

Charles Darwin was a modern naturalist with a passion for Geology, even if most people would think of him as a biologist. He believed in the words of Alexander von Humboldt: “It is by isolating facts that travellers (...) have given birth to so many false ideas (...). The great geological phenomena are subject to the same laws, as well as the forms of plants and animals”. He studied with some of the first scientific geologists, like John Stevens Henslow, Adam Sedwick (the Geology Museum of Cambridge University is devoted to this man that took Darwin to his fieldtrips) and Charles Lyell (who insisted upon Darwin the importance and urgency of publishing his Origin of Species). In fact, the only paid job in Darwin’s life was the position of Secretary of the Geological Society of London.

The offer of Captain Fitzroy to travel with him, on board HMS Beagle, gave Darwin an opportunity to explore the Earth. When Darwin chose a little bunch of books for his luggage, he took Lyell’s *Principles of Geology* where he read: “A sketch of the progress of Geology is the history of a constant and violent struggle between new opinions and ancient doctrines...” When the Beagle set sail from Davenport on 27 December 1831, he wanted to play a role on this history. Moreover, when he arrived to Falmouth 2 October 1836, almost five years later, he had done even more: his contributions to Geology, being important, where to be shadowed by his contributions to Biology.

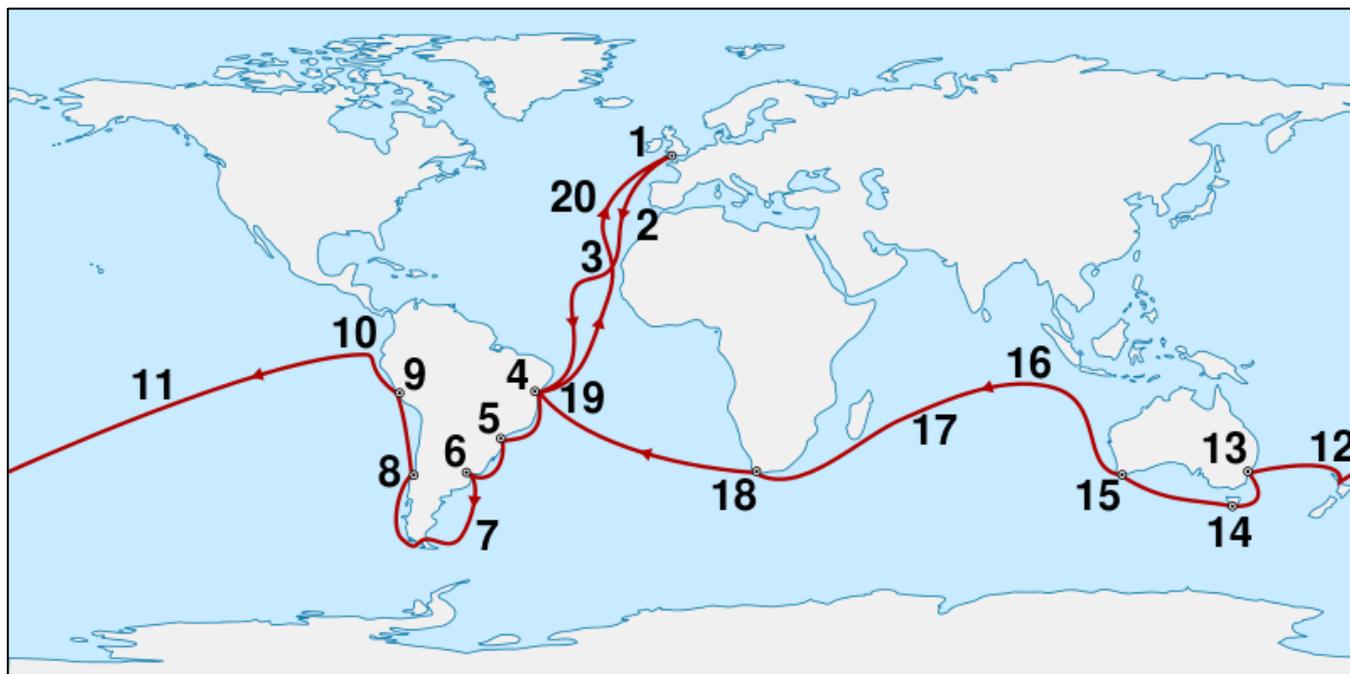


Figure 1. Voyage of the Beagle. Key : 1 Plymouth - 2 Tenerife - 3 Cape Verde - 4 Babia - 5 Rio de Janeiro - 6 Montevideo - 7 Falkland Islands - 8 Valparaiso - 9 Callao / Lima - 10 Galapagos - 11 Tahiti - 12 New Zealand - 13 Sydney - 14 Hobart - 15 King Sound – 16 Cocos (Keeling) Islands - 17 Mauritius - 18 Cape Town - 19 Babia - 20 Azores

During the Beagle expedition, Darwin made many important geological observations and interpretations –some still accepted. However, he also passed across geological phenomena impossible to understand with the knowledge and tools of the day. Therefore, following Charles Darwin and the Beagle is still a trip of geological exploration.

- The Beagle main target was mapping. To take precise measures it carries some 28 precision chronographs (the best then manufactured). Watches were essential (and still are useful) to measure...
 - Navigation distance
 - Geographic Latitude
 - Geographic Longitude
 - Tide amplitude
 - Coastal drift
 - Sea Altitude
 - Relative Humidity
 - Atmospheric pressure
- Mark the tectonic plates that the Beagle crossed in its route...
 - African
 - Antarctic
 - Arabian
 - Atlantic
 - Australian
 - Cocos
 - Eurasian
 - Indian
 - Nazca
 - North-American
 - Pacific
 - Scottish
 - African
 - South-American
- Between the voyages of Christopher Columbus (1492-1493) and Charles Darwin (1831-1832) had passed some 350 years. Assuming that tectonic activity has remained constant, Darwin found an Atlantic Ocean approximately...
 - 300 m wider
 - 100 m wider
 - 15 m wider
 - Equal in width
 - 15 m narrower
 - 100 m narrower
 - 300 m narrower
 - Impossible to know even today

Atlantic TROPICAL STORM IRENE Model Tracks
Valid Time: 1200 UTC 21 August 2011

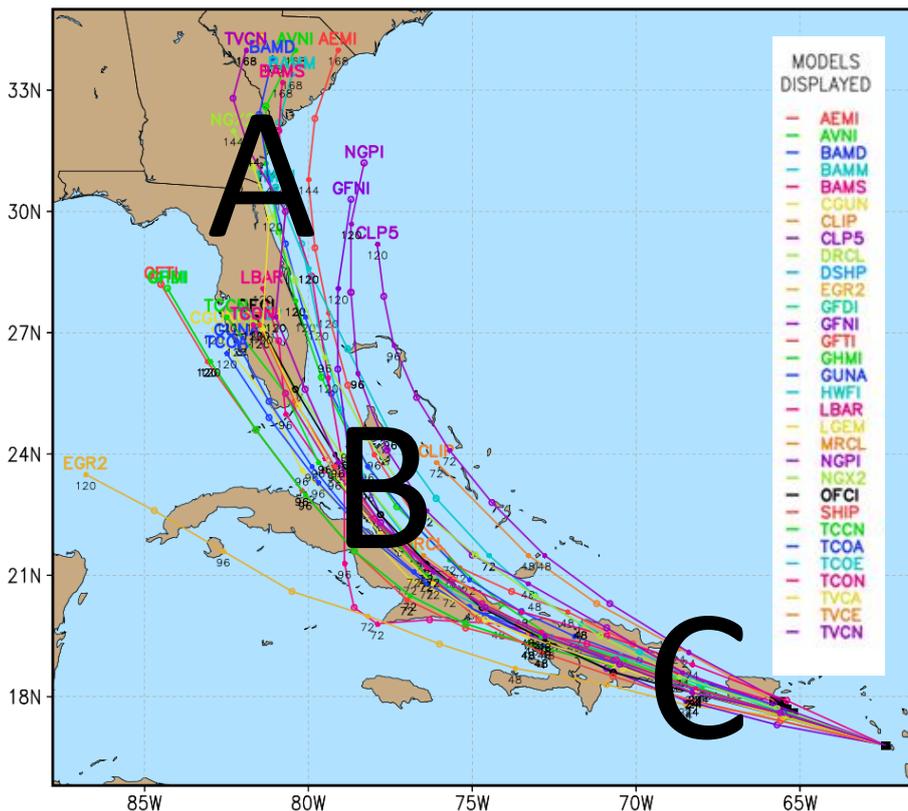


Figure 2. Spaghetti plot for tropical storm Irene, August 2011

Modern ocean navigation gets important information from meteorological agencies and models. For instance, many institutions, using different physical and mathematical models, predict the trajectory of hurricanes. A common way to ensemble the diversity of predictions is a Spaghetti Plot (figure 2). Each individual forecasts is represented by one line, and merged into one image.

- The purpose of a spaghetti plot is to give the user some idea of the...
 - Width of the hurricane
 - Reliability of the prediction
 - Straightness of trajectories
 - Time of arrival of hurricanes
 - Area affected by hurricane

- Which of the three areas marked in figure 2 provides the shortest term prediction within this diagram
 - A
 - B
 - C
 - None

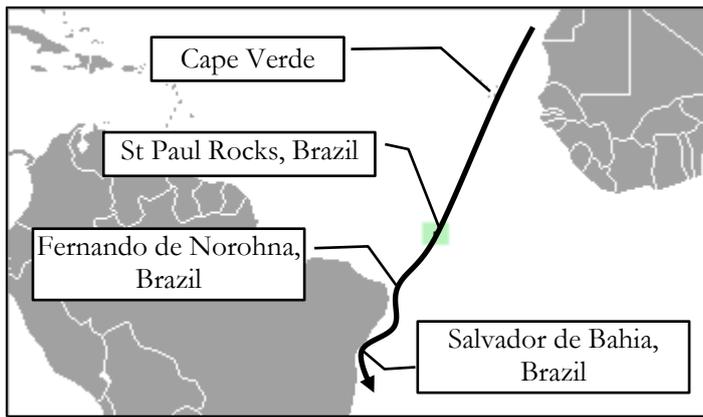


Figure 3. The route of the Beagle across the Atlantic Ocean, with indication for the islands that Darwin could explore.

After a visit to Cape Verde Islands, the Beagle sailed across the Atlantic Ocean and that included the visit to St. Paul's Rocks (figure 3). St. Paul's Rocks (Brazil) is uninhabited set or rocky islets in the Atlantic Ocean, very close to the equator ($00^{\circ}55' N 29^{\circ}20'$). The Beagle docked on the islets on 16 February 1832 and Darwin set to explore a place that was to challenge his geological knowledge. Darwin wrote "Is not this the first Island in the Atlantic which has been shown not to be of volcanic origin?" and "unlike anything which I have met with". Late in 20th century the samples that Darwin had taken in the spot where identified as "mylonitized amphibole-rich peridotites". Mylonites were defined in the 1880s, peridotites in the 1840s and plate tectonics did

not arrive until the 20th century. Hence, we can feel like the astonished Darwin.

6. According with General Atmosphere Circulation models, which wind direction? Should dominate in St. Pauls Rocks?
 - a) Northward
 - b) Eastward
 - c) Southward
 - d) Westward
7. What is a mylonite?
 - a) An igneous rock extruded in ocean ridges
 - b) A sedimentary rock formed in ocean abyssal plains
 - c) A metamorphic rock produced from friction and pressure in a fault
 - d) An weathering product of volcanic rocks under salty and tropical conditions
8. Given the composition of a peridotite, an igneous rock rich in olivine, and given the setting of St. Paul's Rocks, the most likely origin of them must be a fragment of...
 - a) South-America or Africa continental lithosphere, trapped during the first phases of splitting.
 - b) Some old subduction zone in the Atlantic coast, when the ocean was narrower.
 - c) Mantle brought to the surface during the splitting of Africa and America.
 - d) The Earth's outer core brought to the surface by deep convection.
9. The mylonitization of the rock is a example of dynamic metamorphism that, given the setting of the rocks, can also be related to...
 - a) Ocean ridge vulcanism
 - b) Tranform fault movement
 - c) Subduction friction
 - d) A triple point between three plates

On 22 August 1832, the Beagle was sailing from Montevideo to Bahia, North of Cape St Antonio (approx. $36^{\circ} S 56^{\circ} W$).

10. Given the Earth radius is 6371 km and the sky was very similar to present, how far should the Beagle travel to see both α Ursae Polaris (the Northern Star) and σ Octantis (very close to the Southern Cross)?
 - a) 6371 km northwards
 - b) 4000 km northwards
 - c) 2000 km northwards
 - d) 6371 km westwards
 - e) 4000 km eastwards
 - f) 2000 km southwards
 - g) 4000 km southwards
 - h) 6371 km southwards

The Beagle arrived in Buenos Aires (Argentina) 311 days after its departure from Britain, on 2 Nov 1832. Until January 1833, Darwin had countless occasions to explore the Atlantic Argentina coast, the Pampa and the Patagonian regions. This rather flat area, covered by loess, hides a complex geologic history and structure. Study the following idealized profile and answer the following questions (figure 4).

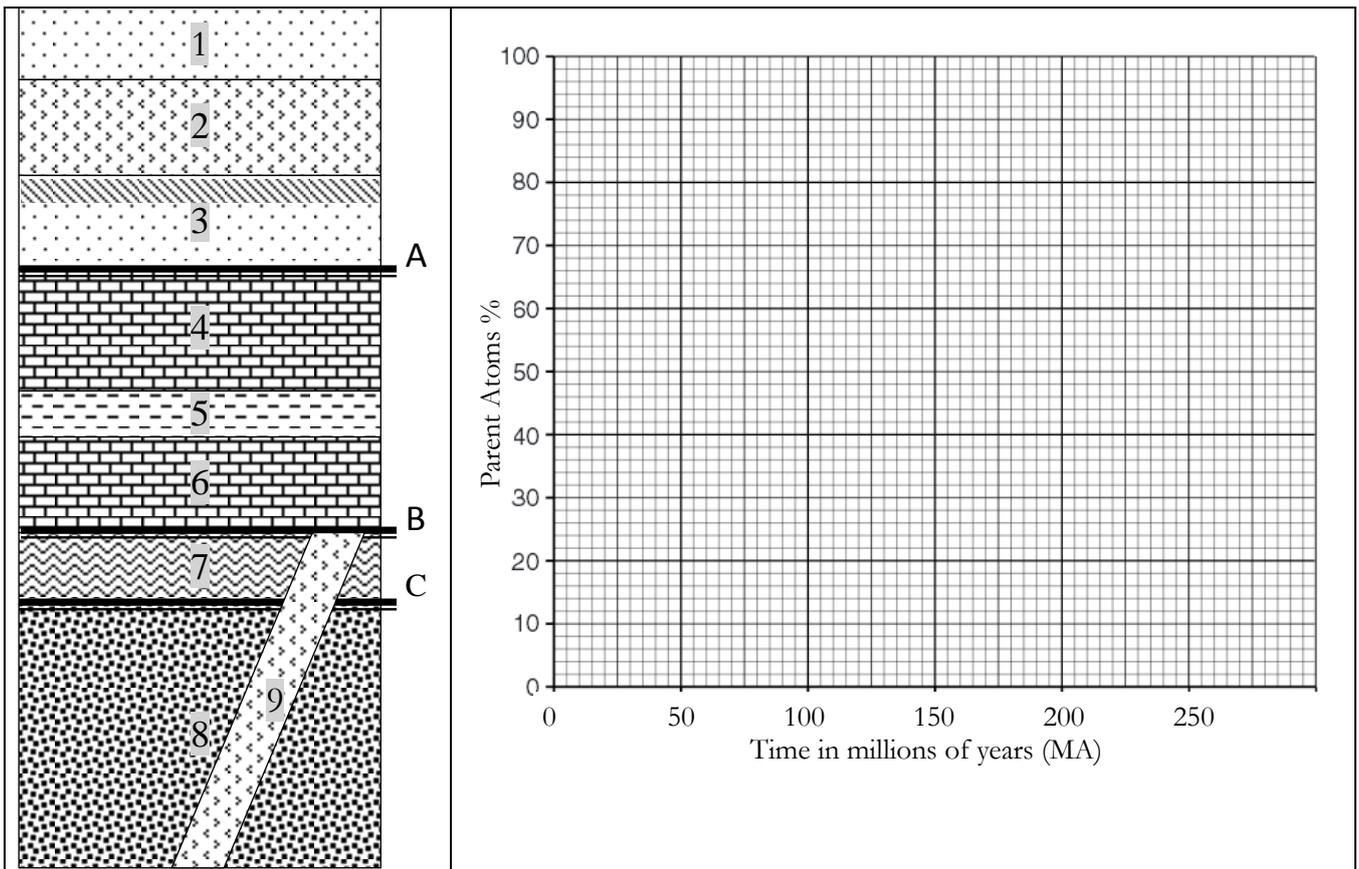


Figure 4. LEFT: Schematic section of the geological units in a region of the Atlantic Coast of South America. Key: 1. Loess. 2. Igneous rock with concentration of $[^{x}Gx]=70\%$ of original. 3. Sandstone with rodents teeth and contact metamorphism on top. 4. Nummulithic Limestone. 5. Late ~~Mesozoic~~ Mesozoic Clay with Ammonites. 6. Limestone. 7. Folded Schist. 8. Granite ($[^{x}Gx]=4.42\%$ of original). 9. Aplite ($[^{x}Gx]=6.25\%$ of original). A, B and C. Disconformities. RIGHT: Blank disintegration diagram for isotope ^{x}Gx .

11. Loess is a deposit that covers huge extensions of Patagonia. The thin dust is transported by the wind but it most often is produced from...
 - a) Settled volcanic ashes
 - b) Alluvial flooded plains
 - c) Glacial dust
 - d) Coastal plain dunes

12. The present concentration of a hypothetical radioactive isotope (^{x}Gx) related to original concentration has been measured in geological units 2, 8 and 9. The half-life ($t^{1/2}$) of ^{x}Gx is 50 million years. The geological unit 2 was formed... ago (1 Ma = 1 million years).
 - a) 10 Ma
 - b) 30 Ma
 - c) 50 Ma
 - d) 70 Ma
 - e) 90 Ma
 - f) 110 Ma

13. The origin of geological unit 2 is necessarily related to...
 - a) A sedimentary process
 - b) An intrusive process
 - c) A faulting process
 - d) A volcanic process
 - e) An edaphic process
 - f) A glacial process
 - g) An orthomagmatic dike
 - h) A plutonic process

14. Which of the three disconformities could be an angular discordance?
 - a) A
 - b) B
 - c) C
 - d) None

15. Which of the following pairs of units show evidence of a marine regression?
- | | | |
|--------|--------|---------|
| a) 9>8 | d) 6>5 | g) 3>2 |
| b) 8>7 | e) 5>4 | h) 2>1 |
| c) 7>6 | f) 4>3 | i) None |
16. Which of the following is closest to the age of the folding of unit 7?
- | | |
|-----------|---------------|
| a) 125 Ma | f) 125-150 Ma |
| b) 150 Ma | g) 150-175 Ma |
| c) 175 Ma | h) 175-200 Ma |
| d) 200 Ma | i) 200-225 Ma |
| e) 225 Ma | j) 225-250 Ma |

After exploring the Atlantic coast of South-America, the Beagle paid a second visit to Tierra del Fuego and sailed toward the Pacific Ocean, across the Beagle Channel.

17. In this area, Darwin could have experienced the Antarctic Circumpolar Current (ACC) but could not suspect the existence of the Bottom Antarctic Waters (BAW). Which of the following is most correct?
- ACC is a valuable wind for sailing and BAW is dangerous due to the presence of icebergs
 - ACC was active in the times of Darwin and BAW is a recent current due to climate warming and Antarctic ice melting.
 - ACC is very saline and BAW has a very low salinity
 - ACC is a wind driven current and BAW is a density driven current
18. The Beagle channel is a valley excavated by Pleistocene glaciers and consequently it can be described as...
- | | |
|--|--|
| a. A glacial eroded horn | d. A periglacial environment |
| b. A gelifraction valley | e. A fluvial invasion of glacial crevasses |
| c. A fiord inundated by sea level rise | f. An isostatic subsidence valley |

On 20th February 1835 the Beagle was in Valdivia when an earthquake hit the region. Darwin wrote in his journal: "This day has been remarkable in the annals of Valdivia for the most severe earthquake which the oldest inhabitants remember". By 5th March, he landed in Concepcion (Chile) 36°52' S 73°01' W and found "That not a house in Concepcion or Talchuhano (the port) was standing, that seventy villages were destroyed, & that a great wave had almost washed away the ruins of Talchuhano".

