16. Innes was concerned Andy and the other team members might be in danger too but he explained that their research station, not far from Tycho City, was deep underground having been built within an ancient lava tube. The rocks were more than enough to protect them, even without the modern shielding found in places like Tycho City and New London on Mars. Andy also noted that high latitude Earthlings were in for a good show but high latitude Martians were not.

Q: What did Andy say when Innes asked him to please explain… (1 mark)

a. Earth’s magnetosphere changes the trajectories of charged particles, directing them into the upper atmosphere of high latitudes where they ionise oxygen and nitrogen and create visible light displays known as aurora. Mars' magnetosphere is too weak and diffuse to direct charged particles and its atmosphere doesn't contain gases that visibly glow.
b. Mars’ magnetosphere changes the trajectories of charged particles, directing them away from the upper atmosphere of high latitudes so no ionisation of oxygen and nitrogen to form visible light displays is possible. Earth’s magnetosphere directs them into the upper atmosphere at low latitudes where they ionise oxygen and nitrogen to create visible light displays known as aurora.
c. Mars has too much CO_2 for aurora to be seen because it absorbs all the colours generated by the ionisation of oxygen and nitrogen. Earth doesn’t have enough CO_2 to mask the colours so Earthlings still see aurora but Martian don’t.
d. Aurora only form in a warm atmosphere and Mars is far too cold for them to occur.
e. Aurora only form in a water-vapour-rich atmosphere and Mars is far too dry for them to occur.
f. Aurora only form in an atmosphere polluted by anthropogenic gasses such a hydrofluorocarbons, chlorofluorocarbons and sulfur hexafluoride. Mars doesn’t have that kind of pollution thanks to the work of Areologists like Roxanne who helped the Martian Congressional Republic write the strictest environmental protection laws in the solar system.

17. Ooutta was keen to have a sample from a Martian volcano. Andy explained that quarantine rules meant he couldn't bring any Mars samples home to Earth from the lab on Luna but added that the very runny lava that flowed out of Olympus Mons was similar to a sample he collected from a volcano on Earth.

Q: What type of rock did he show Outta that was sitting on a shelf in the office on Luna? (1 mark)

a. Rhyolite from Mt St Helens in the continental USA
b. Dacite from Mt Pinatubo in the Philippines
c. Granodiorite from Mt Kosciusko in Australia
d. Pyroclastic Andesite from Mt Villarrica in Chile
e. Basalt from Mauna Loa in Hawaii
f. Gabbro from drill core taken from 3 km below a mid ocean ridge

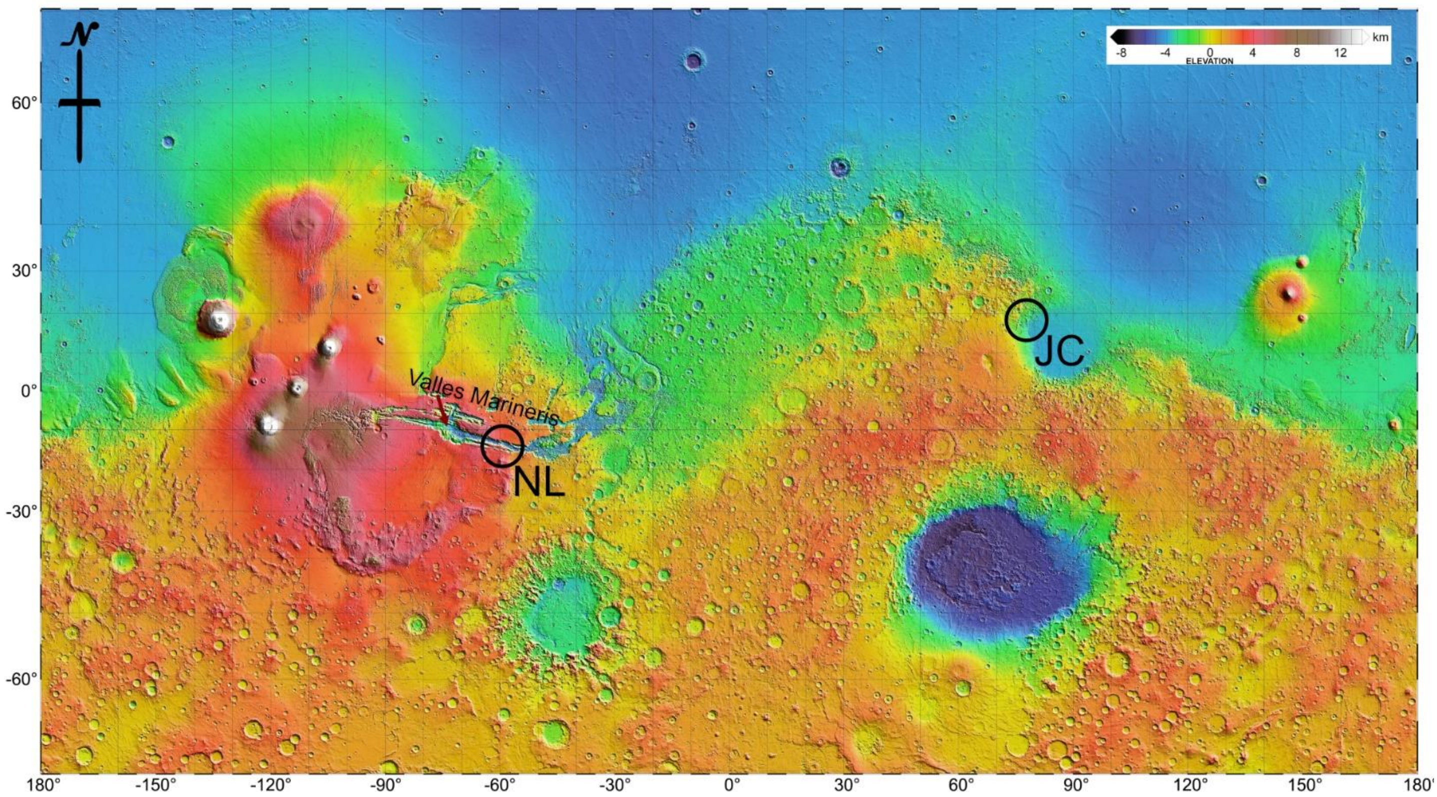

Figure 4: Topographic shaded relief map of Mars, based on the Mars Orbiter Laser Altimeter (MOLA) data set from the Mars Global Surveyor spacecraft. Elevations greater than 15 km above the baseline (zero on the key) are white. Elevations deeper than 8 km below the baseline are deep purple to black. Martian north is shown by the compass rose. Martian longitude and latitude are shown on the map margins. New London is within the circle marked NL. Jezero Crater is within the circle marked JC. Map courtesy of NASA (modified from the original).

