

## **Written Test, Part 1 + Part 2 (3 hours)**

### Grading of Questions

Each question with only one correct answer will be scored as follows:

- if the correct answer is chosen: +1 point.
- if the incorrect answer is chosen: 0 point.
- if several answers are chosen: 0 point.

Each question where one or more correct answers possible will be scored as follows:

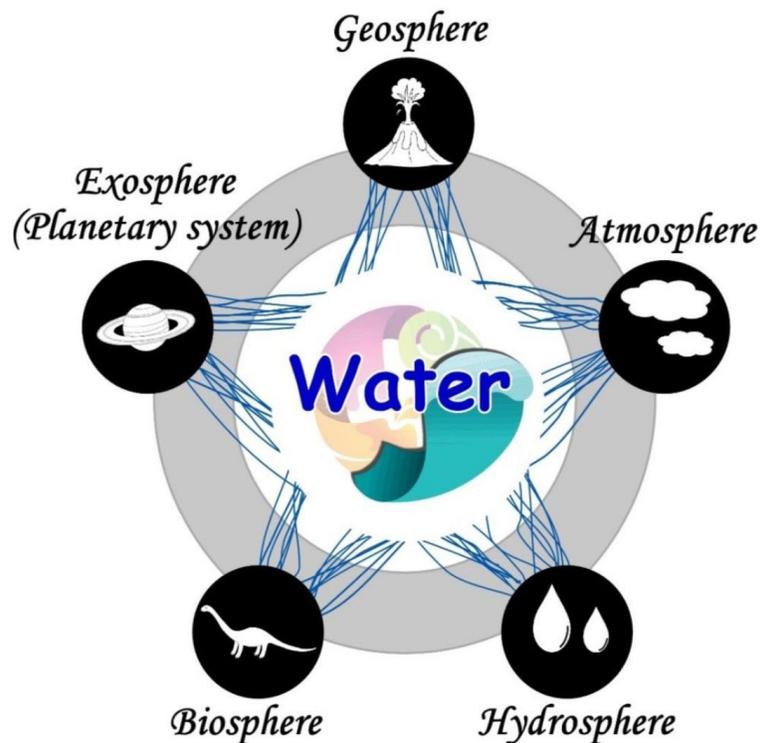
- each correct answer: +1 point.
- each incorrect answer: -0.5 point.
- if the combination of answers includes correct answers and incorrect answers, the minimum grade received is 0.

## Part 1 Theme: Water

Water is distributed over the entire surface and interior of the Earth, not just in seas, lakes and the atmosphere, but also in rocks and soils. Water circulates through the Earth system and causes several phenomena.

Through its presence, life arose and many forms of life evolved and endured. The Earth has become a dynamic habitable space.

In addition, water is present in different forms in the celestial bodies of the Solar System. It exists, as on Earth, especially in solid form: ice.



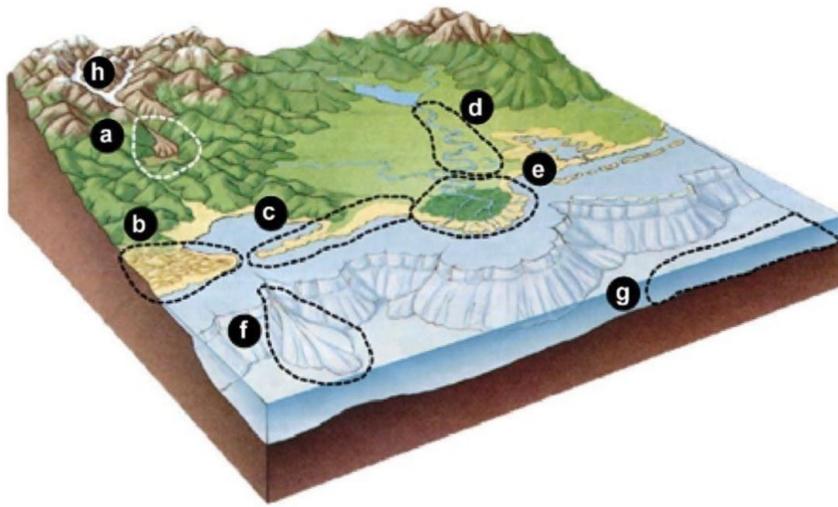
In this test, we will assess your knowledge and inference skills about the presence of water on Earth and the Solar System and the interactions within the geosphere, atmosphere, hydrosphere and the biosphere.

**Introduction to question Q1**

Figure A depicts various depositional environments, ranging from continental to marine environments. The symbols from (a) to (h) represent different environments:

- (a) alluvial,
- (b) aeolian,
- (c) beach,
- (d) fluvial,
- (e) delta,
- (f) submarine canyon,
- (g) abyssal plain,
- (h) glacial environment.

Figure B shows the topography and sediments of the depositional environments (a) through (h) in Figure A.



**Figure A**



**Figure B**

**Q1)** Water and wind are the main agents responsible for sediment transport. Choose ALL of the correct statements in the context of water and wind sediment transport.

- a) The overall size of alluvial sediments (a) is generally larger than that of submarine fan sediments (f)
- b) Beach sediment (c) contain a high proportion of angular rock fragments
- c) In fluvial environments (d), finer particles are transported in suspension while larger particles are transported in contact with the bottom of the stream bed
- d) When sediments are transported in rivers, their grain size gradually increases and they become less and less rounded
- e) The coarsest sediments between (a) and (h), settle in the delta (e)

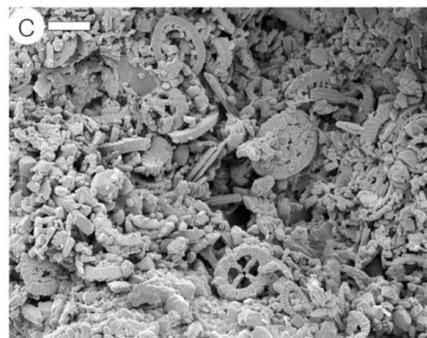
**Introduction to questions Q2-Q3**

The sea cliffs along the Strait of Dover between France and Great Britain are made up of horizontal beds of white rock (Figure A).

A sample (Figure B) taken from these cliffs effervesces on contact with a drop of dilute hydrochloric acid. An electron microscope image (Figure C) of the sample in Figure B shows that the rock is made up of very fine particles and fragments of coccolithophores, a single-celled species of calcareous phytoplankton (the scale is 1cm for Figure B and 5 $\mu$ m for Figure C.)



Figure A



The sediments that make up the rock in Figure B (above) are being deposited in the blue area in Figure D. Such sediments are also found around the Hawaiian Islands. Figure E shows the ocean floor topography and water depth along the X-Y segment of Figure D. These sediments are not found on an ocean floor located at a water depth > 3500m. The primary reason for this observation is the balance between input and dissolution of carbonate sediments, which refers to carbonate compensation depth (CCD).

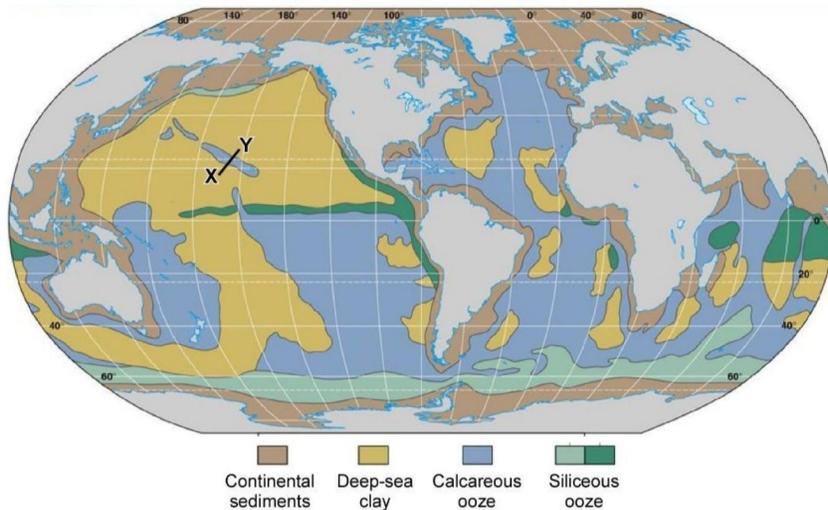


Figure D

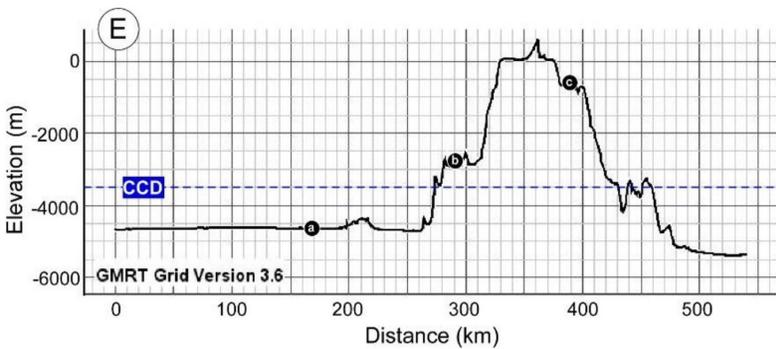


Figure E

**Q2)** Select ALL of the correct statements about the sediment and depositional environment involved in the formation of the white rock in Figure B.

- a) This rock can be classified as chemical sediment / sedimentary rock
- b) This rock is mainly composed of calcium carbonate, a mineral called calcite
- c) Calcite originates from calcium carbonate secreted by living planktonic organisms near the ocean surface
- d) Similar rocks are formed today in tropical marine environments by aggregation of calcium carbonate skeletons, leading to the formation of coral reefs
- e) This rock is a residue of silica secreted by planktonic organisms accumulated on the ocean floor
- f) This rock represents direct interactions between the geosphere and the biosphere
- g) This rock represents only the influence of the biosphere on the geosphere

**Q3)** Select ALL of the correct statements about the sediments (a), (b) and (c) around the Hawaiian Islands in Figure E.

- a) The solubility of the mineral calcium carbonate tends to decrease when the water depth increases from (c) to (a)
- b) High water pressure increases the solubility of the mineral calcium carbonate in (a)
- c) The sediments in (b) are mainly composed of residues of calcareous organisms
- d) The sediments in (a) are mainly composed of foraminifera shells and fragments of other calcareous organisms
- e) The sediments in (b) and (c) contain both siliceous and calcareous sediments

**Introduction to questions Q4-Q6**

P and Q are magmas of different compositions. The figures below illustrate the relationship between viscosity and temperature of magma in dry conditions (Figure A), and the relationship between viscosity and water content in wet conditions (Figure B).

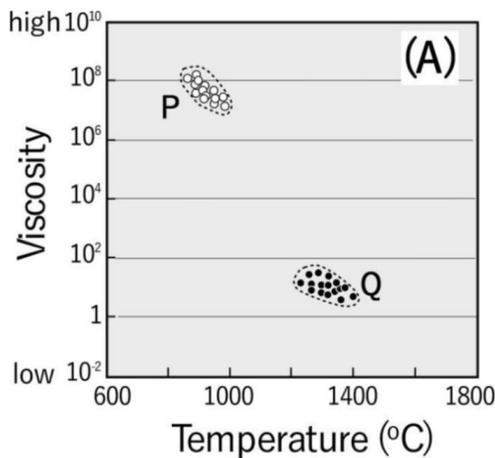


Figure A

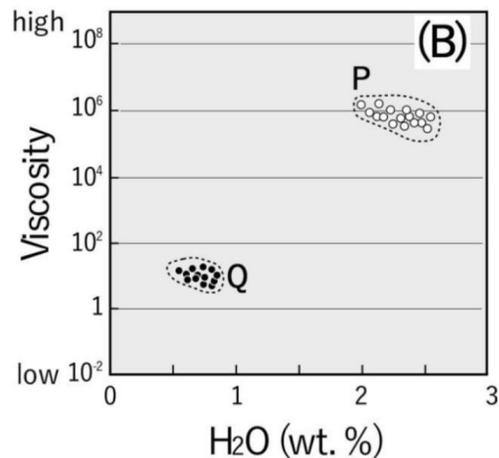
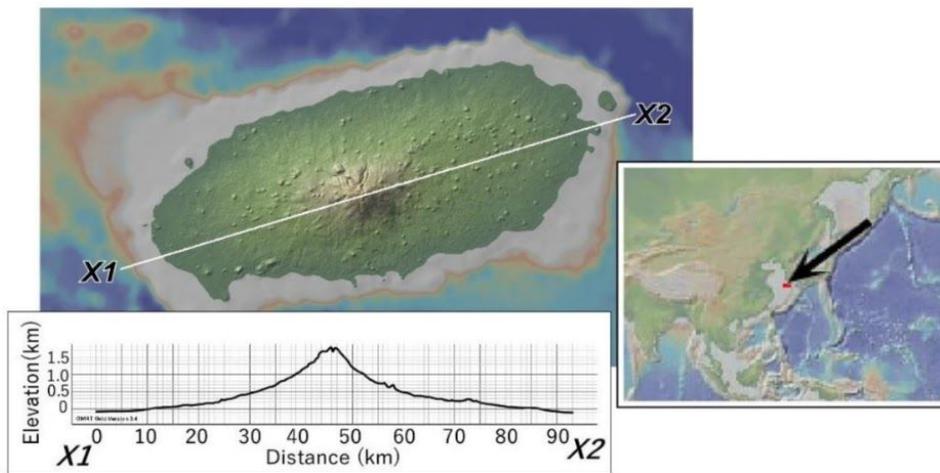


Figure B

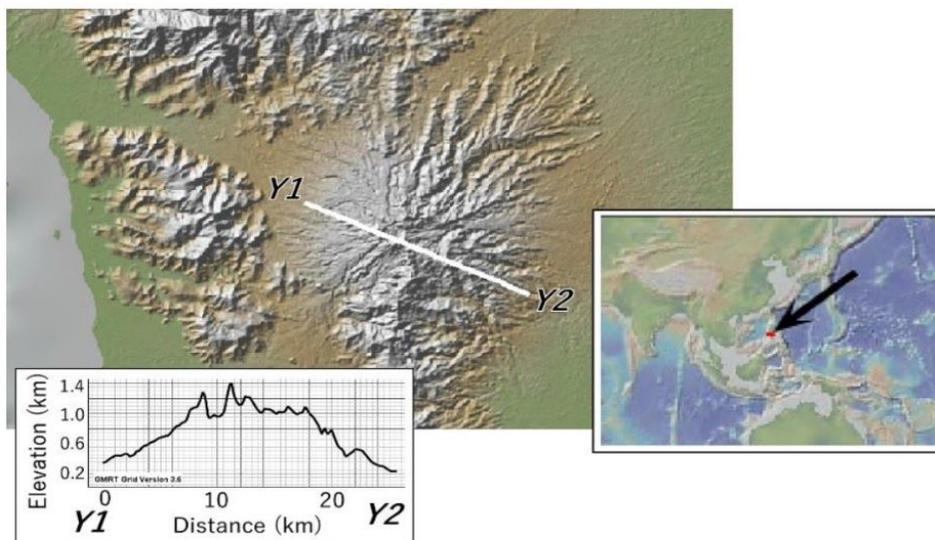
**Q4)** Select ALL the correct statements about P and Q magmas in Figures A and B.

- a) Magma P forms at a higher temperature than magma Q
- b) Magma P forms at a lower temperature than magma Q
- c) Magma Q has a higher water content than magma P
- d) The viscosity of magma P decreases when the water content increases
- e) Magma P has a lower silica content than magma Q
- f) Magma P has a higher silica content than magma Q

Two types of volcanoes are represented on the satellite images below (with the topographic profile in section): the volcanic island Jeju is located south of the Korean peninsula (Figure C) and the Pinatubo volcano is located north of the Luzon Island in the Philippines (Figure D).



**Figure C**

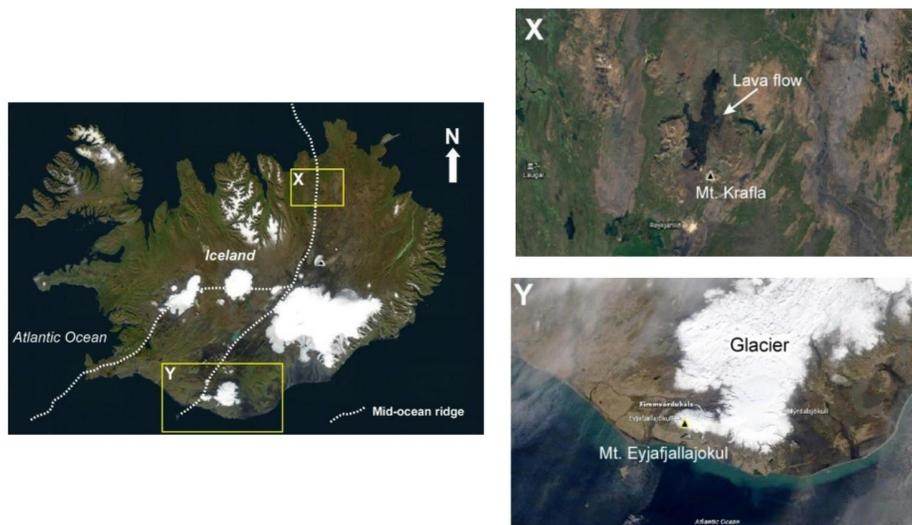


**Figure D**

**Q5)** Select ALL of the correct statements about the volcanoes in Figures C and D.

- a) The volcano in Figure C is formed from magma P in Figures A and B
- b) The volcano in Figure D is formed from magma P in Figures A and B
- c) The volcano in Figure C is formed from magma Q of Figures A and B
- d) The volcano in Figure D is formed from magma Q of Figures A and B
- e) The volcano in Figure C is mainly composed of rhyolite
- f) The volcano in Figure C is mainly composed of basalt
- g) The difference in slope between the two volcanoes is the result of the variation in the composition of the magma

Figure E is a satellite image of Iceland with the Mid-Atlantic Ridge and associated volcanic activity. Figure F shows enlargements of regions X and Y in Figure E. The Krafla volcano (region X), located in northern Iceland, erupted along fissures because magma has a low viscosity. On the other hand, in the southern part, the Eyjafjallajökull volcano (region Y) is an explosive volcano that releases a large amount of volcanic ash.



**Figure E**

**Figure F**

**Q6)** Select ALL of the correct statements about the two volcanic regions of Iceland.

- a) The volcanoes of regions X and Y are formed from magma P shown in figures A and B
- b) The volcanoes of regions X and Y constitute a divergent plate boundary
- c) Region X forms a high altitude terrain due to the high viscosity of the lava
- d) The volcanoes of the X and Y regions mainly emitted basalt formed from magma Q shown in Figures A and B
- e) The explosive volcanic activity of region Y is due to an inflow of water from outside
- f) Regions X and Y are not suitable for the installation of geothermal power plants

**Introduction to questions Q7-Q8**

Figure 1 is a map of the total water vapor column (monthly average). The total column means quantity integrated vertically, in  $[g/cm^2]$ .

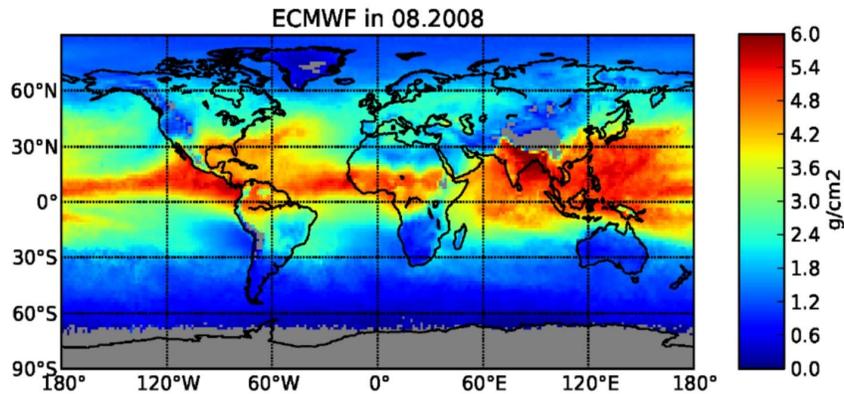


Figure 1

Figure 2 illustrates an experimental protocol for measuring the saturated vapor pressure of pure water at a specific temperature ( $T$ ) and pressure ( $P$ ), where  $h$  is the height of the mercury column ( $Hg$ ).

