37. Jiki was keen to learn more, especially after another Jezero Crater map caught their eye (Figure 16 above). They were satisfied the feature marked A on the map was the inflow channel that supplied sediments to build the delta at B in Jezero Crater that Perseverance landed close to. However, they asked for more information about locations C, D, E and F.

Q: How did Sandra explain what Jiki was looking at? (1 mark)

a. Location E is the outflow channel that formed when Jezero Crater became too full and overflowed. Location F is in the eroded channel created as the outflow cut down through the crater wall. Location C marks another inflow channel and location D another deltaic sediment accumulation that formed in Jezero Crater lake as a result.
b. Location E is the outflow channel that formed when Jezero Crater became too full and overflowed. Location F is in the eroded channel created as the outflow cut down through the crater wall. Location C marks an impact crater and location D the impact ejecta from that event.
c. Location C is the outflow channel that formed when Jezero Crater became too full and overflowed. Location D is in the eroded channel created as the outflow cut down through the crater wall. Location E marks another outflow channel and location F the deltaic sediments left behind in the lake.
d. Location E is the outflow channel that formed when Jezero Crater became too full and overflowed. Location F is in the eroded channel created as the outflow cut down through the crater wall. Location C marks a tectonic fissure. Location D is a series of lava flows from that fissure.
e. Location C is the outflow channel that formed when Jezero Crater became too full and overflowed. Location D is in the eroded channel created as the outflow cut down through the crater wall. Location E marks another inflow channel and location F another deltaic sediment accumulation that formed in Jezero Crater lake as a result.
f. Location E marks a tectonic fissure. Location F is the channel followed by lava flowing from that fissure into Jezero Crater. Location C marks another inflow channel and location D another deltaic sediment accumulation that formed in Jezero Crater lake as a result.

38. Intrigued by the contour map, Jiki pointed at the small crater just to the west of location X (Figure 16 above). They wanted to know if that would be a good place to look for fossils.

Q: How did Sandra respond? (1 mark)

Sandra enlarged the image (Figure 17 below) to allow a closer inspection and said …

In this area, fossils are most likely to be found in sedimentary deposits, either lake sediments, lake shore sediments or deltaic sediments. Locations D and F (Figure 16) both sit on the likely maximum lake level after the Jezero Crater wall was breached. To the west of X, the small crater …

a. …sits just above this level and would never have filled with water from Lake Jezero.
b. …sits at the same level as Lake Jezero but the small crater's wall would have prevented water from spilling over into it.
c. ….rim sits just below the maximum height of Lake Jezero but Lake Jezero never filled to over flowing so the small crater could not have filled from Lake Jezero.
d. …rim sits just below the maximum height of Lake Jezero and would have filled with water when Lake Jezero was full to over flowing.
e. …would have got wet when Lake Jezero was full to over flowing but would never have filled with water because the rim on the other side of the small crater is too low to keep water in.
f. …post-dates formation of Jezero Crater and could never have filled with water from Lake Jezero.

Figure 17: Enlargement from Figure 16

39. Meanwhile geochemist, Ellie Mints, has been getting excited about the possibility of visiting the Jezero site to ground truth the much-debated association between olivine bearing deposits and carbonate bearing deposits – first detected using remote sensing satellites way back in 2019 and 2020. Palaeontologist, Traci Menandai, wasn't sure what all the fuss was about but said she remembered the mineral olivine had something to do with igneous rocks.

Q: What did mineralogist Rose Kortz, say to inform Traci about the association with igneous rocks to help explain Ellie's excitement? (1 mark)

a. Olivine is a silicate mineral that often forms when magma interacts with water.
b. Olivine is a silicate mineral that is commonly found in mafic and ultramafic igneous rocks.
c. Olivine is a silicate mineral that is commonly found in felsic igneous rocks.
d. Olivine is a silicate mineral that is only found in mafic volcanic rocks.
e. Olivine is a silicate mineral that is only found in felsic volcanic rocks.
f. Olivine is a silicate mineral that forms when magma interacts with atmospheric CO_2.

