AUSTRALIAN SCIENCE INNOVATIONS

School ID

Australian Science Olympiads

2018 AUSTRALIAN SCIENCE OLYMPIAD EXAM
EARTH & ENVIRONMENTAL SCIENCE – SECTIONS A & B

TO BE COMPLETED BY THE STUDENT. USE CAPITAL LETTERS.

Student Name: ……………………………………………………………………………..

Home Address: ……………………………………………………………………………

…………………………………………………………………… **Post Code:** ………………

Telephone: (……….) ……………………………… **Mobile:** ………………………………

E-Mail: ……………………………………………………… **Date of Birth:** ……/……/……

☐ **Male** ☐ **Female** ☐ **Unspecified** **Year 10** ☐ **Year 11** ☐ **Other:** ……………

Name of School: ……………………………………………………………… **State:** ………

To be eligible for selection for the Australian Science Olympiad Summer School, students must be able to hold an Australian passport by the time of team selection (March 2019).

The Australian Olympiad teams in Biology, Chemistry, Earth and Environmental Sciences and Physics will be selected from students participating in the respective summer schools.

Please note - students in Year 12 in 2018 are not eligible to attend the 2019 Australian Science Olympiad Summer School.

Data is collected for the sole purpose of offering eligible students a place at summer school. Visit www.asi.edu.au to view our privacy policy.

☐ **I am an Australian public high school student and would like to be considered for the Australian Science Olympiad Summer School Scholarship.**

Examiners Use Only:

2018 AUSTRALIAN SCIENCE OLYMPIAD EXAM
EARTH & ENVIRONMENTAL SCIENCE

Time Allowed
Reading Time: 15 minutes
Exam Time: 120 minutes

INSTRUCTIONS

- *Attempt ALL questions in ALL sections of this paper.*
- Permitted materials: Non-programmable, non-graphical calculator, pens, pencils, erasers and a ruler.
- Answer SECTION A on the Multiple Choice Answer Sheet provided**. Use a pencil.**
- Answer SECTION B in the spaces provided in this paper. Write in pen and use pencils only for annotating or making diagrams.
- Ensure that your diagrams are clear and labelled.
- All numerical answers must have correct units.
- Marks will not be deducted for incorrect answers.
- Rough working must be done only on page 61 of this booklet.
- Data that may be required for a question will be found on pages 3 to 5.
- Do NOT staple the multiple choice answer sheet to this booklet.

MARKS

SECTION A	60 multiple choice questions Each question worth one mark	60 marks
SECTION B	5 written answer questions Marks for each question are specified	20 marks

Total marks for the paper 80 marks

DATA & DEFINITIONS

Material supplied:

- Mohs hardness scale – page 3
- Universal constants - page 3
- Character disclaimer – page 3
- Periodic Table of the Elements –page 4
- International Chronostratigraphic Chart 2017/02 – page 5

Hardness	Example Materials
1	Talc
2	Gypsum
2.5	Fingernail, pure gold, silver, aluminum
3	Calcite, copper coin (penny)
4	Fluorite
4.5	Platinum, iron
5	Apatite
6	Orthoclase, titanium, spectrolite
6.5	Steel file, iron pyrite, glass, vitreous pure silica
7	Quartz, amethyst, citrine, agate
7.5	Garnet
8	Hardened steel, topaz, beryl, emerald, aquamarine
9	Corundum, ruby, sapphire
9.5	Carborundum
10	Diamond

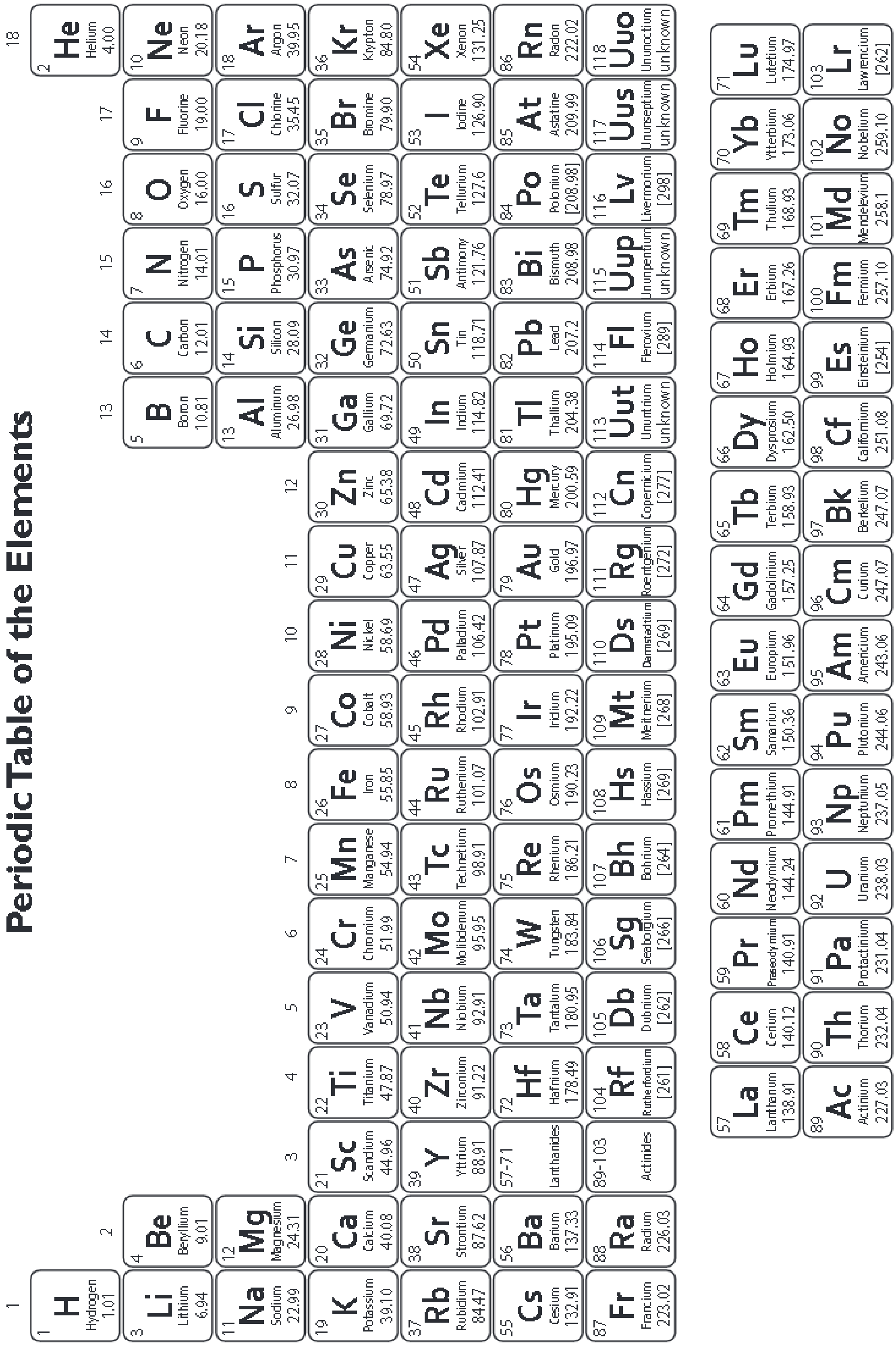
Mohs hardness scale

Physical constants

Constant	Symbol	Value
Universal gravitational constant	G	6.67×10^{-11} Nm^{2}kg^{-2}
Earth's gravitational acceleration	g	9.8 ms^{-2}
Earth mass	$M_{\oplus}$	5.98×10^{24} kg
Earth radius	$R_{\oplus}$	6.37×10^{6} m
$g_{planet} = G \times M_{planet} / R^2_{planet}$		

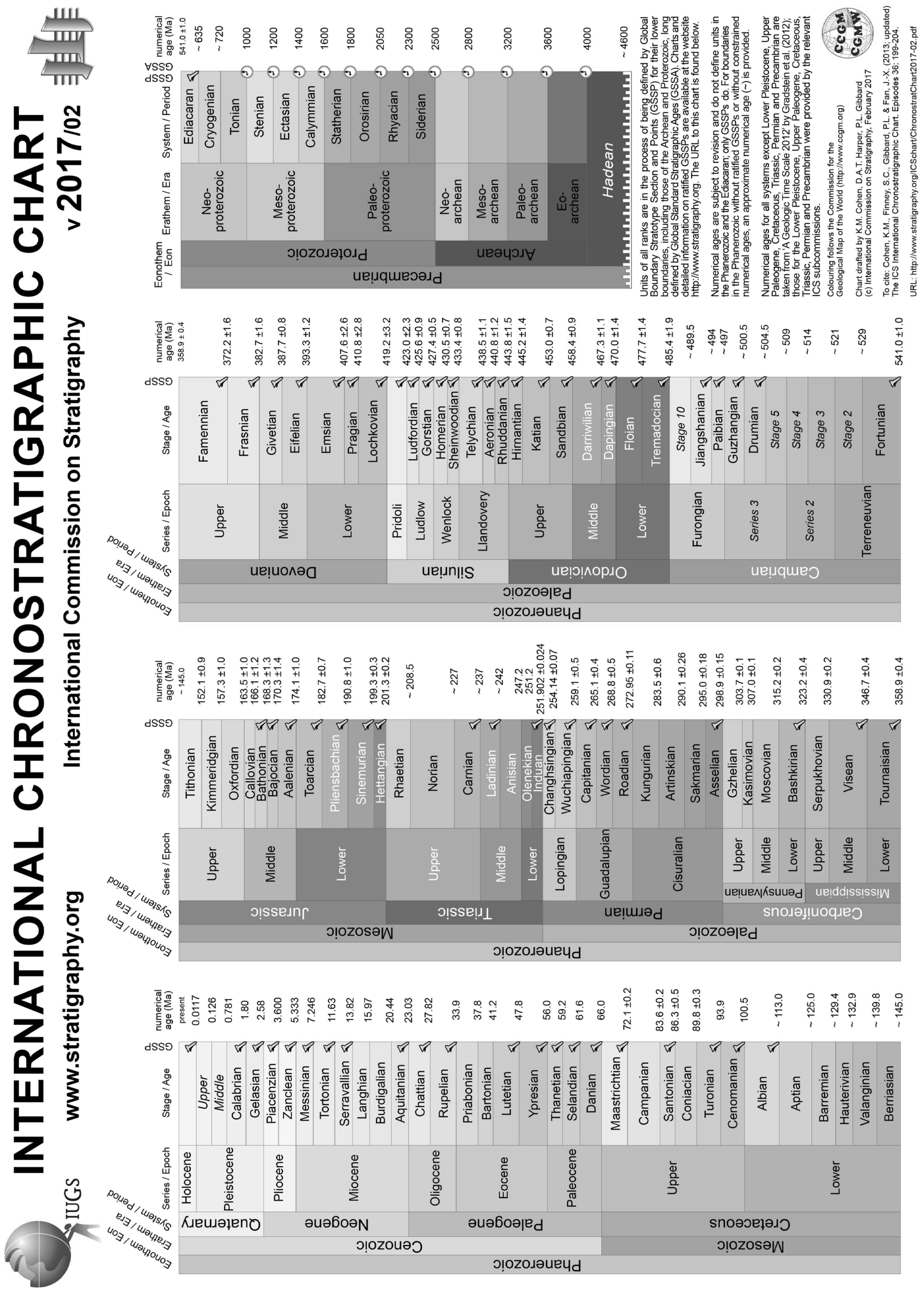
Characters

With the exception of John Lennon, the names of characters, locations and events portrayed in this paper are fictitious. John Lennon was a rock star and, unlike some other rock stars, was not an astronomer.



Periodic Table of the Elements courtesy of

http://sciencenotes.org/category/chemistry/periodic-table-chemistry/



International Chronostratigraphic Chart 2017/02 courtesy of

http://www.stratigraphy.org/index.php/ics-chart-timescale

Note: Numerical age (Ma) means the age in millions of years

SECTION A: MULTIPLE CHOICE
USE THE ANSWER SHEET PROVIDED

Imagine it is sometime later in the 21st century and humans are colonising the solar system and preparing to launch probes to other star systems …

The following information relates to questions 1, 2 and 3.

TRAPPIST-1 is a Red Dwarf star with a solar system of seven rocky planets located 39.6 light years from Australia in the constellation of Aquarius. The graph below presents known properties of the seven known TRAPPIST-1 exoplanets (labelled b through h).

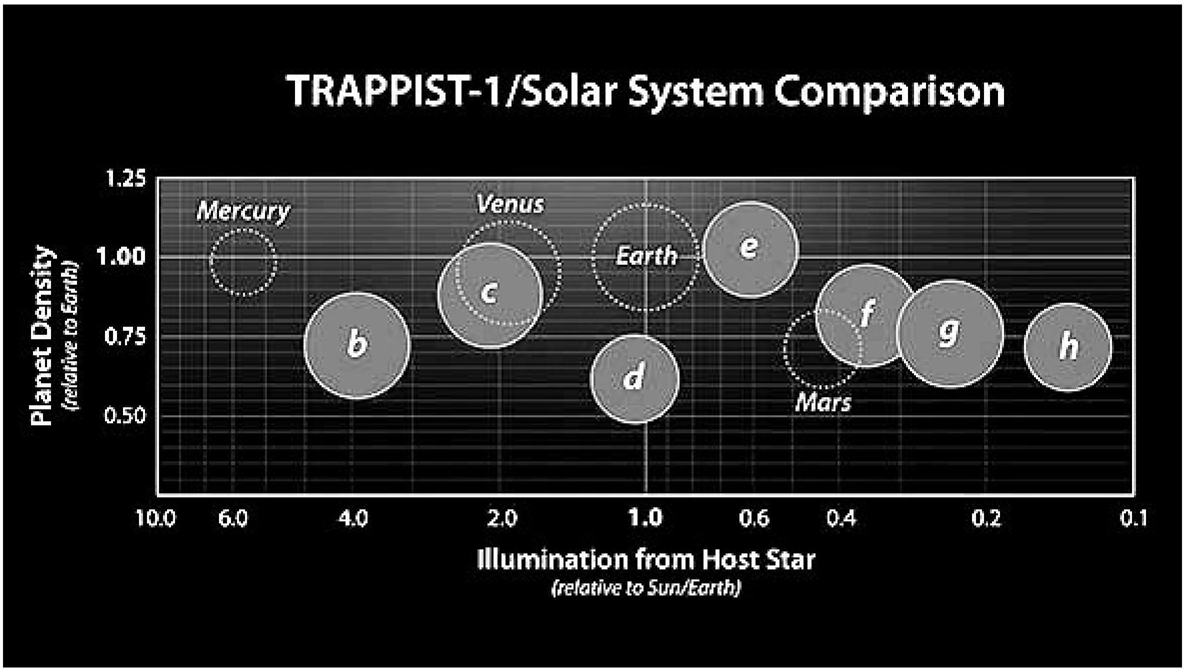


Figure 1: TRAPPIST-1 planet density and illumination relative to Earth's density and illumination. The relative sizes of the planets are indicated by the circles.

