

USESO 2023



Training Camp Exam

Multiple Choice

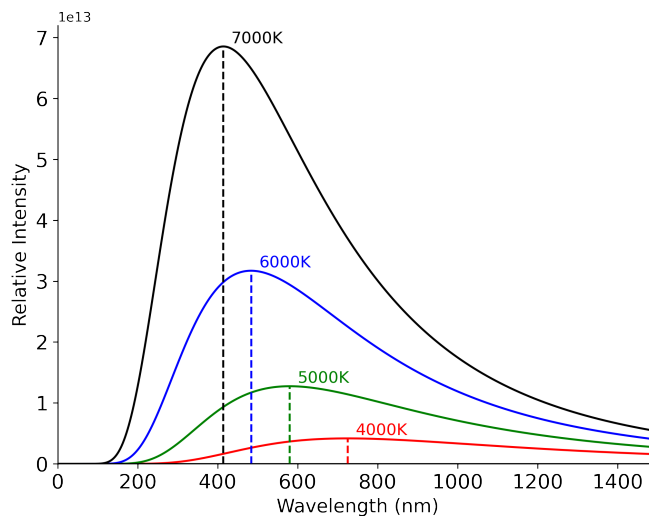
Instructions:

- Section I consists of 20 multipart questions that assess geoscience knowledge in the form of multiple choice questions. Each question is worth 2 points.
- You have 45 minutes.
- Any type of calculator is allowed.
- Participating in this exam is agreement to our academic integrity policy.

- Oxbow lakes can indicate a hypothetical maximum meander size somewhere along a river. Which of the following processes is responsible for keeping meander size below this limit?
 - Deposition at outer bank
 - Erosion at outer bank**
 - Deposition at inner bank
 - Erosion at inner bank

Solution: Oxbow lakes are formed in meandering rivers. The outer banks are eroded while sediment is deposited at the inner banks. Eventually, the erosion on the outer bank causes the river to cut through the narrow neck of a meander, creating a straighter channel that leaves the oxbow lake disconnected. As such, erosion at the outer bank will prevent the largest oxbow lakes from growing.

- Planck's law gives the intensity of light as a function of its frequency ν emitted by a blackbody at a temperature T . At high frequencies, the intensity is proportional to $\nu^3 e^{-k\nu/T}$ where k is a constant. The following figure shows the relative intensity of light as a function of wavelength for four blackbodies with temperatures labeled.



Which of the following statements are true?

- At small wavelengths such as those shown here, peak wavelength is inversely proportional to temperature.
 - As the temperature of the object increases, the intensity at any wavelength increases.
 - If the maximum intensity of light emitted by a blackbody is at 5000 nm, then its temperature, to one significant figure, is 600 K.
- II only
 - I and II
 - I and III
 - I, II, and III**

Solution: Wien's law states that maximum wavelength is inversely proportional temperature, a property also seen in the graph - I is true. For each successive increase in temperature, the intensity at every wavelength is strictly higher - II is true. Since the wavelength of maximum intensity of a black body at 5000 K is about 600 nm and the two have an inverse relationship, the inverse is also true - III is true.

3. You are using a machine learning algorithm that takes in satellite imagery to map out river basins from different climate regions. You find that the rate of meander formation tends to decrease with aridity. Why might this be the case?

A. Regions with lower aridity tend to have increased bank strength

B. Regions with lower aridity tend to have decreased bank strength

C. Aridity has no effect on bank strength

D. Bank strength has no effect on rate of meander formation

Solution: In order to form meanders, rivers must have a certain level of bank strength in order to stabilize the river path; in fact, it has been suggested that meandering rivers only came into existence after the development of land plants. Regions with lower aridity would have more vegetation to stabilize banks, allowing strong meanders to form.

4. After the Great Oxidation Event approximately 2.3 billion years ago, greater carbon burial resulted in global lubrication of tectonic activity due to the ductile nature of organic shales and their metamorphism to low-friction graphite. Which of the following would **not** be expected to increase as a result of this change?