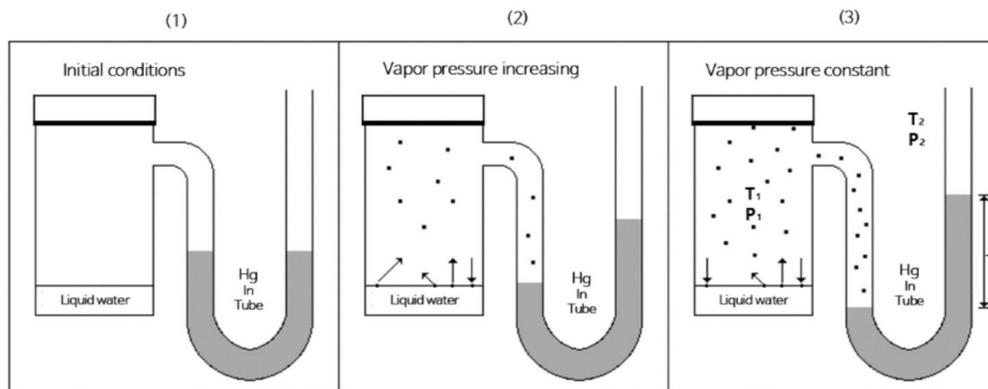


Figure 2

**Q7)** Select ALL correct statements about Figure 2.

- a) The height of mercury in the sticker tube (3) rises when  $T_1$  increases
- b) The height of mercury in the sticker tube (3) rises when  $P_1$  increases
- c) The height of mercury in the sticker tube (3) rises when  $T_1$  decreases
- d) The height of mercury in the sticker tube (3) rises when  $P_2$  decreases
- e) The height of mercury in the sticker tube (3) rises when  $P_2$  increases
- f) The height of mercury in the sticker tube (3) rises when  $T_2$  and  $P_2$  simultaneously increase

**Q8)** Based on the experiment in Figure 2, select ALL descriptions explaining the distribution of the water vapor column in the Earth's atmosphere in Figure 1.

- a) A higher temperature at lower latitude implies a greater amount of water vapor in the atmosphere
- b) Atmospheric pressure over the western tropical Pacific Ocean is greater than that of the eastern tropical Pacific Ocean
- c) The atmospheric temperature of the western tropical Pacific Ocean is greater than that of the eastern tropical Pacific Ocean
- d) The column of water vapor over the equatorial ocean is greater than that of the subtropical ocean
- e) The air over the oceans on the eastern coasts of the continents at mid-latitudes contains more water vapor than that present over the oceans of the western coasts because of the more frequent presence of low pressure zones

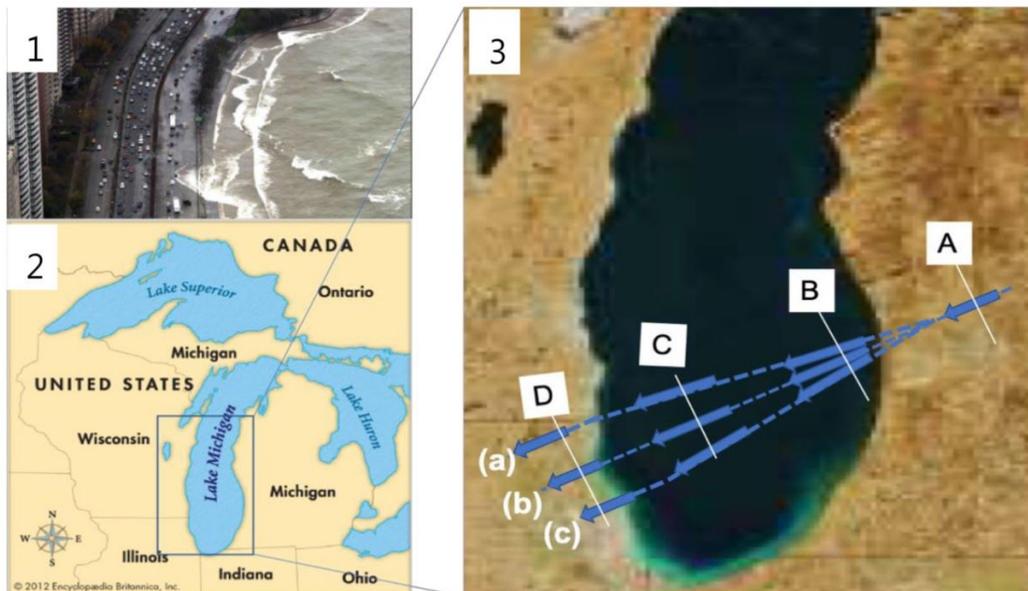
**Introduction to question Q9**

Strong winds blowing over an open area of water, such as a lake, can generate waves that oscillate back and forth (Figure 1). Figures 2 and 3 show the wind speed and direction as warm, humid air flows over a large lake in the Northern Hemisphere.

In position A, the wind blows at 5 m / s from the ENE;

In position B, the wind blows at 7.5 m / s;

In position D, the wind blows again at 5 m / s from the ENE.



**Q9)** Choose ALL of the correct statements about local winds that cross a large body of water, as in the figure above.

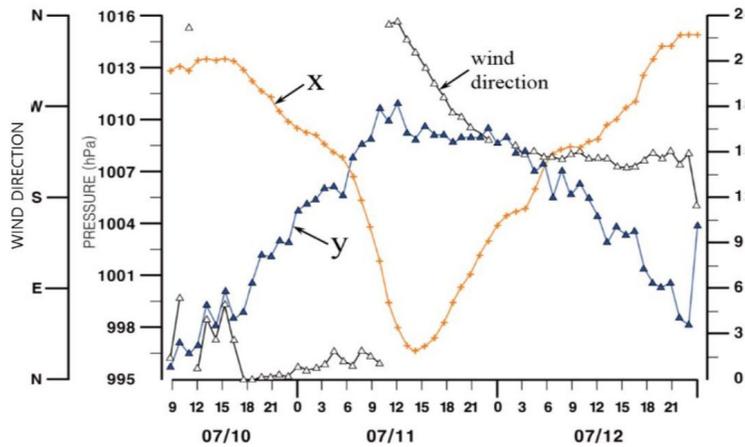
- a) The possible wind path is (a)
- b) The possible wind path is (b)
- c) The possible wind path is (c)
- d) The wind blows faster in position B because the friction with the surface is lower
- e) Increasing the wind speed on the lake decreases the Coriolis force
- f) The difference between the air temperature and the dew point in position C is greater than that in position D
- g) Waves can cause great flooding on the windward lake coast

**Introduction to question Q10**

A typhoon (tropical storm) is a meteorological phenomenon caused by the interaction between the atmosphere and the hydrosphere. Figure A is a satellite image showing the appearance of a typhoon. Figure B shows the atmospheric pressure, wind speed and direction at point P (Figure A) during the passage of the typhoon.



**Figure A**



**Figure B**

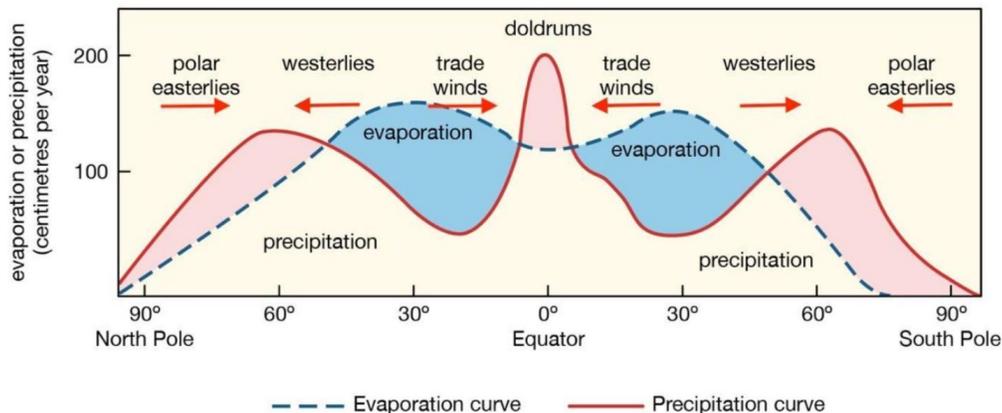
**Q10)** Choose ALL the correct statements with regard to the above figures.

- a) This typhoon occurred in the southern hemisphere
- b) 'x' is atmospheric pressure and 'y' is wind speed
- c) Point P is located to the right of the typhoon's path
- d) The center of the typhoon passed near point P around 2:00 p.m. on July 11
- e) After the center of the typhoon passed, the wind direction at point P changed from south-east to north-east

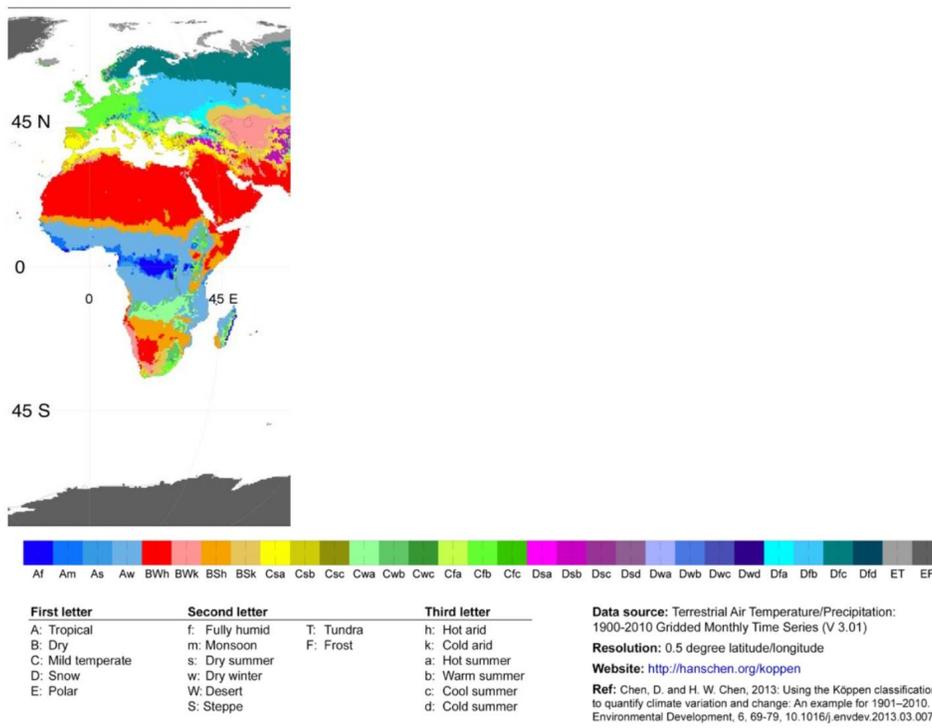
**Introduction to question Q11**

As shown in Figure A, the latitudinal distribution of the average annual amount of water in the atmosphere is not balanced. The atmosphere loses water because precipitation is greater than evaporation at the level of the tropics and at the level of mid and high latitudes while the atmosphere gains water in the subtropics because the evaporation is greater than precipitation. The red vectors indicate the southern directions of each wind (polar easterly, west wind and trade winds). This latitudinal difference in the water balance determines the global climatic distribution. Figure B (next page) shows the best-known climate classification scheme, which is mainly based on precipitation and temperature.

**Latitudinal variation in precipitation and evaporation**



**Figure A.**



**Figure B**

**Q11)** Based on Figures A and B, choose ALL of the correct statements about water in the atmosphere and its impact on the regional climate.

- a) Near 30°N and 30°S, the fact that evaporation is more intense than precipitation contributes to the formation of large zones BWh (hot dry and arid desert)
- b) The water deficit in the atmosphere above the doldrums due to more precipitation than evaporation is supplemented by the horizontal convergence of the water due to the trade winds of the two hemispheres
- c) The atmosphere loses a lot of water due to more precipitation than evaporation at the doldrums, resulting in a dry atmosphere and a predominantly BWh climate (hot dry and arid desert)
- d) The atmosphere gains more water due to greater evaporation than precipitation near 30°N and 30°S, resulting in a humid atmosphere and a predominantly Cfa climate (mild temperate, fully humid and hot in summer)
- e) As the peak rainfall in the tropics does not vary throughout the year, the Af climate (tropical, fully humid) can be seen near the equator

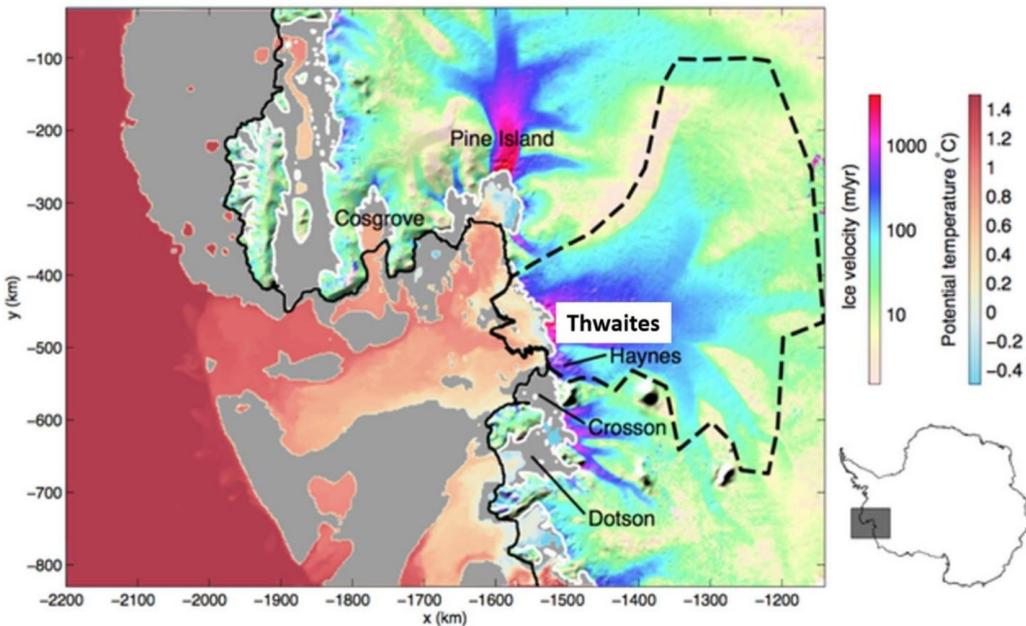
### **Introduction to questions Q12-Q13**

The Thwaites Glacier in West Antarctica covers an area of 182,000 square kilometers. Satellite measurements show that its rate of ice loss has doubled since the 1990s. This glacier has the potential to raise sea levels by several centimeters in the near future.

Glaciers have beds just like rivers, and most glacier beds descend in the same direction, as river beds do.

The bed of the Thwaites Glacier does the opposite: it progresses in the opposite direction of flow. The bedrock below the glacier's front toward the ocean is larger than the bedrock further inland, which has been pushed down over millennia by its thick ice.

Thwaites has lost so much ice that the side closer to the ocean now floats where it was attached to the bedrock. This opened a passage under the glacier where ocean water can seep. Each year the stranding line (where rock, ice and seawater meet) sinks further. The ice cliffs are unstable at heights above 200 m. They collapse.



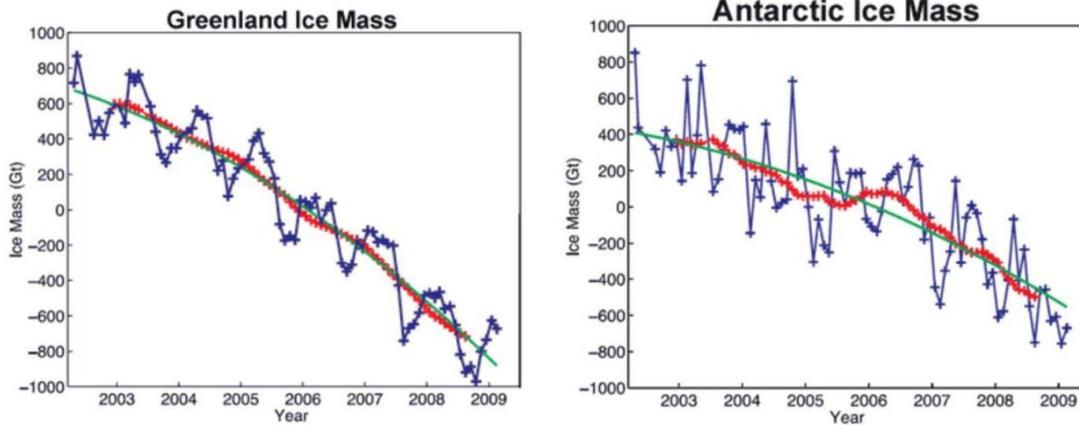
**Figure 1.** Ice speed (meters per year) of the Thwaites Glacier (approximate location delimited by a dotted line) and neighboring glaciers in West Antarctica; the inset map indicates the position. The temperature of the ocean floor appears in shades of red (degrees Celsius). The oceanic areas shown in gray are too shallow to affect the ice bottom. Credit: NASA / JPL-Caltech

**Q12)** Which of the following could accelerate both the melt and flow of the Thwaites Glacier? Choose ALL of the correct answers.

- a) An increase in the temperature of the ocean at the level of the oceanic face of the glacier
- b) A decrease in the temperature of the ocean below the glacier where it floats
- c) The marshy canals and waterways under the glacier
- d) A decrease in the salinity of ocean water in contact with ice
- e) An increase in sea level
- f) An increase in the albedo of the glacial surface

The graphic on the following page is taken from Skeptical Science; it shows Isabella Velicogna's estimates of the mass of the Greenland ice sheet. Blue crosses represent unfiltered data. The filtered data, to eliminate seasonal variations, is represented by red crosses. The best fit by a square function is indicated in green. The data comes from the GRACE experiment (Gravity Recovery and Climate Experiment).

This remarkable project uses a pair of satellites to accurately measure small variations from one location to another in the Earth's gravitational field. When the ice caps melt, GRACE can detect it.



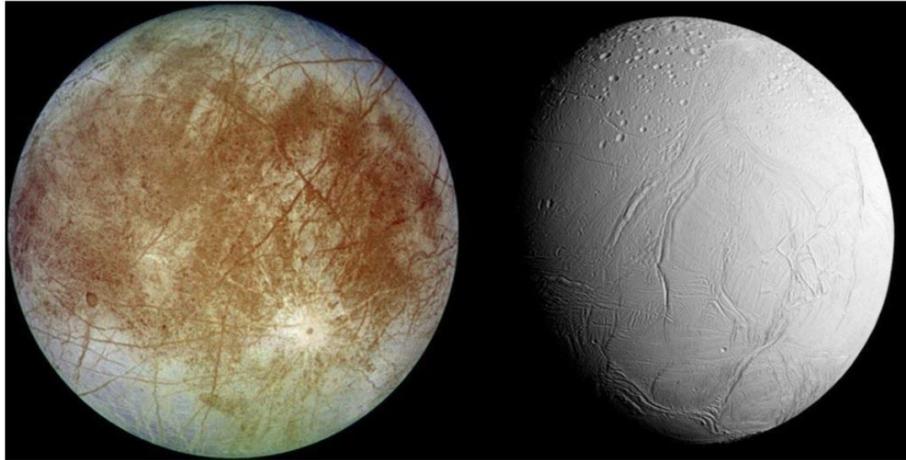
The Y axis (ice mass) indicates the deviation from the climatological mean over the period indicated in X.

**Q13)** Based on the two graphs above, choose ALL of the correct statements.

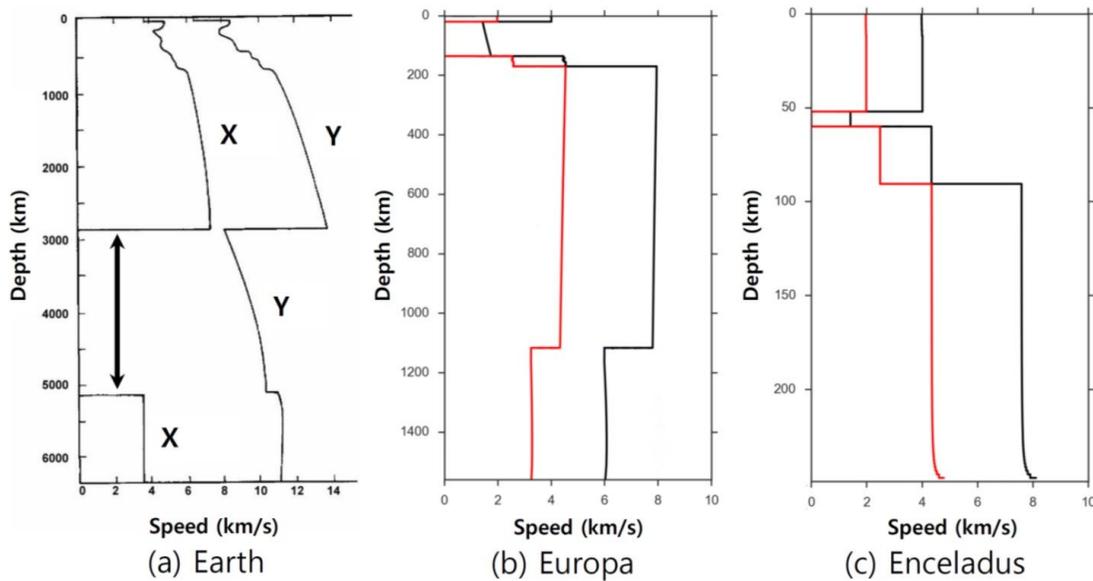
- a) Greenland is losing ice mass faster than Antarctica
- b) The difference between ice mass loss in Greenland and Antarctica can be attributed, in part, to the difference in latitude.
- c) The difference between ice mass loss in Greenland and Antarctica can be attributed, in part, to a difference in the size of the ice caps.
- d) The difference between ice mass loss in Greenland and Antarctica can be attributed, in part, to the fact that Greenland is exposed to warmer air and ocean currents.
- e) The difference between ice mass loss in Greenland and Antarctica can be attributed, in part, to the fact that Greenland is exposed to more soot, dust, and black carbon from the more industrialized Northern Hemisphere
- f) The difference between ice mass loss in Greenland and Antarctica can be attributed, in part, to the fact that the Southern Hemisphere has a much larger area covered by deserts which contributes to the formation of more desert derived dust in the Southern Hemisphere
- g) Both graphs show an annual cycle of ice mass accumulation during cold months and loss of ice mass during hot months
- h) Greenland has a larger annual variation in ice loss than Antarctica

**Introduction to questions Q14-Q15**

Seismology can be used to understand the internal structure of the Earth as well as other planets or satellites, particularly to find out if there are seas on the satellites of large gas planets like Europa and Enceladus, of which ice is the main component (Fig. A). Figure B represents the predictive model of propagation of the velocities of P and S waves as a function of the depth from the surface of the Earth (a), the satellite of Jupiter Europa (b) and the satellite Enceladus of Saturn (c). The depth interval of the Y axis corresponds to the radius of each of the celestial bodies.