The horizontal axis shows the level of illumination that each planet receives from its host star. TRAPPIST-1 is only 9 percent the mass of the Sun, and its temperature is much cooler. However, because the TRAPPIST-1 planets orbit so closely to their star, they receive comparable levels of light and heat to Earth and its neighbouring planets. The vertical axis shows the densities of the planets. The relative sizes of the planets are indicated by the circles.

Planetary scientists, Cameron Brian and Holland Listerfield are working on Mars and have been preparing a presentation, making the case for a probe to be sent to the TRAPPIST-1 system.

Cameron and Holland were keen to emphasise the Earth-like nature of some of the planets using a table of data derived from observations made with the Hubble and James Webb telescopes. However, just as they were logging into the virtual holographic seminar auditorium, Cameron realised that one of their slides was missing some data (Table 1).

Planet	**b**	**c**	**d**	**e**	**f**	**g**	**h**
Orbital period (Earth days)	1.51	2.42	4.05	6.10	9.21	12.36	18.76
Distance to star (AU)	0.0115	0.0158	0.0223	0.0293	0.0385	0.0469	0.0619
Radius R_{Earth}	1.12	1.10	0.78	0.91	1.05	1.15	0.77
Mass M_{Earth}	1.02	1.16	0.30	0.77	0.93	1.15	0.33
Density ρ_{Earth}	0.73	0.88	0.62	1.02	0.82	0.76	0.72
Surface gravity (g)	?	?	?	?	?	?	?

Table 1: Presentation table with missing data in the gravity row. Radius, Mass and Density figures are relative to Earth's radius, mass and density.

1. Holland quickly filled in the table correctly using the other data in the table as the source for his calculations but Cameron thought he might have got his calculations wrong for two of the Earth-like planets, c & e. The correct values for c & e, to two decimal places, are:

    a. c = 0.96 e = 0.93
    b. c = 0.93 e = 0.96
    c. c = 0.96 e = 0.96
    d. c = 0.93 e = 0.93
    e. c = 0.63 e = 0.96
    f. c = 0.96 e = 0.63

2. Mars has a density of 0.71 and a radius of 0.53 relative to Earth. Like Mars, all seven planets orbiting TRAPPIST-1 are rocky but planet d has a lower density than Mars even though it is quite a bit bigger than it. One good explanation for planet d's lower density would be that …

   a. liquid water that has a lower density than ice and planet d is ideally located to host liquid water.
   b. water has a lower density than rock so surface oceans will be common on a planet with Earth-like illumination, lowering the density at the surface.
   c. water has a lower density than rock, suggesting planet d has a higher percentage of water in the planet than Mars and this lowers the average density.
   d. planet d has a water cycle just like Earth. This means lots of water is in the vapour phase which lowers the density of the planet.
   e. planet d has lots of volcanoes so a higher percentage of the rocks are full of gas bubbles (vesicles), making them less dense and lowering the density of the planet.
   f. there is no deuterium or tritium in the TRAPPIST solar system.

3. Holland proposes that planet g would be the best one to visit because it has the most real estate and he thinks developers might fund the project. Cameron agrees they need venture capital and approaches well known entrepreneur Jeff Gnathostomes to fund the project but he suggests planet e is a better prospect, appealing to Jeff's love of science rather than profit. His arguments included:

   a. Planet c is likely to be too cold for earthlings.
   b. Planet g is likely to be too hot for earthlings.
   c. Planet e is likely to have an ok temperature for earthlings.
   d. Planet e is certain to have Plate Tectonics.
   e. Both c and d.
   f. Planet e is certain to have Plate Tectonics and lots of ore bodies.

The following information relates to questions 4 and 5.

TRAPPIST-1 is a red dwarf star. Fifty of the nearest sixty stars are red dwarf stars but none are visible without a telescope. Proxima Centauri (Figure 2), the nearest star to the Sun, is a red dwarf. It is only ~4.25 light years away. The red super giant, Antares (Figure 2), is visible from Earth but is ~550 light years away. In astronomy, luminosity is a measure of the total electromagnetic energy emitted. The brightness of a star depends upon its luminosity and its distance from the observer while the colour of a main sequence star depends upon its temperature.

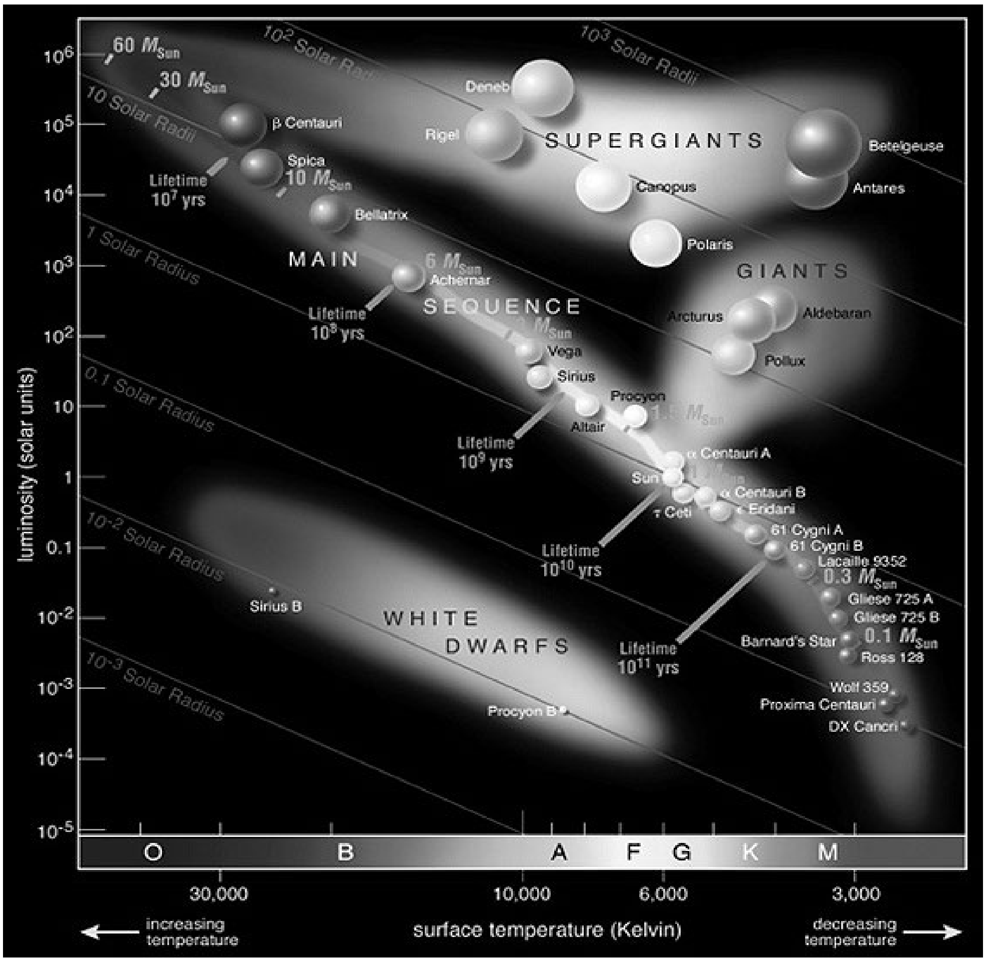


Figure 2. Source: http://en.wikipedia.org/wiki/File:Hertzsprung-Russel_StarData.png

4. Proxima Centauri is not visible from Earth without a telescope because:

   a. It is only visible in the infra-red.
   b. It is too hot to see without sunglasses.
   c. It is too dense to let light escape.
   d. Its brightness is too low.
   e. It is on the other side of the galaxy.
   f. Its density is too low for it to make enough light for it to be seen.

5. The Sun is a G-type main sequence star (Figure 2). Holland thinks other G-type stars should be targeted by exoplanet researchers if we plan to colonise the planets we find because:

   a. Planets around G-type stars will have oxygen and greenhouse gases because of the composition of the materials the system formed from.
   b. Planets around G-type stars will have Plate Tectonics because of the amount of silicon present in the primordial disc.
   c. G-type stars will have similar spectral characteristics to the Sun, making rocky planets around them more suitable for plant life from Earth.
   d. G-type stars will have more rocky exoplanets around them than other stars because the stars are burning silicon
   e. G-type stars have similar gravitational characteristics to the Sun, making rocky planets around them more suitable for life from Earth.
   f. All of the above.

6. In 2005 the red dwarf star Gliese 581 was found to host a planetary system. On October 9, 2008, the active SETI program sent a radio message to the planet Gliese 581c. It is expected this signal will arrive in April 2029 Earth-time. How far way is Gliese 581 and when will we receive a reply if a sentient species receives the message and answers immediately?

   a. 10.25 light years, April 2025
   b. 10.25 light years, October 2025
   c. 20.5 light years, April 2049
   d. 20.5 light years, October 2049
   e. 41 light years, October 2099
   f. 41 light years, April 2099

Meanwhile back on Earth …

A group of students, learning Earth Systems Science, are naturally curious to understand the interactions between the different systems – also known as spheres - and how evidence of those interactions are recorded.

The following information in Table 2 relates to questions 7 to 15

In Earth Systems Science each system is known as a sphere (Table 2):

Atmosphere	Gases surrounding the planet form the atmosphere
Biosphere	Things that are alive, were alive a short time ago or are recently derived from living materials are all constituents of the biosphere
Geosphere	The Geosphere is all the minerals and rocks forming the solid crust and the interior of the planet (mantle and core).
Hydrosphere	Water, in any state (solid, liquid, gas) or location forms the hydrosphere

Table 2: The spheres.

In class, Gabi Roe argued that rocks are boring because they are just part of the geosphere and don't have anything to do with the other spheres. In her defence she noted *lithos* is Greek for *rock*. In response, other students argued for or against Gabi's position.

- Roxanne Stone disagreed with Gabi. She contended sedimentary rocks are formed from particles laid down by water or transported by wind and this represents interactions between the hydrosphere, atmosphere and geosphere but not the biosphere which plays no part in rock formation.
- Andy Syght disagreed with Gabi and Roxanne. He argued that four spheres can contribute to forming rocks, using coal as his primary piece of evidence, stating the Earth is a closed system so everything must get recycled.
- Ashleigh Hammer acknowledged that four spheres can contribute to forming rocks. However, he noted that meteorites are evidence that a fifth sphere beyond Earth, the exosphere, has also contributed to the geosphere.
- Kimberly Piper disagreed with everybody, dismissing the conversation as silly and pedantic.
- Wade Beachly agreed with Gabi. However, he argued this is because rocks are chemically unreactive, not because of Greek-English semantics.

7. Amongst the passionate statements made in class only one was totally right. Who did their teacher, Ms Luciana Day, cite as completely correct?

   a. Andy
   b. Ashleigh
   c. Gabi
   d. Kimberly
   e. Roxanne
   f. Wade

The following information relates to questions 8, 9 and 10.

The student's teacher, Ms Luciana Day, noticed the passion with which the students attacked the subject and decided to extend their thinking further with several challenges that she hoped would shine a light on the subject. She provided the students with 25 words or phrases (Table 3):

Weathering	Slate	Sedimentation	Longshore drift	Pyroclastic flow
Hot spring	Chalk	Fossil wood	Basalt	Sink hole
Gneiss	Bituminous coal	Limestone	Tsunami	Sand dune
Clouds	Cyclone	Earthquake	Soil	Sandstone
Conglomerate	Erosion	Aquifer	Trilobite fossil	Oil

Table 3: Ms Day's list.

8. In Ms Day's first challenge, she wrote 6 examples, from the 25 provided in Table 3, on the board. They were:

Sink hole, Pyroclastic flow, Erosion, Hot spring, Weathering, Sedimentation

She said they were examples of interactions between the **geosphere** and the **hydrosphere** but one of them was actually wrong. She challenged the students to identify the incorrect one and substitute it with a correct word from the list. Only one student was correct, who was it?

a. Andy. He replaced Weathering with Longshore drift.
b. Ashleigh. She replaced Pyroclastic flow with Oil.
c. Gabi. She replaced Weathering with Aquifer.
d. Kimberly. He replaced Sedimentation with Oil.
e. Roxanne. She replaced Erosion with Aquifer.
f. Wade. He replaced Pyroclastic flow with Longshore drift.

9. In Ms Days' second challenge she wrote 6 more examples on the board:

Chalk, Fossil wood, Limestone, Basalt, Bituminous coal, Oil

She said they were examples of interactions between the **biosphere** and the **hydrosphere** but one of them was actually wrong. As a clue, she noted most oil was really the soft-tissue remains of aquatic organisms chemically processed by the geosphere, a kind of chemical fossil. She challenged the students to identify the incorrect word and substitute it with a correct word from the list (Table 3). Only one student was correct, who was it?

a. Andy. He replaced Oil with Trilobite fossil.
b. Ashleigh. She replaced Chalk with Conglomerate.
c. Gabi. She replaced Oil with Sandstone.
d. Kimberly. He replaced Basalt with Sandstone.
e. Roxanne. She replaced Basalt with Trilobite fossil.
f. Wade. He replaced Fossil wood with Gneiss.

10. In Ms Days' third challenge she wrote one phrase on the board:

Sand dune

She challenged the students to name the spheres that interact to form sand dunes on the down-wind side of an inland hypersaline lake which is too salty for macrofauna. Only one student was correct, who was it?

a. Andy. He listed atmosphere, hydrosphere and geosphere.
b. Ashleigh. She listed biosphere, hydrosphere and geosphere.
c. Gabi. She listed exosphere, hydrosphere and geosphere.
d. Kimberly. He listed hydrosphere and geosphere.
e. Roxanne. She listed atmosphere and geosphere.
f. Wade. He listed atmosphere, exosphere, hydrosphere and geosphere.

11. Ms Day extended her students further with another question:

Which of the topical issues listed below requires an understanding of the interactions between the atmosphere, biosphere, geosphere and hydrosphere?