A. Formation of volcanic andesites

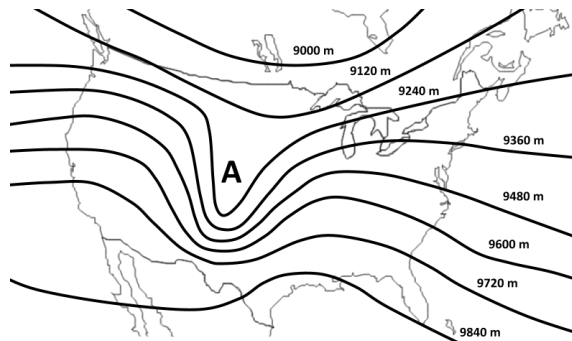
B. Global sea level

C. Metamorphic grade of continental orogens

D. Ocean magnesium concentration

Solution: The primary effect of sediment lubrication is an increase in tectonic activity, since there is less friction to slow down plate movement. This activity results in an increase in mountain building, causing an increase in both granite formation and continental deformation. An increase in tectonic activity and spreading rate also typically increases sea level by reducing the average age of oceanic crust, making it thicker and reducing ocean volume. An increase in tectonic activity would speed up the carbonate-silicate cycle but likely not cause a significant shift in ocean pH without external forcing. In this time period, the primary cause of a pH change would be the massive drop in CO₂ concentrations after the GOE, which would reduce the formation of carbonic acid and therefore reduce ocean acidity. For further discussion of this topic, see Parnell et al., 2021.

5. Consider the following upper-level isobaric map. Based on the inferred surface conditions from this map, the surface wind at point A is most likely blowing toward which of the following directions?



A. Northeast

B. Northwest

C. Southeast

D. Southwest

Solution: Surface level conditions can be inferred from an upper level map based on areas of convergence and divergence. To the west of point A, upper level convergence indicates sinking air and high surface pressure, while to the east of point A, upper level divergence indicates rising air and low surface pressure. Air flow between these two systems is directed east because it moves from high pressure to low pressure and south because the high-pressure western system rotates clockwise and the low-pressure eastern system rotates counterclockwise. As a result, the most likely direction of air flow is southeast.

6. A hyperpycnal plume is a type of turbidity current that forms when sediment-rich river water enters the ocean and sinks. The formation of these plumes is rarely consistent, often depending on seasonal factors. Which of the following summertime conditions would favor hyperpycnal plume formation?

- I) High sea surface temperature
- II) Decreased precipitation over the ocean
- III) Glacial meltwater feeding the river

- A. II only
- B. III only
- C. I and II
- D. I and III**
- E. None

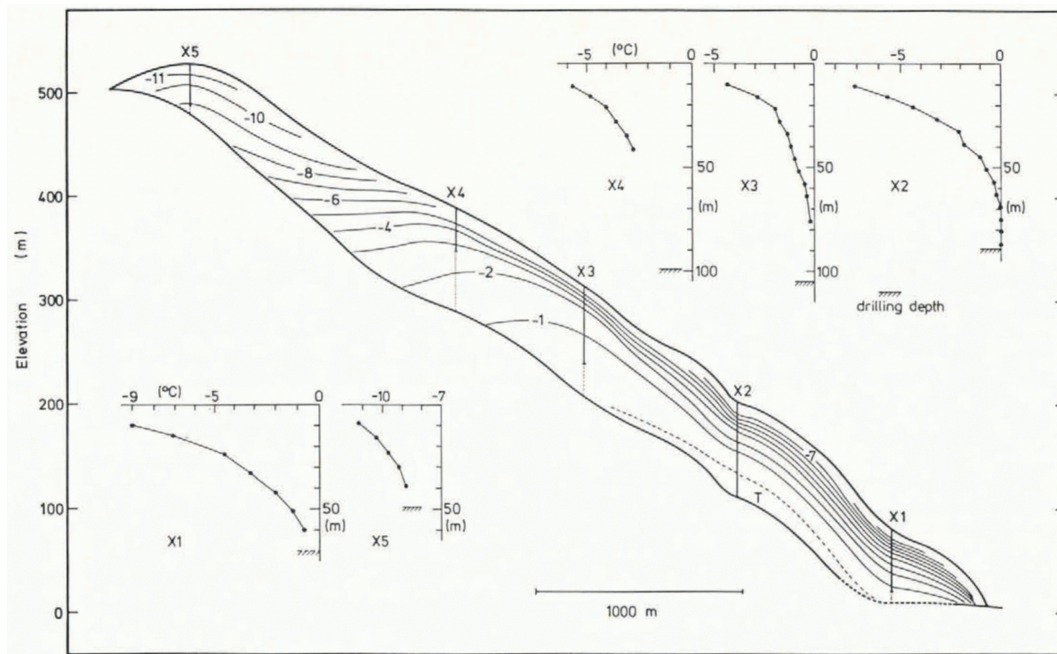
Solution: Hyperpycnal plumes form when river water has high density and ocean water has low density. High sea surface temperature decreases ocean density, favoring plume formation - I is true. High evaporation rates increase ocean salinity and therefore density, limiting plume formation - II is false. Glacial meltwater does not change the density of the water itself, but meltwater typically contains high sediment concentrations, increasing river water density and favoring plume formation - III is true.