40. Traci recalled olivine had a chemical formula of X_2SiO_4, where X could be 100% Fe, 100% Mg or some ratio of Fe & Mg equal to 100%. She also remembered some fun facts about olivine and other minerals she shared with the team.

Q: What fun facts did mineralogist Rose confirm to be correct? (1 mark)

a. Mg-rich olivine is often a green-yellowish coloured mineral with a hardness the same as quartz, which can be green in rare circumstances.
b. Mg-rich olivine is often a green-yellowish coloured mineral with a hardness the same as corundum which is also green sometimes.
c. Mg-rich olivine is often a green-yellowish coloured mineral with a hardness the same as emerald, which is a green-coloured beryl.
d. Mg-rich olivine is often a green-yellowish coloured mineral with a hardness the same as fluorite, which comes in green varieties.
e. Mg-rich olivine is often a green-yellowish coloured mineral with a hardness the same as apatite, which is also green sometimes.
f. Mg-rich olivine is often a green-yellowish coloured mineral with a hardness the same as amazonite, which is a green-coloured feldspar.

41. Rose commented that the satellite data from Mars, and Jezero Crater in particular, was interesting because olivine is very susceptible to chemical alteration and/or weathering. To make this point she wrote these chemical equations on the screen in front of the team while noting that the mineral Forsterite (Fo) is a 100% Mg olivine and the mineral Fayalite (Fa) is a 100% Fe olivine. In olivine that contains both Mg,and Fe the ratio is expressed as a ratio of Fo to Fa such $Fo_{50}Fa_{50}$.

$2Mg_2SiO_4$ (forsterite) + $3H_2O$ = $Mg_3Si_2O_5(OH)_2$ (serpentine) + $Mg(OH)_2$ (brucite)

$2Mg_3Si_2O_5(OH)_4$ (serpentine) + $3CO_2$ = $Mg_3Si_4O_{10}(OH)_2$ (talc) + $3MgCO_3$ (magnesite) + $3H_2O$

Philip immediately added that the formation of the phyllosilicate serpentine from olivine and the formation of talc and magnesite from serpentine was a metamorphic process (serpentinisation) that typically happened when olivine rich rocks are subjected to a low-temperature metamorphic process involving heat and water.

Q: What did Philip say when Zoe asked him why that could occur since Mars has no plate tectonics? (1 mark)

a. Mars was and maybe still is volcanically active. Heat from subsurface magmatic intrusions could have driven water circulation through near surface olivine-rich rocks to serpentinise them.
b. Mars was and maybe still is volcanically active. Heat from runny lava flows could have driven water circulation through near-surface olivine-rich rocks to serpentinise them.
c. Mars was and maybe still is volcanically active. Heat from pyroclastic flows could have driven water circulation through near surface olivine-rich rocks to serpentinise them.
d. Mars was and maybe still is volcanically active. Heat from hot gases erupted into the atmosphere could have driven water circulation through near surface olivine-rich rocks to serpentinise them.
e. Mars was and maybe still is volcanically active. However, serpentisation could only happen to olivine-rich rocks in subduction zones, so Mars once had active plates.
f. Mars was and maybe still is volcanically active. However, because Mars is so cold serpentisation could only happen to olivine-rich rocks at the surface on really sunny days.

42. Zoe was surprised to hear Mars might still be volcanically active. She wasn't sure she wanted to ground truth in an area that could be blanketed by volcanic ash or lava while they were there. Andy reassured her that no surface activity has been detected and the most recent eruptive event found thus far is estimated to be 50,000 years old. He added this means volcanism could still occur but seismic monitors have not detected anything unusual in the Jezero Crater area recently, so the chances of an event occurring while they were there is low. She was reassured by this but had another question:

How did you figure out the age of the eruption if you don't have samples to radiometrically date?

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

Relative dating of lava flows from satellite images is possible because...

a. …the younger a lava flow is, the more impact craters it has.
b. …the older a lava flow is, the more impact craters it has.
c. …the younger a lava flow is, the more cinder cones it has.
d. …the older a lava flow is, the more cinder cones it has.
e. …the younger a lava flow is, the further it has flowed from its vent.
f. …the older a lava flow is, the further it has flowed from its vent.

