

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.

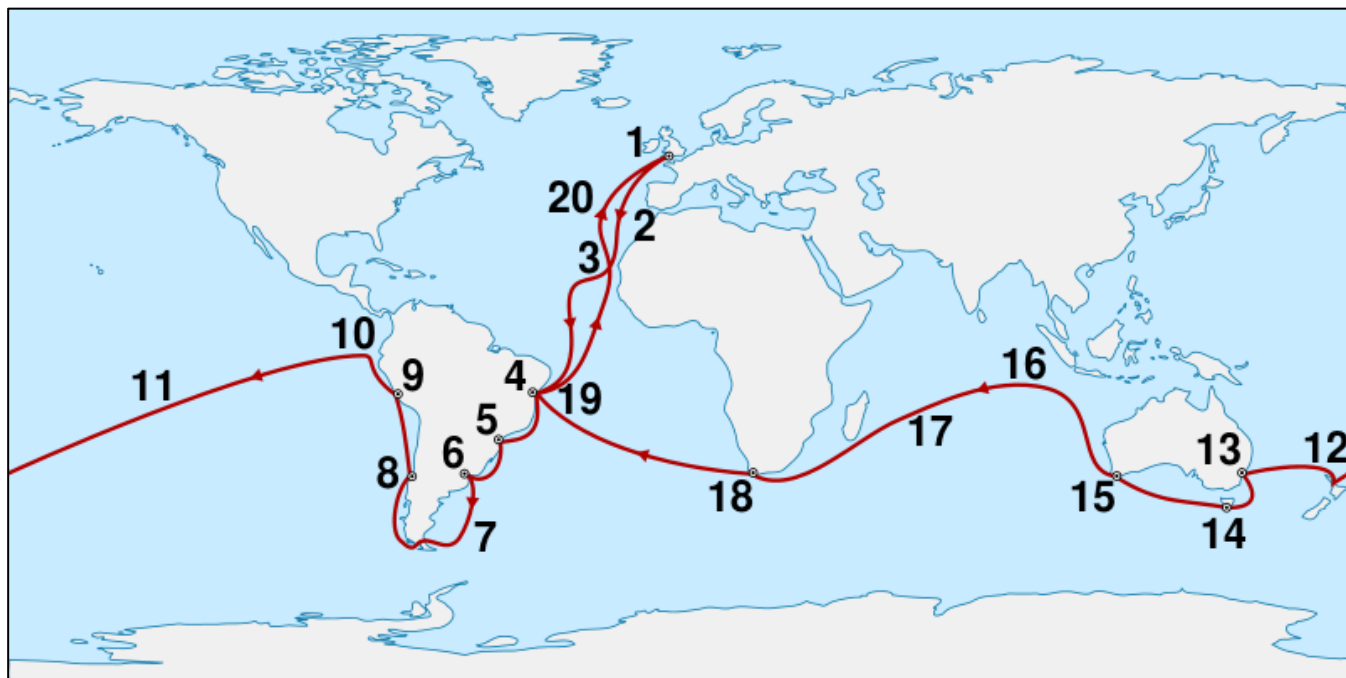


Figure 1. Voyage of the Beagle. Key : 1 Plymouth - 2 Tenerife - 3 Cape Verde - 4 Bahia - 5 Rio de Janeiro - 6 Montevideo - 7 Falkland Islands - 8 Valparaiso - 9 Callao / Lima - 10 Galapagos - 11 Tahiti - 12 New Zealand - 13 Sydney - 14 Hobart - 15 King Sound - 16 Cocos (Keeling) Islands - 17 Mauritius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