7. Which of the following strata is least likely to be found in a fold?

- A. Near-surface quartzite strata**
- B. Near-surface shale strata
- C. Deep quartzite strata
- D. Deep shale strata

Solution: Folds form as a result of ductile deformation. The degree of folding that a bed experiences depends on its composition and the pressure-temperature conditions it is subject to with depth. Because quartzite is much less ductile than shale and ductility increases with depth below the surface, near-surface quartzite strata would be least likely to undergo ductile deformation.

8. The figure below is a profile of the Laika ice cap in Canada showing temperature contours in °C. X1-X5 are drilling sites where the temperature vs. depth was measured.



Which of the following accurately compares the ice at X2 relative to other drill sites?

- A. Ice at X2 likely entrains more sediments than at X4.**
- B. More liquid at the base of the glacier was generated by surface melt at X1 than X2 at the time of data collection.
- C. A glacial surge is more likely to occur at X3 than X2.
- D. X2 only flows by basal slip while X4 flows only by internal deformation.

Solution: At X2, ice contacting the bed melts to create liquid water, which reduces friction and increases sediment uptake - A is correct. Liquid at the base of the glacier cannot be generated by surface melt because the glacier's surface is above freezing - B is incorrect. Ice at X3 is likely still frozen to the bed, while X2 has liquid water that would make a glacial surge more likely - C is incorrect. Internal deformation will occur throughout the glacier, so no region will only flow by basal slip - D is incorrect.

9. The light-colored areas of the lunar surface are composed of anorthosite, a rock mostly composed of Ca-rich plagioclase feldspar, formed billions of years ago. Which of the following mechanisms best explains how this anorthosite formed?
- A. Large mantle plumes pushed ultramafic mantle material through early crust
 - B. Lunar crust solidified before differentiation due to heat loss from radiation
 - C. Impacts exposed ultramafic mantle material that solidified into anorthosite
 - D. Anorthite crystals formed early in crystallization and floated upwards**

Solution: Although anorthite crystallizes relatively early, it is a type of feldspar and is relatively felsic. As a result, anorthite has a lower density than is typical of magmas on the Moon and on Earth. When it crystallized early in the Moon's formation, it rose to form the early solid crust. This is the only mechanism that would create anorthosite, as any mantle material that solidified would also form other early-crystallizing minerals like olivine and pyroxene.

10. Which of the following statements are typically true about clouds in the presence of an atmospheric inversion?

- I) Most updrafts under these conditions will form cumuliform clouds.
- II) Air lifted up to the inversion forms clouds similar to some at warm fronts.

- A. I only
- B. II only**
- C. I and II
- D. None

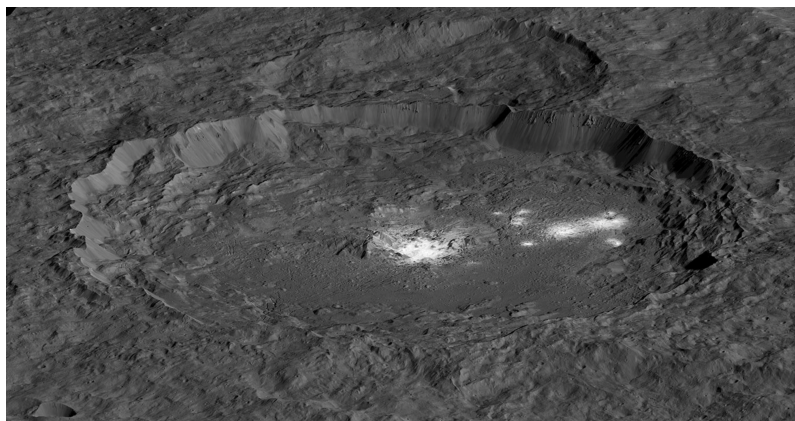
Solution: Cumuliform (or convective) clouds form when warm humid air rises through cooler surrounding air in the atmosphere. These clouds form in an unstable atmosphere, so they are less common with low inversions where warm air lies above denser cold air - I is false. Air lifted into a stable layer forms stratus or nimbostratus clouds, which are also produced by the frontal inversion of warm fronts - II is true.