43. Rose was still interested to hear more about the olivine they might find in Jezero Crater. She has a peridot brooch that came with a certificate that claimed it is 100% pure peridot and listed the following "chemical analysis":

> *Your beautiful peridot is pure olivine, one of nature's most amazing minerals! It contains iron (great for all blood disorders and circulation) and magnesium (great for muscle aches and postural problems) and your very special stone has a laboratory certified molecular mass of 153.31, the perfect number to ensure you have a completely balanced life when you wear this exquisitely crafted brooch.*

Q: Rose, a mineralogist, knew peridot is the gem-quality name for olivine. What else was she able to tell the team about her brooch? (1 mark)

a. The peridot is a fake because that molecular mass is impossible.
b. The peridot is $Fo_{90} – Fa_{10}$
c. The peridot is $Fo_{80} – Fa_{20}$
d. The peridot is $Fo_{70} – Fa_{30}$
e. The peridot is $Fo_{20} – Fa_{80}$
f. The peridot is $Fo_{10} – Fa_{90}$

44. Geochemist Ellie Mints commented that the brooch looked very nice but added that olivine has other more practical uses. To illustrate the point, she showed the team more chemical equations:

$$H_2O + CO_2 \rightarrow H_2CO_3$$
$$Mg_2SiO_4\,(s) + 4H_2CO_3(aq) \rightarrow 2Mg^{2+}\,(aq) + 4HCO_3^-(aq) + H_4SiO_4(aq)$$
$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$$

Q: What did Ellie say after presenting these equations? (1 mark)

All igneous eruptions inject CO_2 into the atmosphere over a short period of time, raising the level of CO_2 and contributing to greenhouse gas load in the atmosphere immediately after the eruption. However, due to the presence of olivine....

a. …rhyolitic pyroclastic eruptions weather quickly, reducing the CO2 in the atmosphere.
b. …weathering of basalts is associated with increased deposition of limestone over a longer time period and atmospheric cooling.
c. …weathering of andesites is associated with increased deposition of sandstone over a longer time period and atmospheric cooling.
d. …weathering of basalts is associated with increased deposition of limestone over a longer time period and atmospheric warming.
e. …weathering of andesites is associated with increased deposition of sandstone over a longer time period and atmospheric warming.
f. …rhyolitic pyroclastic eruptions weather quickly, increasing the CO2 in the atmosphere.

Traci, the palaeontologist, was feeling a bit left out of the conversation. She jokingly exclaimed,

Forget the minerals – show me the fossils!

They all laughed because they knew that definitive fossils have not been found on Mars, even though Roxanne did, rather famously, discover traces in some rocks at Gale Crater that might be indicative of biological activity. Jean Luc challenged them to tell him what they would need to find to be sure they had found a fossil.

Q: What claims did he make, that he knew were either true or false, to test them?
Circle the correct answers ➔ next page

45. Claim: Fossils can be found in low grade metamorphic rocks such as slate.

    True or False **(0.25 mark)**

46. An object can only be called a fossil if the organism that formed it is extinct.

    True or False **(0.25 mark)**

47. Some chemicals found in rocks can also be fossils.

    True or False **(0.25 mark)**

48. Fossils can be found in pyroclastic igneous rocks such as tuff.

    True or False **(0.25 mark)**

49. Traci shared their conversation with her friend back on Earth, Jeff Gnathostomes. Jeff is also a palaeontologist, but is perhaps more famous for his love of fish-flavoured ice-cream. He was keen to find fossils on Mars too and very happy they were exploring Jezero Crater. Perseverance didn't find fossils but with so many people exploring the outcrops while they ground-truth satellite maps and observations made by Perseverance he thought there was an excellent chance of finding fossils if life ever did exist there.