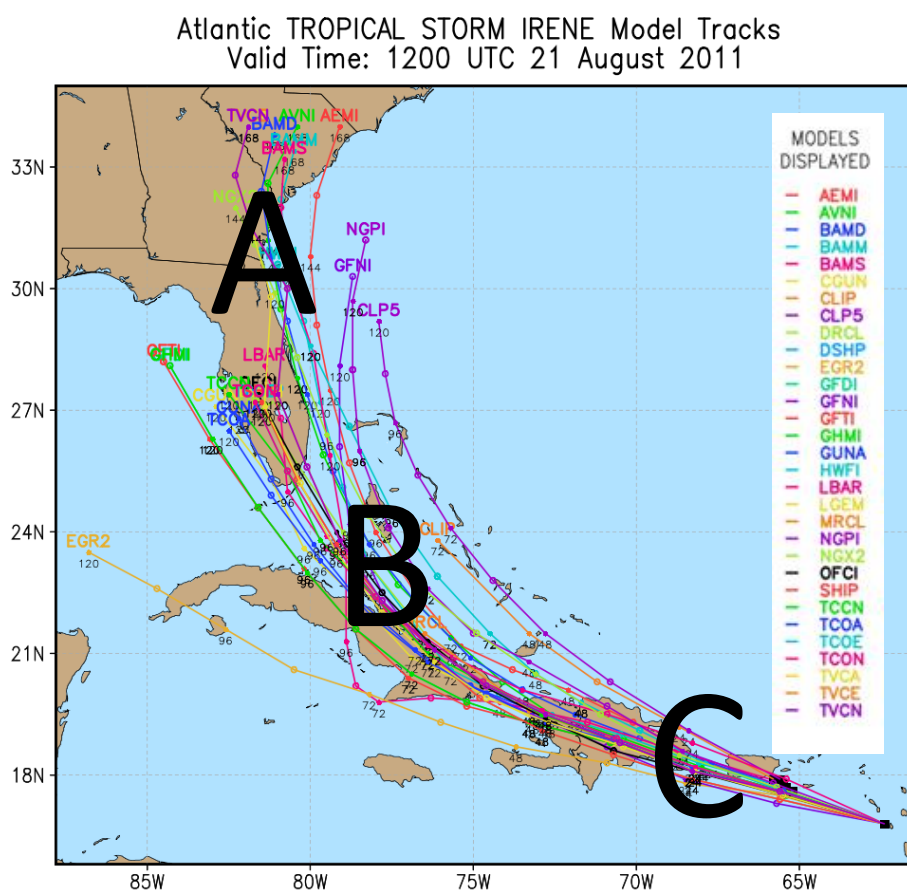


Figure 2. Spaghetti plot for tropical storm Irene, August 2011

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

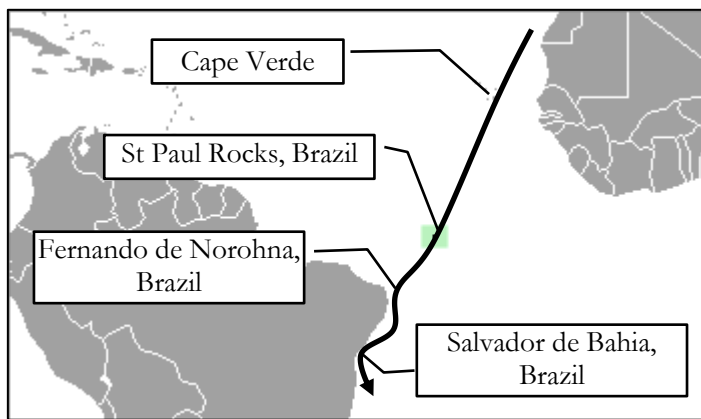


Figure 3. The route of the Beagle across the Atlantic Ocean, with indication for the islands that Darwin could explore.

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 "mylonited 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. Paul's 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) Transform 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).