18. Ooutta was full of questions. He wanted to know if they would be landing on Mars and exploring Jezero Crater in winter or summer. Andy showed Ooutta a map (Figure 4 above) and pointed out that they would be landing close to the Valles Marineris, near the city of New London within the circled area labelled NL. He added they would only stay there for a short time in a research station before relocating to the Jezero Crater area, marked by a circle labelled JC.

Q: What else did Andy say to correctly answer Ooutta's question? (1 mark)

a. New London is located in the Southern Hemisphere and Jezero Crater is located in the Northern Hemisphere, so even though we land on Mars in the summer time we'll be exploring Jezero Crater in the winter time.
b. New London is located in the Northern Hemisphere and Jezero Crater is located in the Southern Hemisphere, so even though we land on Mars in the summer time we'll be exploring Jezero Crater in the winter time.
c. New London is located in the Western Hemisphere and Jezero Crater is located in the Eastern Hemisphere, so even though we land on Mars in the summer time we'll be exploring Jezero Crater in the winter time.
d. New London is located in the Eastern Hemisphere and Jezero Crater is located in the Western Hemisphere, so even though we land on Mars in the summer time we'll be exploring Jezero Crater in the winter time.
e. New London is located in the Southern Hemisphere and Jezero Crater is located in the Northern Hemisphere, but both locations are so close to the equator that there will be no obvious seasonal difference.
f. New London is located on the equator where there are no seasons and Jezero Crater is located in the Northern Hemisphere, so we'll be exploring Jezero Crater in the summer time.

19. Ooutta also wanted to see New London and asked if it could be seen on the map. Andy zoomed in to show him the detail (Figure 5 below). Ooutta still couldn't see any sign of a city. Andy explained that the map was not detailed enough to show surface infrastructure but also explained that most of the habitation was built below ground. He drew a circle on the map and labelled it RS, saying this is where the research station is. It has an entrance at the surface that is 5 km above baseline, an entrance in the cliff face of *Valles Marineris* and another entrance at the level of the valley floor.

Q: What did Ooutta correctly exclaim as he drew a line matching the valley floor colour on the map to the elevation key (Figure 5)? (1 mark)

a. …25 km deep!
b. …20 km deep!
c. …15 km deep!
d. …10 km deep!
e. …8 km deep!
f. …5 km deep!

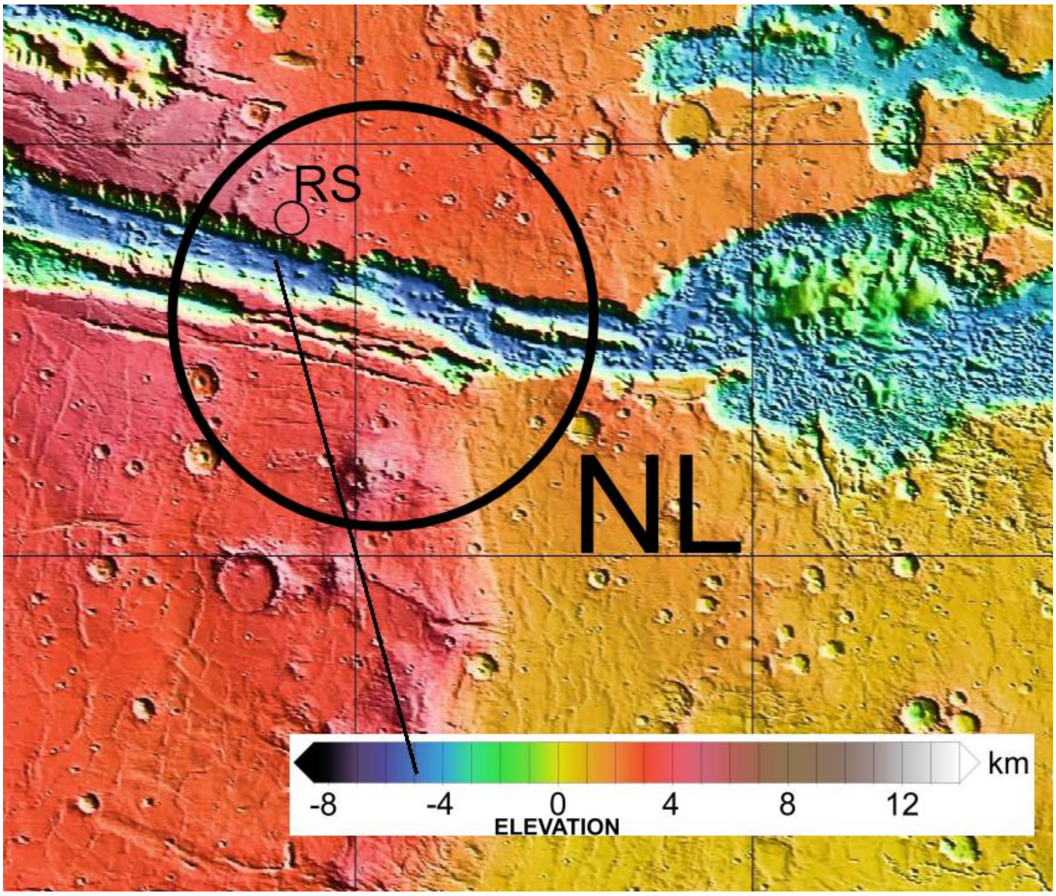

Figure 5: The New London area (circled and labelled NL) with the location of the research station's surface entrance circled and labelled RS. Map modified from the original at https://tinyurl.com/yz674dpj

20. Andy needed to get back to work so he answered just one more question from Ooutta. Andy zoomed in to show the detailed geography of the Jezero Crater area (Figure 6 below) and added a satellite image to show even more detail (Figure 6 grey scale inset). He told Ooutta that the Perseverance rover was in the north west section of Jezero crater, near an apparent sedimentary deposit formed when the crater was much younger and full of water.

