Paper 3

Exploring Mars with… Curiosity!

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

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

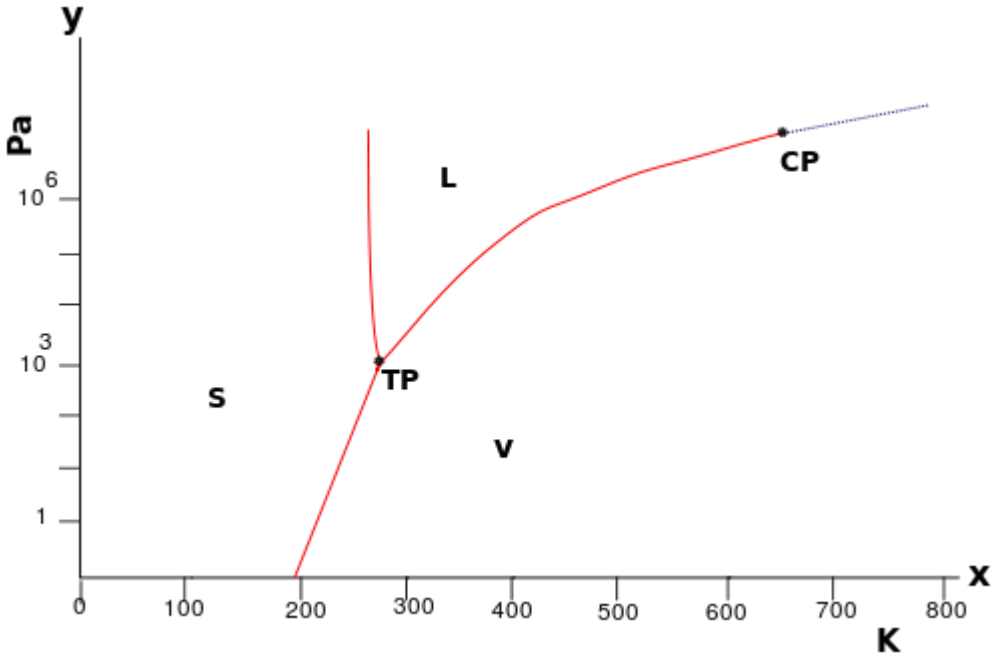

Figure 2. Erurico Zimbres in http://commons.wikimedia.org/wiki/File:Water_phase_diagram.svg

a) Liquid
b) Solid
c) Gas
d) Liquid+Gas
e) Liquid+Solid
f) Solid+Gas
g) Liquid+Solid+Gas
h) Ether
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
b) Hornblende
c) Pyrite
d) Limonite
e) Calcite
f) Olivine
g) Quartz
h) Hematite
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
b) Diffraction
c) Ejection
d) Karstification
e) Corrosion
f) Dissolution
g) Creep
h) Deflation
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
b) Increase the planet temperature
c) Increase the planet pressure
d) Reduce the planet albedo
e) Reduce the planet temperature
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
b) Conglomerates
c) Mylonites
d) Sandstones
e) Carbonates
f) Dolerite
g) Breccia
h) Andesite
i) Granite

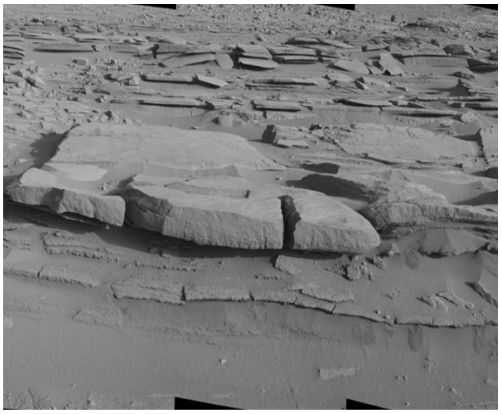

Figure 3. Crater Gale. Image take by Curiosity rover. Courtesy of MSL/JPL/NASA.