19. Given the three seismograms and the provided map, choose the location of the epicentre.
[Choose a, b, c or d in your answer sheet]

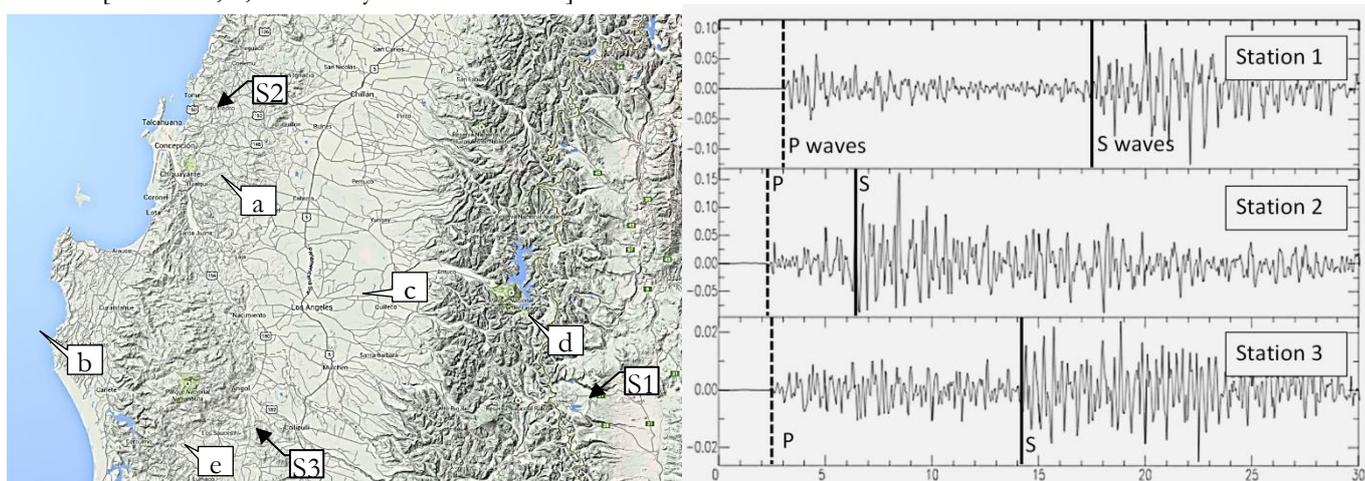


Figure 5. A. Map of a region of Chile, with the Pacific Ocean to the West and the Andes to the East. S1, S2 and S3 are three seismic stations. The points a-d show possible epicenters of an earthquake. B. Seismograms registered in stations S1-S3, with indication of the arrival times of P and S waves.

Along the journey, the Beagle visited many kilometres of coast. Look at figure 6 and decide:

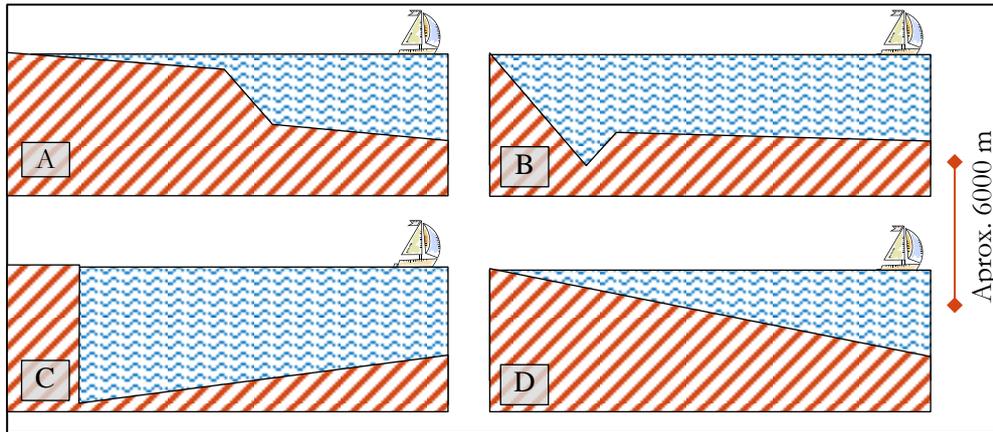


Figure 6. Four simplified hypothetical types of coast profiles.

20. Which drawing is the best representation of the coast of Santa Fe (Argentina)?
[Choose a, b, c or d in your answer sheet]
21. Which drawing is the best representation of the coast of Concepción (Chile)?
[Choose a, b, c or d in your answer sheet]

Galapagos Islands are a milestone for Darwin and any later biologist. From an Earth Science point of view, they also represent a rather special setting.

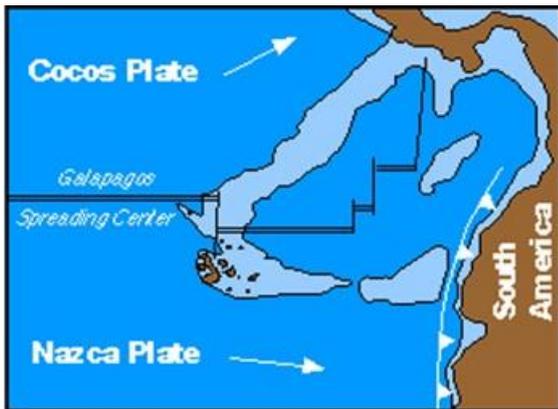


Figure 7. Simplified tectonic setting of Galapagos Islands. Arrows show plate movement.

24. The volcanism of Galapagos Islands is...

- | | |
|---------------------------------------|-------------------------|
| a) Of the same age in all the islands | f) Younger in the east |
| b) Of random age in the archipelago | g) Older in the north |
| c) Older in the west | h) Younger in the north |
| d) Younger in the west | i) Older in the south |
| e) Older in the east | j) Younger in the south |

By the time the Beagle arrived in the Cocos-Keeling Islands, Darwin had observed a lot of evidence of uplifting processes (seashells in mountains, volcanic islands, etc.) and he felt there must be evidence of subsidence somewhere to guarantee some Earth equilibrium. In fact, *The Structure and Distribution of Coral Reefs* was published in 1842 as the first part of the geology of the voyage of the Beagle. In his map of coral reefs he identified two main types of reefs: "Red for active volcanos and blue for fringing reefs". In the Cocos-Keeling Islands, Fitzroy sounded the reef and produced a precise chart that remained the standard until World War II.

This precise survey and his observations allowed Darwin to develop an explanation of reef and atoll formation that is still accepted.

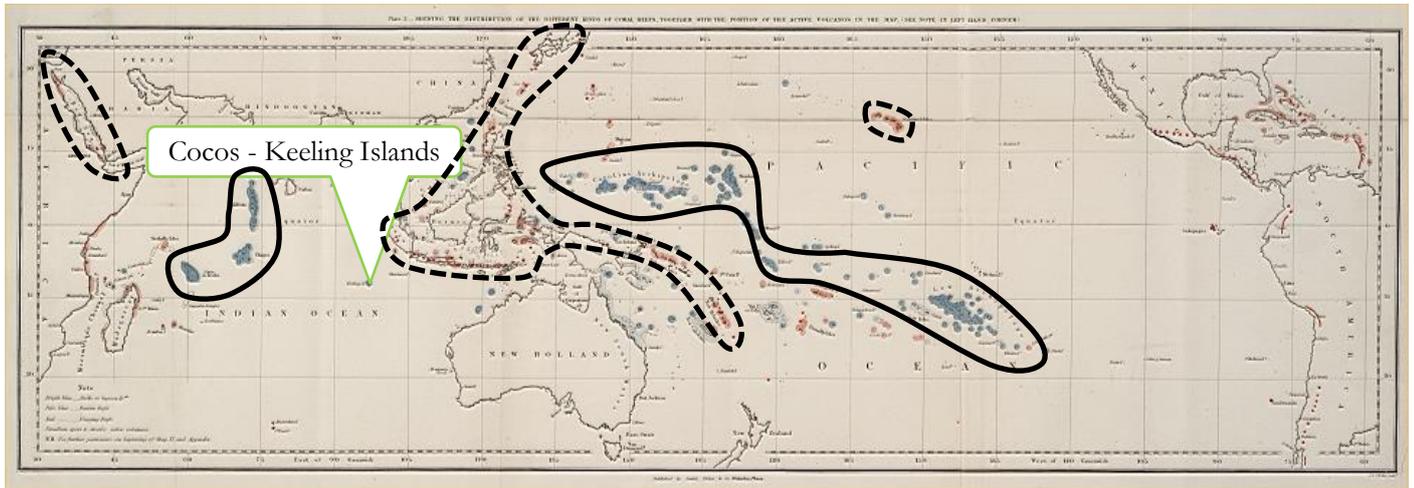


Figure 8. Darwin's map of coral reefs. Some of his "red" reefs, associated to active volcanos, are marked with solid lines. Some of his "blue" reefs, or fringe reef, are marked with dotted lines. Cocos-Keeling Islands are also marked.

25. The red reefs (dotted lines) of Darwin's map are essentially related to
- | | |
|---------------------|----------------------------|
| a) Subduction zones | d) Transforming faults |
| b) Dorsal zones | e) Continental lithosphere |
| c) Hot spots | |
26. The atolls are formed in...
- Extinct volcanos uplifted due to mantle plumes push
 - The crater of active volcanos', producing atoll ring of corals
 - The slopes of extinct, subsiding volcanos, with the corals growing to reach sun light
 - Active volcanos of low temperature
 - Active explosive volcanos

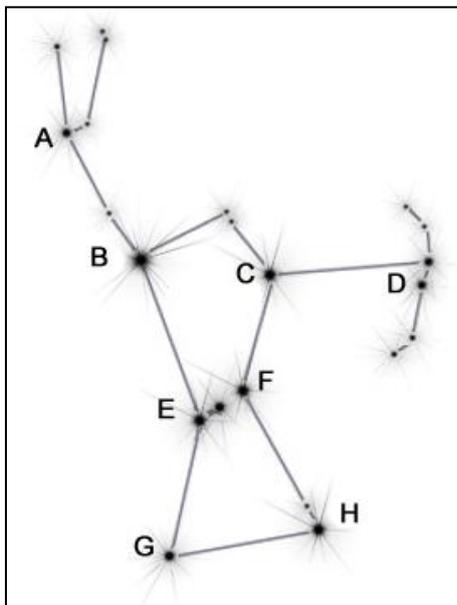


Figure 9. Simplified stellar map of constellation Orion

Along the trip, Darwin didn't pay much attention to stars, but it's sure that Fitzroy did. On Sunday, 21 Aug 1836, the Beagle crossed the Equator in his return trip to England. Along the trip, they could very often observe the constellations of the celestial equator, such as Orion. Among the stars of Orion, some are rather prominent stars, as Betelgeuse and Rigel.

27. Identify Betelgeuse in the map.
[Choose a letter from a to h in your answer sheet]

28. Identify Rigel in the map.
[Choose a letter from a to h in your answer sheet]

Figure 10 shows two versions of an H-R Diagram. You need to deduce or know the variables represented on all the axis and use the diagram to answer questions below.

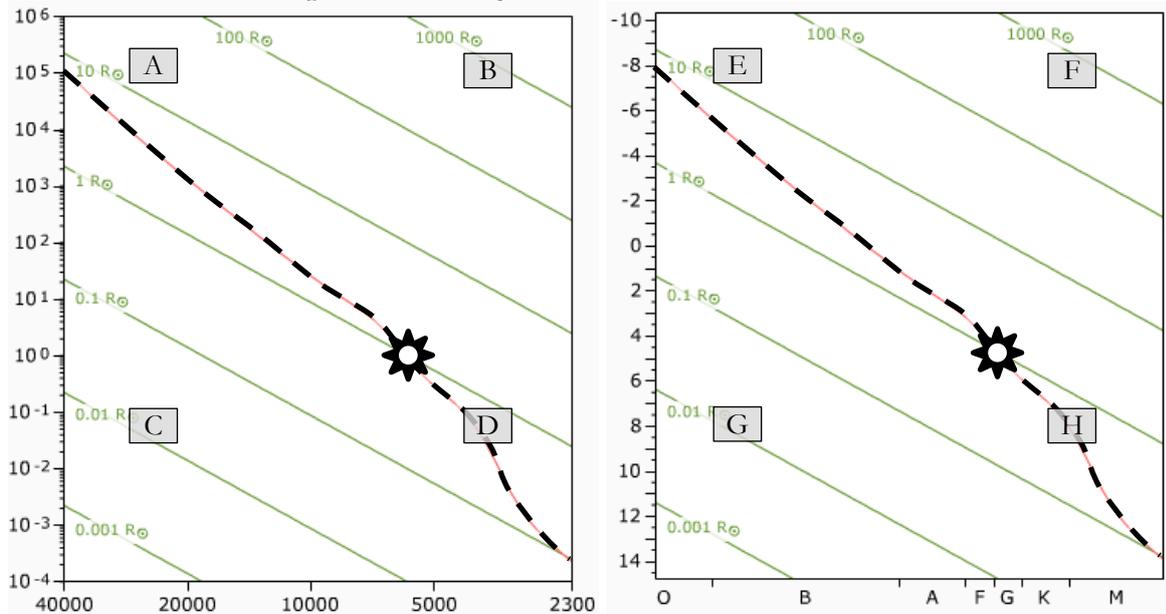


Figure 10. HR Diagram with the Sun represented by the black star.

29. Betelgeuse (in Orion) has a temperature of 3500 °K and luminosity 140,000 times that of our Sun. Where does this place it on the HR diagram? Choose the correct letter from each graph.

- | | | |
|------|------|------|
| a) A | d) D | g) G |
| b) B | e) E | h) H |
| c) C | f) F | |

30. What is the radius of Betelgeuse (B) compared to our Sun (S)?

- | | |
|----------------------------|---------------------------------------|
| a) Very similar | f) B is 100 times S |
| b) B is about twice S | g) S is 100 times B |
| c) B is about half S | h) B is 1000 times S |
| d) B is about a tenth of S | i) S is 1000 times B |
| e) S is about a tenth of B | j) Impossible to know with these data |

31. What kind of star is Betelgeuse?

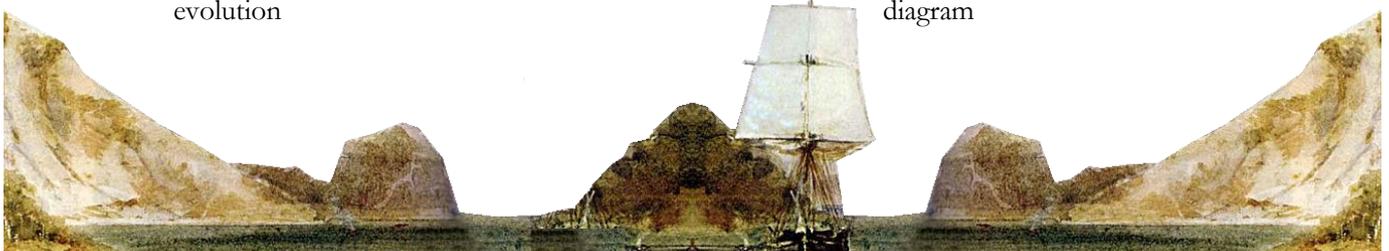
- | | |
|--------------|---------------|
| a) Red Giant | c) Blue Giant |
| b) Red Dwarf | d) Blue Dwarf |

32. What is the spectral type of Betelgeuse?

[Write the name of the spectral class in your answer sheet]

33. What is the meaning of the dashed line?

- | | |
|--|--|
| a) It marks the evolution of the Sun from top-left to bottom-right | d) It marks the limit between first and second generation stars |
| b) It marks the evolution of the Sun from bottom-right to top-left | e) It indicates the limit between stars with and without a magnetic field. |
| c) It is the Main Sequence of stars evolution | f) Nothing –the line is not part of the HR diagram |



Olduvai Gorge and the Cradle of the Humankind



The Great African Rift Valley

Olduvai Gorge (in northern Tanzania) has often been called the "Cradle of Mankind" and is part of a UNESCO World Heritage Site since 1979. It is a site in Tanzania that holds the earliest evidence of the existence of human ancestors. Paleoanthropologists have found hundreds of fossilized bones and stone tools in the area dating back two millions of years, leading them to conclude that humans evolved in Africa. This site was occupied by *Homo habilis* approximately 1.9 million years ago, *Paranthropus boisei* 1.8 million years ago, and *Homo erectus* 1.2 million years ago.

From a geological point of view, Tanzania is part of a large Precambrian craton, composed of metamorphic and igneous rocks such as gneiss and granite, which is a fragment of an ancient continent. This basement, large and geologically stable, has evolved to the present flat landscapes, dotted with inselbergs in the outcrops of the more resistant metamorphic rocks. A good example of this is the great plain of the Serengeti, in northern Tanzania, dotted with isolated hills (inselbergs).

However, the Tanzania craton is crossed by a north-south fracture-system, known as the Great African Rift Valley. A rift is a great geological feature related to the breaking of a lithospheric plate and its separation into two tectonic plates. The Great Rift Valley of Africa is 4,000 km in length, from the Red Sea to Malawi, through Ethiopia, Kenya and Tanzania (Figure 1). The rift is largely found along a single line except in northern Tanzania where it divides into two branches. Africa began splitting some 30 million years ago, and the rift is still active, with fractures moving and volcanoes bringing magma to surface. With time, it will end up separating eastern Africa from the rest of the continent, with a new ocean in between, as has already occurred in the Red Sea.

The rupture of a continent has important consequences for the climate and landscape. The breaking process associates often with the intrusion of large volumes of magma in the crust, creating large raised areas, which represent an important climatic and ecological barrier. In spite its name; the Great African Rift is not exactly a valley (

Figure 2). In fact, it forms a series of highlands crossed by a line of depressions with huge lakes in the bottom (hence the name). Thus, the rift valley separates today the humid tropics to the West (forest) and dry tropical East (savannah). However, the growing of the rift is very slow, and has produced a progressive environmental shift, transforming tropical forest into savannah, leaving for some time isolated patches of forest. This change in vegetation could force some apes to move from one jungle area to another, across savannahs to where bipedism is an important advantage.

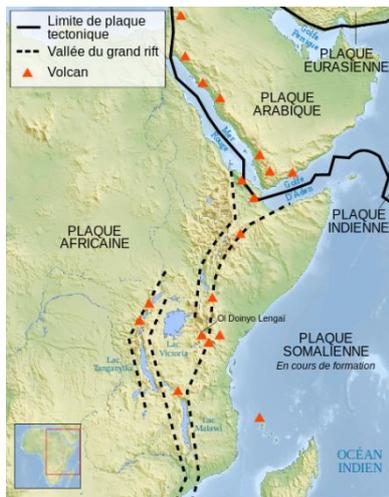


Figure 2. Plate Tectonics and West Africa structure.

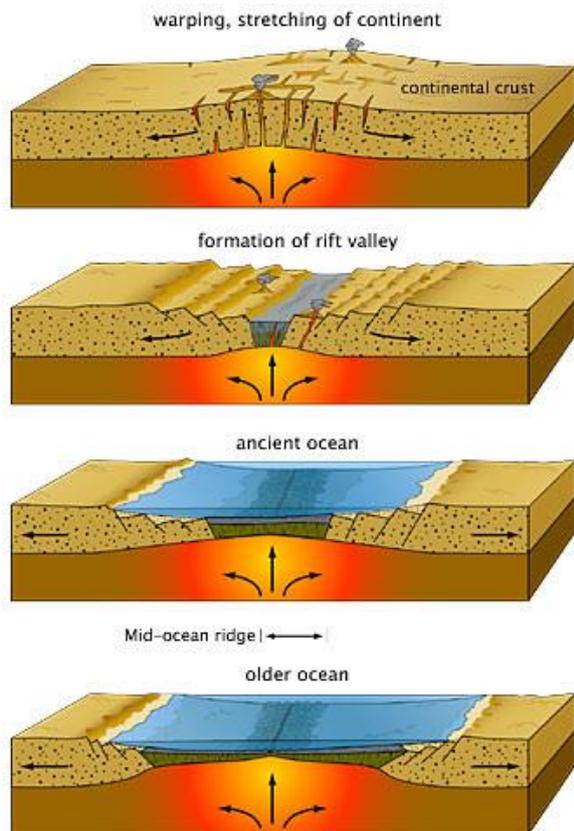


Figure 2. Evolution of a Rift. The Rift valley phase is represented by the current structure in African Rift Valley. The New Ocean Phase is represented by the Red Sea. The Mature Ocean Phase is represented by the Atlantic Ocean.

At the same time, large, shallow, and elongated lakes formed in the lowlands between elevations –Eyasi, Manyara and Natron lakes are located in northern Tanzania. Lakes get surface water, groundwater and, very often, hydrothermal waters. Under the influence of volcanic activity, there is a diversity of lake geometry and water-chemistry resulting in carbonated, salty and freshwater lakes. These lakes are wet places in the middle of arid savannah around.

Finally, the main volcanoes in northern Tanzania are Kilimanjaro, Meru and group Ngorongoro (8 volcanoes). Their emissions of lava and pyroclastic material (ash) during the Quaternary favored burial of the remains (bones) and artifacts (stone tools) generated by early hominids. Pyroclastic ashes added large amounts of calcium and magnesium into the medium, favoring a rapid process of fossilization. Some of these volcano-sedimentary deposits fossilized even the footprints of early *Paranthropus bipeds*, 3.5 Ma ago in Lemagrut slopes.