Q: What did Ooutta correctly say in response to Andy asking him what the sedimentary deposit in Jezero Crater told us about early Mars? (1 mark)

a. It told us the surface of Mars was wetter and colder in the past.
b. It told us the surface of Mars was wetter and warmer in the past.
c. It told us the surface of Mars was greener in the past.
d. It told us the surface of Mars was dryer and warmer in the past
e. It told us the surface of Mars was dryer and colder in the past.
f. It told us Martians could swim.

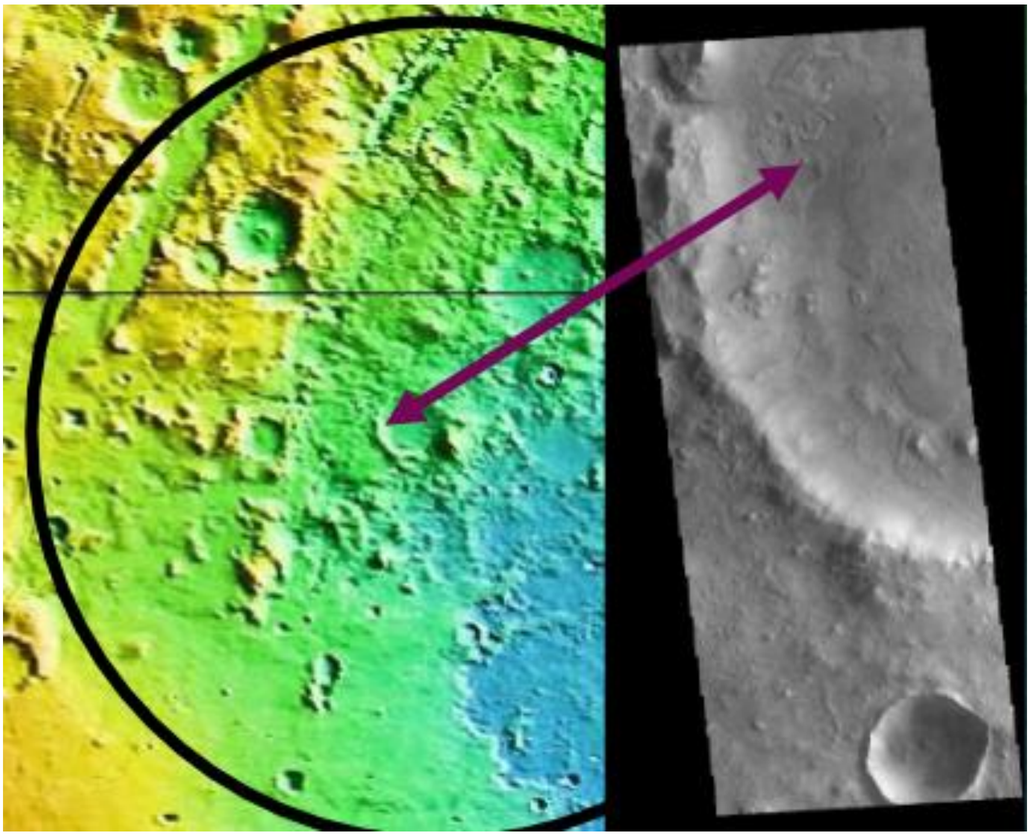

Figure 6: Jezero Crater, with satellite image inset showing the north east area of the crater where the Perseverance rover landed and explored way back in 2021. False colour image map modified from the original. THEMIS Satellite image courtesy of NASA/JPL/ASU (https://tinyurl.com/yjgylrkk).

21. Ooutta begged for one more question! He pointed to a tiny grey dot on the satellite image (seen just to the right of the arrow head in the Figure 6 inset image and asked what it was. Andy found an even better close up image (Figure 7a and Figure 7b enlargement below) to show Ooutta what it was. By this time the whole team was listening to the Q&A between Andy and Ooutta so sedimentologist Sandra helped Andy, explaining it was a small hill left behind as some of the sediment eroded away. However, as soon as he saw the new close-up image Oouta lost interest in the hill and shouted,

Oo, what's that? …as he pointed to the feature circled in Figure 7.

Q: What did Sandra say it was? (1 mark)

a. An old volcanic vent, called Belva, full of liquid CO_2 with big waves on the surface.
b. A small impact crater, called Belva, full of water with big waves on the surface.
c. A sinkhole, called Belva, revealing tilted layers of limestone at the bottom.
d. A volcanic caldera, called Belva, with a floor covered in ropy lava.
e. A sinkhole, called Belva, with a sandy floor covered in animal tracks.
f. A small impact crater, called Belva, with a floor covered in sand dunes.