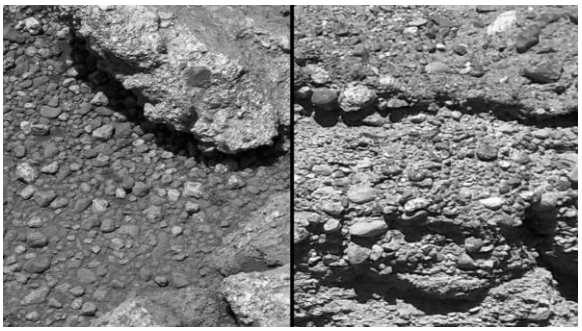

Figure 4. Crater Gale. Image take by Curiosity rover. Courtesy of MSL/JPL/NASA.

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
b) Andesite
c) Slates
d) Conglomerates
e) Mylonites
f) Quartzite
g) Marbles
h) Basalts
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) Parallell
   b) Radial
   c) Concentric
   d) Reticular
   e) Trellis
   f) Rectangular
   g) Angular
   h) Braided
   i) Dendritic

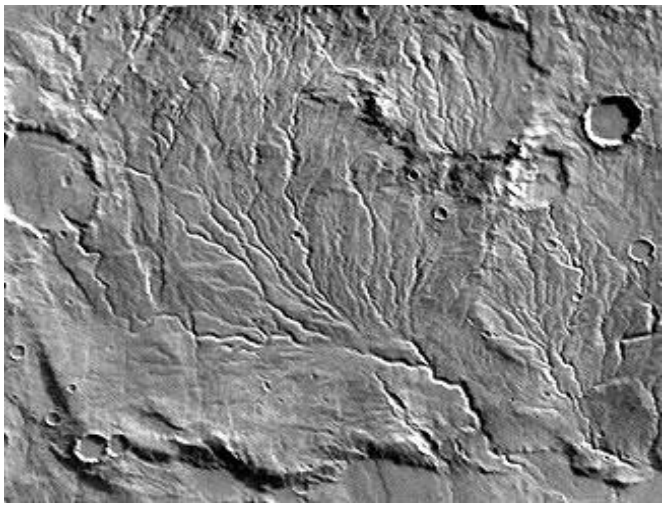

Figure 5. Warrego Vallis. Courtesy of Viking/JPL/NASA.

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 ≤ SI <1.25: winding
   c) 1.25 ≤ SI <1.50: twisty
   d) 1.50 ≤ SI: meandering

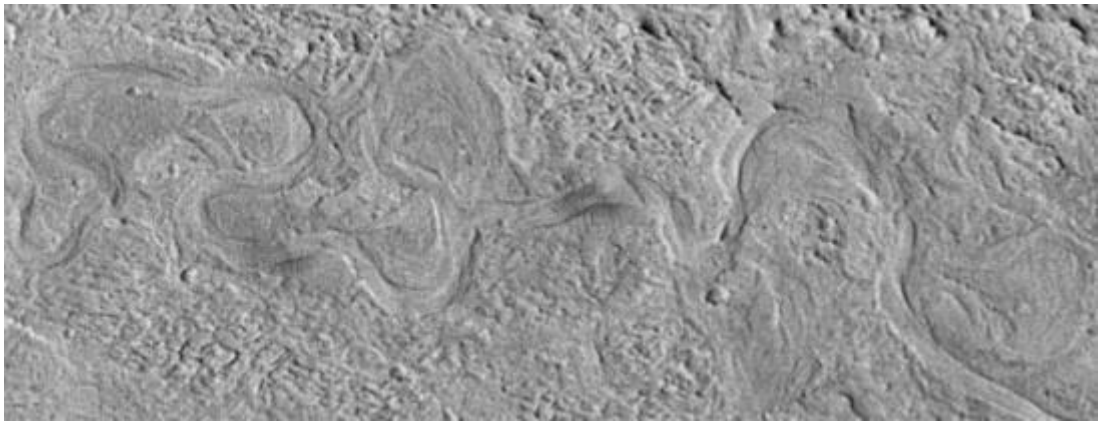

Figure 6. Unnamed channel in Mars. Courtesy of THEMIS/JPL/NASA.