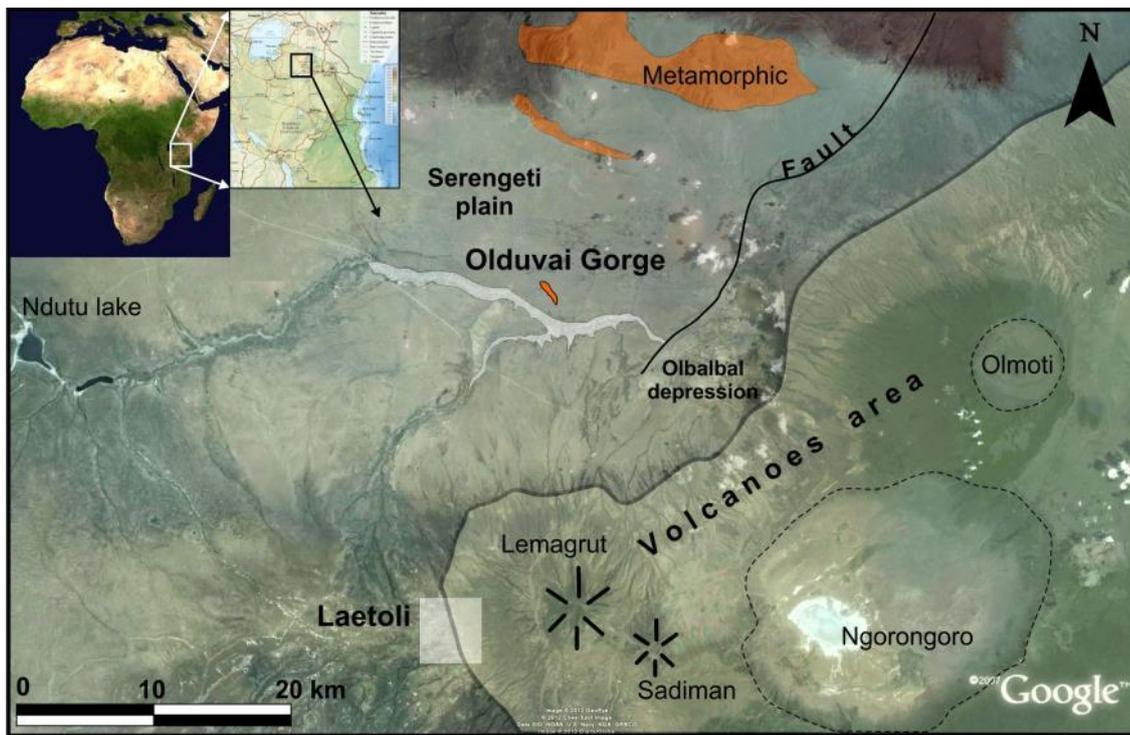


Figure 3. Olduvai Gorge, the Serengeti plains and the main volcanoes around.

Olduvai Gorge

At the southern boundary of Serengeti, is the Olduvai Gorge beside the major Rift fault. Two million-year ago, this place was a large sedimentary basin with a shallow lake in the center (Olduvai lake). The basin's southern limits were the lava flows of Lemagrut and Ngorongoro; while the north limit was a large inselberg of metamorphic rock (quartzite) (Figure 3)

As the Olduvai Lake was fed by the waters of rivers descending from the slopes of volcanoes, during periods of drought, the size of the lake decreased dramatically and even got dry.

The sedimentation in the basin was the result of fluvial transport (material with transport marks and abrasion) and volcanic materials (ash, lapilli, bombs, etc). The volcanic coarser sizes (lapilli, bombs, etc.) correspond to pyroclastic surges, with high speed and temperature. However, the ash typically deposited as ashfall and volcanic dust transformed into clay, deposited on the lake bottom.

The availability of water and vegetation represented an attraction for animals in the region. The early hominids, came here for water and hunting, but also took advantage of the presence of basalt and quartzite, as raw materials for their stone tools. In addition, the chemistry of volcanic emissions influenced the composition of the lake water, increasing pH considerably, and helped the sedimentation processes and mineralization, to preserve animal remains and stone tools, forming archaeological deposits.

Scientists of several specialties have divided the sedimentary sequence of the basin into 4 main units (Beds I, II, III and IV). They represent the last 2 million-years of earth history and contain various hominid fossils that evolved in that time (*Paranthropus*, *Homo habilis*, *Homo ergaster*, *Homo sapiens*).

Bed I and II are the most interesting from a paleontological and archaeological view. During the sedimentation of Bed I (Figure 4), the great central lake was a landmark of the landscape, and the focus of activity for the first hominids. In the Bed II at (1.78-1.2 Ma. approx.), the climate became dryer and the lake divided into small ephemeral lakes, and rivers became also ephemeral. Over time, this basin accumulated 100 meters of sediments, to form the current great plain.

However, towards the end of the Pleistocene, large faults associated to the Eastern Rift caused a 100 m entrenchment of the Olduvai River. What started as a small groove (oriented WE, to reach the Olbalbal depression) became the current Olduvai Gorge, which cuts across the strata that filled the lake and provides access to the paleontological and archaeological remains they contain (Figure 5).

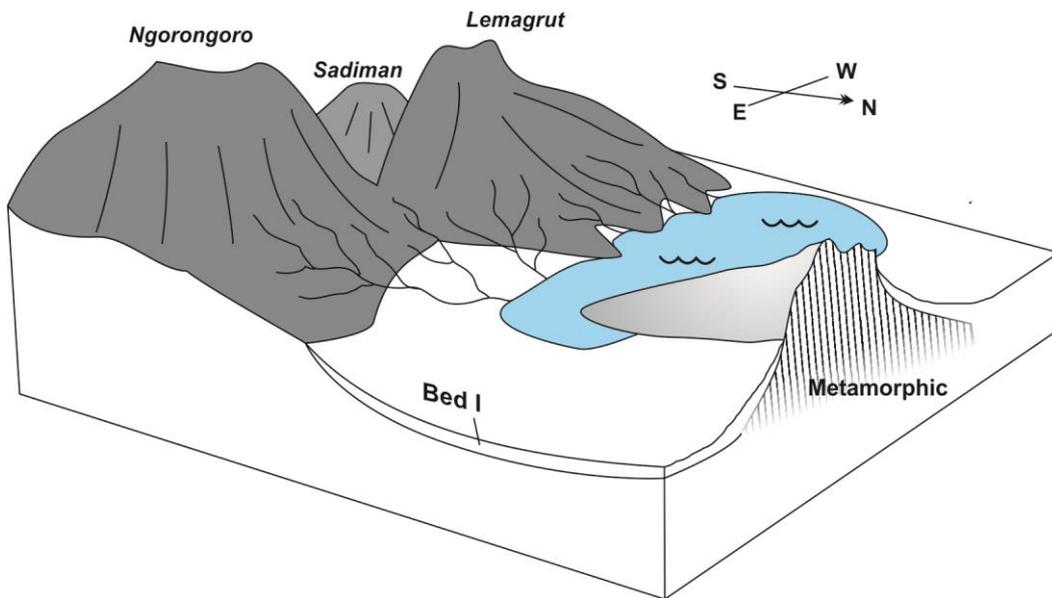


Figure 4. The Olduvai basin during the sedimentation of Bed I (2.0-1.78 Ma).

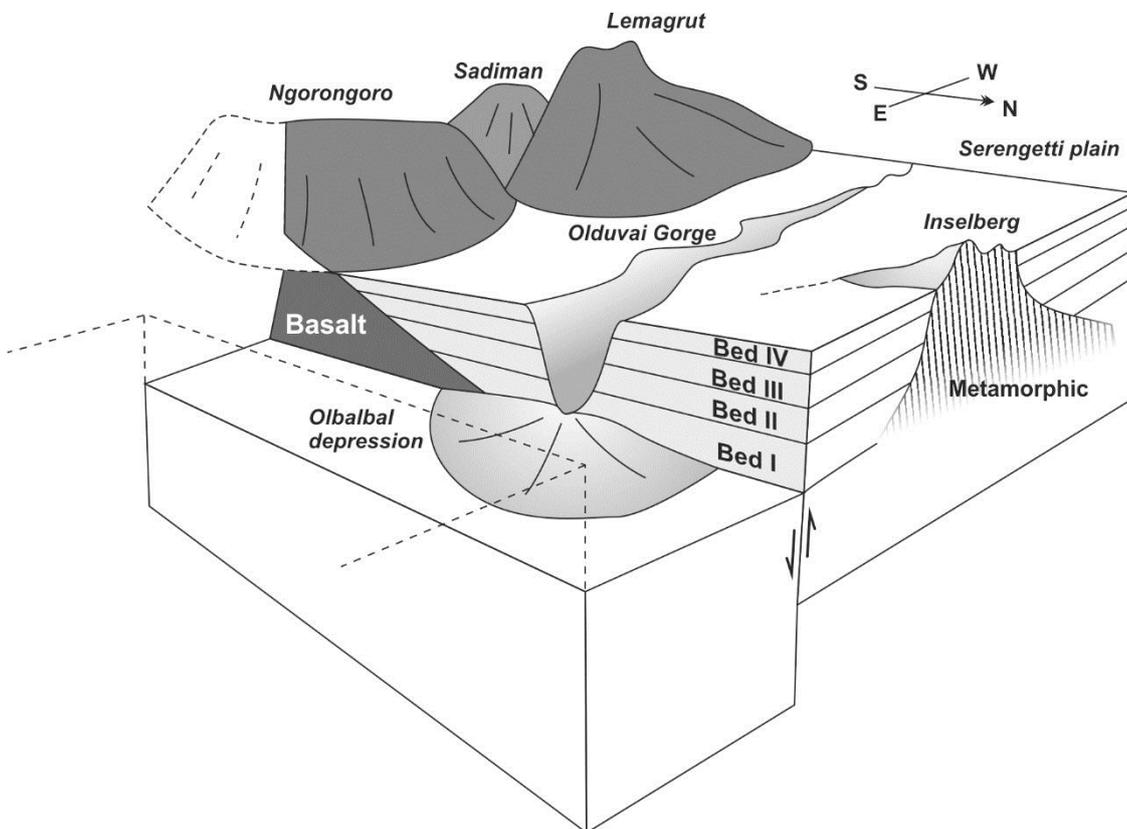


Figure 5. Diagram showing Olduvai Gorge today

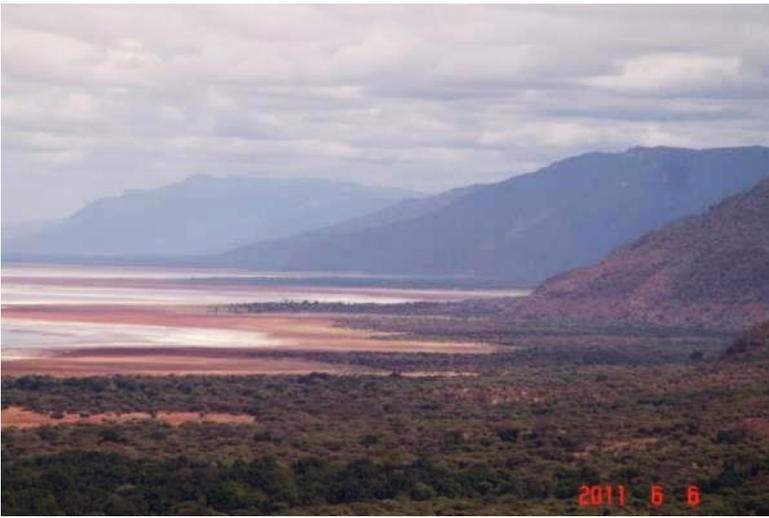


Figure 6. *Lake Manyara in the African Rift (Tanzania)*



Figure 7. *Effect of pyroclasts today. Source: <http://volcano-club.blogspot.com.es>*

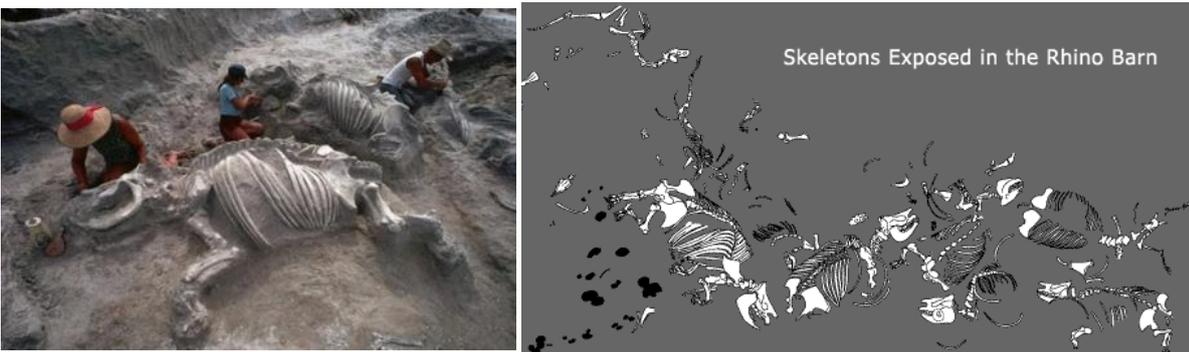


Figure 8. *Effect of pyroclasts in the past: hundreds of fossilized skeletons at Nebraska's Ashfall Fossil Beds.*

- Which of the options below best describes the impact of the opening of the African Rift on the emergence of bipedism in early hominids?
 - The rainshadow effect transformed the forest into savanna.
 - The volcanic activity caused a greater diversity of ecosystems.
 - The emergence of numerous lakes.
 - The formation of a continental north-south communication corridor.
- Why are there so many archaeological sites in the African Rift Valley?
 - Because the emission of pyroclastic material that preserved the remains.
 - Because there are numerous water resources around.
 - Because there are many rocks to make stone tools.
 - Because the presence of salts in the Rift's lakes.
- Which rocks are best suited for making stone tools in Olduvai?
 - Gneiss (glandular)
 - Metamorphic quartzite foliated
 - Slates (with garnet)
 - Basaltic lava (or very fine grained microgranular)
 - Basaltic lava (with large crystals of olivine)
- In the stratigraphic column of Figure 9, the archaeo-paleontological site B is on lacustrine clays, covered by a pyroclastic surge with cross bedding. Site A is located on the top of this lapilli pyroclastic layer, covered by volcanic ash with parallel lamination. Where would an intact skeleton most likely be found?
 - In any one, because the sediment density is very low.
 - At Site A, because the ash was deposited at low speed.
 - In the Site B, because the surge was deposited very quickly.
 - None, because the high temperature of pyroclasts destroys the bones.
- Which type of material covered and preserved the Laetoli footprints?

a) Ashes	d) Lava
b) Lapilli	e) Gravel
c) Tephra	f) Coarse Sand
- Which type of geologic event occurred while the Parantropus' family walked by the slopes of Lemagrut?
 - Tsunami (lake-type)
 - Earthquake (magnitude 8 on the Richter scale)
 - Strombolian Volcanism
 - Hawaiian Volcanism
- What can explain the excellent fossilized bones at Olduvai?
 - The presence of shallow lakes with salt precipitation.
 - The weathering of metamorphic rocks.
 - The eruption of the volcano Oldoinio Lengai carbonatites.
 - The presence of volcanic tuffs, in addition to calcium feldspar basalt.

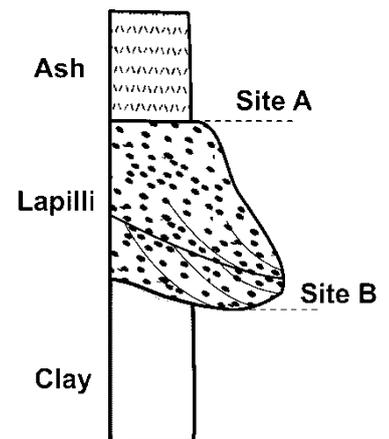


Figure 9. Stratigraphic column at sites A and B

8. Referring to Bed II, which process may explain why 90% of the fossil fauna was preserved in a fluvial environment?
- The arid climate reduces the size of the lakes and the fauna spend more time around the rivers.
 - The climate is more humid and therefore the rivers are flowing.
 - The fauna was better adapted to the riverbanks.
 - The rivers are the main agent of transport and deposition of bones and archaeological remains.

Refer to Figure 10 to solve the following questions:

9. Choose the most likely sedimentary environment (bottom of figure) for sites A and D (top of figure).
[Choose the right answer in your answer sheet]
10. Choose the most likely sedimentary environment (bottom of figure) for sites C and B (top of figure).
[Choose the right answer in your answer sheet]
11. Considering the sedimentation environment and the orientation diagrams, what is the most likely site to find remains in with complete skeletons?
- A
 - B
 - C
 - D
12. Taphonomy studies the post-sedimentary geological and biological processes on fossils. Given that 1.35 Ma ago the climate was very arid, where will you find better bones with the best evidences of manipulation by hominids?
- A
 - B
 - C
 - D

One of main challenges in paleontology is determining the age of the fossils. Finds are meaningless unless we can date them, and dating is a complex process. From the very basic methods of the first geologists to modern techniques dating has evolved enormously.

13. Back to Figure 10, which of the following is the correct order of the age of the sites, from oldest to youngest?
- $A > B > C > D$
 - $B > C > D > A$
 - $C > D > A > B$
 - $D > A > B > C$
 - $D > B > C > A$
 - $A > C > B > D$
 - $D > C > B > A$
 - $D > B = C > A$
 - $A > C = B > D$
 - Impossible to know
14. When you solved the previous question, you were using a method. Choose the two best options to describe the method you have just used.
- Absolute dating
 - Correlative dating
 - Relative dating
 - Chrono-stratigraphic dating
 - Radiometric dating
 - Principle of Uniformity
 - Principle of Superposition of Strata
 - Principle of Cross Bedding
 - Principle of Cross-Cutting

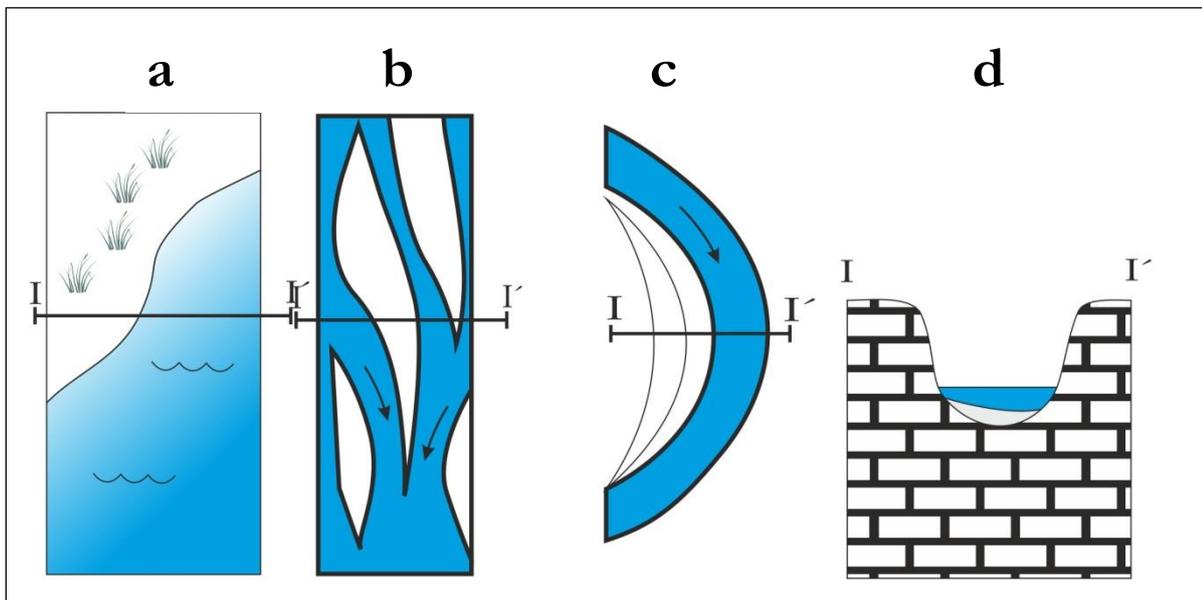
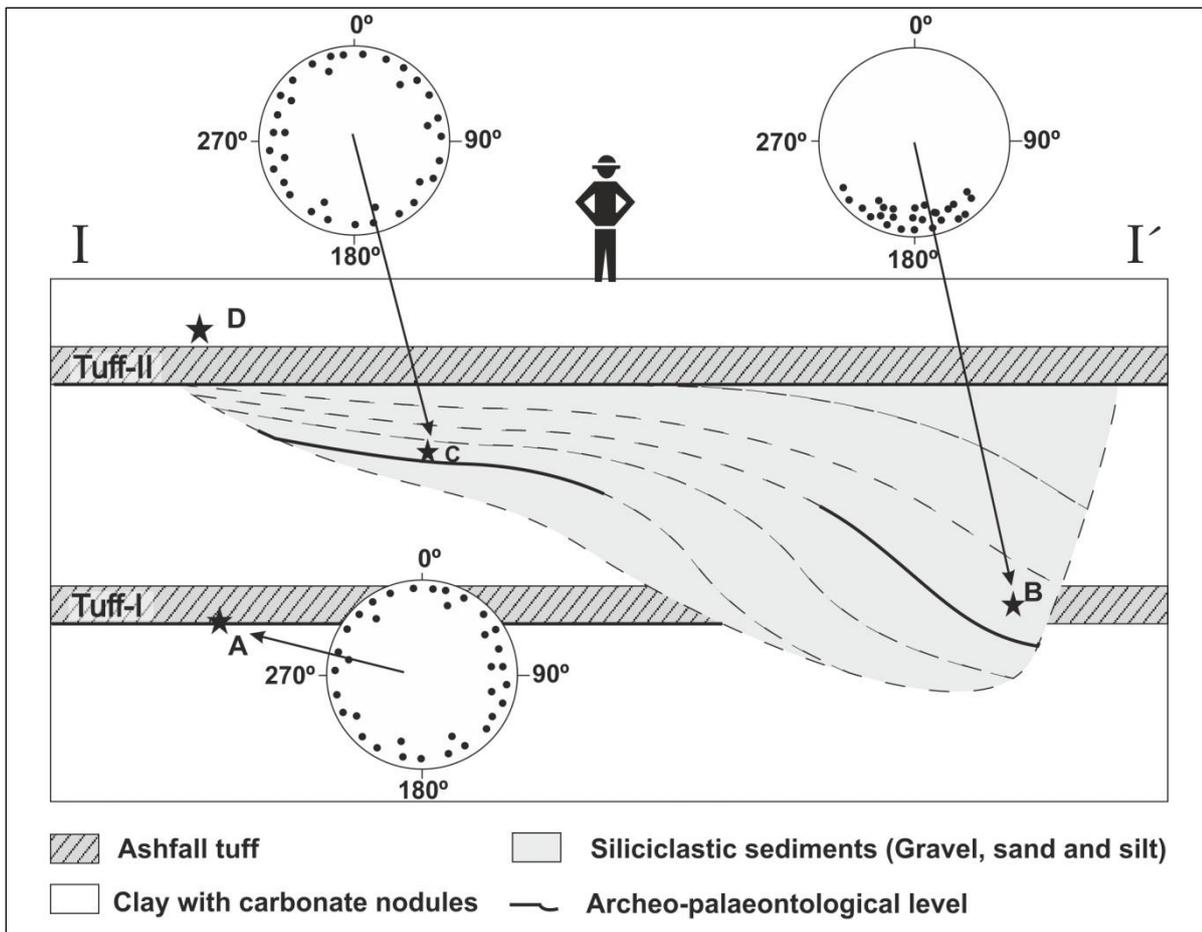


Figure 10. TOP: Geological section of the BK site (Bell's Korongo), located on the top of Bed II of Olduvai. The diagram shows the 4 archaeological levels (A, B, C and D). The circles represent the orientation diagrams of bones found in levels A, B and C. BOTTOM: Simplified representations of four sedimentary environment (a, b, c and d).