11. Potassium-40 can decay into argon-40 or calcium-40, with the decay to argon occurring 10.7% of the time. The *overall* half-life of the decay of potassium-40 is 1.25×10^9 years. You find a sample of dacite from the Mount St. Helens eruption from 1980. The concentrations of potassium-40 and argon-40 in the rock is measured to be 1.35 ppm and 0.017 ppm, respectively. Calculate the age of the sample, in years.

- A. 2.4×10^6 years
- B. 2.3×10^7 years
- C. 2.0×10^8 years**
- D. 4.1×10^9 years

Solution: The 0.017 ppm of argon-40 that has been found is 10.7% of the total concentration of potassium-40 that has decayed; that value is $\frac{0.017}{0.107} = 0.16$ ppm. The starting concentration of potassium-40 must be the current concentration plus the concentration that has decayed; that value is $1.35 + 0.16 = 1.51$ ppm. The time elapsed is equal to $(t_{1/2}) \log_{1/2}(\frac{N}{N_0}) = (1.25 \times 10^9 \text{ years}) \log_{1/2}(\frac{0.16\text{ppm}}{1.51\text{ppm}}) = 2.0 \times 10^8$ years.

12. The surface of Ceres shows several small bright spots (depicted below) which have been shown to be primarily composed of hydrated salts. Given the reconstructed image below, which of the following gives a reasonable explanation for the formation of these salt deposits?

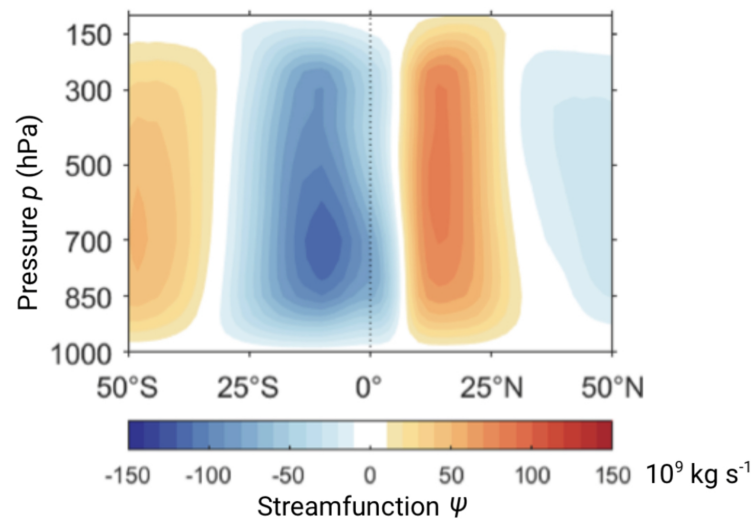


Cerealia and Vinalia Faculae, two bright spots in the Occator Crater

- A. Addition of material during impact cratering
- B. Brine release from the mantle in localized events of cryovolcanism**
- C. Uplift of a salt dome
- D. Melt of dispersed ice deposits during solar storms

Solution: This material would have to originate from the planet, as a body impacting the surface would likely form larger deposits with a clearer pattern - A is incorrect. However, it's unlikely that Ceres would have a salt dome beneath its surface or ice deposits that would melt due to solar activity - C and D are incorrect. Ceres, like many other dwarf planets, is known to have cryovolcanism on its surface that releases water and other compounds - B is correct.

13. Consider the following plot of climatologically averaged, zonal mean (i.e., averaged east-west) streamfunction ψ of the Hadley cells. The magnitude of ψ is related to the circulation strength, and the northward wind velocity v is related to the vertical gradient $\frac{\Delta\psi}{\Delta p}$.



(adapted from Li et al. 2022)

Additionally, idealized models show that both cells have the same poleward mass fluxes when solar heating is centered at the equator. Which of these is/are true about Hadley cell dynamics?