**Figure A.** A satellite of Jupiter, Europa (left) and a satellite of Saturn, Enceladus (right). (not to scale)



**Figure B**

**Q14)** Select ALL correct interpretations relating to Figure B.

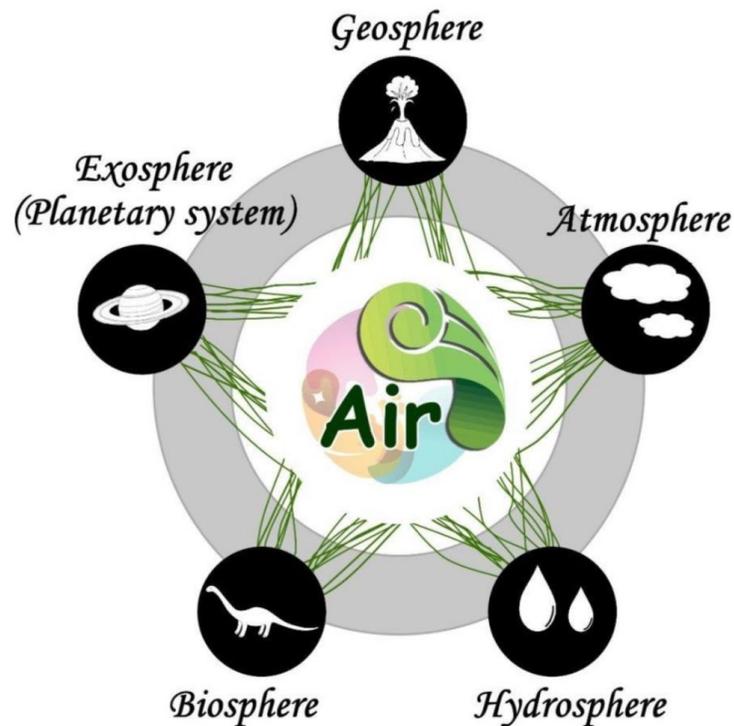
- a) In graph (a), X represents the depth-velocity curve of the P wave and Y that of the S wave
- b) In graph (a), the density increases from 1000 kg m<sup>-3</sup> to 2900 kg m<sup>-3</sup> at 2900 km depth
- c) In graph (a), the double arrow refers to a fluid zone
- d) In the range of 200 to 1100 km from the surface of Europa [graph (b)], density is expected to decrease with depth
- e) The interior of Enceladus [graphic (c)] is clearly divided into four distinct areas in agreement with the seismic velocity discontinuities

**Q15)** Europa and Enceladus are far from the Sun. Their surface temperature is therefore very low, resulting in a layer of ice. There may be water or sea ice below this layer of ice. Select ALL of the correct statements.

- a) The ice sheet is thicker on the surface of Europa than on the surface of Enceladus
- b) The ice sheet is thinner on the surface of Europa than on the surface of Enceladus
- c) The thickness of the sea on Europa is greater than that of Enceladus
- d) The thickness of the sea on Europa is less than that of Enceladus
- e) The volume of the sea on Europa is greater than that of Enceladus
- f) The volume of the sea on Europa is less than that of Enceladus

## Part 2 Theme: Air

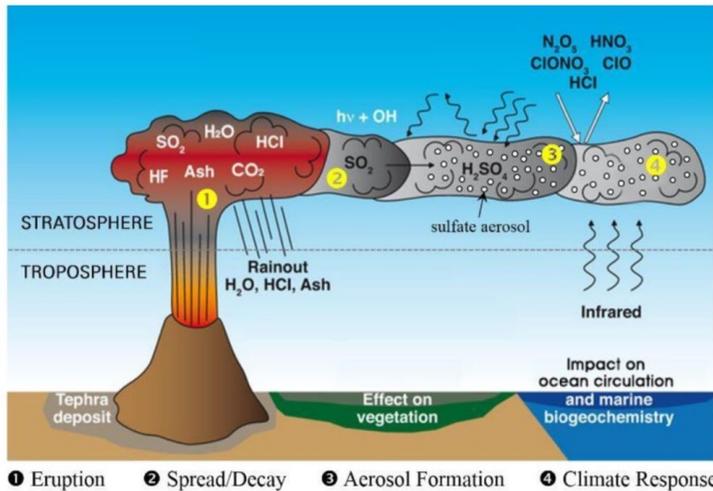
Air is made up of many gases and fine particles in suspension, which makes it an important storage medium for solar energy and sustains life. The atmosphere stores or absorbs water vapor as well as energy and redistributes it to the whole Earth as heat, producing winds and varying the weather. Air currents occur when various fluids move from place to place in response to barometric pressure. The atmosphere that surrounds the other celestial bodies of the Solar System also exhibits various characteristics which depend on their composition and gas proportion.



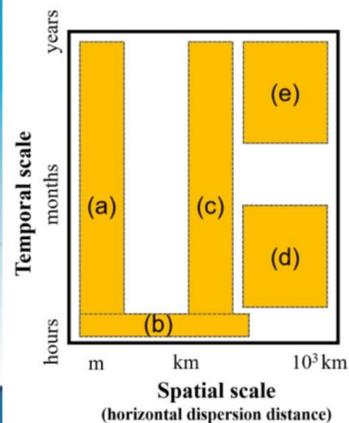
In this test, we will assess your knowledge and thinking skills about the air surrounding the Earth and other celestial bodies in the Solar System, and the interactions between geosphere, atmosphere, hydrosphere and biosphere.

**Introduction to question Q1**

Aerosols are tiny solid or liquid particles that float in the atmosphere and are naturally produced by sandstorms, crashing waves and volcanic eruptions as well as certain human activities such as the burning of fossil fuels. They are mainly present at low altitude. However, when huge volcanoes like Pinatubo explode, aerosols are released into the stratosphere and affect the climate. Figure A shows the gases from volcanoes emitted to the stratosphere during an eruption as well as the formation of sulfate aerosols. Figure B schematically represents the influence of gases generated by volcanic eruptions.



**Figure A**



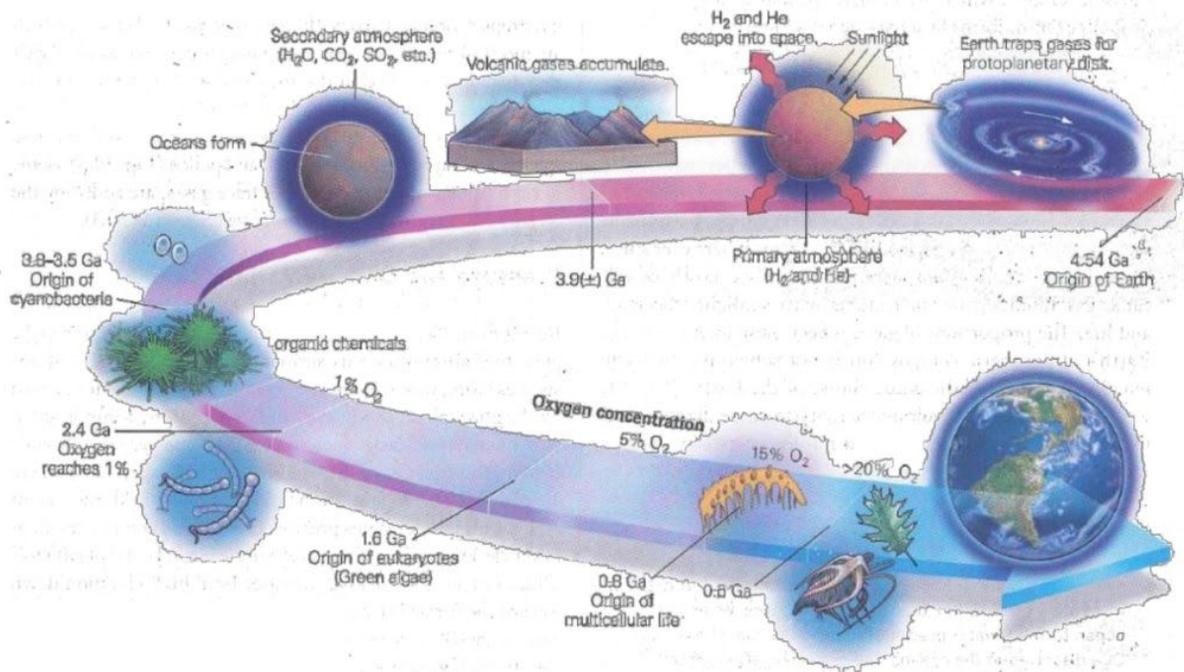
**Figure B**

**Q1)** Select ALL of the correct statements.

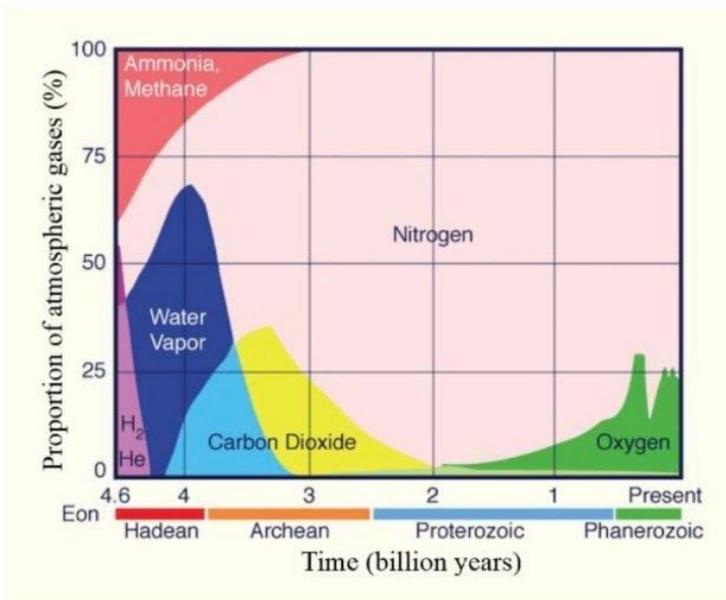
- a) The most abundant gas component during a volcanic eruption is CO<sub>2</sub>
- b) Sulfate aerosols cool the Earth's surface
- c) Sulfate aerosols reduce acidification of the surface
- d) The gases emitted by a volcanic eruption can destroy the ozone layer
- e) In figure B, the spatio-temporal scale affected by sulfate aerosols is the best represented by (b)

**Introduction to question Q2**

In the past, the Earth's atmosphere was very different from what we know today. It has changed over time under the influence of living organisms and the input of materials from the mantle. Figure A illustrates the change in composition of the Earth's atmosphere and the evolution of life. Figure B shows the temporal changes in the composition of the atmosphere.



**Figure A**



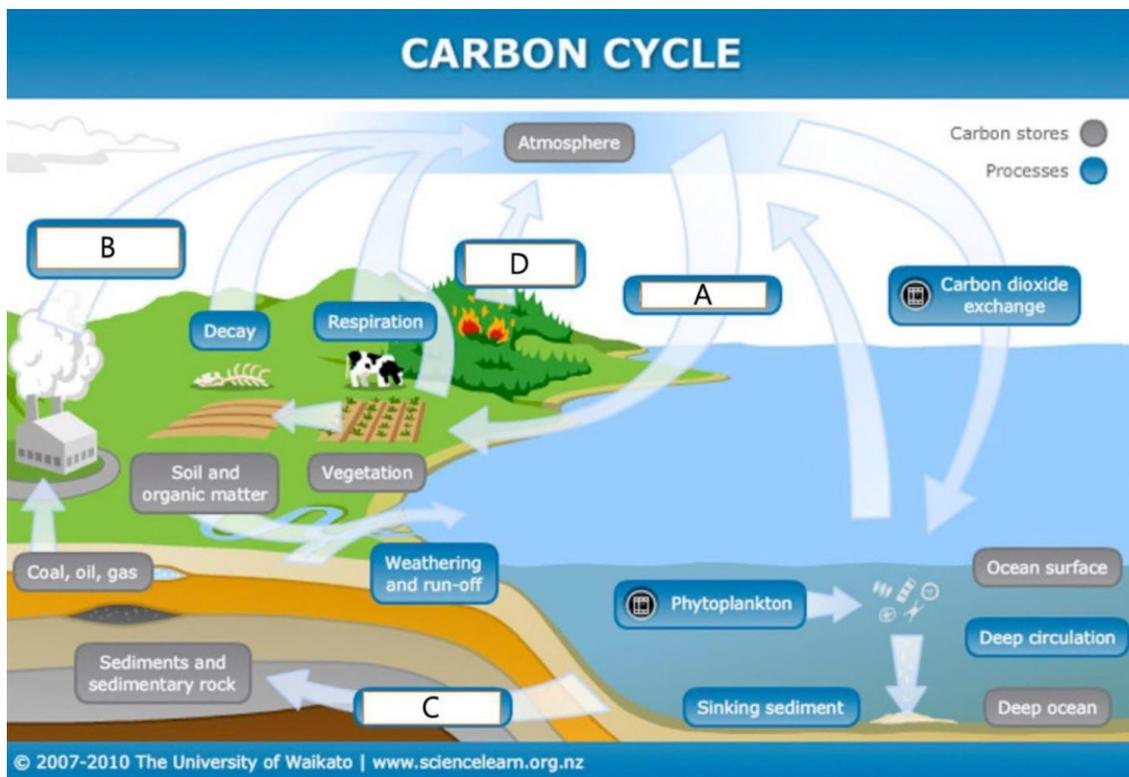
**Figure B**

**Q2)** Choose ALL of the correct statements to explain the phenomena described.

- a) The current greenhouse effect is greater than that of the Archean
- b) The ozone layer formed about a billion years ago
- c) Photosynthesis first started 1.6 billion years ago when eukaryotes first appeared
- d) Life was limited to the oceans two billion years ago
- e) One of the main reasons for the decrease in atmospheric CO<sub>2</sub> content, which represented more than 25% of the primordial atmosphere, is the formation of oceans

**Introduction to questions Q3 to Q5**

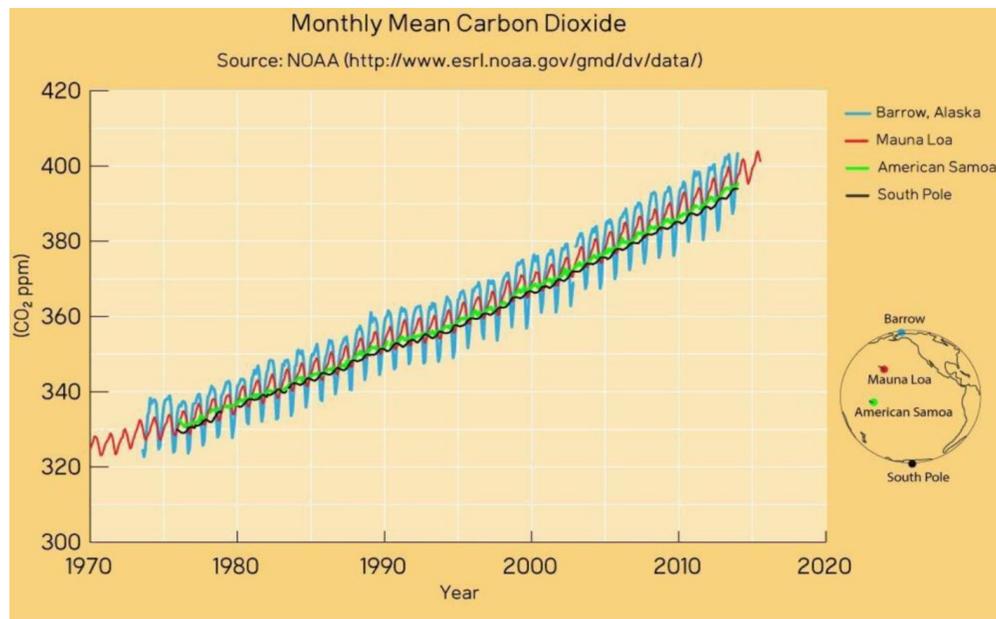
Understanding the carbon cycle is important to better predict future climate change, as one form of carbon is CO<sub>2</sub>, the most controversial greenhouse gas. The atmosphere transfers carbon to other reservoirs on Earth, such as the lithosphere, hydrosphere or biosphere, at various time scales (Figure A). Thus, the atmospheric concentration of CO<sub>2</sub> fluctuates daily as a function of geological time scales.



**Figure A**

**Q3)** Based on Figure A above, choose ALL of the correct descriptions corresponding to boxes A to D.

- a) Vegetation-related process A in the southern hemisphere is most active during the boreal summer
- b) Process B associated with various human activities is probably responsible for the recent increase in CO<sub>2</sub> in the atmosphere
- c) Process C can permanently isolate carbon from the atmosphere and the ocean
- d) Process D often occurs during hot and humid seasons
- e) Without process A, the Earth's atmosphere cannot contain abundant free oxygen



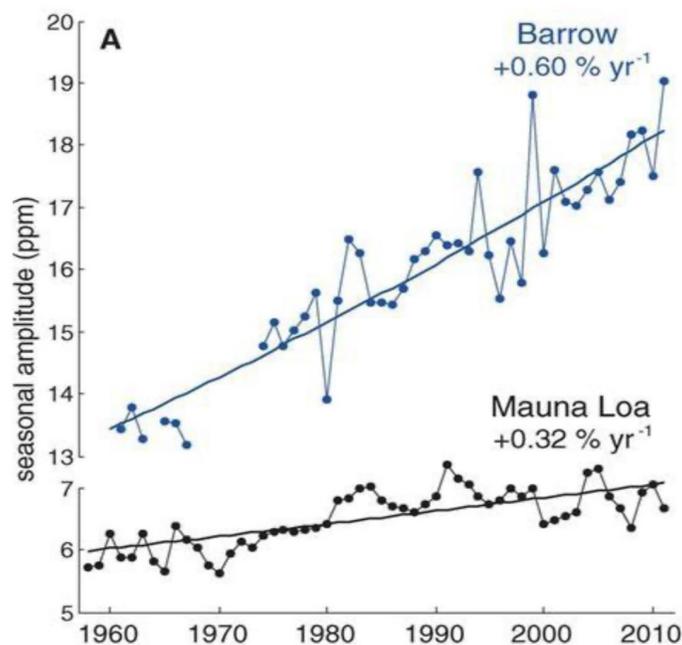
**Figure B**

Figure B shows the monthly atmospheric CO<sub>2</sub> concentration measured at Barrow, Mauna Loa, American Samoa and the South Pole, the locations of which are shown. The CO<sub>2</sub> concentration has increased considerably since 1958 for each of these observatories. In addition to a long term trend, one can also observe a noticeable seasonal cycle, especially in Barrow and Mauna Loa.

**Q4)** Based on Figures A and B above, choose ALL of the appropriate interpretations of the seasonal variations in CO<sub>2</sub> concentration.