15. Which of the following radiometric series can be used in these paleo-archeological sites?
- a) K/Ar
 - b) Ce/U
 - c) Pb/Ca
 - d) He/Ar

Geologic structures are also a clue for paleontological research. Figure 11 shows a simplified geological map; but even such simple scheme would help in paleo-archeological excavations.

16. What kind of fault is F1
- a) Normal
 - b) Reverse
 - c) Strike – Slip
 - d) Rotation
17. What kind of fault is F2 if the fault plain dips 30° toward the east?
- a) Normal
 - b) Reverse
 - c) Strike – Slip
 - d) Rotation
18. Choose the best explanation for the movement of F2.
- a) BL is uplifted in relation to BC
 - b) BC is uplifted in relation to BR
 - c) BR is uplifted in relation to BL
 - d) Impossible to decide
19. These faults “cut” across a general structure than can be defined as...
- a) Diaper intrusion
 - b) Lopolite intrusion
 - c) Parallel bedding
 - d) Cross bedding
 - e) Symmetrical fold
 - f) Asymmetrical fold
 - g) Horst and graben
20. Dip values in the northern part of the map should be...
- a) Equal to the value in the south
 - b) Bigger than in the south
 - c) Smaller than in the south
 - d) Impossible to know

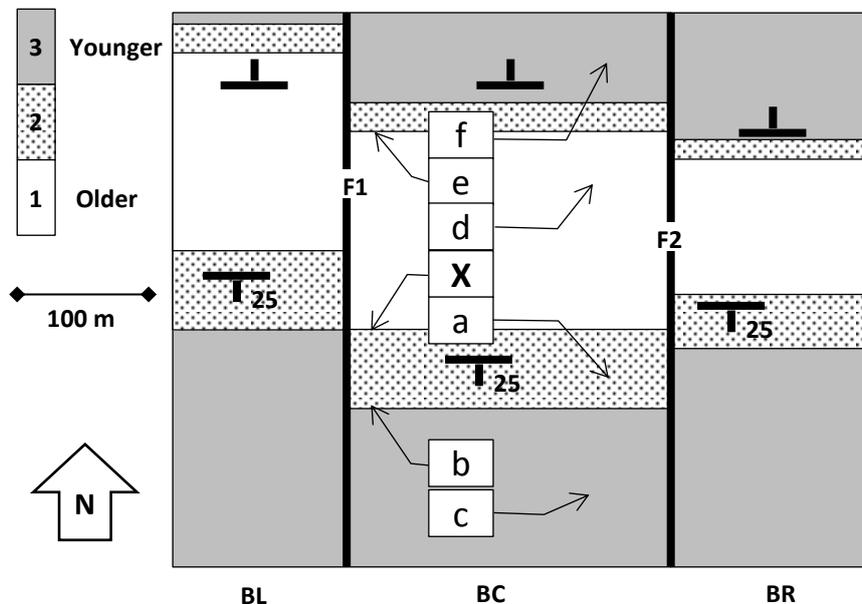


Figure 11. Simplified Geological Map of a folded paleontological site. F1 and F2 are faults. The three sedimentary units have been relatively dated, as shown in the column. The “T” symbols (and figures) give sense (and value) of strata tilting. BL=Block Left; BC=Block Center; BR=Block Right.

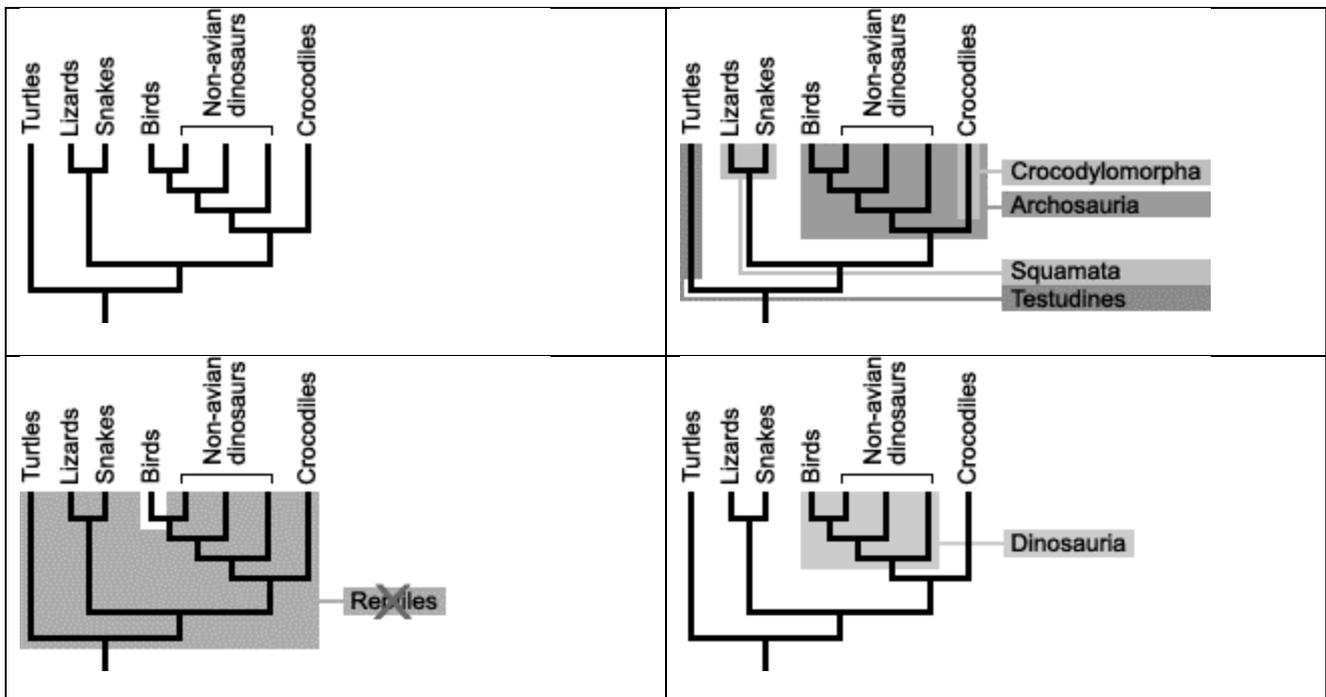
Mean surface temperature (K)	726	310	281	452
Atmosphere	96.5% carbon dioxide 3.5% nitrogen	95.3% carbon dioxide 2.7% nitrogen 1.6% argon 0.15% oxygen trace amounts of water	70% nitrogen 26% oxygen 2% argon trace amounts of carbon dioxide and water	no atmosphere
Satellites	0	2	1	0

<http://evolution.berkeley.edu/evosite/evohome.html>

Phylogenies are basic in Evolutionary Biology. **Cladograms** are phylogenetic representations to define **clades**—groups in which all organisms that are descended from a common ancestor. As an example, we can look more closely at reptiles and birds. Use this information to answer the following questions.

27. Choose the right answers that can be deduced from the table.

- Non-avian dinosaurs form a clade.
- Testudines, Squamata, Archosauria, and Crocodylomorpha all form four (4) clades.
- Turtles and Crocodiles share the same level of diversification.
- Birds and Snakes are closer than Birds and Crocodiles, from the point of view of evolution.
- Either “reptile” is not a valid phylogenetic clade or we have to start thinking of birds as reptiles.
- Dinosaurs are not extinct. Birds are, in fact, part of the clade Dinosauria.





28. Choose the right sentences about Figure 12. The sections is...
- A sedimentary sequence.
 - A soil
 - A weathering profile
 - An organic matter accumulation
29. Choose the right sentences about Figure 12.
- According to the principle of superposition of strata, A is younger than E
 - According to the principle of superposition of strata, E is younger than B
 - Except O, that is younger, all the other levels have the same age.
 - Except C, that is younger, all the other levels have the same age.
 - All the levels are contemporary.
30. Plants take nutrients only from horizon(s)...
- A
 - B
 - C
 - O
 - A+B
 - All
31. In relation to Figure 12, mechanical agriculture practices, such as ploughing, disrupts...
- All levels
 - Upper levels
 - Lower levels
 - None
32. In relation to Figure 12, intensive agriculture practices disrupts chemically...
- All levels
 - Upper levels
 - Lower levels
 - None

Figure 12. Section.



In August 6th, 2012, the crane of the Mars Science Laboratory Mission started the descent of the rover “Curiosity” on the surface of Mars. The operation was the end of a long trip of more than eight months after its launch in Cape Canaveral (Florida, USA) in November 2011. In fact, the engineers and scientists had lost the connection with the spacecraft a few minutes before, when it started its entrance to the Martian atmosphere. Only after “7 minutes of terror”, did they recover the connection to find that the spacecraft had automatically followed the plans: reduce its speed, descend towards the target site (Gale Crater), drop the thermal shield, start the engines of the crane, download the rover, and leave it smoothly and surely on the surface of the red planet ready to start its operations to explore Mars. Suddenly, the operating room in Pasadena (California, USA), was filled with cheers and applause. The rover Curiosity was safe on the surface of Mars. The first evidence of this was the first data pack with the first pictures! This happy moment was the starting point of the many activities of engineers and scientists. They could steer and drive the vehicle remotely in order to study the geology of the Gale Crater, located on the Equator of Mars. Since then (2 years ago), the vehicle has been traveling for many kilometers stopping here and there to take pictures, analyze samples, take measurements of various environmental parameters, and to drill and take core samples in the rocks along its path.



Figure 1. Crater Gale. Image take by Curiosity rover. Courtesy of MSL/JPL/NASA.

1. Images from Curiosity confirmed the observations of previous missions (orbiters, landers and rovers): Mars is a desert. In this case, which of the next features do you expect to observe in the images taken by Curiosity, like Figure 1?

- | | | |
|------------------|---------------------|-------------|
| a) Dunes | d) Meanders | g) Moraines |
| b) Eskers | e) Deflation basins | h) kettles |
| c) Alluvial fans | f) Pits | |

2. However, Mars is a cold desert. The mean temperatures are below 0°C and, in fact, the air temperatures measured by the instruments aboard Curiosity reach -80°C. If the pressure is as low as 600 Pa, what are water stable phases on Mars?

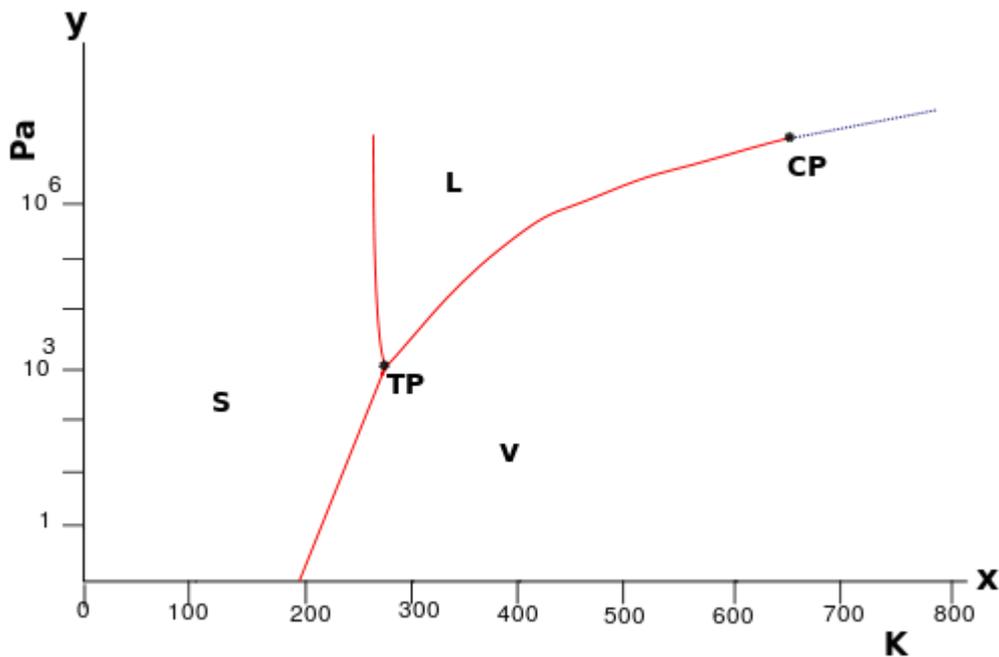


Figure 2. Erurico Zimbres in http://commons.wikimedia.org/wiki/File:Water_phase_diagram.svg

- | | | |
|-----------|-----------------|---------------------|
| a) Liquid | d) Liquid+Gas | g) Liquid+Solid+Gas |
| b) Solid | e) Liquid+Solid | h) Ether |
| c) Gas | f) Solid+Gas | i) Plasma |

3. Pictures from this cold desert (at least on this day) show that the surface of Mars has a reddish color, sometimes orange. Which mineral/s from the next list do you think that could explain this color in the Martian surface?

- | | | |
|------------------|-------------|-------------|
| a) Sulfur native | d) Limonite | g) Quartz |
| b) Hornblende | e) Calcite | h) Hematite |
| c) Pyrite | f) Olivine | i) Galena |

4. The surface of Mars is dry but also dusty, due to aeolian transport in normal conditions, and especially during the periodic global dust storms. What is/are the name/s of the transportation processes caused by the wind?

- | | | |
|----------------|-------------------|---------------|
| a) Saltation | d) Karstification | g) Creep |
| b) Diffraction | e) Corrosion | h) Deflation |
| c) Ejection | f) Dissolution | i) Suspension |

5. During the global dust storms, the atmosphere has a high content of fine particles. What do you think are their effects on the planet?

- | | |
|------------------------------------|----------------------------------|
| a) Increase the planet albedo | d) Reduce the planet albedo |
| b) Increase the planet temperature | e) Reduce the planet temperature |
| c) Increase the planet pressure | f) Reduce the planet pressure |

6. **Aeolian deposits do not cover all of the surface. Rocky outcrops are often visible in the pictures acquired by the multiple cameras of the rover, some of them with clear geological structures. Based on these observations, what are the materials in Figure 3?**

- | | | |
|------------------|---------------|-------------|
| a) Basalts | d) Sandstones | g) Breccia |
| b) Conglomerates | e) Carbonates | h) Andesite |
| c) Mylonites | f) Dolerite | i) Granite |

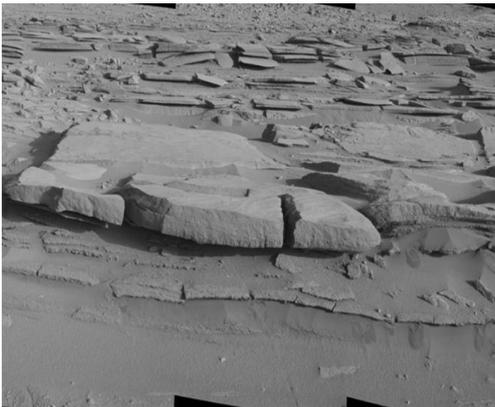


Figure 3. Crater Gale. Image take by Curiosity rover. Courtesy of MSL/JPL/NASA.

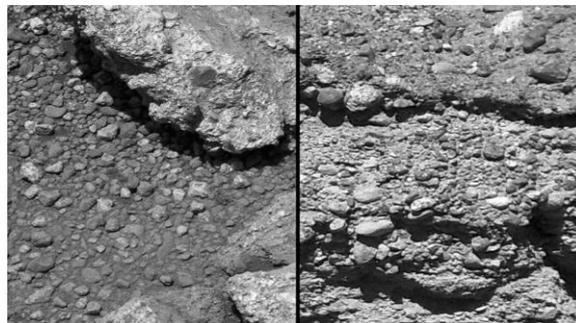


Figure 4. Crater Gale. Image take by Curiosity rover. Courtesy of MSL/JPL/NASA.

7. However, the materials on Gale Crater seem to be largely eroded and weathered. Detailed images from the Curiosity cameras, provide a picture (Figure 4-left), which looks similar to rocks on Earth (Figure 4-right). How do you think a geologist would classify this rock?

- | | | |
|---------------|------------------|---------------|
| a) Carbonates | d) Conglomerates | g) Marbles |
| b) Andesite | e) Mylonites | h) Basalts |
| c) Slates | f) Quartzite | i) Sandstones |

8. The photo **below** shows features that could be evidence of surface water being part of the history of the area. Which kind of fluvial network best describes the pattern in Figure 5?

- a) Parallel
- b) Radial
- c) Concentric
- d) Reticular
- e) Trellis
- f) Rectangular
- g) Angular
- h) Braided
- i) Dendritic

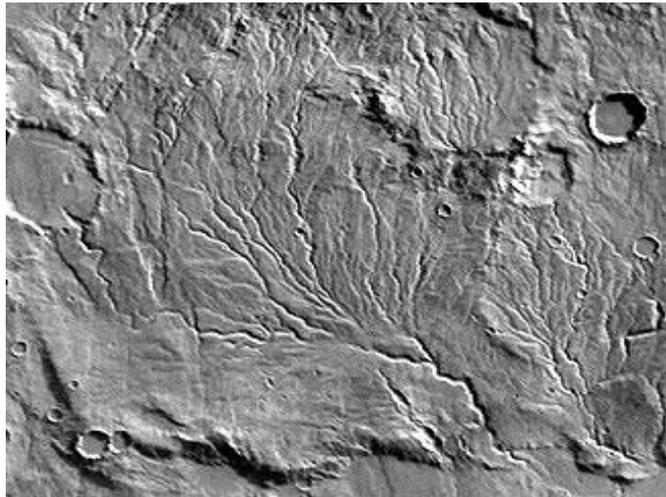


Figure 5. Warrego Vallis. Courtesy of Viking/JPL/NASA.

9. Could you calculate the sinuosity index (SI) of the stream shown in Figure 6 and classify it depending on that sinuosity? You will need your imagination, and develop your own tool to solve this problem –as happens very often in actual research.

- a) $SI < 1.05$: almost straight
- b) $1.05 \leq SI < 1.25$: winding
- c) $1.25 \leq SI < 1.50$: twisty
- d) $1.50 \leq SI$: meandering



Figure 6. Unnamed channel in Mars. Courtesy of THEMIS/JPL/NASA.

