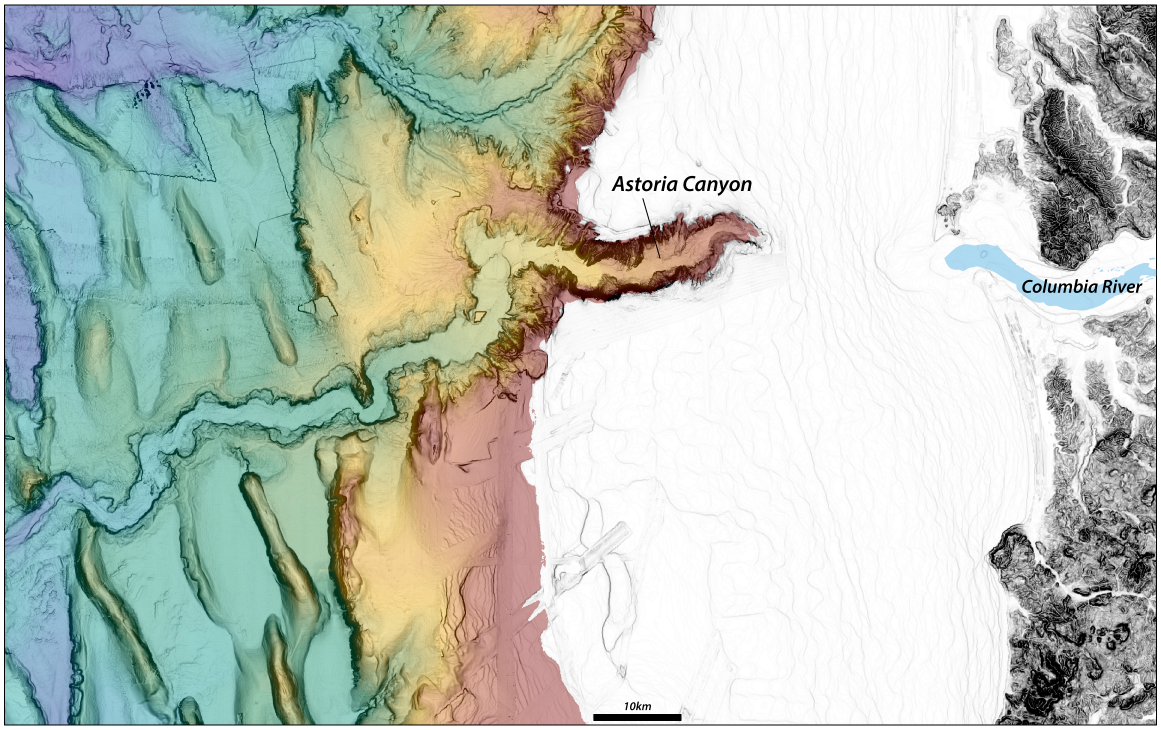
D. A reverse fault with $\delta \geq 69.4$ degrees

E. A thrust fault with $\delta \leq$ 20.6 degrees

F. A thrust fault with $\delta = 20.6$ degrees

Solution: The apparent dip of the fault is $\arctan 150/400 = 20.6°$. Because the true dip is always less than or equal to the apparent dip, we can eliminate all options other than B and E. The fold appears to be caused by the fault, so we can reason that the hanging wall should have moved up relative to the footwall. Thus, the answer is E.

9. (2 points) The figure below shows the multibeam bathymetry of Astoria Canyon, a structure off the Northwest Coast of the United States.



Based on the tectonic and depositional setting, which of the following best describes the sandstone found in Astoria Canyon?

A. Greater than 25 percent feldspar, poorly sorted, angular grains

B. Almost entirely composed of quartz, well sorted, rounded grains

C. Greenish color from abundant glauconite mica and other clay minerals, fossil-rich, rounded grains

D. Mostly carbonate mineral grains and calcareous shell fragments cemented together

E. Angular quartz grains, feldspar grains and rock fragments surrounded by a clay matrix, poorly sorted

Solution: Based on the location and bathymetry of Astoria Canyon, it can be deduced that it is a submarine canyon. The final choice describes graywacke, which would be deposited by turbidity currents in submarine canyons.

10. (2 points) Which of the following is **false** regarding contact metamorphism around an igneous intrusion?