- I) Surface convergence occurs below a region with a positive streamfunction gradient ($\frac{\Delta\psi}{\Delta\phi} > 0$ where ϕ is latitude)
- II) At 300 hPa, maxima in westerly winds can be found at latitudes directly above the highest magnitude ψ values in each hemisphere

- A. I only**
- B. II only
- C. I and II
- D. None

Solution: Surface convergence occurs where the two Hadley cells meet, which on average is slightly north of the equator. Above the surface, values of ψ increase with latitude. Alternatively, since ψ decreases in the southern cell and increases in the northern cell with decreasing p , $v > 0$ winds from the south converge with $v < 0$ winds from the north - I is true. Although subtropical jets in both hemispheres are westerly (their winds blow from west to east), they are strongest at the edges of both Hadley cells, which is around 30°N or $^\circ\text{S}$ from the plot. These are *not* directly above the highest ψ values - II is false.

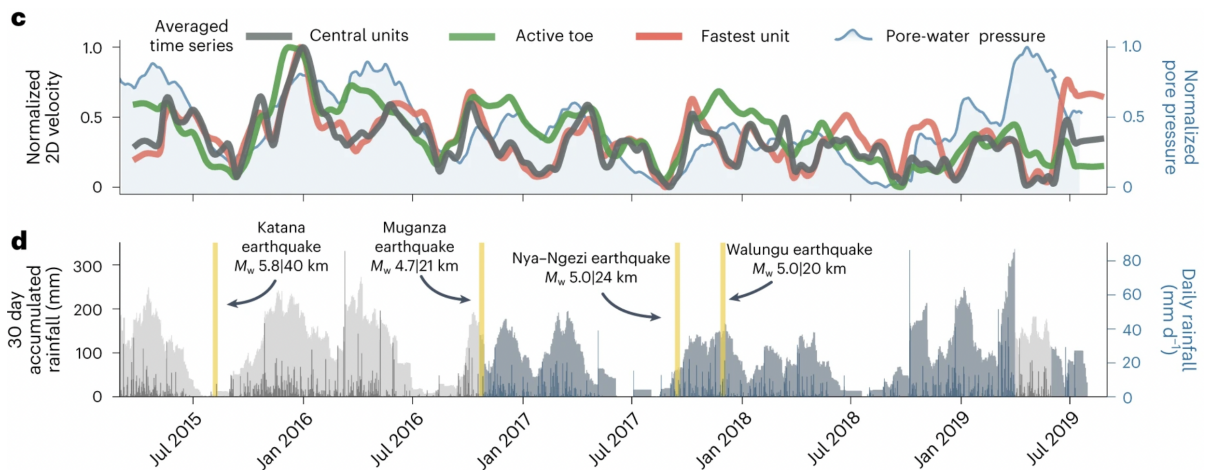
14. A commonly studied analogue for the effects of modern-day climate change is the Paleocene-Eocene Thermal Maximum, a short time period approximately 55 million years ago in which global temperatures rose by 5-8 $^\circ\text{C}$. One of the proposed causes for this event is large-scale volcanic activity injecting both CO_2 and CH_4 into the atmosphere. After the phase of temporary cooling, which of the following best describes how this injection affected oceanic primary productivity and then dissolved oxygen concentrations, respectively?
- A. Increase; increase
 - B. Increase; decrease**
 - C. Decrease; increase
 - D. Decrease; decrease

Solution: The PETM is notable for experiencing strong ocean anoxia, thought to have been caused by an abundance of surface marine organisms. Increased CO_2 concentrations typically increase primary productivity because primary producers use CO_2 during photosynthesis. This increased productivity results in a broader increase in marine biological activity, including many organisms that depend on dissolved oxygen. As demand for dissolved oxygen increases, much of it is used up, leading to anoxic conditions.

15. Since the length of a day on Earth is much shorter than the length of a year, the sidereal day on Earth is almost exactly the same as a solar day. However, on other planets, such as Mercury and Venus, the length of the sidereal day is significantly different from the solar day. Which of the following statements is true?
- I) Unlike the Earth, the sidereal day on Venus is shorter than its solar day.
 - II) A planet tidally locked to its parent star will have an infinitely long solar day.
- A. I only
 - B. II only**
 - C. Both I and II
 - D. None

Solution: Venus's retrograde rotation means its solar day is shorter than its sidereal day, the opposite of Earth - I is false. A tidally locked planet will never cycle between day and night, so its solar day will never end - II is true.

16. The following image shows how the velocity of a slow, deep-seated landslide (top, bold lines) depends on sub-surface pore pressure (top, thin line) and rainfall (bottom). Which of the following human-related factors would likely increase the velocity of this landslide?