    Q: What did Jeff speculate evidence of life might look like, given he thinks multicellular life is unlikely to have evolved on Mars? (1 mark)

    a. Cross-bedding in siltstones.
    b. Horizontal planar laminations in mudstones.
    c. Deep polygonal cracks in mudstone, in-filled with siltstone.
    d. Undulating laminations in siltstones.
    e. Carbonate veins anastomosing through silicate rocks.
    f. Laminations in fine sandstone, truncated by erosional scours that are infilled with coarser sands.

50. Jeff was also keen to tell Traci and the rest of the team about his latest fossil find back on Earth. He said it was the most perfectly preserved specimen of a placoderm fish ever found. He said,

You will never guess where I found it!

Q: Traci did guess correctly but not by naming a location. What she said was, You found it in....
(1 mark)

a. …a Devonian sandstone concretion.
b. …a Triassic ash-fall deposit.
c. …a Cambrian mudstone concretion.
d. …an Ordovician limestone.
e. ….a Cretaceous chalk concretion.
f. …a Neogene amber bead.

51. Jeff bemoaned the fact that Traci was right, but didn't play the game fairly. However, in the spirit of her version of the game he challenged all the team members to nominate a favourite fossil (Table 4 below) and list them in a chronological order (oldest to youngest) that would reflect the stratigraphy if they were all found in different rock layers at the one location. Jean Luc, always the joker, said he didn't like fossils, but he did like chicken wings, especially deep fried, so he nominated the chicken! Andy said he didn't have a fossil he liked either, adding he thought an event that marked the extinction of trilobites might count in the absence of a fossil. Sandra said her favourite fossil evolved in the Precambrian and is still alive today so it can't represent any particular layer.

Q: What did the final, punny, biostratigraphy look like (complete the table on the next page)?
(1.5 marks)

Table 4

• **Andy – Trilobite extinction** ➔ Andy's Extinction Level Event	• Philip Light – **Tyrannosaurus** ➔ Philipaceous
• Ellie Mints – **Whales** ➔ Ellieogene	• Sandra Shore – **a long lived fossil** ➔ Sandarzoic
• Gabi Roe – **Archaeopteryx** ➔ Gabian	• Rose Kortz - **Redlichiida trilobite** ➔ Rosean
• Jean Luc – **Chicken (yum)** ➔ Picardian	• Traci Menandai – **Placoderm fish** ➔ Jeffian
• Jiki Nakamura – **Monograptus graptolite** ➔ Jikian	• Zoe Guāng – **Phyllograptus graptolite** ➔ Zoean

Complete the final biostratigraphy: Oldest unit at the bottom, progressing to the youngest unit at the top.

	Picardian	Youngest
		Oldest

52. Roxanne tried unsuccessfully to steer the meeting back to planning for their expedition. Everybody still wanted to talk about their favourite fossil or their favourite mineral so she decided to join in. She nominated the beautiful opalised marine shells found in Australia as both her favourite fossil and her favourite mineral! She pointed out her ear-rings were actually opalised gastropods. In her ear-rings the opal material ($SiO_2.nH_20$) has taken the shape of gastropods.

Q: What else did she say about her jewellery? (1 mark)

a. Opal is a carbonate mineral. In this jewellery it has replaced the shell carbonate after the animal has died but prior to burial.
b. Opal is a sulphide mineral. In this jewellery it has replaced the shell carbonate after the shell has been deeply buried in anoxic mud.
c. Opal is a hydrated silica mineral. In this jewellery it has in-filled a space left behind after a gastropod burrowed through a very thick mud.
d. Opal is a hydrated silica mineral. In this jewellery it has in-filled a space left behind after a gastropod shell was dissolved by groundwater.
e. Opal is a hydrated silica mineral. In this jewellery it has replaced the shell carbonate after the shell was buried in a fine-grained sandstone.

f. Opal is a silicate mineral. In this jewellery it has replaced the shell carbonate after the shell was buried in a mudstone.

53. Jiki said they loved opal too, especially opalised pineapples! Everyone was a bit surprised by this but they explained that the so-called pineapples were in fact originally clusters of a spikey carbonate mineral called Ikaite, not actual pineapples. They added that Ikaite was originally discovered growing in mud at the bottom of fjords in Scandinavia where the ocean bottom water temperature is always around 4ºC.