A. The contact aureole commonly exhibits granoblastic texture

B. Metamorphic grade decreases with increasing distance from the intrusion

C. As the magma's latent heat of crystallization increases, contact aureole size decreases

D. Assuming the intrusion is below the water table, higher country rock permeability allows for greater rates of heat transfer

E. None of the above (All of the statements are true)

Solution: If the magma's latent heat of crystallization increases, more heat is released, which causes more of the country rock to contact metamorphose, increasing aureole size.

Section II: Problem 1

Question	1	2	3	4	Total
Points	1	5	2	7	15 (30%)

Deltas are fascinating environments at the land-water interface to study. Occurring throughout the world, their diverse morphologies uniquely reflect the interplay of terrestrial, hydrologic, and climatic processes on multiple scales.

1. (1 point) In the most fundamental sense, deltas exist because rivers deposit their sediment load where they meet a larger body of water. Within a deltaic setting, which of the following is deposition best attributed to?

   A. Decrease in competence as fast-moving river water slows

   B. Frequent delta switching as distributaries form more stable paths

   C. Lower capacity from the river splitting into distributaries

   D. Shallower grade creating more resistance to river flow

   E. Point of maximum discharge located at the river mouth

Solution: Deltas are depositional features that result from streams reaching a base level, whether it is a lake or the ocean. Stream velocity is reduced upon reaching base level, decreasing competence and depositing its load.

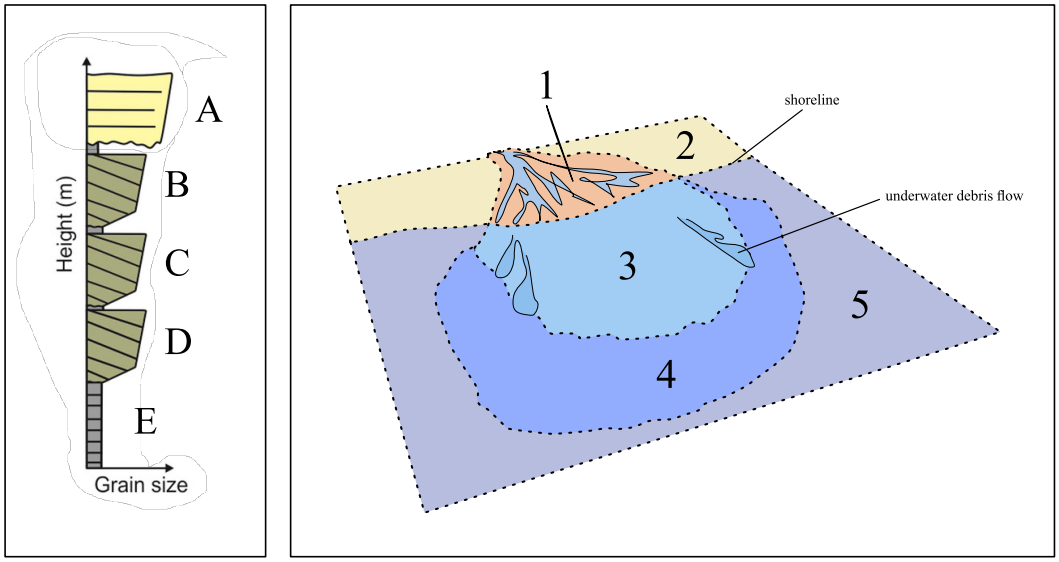


Figure 1 (left): Stratigraphic column labeled A-E representing a set of generic deltaic deposits. **Figure 2 (right)**: An overhead view of the present delta from which the column in Figure 1 represents. Distinct deltaic and surrounding depositional regions are labeled 1-5. Note that 1-2 are above water while 3-5 are below water.

2. (a) (2 points) Match each letter (A-E) in Figure 1 to *one* of the regions numbered 1-5 in Figure 2. Each number may be used more than once or not at all.

Solution: A—1, B—3, C—3, D—3, E—4

(b) (3 points) The degree of mixing between river outflow and the larger body of water depends partly on the density contrast of the two waters. If the density contrast was increased while all other factors remain constant, explain why the area of region 4 in Figure 2 might expand outwards.

In your answer, be sure to consider the following: Would a higher density contrast increase or decrease mixing? How does mixing affect flow velocity? How is flow velocity related to deposition?

Solution: A greater difference in density would decrease the amount of mixing between river flow and the larger water body it flows into, allowing river flow to move farther from the river mouth at a higher velocity for a given distance. Suspended sediments, therefore, can be transported farther before being deposited. Because region 4 (corresponding to E) consists of fine-grained sediments typical of a river's suspended load, its area expands.