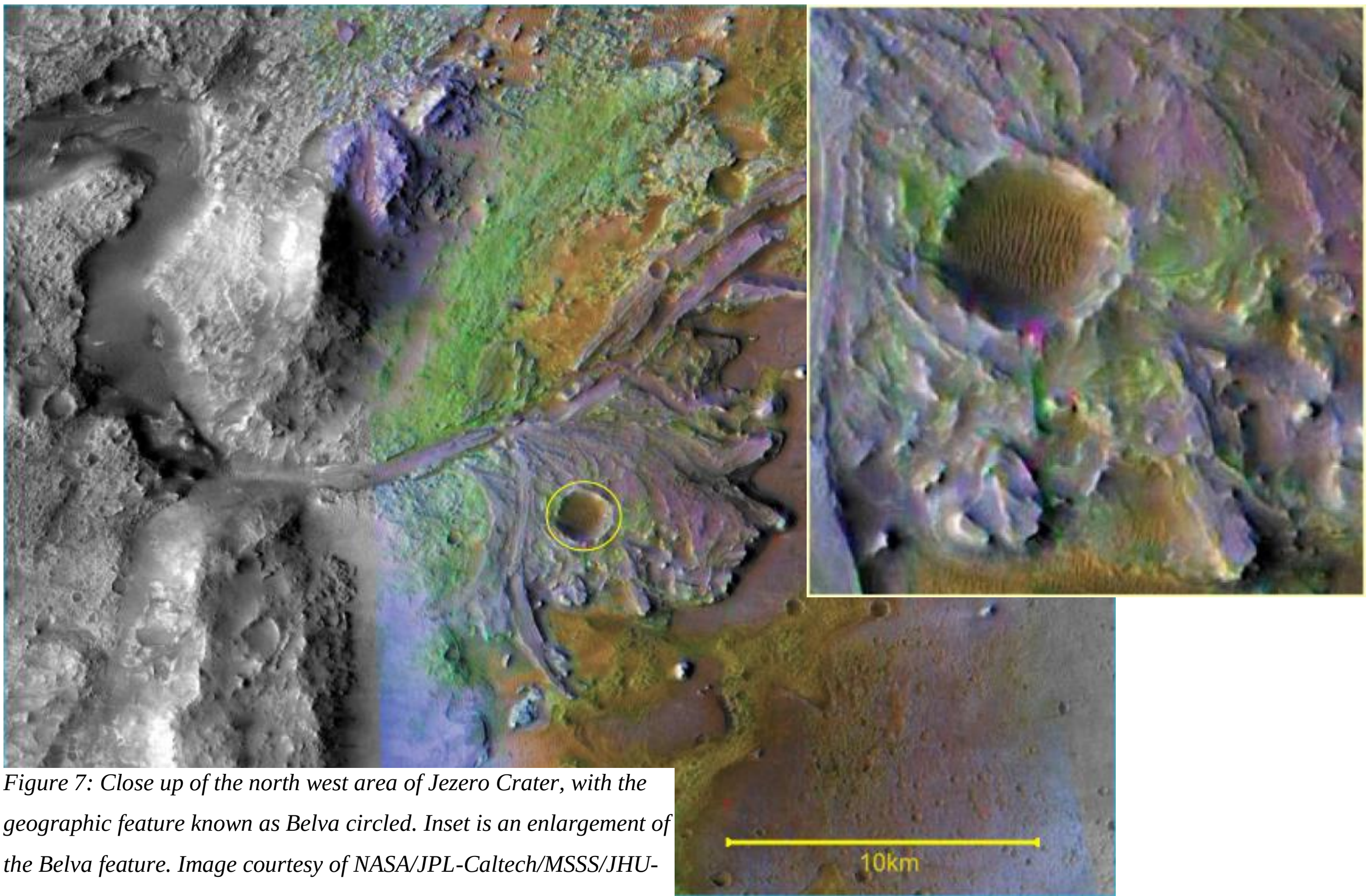

Figure 7: Close up of the north west area of Jezero Crater, with the geographic feature known as Belva circled. Inset is an enlargement of the Belva feature. Image courtesy of NASA/JPL-Caltech/MSSS/JHU-APL (https://tinyurl.com/zazcyazh).

22. Roxanne found a room for Ooutta to sit quietly in and surf the system-wide-web while the team got to work but before they could start she received a message from her sister Gemma.

Roxanne's sister, Gemma, is also a planetary geologist. She delights in asking her sister tricky questions! In this message she said …

Hi Roxy. I hope planning is going well. I have looked over some old satellite survey data and wondered if the climate has changed since the establishment of New London and other Martian cities. I've attached a graph for your comments (Figure 8 below). I'd like to know what this graph tells us about the Martian atmosphere and its seasonal CO_2 cycle.

Roxane figured her sister probably knew the answer to this question already but she couldn't resist answering her anyway.

Q: What did Roxanne say in reply to the comment about Martian seasons? (1 mark)

Hi Gemma – the Martian climate has not changed yet but if the terraforming plans work, it will. As you know, Mars has a longer orbital period than Earth and thus longer seasons too. You can even tell from the graph you sent that the Martian year is ...

a. …approximately 1.1 Earth years long.
b. …approximately 1.5 Earth years long.
c. …approximately 1.9 Earth years long.
d. …approximately 2.5 Earth years long.
e. …approximately 2.9 Earth years long.
f. …never the same twice.