They all chose the correct answer. Now it is your turn!

a. The greenhouse effect.
b. Acidification of the oceans.
c. Sea-level rise.
d. Carbon sequestration (removal of CO_2 from, and storage away from, the atmosphere).
e. Fracking (injecting high pressure fluids into subterranean rocks to force open fractures to extract hydrocarbons).
f. All of the above.

12. Roxanne wanted to know more. She asked Ms Day to shed more light on interactions between the geosphere and the exosphere. Which statement did Ms Day illuminate with her radiant voice?

a. Solar energy drives the hydrological cycle.
b. Glacial-interglacial fluctuations are due to changes in the Earth's axial tilt.
c. The formation of the Earth's Fe-Ni core happened during the early heavy bombardment.
d. Some mass extinction events were caused by meteorite impacts.
e. Comets seeded the Earth with water (and possibly life).
f. Ms Day used all the five examples above.

13. Wade had recently come back from a family holiday to Iceland where they went to see the amazing geological landscapes. However, while there he is pretty sure he also saw an interaction between the exosphere and the atmosphere. What phenomenon did he see?

a. A comet.
b. A meteorite impact crater.
c. The Coriolis effect.
d. The aurora (northern lights).
e. Volcanic gas fog, also known as Vog.
f. Fish flavoured ice cream (Jeff Gnathostomes' favourite).

14. Ms Day was keen for the students to understand how the spheres interact dynamically. She pointed out that global climate is responsive to many dynamic feedback loops (positive and negative) between and within spheres but not every process between or within spheres is involved in climate. Andy correctly identified one process not involved in Earth's climate system in a presentation he gave to the class. Which was it?

a. The formation of metamorphic rocks.
b. The formation of soil.
c. The formation of limestone.
d. The formation of glaciers.
e. The growth of forests.
f. The development of permafrost.

15. New students, Amber Gris and Jett Black, joined the class during the lessons on spheres. Ms Day challenged them to think of examples that demonstrate interactions between the hydrosphere and the atmosphere. Amber got full marks for writing …

a. Clouds.
b. Cyclones.
c. Acidification of the oceans
d. Clouds, cyclones and ocean acidification.
e. Clouds and evaporites (e,g, salt, gysum).
f. Clouds, cyclones, ocean acidification and evaporites.

The following information relates to questions 16 to 20.

The lessons on spheres led into lessons on chemical cycles within and between the spheres. Ms Day explained that the Water Cycle (Figure 3), the Carbon Cycle (Figure 4), the Phosphate Cycle (Figure 5) and the Nitrogen Cycle (Figure 6) are key cycles that explain many critical, complex processes on Earth.

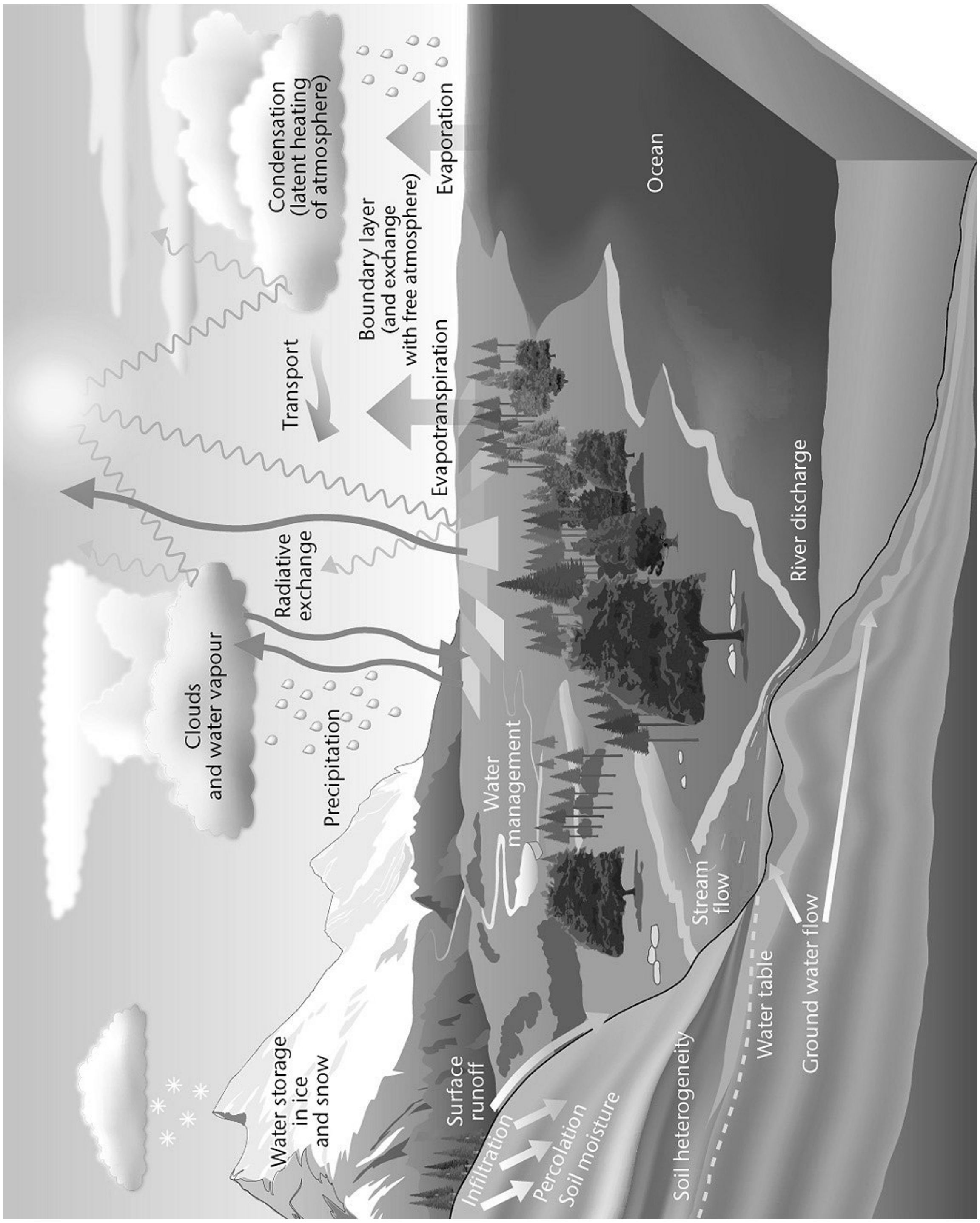


Figure 3: The water cycle. Modified from UK metoffice image https://tinyurl.com/y73g4993

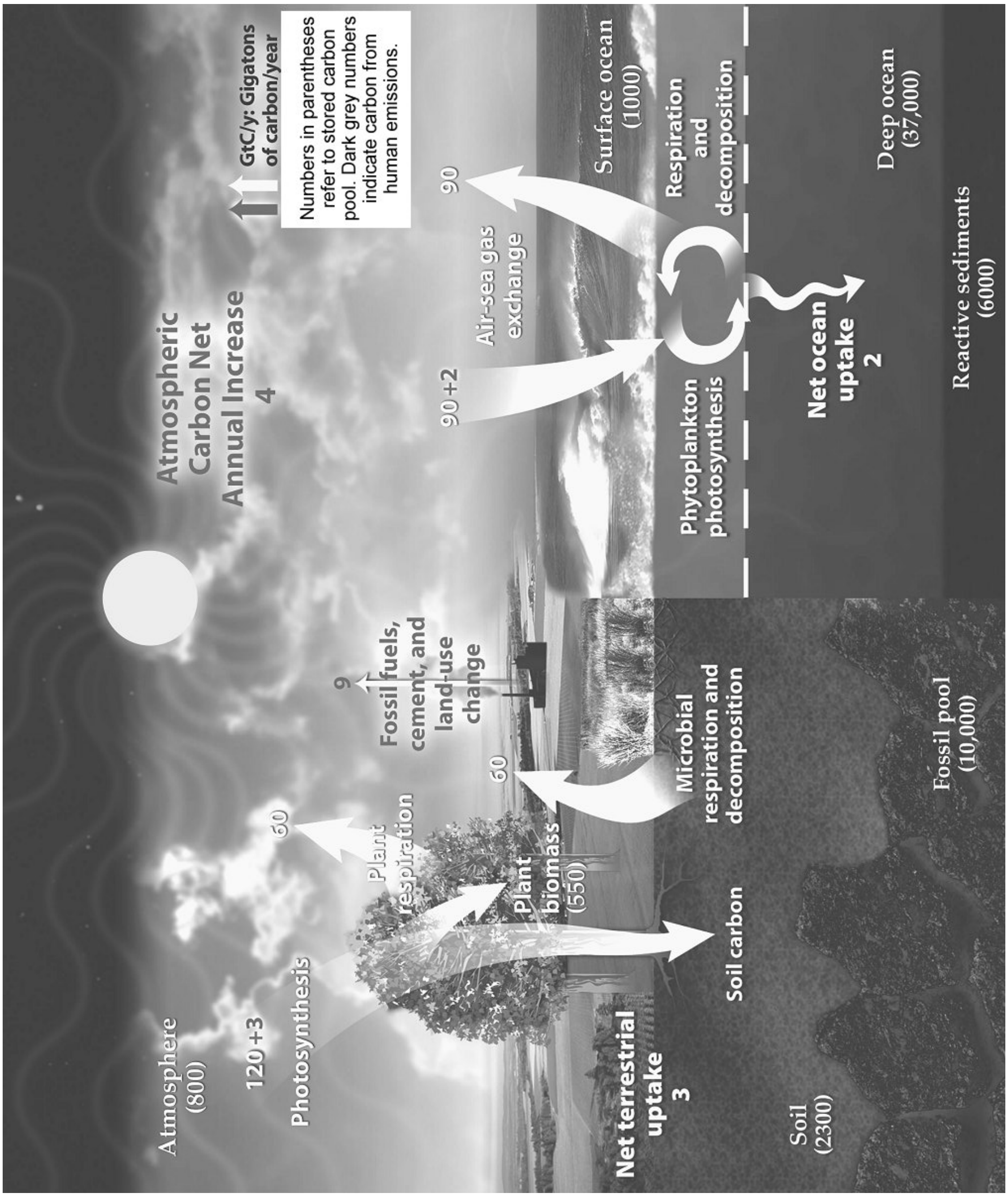


Figure 4: The carbon cycle (simplified). Modified from USGS image https://tinyurl.com/y6waqzxn