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

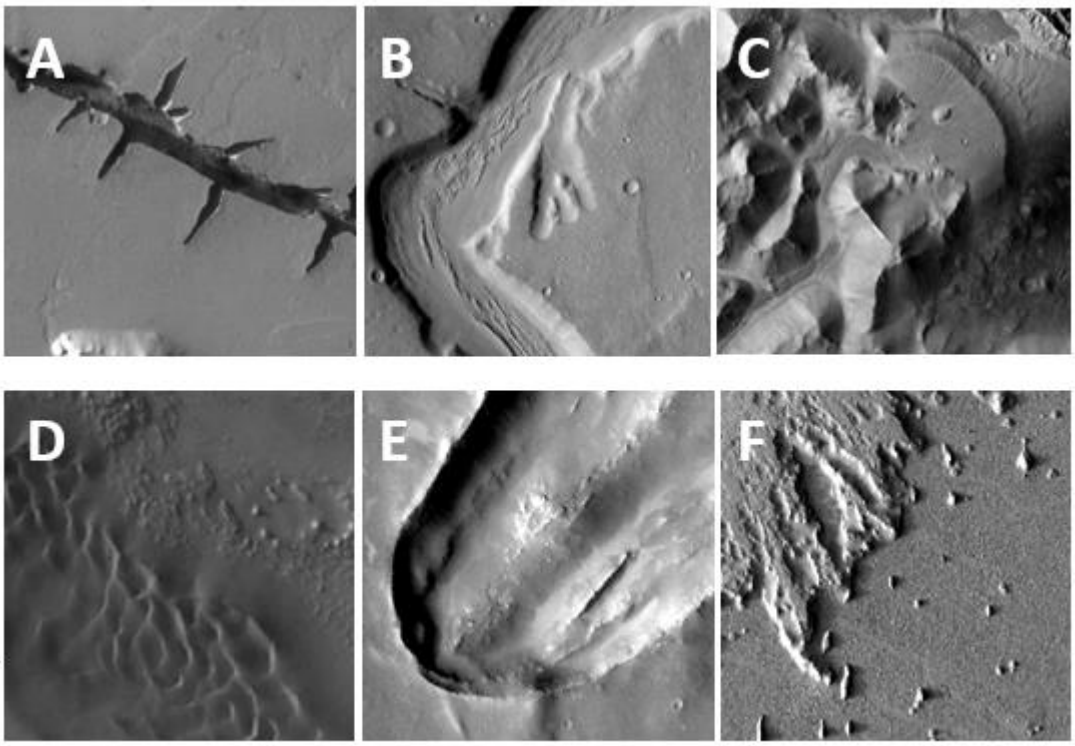

Figure 7. Images from Mars. Courtesy of THEMIS/JPL/NASA.

11. Your answer to the previous question is derived from presence in the chosen image of…
    a) Littoral dunes
    b) Beach ripples
    c) Beach crescents
    d) Deltas
    e) Faults
    f) Marsh sediments
    g) Fluvial channels
    h) Glaciers
    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
    b) Decrease of the volcanic activity
    c) Changes of the planetary rotation axis angle
    d) Increase of the distance to the Sun
    e) Reduction in the rate of impacts
    f) Changes on the position of the equator

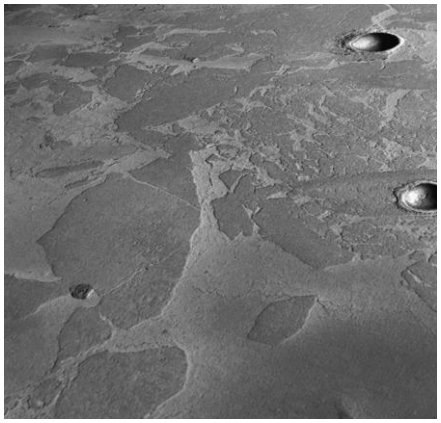

Figure 8. Utopia Planitia. Courtesy of HRSC/MEx/ESA.