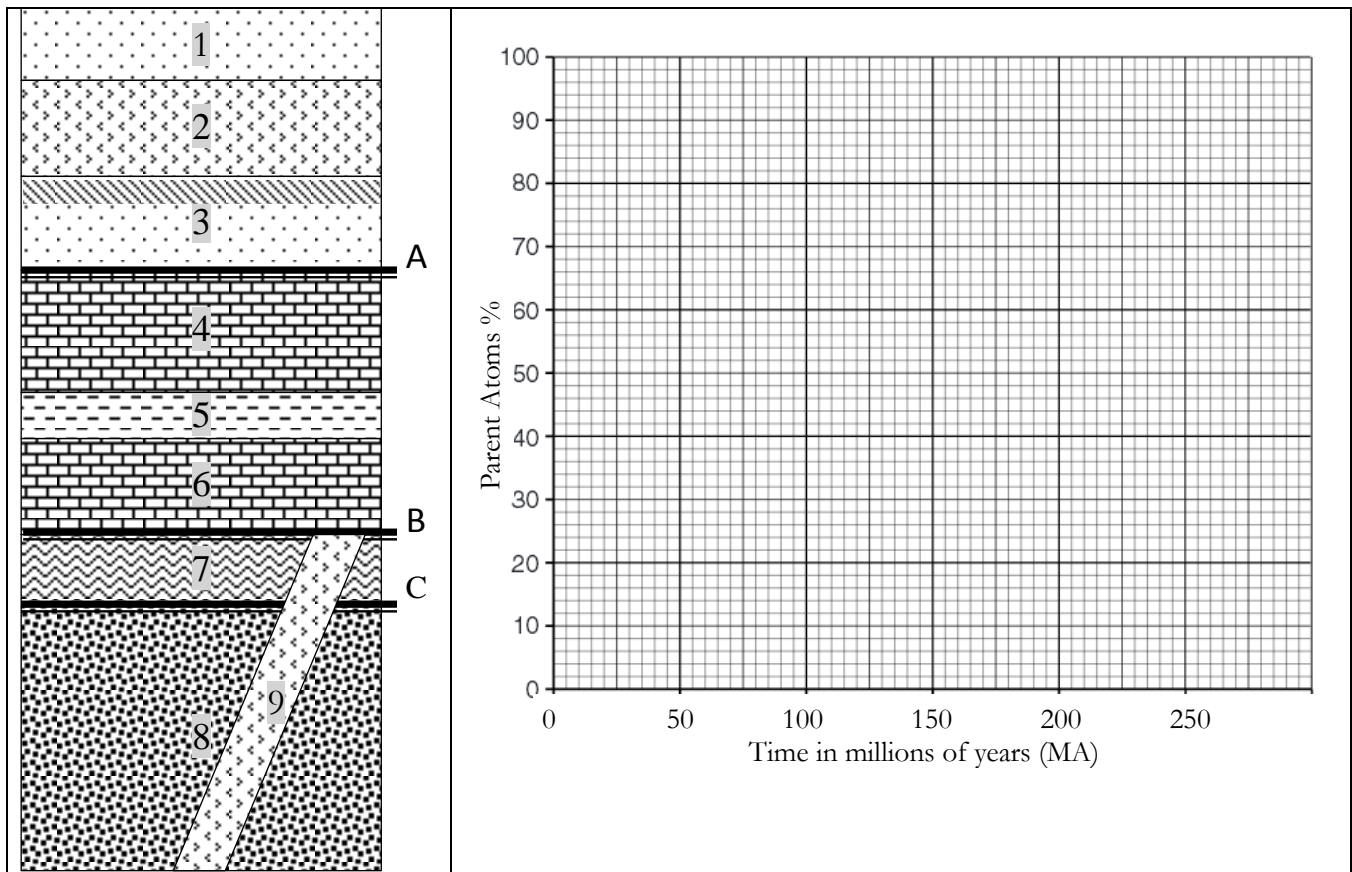


Figure 4. LEFT: Schematic section of the geological units in a region of the Atlantic Coast of South America. Key: 1. Loess. 2. Igneous rock with concentration of $[^{x}\text{Gx}] = 70\%$ of original. 3. Sandstone with rodents teeth and contact metamorphism on top. 4. Nummulithic Limestone. 5. Late ~~Mesozoic~~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

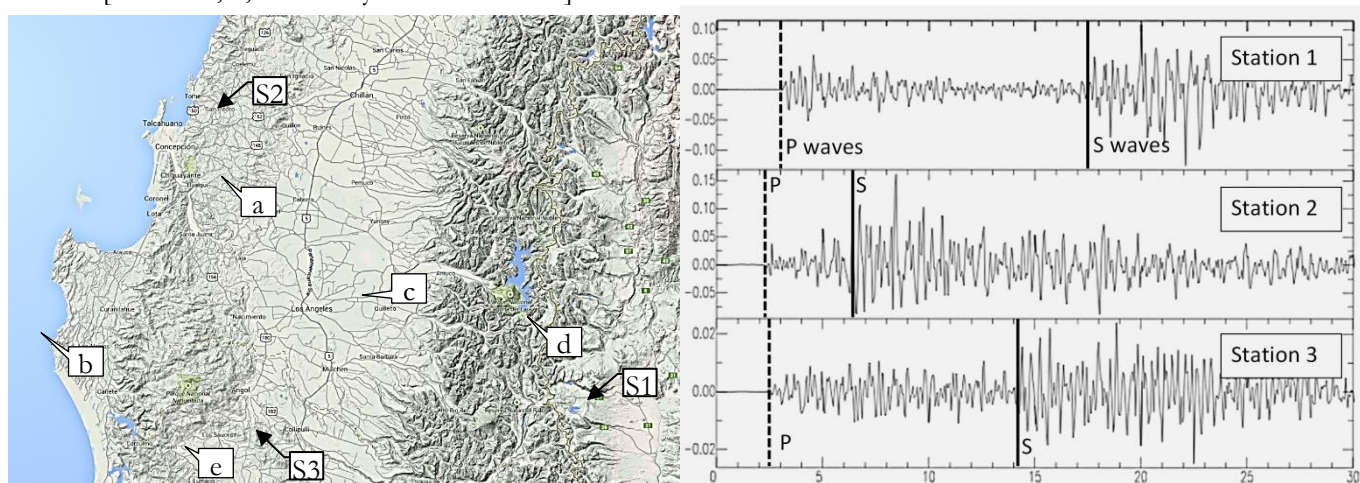


Figure 5. A. Map of a region of Chile, with the Pacific Ocean to the West and the Andes to the East. S1, S2 and S3 are three seismic stations. The points a-d show possible epicenters of an earthquake. B. Seismograms registered in stations S1-S3, with indication of the arrival times of P and S waves.