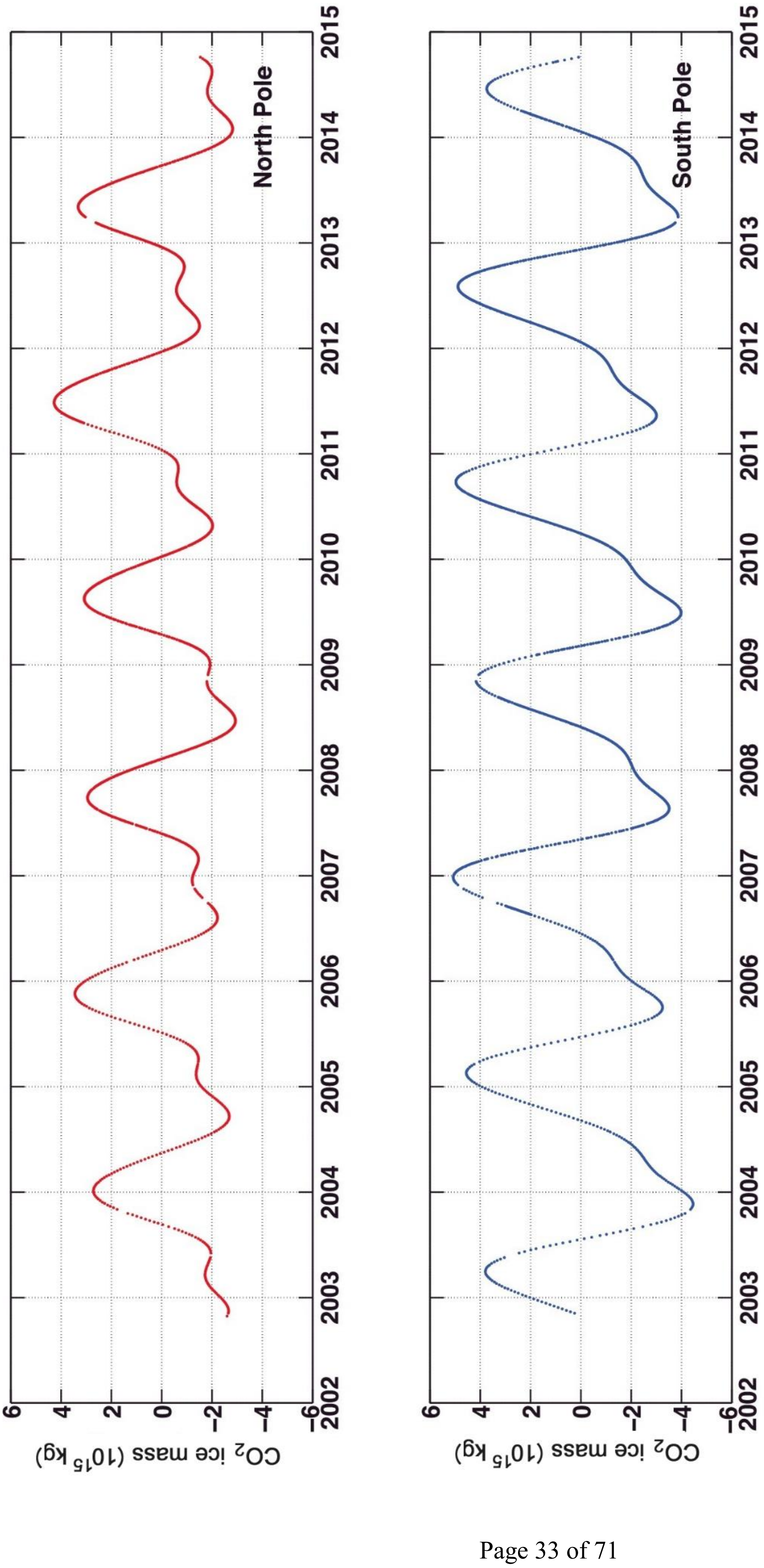

Figure 8: Changes in CO_2 ice masses over the Martian poles between Earth years 2002 and 2015, as determined by measurements in local gravity changes observed by satellites. Modified from Figure 16 in Genova et al, Seasonal and static gravity field of Mars from MGS, Mars Odyssey and MRO radio science, Icarus, Volume 272, 2016, Pages 228-245,

23. Roxanne also knew the data in the graph (Figure 8 above) has been shown, from longer studies, to represent the climate variability expected on Mars until such time as terraforming – as proposed by the Martian Congressional Republic – starts to change the atmospheric composition.

Roxanne sent Gemma this note:

> *The graph is also interesting because you can use this gravity data to determine changes in atmospheric CO2 gas concentrations over time. If you examine the data for the 2004 Earth year, you can see that at the start of 2004 the Northern Hemisphere winter peaked and locked away ~3 x 1015 kg CO2 ice at the North Pole. At the same time, the Southern Hemisphere summer had already peaked and was beginning to cool but the CO2 released from the South Pole ice into the atmosphere still amounted to the equivalent of...* **(1 mark)**

a. …4.5 x 10^{15} kg CO_2 ice.
b. ….1 x 10^{15} kg CO_2 ice.
c. …1.5x 10^{15} kg CO_2 ice.
d. …4 x 10^{15} kg CO_2 ice.
e. …3 x 10^{15} kg CO_2 ice.
f. …2 x 10^{15} kg CO_2 ice.

24. Roxanne added ...

... This graph of polar ice mass (Figure 8 above) can be used to predict how the CO_2 content of the atmosphere changes over time and in step with seasonal changes (with some lag due to the time it takes for the atmosphere to mix). Comparing all Northern Hemisphere winter peaks, which one would correspond with the lowest atmospheric CO_2 content?

Q: What did Gemma correctly say in reply to Roxanne's question, based on the variability shown in the graph? (1 mark)

... Of all the Northern Hemisphere winter peaks, the one that corresponds with the lowest CO_2 content in the atmosphere is...

a. …the 2004 Northern Hemisphere winter peak.
b. …the 2005 Northern Hemisphere winter peak.
c. ….the 2007 Northern Hemisphere winter peak.
d. ….the 2009 Northern Hemisphere winter peak.
e. ….the 2011 Northern Hemisphere winter peak.
f. …the 2013 Northern Hemisphere winter peak.

25. Not be outdone, Gemma challenged Roxanne with another question based on another graph (Figure 9 below and here) and some notes she sent with it, saying...

> *...Very good, but looking at the previous graph (Figure 8) and the graph I just sent (Figure 9 below), and assuming the Northern Hemisphere winter solstice coincides with the maximum CO_2 ice mass accumulation on the north pole, why does atmospheric pressure start to drop before the Northern Hemisphere winter solstice and not after?*

Note: The solar longitude, Ls, is the Mars-Sun angle, measured from the Northern Hemisphere.

- L_s 360 is the northern spring equinox,
- L_s 90 is the northern summer solstice,
- L_s 180 is the northern autumn equinox and
- L_s 270 is the northern winter solstice.

The annual average atmospheric composition in Gale Crater was measured as 95.1% carbon dioxide, 2.59% nitrogen, 1.94% argon, 0.161% oxygen, and 0.058% carbon monoxide.