- I) Increase in road and building cover
 - II) Storm drains rerouting runoff via restricted channels
 - III) Climate change-induced shortening of wet season
- A. II only
 - B. III only
 - C. I and II
 - D. I and III
 - E. None

Solution: As seen in the image, the velocity of the landslide is directly related to pore water pressure. An increase in road and building cover reduces infiltration and increases runoff, reducing the amount of water that enters pores and reducing landslide speed - I is false. The same effect occurs due to the rerouting of runoff, as runoff infiltrates and destabilizes soil more quickly when it is distributed rather than concentrated - II is false. Lastly, a shorter wet season reduces the time available for water to infiltrate, again resulting in more runoff and lower pore water pressure that stabilizes soil - III is false. For further discussion of this topic, see Dille et al., 2022.

17. A continuously-pumped well reduces pressure around it, creating a cone of depression where water is drawn down. The shape of the cone depends on the transmissivity of the aquifer, defined as the volumetric rate of flow per unit thickness per unit hydraulic gradient. Given the same flow rate, how would the steepness of a cone of depression in an aquifer with lower transmissivity compare to that with a higher transmissivity?
- A. Steeper, since the hydraulic gradient compensates for transmissivity
 - B. Shallower, since the hydraulic gradient compensates for transmissivity
 - C. Steeper, since lower transmissivity increases the permeability of the aquifer
 - D. Shallower, since lower transmissivity decreases the permeability of the aquifer

Solution: Lower transmissivity can be loosely described as water less easily moving through a medium. To maintain the same pumping rate, a stronger (steeper) gradient would have to form to compensate for the restriction of water movement due to low transmissivity. Transmissivity and gradient steepness are inversely proportional.

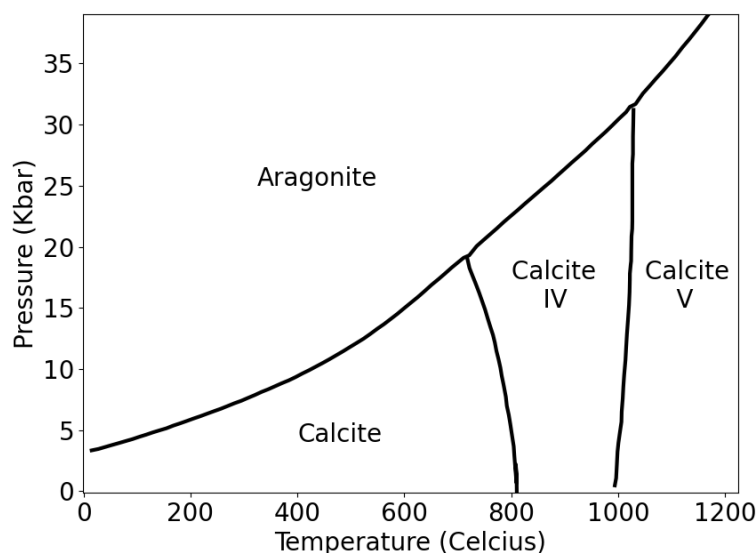
18. Suppose you are testing different models of Earth's radiative budget, and notice that some models overestimate the global mean surface temperature T_{sfc} compared to observations. Assuming no other errors are made in each case, which of these errors will result in an overestimate of T_{sfc} ?

- I) Overestimating the concentration of tropospheric ozone, with an absorption peak within the atmospheric window
- II) Overestimating energy flux from convection and latent heat transfer
- III) Overestimating coverage of cirrus clouds, which are thin and located in the upper troposphere

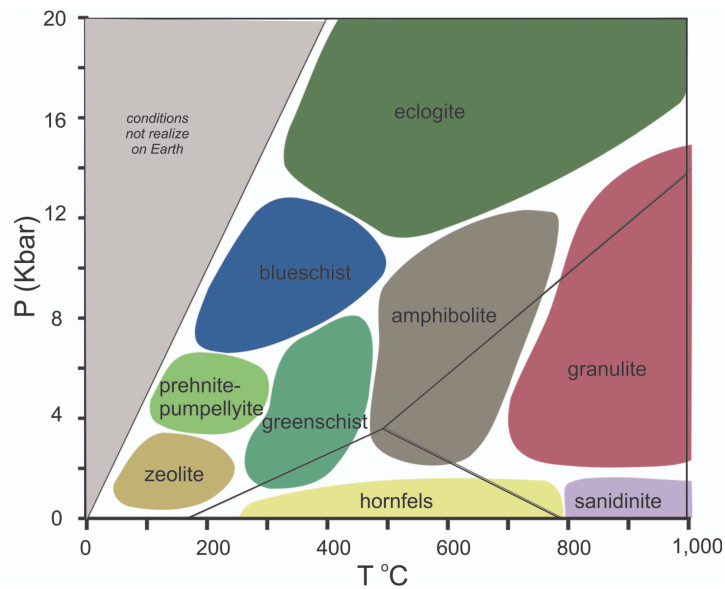
- A. I only
- B. III only
- C. I and II
- D. I and III**
- E. II and III
- F. I, II, and III