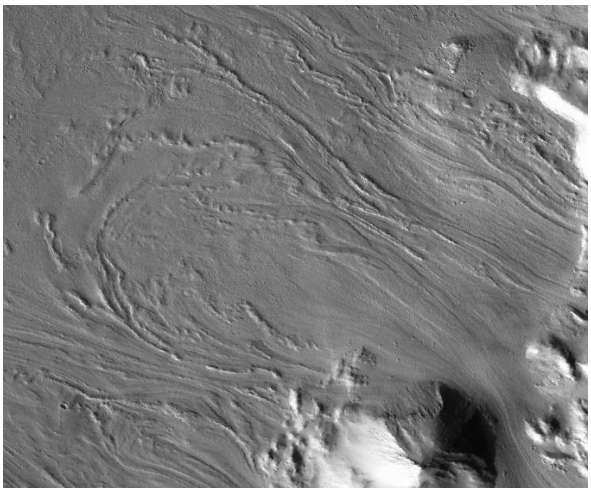

Figure 9. Hecates Tholus. Courtesy of CTX/MRO/JPL/NASA.

16. Ice processes could explain some features observed at the Mars Equator, such as those shown in Figure 8, interpreted to be…
    a) Pingos
    b) Icebergs on an ice sheet
    c) Poligonal terrains
    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
    b) Crevasse
    c) Arête
    d) Drumlin
    e) Moraine
    f) Roche moutonèe
    g) Bergschrund
    h) Mouline
    i) Kettle

18. The Martian atmosphere is poor in water vapor, but rich in CO_2, 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
    b) Absence of life
    c) Materials oxidation
    d) Springs
    e) Glaciers melting
    f) Volcanic eruptions
    g) Landslides
    h) Run-off
    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

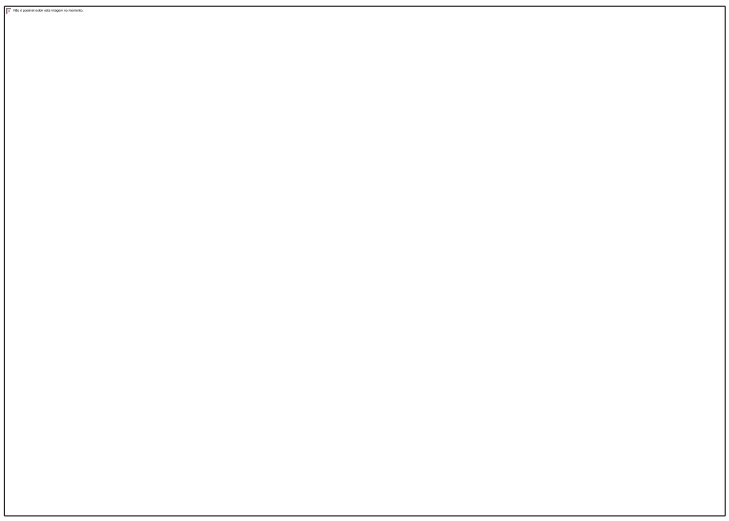

Figure 10. The sky as seen from Mars solid surface. Courtesy of MSL/JPL/NASA.

20. The content of O_2 in the atmosphere of Mars is about 0.15%, much lower than the content in the Earth's atmosphere (aproximately 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 diferent moments in Earth's atmosphere
    f) A and B can represent diferent moments in Mars' atmosphere
    g) Neither A or B can represent Earth's atmosphere
    h) Neither A or B can represent Mars's atmosphere

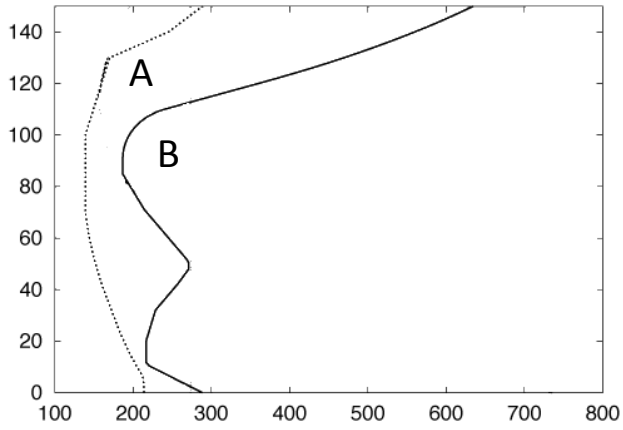

Figure 11. Atmospheric thermal structures of the two planets. X = Temperature (K),Y = Altitude (km).