Q: What did Roxanne correctly say in reply? (1 mark)

a. Atmospheric pressure on Mars is proportional to the CO_2 gas content. The decrease in pressure is coincident with the Southern Hemisphere already cooling and starting to add ice to the south pole before the Northern Hemisphere solstice.
b. Atmospheric pressure on Mars is inversely proportional to the CO_2 gas content. The decrease in pressure is coincident with the Southern Hemisphere already cooling and starting to add ice to the south pole before the Northern Hemisphere solstice.
c. Atmospheric pressure on Mars is proportional to the CO_2 gas content. The decrease in pressure is coincident with the Southern Hemisphere already warming and starting to liberate CO_2 gas from the south pole before the Northern Hemisphere solstice.
d. Atmospheric pressure on Mars is not proportional to the CO_2 gas content. The decrease in pressure is not explained by atmospheric gas concentrations.
e. Atmospheric pressure on Mars is proportional to the CO_2 gas content. The decrease in pressure is coincident with the Southern Hemisphere already cooling and starting to add ice to the south pole after the Northern Hemisphere solstice.
f. Atmospheric pressure on Mars is proportional to the content of all the gasses in the atmosphere because they all freeze or sublime at the same temperature.

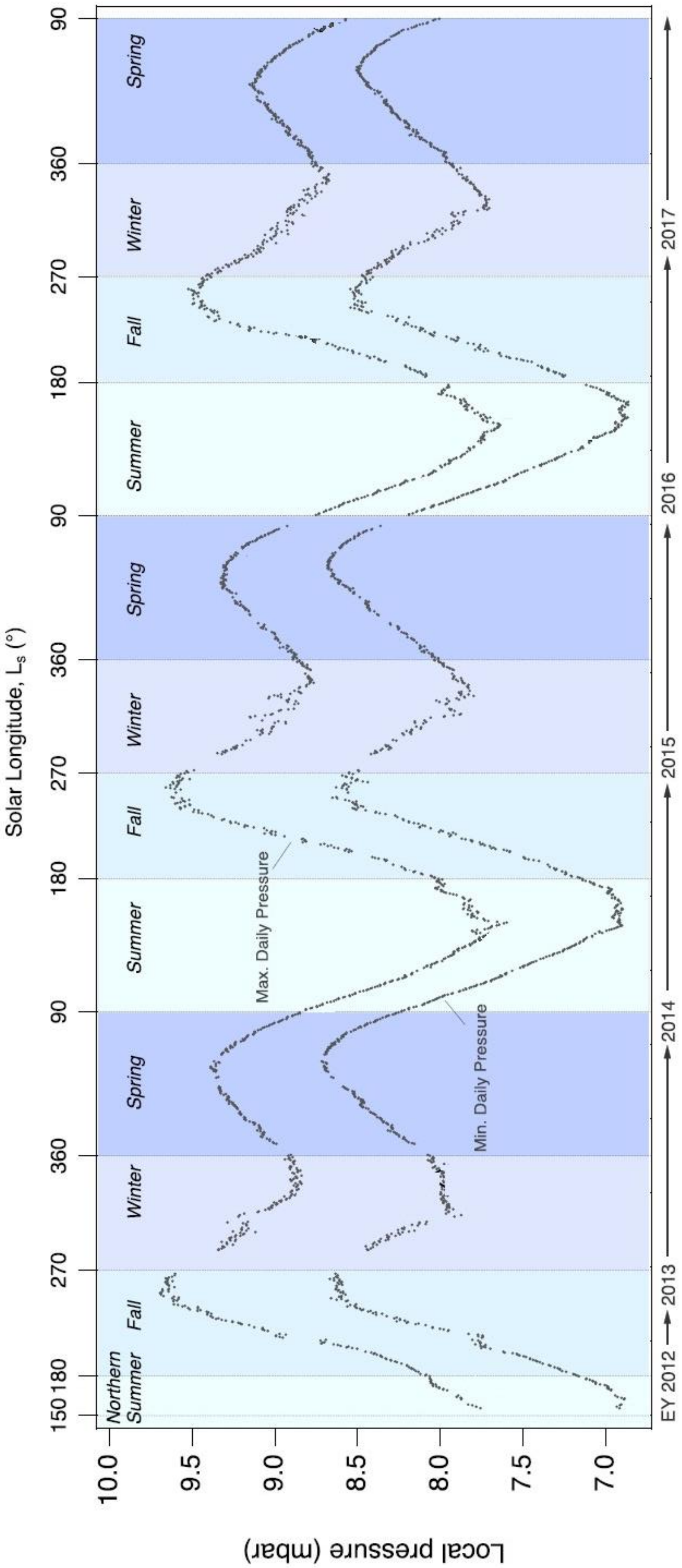

Figure 9: Atmospheric pressure on Mars during Earth Years (EY) 2012 – 2017 as measured at Gale Crater by Curiosity Rover's weather station instruments. Image modified from Trainer et al, 2019. Note: *Fall* is another word for Autumn.

The following information relates to Questions 26 ad 27

The team were very keen to examine the Jezero Crater area on the map to determine what they need to ground truth upon arrival.