Q: What else did they say about their favourite mineral? (1 mark)

a. Fossils found in the same layers as opal pineapples indicate the fauna was adapted to living in warm conditions and died when it got too cold.
b. Fossils found in the same layers as opal pineapples indicate the fauna was adapted to living in cold conditions and died when it got too warm.
c. Fossils found in the same layers as opal pineapples indicate the fauna was adapted to living in warm conditions and died when they burrowed too deeply into the cold layer containing the Ikaite crystals.
d. Ikaite crystal clusters only record the temperature of the seawater, not the mud which is always much warmer. The fauna was adapted to living in mud at its normal temperature.
e. Fossils found in the same layers as opal pineapples indicate the fauna was adapted to living in cold conditions and lived in the mud alongside the Ikaite crystal clusters.
f. Ikaite crystal clusters are toxic to marine life.

54. Philip has always been a dinosaur fan. He commented that there are some very nice opalised dinosaur fossils found in association with the marine fossils in parts of Australia. Jiki, corrected him asking...

Don't you mean marine reptiles, like the plesiosaurs and ichthyosaurs?

No, Philip replied, *I mean actual bipedal dinosaurs.*

Q: How did Sandra help Philip explain this conundrum? (1 mark)

a. Crocodiles live on both land and in the ocean. It is no surprise their fossils sometimes turn up in marine deposits.
b. Marine reptiles hunted on shore and dragged their catches, including small dinosaurs, out to sea. Some carcasses would have sunk to the seafloor and be buried for sure.
c. Dinosaurs migrated, a bit like birds do today, but by swimming between continents. Some drowned making the ocean crossing. Their remains would sink to the seafloor and be buried.
d. Dinosaurs living close to the coast or estuaries sometimes died in the tidal zone and were washed out to sea. Their remains would sink to the seafloor and be buried.
e. Pterosaurs hunted over the oceans even though they lived on land. It is no surprise their fossils sometimes turn up in marine deposits.
f. All Mesozoic reptiles are dinosaurs.

55. Both Zoe and Jiki are fans of graptolites and each has a small collection. When they compared notes, they realised they also have an overlapping interest in index fossils.

Q: What did Jiki, the geochronologist, have to say about graptolites? (1 mark)

Graptolites make excellent index fossils because...

a. …they are abundant.
b. …they are morphologically complex and easy to identify.
c. …they evolved rapidly, with each species only present for a short period of time.
d. …answers A and B.
e. …answer B and C.
f. …answers A, B & C.

56. Zoe agreed with Jiki and added...

Based on what we know from the best fossils, graptolites were colonial, filter-feeding animals. Most lived in planktonic colonies, although some did live on the seafloor. This is why we find most of their fossils in... **(1 mark)**

a. …coastal shallow marine limestones.
b. …muddy lake sediments.
c. …subduction zones.
d. …open ocean conglomerates.
e. …deep sea mudstones.
f. …deltaic deposits.

57. Gabi chimed into the conversation, saying she loved the delicate bones and feather impressions seen in the Archaeopteryx fossils. She even saved up and purchased a small fossil from the limestone beds where the famous fossil was found.

Q: What else did she say about her favourite fossil? (1 mark)

a. Archaeopteryx is the ancestor of modern birds.
b. Modern birds and Archaeopteryx have a crocodile as a common ancestor.
c. Modern birds and Archaeopteryx have a pterosaur as a common ancestor.
d. Modern birds and Archaeopteryx have an ornithischian dinosaur as a common ancestor.
e. Modern birds and Archaeopteryx have a theropod dinosaur as a common ancestor.
f. Modern birds and Archaeopteryx are good examples of convergent evolution.

58. Roxanne tried one more time to get the team focussed on planning for Expedition Jezero!

Using the team's interest in fossils, she suggested one facet of the ground truthing could be a survey of carbonate-bearing units. This is because carbonate minerals observed from satellites might not all be derived from serpentinisation, some could be associated with shallow water algal mats, not unlike living stromatolites on Earth.