10. Which images in Figure 7 could be evidence of an ocean or lake on Mars?

- a) A
- b) B
- c) C
- d) D
- e) E
- f) F
- g) D and F
- h) All of them
- i) None of them

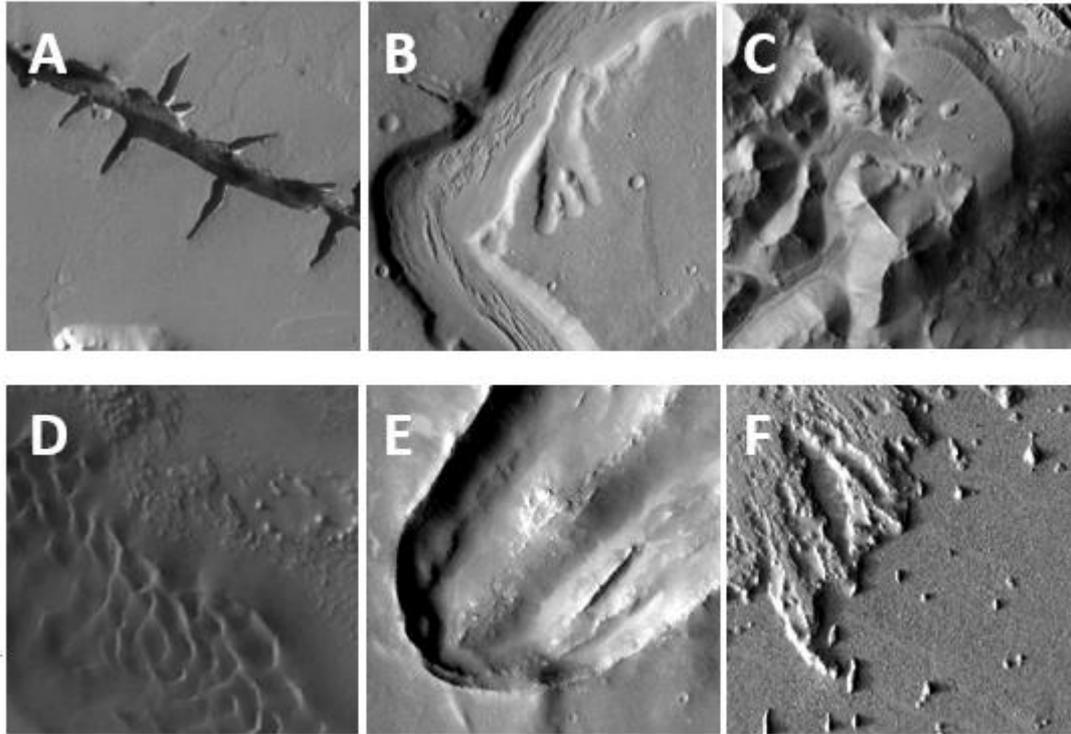


Figure 7. Images from Mars. Courtesy of THEMIS/JPL/NASA.

11. Your answer to the previous question is derived from presence in the chosen image of...

- | | | |
|--------------------|--------------------|---------------------|
| a) Littoral dunes | d) Deltas | g) Fluvial channels |
| b) Beach ripples | e) Faults | h) Glaciers |
| c) Beach crescents | f) Marsh sediments | i) Sand spit |

12. By the way, in which of the images is the main geological feature most probably a fault?
[Chose the letters a-f in your answer sheet]

13. In which of the images is the main geological feature most probably a fluvial channel?
[Chose the letters a-f in your answer sheet]

14. In which of the images is the main geological feature is most probably a dunes field?
[Chose the letters a-f in your answer sheet]

15. In the past, Mars not only had streams and oceans, but also had ice ages and the glaciers covered a large part of the planet from the Equator to high latitudes. Which process could explain better the existence of ice ages on Mars?

- | | |
|---|---|
| a) Reduction of solar energy income | d) Increase of the distance to the Sun |
| b) Decrease of the volcanic activity | e) Reduction in the rate of impacts |
| c) Changes of the planetary rotation axis angle | f) Changes on the position of the equator |

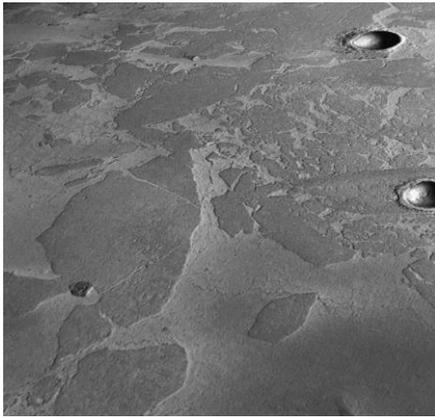


Figure 8. Utopia Planitia. Courtesy of HRSC/MEx/ESA.

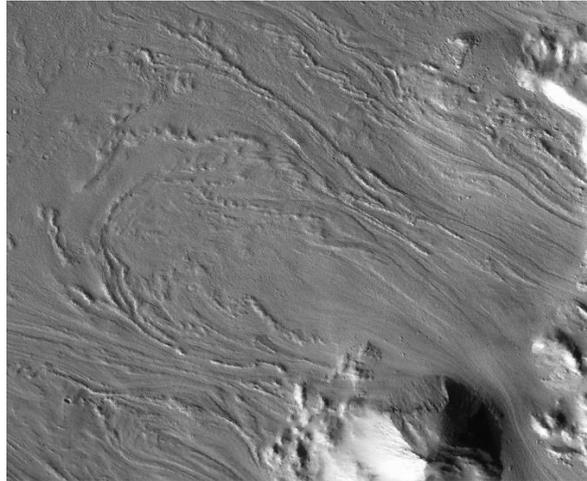


Figure 9. Hecates Tholus. Courtesy of CTX/MRO/JPL/NASA.

16. Ice processes could explain some features observed at the Mars Equator, such as those shown in Figure 8, interpreted to be...

- | | |
|-----------------------------|-----------------------|
| a) Pingos | c) Polygonal terrains |
| b) Icebergs on an ice sheet | d) Glacial cirques |

17. Scientists think that glacial processes formed the ridge-like features observed in Figure 9 but, which of the following is the best name for this “marsform”?

- | | | |
|-------------|-------------------|----------------|
| a) Esker | d) Drumlin | g) Bergschrund |
| b) Crevasse | e) Moraine | h) Mouline |
| c) Arête | f) Roche moutonée | i) Kettle |

18. The Martian atmosphere is poor in water vapor, but rich in CO₂, an important greenhouse gas. Which of the following processes could naturally increase the content of greenhouse gases in the atmosphere of Mars (as well as on the Earth)?

- | | | |
|------------------------|-----------------------|-----------------|
| a) Earthquakes | d) Springs | g) Landslides |
| b) Absence of life | e) Glaciers melting | h) Run-off |
| c) Materials oxidation | f) Volcanic eruptions | i) Solar storms |

19. Pictures of the sky reveal the presence of clouds. Based on the classification of terrestrial clouds, which kind of clouds are those Figure 10?

- a) Cumulus
- b) Stratus
- c) Nimbostratus
- d) Cirrus

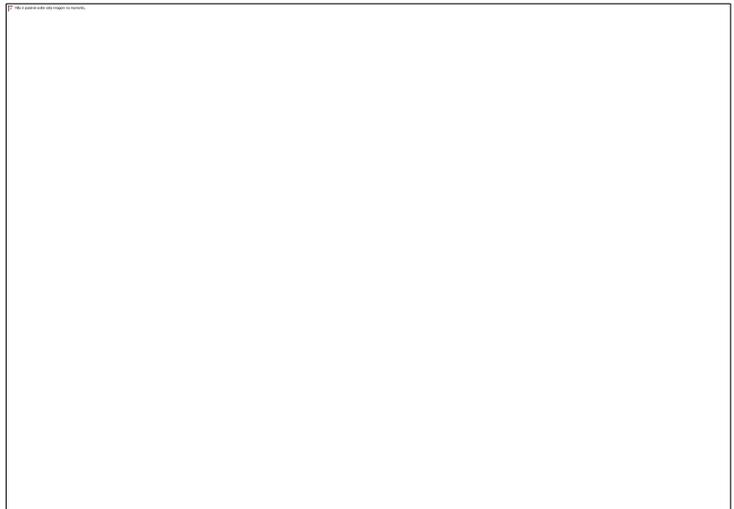


Figure 10. The sky as seen from Mars solid surface. Courtesy of MSL/JPL/NASA.

20. The content of O₂ in the atmosphere of Mars is about 0.15%, much lower than the content in the Earth's atmosphere (approximately 21%). What is the most accepted explanation of the low concentration of oxygen in Mars' atmosphere?

- a) Earthquakes
- b) Absence of life
- c) Materials oxidation
- d) Springs
- e) Volcanic eruptions
- f) Glaciers melting
- g) Landslides
- h) Run-off
- i) Solar storms

21. Figure 11 shows the vertical thermal structure (variation of temperature with height) of Earth and Mars atmospheres. Identify the thermal structure of the Earth and Mars.

- a) A represents Earth's atmosphere
- b) B represents Earth's atmosphere
- c) A represents Mars' atmosphere
- d) B represents Mars' atmosphere
- e) A and B can represent different moments in Earth's atmosphere
- f) A and B can represent different moments in Mars' atmosphere
- g) Neither A or B can represent Earth's atmosphere
- h) Neither A or B can represent Mars's atmosphere

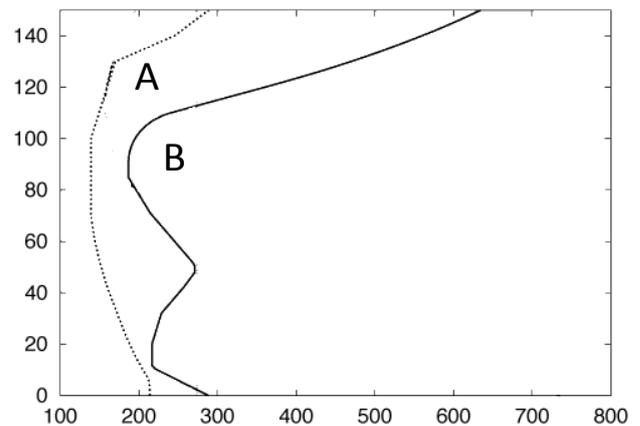


Figure 11. Atmospheric thermal structures of the two planets. X = Temperature (K), Y = Altitude (km).

22. Mars, like the Earth, have different seasons during the year (summer, autumn, winter and spring). Which of the following parameters could explain the existence of seasons on Mars?
- | | | |
|---------------------------|-------------------------|-------------------|
| a) Ellipticity | d) Precession angle | g) Magnetic field |
| b) Distance to the Sun | e) Tides | h) Year duration |
| c) Angle of rotation axis | f) Existence of 2 moons | i) Solar storms |
23. The meteorological station aboard Curiosity measures UV radiation. The first results reveal high UV radiation on the surface –relatively higher than on the terrestrial surface. With this information, what could you deduce about the atmosphere of Mars, compared to Earth’s atmosphere?
- | | |
|--------------------------------|--------------------------|
| a) It does not have mesosphere | d) It has less nitrogen |
| b) It is 5 times thicker | e) It has less ozone |
| c) There is not magnetic field | f) It is 10 time thinner |
24. Curiosity is the first rover able to provide an absolute age of a rock outside the Earth. However, from previous planetary missions, planetary geologists have used observations of rock structures and the Basic Principles of Geology to relative date the rocks. Choose Basic Principles used for relative dating on Mars or Earth.
- | | | |
|---------------------------|-------------------------|-------------------------|
| a) Inclusions | d) Original verticality | g) Law of superposition |
| b) Radioactive decay | e) Type of fossils | h) Cross cutting |
| c) Original horizontality | f) Cooling rate | i) Cosmic rays |
25. In general, planetary geologists use the cross-cutting relationships to decide which materials are older or younger. Which sequence best explains, the units observed in Figure 12 from oldest to youngest?
- | | | |
|----------|----------|----------|
| a) A-B-C | c) A-C-B | e) C-A-B |
| b) C-B-A | d) B-C-A | f) B-A-C |
26. The rocky outcrops reveal important information about the most recent environmental conditions. What would be the most likely origin of the features observed in Figure 13? Take into account that the front left wheel of the rover shown in the picture is about 50 cm width.
- | | | |
|-----------------------|--------------------|-------------------------|
| a) Tectonic faults | d) Glacial erosion | g) Aliens’ ichnites |
| b) Polygonal terrains | e) Fluvial erosion | h) Desiccation cracks |
| c) Wind erosion | f) Stratification | i) Metamorphic cleavage |

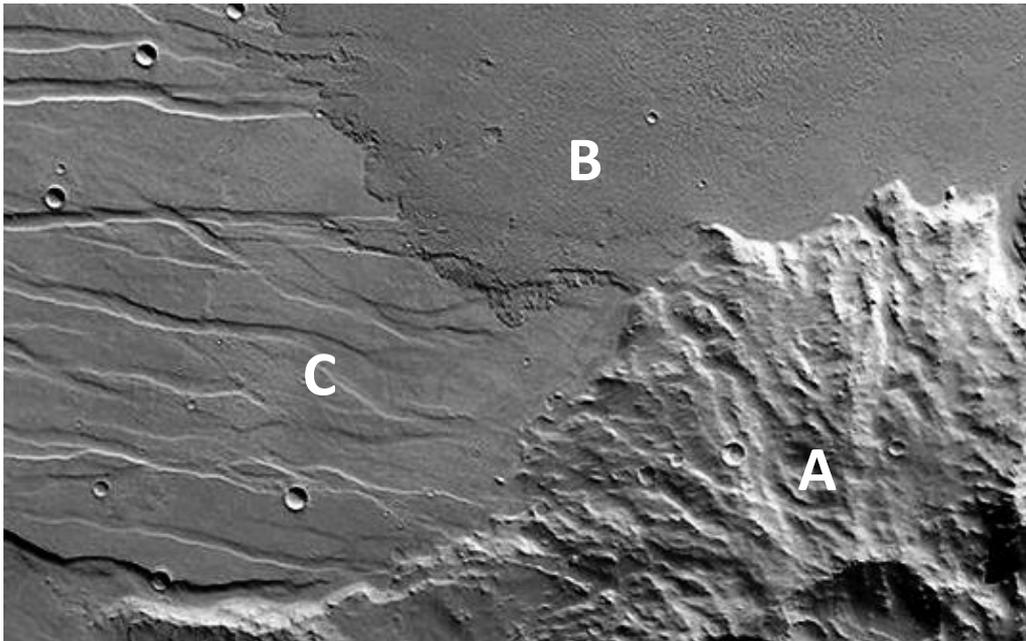


Figure 12. Claritas Fossae. Courtesy of HRSC/MEx/ESA.

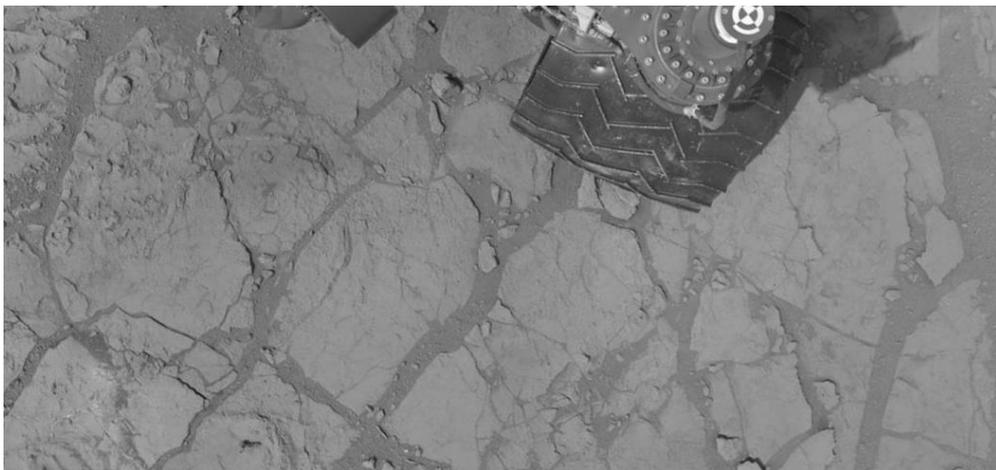


Figure 13. Gale Crater. Courtesy of MSL/JPL/NASA.

27. Combining data from the rover and several artificial satellites orbiting the planet, planetary geologists drew a geological section of sedimentary materials in Mount Sharp (the hill located in the center of Gale Crater). What kind of unconformity do we have?

- a) Disconformity
- b) Angular unconformity
- c) Nonconformity
- d) Paraconformity
- e) Conformity
- f) Any of them

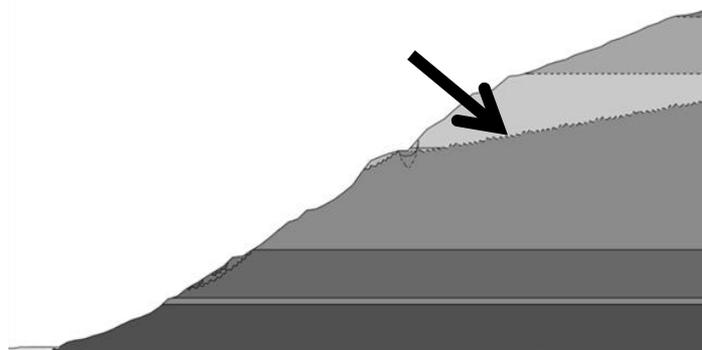


Figure 14. Geological Cross Section. Courtesy of MSSS.

28. If plate tectonics existed on Mars, which of the following features do you expect to observe on the surface of that planet?

- a) Mountain ranges
b) Only old terrains
c) Elongated depressions (trends)
- d) Disperse volcanic activity
e) Absence of faults
f) Alignments of volcanic edifices
29. To know more about the inner structure of Mars, future missions will include seismometers. However, imagine that we detected seismic waves with period of 1s, 10s and 100 s, with associated wavelengths of 5 km, 50 km and 500 km, respectively. Which should be the seismic wave propagation velocity?
- a) 2.5 km/h
b) 5 km/h
c) 10 km/h
- d) 2.5 m/h
e) 5 m/s
f) 10 km/h
- g) 2.5 km/s
h) 5 km/s
i) 10 km/s
30. If a future seismometer would record a “marsquake”, but only its P waves. What could you deduce respect to the inner structure of the planet?
- a) Does not exist a core
b) There is a liquid layer inside
- c) All the planet is solid
d) The planet does not have mantle
31. Tharsis and Elysium are two huge volcanic provinces of Mars, more than 2000 kilometers in diameter each. As we do not have evidences of plate tectonics in Mars, which process could better explain the existence of those important volcanic regions?
- a) Impact craters
b) Hot spots
c) Subduction processes
- d) Batholiths
e) Diapirism
f) Magma crystallization
- g) Solar storms
h) Aliens activity
i) Any of them
32. Some Martian volcanoes had erupted about 350 Million year ago. In which geological period was the Earth at that moment?
- a) Upper Devonian
b) Middle Triassic
c) Lower Cambrian
- d) Upper Carboniferous
e) Middle Cambrian
f) Lower Cretaceous
- g) Upper Jurassic
h) Middle Silurian
i) Lower Holocene
33. None of the previous rovers have detected the presence of fossils or any other biological marker on Mars, not even when the landing sites was located on the floor of the ancient ocean of Mars. On Earth, which of the following are markers of the presence of life in the ancient oceans?
- a) Belemnite
b) Calamites
c) Equus
- d) Hyperion
e) Mammoth
f) Quercus
- g) Tyrannosaurus
h) Crinoid
i) Sigillaria

34. During its trip on the surface of Mars, Curiosity photographed this rock (Figure 15), interpreted by the scientific team as a meteorite. What is the most likely origin?

- a) Moon
- b) Earth
- c) Asteroids belt
- d) Oort cloud
- e) Mercury
- f) Jupiter
- g) Sun
- h) Titan



Figure 15. Gale Crater. Courtesy of MSL/JPL/NASA.

35. Some Earth meteorites may have come from Mars, as ALH84001 located in Antarctica in 1984. What is the name of these meteorites?

- a) Enstatites
- b) NRL
- c) Pallasites
- d) SNC
- e) Condrites
- f) APF
- g) Acondrites
- h) FPA
- i) Ferrodriles

36. Because it is not possible to use a compass or a Global Positioning System (GPS) to locate and track the rovers on Mars, engineers use the positions of the stars to find them. The main star in the sky of Mars is the Sun, at a distance of 1.5 AU. On Earth the Sun has an angular diameter of 0.5° . What is the angular diameter of the Sun in the sky of Mars?

- a) $40'$
- b) $30'$
- c) $20'$
- d) $10'$
- e) $5'$
- f) $1'$
- g) 0.4°
- h) 0.5°
- i) 0.6°

Read the following text and study carefully Figure 16

“Scientists used the Chemistry and Camera (ChemCam) instrument on NASA’s Curiosity Mars rover in June 2014 to examine a Martian rock “shell” about one inch (two to three centimeters) across, embedded in fine-grained bedrock and with a dust-filled hollow interior. This graphic (Figure 16) combines an image of the target, called “Winnepesaukee,” with spectrographic results from using ChemCam’s laser on a row of points including the rock, the matrix around it and the material filling it.”

(Credit: NASA/JPL-Caltech/LANL/CNES/IRAP/LPGNantes/CNRS/IAS/MSSS).