3. (2 points) Rivers are often the most significant source of sediment at shorelines. Select all of the following that accurately describe the general relationship between sedimentation and passive margins. (*)

A. Regions of nondeposition are being uplifted because of isostatic adjustment

B. Delta-derived sediments are currently widening continental shelves

C. Erosion and deposition balance in deltas as passive margins increase in age

D. Much of the sediment output is captured by oceanic trenches parallel to shore

E. Relatively cool oceanic lithosphere tends to create sedimentary basins

F. Sediment accumulation results in lithospheric subsidence

Solution: While the accumulation of sediments can cause the lithosphere beneath to isostatically adjust, the absence of deposition isn't associated with uplift, so F is true and A is not. B: Deltas are deposited on top of continental shelves rather than at their borders, and operate on much smaller scales. C: They are depositional by nature, features of low grade. D: Ocean trenches are present at active margins. E: Cooling lithosphere is relatively less buoyant and therefore subsides, forming a basin conducive to sedimentation.

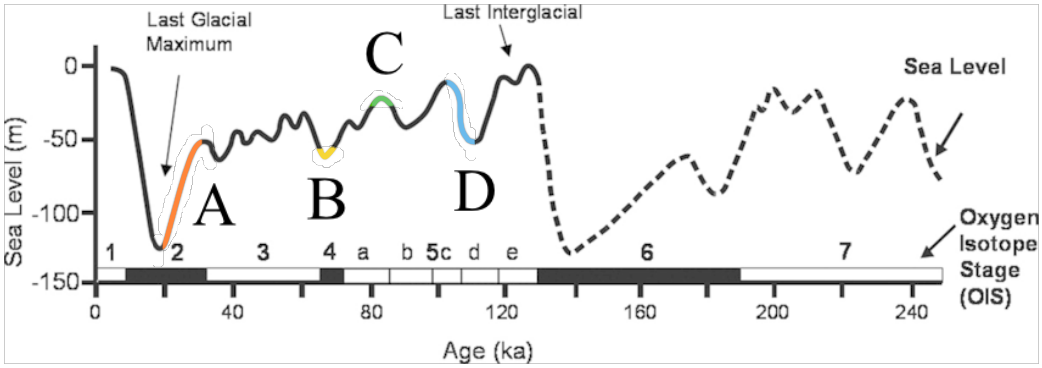


Figure 3: Sea level curve for the last 240,000 years.

4. (a) (3 points) Assuming that the course of the river remains unchanged, what is a reasonable location of its delta active approximately 15,000 years ago *relative* to the presently active delta? Answer in terms of the horizontal (landwards/seawards) and vertical dimensions (higher/lower elevation). Provide a justification for this shift in location using the sea level curve in Figure 3.

Solution: The delta active at 15 ka would be seawards of and at a lower elevation than the present delta. At 15 ka, global sea levels were below the present sea level, so it follows that the river base level and thus delta sediments were deposited lower as well. As the sea level rose, the shoreline moved landwards, transgressing up the gently sloped continental shelf, leaving the old delta submerged offshore.

(b) Depositional sequences often preserve incised valleys where rivers and distributaries downcut in the past.

i. (2 points) Choosing from A-D, from which time would one *least* expect to observe valleys being incised? Briefly explain.

Solution: D. Rising sea levels during this time would slow erosion rather than promote it; base level would have to decrease for downcutting to reestablish a graded state.

ii. (2 points) In one sequence of a particular locality, a stratigrapher finds incised valleys that correlate to this time interval. Propose *one* physical process that accounts for evidence of downcutting. Give your reasoning for this apparent contradiction.

Solution: (Multiple possible answers) The region may have experienced local tectonic uplift. Relative sea level change depends on both global sea level changes and local changes. In this case, for a period of time the rate of uplift may have exceeded the rate of global sea level rise such that the relative sea level fell.

Section II: Problem 2

Question	1	2	3	Total
Points	4	7	4	15 (30%)

Baekdusan (Chinese: Changbaishan, 长白山) is a large active stratovolcano on the China-North Korea border. Explaining its volcanism has proved to be quite enigmatic: it appears to be intraplate, there are no geochemical signs of flux melting, and there is no seismic signature of a deep mantle plume (hotspot).