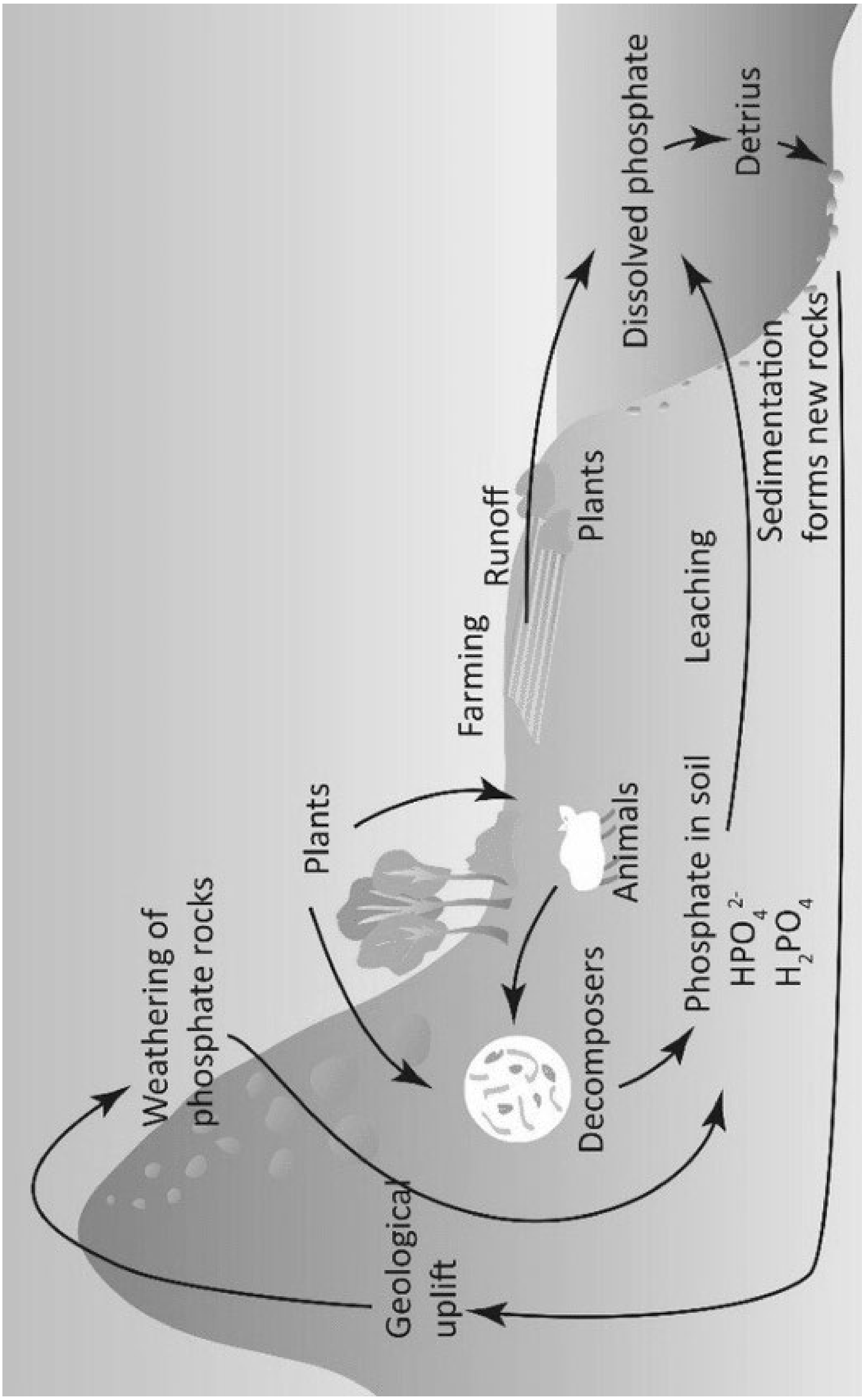


Figure 5: The phosphate cycle. Modified from https://tinyurl.com/ycflqnqo

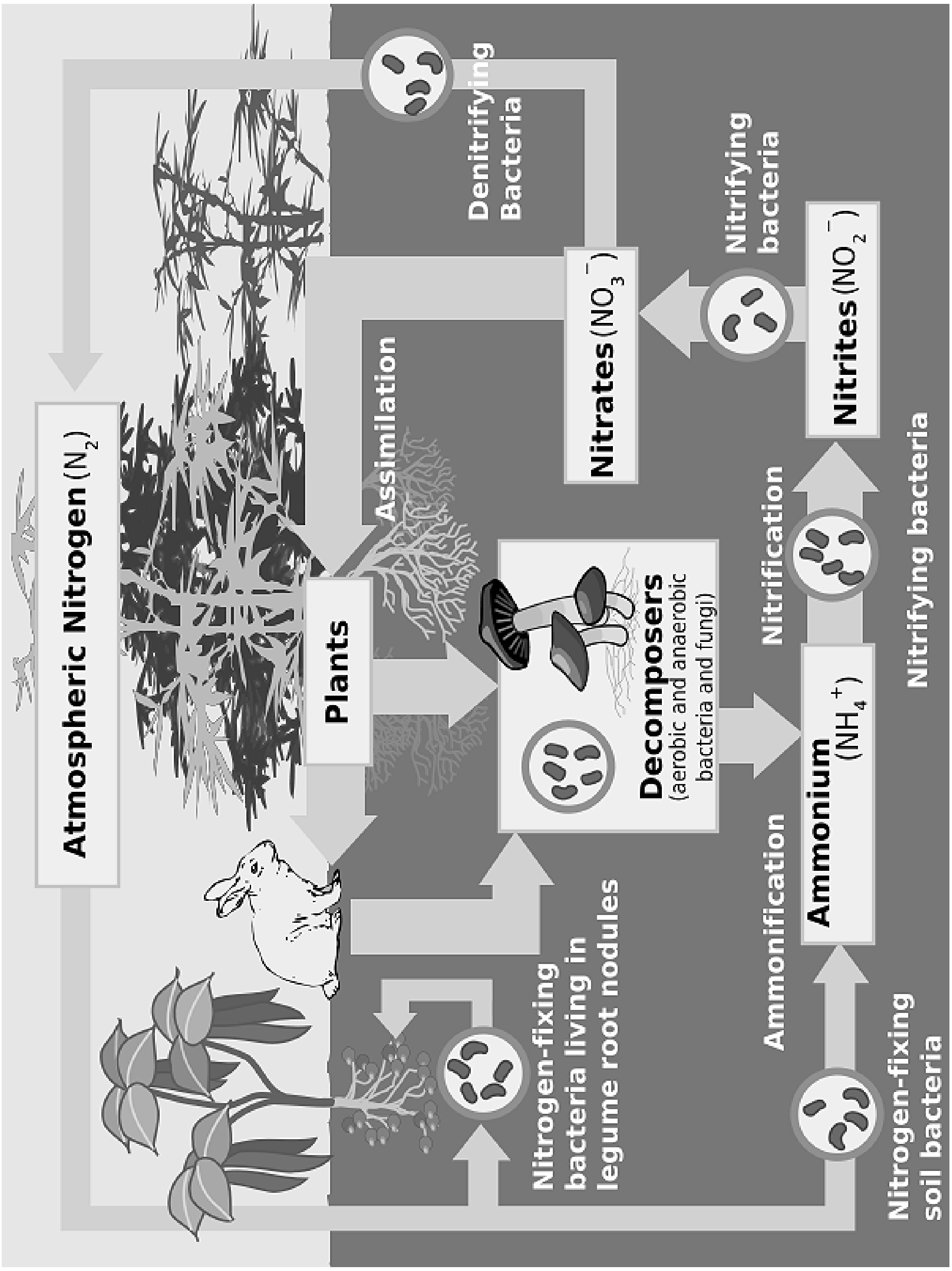


Figure 6: The nitrogen cycle. Modified from https://tinyurl.com/y84vykjw

16. Ms Day challenged the students to determine which of the spheres are involved in each of the four cycles (carbon, nitrogen, phosphate and water).

● Roxanne concluded that all for cycles involve the four spheres of the Earth, with all cycles driven by the incoming energy of the sun.
● Gabi disagreed with Roxanne. She argued that the Nitrogen Cycle doesn't involve any lithospheric processes.
● Wade mostly agreed with Gabi but added that the Phosphate Cycle doesn't involve any atmospheric processes.
● Andy disagreed with everyone. He argued that each cycle only involves interactions in three of the four spheres.
● Ashleigh argued that the Water Cycle doesn't involve any lithospheric processes, and that these are all fundamentally biological cycles.
● Kimberly was inclined to agree with Roxanne but also suggested this was another silly, pedantic conversation.

Amongst the passionate statements made in class only one was totally right. Who was it?

a. Andy
b. Ashleigh
c. Gabi
d. Kimberly
e. Roxanne
f. Wade

17. Kimberly did make one interesting observation. He drew the classes attention to the fact that there is one important variable, critical to the understanding of all four cycles, not explicitly represented in the cycle diagrams. What is it?

a. Time
b. Space
c. Gravity
d. Volume
e. Chemical reactivity
f. pH

18. In further discussions, Andy noted that there are critical geological processes missing from some of the cycle diagrams. What missing processes did he mention to the class?

   a. Soil formation for the Nitrogen Cycle.
   b. Sediment transport and weathering for the Water Cycle.
   c. Subduction of sediments for the Carbon Cycle.
   d. Volcanic eruptions for the Carbon Cycle
   e. He mentioned both a) and b) above.
   f. He mentioned b), c) and d) above.

19. New student Jett Black started a discussion with Roxanne about exoplanets after they both read about the TRAPPIST-1 planetary system in the New Scientist magazine. Jett wondered if the Carbon Cycle, the Phosphate Cycle, the Nitrogen Cycle and the Water Cycle also occurred on exoplanets. After a vigorous class discussion, Ms Day chose one student's response as the best. Which response did she choose?

   a. The response from both Ashleigh and Kimberly.
      They both thought exoplanets are too cold for the water cycle to work.
   b. Andy's response.
      He claimed all four cycles need life forms to work and only Earth has life so the cycles won't occur on exoplanets.
   c. The responses of Wade, Jett and Amber
      They argued all cycles will operate, given the right planetary composition and temperature, irrespective of life forms.
   d. Gabi's response. She agreed with Wade but added that some sort of geologic recycling process, similar to plate tectonics, must be present for the cycles to work.
   e. Roxanne's response. She accepted the arguments of Wade and Gabi but pointed out that the Earth's Nitrogen Cycle cannot work without life. She also noted a nitrogen cycle without life may be possible given the right chemical and physical conditions on a planet.
   f. No response was acceptable. Ms Day was very dark about that.

The following information relates to questions 21 to 25

Recent events in Hawaii, where new lava flows have over-run suburbs, forests, lakes and bays, naturally saw the students discussing volcanoes with Ms Day. She advised them to revise their notes on the structure of the Earth and gave them a diagram (Figure 7) to remind them.

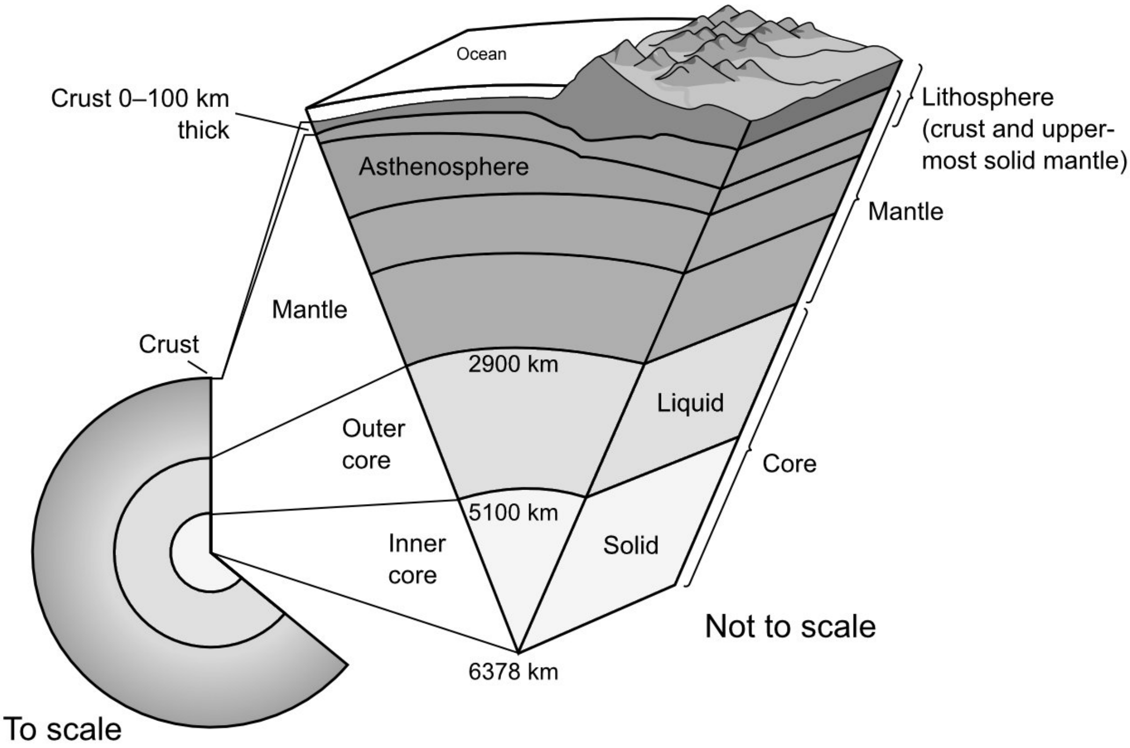


Figure 7: Inside the Earth. Modified from https://pubs.usgs.gov/gip/dynamic/inside.html

In revising the structure of the Earth they also began learning more about **Plate Tectonics**, another important recycling mechanism on Earth. The Earth's outer most rock layer, the **crust**, is rigid. Below the crust is the **mantle**. It is chemically and physically a bit different to most of the rocks in the crust. However, the top most part of the mantle is also rigid. This part of the mantle and the crust form a rigid outer layer called the **lithosphere**. Pieces of the lithosphere, known as **tectonic plates**, are moving relative to each other and the underlying mantle. The mantle immediately under the lithosphere is not as rigid and is known as the asthenosphere.

The relative motions of the tectonic plates gives rise to seismic activity, creates most volcanoes and recycles the lithosphere over millions of years. One method of determining how fast and in what direction the plates move is to determine the age of a related chain of volcanoes that form as a plate moves over a relatively fixed "hot spot", which burns through the overriding crust forming magma.

Ms Day gave the students a map of Snake River Plain, an area next to Yellowstone National Park in the United States of America (Figure 8).

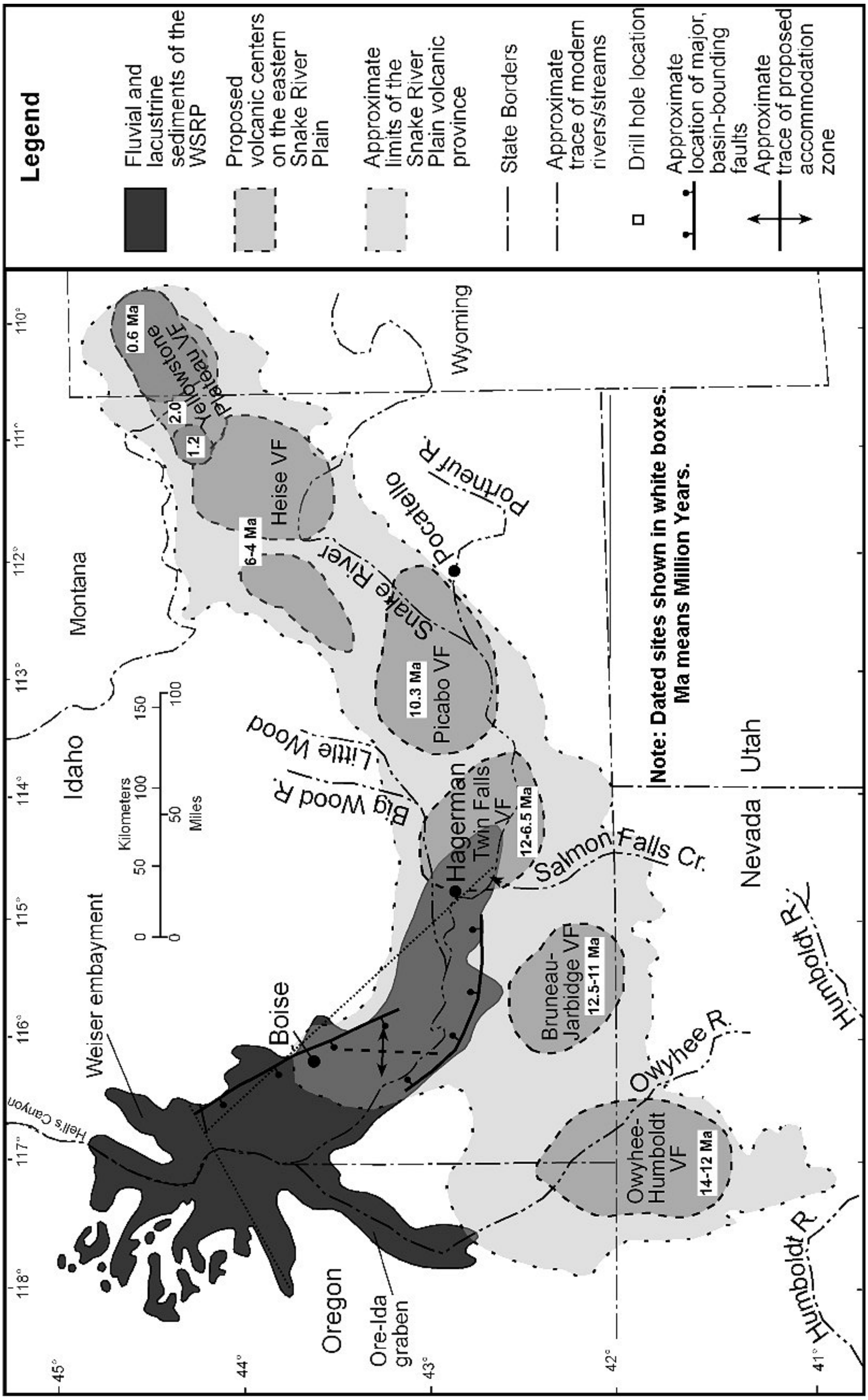


Figure 8: Eruption centres on eastern Snake River Plain. The crustal thickness here is ~45km.