- a) In comparison with the Southern Hemisphere, the seasonal cycle of the stronger CO<sub>2</sub> concentration in the Northern Hemisphere is due to the stronger solar radiation during the boreal winter
- b) The maximum CO<sub>2</sub> concentration in late spring is mainly due to the significant CO<sub>2</sub> emissions from the permafrost that has just melted
- c) From late spring to autumn, it is the intensity of photosynthesis, greater than that of respiration in the boreal forest, which is mainly responsible for the low CO<sub>2</sub> concentration in September and October
- d) A greater absorption of CO<sub>2</sub> by the ocean is responsible for the low level of CO<sub>2</sub> concentration during the summer
- e) The lower CO<sub>2</sub> concentration in early fall is due to the rapid decomposition of organic matter in summer
- f) The large area of deciduous forests in the northern hemisphere explains a seasonal cycle of higher CO<sub>2</sub> concentrations than in the southern hemisphere
- g) The combustion of fossil fuels influences the seasonal cycle of CO<sub>2</sub> concentration

Figure C shows the amplitudes of the seasonal cycle of CO<sub>2</sub> concentrations in Barrow (Alaska) and Mauna Loa (Hawaii). The seasonal variation in atmospheric CO<sub>2</sub> concentration is high, especially at high latitudes, where the continental area is large compared to the ocean area.



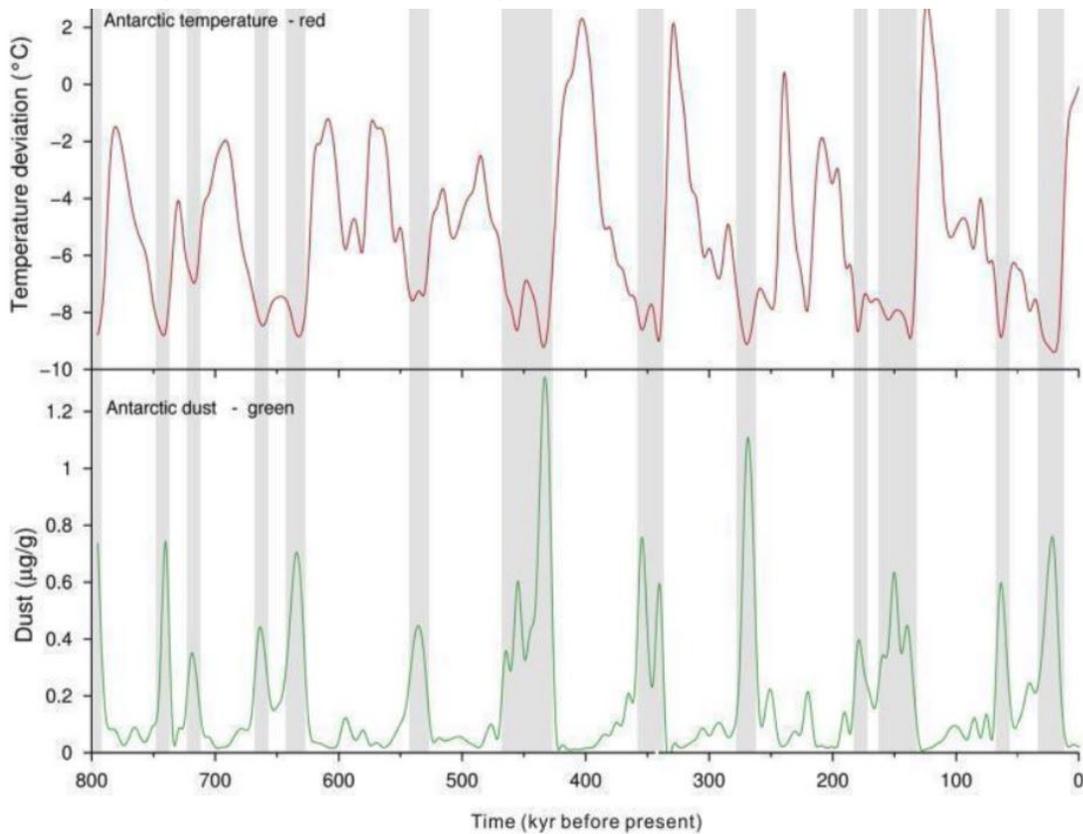
**Figure C**

**Q5)** What environmental changes could lead to an amplified seasonal variation of CO<sub>2</sub>? Choose ALL of the correct statements.

- a) Desertification
- b) Greater absorption of carbon by the ocean
- c) Greening of the tundra
- d) More frequent sunspot activity
- e) More volcanic activity
- f) Intensive agriculture
- g) Increase in primary productivity

**Introduction to question Q6**

The document below shows the variations in temperature and amount of dust in Antarctic ice cores over the past 800 ka (thousands of years).

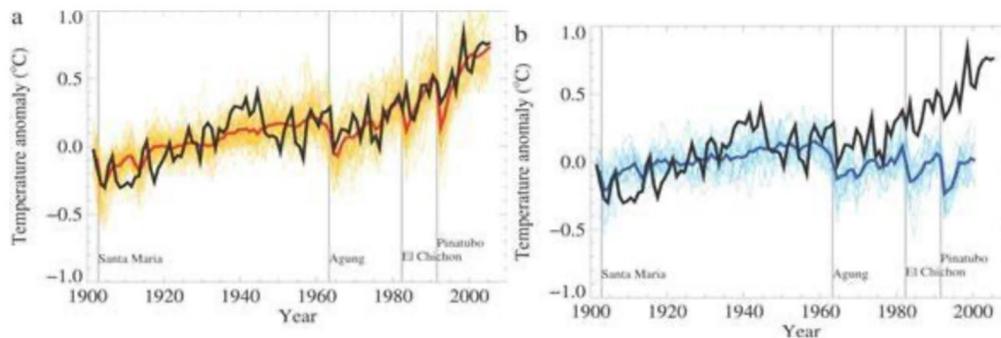


**Q6)** Choose the **ONLY** correct answer according to the figure above.

- Periods of high dust concentrations are characterized by high temperatures
- Increased amounts of dust in the atmosphere during cold periods increase albedo, resulting in high temperatures
- Increased amounts of dust in the atmosphere during cold periods decrease albedo, resulting in high temperatures
- Dust is dispersed by winds from large deserts that form during dry spells caused by an ice maximum
- Dust is dispersed by winds from large deserts that form during dry spells caused by an ice minimum

**Introduction to question Q7**

The figures below show the anomalies of the global mean temperature of the Earth's surface during the period 1901-1950, as observed (black line) and as obtained from simulations of climate models by considering (a) factors of human origin and natural factors (red line) or by considering (b) natural factors only (blue line). The gray vertical lines indicate the time of the main volcanic eruptions. The thick red and blue lines show the average of many different simulations which are represented by thin yellow and blue lines.

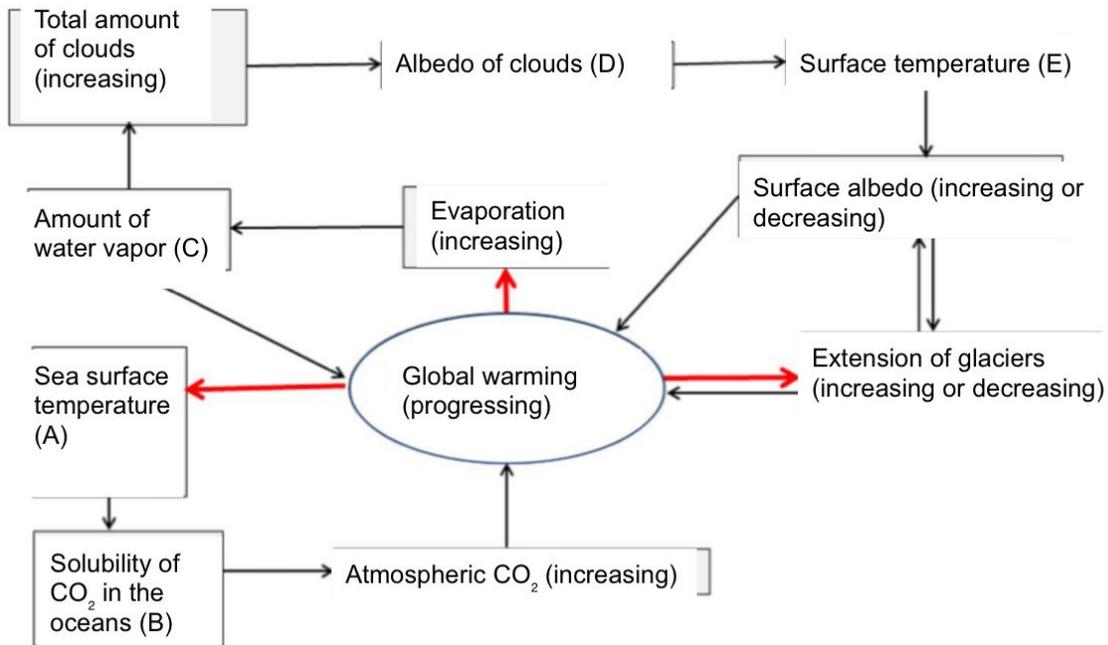


**Q7)** Choose **ALL** of the correct explanations describing the results in the figures above.

- Natural factors such as volcanic activity and solar activity caused rapid warming in the second half of the 20th century
- The observed rapid global warming cannot be simulated even if anthropogenic factors (including greenhouse gas and aerosol emissions) are included in the most recent computer simulations of the climate model
- Powerful volcanic eruptions, causing surface cooling by ejecting ash and aerosols into the stratosphere, could reduce recent rapid global warming
- Computer climate model simulations have verified that most of the observed global warming over the past 50 years is most likely due to human activities
- The cooling effect of individual volcanic eruptions on the global climate is generally short-lived compared to the long-term warming trend due to the increased greenhouse effect

**Introduction to question Q8**

The figure below shows the possible positive or negative feedback relationships related to the progression of global warming.



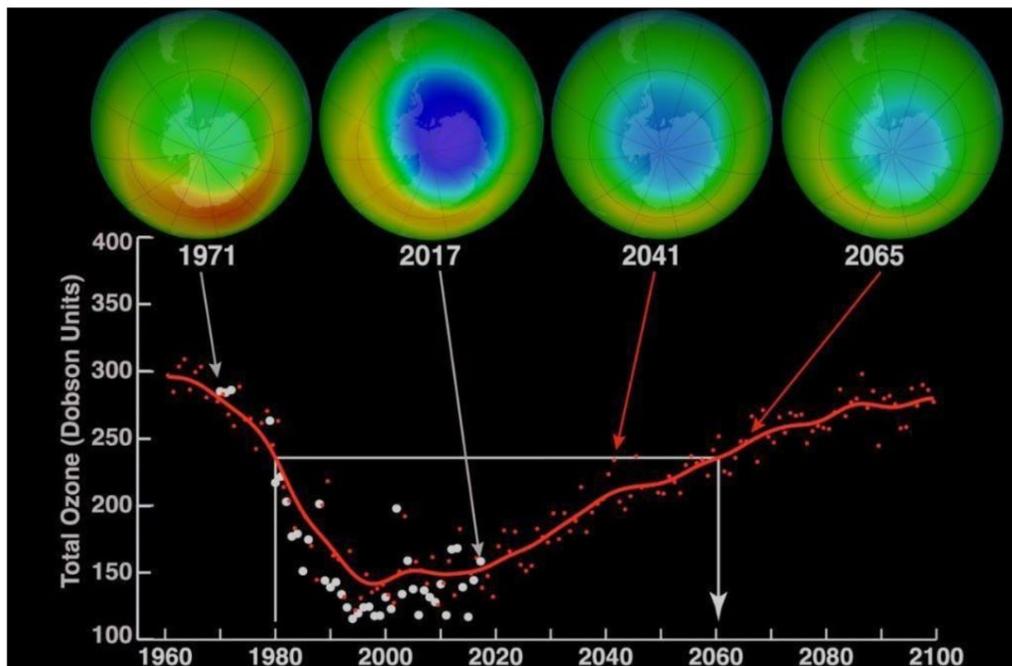
**Q8)** Choose ALL of the correct statements relating to the figure above.

Note: The word that is inserted in place of (A) to (E) above is "decreasing" or "increasing".

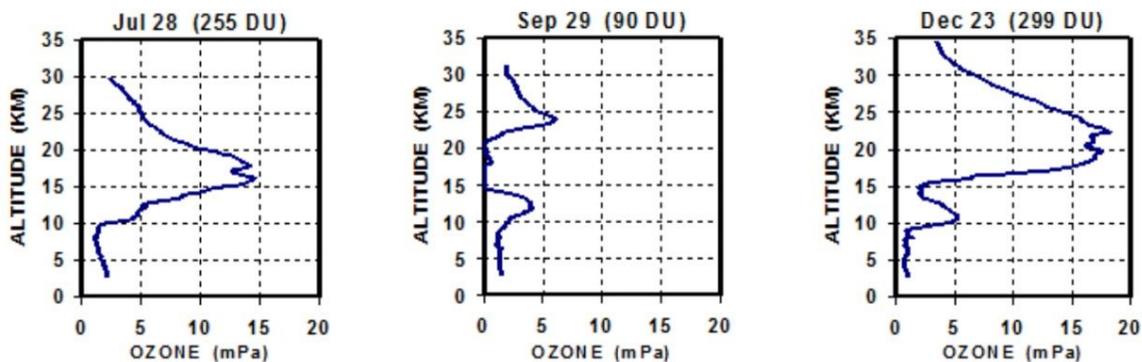
- a) The increase in atmospheric CO<sub>2</sub> due to deforestation causes the temperature at the sea surface to increase in this feedback relationship
- b) If the solubility of CO<sub>2</sub> in the ocean decreases, the pH of the ocean increases in this feedback relationship
- c) E is "increasing"
- d) Due to the increase in total cloud cover, the increase in glacier surface induces a positive feedback
- e) The decrease in the area of glaciers leads to negative feedback

**Introduction to question Q9**

The ozone layer is important because it prevents harmful ultraviolet rays from reaching the Earth's surface. In 1966, scientists from the British Antarctic Survey discovered a hole in the ozone layer over Antarctica. In 1974, Sherwood Roland suggested that chlorofluorocarbons (CFCs) used in refrigerators and other household appliances were destroying the ozone layer. The subsequently adopted Montreal Protocol has regulated ozone-depleting substances since 1987. Global efforts have shown that total ozone reduction is recovering since 2000. Figure A shows the temporal and spatial distribution of total ozone simulated up to 2065 from satellite observations from 1971 to 2017. Figure B shows vertical profiles of ozone pressure (mPa) over Antarctica in 1999 on three dates: July 28, September 29 and December 23.



**Figure A**



**Figure B**

**Q9)** Choose ALL the correct explanations.

- a) The size of the ozone hole was larger in 2017 than in 2000
- b) The hole in the ozone layer of September 29, 1999 (Figure B) also occurred at the same moment in the arctic
- c) The amount of ultraviolet rays reaching the surface of Antarctica increased more in 2017 than in 1971
- d) The ozone hole over Antarctica was noted during the autumn of the Southern Hemisphere
- e) Restoration of the ozone layer shown in Figure B begins at the top of the ozone layer
- f) The main cause of the depletion of the ozone layer and the formation of holes in this ozone layer is the manufacture of chemicals by humans

**Introduction to questions Q10-Q12**

Normally, strong trade winds blow over the equatorial Pacific from east to west. They tend to bring warm waters to the western equatorial Pacific, generating a warm basin around Indonesia. To compensate for this, cold water from the seabed rises (upwells) to the sea surface along the coasts of South America and in equatorial regions. The upwelling produces a steep thermocline in the upper ocean and also generates a (cold) sea surface temperature anomaly in the eastern equatorial Pacific. On the other hand, an ascending convective movement in the air generates very high clouds, cumulus clouds, in the western equatorial Pacific, which often results in heavy rains. In contrast, downward movement of air in the eastern equatorial Pacific tends to produce dry, sunny weather. This vertical atmospheric circulation is called the Walker circulation. If there is an anomaly with that circulation, El Niño or La Niña occurs. This is a phenomenon where the sea surface temperature rises above normal conditions and vice versa.

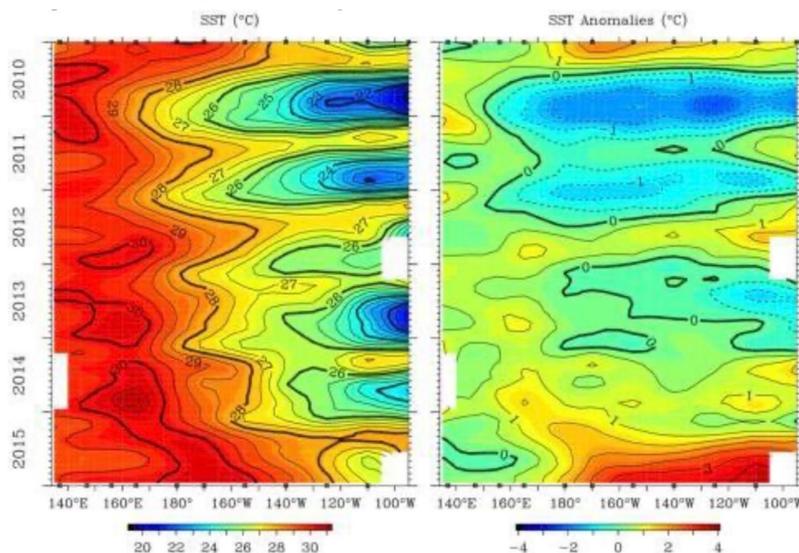


Figure 1. Sea surface temperatures (SST) as a function of years (left panel) and SST anomalies (right panel) after the removal of seasonal cycles in the equatorial Pacific. Credit: NOAA.

**Q10)** Referring to Figure 1 above, choose ALL of the correct statements to explain the episodes of El Niño and La Niña.

- a) El Niño episodes have occurred each year
- b) Convection is still active in the East Pacific where SST (see Figure 2) is still high
- c) The trade winds along the equatorial Pacific in an El Niño situation are weaker than in normal conditions (non-El Niño)
- d) An episode of La Niña occurred from 2010 to 2011
- e) El Niño episodes are caused by warm waters transported from the East Pacific to the West Pacific
- f) During an El Niño episode, Indonesia experiences a drought
- g) During an El Niño episode, the sea level is below normal along the coast of western South America

Figures 2(a) and 2(b) below show the spatial distribution of the SST (a) and surface chlorophyll-a anomaly during El Niño and La Niña (may or may not be in that order). Figure 2(c) is a time series of the Southern Oscillation Index (SOI). The SOI is calculated using the pressure difference at sea level (SLP) between Tahiti in the central Pacific and Darwin in northern Australia.

Therefore, this index can represent the strength of the Walker circulation, which is a large-scale vertical air circulation associated with the pressure difference at sea level in the equatorial Pacific area.

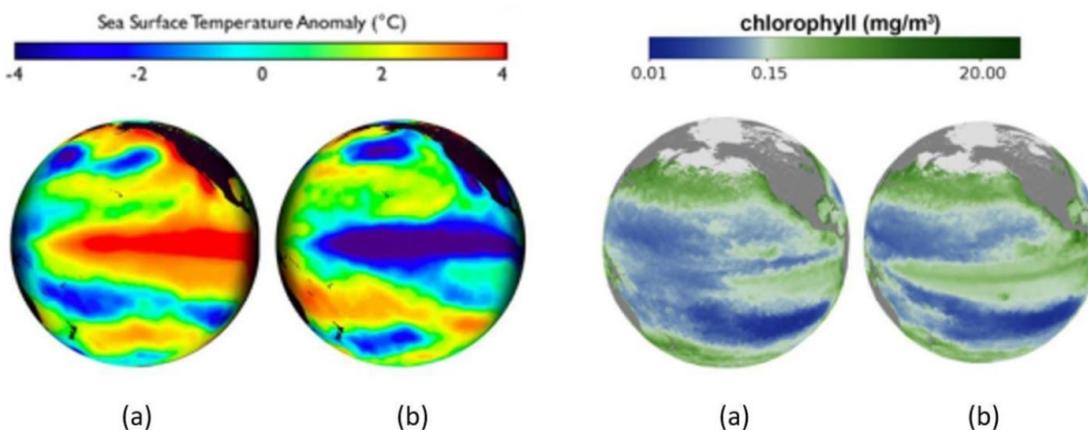


Figure 2: The left panel shows the sea surface temperature anomaly, the right panel shows chlorophyll a. (a) and (b) are the data during El Niño and La Niña (may or may not be in that order).