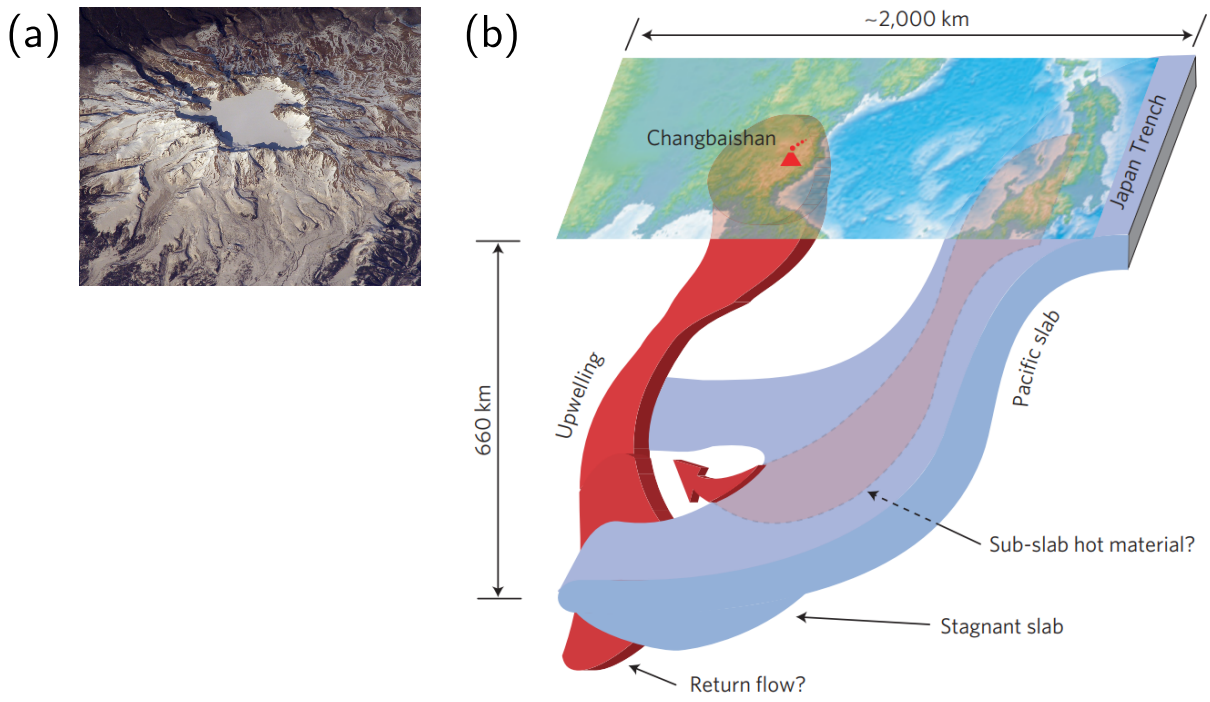


Figure 1: (a) Baekdusan as viewed from space; its caldera lake is covered with ice in the picture. (b) Tang et al. model of Northeast China intraplate volcanism.

1. One model is given by Tang et al. (2014), where a gap in the subducted Pacific plate has led to mantle upwelling and decompression melting.

   (a) (2 points) Why does the subducted slab flatten out at 660 km?

   Solution: Phase discontinuity at 660 km marks a "jump" in mantle density; the Pacific plate is too buoyant to penetrate and flattens due to this density stratification.

   (b) (2 points) Geochemical evidence has shown that magmatism at Baekdusan is associated with the partial melting of clinopyroxene-rich eclogite. What does this suggest about the upwelling in the Tang et al. model?

   Solution: Eclogites are associated with high T, high P metamorphism deep in subduction zones. The presence of eclogite suggests that the upwelling must carry up some parts of the subducted slab, as that is the only source of eclogite at that depth.

Jeju Island, a nearby volcanic island in the East China Sea, tells a different story.