37. Which rocks on Earth have high concentrations of Mg and Fe, and dark color, like the one in the image?

- a) Basalt
- b) Biotite
- c) Conglomerate
- d) Clay
- e) Granite
- f) Gabro
- g) Gneis
- h) Sandstone

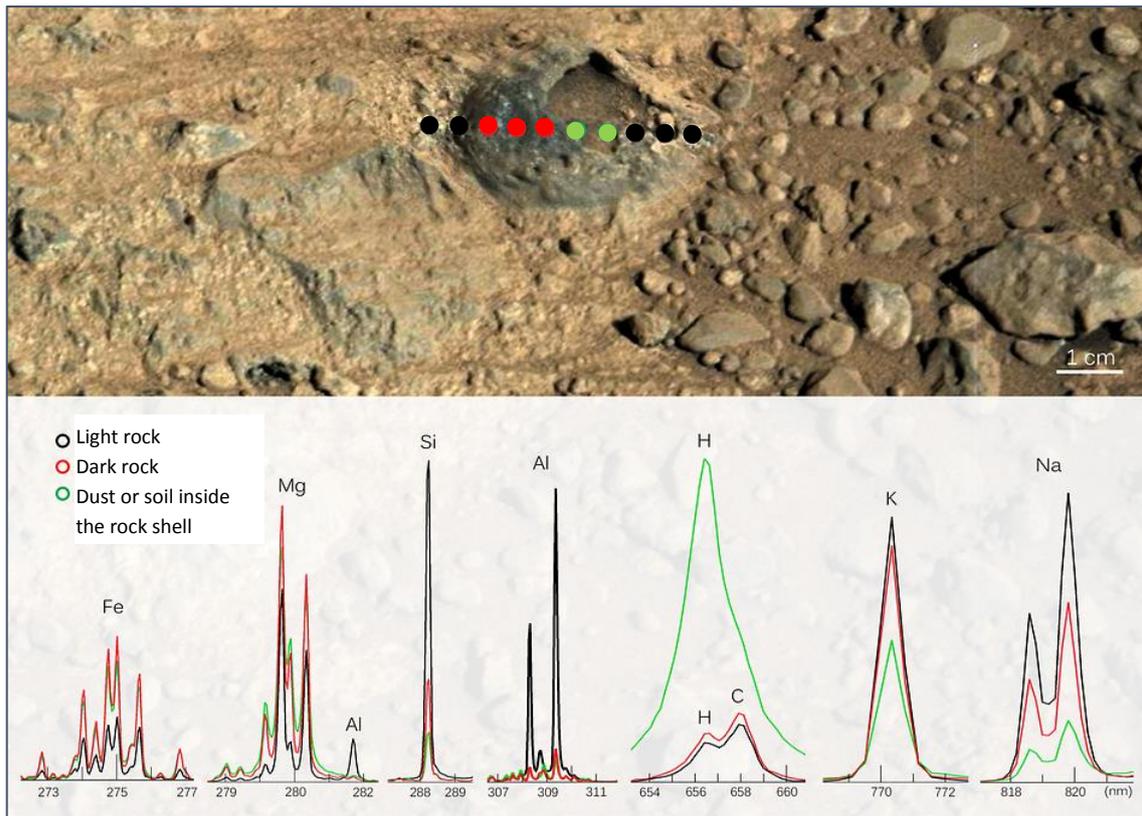


Figure 16. ChemCam image and analysis. Credit: NASA/JPL-Caltech/LANL/CNES/IRAP/LPGNantes/CNRS/IAS/MSSS.

38. Which rocks on Earth do typically have a high concentration of Al, K, Na and Si, like the light rock in the image?

- | | | |
|-----------------|------------|--------------|
| a) Basalt | d) Clay | g) Gneis |
| b) Biotite | e) Granite | h) Sandstone |
| c) Conglomerate | f) Gabro | |

39. What can explain the high content of H in the dust or soil samples?

- The water involved in weathering processes
- The methane involved in weathering processes
- The lower albedo of dark soil
- The higer albedo of dark soil
- The Mars' gravity, that is bigger than Earth's gravity and holds H in the atmosphere
- The Mars' gravity, that is smaller than Earth's gravity and allows H in the geosphere

40. The rounded pebbles on the right side of image show evidence of...

- | | |
|------------------------|---------------------------|
| a) Fluvial environment | d) Transport of sediments |
| b) Magma intrusion | e) Weathering of rocks |
| c) Marine environments | f) Wind abrasion |

The skies of Mars and Earth are similar, and the scientists of the mission are able to identify the same constellations that you can see on the terrestrial sky, as shown in Figure 17.

41. Identify the constellation X.

- | | | |
|----------------|------------|----------------|
| a) Canis major | d) Geminis | g) Scorpion |
| b) Lupus | e) Cignus | h) Canis minor |
| c) Dragon | f) Crux | i) Cassiopeia |

42. Identify the constellation Y.

- | | | |
|----------------|------------|----------------|
| a) Canis major | d) Geminis | g) Scorpion |
| b) Lupus | e) Cignus | h) Canis minor |
| c) Dragon | f) Crux | i) Cassiopeia |

43. Identify the main star and the name of constellation Z?

- | | |
|----------------------------|------------------------|
| a) Betelgeuse, Canis major | f) Beta-Polaris, Crux |
| b) Aldebarán, Lupus | g) Antares, Scorpion |
| c) Rigel, Dragon | h) Sirius, Canis minor |
| d) Castor, Geminis | i) Pollux, Cassiopeia |
| e) Deneb, Cignus | |

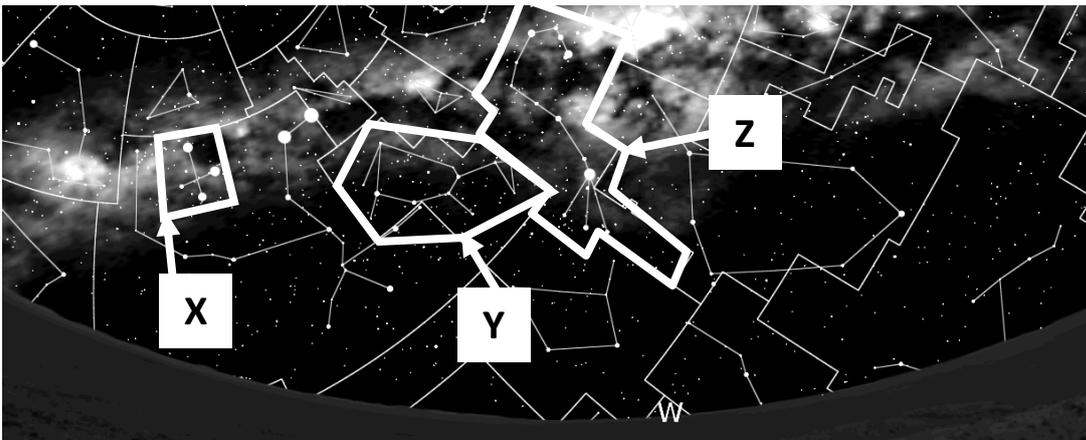


Figure 17. Constellations as seen from Mars. Source: Stellarium.

As we see, planet Mars has many features similar or equivalent to those that geologists study on Earth. Thanks to the rovers and spacecraft sent to Mars, we already have a good knowledge about general questions such as the origin, evolution and main characteristics of the Red Planet.

However, many observed elements have formation mechanisms and origins still undiscovered – many detailed questions still wait for an answer. Would you become a planetary geologist to research the mysteries of Mars and other planets?

The Delicate Coastal Equilibrium

Paper 4



Canada has the longest coastline: 243791 km. The Federated States of Micronesia have the biggest coast length/surface ratio: 8706,553 m/km². Without these record figures, the Iberian Peninsula has a long coastline (9669 km). The history and economy of Spain and Portugal has been linked to the Cantabrian Sea due North, the Atlantic Ocean due West and the Mediterranean Sea due South and East. Within this paper, we will visit three segments of the Iberian coast and explore the landscapes and processes around.

From the Earth Science point of view, coastal areas are among most dynamic and fragile environments and the source of important eco-services to our societies. In addition, most metropolitan areas in the world are in the coast. The efficiency of ship transport, the sea resources (food, salt, etc.) have concentrated humans in the coast for centuries. Consequently, coastal processes affect millions of persons in the world –while the human activity affects the coastal processes in a variety of ways.

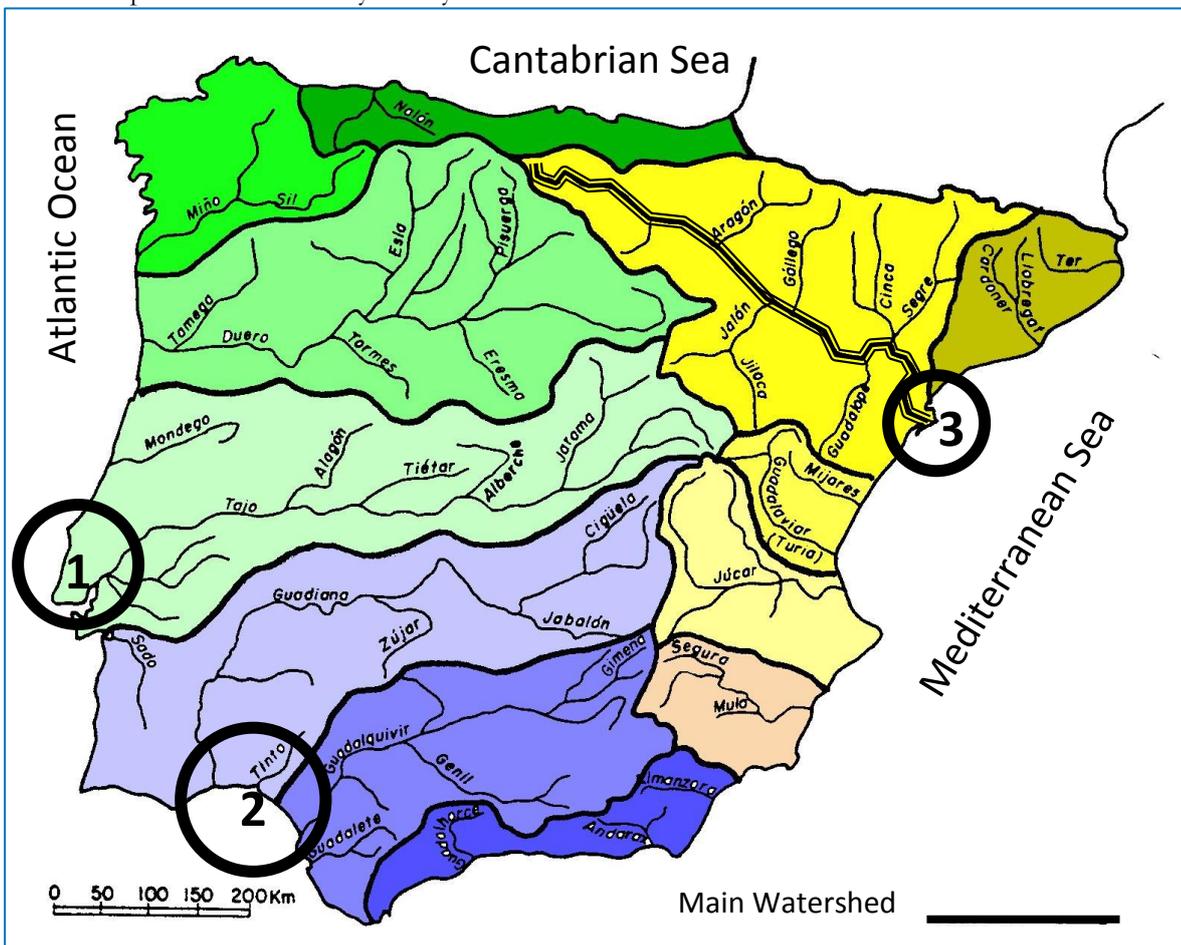


Figure 1. The Iberian Peninsula and its main watersheds. The three circles mark the areas you will have to work on in this paper: 1. The Coast off Lisbon; 2. The coast of Huelva; 3. The Delta of Ebro River. Triple line marks Ebro River. Credits: http://www.aularagon.org/files/esp/a/atlas/riosEspana_cuencas.htm

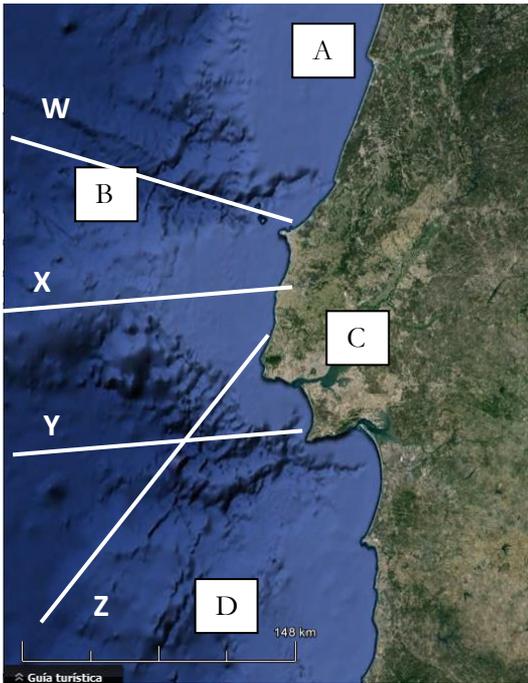


Figure 2. Image of the coastal area and sea bottom in the area of Lisbon (Portugal)

The coast off Lisbon (Portugal)

The coast in front of Lisbon (Portugal) is similar to many coast in the world, and has some element that can be found in any Atlantic Coast

1. The flat areas marked A (Figure 2), are...
 - a) Delta
 - b) Continental Platforms
 - c) Abyssal Plains
 - d) Continental Slope

2. The most likely point for turbidite formation is

a) A	c) C
b) B	d) D

3. Which point marks the position of an estuarine environment

a) A	c) C
b) B	d) D

4. If you were to lay a submarine cable, which option would be safer in terms of turbidity flows?

a) W	c) Y
b) X	d) Z

5. The Atlantic coast has this configuration because it is in...
 - a) Destructive ocean margins
 - b) Constructive ocean margins
 - c) Active continental margins
 - d) Passive continental margins

The coast of Huelva (Spain)

The coast in front of Lisbon (Portugal) is similar to many coast in the world, and has some element that can be found in any Atlantic Coast

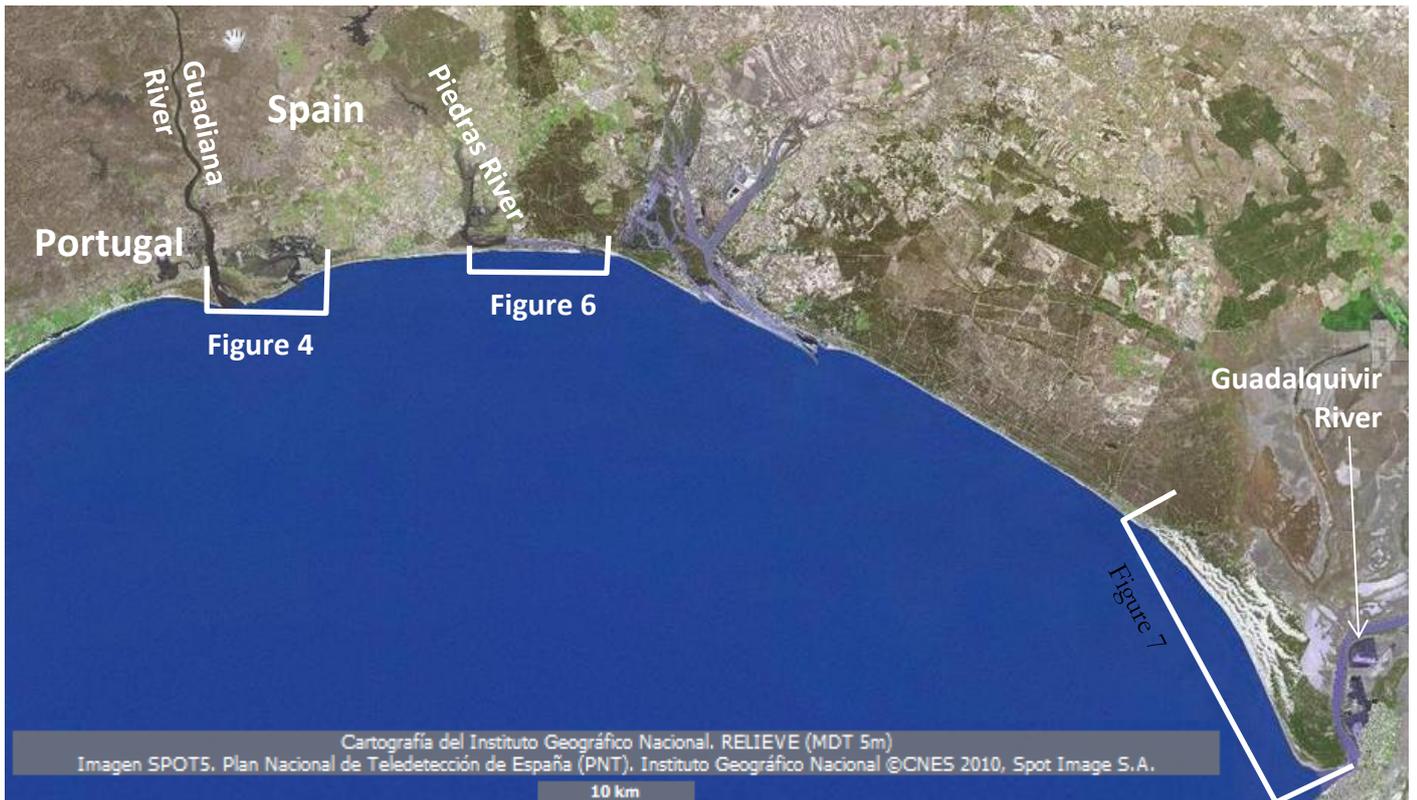


Figure 3. The coast of Huelva province (Spain) and part of the Algarve (Portugal). The border is marked by the Guadiana river –with reference to the area showed in following figures.



Figure 4. Isla Cristina-Ayamonte marshes and harbours. 1. Guadiana River Mouth. 2. Ayamonte harbour. 3. Isla Cristina harbour. 4. Salt pans. 5. Aquaculture.

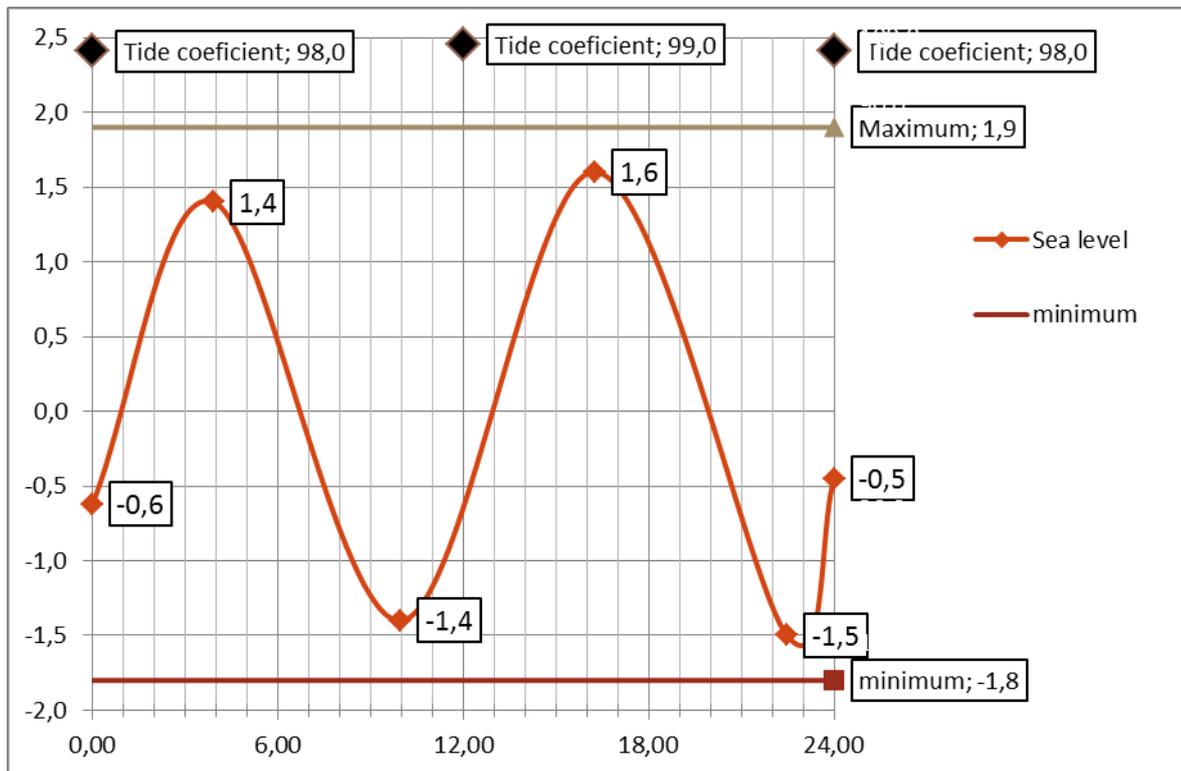


Figure 5. Tide diagram for 13 June 2014.