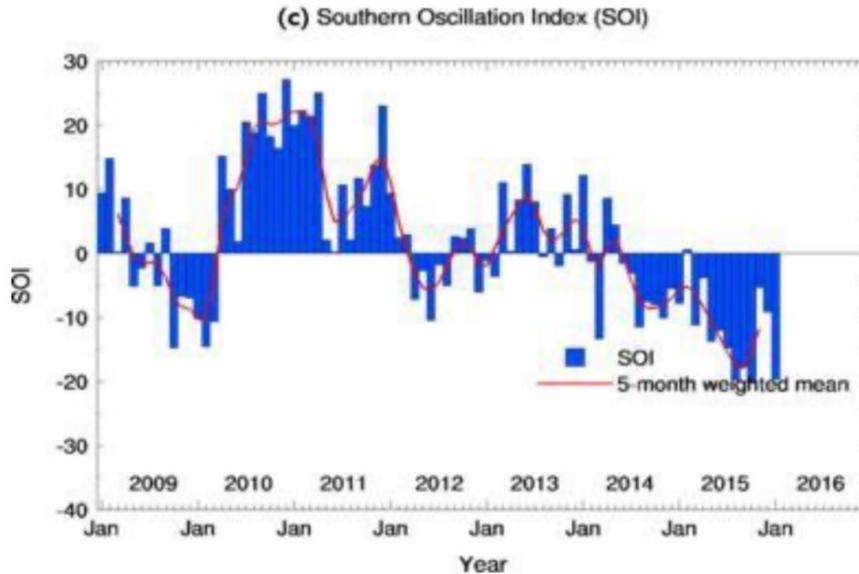


Figure 3. Southern Oscillation Index (SOI): Monthly time series of the Southern Oscillation Index (SOI, blue bar) and its five-month weighted average (red line).

**Q11)** Choose ALL of the correct answers.

- a) (a) corresponds to La Niña and (b) to El Niño
- b) During period (a), the Walker circulation is weaker than normal
- c) During period (a), the fishing potential decreases in the eastern Pacific
- d) During the period of (b), the difference in SLP between Darwin and Tahiti is reduced compared to a normal year
- e) During period (b), the zonal gradient of a thermocline is reduced compared to a normal year
- f) A situation like that in 2010/2011 corresponds to the case of (a), and a situation like that of 2015/2016 is the case of (b)

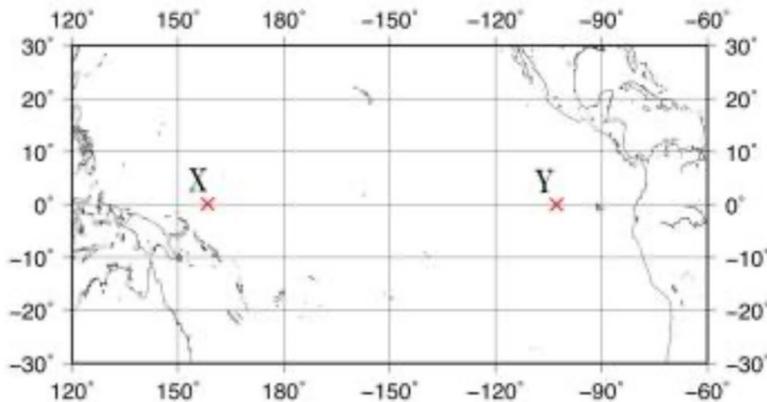


Figure 4. Location of observations made on temperature and salinity

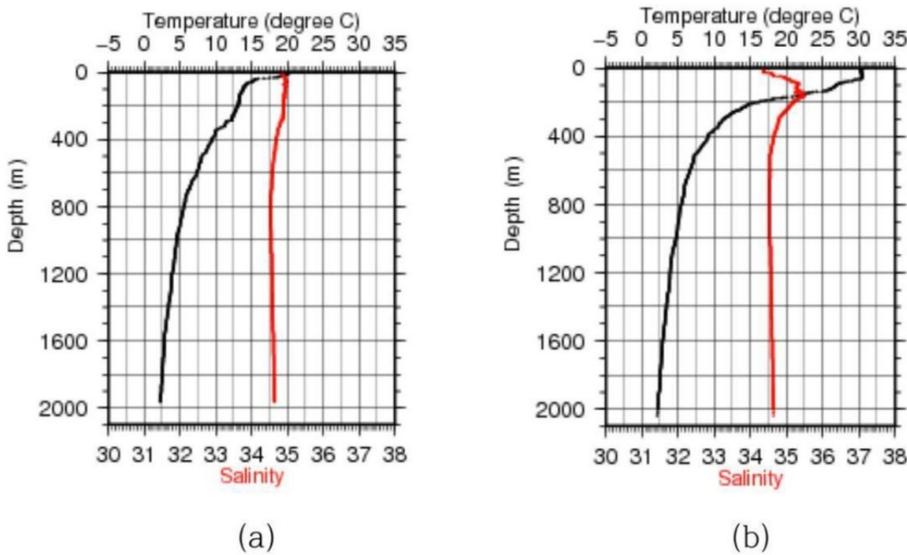


Figure 5. Temperature and salinity profiles observed in X and Y, which may or may not be in order

Figure 4 shows the location of stations X and Y whose temperature and salinity profiles are shown in Figure 5. The profiles were taken during the boreal summer of 2007 when a La Niña event occurred.

**Q12)** Choose ALL the correct answers.

- a) The profiles recorded at station X correspond to (a)
- b) The atmospheric pressure at sea level at station X was low compared to a normal annual value (long-term average)
- c) The direction of the current at the two stations X and Y is oriented towards the east by the westerly winds
- d) The seawater at a depth of 1000 m at the two stations X and Y was produced near the polar regions
- e) The main driving force of the deep ocean circulation is the surface wind
- f) Around the region of station X, precipitation is greater than evaporation

**Introduction to questions Q13-Q14**

Figure A shows the mid-infrared spectra of three terrestrial planets in our solar system. The solid lines are the actual spectra observed with many absorption structures due to the molecules that make up the atmosphere of each planet, while the dotted lines correspond to the best fits of black body emission at the corresponding temperatures. (For example, the spectrum of planet "c" shows an absorption trough due to CO<sub>2</sub> and its approximate black body temperature is 220 K). Figure B shows the changes in atmospheric temperature with altitude for the three terrestrial planets, marked (1), (2) and (3).

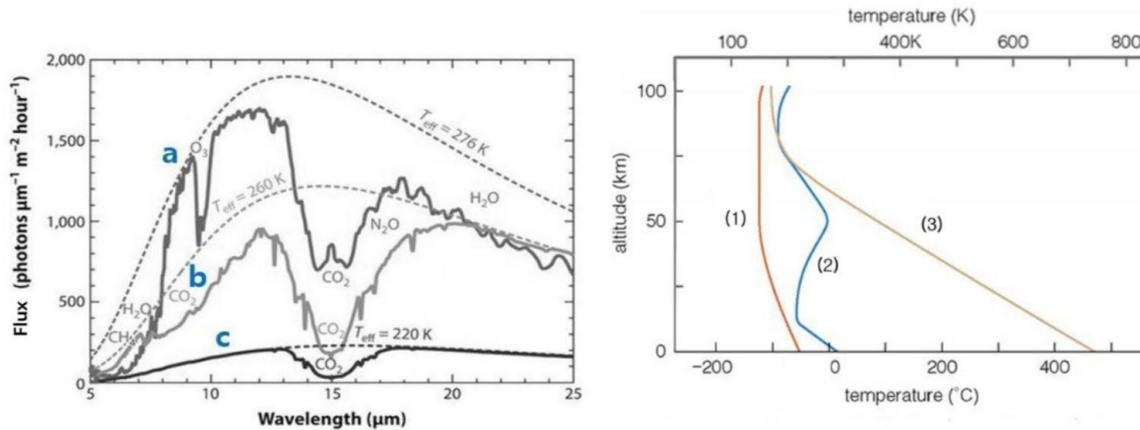


Figure A (left), Figure B (right)

**Q13)** Refer to Figure A and choose ALL of the correct statements.

- a) The spectrum of planets 'a', 'b' and 'c' are in the visible wavelengths
- b) The atmosphere of the three terrestrial planets contains CO<sub>2</sub>
- c) The molecule which is not present in the atmosphere of planets 'a' and 'b' but only in the atmosphere of 'c' is O<sub>3</sub>
- d) In the atmosphere of planets 'a', 'b' and 'c' in figure A, only H<sub>2</sub>O, CO<sub>2</sub> and O<sub>3</sub> can be present
- e) Of the three planets, planet 'a' emits the greatest amount of energy

**Q14)** Refer to Figures A and B, and choose ALL of the correct statements.

- a) In figure B, the atmospheric temperature of the planet (1) increases with altitude
- b) In figure B, the planet (2) has an atmospheric layer in which the temperature increases with altitude
- c) In figure B, among the three planets, planet (2) has the highest surface temperature
- d) Planet (1) in figure B is planet 'a' in figure A
- e) Planet (2) in figure B is planet 'a' in figure A
- f) Planet (3) in figure B is planet 'a' in figure A

## **Written Test, Part 3 + Part 4 (3 hours)**

### Grading of Questions

Each question with only one correct answer will be scored as follows:

- if the correct answer is chosen: +1 point.
- if the incorrect answer is chosen: 0 point.
- if several answers are chosen: 0 point.

Each question where one or more correct answers possible will be scored as follows:

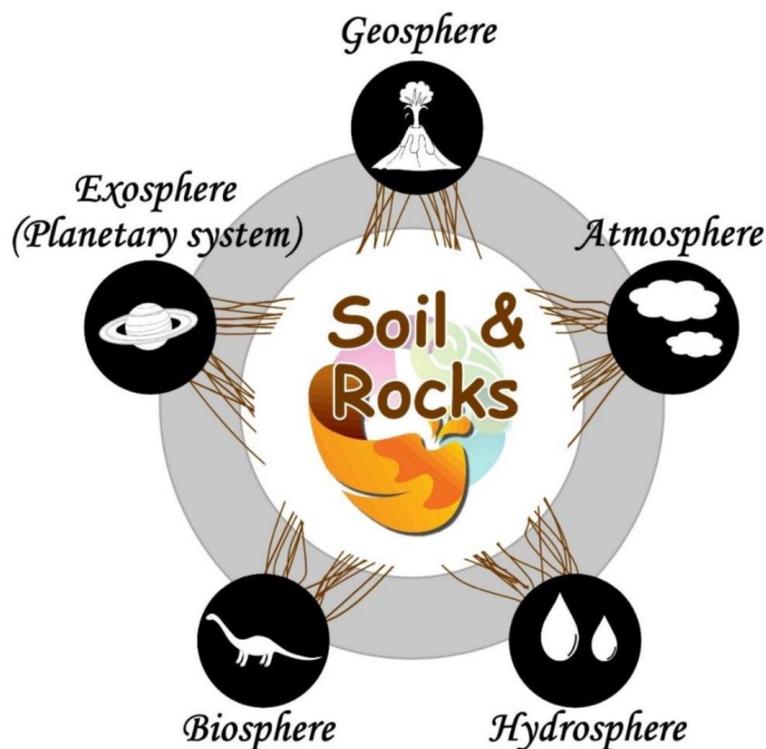
- each correct answer: +1 point.
- each incorrect answer: -0.5 point.
- if the combination of answers includes correct answers and incorrect answers, the minimum grade received is 0.

### Part 3 Theme: Soil and Rocks

The planets of the solar system can be broadly classified into 2 categories: terrestrial and gaseous. The element that characterizes terrestrial planets is their rocky crust.

The primitive Earth was a gigantic ball of magma which gradually cooled, differentiating the mantle, the core and the crust (which corresponds on the surface to the hard shell of our planet).

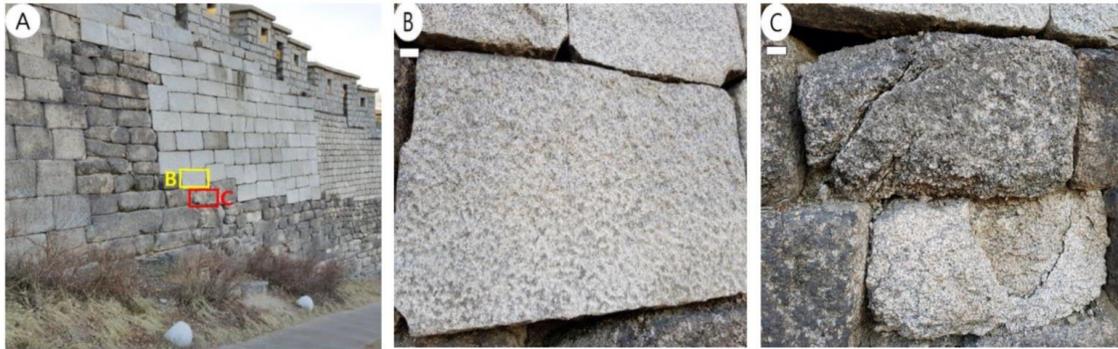
The rock that makes up the crust is subject to weathering and erosion over geological time. The resulting soil particles are transported and deposited by water or air in sedimentary basins. This slow and permanent cycle has been repeated ever since.



In this test, we will assess your knowledge and reasoning skills about soil and rocks as well as the materials that make up the crust, their interactions with the geosphere, atmosphere, hydrosphere and biosphere.

### Introduction to question Q1

The area of present-day Seoul Metropolis is located on the site of Hanyang, the capital of the Joseon dynasty (1392-1897). Hanyang was surrounded by a stone wall called Hanyang-doseong (Seoul Wall). The wall was erected in 1396 and partially rebuilt in 1422, 1711 and 1974. Document A shows part of the Hanyang-doseong wall with the location of rocks B and C. These are of the same lithological nature. The scale of documents B and C is 2 cm (white rectangle).



**Q1)** Choose ALL of the correct statements about the rocks used in the construction of the Hanyang-doseong.

- a) B and C correspond to metamorphic rocks with foliation
- b) The part of the wall made up of the rocks of document C is older than the part of wall shown in document B
- c) The differences between the surfaces of rocks B and C reflect the effects of physical erosion
- d) The color differences between the rocks in document A are related to time exposure to the atmosphere of each block
- e) The weathering of the rocks in document C is characteristic of an arid climate

**Introduction to questions Q2-Q3**

Table 1 shows the mineralogical composition, texture, chemical composition and appearance of rocks A and B. Table 2 shows the color and chemical composition of soils C and D formed respectively from rocks A and B.

Table 1

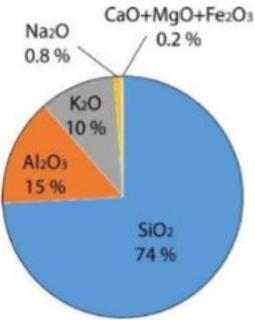
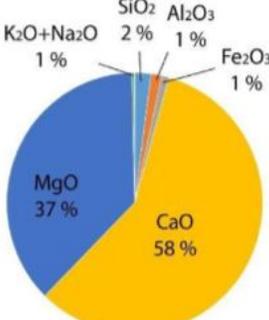
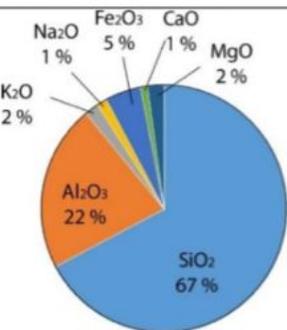
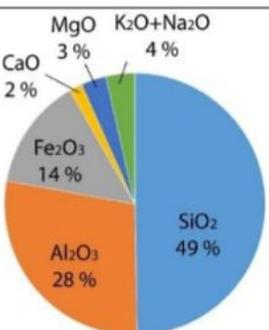
	Rock A	Rock B
Appearance		
Main minerals	Quartz, Feldspar, Biotite, Muscovite	Calcite, Dolomite
Texture	Coarse texture, grainy	Fine grained, layered
Chemical composition		

Table 2

	Soil C	Soil D
Color	Yellowish brown	Reddish brown
Chemical composition		

**Q2)** Choose ALL of the correct statements about rocks A and B in Table 1.

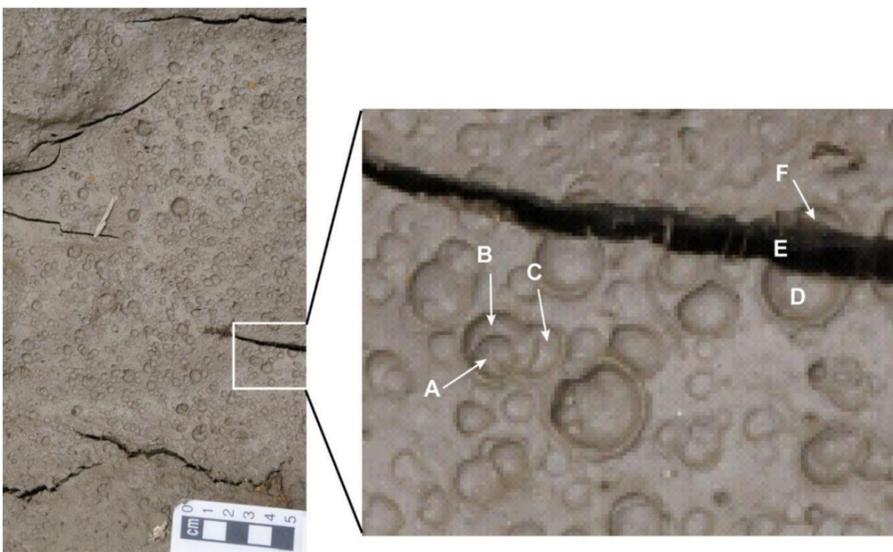
- a) Rock A is granite
- b) Rock B is gneiss
- c) Rock B forms at a higher temperature than rock A
- d) Rock B forms at a higher pressure than rock A
- e) The minerals that make up rock A are all silicates
- f) The predominant minerals in rock B are mainly carbonates

**Q3)** Choose ALL of the correct statements about soils C and D formed from rocks A and B, respectively.

- a) The increase in the  $\text{Al}_2\text{O}_3$  content of soil C, formed from rock A, is explained by the increase in its kaolinite content
- b) The increase in the  $\text{Fe}_2\text{O}_3$  content of soil C, formed from rock A, is explained by the formation of magnetite
- c) The difference in color between soils C and D is explained by a difference in  $\text{SiO}_2$  content
- d) The great decrease in the CaO content of soil D, formed from rock B, is the result of chemical weathering
- e) The significant increase in the  $\text{Al}_2\text{O}_3$  content of soil D, formed from rock B, is the result of the formation of feldspar

#### Introduction to question Q4

The photos below illustrate the surface texture of loose sediments composed mainly of mud. A, B, C, D and F indicate depressions similar to lunar meteorite impact craters. E indicates a narrow and deep crack.



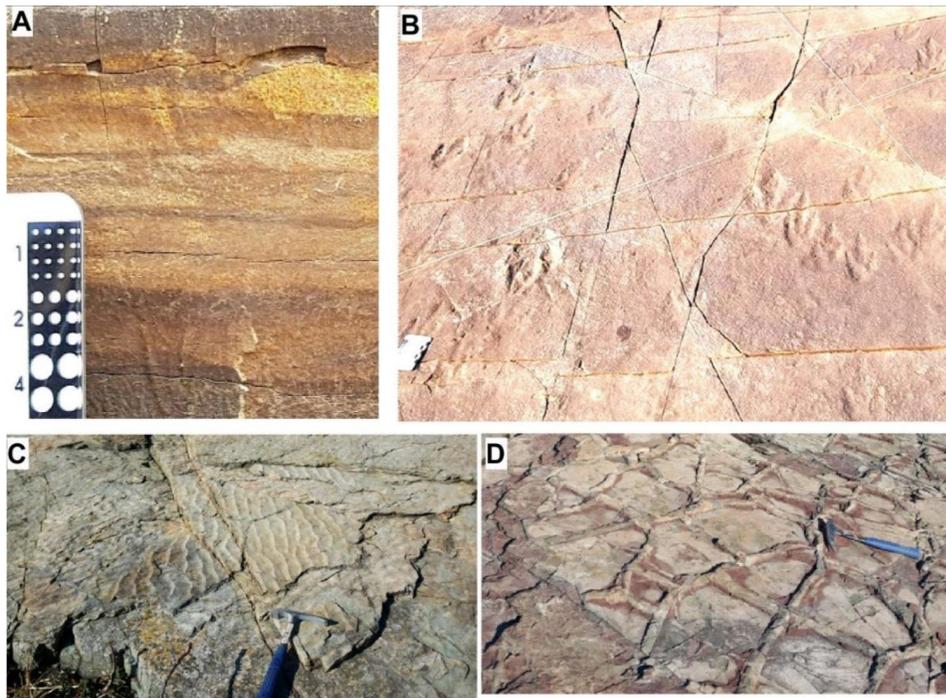
**Q4)** Choose ALL of the correct statements that can be inferred from the information from the images.

- a) Depressions are produced by raindrops
- b) B formed before A
- c) B was formed before C
- d) F formed before D
- e) E formed due to heavy precipitation

**Introduction to question Q5**

The sedimentary structures described below are found on the same site.

Photograph A is a section of a sedimentary bed. Photographs B, C and D show footprints of dinosaurs and sedimentary figures on the surface.