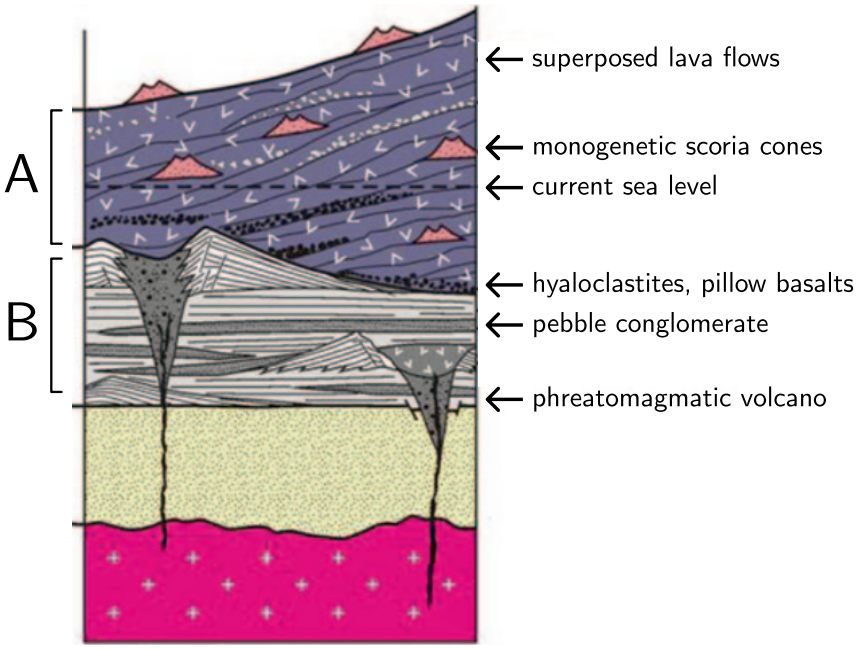


Figure 2: subsurface stratigraphy of Jeju Island. Monogenetic scoria cones are small vents that form from a single eruption. Letters A and B denote rocks generated by two separate stages of volcanism.

2. (a) (2 points) Jeju Island is a _____volcano generated from _____.

   A. Shield; a hot-spot

   B. Shield; subduction of the Pacific plate

   C. Composite; a hot-spot

   D. Composite; subduction of the Pacific plate

Solution: From the morphology and lava composition as given in Figure 2, we can reason that Jeju Island is a shield volcano. The cause of Jeju Island volcanism is debated, so both A and B were accepted during grading. In most cases, however, shield volcanos are generated by high magma production rates found above hotspots.

(b) (2 points) The lava flows on Jeju Island are mostly composed of a plagioclase clinopyroxene phyric (i.e., phenocryst-bearing) basalt. Briefly discuss what the presence of phenocrysts indicates about the cooling history of the basalts.

Solution: Phenocrysts are formed from initial slow cooling (e.g., in a magma chamber) followed by rapid cooling (e.g., during an eruption).

(c) (1 point) The eustatic sea level during the petrogenesis of B was _____than now.

A. Higher

B. Lower

C. Not enough information

(d) (2 points) Justify the above answer.

Solution: Presence of pebble conglomerate indicates that the depositional environment was relatively high energy (e.g., beach face, river mouth). Thus, the sea level during the petrogenesis of B was likely lower than now.

3. The most common volcanism on Earth happens out of sight, deep in the oceans. Ophiolites, remnants of oceanic lithosphere that have been emplaced onto land, allow us to study mid ocean ridge volcanism in more detail. Obduction is one mechanism by which ophiolites are displaced onto land, where compressive forces thrust the ocean floor onto continental crust.

(a) (2 points) Which of the following is true about ophiolites?

I) Obduction occurs more commonly for young oceanic crust than for old oceanic crust

II) Obducted mantle peridotite is usually enriched in incompatible elements

III) Ophiolites are often heavily metamorphosed

A. I only

B. II only

C. III only

D. II and III

E. I and III

F. I, II, and III

Solution: Younger oceanic crust is hotter, more buoyant, and more likely to obduct rather than subduct if subjected to compressional tectonic environments - I is true. Obducted mantle peridotite is almost always depleted in incompatible elements due to previous partial melting - II is false. Finally, considering the intense compressive forces necessary for obduction, it is reasonable for most ophiolites to be heavily metamorphosed - III is true.

(b) (2 points) Briefly discuss how variation in the global mean spreading rate at mid-ocean ridges can cause variation in the eustatic sea level.

Solution: Two lines of reasoning are provided: (1) Faster spreading $\longrightarrow$ prolific volcanic activity at ridges and margins $\longrightarrow$ more GHGs and enhanced GH effect $\longrightarrow$ thermal expansion of ocean water and ice sheet melt $\longrightarrow$ higher eustatic sea level; (2) Faster spreading $\longrightarrow$ greater buoyancy of ocean lithosphere $\longrightarrow$ oceanic crust displaces more volume $\longrightarrow$ higher eustatic sea level. The opposite applies for slower spreading.

END OF EXAM