Examining the general geological map of the site, that was constructed solely from satellite images (Figure 10 below) but more-or-less confirmed by Perseverance, they concluded they must test the results of rock analyses performed by the Perseverance rover with rocks visually confirmed to be from outcrops. The main target of their investigations would be the following units (Table 1 below):

Table 1

Unit Name and description	Unit map code	Original interpretation
Jezero fan unit 2: Lightly cratered layered unit with margins defined by steep cliffs	$NHjf_2$	Deltaic-fan lake deposit
Jezero fan unit 1: Sparsely cratered unit similar to unit 2	$NHjf_1$	Deltaic or lake deposit
Jezero floor unit: Rugged, highly cratered planar unit	Njf	Volcanic ash or windblown deposit or possibly lava flows
Lower etched unit: Lightly cratered unit, adjacent to Njf, topographically lower than Nue	Nle	Volcanic ash deposit, similar to Nue
Upper etched unit: Cratered unit adjacent to Jezero Crater rim.	Nue	Volcanic ash deposit or other windblown sediment

Table 2

Texture #	Primary descriptors	Secondary descriptors
1	Entirely crystalline, only one type of crystal	No alignment of crystals. Most crystals the same size.
2	Crystalline, but with a lot of glassy material and a foam-like appearance	No alignment of crystals. Most crystals less than 1mm in diameter.
3	Entirely crystalline, several types of crystals	No alignment of crystals. Most crystals greater than 2mm in diameter.
4	Granular, horizontal layers or layers draped at angles over older topography	Tiny rock fragments and crystals with a glassy material between the grains.
5	Granular, horizontal and inclined layers	Multiple grain types, grain size varies between layers but often well sorted in each layer.
6	Entirely crystalline, several types of crystals	Some sheet-like crystals showing a parallel alignment, giving the rock a distinct layered appearance.

26. **Q: They drew up a list of rock textures they would expect to see if the satellite interpretations of NHjf1 and NHjf2 (Figure 10 below) are correct. Out of their more comprehensive list of textures listed in Table 2 above, which suite of textures would be most likely seen in NHjf1 and NHjf2? (1 mark)**

a. Texture 1
b. Texture 2
c. Texture 3
d. Texture 4
e. Texture 5
f. Texture 6

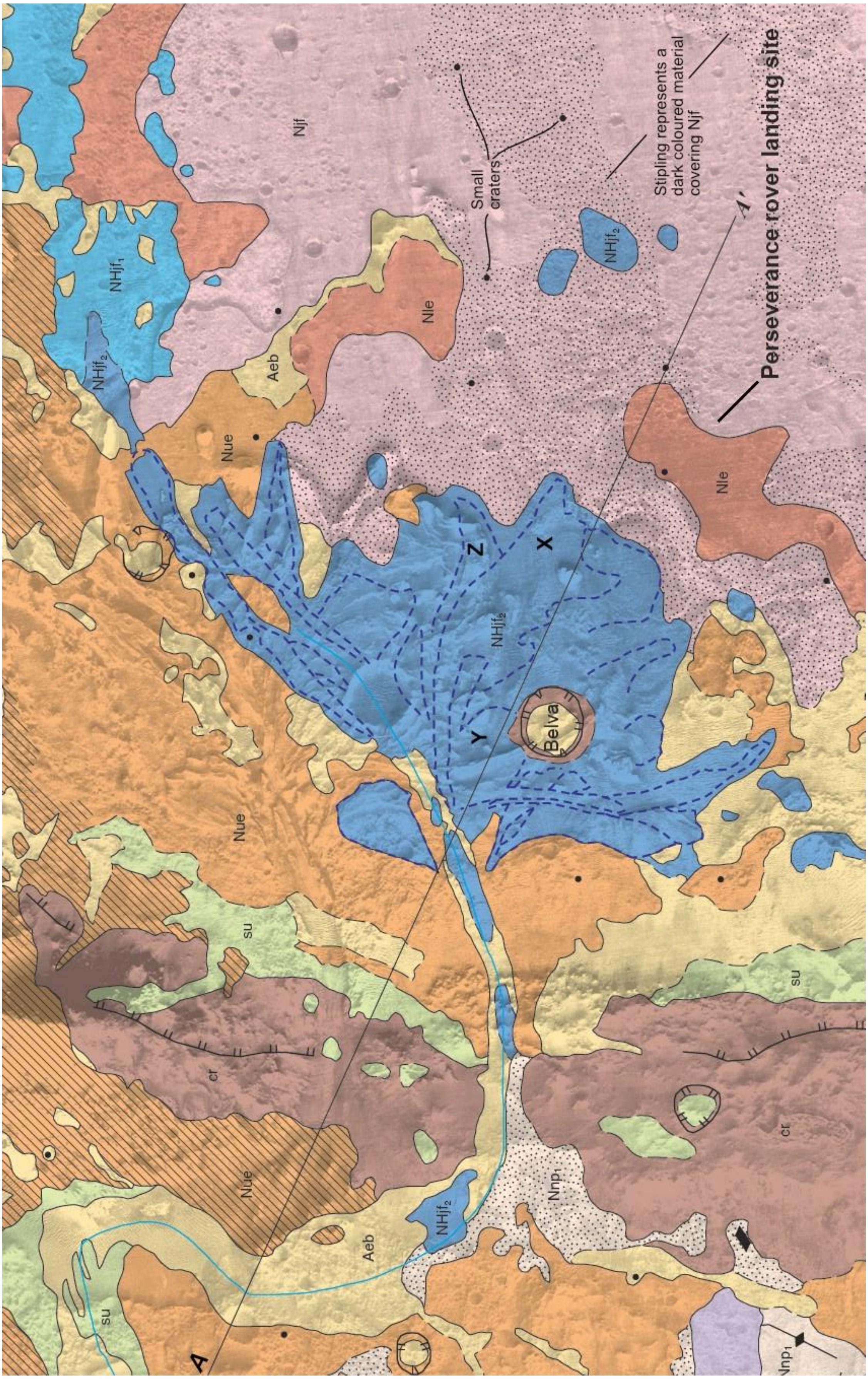

Figure 10: General geology of the Perseverance rover landing site. Modified from Sun & Stack 2020 (USGS publication, https://tinyurl.com/39tk3fkm).

27. **Q: Out of their more comprehensive list of textures listed in Table 2 (above), which suite of textures would be most likely seen in Nue if it is of pyroclastic origin? (1 mark)**

   a. Texture 1
   b. Texture 2
   c. Texture 3
   d. Texture 4
   e. Texture 5
   f. Texture 6

28. The astronomer in the team, Zoe, was puzzled by the dark blue dashed lines drawn on NHjf2 (Figure 10 above). Sandra explained that the dashed lines outlined lobes of sediment, interpreted to be channel deposits, that were emplaced by different outflows of river water across the delta over time.