**Q5)** Choose ALL of the correct statements about the inferred structures and paleoenvironments.

- a) Photograph A shows current ripples
- b) Photograph C shows cross-bedding
- c) Photograph D shows cracks in the mud
- d) The dinosaur footprints in photograph B can be used to determine the geological age of the deposit
- e) The photographs tell us that this area was a deep water environment at the time of deposit
- f) This environment had a dry lake or fluvial environment at the time of deposit

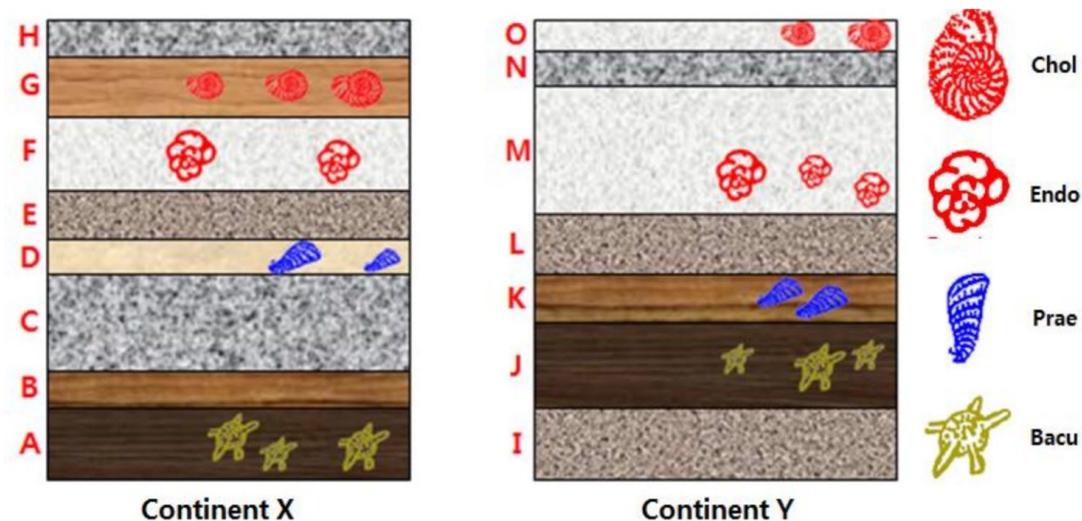
**Introduction to question Q6**

The stratigraphic correlation based on lithology is complex for sedimentary units distributed in ancient submerged continents.

However, fossils can provide useful information.

The documents below present a simplified stratigraphic column of 2 different continents: X and Y, as well as an index of the different fossils discovered in the different strata. The capital letters A to O represent the names of these strata.

The 4-letter words in the documents indicate the names of the fossils. There is no reversal of formations.



**Q6)** Choose ALL of the correct statements based on the information provided above.

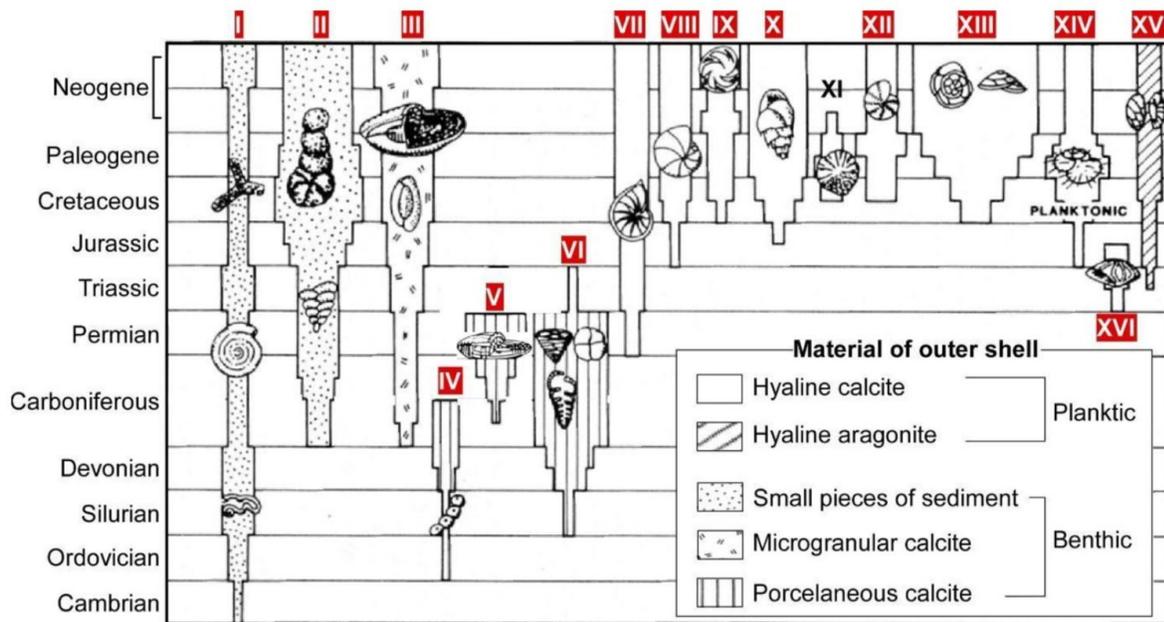
- a) Strata A and J were deposited at the same time
- b) There could be a period of non-sedimentation between the J and K strata
- c) The H and N formations were deposited at the same time
- d) The Bacu fossil was the last to appear
- e) D and K formations were deposited under identical conditions

**Introduction to question Q7**

Foraminifera are a form of life that has evolved significantly since its appearance on Earth in the Paleozoic.

The development, decline and extinction of different species of foraminifera have helped scientists to distinguish different geological eras. The document below depicts the evolution of foraminifera through geological ages.

Roman numerals from I to XVI indicate the different types of foraminifera.



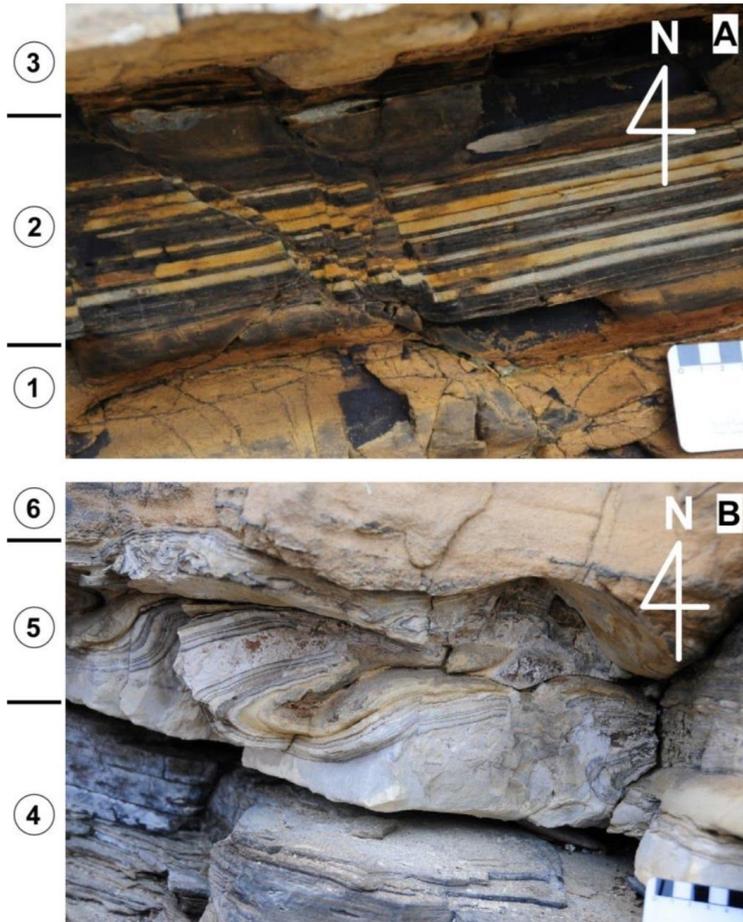
**Q7)** Choose ALL of the correct statements from the following:

- a) The most suitable stratigraphic fossils are VII foraminifera
- b) XVI foraminifera can be used as a stratigraphic fossil
- c) Planktonic foraminifera can be found in larger sedimentary deposit environments than benthic foraminifera
- d) The disappearance of Foraminifera V is probably linked to the Permian mass extinction
- e) Foraminifera VII was significantly affected by the mass extinction of the late Mesozoic

**Introduction to question Q8**

Photographs A and B depict outcrops that show sections and folds of strata within sedimentary rocks.

The bottom layer of structure A is 1 and the bottom layer of structure B is 4



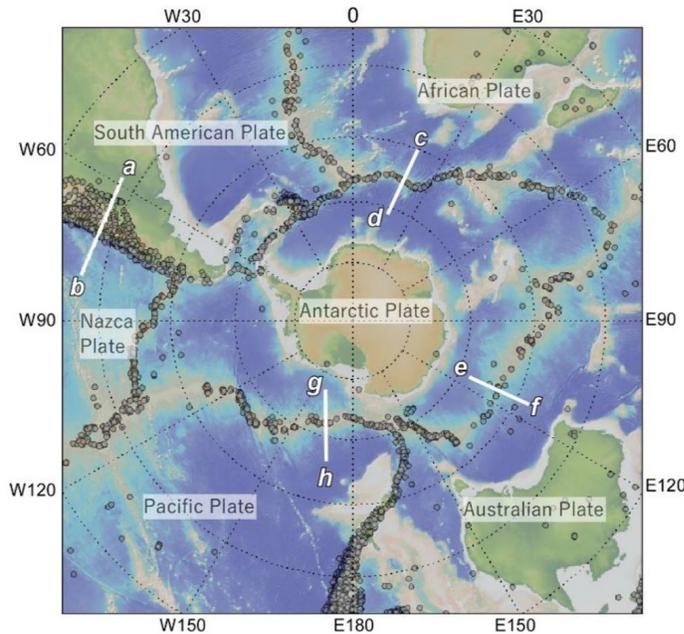
**Q8)** Choose ALL of the correct statements about the two outcrops above.

- a) The structures in photograph A represent normal faults
- b) The structures in photograph A represent inverse faults
- c) The direction of dip of the faults in photograph A is west
- d) The direction of the faults in photograph B is east-west
- e) The structure presented by stratum 5 of photograph B was formed when the sediments were not fully lithified (consolidated)
- f) The structure presented by stratum 5 of photograph B was formed by an east-west compression after the deposition of stratum 6

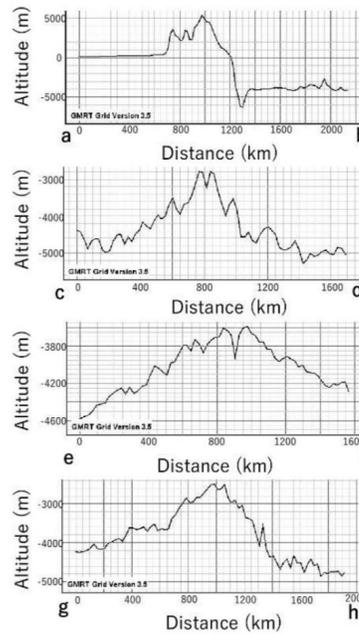
**Introduction to questions Q9-Q10**

Figure A shows the plate boundaries around Antarctica, and the distribution of epicenters of earthquakes of magnitude 5.5 or greater in this region for the past 60 years.

Figure B shows a topographic section along the ab, cd, ef and gh axes shown in Figure A (positive altitudes correspond to above sea level, negative altitudes below sea level).



**Figure A**



**Figure B**

**Q9)** Select ALL of the correct statements to describe the a-b axis, using figures A and B.

- a) There is an oceanic trench in the section
- b) The surface of the Nazca plate increases gradually over time
- c) Volcanic activity takes place on the continental margin of the section
- d) The earthquakes that occur along the section are due to subduction of the South American plate
- e) The depth of the seismic foci that appear along the section increases towards the continent

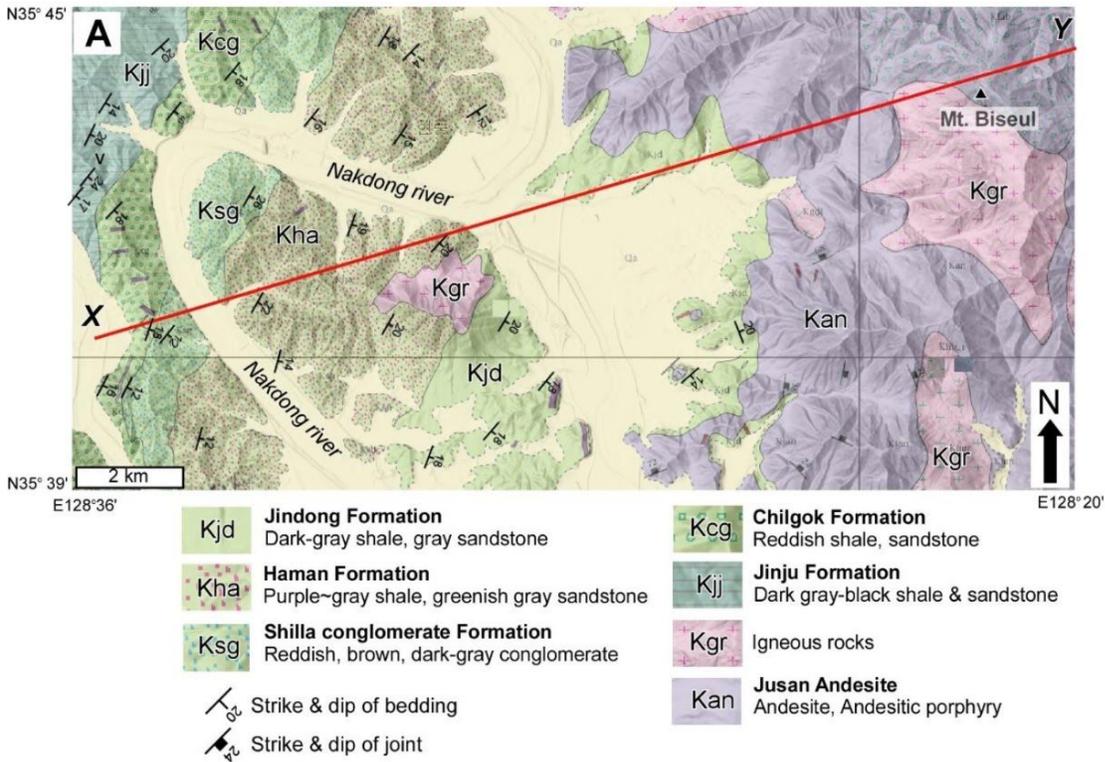
**Q10)** Select ALL of the correct answers for the Antarctic Plate and neighboring plate boundaries.

- a) The Antarctic plate is composed only of continental crust
- b) The border between the Antarctic plate and the African plate corresponds to subduction
- c) Earthquakes that occur along the c-d and e-f axis have shallow seismic foci
- d) The border between the Antarctic and Pacific plates shows a divergence
- e) The plate boundaries along the c-d and g-h axes were formed at the start of the Paleozoic

**Introduction to questions Q11-Q13**

Figure A is a geological map showing the presence of igneous rocks and sedimentary rocks of Cretaceous age. Intrusions of igneous rocks occurred at the end of the Cretaceous in the eastern part of the map, while sedimentary clastic rocks, which formed in the early Cretaceous, have outcrops in the western part of the map.

Figure B is a topographic section along the X-Y axis shown in Figure A.



**Q11)** What is the oldest sediment formation in this geological map? ONE CORRECT ANSWER

- a) Kjd (the Jindong formation)
- b) Kha (the Haman formation)
- c) Ksg (the formation of the Shilla conglomerate)
- d) Kcg (Chilgok formation)
- e) Kjj (the Jinju formation)

**Q12)** What is the geological principle used to answer the previous question Q11? ONE

CORRECT ANSWER

- a) The principle of original horizontality
- b) The principle of superposition
- c) The principle of faunal succession
- d) The principle of discontinuity
- e) The principle of cross cutting relationships

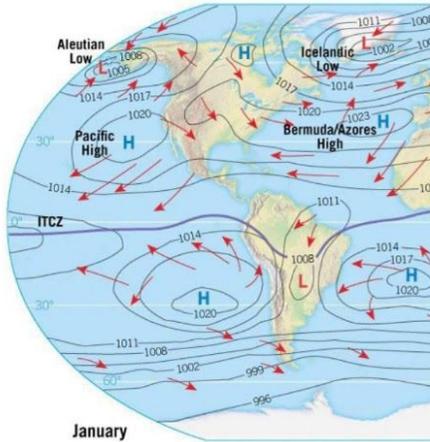
**Q13)** In the topographic section (Figure B), the highlands lie to the east and the lower lands to the west. What is the most probable cause to explain the formation of this ground? ONE

CORRECT ANSWER

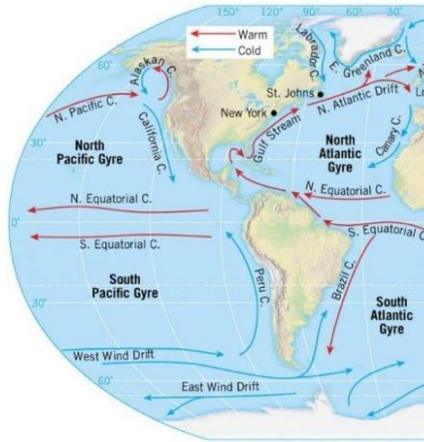
- a) A temporal difference between the intrusion of igneous rocks and the formation of sedimentary rocks
- b) A process of alteration / differential erosion due to lithological differences
- c) An inclination of the ground due to a fault
- d) The development of an anticline and a syncline
- e) Different joint development

**Introduction to question Q14**

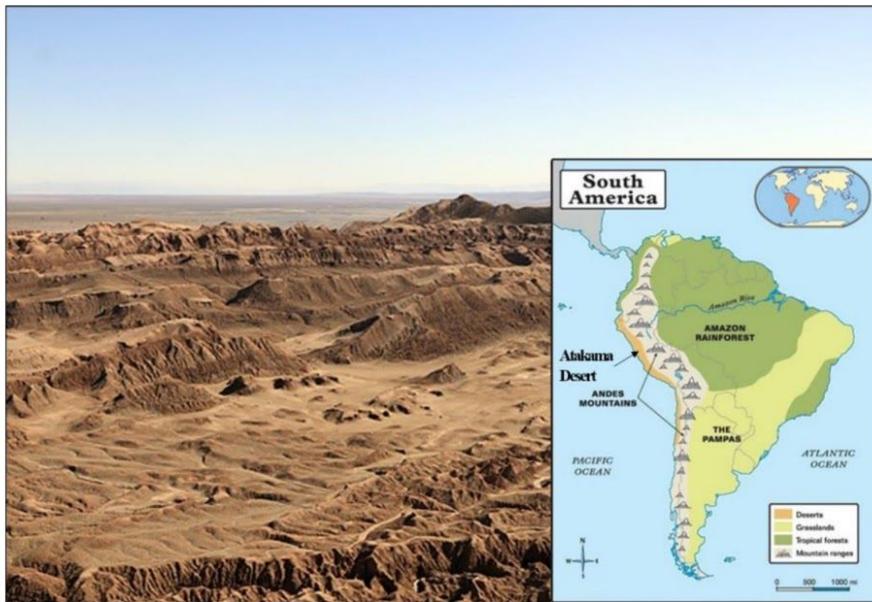
Figure A shows the average surface pressure and winds in January, and Figure B shows the main sea surface currents. Figure C is a photograph of the Atacama Desert located between the Pacific Ocean and the Andes. This desert is the driest in the world (the average annual rainfall is less than 3 mm), but like other tropical deserts located on the western coasts of continents, it is a place with frequent fog due to advection of water vapor and relatively cold.



**Figure A**



**Figure B**



**Figure C**

**Q14)** Choose ALL of the correct answers to explain the characteristics of the Atacama Desert.

- a) This region is affected by high pressure in the eastern part of the South Pacific
- b) The lower atmosphere of this region is unstable because of the Peruvian current which runs along the coast
- c) This region is affected by cold and humid air which crossed the Andean mountains from the east
- d) The Peruvian current produces a high relative humidity in this region
- e) The climate in this region is partially the result of the influence of the geosphere on the atmosphere
- f) The demand for water from the biosphere exceeds the water supply from precipitation, causing a water shortage

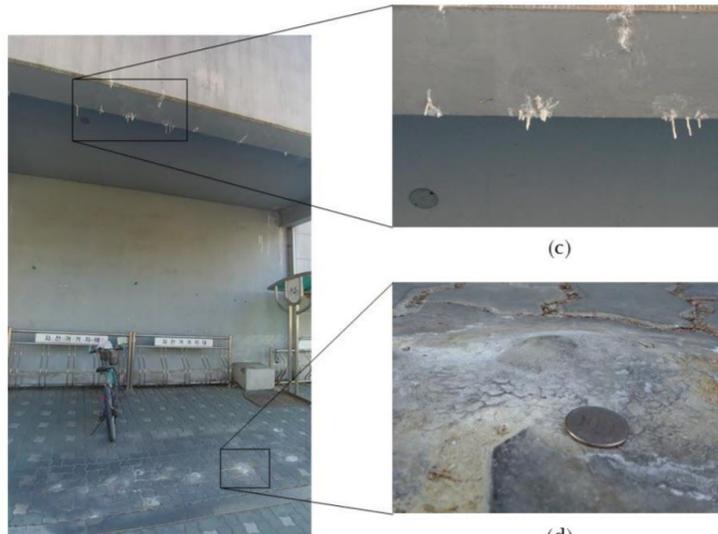
**Introduction to question Q15**

When the limestone undergoes a chemical alteration by the action of groundwater, we see the formation of caves, due to the dissolution and disappearance of the rock. Precipitation causes the formation of stalactites and stalagmites (a).