Modified from image at http://tinyurl.com/y7qrpjkn as simplified by *Link and Phoenix (1996)*, from *Pierce and Morgan (1992)*.

20. Andy examined the Snake River Plain map (Figure 8). He was excited to discover he could tell what direction the North American plate was moving over the last 14 million years. What direction did he decide on?

a. North
b. South
c. Northeast
d. Southwest
e. East
f. West

21. Ashleigh was even more excited when she worked out approximately how fast the North American plate was moving. What approximate velocity did she calculate?

a. 1 mm/year
b. 1 cm/year
c. 10 cm/year
d. 1 m/year
e. 10 m/year
f. Her excitement was short lived when she realised the velocity cannot be quantified from the information on the map.

The following information and map relates to questions 22 to 25

Gabi and Wade remembered they discussed a similar hot spot chain, forming the Hawaiian Islands, in year 9. Going back through their science notes, which of course they kept, they found a map of the Hawaiian-Emperor Seamount chain (Figure 9).

22. Using the Hawaiian-Emperor Seamount chain map (Figure 9), what direction did they decide the Pacific Plate has been travelling for the past 45 million years?

a. North
b. South
c. Northwest
d. Southwest
e. Northeast
f. Southeast

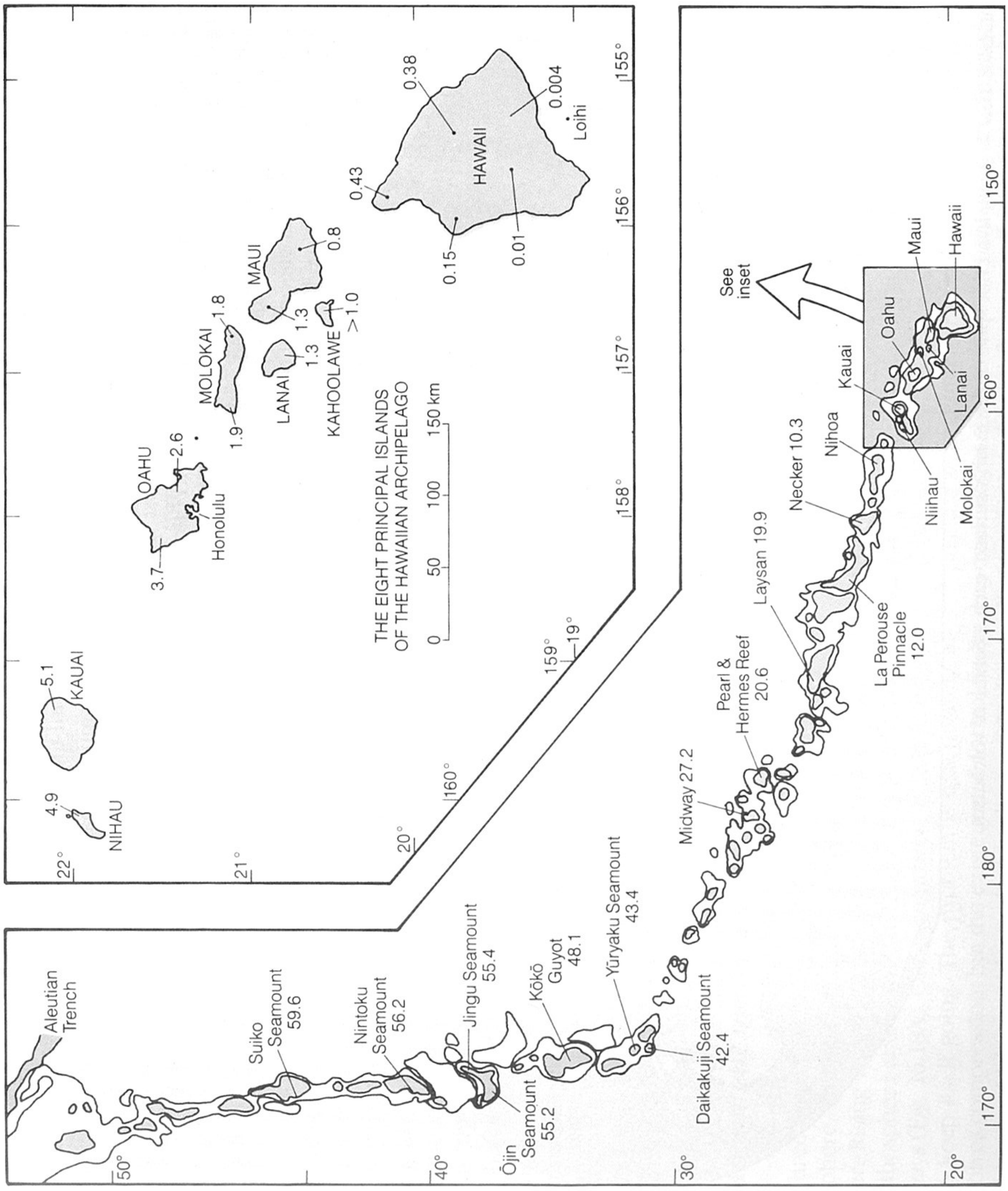


Figure 9: Hawaiian-Emperor Seamount chain in the central Pacific Ocean with radiometric dates (in millions of years). Crustal thickness is approximately 10 km. Modified from Skinner & Porter, The Dynamic Earth 2nd Ed 1992.

23. Using the Hawaiian-Emperor Seamount chain map (Figure 9), what direction did they decide the Pacific Plate has been travelling prior to 45 million years ago?

a. North
b. South
c. Northwest
d. Southwest
e. Northeast
f. Southeast

24. The obvious bend in the seamount chain puzzled them but Ms Day had the answer. She arranged a special visit from two geoscientists, Philip Light and Tracee LeMents. They discussed recent developments in plate tectonic theory based on ocean drilling programs and improved geophysical modelling with the students. It came out that there are two possible explanations for the bend in the seamount chain. What are they?

a. A crumpling of the Earth's surface due to shrinking **OR** stretching due to planetary expansion.
b. A massive earthquake rotating the older part of the plate clockwise **OR** a change in plate movement direction relative to a fixed hotspot.
c. Hotspot motion relative to the overriding plate **OR** a massive earthquake rotating the older part of the plate clockwise.
d. Hotspot motion relative to the overriding plate **OR** a change in plate movement direction relative to a fixed hotspot.
e. A crumpling of the Earth's surface due to shrinking **OR** hotspot motion relative to the overriding plate.
f. Stretching due to planetary expansion **OR** a change in plate movement direction relative to a fixed hotspot.

25. Tracee LeMents told the students she had been to Hawaii collecting samples for her geochemistry studies. She said collecting samples from the flowing lava on the Big Island, labelled Hawaii on the map (Figure 9), was exciting but she was even more excited to have collected samples from the next eruption point in the chain. What location did she visit and what did she use to get there?

a. 19.3° N, 155.9° W - Submarine
b. 19.3° N, 155.4° W - Helicopter
c. 28.1° N, 177.2° W - Navy destroyer
d. 33.0° N, 172.0° E - Helicopter
e. 33.0° N, 170.0° E - Submarine
f. 18.9° N, 155.3° W - Submarine

The following information and map relates to questions 26 to 28

Gabi was really inspired about hotspot volcanism after the talk and went home to find out more about the current activity in Hawaii and Yellowstone, which have both been in the news a lot. She discovered that while both famous volcanic centres formed due to mantle plume activity, their eruption styles are very different. Hawaii has frequent (annual to decadal) and long-lived (years to decades) outpourings of thin lava flows that travel kilometres from their vents, whereas eruptions from Yellowstone are infrequent (thousands to tens of thousands apart) and tend to be the most explosive variety, spewing ash and volatiles into the stratosphere and burying hundreds of square kilometres around the eruption site under a thick blanket of ash (up to 50 metres thick!).

She also learned about two processes by which magmas evolve from ultramafic mantle material into the variety of lava compositions seen at the surface: **fractional crystallisation** and **partial melting**. Both of these processes drive magma composition progressively further to the right on the diagram below (Figure 10) and require additional time and space in the crust to proceed. She also found that dissolved gas content increases with Silica content.

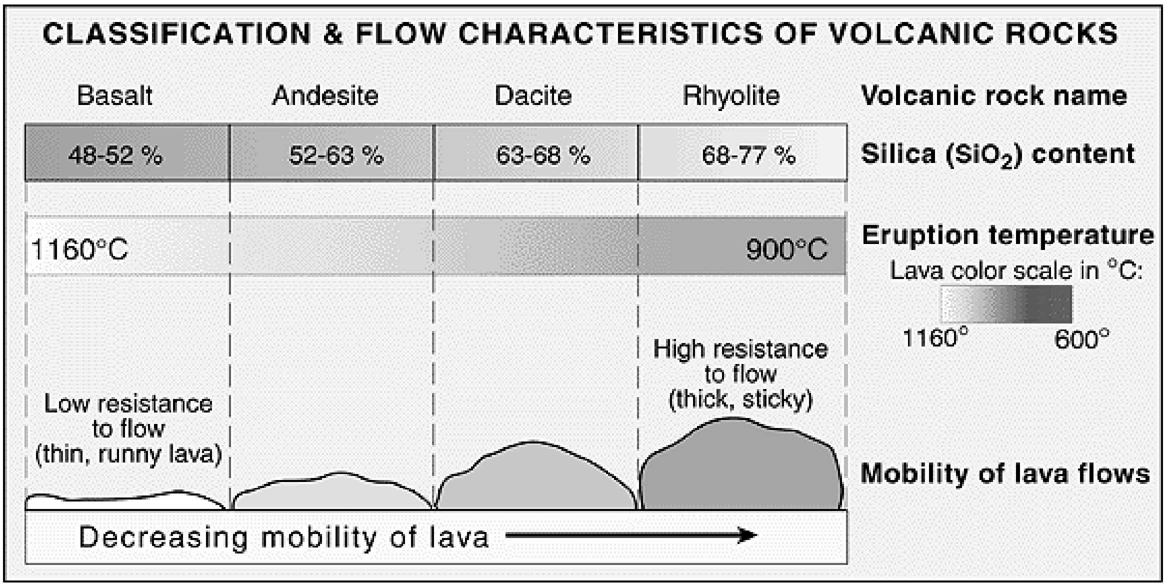


Figure 10: Lava flow properties as a function of composition.
Modified from USGS image by J. Johnson. https://tinyurl.com/ydzx25nm

26. Using this diagram (Figure 10) Gabi thought she understood why Hawaii and Yellowstone have different eruption styles. She wrote her answer down and sent it to Tracey LeMents and Philip Light for comment. They both congratulated on her on being correct. Her explanation was:

    a. Differences in magma composition.
    b. Differences in gas content.
    c. Differences in crustal thickness and crustal composition.
    d. Differences in magma composition and gas content.
    e. Differences in magma composition, crustal thickness and crustal composition.
    f. Differences in magma composition, gas content, crustal thickness and crustal composition.

27. Gabi showed the diagram (Figure 10) to others in her class. *Finally - I get it!* said Amber. Ms Day tested her with the question: What is the most likely lava composition at Hawaii? What was her (correct) answer?

    a. Basalt
    b. Basaltic andesite*
    c. Andesite
    d. Dacite
    e. Rhyodacite*
    f. Rhyolite

*NB: these names reflect rocks compositionally between the rock types their names join.

28. Jett wanted to be tested too. Ms Day asked him: What is the most likely composition of eruptive products from Yellowstone? What was his (correct) answer?

    a. Basalt
    b. Basaltic andesite*
    c. Andesite
    d. Dacite
    e. Rhyodacite*
    f. Rhyolite

The following information and map relates to questions 29 and 30

Andy was also inspired to learn more about volcanoes after Gabi told him about her interesting finds. He discovered that some volcanic eruptions are only dangerous to surrounding communities, whereas others are also of great risk to air traffic much further afield. He found a diagram (Figure 11) of the ash dispersion patterns of several noteworthy eruptions in Alaska, including the largest eruption of the 20th Century from Novarupta in Katmai National Park. Ash from these eruptions was ejected with sufficient vent exit velocity to reach the Stratosphere.

Figure 11: The 1912 Novarupta ash fall compared with ash fall dispersion for eruptions from Augistine 1976, Redoubt 1990 and Spur 1992. Modified from USGS Fact Sheet 075-98 (https://pubs.usgs.gov/fs/fs075-98/fs075-98.pdf).

Andy commented that he'd read about air traffic being diverted around volcanic ash clouds because the ash can cause serious damage or even cause engine failure.

29. Ms Day asked Andy to point out what variables control whether a volcanic eruption will create a hazard for air traffic He didn't quite get it right but what should he have said?

The variables are …

a. geographic location, local population density and meteorological conditions at time of eruption (e.g. prevailing wind direction, wind speed, temperature, precipitation).
b. magma composition, gas content, and geographic location.
c. local population density, meteorological conditions at time of eruption (e.g. prevailing wind direction, wind speed, temperature, precipitation) and gas content.
d. geographic location, local population density and magma composition.
e. magma composition, gas content, geographic location and meteorological conditions at time of eruption (e.g. prevailing wind direction, wind speed, temperature, precipitation)
f. geographic location, local population density, meteorological conditions at time of eruption (e.g. prevailing wind direction, wind speed, temperature, precipitation) and magma composition.

30. Andy was quick to add that he did know the prevailing wind direction (from what direction it comes) in southern Alaska? He correctly stated it comes from the …

a. North
b. South
c. East
d. West
e. Northwest
f. Southeast

The following information and map relates to questions 31 to 35

In order to further understand the threats to aircraft from volcanic ash Andy did some research. He discovered there are several types of threats. Visibility and instrument functionality are compromised but flying through volcanic ash can cause hundreds of thousands of dollars damage to the aircraft even if engine failure does not occur.

Andy's curiosity led him to review the composition of different magmas and the minerals that crystallise from these magmas. He discovered that different magmas produce rocks with different mineral in them (Figure 12).