   Q: What did Sandra add to this explanation? (1 mark)

   From oldest to youngest the lobes were deposited in the sequence …

   a. X, Y, Z
   b. X, Z, Y
   c. Y, Z, X
   d. Y, X, Z
   e. Z, X, Y
   f. Z, Y, X

29. While the team were busy studying the map and discussing what might be found in outcrop, Roxanne was distracted by another message from her sister. This time Gemma was asking about the upcoming trip to Mars, reflecting on what interplanetary travel was like in the bad old days before the invention of the Epstein Drive. Gemma was curious to know how long it would take them to get to Mars. Roxanne sent Gemma an image to show what it was like back in 2020-2021 when the Perseverance rover travelled to Mars (Figure 11 below) adding that prior to the Epstein Drive the team could not travel in a relatively straight line to Mars. In order to leave the Earth from their base on the Moon and intersect with Mars without the need to use lots of extra fuel the flight path needed to be a 'transfer orbit'(Figure 11 below).

Q: What did Roxanne add to the image she sent Gemma (Figure 11)? (1 mark)

The problem with a transfer orbit is not just the time it takes to travel the distance but you need to also factor in…

a. … the relative positions of Earth and Mars in their orbits at launch time - which in our case would mean waiting another 14 months for an appropriate launch window.
b. …the relative position of Venus and Mars in their orbits at launch time - which in our case would mean waiting another 14 months for an appropriate launch window.
c. …the relative position of Jupiter (and the gravity it exerts on the inner planets) at launch time - which in our case would mean waiting another 14 months for an appropriate launch window.
d. …the frequency of sunspots and solar flares at launch time.
e. …the direction of the solar wind during the trip.
f. …the relative position of Earth when the ship arrives at Mars.

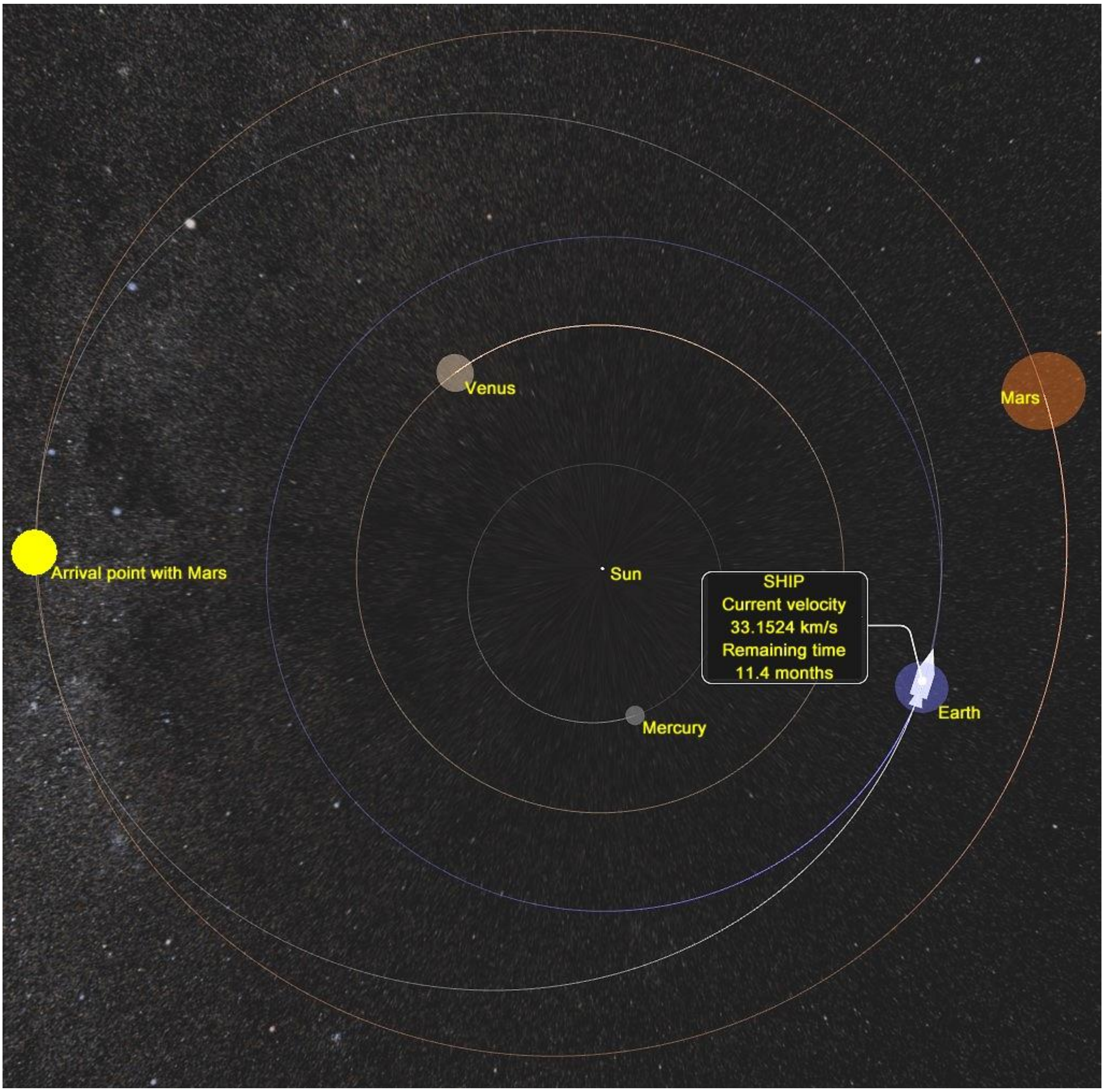

Figure 11: The next transfer orbit for the team if they used one to get to Mars. This option would mean a 14 month wait for the launch window to open. It would also take 11.4 months to arrive at Mars.

Coloured dots indicate location of planets on orbital paths, not the size of the planets.

Image courtesy of Planetary Transfer Calculator.