Q: What locations did the team decide should be the focus of their search for biogenic signatures? (1 mark)

a. All olivine bearing carbonates.
b. The crater rim at the elevation most likely to have been the Jezero Lake shoreline in the past.
c. All carbonates showing no olivine signatures.
d. The central area of the crater where water would have persisted for the longest, even as Mars dried out.
e. Areas mentioned in C and D.
f. Areas mentioned in B and C.

59. Jean Luc wanted to know why some Mars data showed some rock units contained olivine but no carbonate.

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

Olivine is a very reactive mineral both under hydrothermal conditions and during weathering. Hydrothermal conditions require liquid water to serpentinise the olivine, forming carbonates and phyllosilicates as a result. During weathering on Earth, olivine reacts with carbonic acid to liberate Fe^{2+}, Mg^{2+}, HCO^{3-} and H_4SiO_4 species that can then contribute to the formation of oxide, carbonate and silica minerals. This probably means this...

a. …olivine has erupted from Martian volcanoes in the absence of atmospheric CO_2.
b. …olivine has erupted from Martian volcanoes in the absence of liquid water on the surface.
c. …olivine has weathered out of carbonate-free volcanic rocks.
d. …olivine has weathered out of carbonate-free volcanic rocks.
e. …olivine-only magmas have erupted on Mars.
f. …olivine has formed in surface sediments through chemical reactions between quartz and calcite in the presence of water and CO_2.

Roxanne realised the time allocated to the Expedition Jezero planning meeting was just about up and that many meetings were required before they departed for Mars in a few months. To lighten up the meeting she decided to hold a quiz. She started off with some True / False questions.

The team did OK, now it's your turn.

60. Mars is one of the 3 rocky planets in the solar system.
    True or False **(0.25 mark)**

61. Olivine is harder than apatite..
    True or False **(0.25 mark)**

62. Mars is the only planet besides Earth with obvious volcanoes.
    True or False **(0.25 mark)**

63. Olivine is a silicate mineral with one perfect cleavage.
    True or False **(0.25 mark)**

64. Subduction zones are constructive plate margins.
    True or False **(0.25 mark)**

65. All planktonic species make good index fossils.
    True or False **(0.25 mark)**

66. Under metamorphic conditions of elevated temperature and pressure
    shale ==> slate ==> phyllite ==> schist ==> gneiss
    True or False **(0.25 mark)**

67. Conglomerate is a metamorphic rock.
    True or False **(0.25 mark)**

68. There is a subduction zone between Australia and Antarctica.
    True or False **(0.25 mark)**

69. Muscovite is a silicate mineral with one perfect cleavage.

True or False **(0.25 mark)**

70. Martian gravity is only 0.375g.

True or False **(0.25 mark)**

71. Martian ice caps have a higher albedo than Jezero Crater.

True or False **(0.25 mark)**

72. All land vertebrates evolved from a common fish-ancestor.

True or False **(0.25 mark)**

73. All meteorites are composed of iron and nickel.

True or False **(0.25 mark)**

74. Feldspar is the most common mineral group in the Earth's crust.

True or False **(0.25 mark)**

75. The Australian continent is part of the Pacific plate.

True or False **(0.25 mark)**

76. Every large tectonic plate has a convergent margin..

True or False **(0.25 mark)**

77. The island of Hawaii (the Big Island) is a hotspot located on a mid-ocean ridge.

True or False **(0.25 mark)**

78. A phenocryst is a large crystal formed in a high-grade metamorphic rock.

True or False **(0.25 mark)**

79. A porphyritic igneous rock exhibits large crystals amongst many other crystals of a distinctly smaller size.

True or False **(0.25 mark)**

80. Ammonites are extinct gastropods.

True or False **(0.25 mark)**

81. Earth's sunsets are red. Seen from space Earth is blue.

Martian sunsets are blue. Seen from space Mars is red.

True or False **(0.25 mark)**

As the Earth rose, they decided to call the meeting to a close and enjoy some rest and relaxation in Tycho Station.