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
b) Distance to the Sun
c) Angle of rotation axis
d) Precession angle
e) Tides
f) Existence of 2 moons
g) Magnetic field
h) Year duration
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
b) It is 5 times thicker
c) There is not magnetic field
d) It has less nitrogen
e) It has less ozone
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
b) Radioactive decay
c) Original horizontality
d) Original verticality
e) Type of fossils
f) Cooling rate
g) Law of superposition
h) Cross cutting
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
b) C-B-A
c) A-C-B
d) B-C-A
e) C-A-B
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
b) Polygonal terrains
c) Wind erosion
d) Glacial erosion
e) Fluvial erosion
f) Stratification
g) Aliens' ichnites
h) Desiccation cracks
i) Metamorphic cleavage

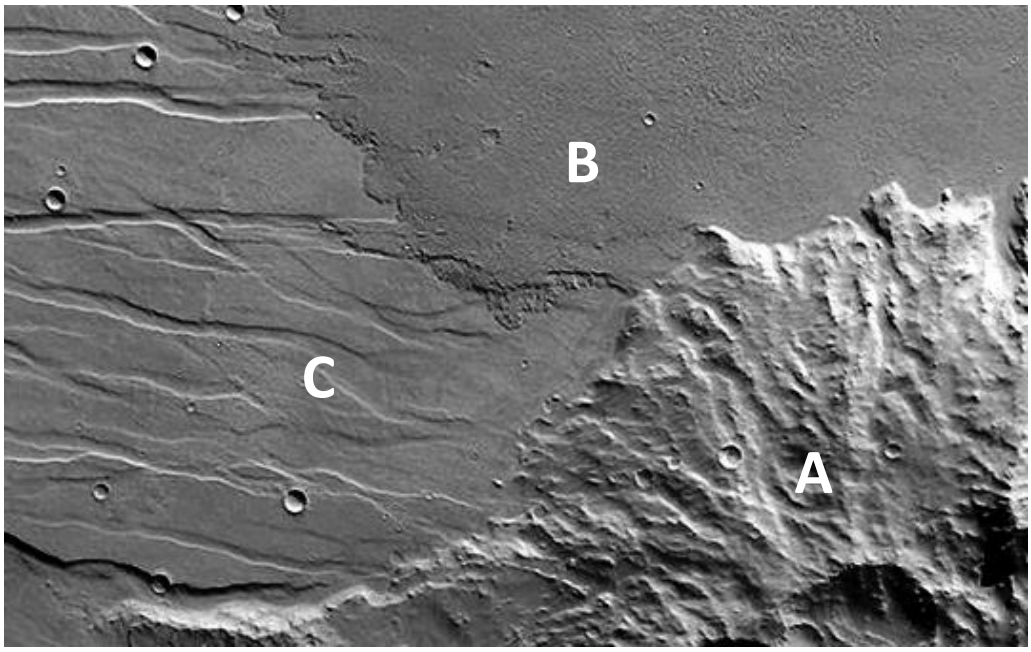

Figure 12. Claritas Fossae. Courtesy of HRSC/MEx/ESA.