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

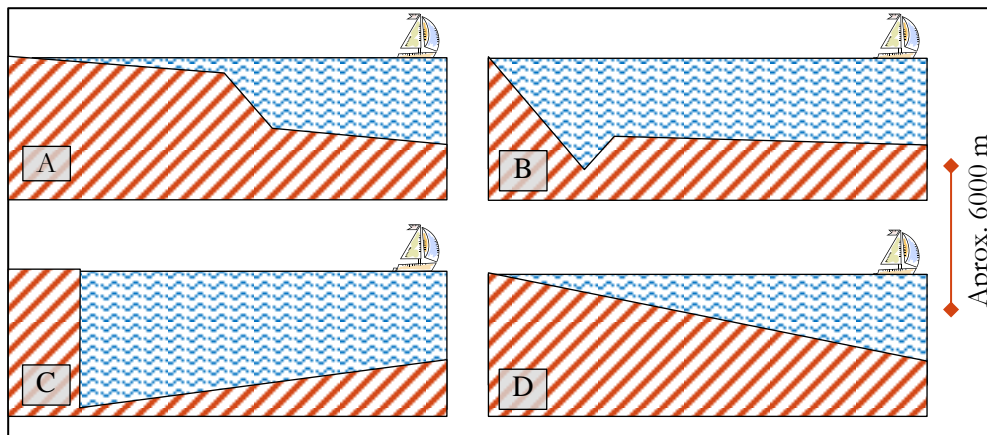


Figure 6. Four simplified hypothetical types of coast profiles.

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.

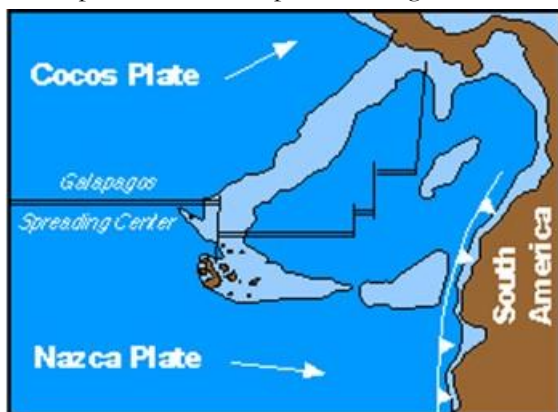


Figure 7. Simplified tectonic setting of Galapagos Islands. Arrows show plate movement.

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.

22. Which of the following statements best describe the Galápagos Geological setting?

- They are similar to Iceland
- They are similar to Japan Islands
- They are similar to Hawaii
- They are similar to Tasmania

23. Which of the following statements best describe the Galápagos Geological setting?

- They are on a Benioff plane
- They are on a mantle plume
- They are on a lithosphere isostasy rift
- They are on one crust guyot