Sometimes structures such as stalactites and stalagmites are also found in structures on the cement or concrete of buildings (c) and (d).



a)



(b)

(c)

(d)

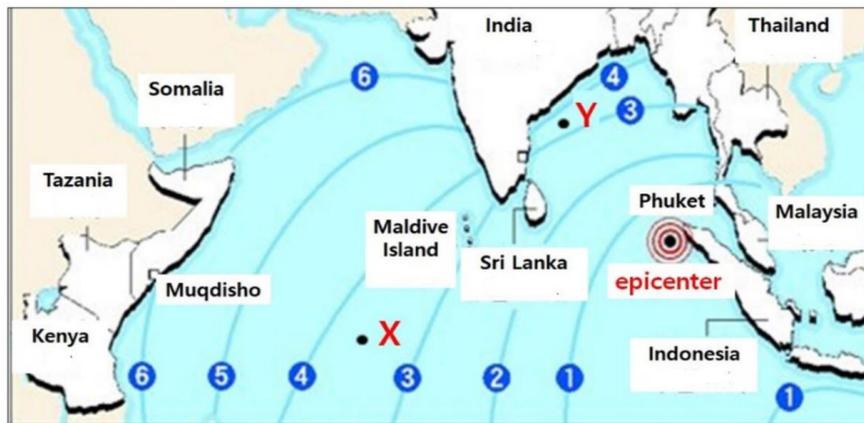
**Q15)** Select ALL of the correct answers.

- a) The chemical reaction of the dissolution of limestone is:  $\text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{Ca}(\text{HCO}_3)_2$
- b) The characteristics visible in figures (c) and (d) are produced by the reaction:  $\text{Ca}(\text{HCO}_3)_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2$
- c) In the limestone weathering process, atmospheric  $\text{CO}_2$  increases
- d) During the formation of stalactites, the  $\text{CO}_2$  of the caves decreases
- e) By opening up the caves that are still 'active' for the formation of stalactites to tourism, we could cause an increase in the rate of stalactite formation
- f) The Earth systems involved in the formation of limestone caves are mainly the geosphere, hydrosphere and biosphere
- g) The Earth systems involved in the formation of limestone caves are mainly the geosphere and hydrosphere

**Introduction to question Q16**

Figure A shows the arrival times (in hours - blue lines with numbers) of the tsunami that occurred following an earthquake in Indonesia in December 2004.

Figure B presents aerial images that show the state before and after the tsunami.



**Figure A**



**Figure B**

**Q16)** Select ALL of the correct answers.

- a) The speed of propagation of tsunami waves at point X is slower than the speed of this same tsunami at point Y
- b) The average water depth between the epicenter and point X is deeper than that at point Y
- c) The wavelength of waves at point X is shorter than that of waves at point Y
- d) The height of the tsunami waves would have increased as they approached the coast
- e) The earthquake that generated the tsunami must have been caused by a transform fault
- f) This region where the earthquake occurred corresponds to a divergent plate boundary
- g) Figure B is a representative example of the interconnection between the geosphere, the hydrosphere and the biosphere

**Introduction to question Q17**

The Apollo Project consisted of a series of NASA exploration missions to the Moon between 1961 and 1972. Since the first Apollo 11 landing on the Moon in 1969 and after several successful lunar landings, the Apollo program has been completed after the launch of Apollo 17 in 1972.

The image below, taken during the Apollo 8 mission on December 24, 1968, shows the Earth rising above the moon's horizon.



**Q17)** Choose ALL of the correct descriptions for the image.

- a) The color blue on Earth shows regions where short wavelengths of sunlight are absorbed by Earth's atmosphere
- b) White color on Earth shows areas where sunlight is reflected directly from clouds
- c) The stars are not visible because the photograph was taken in broad daylight
- d) On the horizon, the edge of the Moon is clear and sharp, and the environment is black like the sky because there is no atmosphere on the moon
- e) For those who look towards the Earth from a fixed point on the surface of the Moon, the Earth will never pass below the horizon
- f) The Earth will look like a crescent Moon seen from the far side of the Moon

### Introduction to question Q18

Scientists recently developed a method to estimate the age of impact craters on the Moon's surface by measuring the heat released by these craters. Figure A is a schematic representation of this method. When a meteorite hits the moon, an impact crater forms; ejecta of different sizes are deposited on the surface of the Moon. Thus, exposed rocks have more thermal inertia than the lunar fine-grained soil. They therefore remain hotter than the particles of the lunar soil during the night.

**\*Thermal inertia:** the degree of slowness with which the temperature of a body approaches that of its environment.

The Diviner Lunar Radiometer aboard NASA's Lunar Reconnaissance Orbiter (LRO), orbiting the Moon, provided information on ejecta abundance by measuring the heat released around small and large craters of impact.

Rocks exposed at the time of meteor impact gradually mingle with the ground due to the meteor shower that continues to fall on the Moon for tens of millions of years. Scientists were able to apply this idea to calculate the age of undated craters. They found that the younger an impact crater, the higher the abundance of ejecta around it.

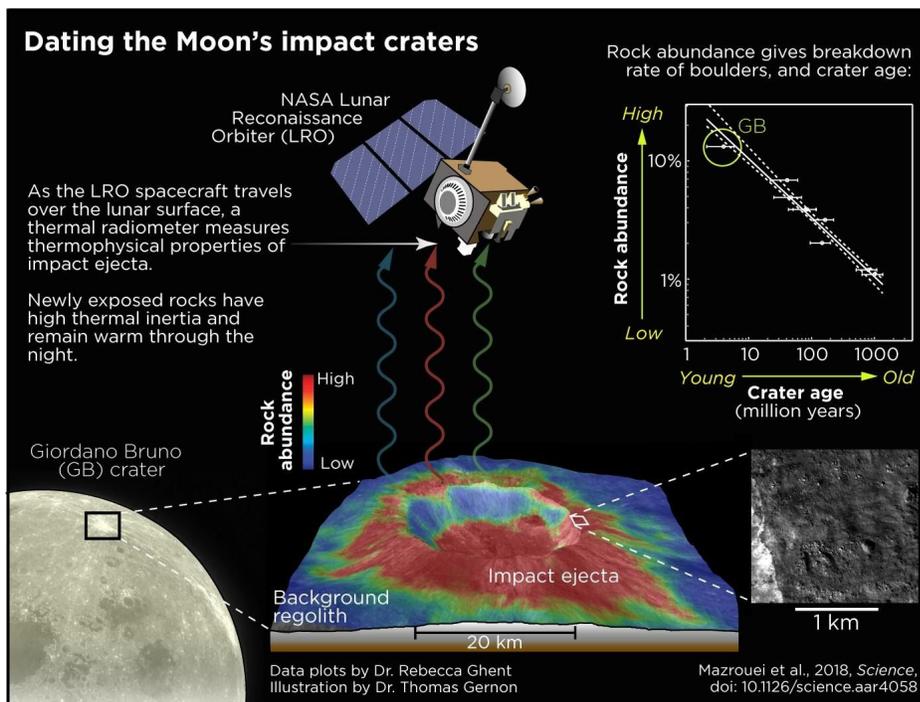
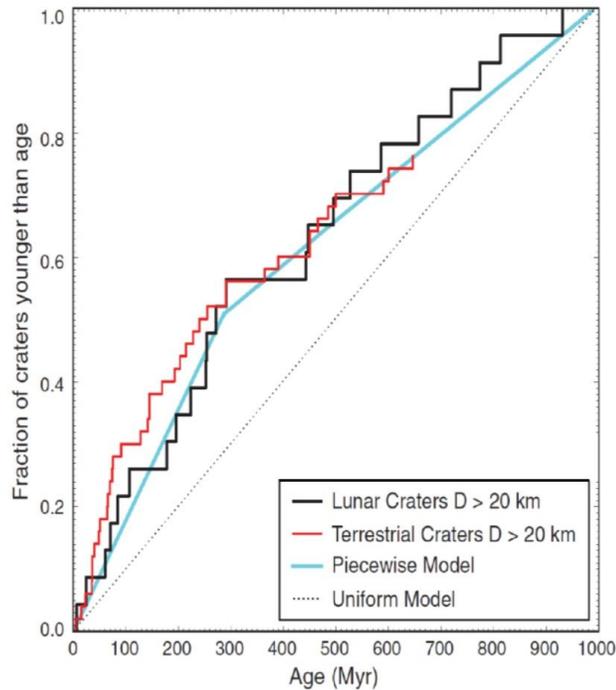


Figure A [Image: NASA/LRO/University of Southampton/University of Toronto]

Figure B is a graph showing the relationship between the age of the crater and the fraction of craters younger than that age.

On the graph, the solid black line is for lunar craters and the red line is for terrestrial craters. The dotted line shows the expected result when the rate of impact crater formation is constant. The blue line shows the result predicted by a model with a constant rate of crater formation, which changes at any given point in time.

Even though the Earth is much larger than the Moon, the number of craters found on the Earth's surface is much lower than on the Moon.



**Figure B**

[Reference: Mazrouei et al. 2018, Science, Vol. 363, Issue 6424, pp. 253-257]

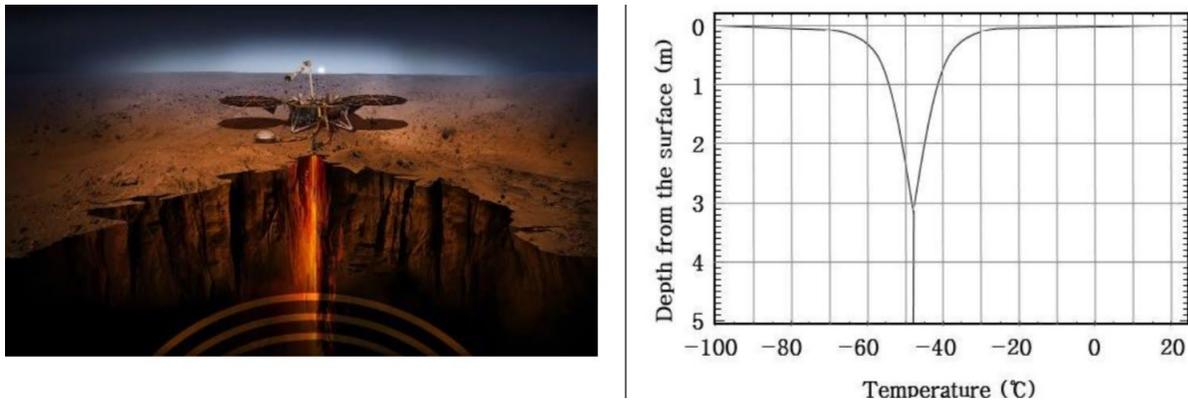
- Q18)** Taking into account the information and the graph, choose ALL the appropriate statements
- Scientists use the same method to date craters on Earth and on the Moon
  - Scientists speculated that plate tectonics had erased many impact craters on Earth
  - Scientists speculated that plate tectonics had erased many impact craters on the Moon
  - Scientists have assumed that the rate of soil formation on the Moon remains constant over time
  - For about 300 million years, the impact rate of meteorites on the Earth and on the Moon has decreased
  - The impact rate of meteorites on Earth and on the Moon during the last billion years is similar

**Introduction to question Q19**

NASA's Martian space probe InSight, launched in May 2018, landed on Mars in November. The HP3 instrument, one of the sensors on the InSight platform, measures temperatures at depth. Depending on the type of rock, we can analyze a difference in thermal conductivity and thus know whether they are rocks similar to Earth or not.

Figure A is an artistic view of the InSight Platform's HP3 instrument penetrating through the surface of Mars and measuring temperature at depth.

Figure B shows the minimum and maximum temperature estimates, for some depths, for a Martian year.



**Figure A, left:** Artist's impression of the InSight platform on the surface of Mars [Image: NASA / JPL-Caltech]

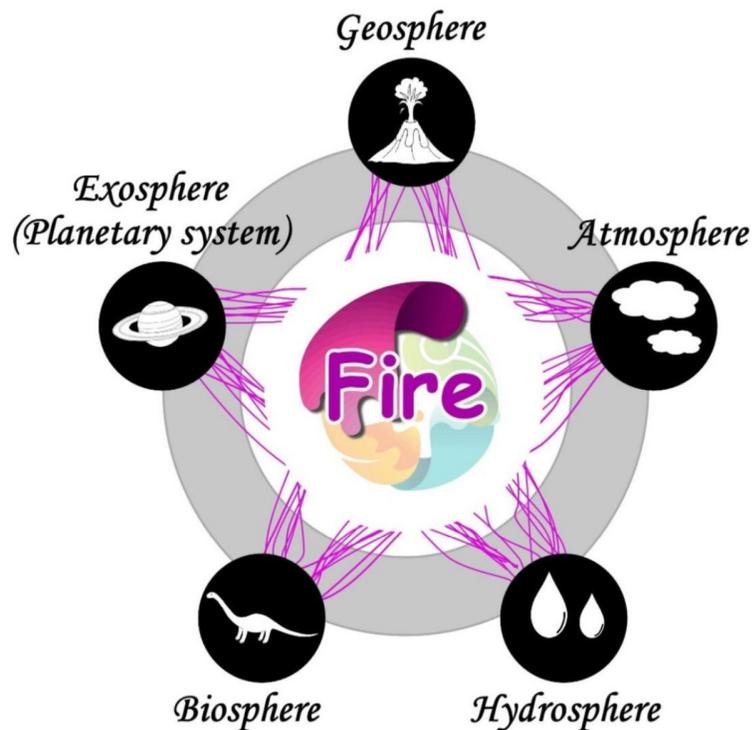
**Figure B, right:** Range of annual maximum and minimum temperatures estimated at depth

**Q19)** Choose ALL the correct statements.

- a) The temperature variation decreases as the depth of the Martian crust increases
- b) According to diagram B, the temperature should be constant for a depth greater than 5 meters
- c) If there was an ocean on Mars, the range of temperature variations on the surface could increase
- d) If the rocks have greater thermal conductivity than expected, the range of temperature changes will increase with depth
- e) If the rocks have greater thermal conductivity than expected, the range of temperature changes will decrease with depth
- f) If the rocks have greater thermal conductivity than expected, the range of temperature changes will be constant at a depth greater than 3 meters
- g) If the rocks have greater thermal conductivity than expected, the range of temperature changes will be constant at a depth less than 3 meters

## Part 4 Theme: Fire (Heat and Energy)

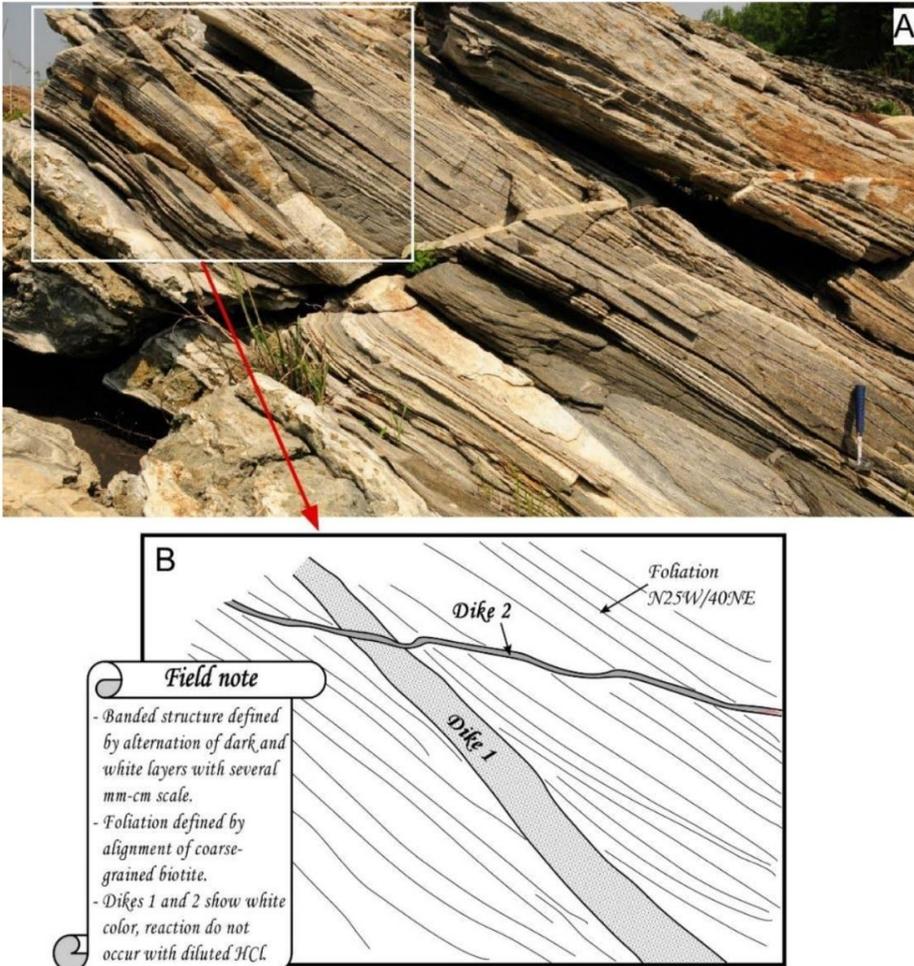
Earth's heat and energy come from different sources. Although most of the heat on Earth comes from the Sun, there are also sources of internal heat. In accordance with the theory of plate tectonics and hot spots (mantle motion, convection) the heat of the young Earth and the radioactive decay of isotopes inside the Earth cause catastrophic events like earthquakes and volcanism. The internal energy of the Earth is useful for humans (hot spring, geothermal energy). Within the Earth system, energy neither stays in one place nor dissipates, it is constantly changing.



In this test, we assess knowledge and thinking around the topic of heat and energy for both the Earth and the celestial objects in the solar system with respect to the geosphere, atmosphere, hydrosphere and biosphere.

**Introduction to questions Q1-Q3:**

Figure A is a photo of an outcrop. Figure B is a sketch of the area framed in white in Figure A which shows the major geological features with partial field notes.



**Q1)** Select ALL the correct statements for this outcrop.

- a) Foliation is formed by overhead pressure
- b) The banded structure results from regional metamorphism
- c) The foliated rock is marble
- d) Quartz and feldspar are major minerals of dike 1
- e) Calcite is the major mineral of dike 2
- f) Calcite is the major mineral of dikes 1 and 2

**Q2)** What is the chronological order of placing the different rock units? (choose only one answer)

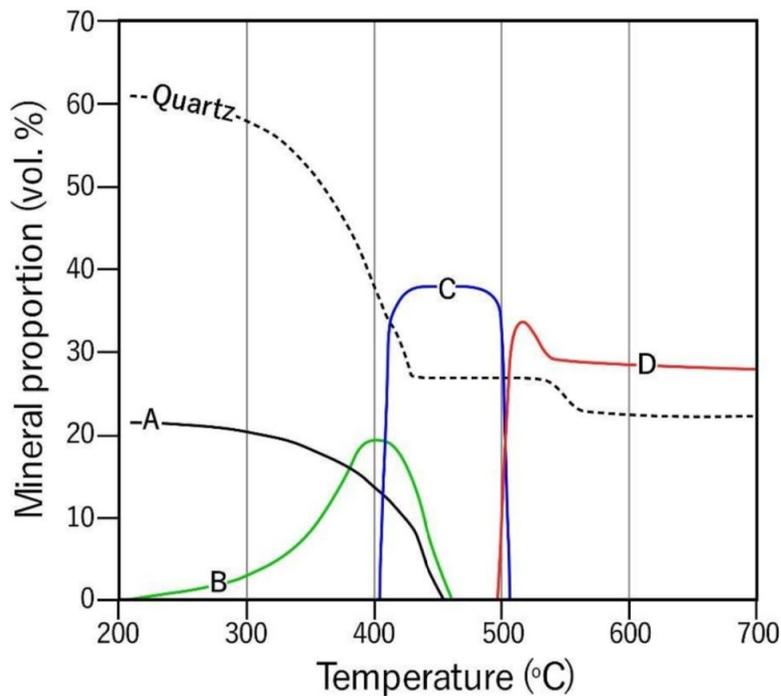
- a) Dike 1 is the oldest unit because it shows no evidence of compression
- b) Dike 2 is the oldest unit because it shows no evidence of compression
- c) The foliated unit is older than dike 2 but younger than dike 1
- d) The foliated unit is the oldest because the dike show no evidence of compression
- e) The foliated unit is the oldest because it appears below the dike

**Q3)** Which of these geological principles is used to answer question 2? (Choose only one answer)

- a) The principle of original horizontality
- b) The principle of superposition
- c) The principle of faunal succession
- d) The principle of discontinuity
- e) The principle of cross cutting relationships

**Introduction to question Q4:**

The figure below shows the change in proportion (volume in %) of metamorphic minerals A to D that were formed as a result of thermal metamorphism involving temperatures up to 700°C.