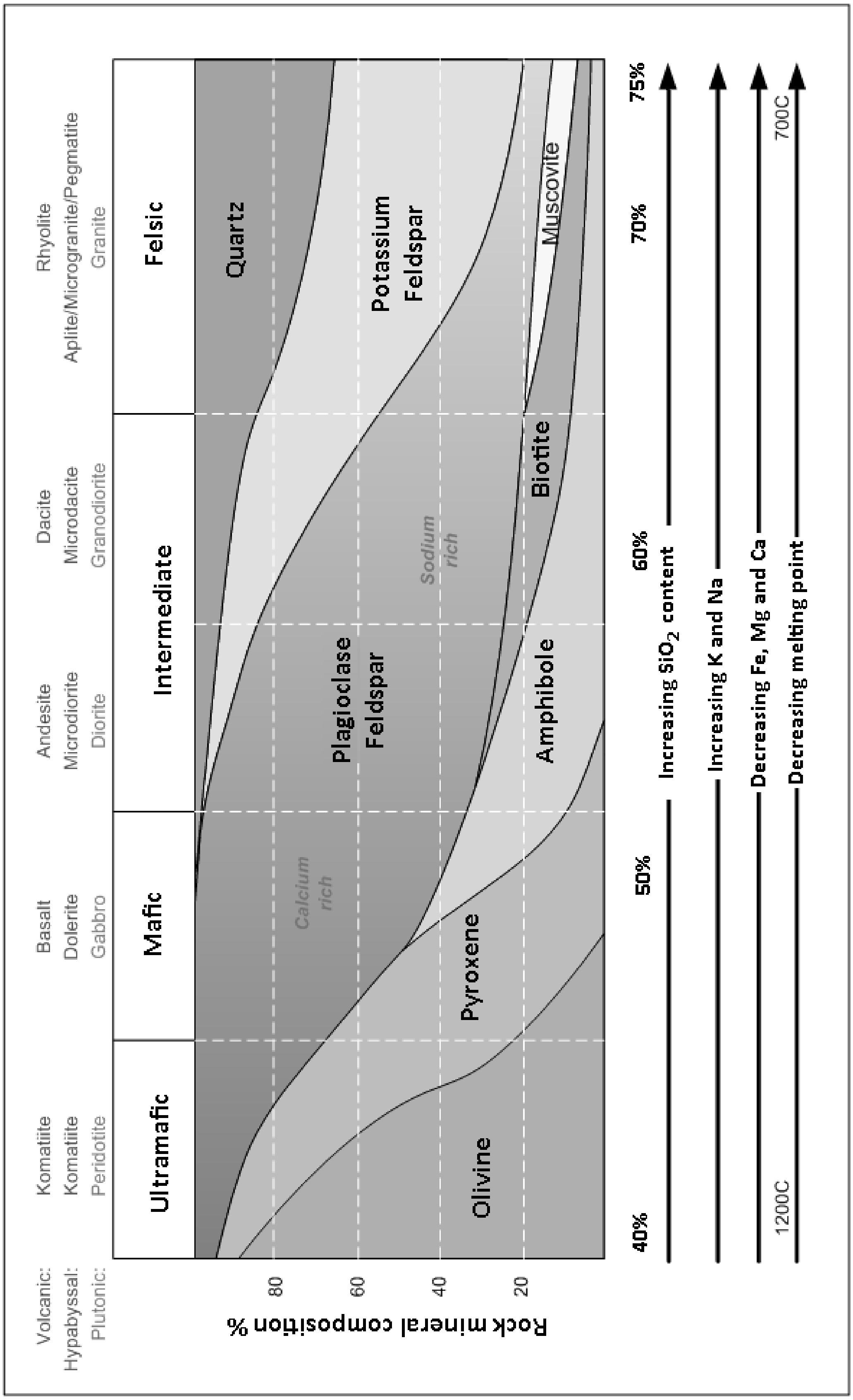


Figure 12: Igneous rock classification by silica content and minerals present

Andy also discovered different minerals have different hardnesses on the Mohs Scale (Table 4)

Mineral	Composition	Hardness (Mohs)	Density (g/cm^3)
Olivine	$(Mg,Fe)_2SiO_4$	6.5	3.4
Pyroxene	$(Mg,Fe)SiO_3$	6	3.3
Amphibole	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	5-6	3.2
Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	2.5-3	3
Muscovite	$KAlSi_3O_{10}(OH)_2$	2-2.5	2.8
Plagioclase	$(CaAl_2)Si_2O_8$ – $(NaAl)Si_3O_8$	6	2.7
Potassium Feldspar	$KAlSi_3O_8$	6	2.6
Quartz	SiO_2	7	2.7

Table 4: Hardness of common minerals found in igneous rocks.

and that industrial materials can also be quantified for hardness in the same way (Table 5).

Industrial material	Hardness (Mohs)
Talc	1
Asphalt	1.3
Tin, Lead, Graphite	1.5
Calcium, Cadmium, Sulphur	2
Gold, Silver, Aluminium	2.5-3.0
Copper, Aluminium alloys	3
Plexiglass	3-4
Iron, Nickel	4
Platinum, Steel, Carbon composites	4.0-4.5
Cobalt, Obsidian	5
Glass, Stainless steel, Pumice	5.5-6.0
Titanium	6.0
Fused quartz, Pyrite	6-7
Hardened steel	7.5-8.0
Tungsten carbide	9.0-9.5
Diamond	10

Table 5: Hardness of industrial materials.

Armed with this information Andy applied it to a materials map of a modern aircraft (Figure 13) to see what materials on the aircraft might be susceptible to damage by volcanic ash.

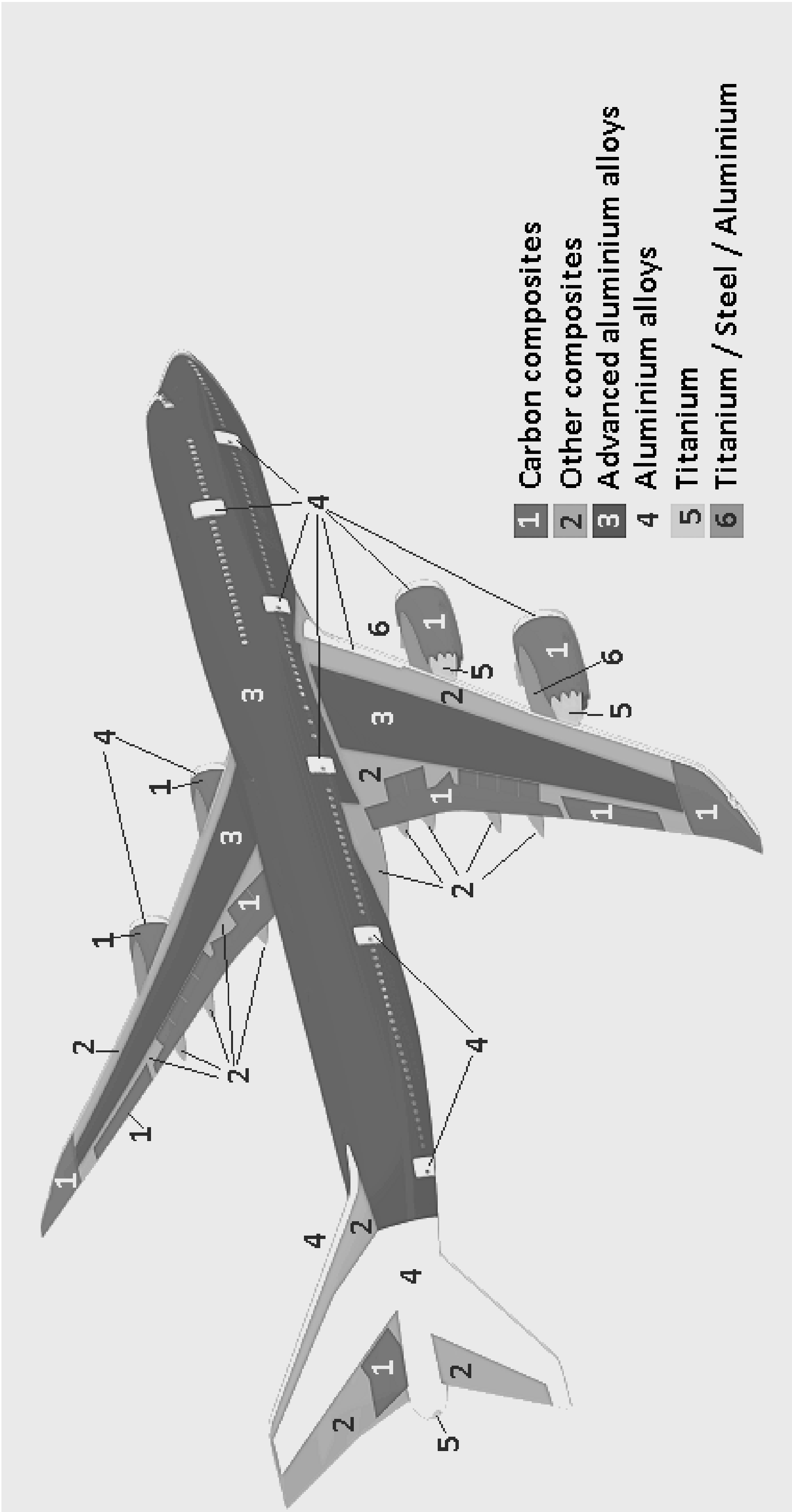


Figure 13: Composition of one type of modern aircraft. Modified from http://tinyurl.com/y9tcnhg9

31. Based on the aircraft design Andy concluded that …

a. only the tail, doors and the fronts of the wings are susceptible to abrasion from ash particles.
b. only the wings and the body are susceptible to abrasion from ash particles.
c. only the rears of the engines are susceptible to abrasion from ash particles.
d. only the fronts of the engines are susceptible to abrasion from ash particles.
e. the entire aircraft except the rears of the engines is susceptible to abrasion from ash particles.
f. the entire aircraft is susceptible to abrasion from ash particles.

32. Andy also concluded that, at high concentrations, the mineral that will inflict the most damage to an aircraft flying through an ash plume is …

a. Quartz
b. Potassium Feldspar
c. Muscovite
d. Biotite
e. Amphibole
f. Pyroxene

Andy shared his discoveries with the class. Roxanne quickly realised the interior of jet engines would also suffer damage but not only from abrasion. She knew from her aviation course that jet engines operate at approximately 1000 °C, with the hottest temperatures and highest pressures in the centre of the engine, with pressure quickly dropping after air passes through the compressor (Figure 14).

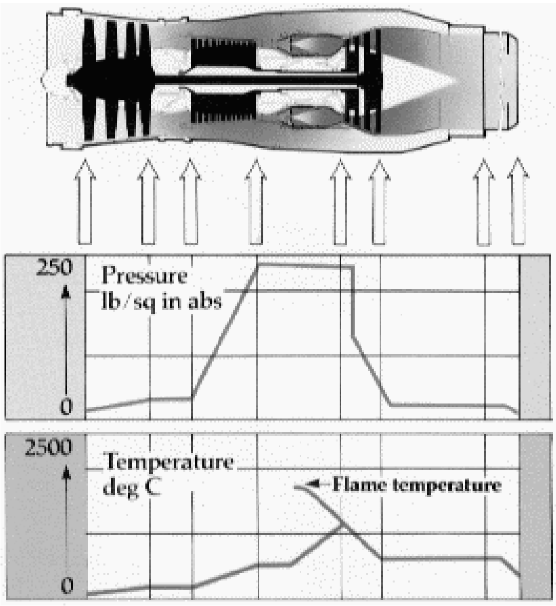


Figure 14: Visualisation of the air temperature and pressure during the operation of a turbojet engine. Modified from https://tinyurl.com/yax4cc85

Gabi pointed out that mineral melting temperatures increase with decreasing pressure and this might have implications for aircraft flying through an ash cloud.

33. Ms Day posed another question: Ash must contain *at least* how much SiO_2 to melt as it enters a jet engine, assuming the maximum pressure reached within the compressor is sufficient for melting to commence?

    a. 40%
    b. 45%
    c. 50%
    d. 55%
    e. 60%
    f. 65%

34. Ashleigh asked: If ash melts within the compressor, what will happen as it passes into the lower pressure rear portion of the engine? Silence filled the room!

    What should the correct answer have been?

    a. Nothing.
    b. It will freeze on to the blades and potentially stop the turbine.
    c. It will flow through as a molten liquid.
    d. It will trigger an alarm to alert the pilot to fly up out of the ash plume.
    e. It will vaporise.
    f. Solid particles cannot pass through an engine.

35. Gabi and Andy partnered to put together a presentation to tell their classmates about all the cool stuff they'd learned about volcanoes. They wanted to do a really bang up job and bowl their friends over by focussing on the most hazardous types of eruptions. What was the very appropriate title for their talk?

    a. Fissure Friends – Basaltic lava flows of the Hawaiian islands.
    b. Dome Domination – Rhyolitic lava dome formation in Northern California.
    c. Caldera Collapse – Rhyolitic supervolcanic eruptions of Yellowstone Caldera.
    d. Pyroclastic Peril – From Unzen to Pelé, running down dacite slopes.
    e. Undersea Understanding – Basaltic pillows and black smokers.
    f. Stratovolcano Superstars – Mt Fuji's majestic andesitic peak

Meanwhile, in the class working on groundwater …

Students, Darcy Law, Florence Underwood, Brooke d'Charge, and Shelly Waters are particularly interested in their local groundwater system and potential sources of contamination. Darcy and Florence investigated how water moves beneath the surface (Figures 15 and 16) and headed to a local core shed to see some of the rock types found locally for themselves. Meanwhile, Brooke and Shelly contacted the local water authority to gather recently collected data from water quality monitoring wells (Table 6, p45 and Table 7, p46).