On 13 June 2014 a team of scientists explored the marshes of Isla Cristina to take samples of clay and organic matter tidal channels bottom –in an area with the bottom at 1 m below average sea level. The probe is a rather heavy machine transported and operate on board a small boat that needs 0,5 m deep waters. Every probe takes about one hour to be completed and the team needs three samples.

The day before, they downloaded a tide graph (Figure 5) to plan their work –horizontal axis is time, and vertical axis is elevation above average sea level.

The tidal coefficient will be 98. With such a high coefficient we will have big tides and the currents will also be very evident. The tide heights will be 1.4 m, -1.4 m, 1.6 m and -1.5 m. We can compare these levels with the maximum high tide recorded in the tide tables for Isla Cristina which is of 1.9 m and a minimum height of -1.8 m.

6. Which of the following is/are the best time to begin the exploration
 - a) 1:00
 - b) 8:00
 - c) 16:00
 - d) 20:00

7. Time in the graph is Local Time, in zone +2h. What is UMT or Z time of the first high tide of the day.
 - a) 1:55
 - b) 3:55
 - c) 5:55
 - d) 14:16
 - e) 16:16
 - f) 18:16

8. Such high tidal coefficient (see text above) indicates that the moon phase is probably...
 - a) New moon
 - b) Waxing crescent
 - c) First quarter
 - d) Waxing gibbous
 - e) Full moon
 - f) Waning gibbous
 - g) Third quarter
 - h) Waning crescent

9. The high tide is mainly produced by the Moon pull on the ocean waters. Consequently, the high tide arrives when...
 - a) The moon is in the Nadir
 - b) The moon is in the Zenith
 - c) The moon is at maximum height over the horizon
 - d) The moon is at minimum height over the horizon
 - e) Shortly after the moon is at maximum height over the horizon
 - f) Shortly after the moon is at minimum height over the horizon

- g) Shortly before the moon is at maximum height over the horizon
 h) Shortly before the moon is at minimum height over the horizon
10. The answer to the previous question depends on...
- The time that light needs to travel across the space
 - The distance between the Moon and the Sun throughout the year
 - The distance between the Earth and the Moon throughout the day
 - The friction that delays water movement
 - The density of water being higher than the density of ice
11. In many regions, the vegetation of marshes includes trees with an adaptation to this changing environment. What is the name of such environment?
- Mud flats
 - Intertidal platforms
 - Intertidal
 - Mangroves
 - Coral reefs
 - Green reef
12. The salt industry and aquaculture requires the clearing of marsh vegetation, a consequence being the reduction of biodiversity and an increase of vulnerability against...
- Dune retreat
 - Storm lightning
 - Tsunamis
 - Choppy waves
 - Fish overgrowing
 - Fish overgrazing



Figure 6. "El Rompido" littoral sand spit, in the mouth of river Piedras.

13. The image of Figure 6 shows a sand littoral spit developed in front of the mouth of the river Piedras. The landform results from
- Fluvial erosion, similar to what happens in any meander
 - Fluvial sedimentation, similar what happens in a typical alluvial fan
 - The change in sea level due to global warming
 - The interaction between tides and winds, as in many semiarid coast
 - The interaction of river and littoral drift sediments
 - The contamination of rivers due to deforestation and mining.
14. To form that sand littoral spit, the prevailing waves come from...
- Any place
 - N
 - S
 - W
 - E
 - N or NW
 - N or NE
 - S or SW
 - S or SE

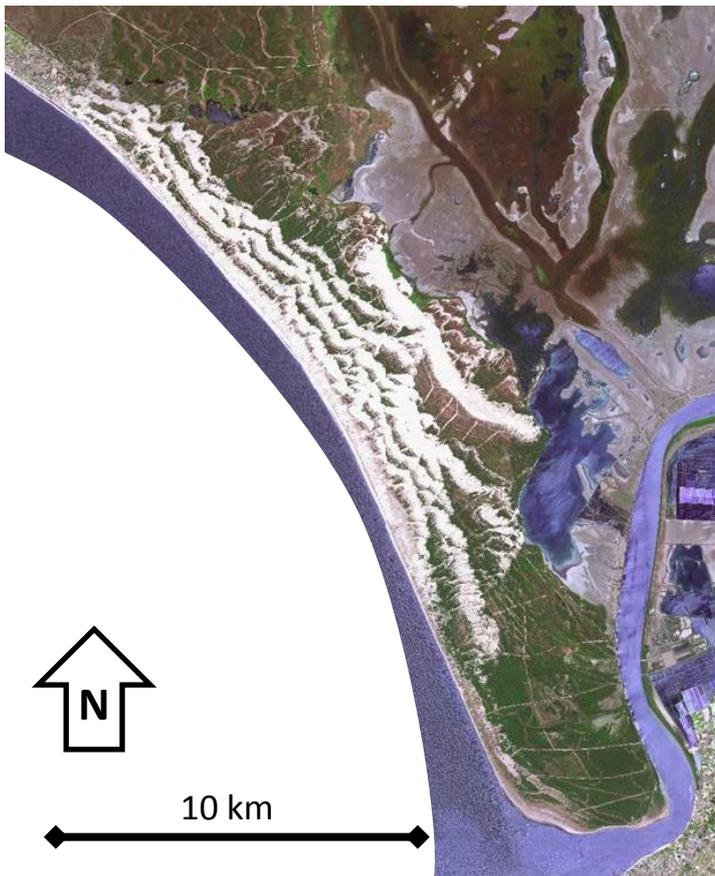


Figure 7 shows the area of Doñana National Park. From left to right, you can see: the Atlantic Ocean, a succession of white bands (the beach, a littoral-dunes field –with some vegetation areas), and the marshes. Only a deep knowledge of the geologic processes makes possible the protection of the fauna and vegetation that make world-famous this National Park. In the bottom right side of the image is the Guadalquivir River.

15. Based on Figure 8, choose the best statement:
- A represents the marshes, B is the sea
 - A represents the sea, B is the marshes area
 - A and B represents the sea
 - Impossible to decide
16. What letter in figure 8 represents the avalanche side of dunes
[Chose a letter from A to F in your answer sheet]

Figure 7. Doñana beach, dunes and marshes, west of the mouth of Guadalquivir river. Source: IGN, Spot Image.

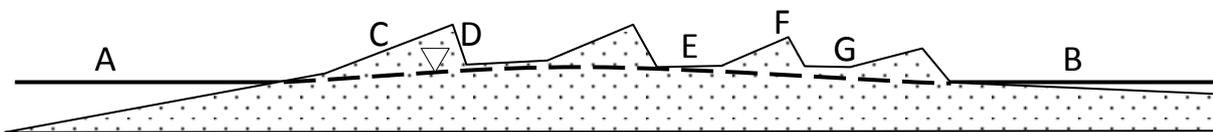


Figure 8. Simplified cross-section of Doñana National Park.

17. Which of the following describes the dashed line, marked with the inverted triangle?
- Limit between beach and dune sands
 - Avalanche side
 - Base of dunes
 - Beach
 - Intertidal zone
 - Water table
 - Maximum sea level during winter storms
 - Surf zone
18. If Figure 8 is correct, and a chemical leak happens in point G...
- Contamination will reach the sea
 - Contamination will reach the marshes
 - Contamination will remain below point G
 - Contamination will not infiltrate
 - It's impossible to forecast the flow of contaminated water

19. As you can see in Figure 7, there are vegetated (with genus *Pinus*) and sandy areas. Choose the best explanation referring to figures 7 and 8...
- C is covered by pines that use the sea humidity
 - F is covered by vegetation, that can grow far from the brackish water
 - E is covered by vegetation, that uses the groundwater
 - G does not have any vegetation because the groundwater is contaminated
20. Marshes are described as carbon sinks because there is:
- Oscillation of sea level with tides
 - Alternating of fresh and salty waters
 - Accumulation of organic matter
 - Accumulation of shells
 - Dissolution of carbon dioxide in water
 - Oxidation of organic matter
 - Erosion of dunes
 - Sand-dunes sedimentation
21. Apart from its huge biodiversity, marshes are very efficient carbon sinks, and this is one of the reasons to preserve marshes. Why are marshes extraordinarily efficient carbon sinks?
- The organic matter accumulates better in intertidal areas
 - The organic matter do not oxides under water
 - Marsh's dynamics produce very high rates of sedimentation
 - We do not build or burn fossil fuels in marshes
22. If you analyze Biological Oxygen Demand (BOD) in sea and marsh waters, you will probably find...
- Higher values of BOD in the marsh
 - Higher values of BOD in the sea
 - The same low values of BOD in the sea and the marsh
 - The same high values of BOD in the sea and the marsh
 - BOD is not a variable measurable in water.

Fishing is an essential part of the economy of the region. Its great productivity relates to several variables and fishing practices which have consequences on the environment.

23. Fishing productivity is incised by...
- Nutrients brought to the area in the water of rivers
 - Cold water brought to the area by the rivers
 - Warm water brought to the area by the rivers
 - Dilution of contamination by the river water
24. Trawl fishing is a common practice in sandy coasts, but it is environmental unfriendly because it destroys...
- Future fossil fuel deposits
 - Sedimentary structures, like ripple-marks
 - Posidonia prairies and other bottom vegetation
 - Shrimp schools
25. Building on littoral dunes and trawl fishing (through the effect that you discovered in the previous question) have the following effects:
- Both improve the accumulation of sand in the beach
 - Both improve the accumulation of sand in the dunes
 - Both increase the erosion of the beach

- d) Both increase the erosion of the dunes
- e) Trawling don't affect to the beach but do affects to the dunes
- f) Building don't affect to the beach but do affects to the dunes

Coast and Atmosphere

In many oceanic coasts, storms and storm surges are a main concern. The understanding of storms and atmospheric stability are a basic concept to forecast and prevent their effects. In the following questions, we will work on these subjects.

26. A storm surge is...
- a) A change in atmospheric pressure that destroys crop plantations
 - b) An increase in atmospheric pressure due to storm clouds
 - c) A decrease in pressure bellow storm clouds that attract clouds to the level of the Earth surface
 - d) A rise of the sea level due to the low pressure in the storm core
 - e) An increase of wave frequencies due to the cyclonic winds in storms
27. Which name is better for the element marked with a circle in Figure 9-left?
- a) Ice stakes
 - b) Cumulus stalactites
 - c) Anvil
 - d) Mammatus
 - e) Hail nets
28. Study Figure 9 and decide which adiabatic gradient best describes the conditions of the right part of the photograph: [Choose a letter a - d in your sheet answer]

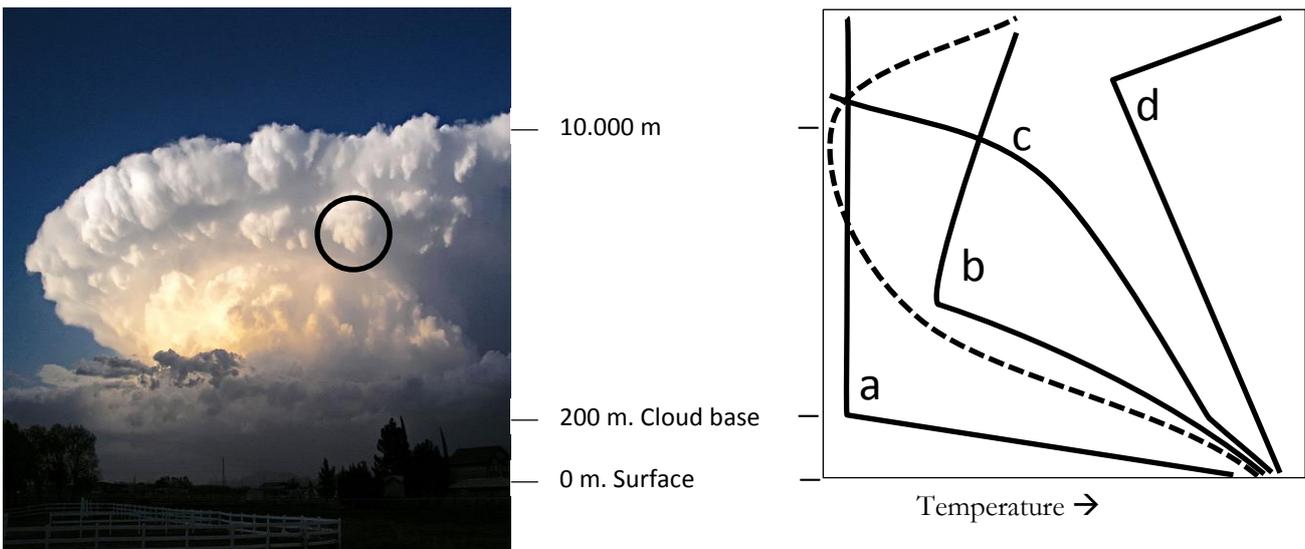


Figure 9. Left: Supercell cloud. Right: Simplified Tephigram with an environmental gradient (dashed line) and four possible adiabatic gradients (solid lines). (Image from Wikimedia Commons, http://commons.wikimedia.org/wiki/Cloud#mediaviewer/File:Chaparral_Supercell_2.JPG, visited 5 June 2014)

29. When air rise in the atmosphere, with speed enough as to avoid substantial interchange of energy with the surrounding air, the rising air changes its temperature according to...
- a) Dry Adiabatic Gradient in lower troposphere
 - b) Dry Adiabatic Gradient in upper troposphere
 - c) Wet Adiabatic Gradient in lower troposphere
 - d) Wet Adiabatic Gradient in upper troposphere
 - e) Environmental Gradient in lower troposphere
 - f) Environmental Gradient in upper troposphere

Contamination in oceans

The authors of Figure 13 “use the term *plastiglomerate* to describe an indurated, multi-composite material made hard by agglutination of rock and molten plastic. This material is subdivided into an ‘*in situ*’ type, in which plastic is adhered to rock outcrops, and a ‘*clastic*’ type, in which combinations of basalt, coral, shells, and local woody debris are cemented with grains of sand in a plastic matrix”. This material has been formally described in a Hawaii beach, although many beaches have plastiglomerates around.

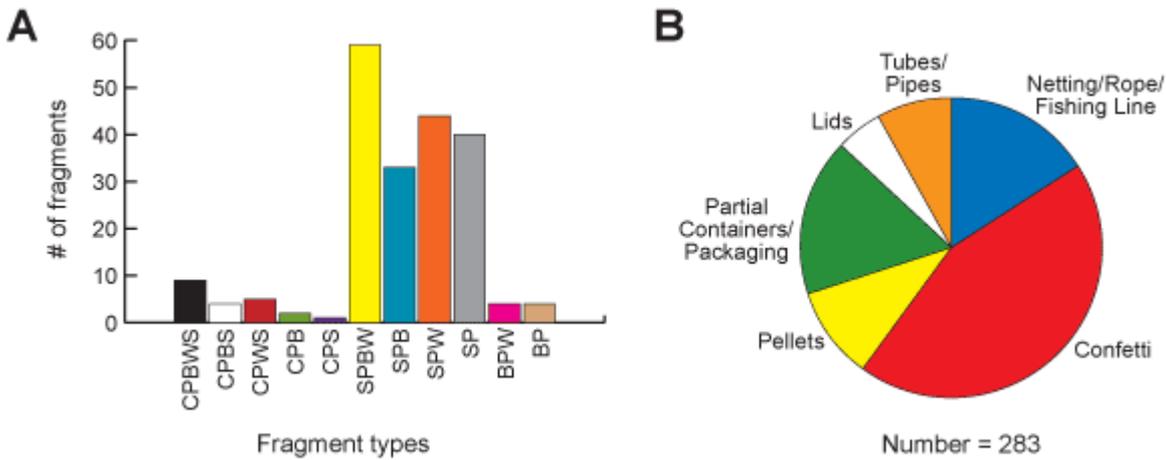


Figure 10. Diagrams illustrating the types of plastiglomerate and relative percentages of adhered plastic fragments. (A) Material composing the sampled plastiglomerate: B—basalt clasts; C—coral fragments; P—plastic; S—sand and sand-size shelly fragments; W—woody. Source: P. L. Corcoran, C. J. Moore, and K. Jazvac. *An anthropogenic marker horizon in the future rock record. GSA Today, Volume 24 Issue 6 (June 2014)* (<http://www.geosociety.org/gsatoday/archive/24/6/article/i1052-5173-24-6-4.htm>).

30. When future Earth Scientists find a plastiglomerate layer in a sedimentary profile they will be able to use it as...
- Sedimentary thermometer
 - Sedimentary barometer
 - Sedimentary environment indicator
 - Relative dating source
 - Absolute dating source
 - Evidence of volcanism
 - Evidence of fossil fuels scarcity
31. For plastic to be useful as an “Index fossil”, it must...
- Be easy to destroy
 - Be sorted in sediments with just one kind of plastic
 - Have existed during a long period (in geological sense)
 - Have existed during a short period (in geological sense)
 - Have been dispersed in few and sparsely distributed environments.
 - Have been dispersed in many and widely distributed environments.
 - Be scarce at a global scale
 - Endemic of an area

The same paper says, “researchers agree that the *Anthropocene* is a time span marked by human interaction with Earth’s *biophysical system*”. In the following questions, match the geological evidence with an interpretation that can be used to identify Anthropocene sediments:

32. Increase in atmospheric CO₂ at approximately 8000 yr B.P. can relate to...
- Atmospheric lead derived mainly from combustion of leaded gasoline
 - Early agricultural practices in Eurasia
 - Mining activities
 - Early forest clearance
33. Methane concentrations measured in ice cores display an increase at approximately 5000 yr B.P. related to...
- Atmospheric lead derived mainly from combustion of leaded gasoline
 - Early agricultural practices in Eurasia
 - Mining activities
 - Early forest clearance

34. Lead (Pb) concentrations prior to approximately 1900 AD, can relate to...
- Atmospheric lead derived mainly from combustion of leaded gasoline
 - Early agricultural practices in Eurasia
 - Mining activities
 - Early forest clearance
35. Second Pb compositional signature in soil younger than 1950 AD, can relate to...
- Atmospheric lead derived mainly from combustion of leaded gasoline
 - Early agricultural practices in Eurasia
 - Mining activities
 - Early forest clearance

The Delta of River Ebro (Spain)

In the NW part of the Mediterranean coast northward, one of the most prominent landforms is the delta of Ebro River (Figure 11A). The Ebro Delta is a mixed kind of delta, as shown is the classification in Figure 11B.



Figure 12A. The Delta of Ebro River in NE Spain. Source: IGN, Spot Image.

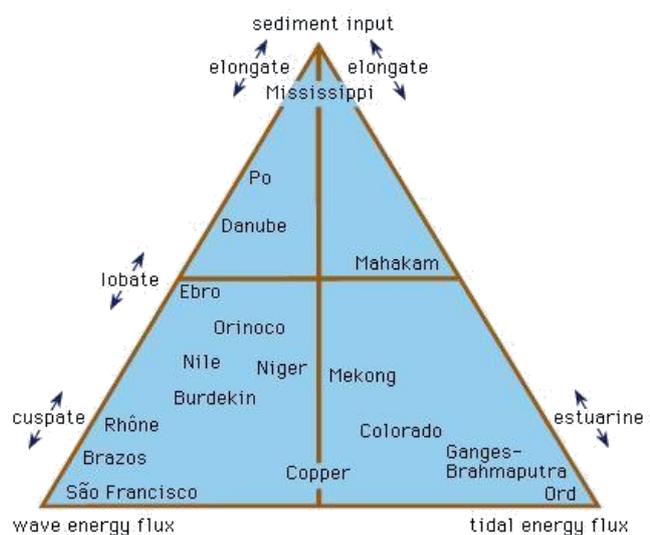


Figure 12B. Classification of river deltas based on the three dominant processes that control delta morphology. Credit: From W.E. Galloway, *Deltas, Models for Exploration* (1975); Houston Geological Society. As showed in *Encyclopedia Britanica*. See the Ebro River in the middle left side.