Solution: Overestimating tropospheric ozone would result in increased absorption of infrared radiation that would otherwise escape to space (due to absorption within the atmospheric window), reducing outgoing longwave radiation. This also causes some infrared radiation to be emitted towards the surface and warms the surface - I is true. The net direction of convective and latent heat transfer (due to evaporation) is from the surface to the atmosphere. Overestimating these outgoing energy fluxes results in an underestimate of T_{sfc} - II is false. Cirrus clouds allow nearly all incoming solar radiation to pass through (and thus reflect little radiation), but absorb some outgoing infrared radiation. They are also cold, so emit little outgoing longwave radiation; overall, they have a net warming effect. Thus, overestimating cirrus coverage would result in an overestimate of T_{sfc} - III is true.

19. Below is a phase diagram for calcium carbonate.



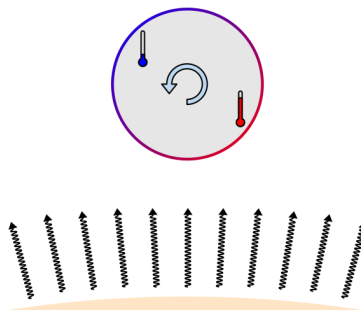
A proposed process for the production of elemental carbon in the earth's crust involves the reaction of CaCO_3 with SiO_2 to form CaSiO_3 during subduction. Reactions with which of the following polymorphs of CaCO_3 would be least energetically favorable per mol carbon produced during subduction? A pressure-temperature diagram for metamorphic facies is provided for reference.



- A. $\text{CaCO}_3(\text{Calcite}) + \text{SiO}_2 \longrightarrow \text{CaSiO}_3 + \text{C} + \text{O}_2$
- B. $\text{CaCO}_3(\text{CalciteIV}) + \text{SiO}_2 \longrightarrow \text{CaSiO}_3 + \text{C} + \text{O}_2$
- C. $\text{CaCO}_3(\text{CalciteV}) + \text{SiO}_2 \longrightarrow \text{CaSiO}_3 + \text{C} + \text{O}_2$
- D. $\text{CaCO}_3(\text{Aragonite}) + \text{SiO}_2 \longrightarrow \text{CaSiO}_3 + \text{C} + \text{O}_2$**

Solution: The least energetically favorable reaction would involve the least amount of energy released, so it would involve the lowest-energy, or most stable, reactant. In conditions corresponding to the blueschist facies, aragonite is the most stable reactant, so the least energetically favorable reaction would begin with aragonite.

20. Now determined to be highly unlikely, near-Earth object 99942 Apophis was once thought to have a small chance of impacting the Earth in the near future. The uncertainty came from the Yarkovsky effect, a mechanism for the propulsion of rotating Solar System bodies through thermal emission (and resulting transfer of momentum). The propulsion relies on solar heating of the surface of a rotating body, shown in the figure below.



Simplified depiction of the surface heat profile of a rotating body orbiting the sun.

Identify all of the following that are true of the Yarkovsky effect on approximately spherical near-Earth asteroids.

- I) The Yarkovsky effect accelerates near-Earth asteroids in prograde rotation in their direction of motion.
- II) Larger asteroids experience greater acceleration.
- III) Amor asteroids (perihelion greater than 1 AU) are generally more affected than Atria objects (aphelion less than 1 AU).

- A. I only
- B. II only
- C. I and III**
- D. II and III

Solution: For an asteroid rotating in the same orientation as its revolution around the Sun, the warmest area faces away from the direction of velocity, so acceleration is in the same direction as velocity - I is true. While larger bodies do have more surface area, which would allow for a greater force, mass grows far faster than surface area because it is proportional to r^3 rather than r^2 - II is false. Bodies closer to the Sun absorb and emit more radiation, so they will have a greater temperature difference - III is true.