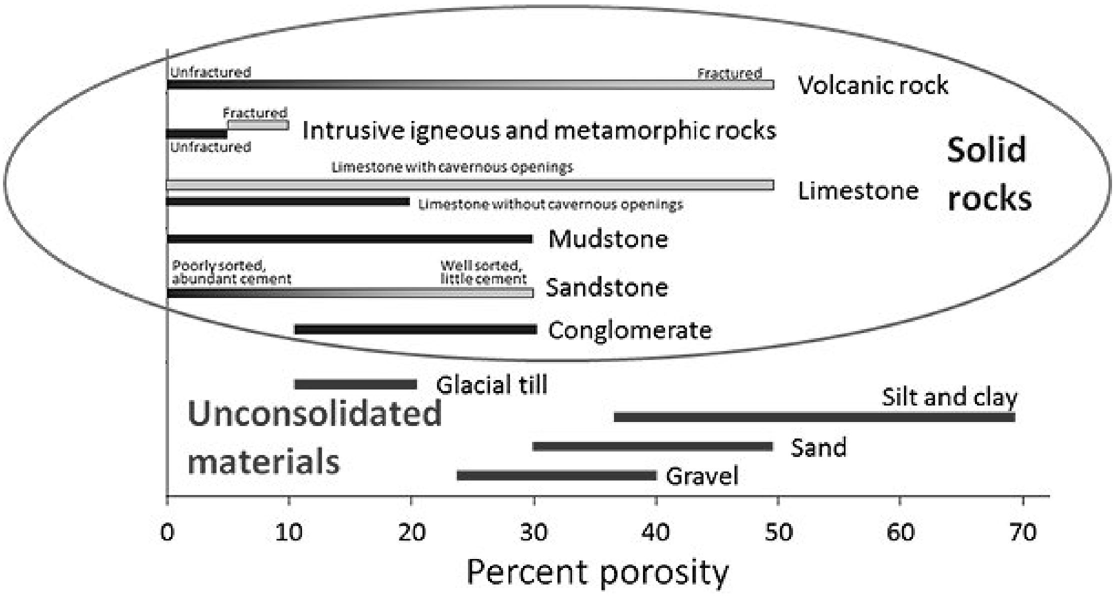


Figure 15: Variations in porosity of unconsolidated materials and rocks (circled). Porosity is the unfilled portion of a solid as a percentage of the total volume of rock plus pore space. Modified from Earle 2015.

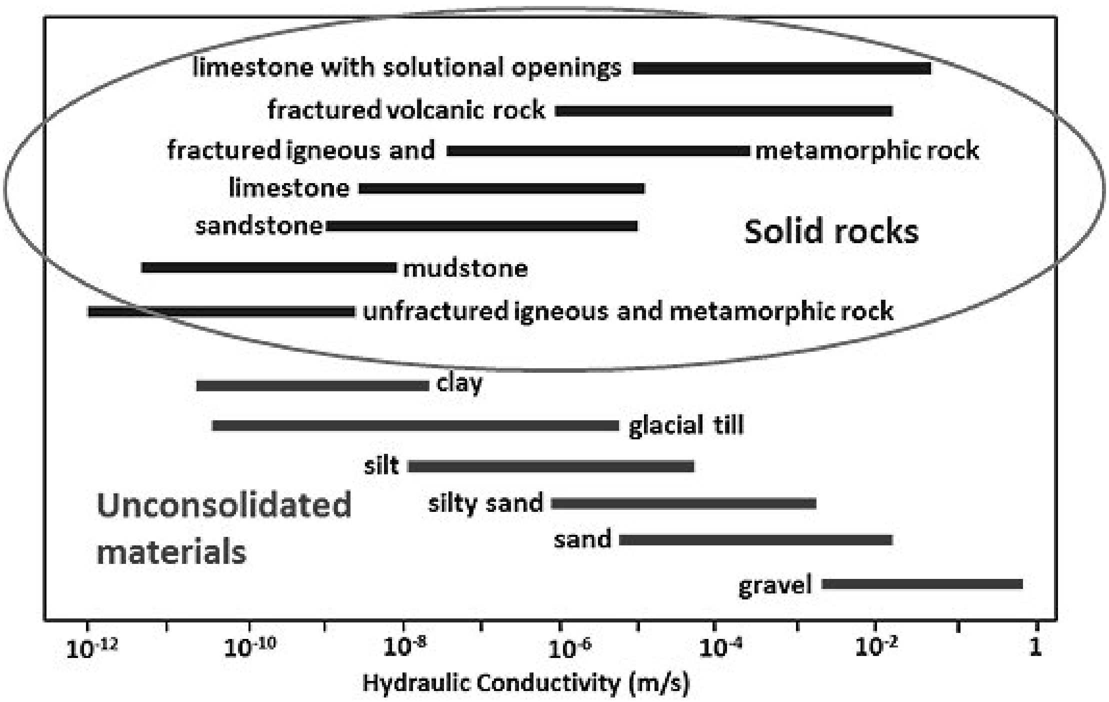


Figure 16: Variations in hydraulic conductivity (how quickly fluid flows through the material in meters/second) of unconsolidated materials and rocks (circled). Modified from Earle 2015.

36. Back in class, Darcy noticed something odd. While unconsolidated silt and clay have very high porosity, greater than nearly all other materials, it seems to lose most of it when it is lithified (turned to mudstone), whereas sand and gravel undergo a smaller percentage change to sandstone and conglomerate respectively. How did Florence correctly explain this observation to him?

  a. Lithification is a metamorphic process that occurs at high temperature and pressure, therefore clay minerals will be transformed into metamorphic minerals, such as micas, that take up more space.
  b. Lithification is an igneous process that requires melting followed by recrystallisation of minerals, which greatly reduces pore space.
  c. Lithification is a sedimentary process whereby minerals, such as clays, settle out of the water column in a quiet basin, therefore the porosity is nearly eliminated.
  d. Lithification is the process whereby silica replaces organic material to form fossil rocks. The silica necessarily takes up more space than the original organic material.
  e. Lithification is the process by which sediments compact under pressure, expel fluids, and gradually become solid rock. Clays, being sheet-like minerals, are more easily squashed together than sphere-like sand grains and pebbles.
  f. Lithification is a weathering process whereby unstable minerals break down to form smaller new minerals that fit together more closely.

37. Darcy was also perplexed by the fact that silt and clay, which have such high porosities, have very low hydraulic conductivity compared to nearly all other geologic materials. What was Florence's accurate explanation of this phenomenon?

a. Water is a polar molecule that is strongly attracted to the slightly irregular mineral grains and is therefore unable to move once it forms a film over the surface. The tiny size of silt and clay minerals, and therefore the pores between them, means that this immobile film takes up nearly all of the porosity.
b. Water is a polar molecule that pulls the silt and clay minerals closer together by Van der Waals forces, thereby eliminating the porosity as it flows through.
c. The high ratio of surface area to volume of silt and clay minerals causes them to be electrostatically attracted to one another and block the flow of water with a charge "force field".
d. Silts and clays are highly chemically reactive minerals, which slows the rate of water flow through them as it picks up charged ions.
e. The hydraulic conductivity of silt and clay just appears to be smaller than other materials because of measurement errors.
f. Silt and clay bake to hardpan when exposed to heat, making them completely impenetrable to fluid flow beneath the surface.

The following information relates to questions 38 and 39

Florence and Darcy discovered through their reading that the best rock formations for drinking water production have both high porosity (>15%) and high hydraulic conductivity (>10^{-6} m/s). Their home town, Kantmella, can be very dry so they thought fractured volcanic rocks might help solve the problem until they examined the local geological map and its cross section (Figure 17). It showed there are only sedimentary rock types present above an unfractured granite basement. They were aware that limestones are carbonate rich rocks but needed to find out more about vugs. They discovered that vugs are solutional openings in carbonate rocks. Solutional openings means the same as Cavernous openings meaning there are caves in the limestone.

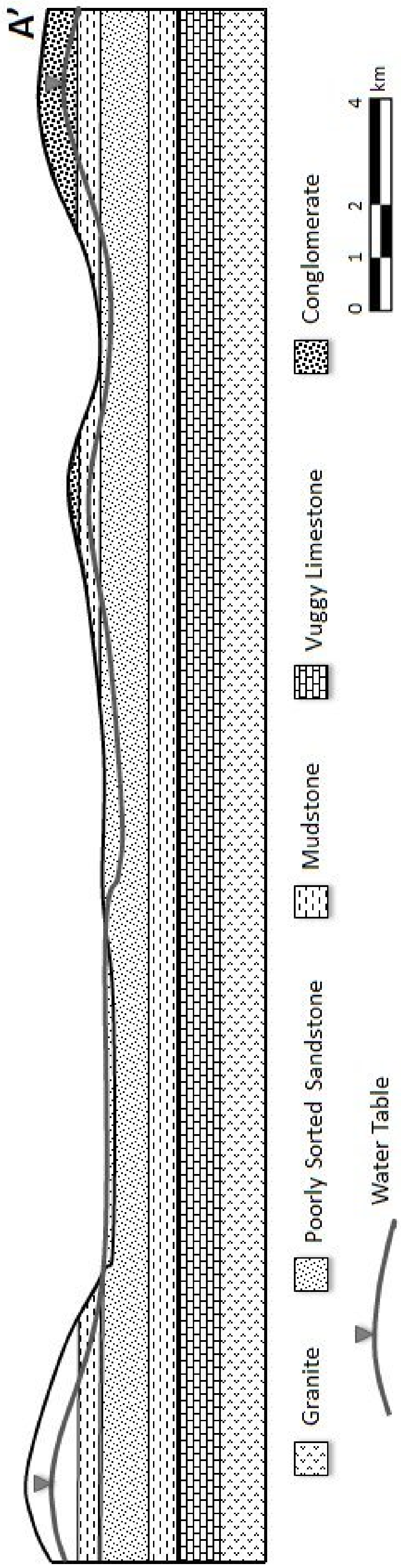


Figure 17: Cross-section through the Kantmella area, showing granite basement overlain by sedimentary rocks.

38. Which rock type would make the best aquifers (rock or sediment layers with enough permeability to be used for groundwater storage and transport) in their home town area?

a. Conglomerate
b. Mudstone
c. Poorly sorted sandstone
d. Vuggy limestone
e. Granite
f. None of the local rocks can hold sufficient water

39. Looking closely at the cross section (Figure 17), Florence and Darcy determined the number and type of local aquifers. What did they find?

    a. There is only one potential local aquifer. It is a perched aquifer, which sits isolated on all sides atop an impermeable layer.
    b. There is only one potential local aquifer. It is an unconfined aquifer, which is exposed at the surface.
    c. There is only one potential local aquifer. It is a confined aquifer, which is closed off from the surface by impermeable layers above and below.
    d. There are two potential local aquifers. One is an *unconfined aquifer* the other is a *confined aquifer*.
    e. There are two potential local aquifers. They are both *confined aquifers*.
    f. There are three potential local aquifers. One is *confined*, one is *unconfined,* and one is *perched*.

The following information relates to questions 40 and 41

At the core shed, Darcy and Florence looked at samples of the rocks from below the surface to gather more information about the local geology. They took their handy Geoscience Australia sedimentary rock card (Figure 18) with them.

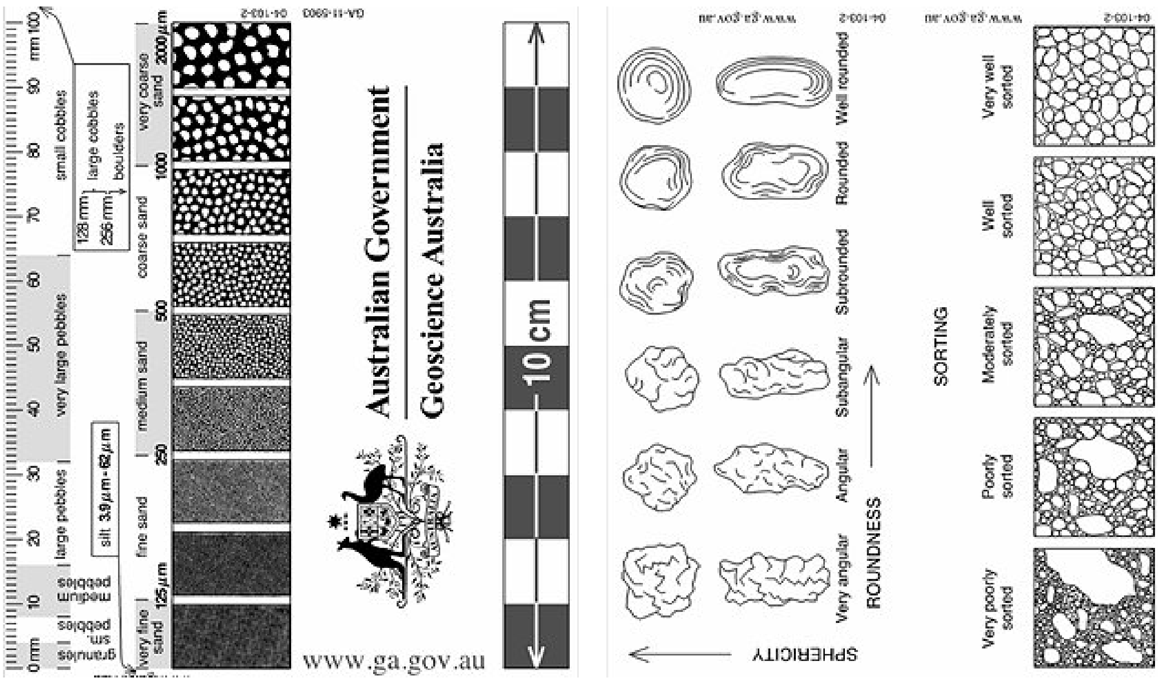


Figure 18: Sand grain size, shape and sorting field card (front and back). Card courtesy of Geoscience Australia.

40. Based on their observations Darcy and Florence estimated that the limestone has a hydraulic conductivity of ~10^{-5} m/s, whereas the sandstone is closer to 10^{-8} m/s. What did they observe that led them to this conclusion?

a. The subrounded sand grains range from 0.66-0.25 mm, are all composed of the same mineral, and are bound by cement that does not react at all with HCl, whereas the limestone is full of holes ranging from 2-15 mm diameter.

b. The angular sand grains range from 0.1-2 mm, are composed of at least three different minerals, and are bound by cement that reacts with dilute hydrochloric acid (HCl) to form lots of bubbles, whereas the limestone is full of holes ranging from 2-15 mm diameter.

c. The well rounded sand grains are all approximately 1 mm, are all composed of the same mineral, and the HCl quickly vanishes into the sample when they place a drop on it with no bubbles or fizzing, whereas the limestone has very few visible holes in it.

d. The angular sand grains range from 0.06-1.5 mm, are composed of at least three different minerals, and are bound by cement that reacts with dilute hydrochloric acid (HCl) to form lots of bubbles, whereas the limestone has very few visible holes in it.

e. The subrounded sand grains range from 0.66-0.25 mm, are all composed of the same mineral, and are bound by cement that does not react at all with HCl, whereas the limestone has very few visible holes in it.

f. The well rounded sand grains are all approximately 1 mm, are all composed of the same mineral, and the HCl quickly vanishes into the sample when they place a drop on it with no bubbles or fizzing, whereas the limestone is full of holes ranging from 2-15 mm diameter.