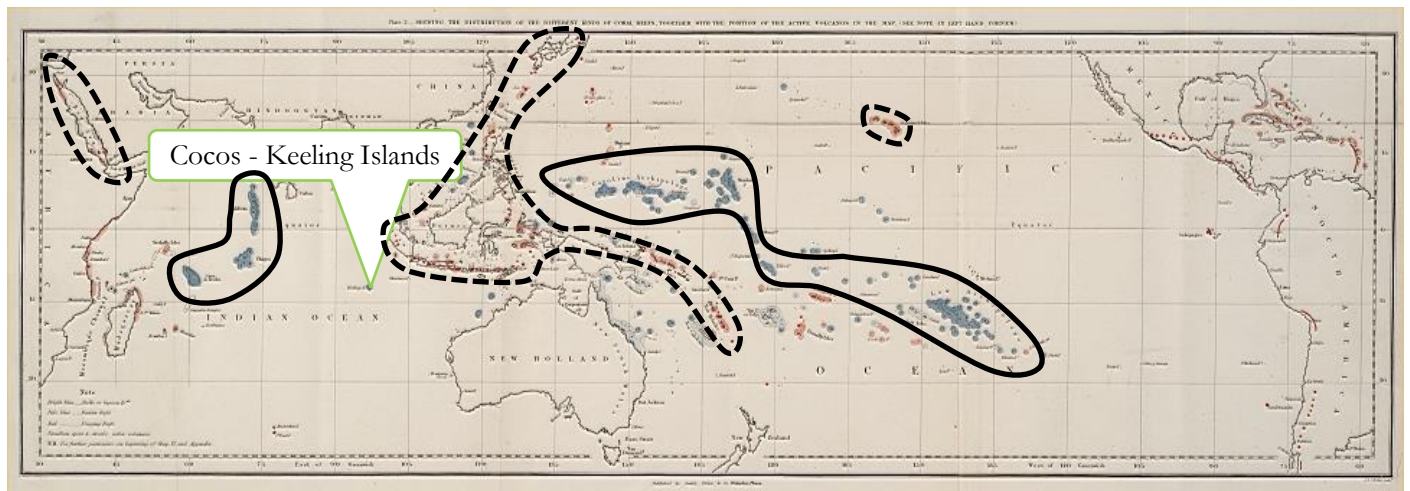


Figure 8. Darwin's map of coral reefs. Some of his "red" reefs, associated to active volcanos, are marked with solid lines. Some of his "blue" reefs, or fringe reef, are marked with dotted lines. Cocos-Keeling Islands are also marked.

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

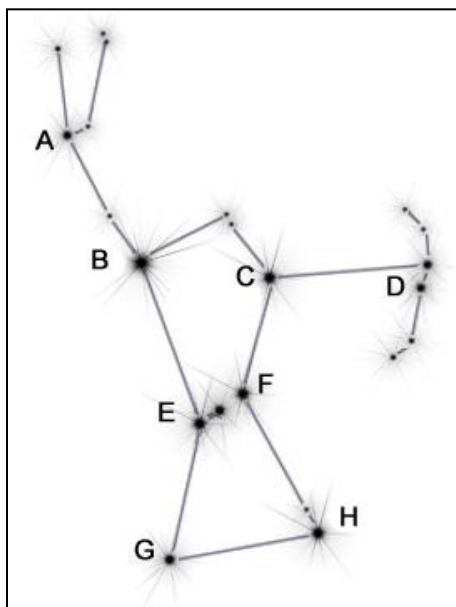


Figure 9. Simplified stellar map of constellation Orion

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.

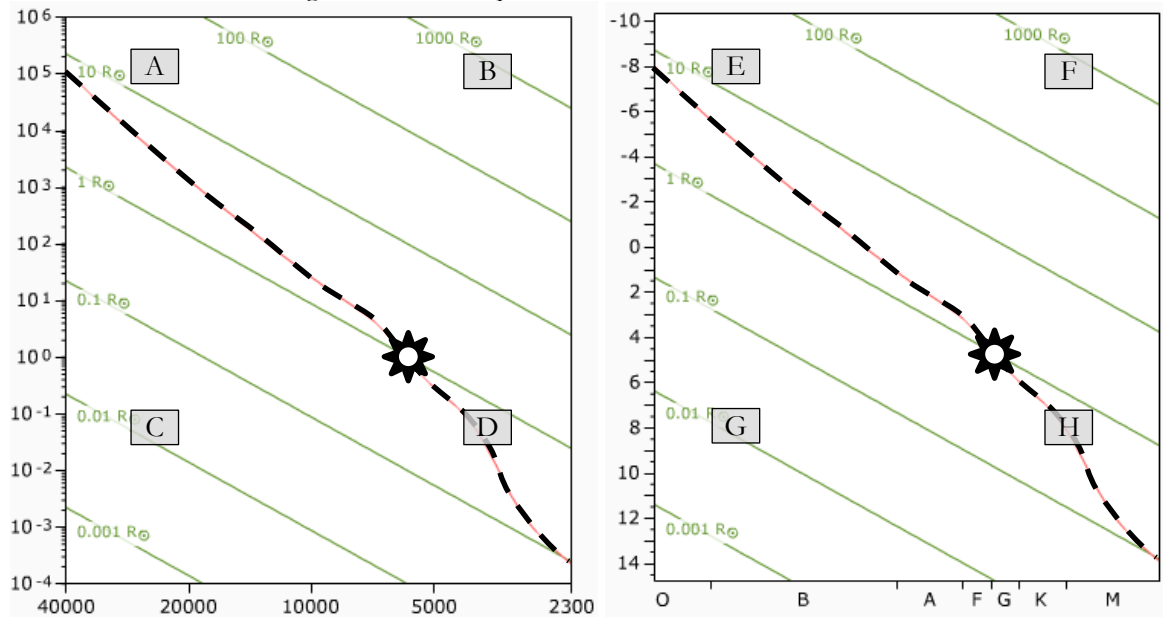


Figure 10. HR Diagram with the Sun represented by the black star.

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 |