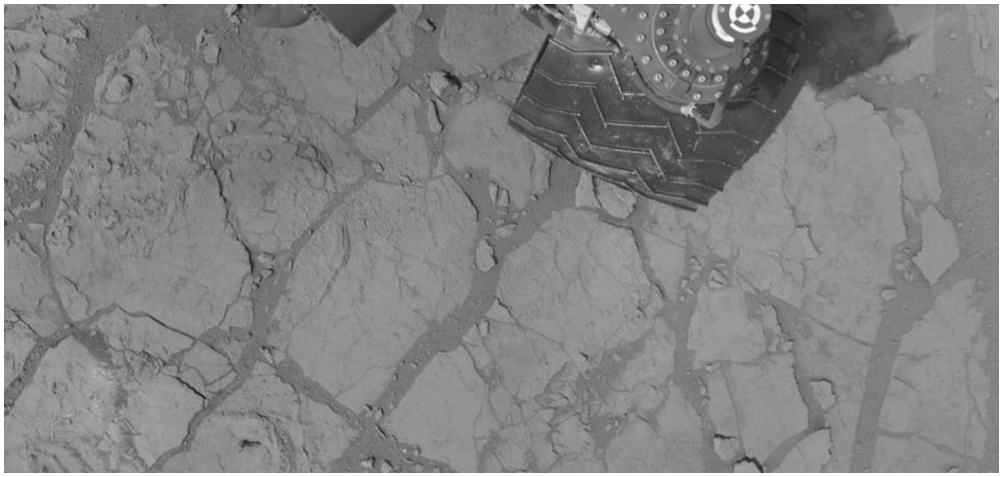

Figure 13. Gale Crater. Courtesy of MSL/JPL/NASA.

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

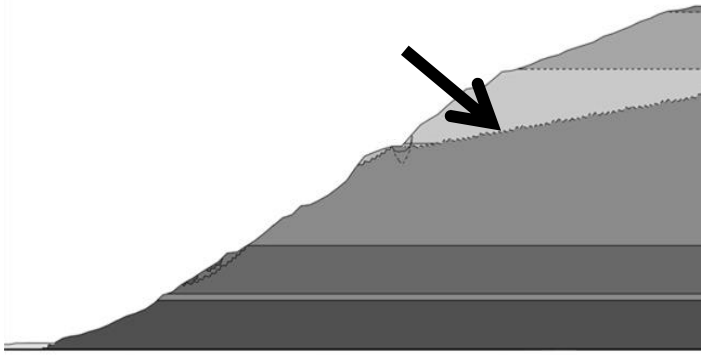

Figure 14. Geological Cross Section. Courtesy of MSSS.

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?

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

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

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) Ferrodrites

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) 0.4º
h) 0.5º
i) 0.6º

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 "Winnipesaukee," 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