36. As you can see in Figure 11, the delta of Ebro is the place for intensive agriculture (rice is one of the main crops). Which of the following processes relates to the usual practices of intensive agriculture?
- Carbonization
 - Flooding
 - Eutrophication
 - Landsliding
 - Oxidation
 - Silting
 - Erosion
 - Surging
37. The position of Ebro in the classification diagram of Figure 11 means that...
- The delta is far from any estuary
 - The influence of tides is bigger that the influence of river sediments
 - The delta is in a delicate conservations equilibrium, close to the limit of destruction
 - The influence of waves is bigger than the influence of tides
 - The influence of waves is much bigger than the influence of river sediments
 - The delta will migrate so the NE along the left side of the triangle

38. The contribution of river sediments is fundamental to delta evolution, and sediment transport depends on river discharge (Q). Given the data included in Figure 12, what is the discharge in that river?
- $10000 \text{ m}^3/\text{s}$
 - $30000 \text{ dm}^3/\text{s}$
 - 20000 l/s
 - $2000 \text{ m}^3/\text{s}$
 - 1500 l/s
 - $24000 \text{ dm}^3/\text{s}$
39. What is the name of a place like the one of Figure 12?
- Discharge station
 - Flow station
 - Volume station
 - Gauging station
 - Watering station
 - Velocity station

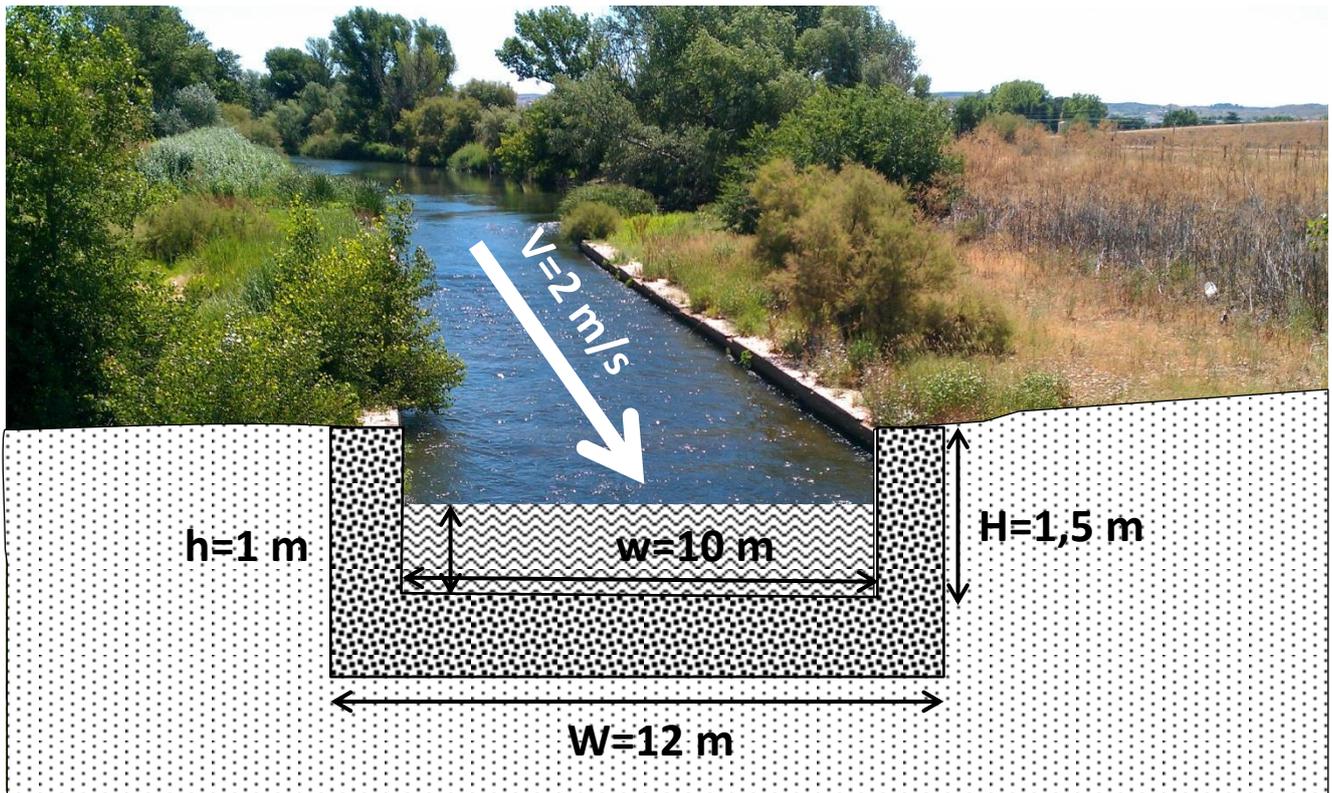
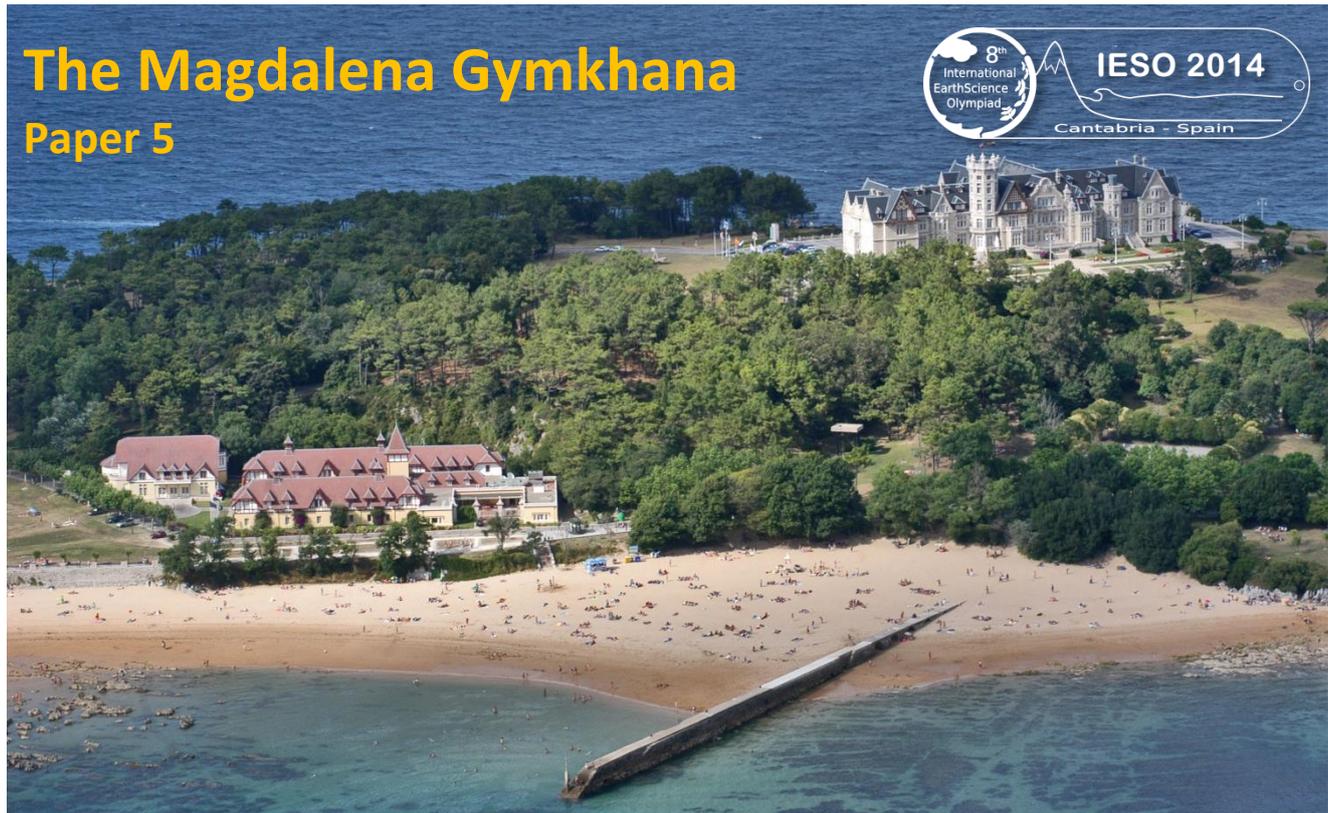


Figure 13. Data to measure discharge.

Back to Cantabria and the link between mountain and sea landscapes

If you follow Ebro River upwards, you will reach again the region of Cantabria. The sources of Ebro are located in the Cantabrian range, a land of pastures, rocks, and glacial landforms. Before returning to Santander, let's make a last exercise connecting very different environments.

40. Mountain cattle do nurture from mountain pastures, but its digestion connects with global processes. Choose the best systems-flow model.
- Pasture eating-Deforestation-Sedimentation-Sea nutrients scarcity
 - Pasture eating-Carbon fixing-Greenhouse effect-Sea water volume reduction
 - Pasture eating-Methane emissions-Greenhouse effect-Sea level increase
 - Pasture eating-Increase in soil microorganisms-Water storage-Sea level decrease



Structure of this paper

Every 5 minutes the staff will ask 5 student to start this exam, and every 5 minutes the staff will ask those into the exam to move to the next set of questions. All questions belong to one of the following subjects:

- 1st part: Materials
- 2nd part: Images interpretation
- 3rd part: Maps and profiles
- 4th part: Field resources

FIRST PART – Set 1. Minerals

1. M1 is...
 - a) Hematite
 - b) Sylvite
 - c) Cinnabar
 - d) Bauxite
2. M1 crystallizes in the system...
 - a) Hexagonal
 - b) Cubic
 - c) Orthorhombic
 - d) Monoclinic
3. M1 is an ore of...
 - a) Iron
 - b) Carbon
 - c) Cupper
 - d) Mercury
4. M2 is...
 - a) Talc
 - b) Muscovite
 - c) Biotite
 - d) Illite
5. M2 is a silicate classified as...
 - a) Tectosilicate
 - b) Inosilicate
 - c) Phyllosilicate
 - d) Nesosilicate
6. Which of the following sets describes better the uses of M2...
 - a) Thermal insulation, absorbing nitroglycerin, and papermaking
 - b) Lamination of metals, windows and horseshoes
 - c) Thermal catalyst, solvent and glassmaking
 - d) Thermal and electrical conductor, and manufacture of plastic
7. M3 is...
 - a) Aragonite
 - b) Tourmaline
 - c) Quartz
 - d) Fluorite
8. Mark possible forms of formation of M3...
 - a) Mollusk shells
 - b) Fluvial sedimentation
 - c) Diagenesis
 - d) Metamorphism
 - e) Geysers
9. M3 is to keep...
 - a) Stable temperature in rooms
 - b) Mooving engine components
 - c) Dry musseums
 - d) Stable pH in aquaria

FIRST PART – Set 2. Rocks

10. R1 is...
- a) Pegmatite
 - b) Granodiorite
 - c) Aplite
 - d) Porphyry
11. R1 forms in...
- a) Diques in early phase of plutonism
 - b) Diques in volcanic environment
 - c) Diques in late phase of plutonism
 - d) Lava flows
 - e) High pressure metamorphism
12. The black mineral of R1 is very typical in this kind of rocks; it is...
- a) Coal
 - b) Andalusite
 - c) Tourmaline
 - d) Pyroxene
13. R2 is...
- a) Limestone
 - b) Sandstone
 - c) Clay
 - d) Radiolarite
14. R2 was sedimented in...
- a) Fluvial environment
 - b) Glacial environment
 - c) Periglacial environment
 - d) Marine environment
 - e) Marsh environment
15. A characteristic property of R2 it is to produce a fizzing effect (effervescence) when you add a drop of...
- a) Water
 - b) Bleach
 - c) Sulfuric acid
 - d) Hydrochloric acid
 - e) Sodium Chloride
16. R3 is ...
- a) Basalt
 - b) Gabbro
 - c) Serpentine
 - d) Tourmaline
17. Due to its content in silica, R3 is classified as...
- a) Felsic
 - b) Mafic
 - c) Ultramafic
 - d) None of them
18. Soils on R3 are...
- a) Highly productive due to the low content of Calcium
 - b) Poorly productive due to elements that are toxic to most plant species, as chromium and nickel.
 - c) Highly productive due to the huge variety of elements the rock supplies.
 - d) Poorly productive due to the low content of Calcium

19. Which one of the following statements related to the sample F1?...
- a) Trilobites first appeared during the Cambrian and are the most important zone fossils for rocks of this period.
 - b) Land plants flourished particularly in the swampy tropical environment of many regions during the Carboniferous.
 - c) Rugose corals were most important in the Upper Palaeozoic era and particularly common in Carboniferous limestone.
 - d) Echinoids are rare in rocks from the Palaeozoic eras but become increasingly common in those to the Mesozoic.
20. The rock of sample F1 has a high content in...
- a) Phosphate
 - b) Limonite
 - c) Basalt
 - d) Organic matter
21. If you find F1 in a rock, you can say that the rock was formed in...
- a) Very deep waters (>1000 m)
 - b) Deep waters (1000-200 m)
 - c) Shallow waters (200-0 m)
 - d) Fluvial waters (above sea level)
 - e) Marshes in intertidal zone
 - f) Continental swamps
22. Which one of the following statements related to the sample F2 is correct?
- a) A mass of colonial corals gives information about a past reef environment
 - b) Unfortunately, the shape of gastropod shells is not usually a reliable guide to the environments in which they lived.
 - c) Ammonoids make particular useful zone fossils.
 - d) Scales evolved both in bony and cartilaginous fish.
23. Which is the mineralogy of the sample F2?
- g) Silica
 - h) Gypsum
 - i) Carbonate
 - j) Fluorite
24. If you find F2 in a rock, you can say that the rock was formed in...
- k) Very deep waters (>1000 m)
 - l) Deep waters (1000-200 m)
 - m) Shallow waters (200-0 m)
 - n) Fluvial waters (above sea level)
 - o) Marshes in intertidal zone
 - p) Continental swamps

25. On a recent fieldtrip I visited a quarry near the Spanish coast. I noted that the quarry face contained beds of fine grained rocks. The manager told me that fossils were often found there and handed me this superb sample F3. 'Tell me', he said, 'what sort of creature was this when it was alive?
- a) Coral
 - b) Trilobite
 - c) Ammonite
 - d) Bivalve
26. Which kind of organic activity can be observed in the shell?
- a) Borings
 - b) Ripple marks
 - c) Bite marks
 - d) Sedimentary infilling

SECOND PART



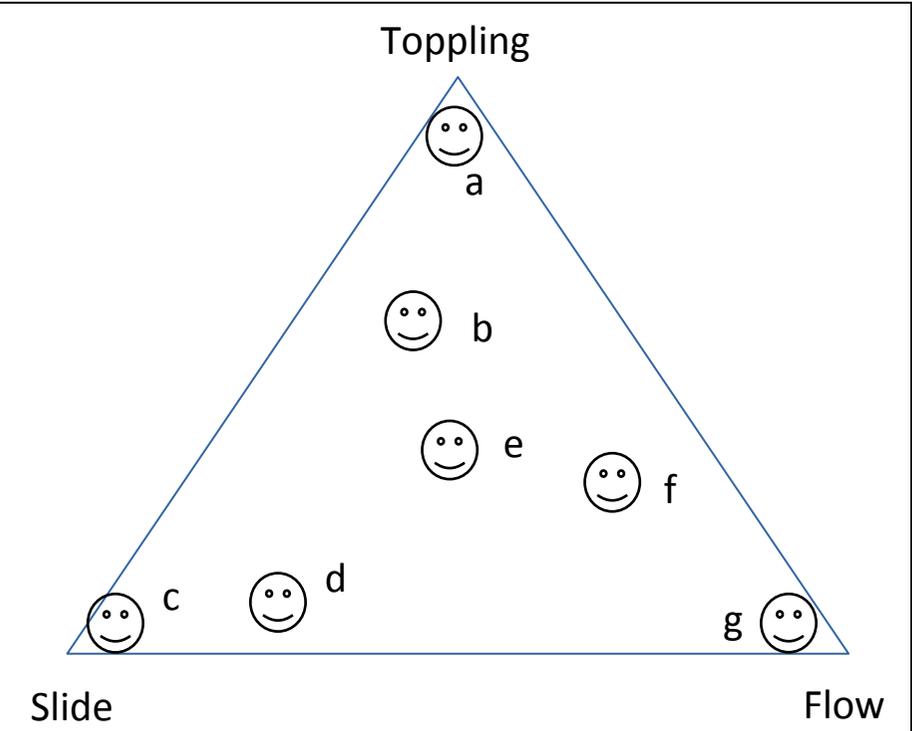
27. Which of the following describe better the landscape?

- a. Landslide – karstic landform
- b. Sink – climatic landform
- c. Doline – karstic landform
- d. Dome – granite landform
- e. Doline – tropical landform
- f. Subsidence – gravitational landform
- g. Lapiaz – structural landform



28. What is the process captured in the image?

- a. Cryoplanation
- b. Salt crystals growing
- c. Permafrost
- d. Fibre Gypsum Crystallization
- e. Cryoturbation
- f. Cross bedding
- g. Human disruption of soils



29. Classify the process of the image according to the diagram.
[Choose the adequate letter or letters in your answer sheet]



30. Identify the best explanations of the landforms shown in these three photos (order may or not be respected) :

- a. Wave-cut platform, bridges and tombolo
- b. Arches, wave-cut platform and beach berm
- c. Beach, tombolo and arches
- d. Wave-cut platform, arches and beach berm
- e. Wave-cut platform, arrow and bows
- f. Dunes, beaches and bows
- g. Beach berm, tombolo



27. This is fluvial environment very close to the coast. Choose the sentences that can be deduced from the image:
- a) Climate is extremely arid, hence the scarce vegetation
 - b) Climate is semiarid with short-intense rains, and this explains the high energy sediments
 - c) Climate is humid but most water infiltrates, as can be deduce from the carbonate pebbles and boulders
 - d) The image is an intertidal area, and transport of detritics happens only during high tides
 - e) The channel is artificial, that the reason for such high energy sediments in a place that is now dry
 - f) The images shows an sporadic channel that is active only during intense storms

THIRD PART

THIRD PART

The provided image shows 5 topographic maps and 10 topographic sections. Some sections correspond to the provided maps, but some are not.

Sections are built along diagonals of the map. Sections **a** to **e** are always NW-SE from left to right, while sections **f** to **j** are always SW-NE from left to right.

In every map one, two or none sections can be adequate. If no section is adequate for a map mark letter **X** in your answer sheet.

28. Which section/s correspond to map 1? [Chose the letter of letters in your answer sheet]

29. Which section/s correspond to map 2? [Chose the letter of letters in your answer sheet]

30. Which section/s correspond to map 3? [Chose the letter of letters in your answer sheet]

31. Which section/s correspond to map 4? [Chose the letter of letters in your answer sheet]

32. Which section/s correspond to map 5? [Chose the letter of letters in your answer sheet]

FOURTH PART – Dry Option

33. Use the provided coordinates to draw in your map the assigned sites.

(In this question, you will get one point for every site correctly drawn in your map, and 0,25 for every wrong site. Maximum allowance: 1 cm).

Point 1. X 438001, Y 4813123

Point 2. X 438152, Y 4813068

Point 3. X 438186, Y 4813031

Point 4. X 437748, Y 4813082

And now, use your map and go to the assigned sites.

34. Site 1. Find the strike and dip of this outcrop

35. Site 2. Do the fossils you can find in the outcrop correspond to some of the fossils mentioned in the map? Which?

36. Site 2. According with your identification of the fossils, at what unit belongs this outcrop?

37. Site 3. The signal reads “Natural Area-Danger” (Area Natural-Peligro) . Identify the natural and human hazards that may happens in this point.

- a) Fire
- b) Falling to the cliff or sink
- c) Earth slide
- d) Rock slide
- e) Subsidence
- f) Collapse
- g) Water columns during storms
- h) Strong rains
- i) It is a mistake there are not natural dangers

38. Site 4. Write in your answer sheet the time of your arrival (ask the volunteer in charge).

Decide the best description for the beach at this moment of the day:

- a) Low tide (approximately)
- b) High tide (approximately)
- c) Tide rising
- d) Tide falling
- e) Impossible to know

39. Site 4. Write the approximate time of the following low tide.

Texts in the map to be translated:

1. Legend
2. Buildings
3. Faults
4. Strike and dip
5. Contacts
 - 5.1. Inferred concordance
 - 5.2. Concordance
 - 5.3. Discordance
 - 5.4. Limit of covered area
 - 5.5. Limit sea-land
 - 5.6. Contours
6. Lithology
 - 6.1. Unit C1 covered/uncovered
 - 6.2. Unit C2 covered/uncovered
 - 6.3. Unit C3 covered/uncovered
 - 6.4. Unit C4 covered/uncovered
 - 6.5. Unit C5 covered/uncovered
 - 6.6. Unit A2 covered/uncovered
 - 6.7. Unit A1
 - 6.8. Marine Terraces
 - 6.9. Slope deposits
 - 6.10. Beach
7. Description of units
 - Q - Marine terraces, slope deposits and beach

- A1 – Limestone – Albian, Cretaceous
- A2 – Brown and yellow sandstone and siltstones – Upper Aptian, Cretaceous
- C5 – Alternate limestone and marls – Upper Aptian, Cretaceous
- C4 – Limestones, nodular marls and sandstone – Upper Aptian, Cretaceous
- C3 – Alternate limestones and marls – Upper Aptian, Cretaceous
- C2 – Limestones with dissolution sub-planar porosity – Upper Aptian, Cretaceous
- C1 – Massive limestones – Upper Aptian, Cretaceous
8. Fossils legend
 - 8.1. *Pseudotoucasia santanderensis*
 - 8.2. Rudists
 - 8.3. Turritellidae, Gastropoda
 - 8.4. Corals
 - 8.5. Gastropoda
 - 8.6. Miliolidae
 - 8.7. Brachiopods
 - 8.8. Orbitolinidae
 - 8.9. Fossil tracks
 - 8.10. Shell fragments

FOURTH PART – Wet Option

Wet Option

Use the provided coordinates to draw in your map the assigned sites.