**Q4)** Select ALL the correct statements.

- a) The coexistence of minerals A and B indicate a low temperature metamorphism (below 400°C)
- b) Minerals B and C appear together around 500°C
- c) The presence of mineral C indicates a limited temperature interval for this metamorphism
- d) The coexistence of minerals C and D indicates a temperature metamorphism of 600°C or more
- e) Minerals C and D appear further from the magmatic intrusion than minerals A and B
- f) The relative proportions of metamorphic minerals can be changed due to the increase in temperature during metamorphism
- g) The water content in metamorphic minerals increases due to the increase in temperature during metamorphism

**Introduction to questions Q5-Q6:**

During the deadliest fire of 2018 in California, 8,527 fires burned 766,439 hectares. This is the largest area burned according to the California Forest and Fire Protection Department and the National Fire Coordination Center. Figure A shows the fire spreading over the side of the hill in Guinda, California on July 1, 2018.

Figure B is a visible satellite image that same day, in this area.

Smoke and clouds can be easily distinguished by their color on satellite imagery. This includes dark carbon particles including black and brown particles, which are a major problem in the context of climate change.



**Figure A**



**Figure B**

**Q5)** Based on the two figures, choose ALL of the appropriate descriptions for the black carbon particles.

- a) Dark carbon particles absorb more solar radiation incident in the atmosphere than clouds
- b) Dark carbon particles in the atmosphere can increase the Earth's surface temperature in the short term
- c) Dark carbon particles can cause an inversion layer in the atmosphere
- d) Dark carbon particles are rarely transported through the atmosphere from their source to other places

The use of fossil fuels also releases dark particles of carbon into the atmosphere. After being deposited on the glacier, they influence the amount of local energy radiation and significantly darken the area, as can be seen in Figure C (below).



Figure D shows the length of the Alpine glacier over time (Fig D-3) which has decreased dramatically since the end of the 19th century. In order to establish the reasons for the rapid retreat of the glacier, the scientists worked on different possible factors such as winter precipitation (Fig D-1), summer temperature (Fig D-2) and estimated soot emissions from Europe (Fig D-4).

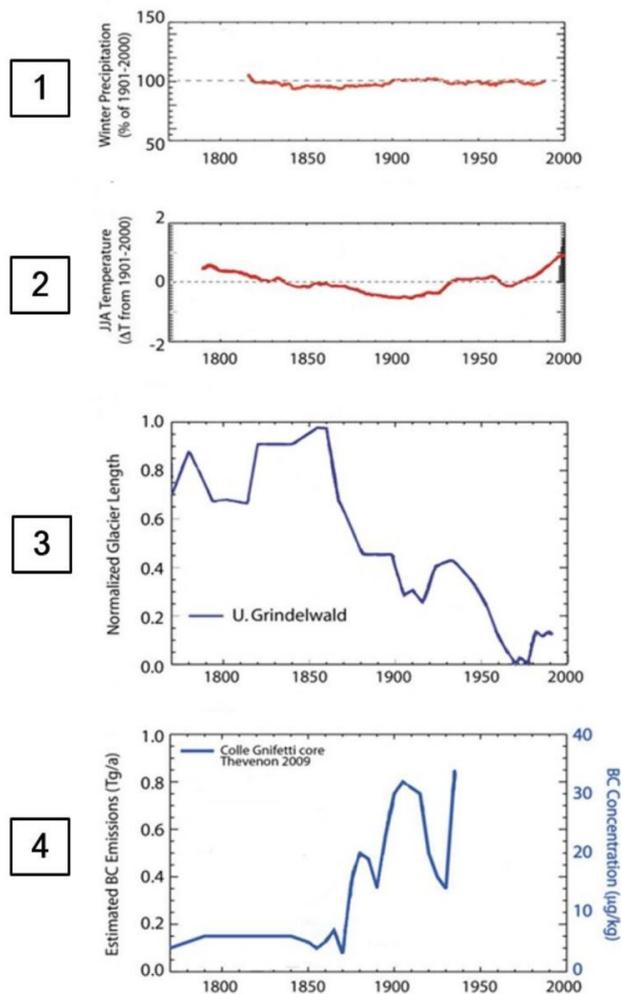


Figure D

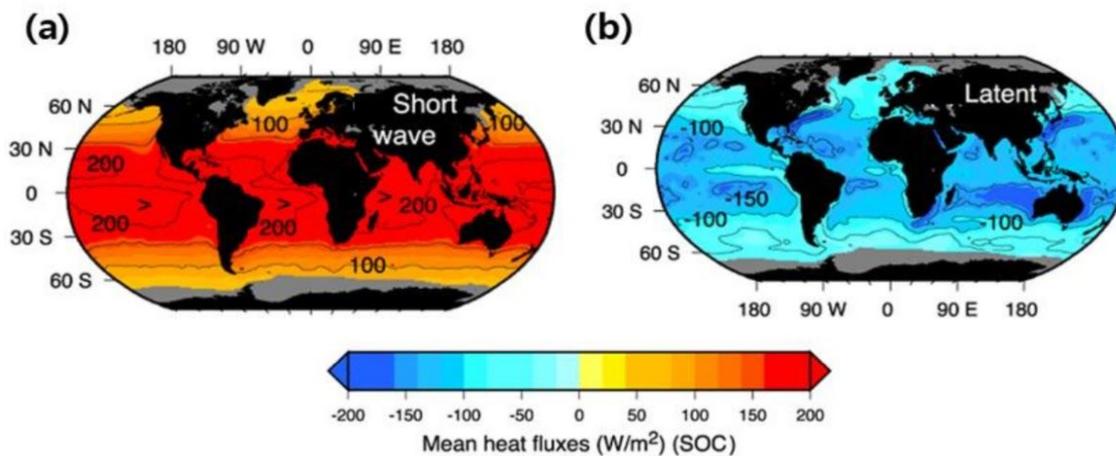
Note: JJA for the Y axis of Fig. D-2 corresponds to summer: June, July, August. BC for the Y axis of Fig. D-4 means “Black Carbon”

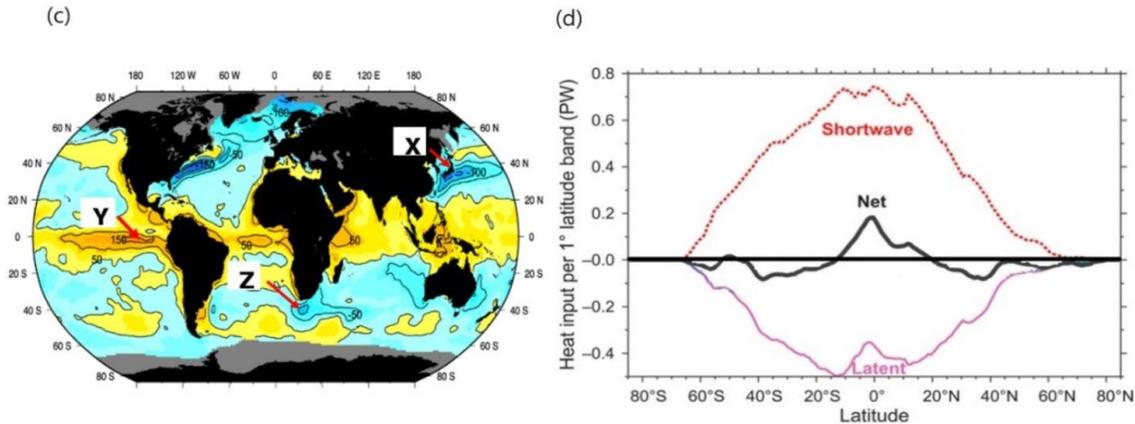
**Q6)** Based on the above information, choose ALL of the appropriate interpretations relating to the rapid retreat of the glacier.

- a) The Alpine glacier began to decline rapidly as the temperature in summer rose rapidly at the end of the 19th century
- b) The gradual decrease in precipitation in winter is responsible for the recent retreat of the Alpine glacier
- c) The retreat of the Alpine glacier at the end of the 19th century is probably not related to temperature
- d) Industrial soot probably influenced the retreat of the Alpine glacier
- e) Higher snowfall during the 20th century was responsible for the rapid retreat of the Alpine glacier

**Introduction to question Q7:**

The ocean and the atmosphere are constantly exchanging heat, as shown in the figures below. Figure (a) shows the distribution of the mean annual incident solar radiation (short wave). Figure (b) is the latent heat loss from the ocean by evaporation. The distribution of net heat flux (c) can be obtained by subtracting the total amount of heat lost due to evaporation by incident solar radiation (a positive sign represents a transfer of heat from the atmosphere to the ocean, the reverse corresponds to a negative sign). Figure (d) shows the latitudinal distribution of each of the three parameters (a) (b) (c). The distribution of the net heat flux in the equatorial Pacific Ocean is related to the El Niño phenomenon which results from the change in mean ocean temperature becoming more important.





Q7) Choose ALL the correct statements.

- The amount of (a) (solar radiation) will increase if a huge volcano erupts
- The major mechanism of heat transfer from the ocean to the atmosphere is evaporation as shown in figure (b)
- In addition to latent heat, there are other processes by which the oceans lose from heat to the atmosphere
- The salinity of the sea at the surface at 20°N and 20°S is lower than the salinity in the equatorial region
- A hot and salty current circulates in the area marked “X”
- The net heat flux in the area marked “Y” will increase when the phenomenon El Niño will take place
- “Y” has the lowest surface temperature among marine areas “X” “Y” and “Z”
- The ocean current around the “Z” zone plays an important role in the transfer of heat from the Indian Ocean to the Atlantic Ocean

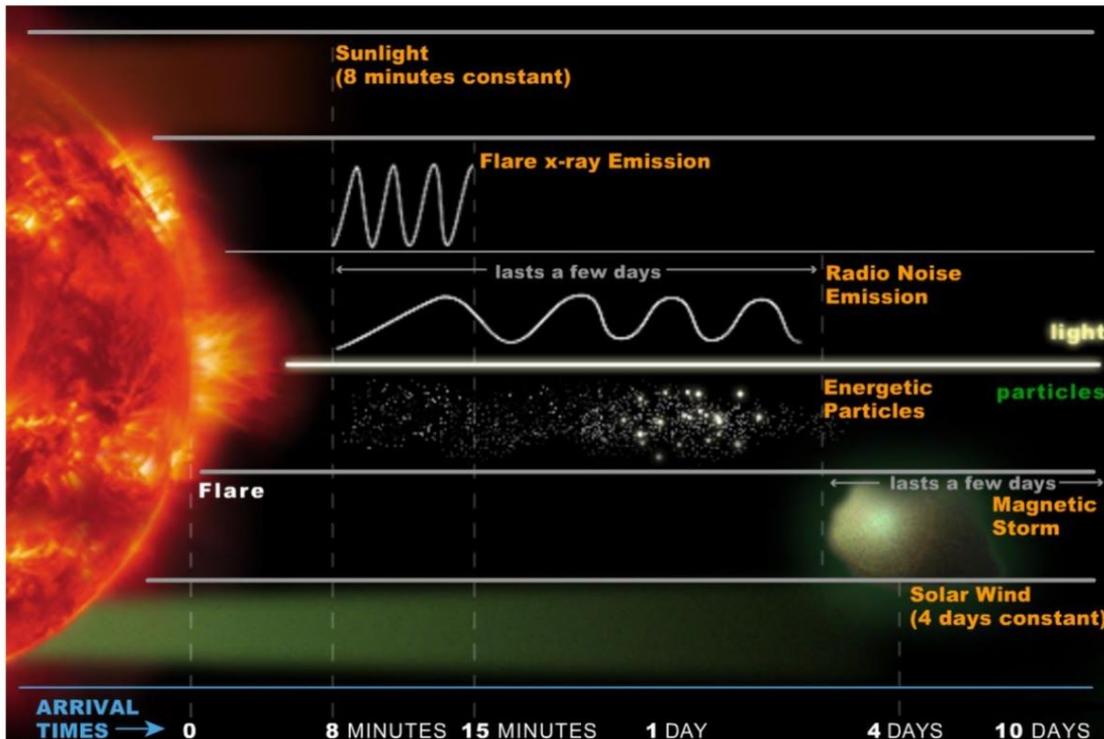
**Introduction to questions Q8-Q9:**

Although active, the Sun appears static in the region of visible wavelengths. Figure A shows images of the Sun in the visible (a) and ultraviolet (b) wavelengths. Image (c) is a solar magnetogram from October 28, 2003. The dark spots in (a) are sun spots. Image (c) shows the strength of the magnetic field in the direction of the line of sight. Here, the regions without a magnetic field are in gray and those with different polarities are in black and white. The bright part in the lower center of (b) is a solar flare. A solar flare releases an enormous amount of matter and energy. The light emitted and charged with particles reaches the Earth and impacts the environment as well as human life. When a large solar flare appears, light and energy will take some time to reach Earth.



**Figure A**

Figure B shows the time of arrival, the time of exposure to different wavelengths of light, charged particles and solar winds from the Sun reaching Earth. If observational data from the Sun is shared in real time to space weather forecasting systems, damage to the Earth could be reduced.



**Figure B**

**Q8)** Select ALL the correct statements which can be deduced from figure A.

- a) The magnetic field is strong around sunspots
- b) The magnetic field is weak around sunspots
- c) The size of the solar flares is independent of the size of the sunspots
- d) If the Sun has several large spots for a long time, the average temperature of the Earth will increase
- e) When a solar flare appears, the gas density is lower compared to areas where there is no solar flare

**Q9)** Based on figure B, choose ALL the correct statements.

- a) Visible light takes about 8 minutes to reach Earth
- b) Visible light travels faster than X-rays emitted by the solar flare
- c) Energetic particles with a greater mass arrive first on Earth
- d) Most high energy particles reach Earth in four days
- e) The high energy particles emitted by the Sun disturb the earth's magnetosphere, generating magnetic storms
- f) Long wavelength electromagnetic energy emitted by the Sun disturbs the Earth's magnetosphere, causing magnetic storms
- g) The meteorology of space around the Earth due to solar activity can be predicted by observing changes in sunspots

**Introduction to question Q10:**

The Mars exploration rover "Curiosity" has assembled a database since it landed on Mars in 2012, constantly monitoring the environment such as temperature and pressure on Mars. Figures A and B show the temperature and pressure changes measured at Gale Crater (near the Martian equator) that "Curiosity" explored for 1,300 sols after landing. "Sol" corresponds to the average Martian solar day. The charts show both the maximum and the minimum of each value by date. Figure A also compares the temperature change in Mars with the annual temperature change in Los Angeles.

The Martian atmosphere is mainly composed of carbon dioxide. There is a 'polar cap' where cold carbon dioxide exists in the form of ice. The 'polar cap' increases or decreases in volume according to the seasons.

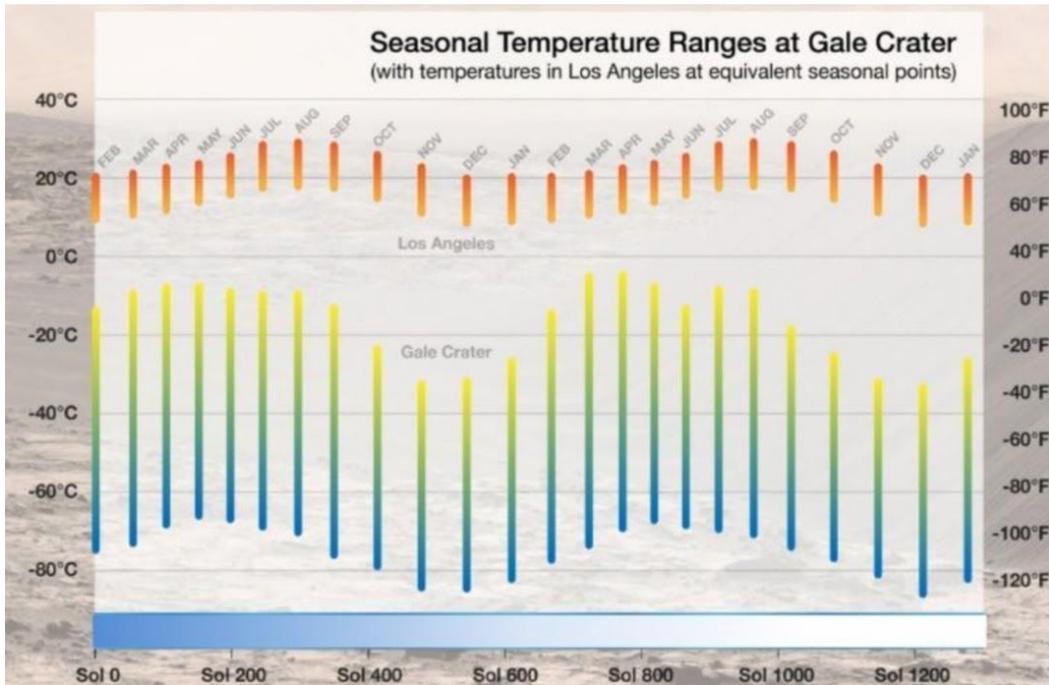


Figure A: Seasonal temperature variations at Gale crater

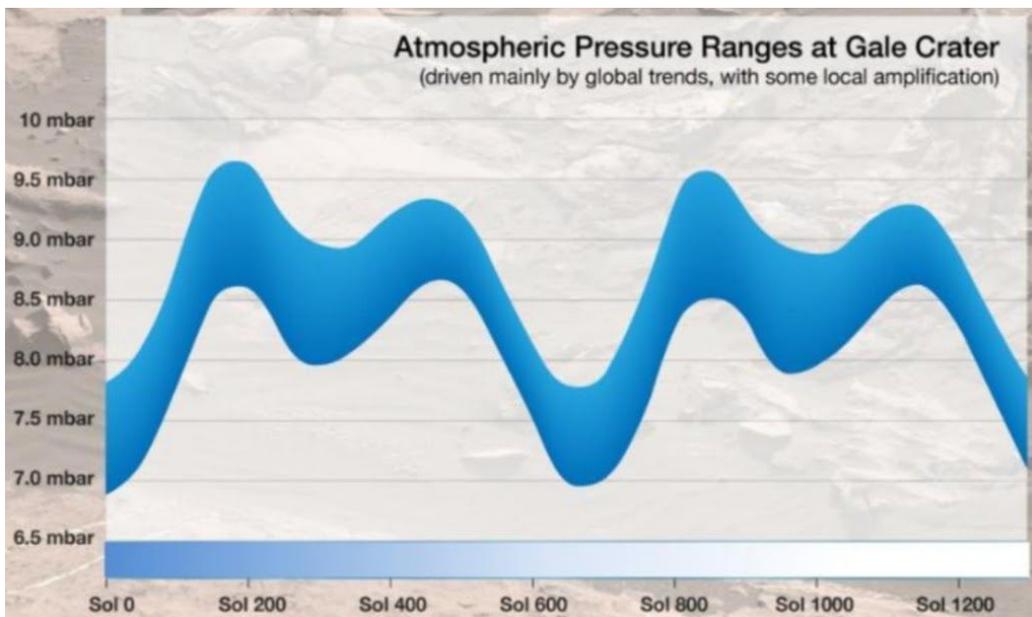


Figure B: Variation of atmospheric pressure at Gale crater

**Q10)** Select ALL of the correct answers for Figures A and B.

- a) A year on Mars corresponds to approximately 350 Sol
- b) The date 900 Sol corresponds to the Martian summer in Gale crater
- c) The diurnal temperature difference on the surface of Mars is greater than that on the surface of the Earth
- d) The annual temperature interval on the surface of Mars is greater than that of Earth
- e) Martian surface temperature is lower than Earth's surface temperature because Mars is smaller than Earth
- f) Martian atmospheric pressure is similar to terrestrial atmospheric pressure.

IESO 2019 Korea: Written Test

**Links to test (IESO 2019 Korea, in French)**

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