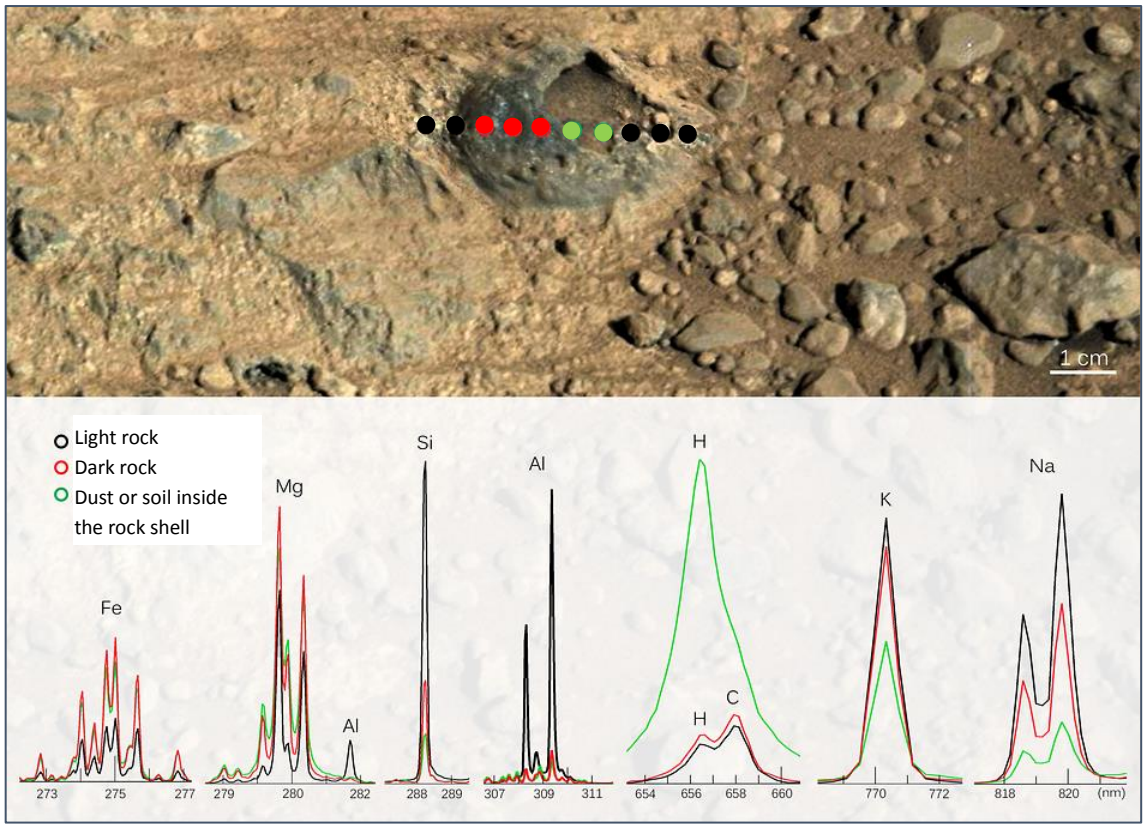

Figure 16. ChemCam image and analysis. Credit: NASA/JPL-Caltech/LANL/CNES/IRAP/LPGNantes/CNRS/IAS/MSSS.

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

39. What can explain the high content of H in the dust or soil samples?
    a) The water involved in weathering processes
    b) The methane involved in weathering processes
    c) The lower albedo of dark soil
    d) The higuer albedo of dark soil
    e) The Mars' gravity, that is bigger than Earth's gravity and holds H in the atmosphere
    f) 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
    b) Magma intrusion
    c) Marine environments
    d) Transport of sediments
    e) Weathering of rocks
    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
b) Lupus
c) Dragon
d) Geminis
e) Cignus
f) Crux
g) Scorpion
h) Canis minor
i) Cassiopeia

42. Identify the constellation Y.

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

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

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

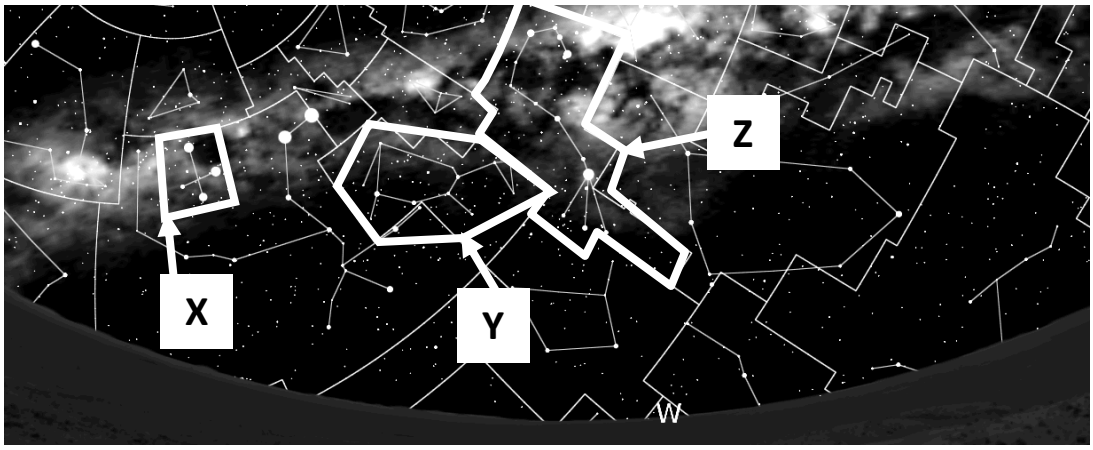

Figure 17. Constellations as seen from Mars. Source: Stellarium.

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?