41. Darcy and Florence discussed the reasons why limestone often develops vugs (cavernous openings). What did they (correctly) conclude?

a. Limestone is mostly composed of carbonate minerals that can dissolve in the weak acidity of rainwater as it infiltrates the rock along joints and faults.
b. Limestone is mostly composed of carbonate minerals that can dissolve in the weak alkalinity of rainwater as it infiltrates the rock along joints and faults.
c. Limestone is mostly composed of silicate minerals that can dissolve in the weak acidity of rainwater as it infiltrates the rock along joints and faults.
d. Limestone is mostly composed of silicate minerals that can dissolve in the weak alkalinity of rainwater as it infiltrates the rock along joints and faults.
e. Limestone is mostly composed of carbonate minerals that react with silicate minerals in the presence of rainwater as it infiltrates the rock along joints and faults.
f. Limestone is mostly composed of carbonate minerals that break down via a series of hydrolysis reactions.

The following information relates to questions 42 to 44

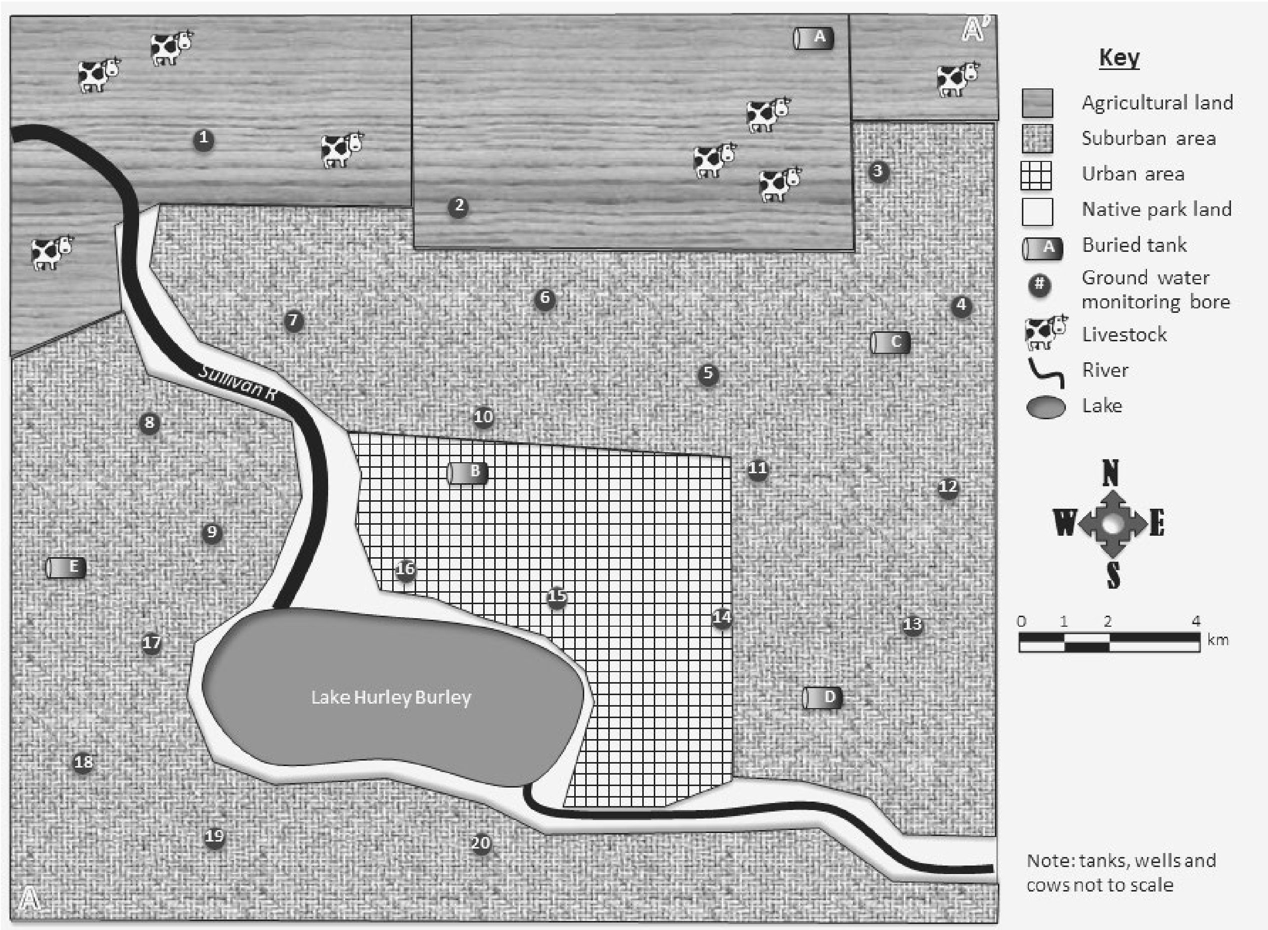


Figure 19: Lake Hurley Burley area land use map.

Shelly and Brooke discovered that there are numerous potential sources of contamination to both the ground and surface waters in their area. They produced a map (Figure 19, p42 above) highlighting the different land uses and locations of groundwater monitoring bore holes. Their contact at the local water authority, hydrogeologist Sandra Shores, informed them that Lake Hurley Burley experienced seasonal algal blooms leading to eutrophication prior to the replanting of native vegetation in the park lands along the Sullivan River and around the lake.

42. Part of their assignment is to determine what is the most likely source of the nutrients that are causing eutrophication of Lake Hurley Burley? What should their answer be?

    a. Hydrocarbon leaks from the tanks buried in the region.
    b. Municipal waste infiltrating groundwater from the suburbs.
    c. Surface runoff from fertilizers used on park grounds, ovals and golf courses in the suburbs.
    d. Surface runoff from the farmland directly adjacent to the Sullivan River in the northwest.
    e. Both a and b are likely culprits.
    f. Both c and d are likely culprits.

43. Another part of their assignment is to determine the effect (if any) of the native park lands adjacent to the Sullivan River and Lake Hurley Burley on surface water quality. What did they conclude after examining the landscape?

    a. None, surface water quality is not affected by vegetation.
    b. It increases Nitrogen entering the surface waters by fixing atmospheric N_2 in the soil.
    c. It increases the dissolved Oxygen content in the surface waters through photosynthesis.
    d. It decreases the phosphate concentrations in surface waters by slowing runoff from urban and suburban areas.
    e. It decreases Nitrogen entering the surface waters by fixing atmospheric N_2 in the soil.
    f. It decreases the carbonate concentration in the surface waters via photosynthesis.

44. Brooke looked at the geological cross section Darcy and Florence were using (Figure 17) and noted that the water table takes an unusual dip on the north eastern side of Lake Hurley Burley. What does she correctly propose is the reason for this unusual water table profile?

a. Water discharge increases dramatically at the lake edge, drawing excess water from the surrounding saturated zone.
b. The sandstone near the lake edge is particularly low porosity.
c. There is excessive gravity below this point pulling the water table down.
d. The area to the north east of the lake receives very little annual rainfall, therefore this area does not get recharged.
e. The urban environment on the lake edge limits water infiltration and municipal water requirements exceed natural recharge.
f. There is a local downward pointing bend (syncline) in the sandstone bedding that the water table simply follows.

The following information relates to questions 45 to 52

Hydrogeologist Sandra Shores provided the students with very useful data tables (Table 6 and Table 7). Table 6 explains the types of common contaminants that may be found in ground and surface waters and their potential sources. The maximum drinking water threshold is the level above which water is deemed un-safe for human consumption. Table 7 contains the data from the most recent ground water monitoring survey. The bore holes are numbered 1 to 20 and their locations are marked on the map Shelly and Brooke made (Figure 19 above) that highlighs the different land uses. It also locates the positions of underground tanks.

Based on the data in Tables 6 & 7, the map (Figure 19) and cross section (Figure 17) , Brooke and Shelly drew some conclusions about groundwater issues in the area.

Contaminant	Sources to groundwater	Units	Max. Drinking Water Threshold
Benzene (Ben)	Industrial uses; component of petrol	ppm	0.005
Chloride (Chl)	Saltwater intrusion, mineral dissolution, industrial & domestic waste	mg/L	250
Cryptosporidium (Cryp)	Human and animal faecal waste	%	0.000
Dissolved solids (D.S.)	Occur naturally; landfill leachate, feedlots, or sewage. A measure of the dissolved minerals and organic compounds in the water.	mg/L	500
Fluoride (Flu)	Occurs naturally or added to municipal water supplies	µg/L	4.0
Giardia lamblia (G.lam)	Human and animal faecal waste	%	0.0
Hardness (H)	Metallic ions dissolved in water; reported as concentration of calcium carbonate. Derived from limestone or discharges from mines.	ppm	Soft: 0-60 Mod. hard: 61-120 Hard: 121-180 Very hard: ≥181
Lead (Pb)	Industry, mining, plumbing, gasoline, coal, water additive.	µg/L	0.015
Nitrate (Nitr)	Occurs naturally in mineral deposits, soils, seawater, freshwater systems, the atmosphere, and biota. Found in the highest levels in groundwater under extensively developed areas. Enters environment from fertilizer, feedlots, sewage.	µg/L	10
Pesticides (Pest)	Herbicides, insecticides, fungicides, rodenticides	µg/L	1
Sulphate (Sul)	Saltwater intrusion, mineral dissolution, domestic or industrial waste.	mg/L	500
Volatile organic compounds (VOCs)	Production of plastics, dyes, rubbers, polishes, solvents, crude oil, insecticides, inks, varnishes, disinfectants, gasoline products, preservatives, pharmaceuticals, paints, paint removers, etc.	µg/L	1

Table 6: Common contaminants and their sources. Courtesy of Sandra Shores.

Table 7: Data from the most recent ground water monitoring survey. Courtesy of Sandra Shores.

Bore#	Cont.	Conc.	Bore#	Cont.	Conc.	Bore#	Cont.	Conc.	Bore#	Cont.	Conc.	Bore#	Cont.	Conc.	Bore#	Cont.	Conc.	Bore#	Cont.	Conc.
1	Ben	0	**2**	Ben	0	**3**	Ben	0	**4**	**Ben**	**0**	**5**	Ben	0.002	**6**	Ben	0	**7**	Ben	0
	Chl	71		Chl	64		Chl	68		Chl	78		Chl	77		Chl	75		Chl	100
	Cryp.	1.674		*Cryp.*	0.846		*Cryp.*	0.414		*Cryp.*	0.122		*Cryp.*	0		*Cryp.*	0.523		*Cryp.*	0.232
	D.S.	780		D.S.	635		D.S.	589		D.S.	523		D.S.	521		D.S.	524		D.S.	430
	Flu	4.9		Flu	4.3		Flu	4.3		Flu	0.4		Flu	0.3		Flu	3.5		Flu	3.1
	G.lam	2.35		*G.lam*	1.412		*G.lam*	0.639		*G.lam*	0.223		*G.lam*	0		*G.lam*	0		*G.lam*	0.001
	H	54		H	33		H	27		H	98		H	172		H	175		H	135
	Pb	0.001		Pb	0		Pb	0		Pb	0		Pb	0.015		Pb	0		Pb	0.001
	Nitr	46		Nitr	31		Nitr	27		Nitr	25		Nitr	21		Nitr	28		Nitr	21
	Pest	1.5		Pest	1.2		Pest	1		Pest	0.8		Pest	0.7		Pest	0.8		Pest	0.9
	Sul	450		Sul	463		Sul	402		Sul	375		Sul	104		Sul	203		Sul	74
	VOCs	0		VOCs	0		VOCs	0		VOCs	0		VOCs	3.12		VOCs	0		VOCs	0
8	Ben	0	**9**	**Ben**	**0.001**	**10**	Ben	0	**11**	Ben	0.008	**12**	Ben	0.002	**13**	Ben	0.001	**14**	**Ben**	**0.006**
	Chl	70		Chl	62		Chl	84		Chl	79		Chl	61		Chl	59		Chl	82
	Cryp.	0		*Cryp.*	0		*Cryp.*	0		*Cryp.*	0		*Cryp.*	0		*Cryp.*	0		*Cryp.*	0.174
	D.S.	234		D.S.	126		D.S.	322		D.S.	110		D.S.	115		D.S.	104		D.S.	235
	Flu	0.2		Flu	0.3		Flu	2.1		Flu	0.6		Flu	0.5		Flu	0.9		Flu	3.2
	G.lam	0.001		*G.lam*	0.001		*G.lam*	0		*G.lam*	0		*G.lam*	0		*G.lam*	0.001		*G.lam*	0
	H	74		H	95		H	87		H	61		H	173		H	96		H	156
	Pb	0		Pb	0.013		Pb	0.009		Pb	0.023		Pb	0.014		Pb	0.007		Pb	0.019
	Nitr	5		Nitr	5		Nitr	13		Nitr	4		Nitr	3		Nitr	6		Nitr	12
	Pest	0.2		Pest	0.3		Pest	0.8		Pest	0.4		Pest	0.2		Pest	0.2		Pest	0.1
	Sul	107		Sul	93		Sul	71		Sul	68		Sul	71		Sul	77		Sul	472
	VOCs	0		VOCs	1.78		VOCs	0		VOCs	10.58		VOCs	2.03		VOCs	0		VOCs	7.65
15	Ben	0.005	**16**	Ben	0.001	**17**	Ben	0	**18**	Ben	0	**19**	**Ben**	**0**	**20**	Ben	0			
	Chl	88		Chl	89		Chl	45		Chl	50		Chl	37		Chl	3			
	Cryp.	0		*Cryp.*	0		*Cryp.*	0		*Cryp.*	0		*Cryp.*	0		*Cryp.*	0			
	D.S.	368		D.S.	420		D.S.	86		D.S.	26		D.S.	45		D.S.	78			
	Flu	3.6		Flu	3.1		Flu	0.5		Flu	0.2		Flu	0.3		Flu	0.2			
	G.lam	0		*G.lam*	0		*G.lam*	0.001		*G.lam*	0.001		*G.lam*	0.001		*G.lam*	0.001			
	H	200		H	243		H	74		H	53		H	68		H	87			
	Pb	0.016		Pb	0.018		Pb	0		Pb	0		Pb	0		Pb	0.001			
	Nitr	13		Nitr	8		Nitr	26		Nitr	2		Nitr	4		Nitr	4			
	Pest	0.1		Pest	0.1		Pest	0.6		Pest	0		Pest	0		Pest	0.1			
	Sul	368		Sul	377		Sul	99		Sul	204		Sul	111		Sul	107			
	VOCs	6.01		VOCs	0		VOCs	0		VOCs	0		VOCs	0		VOCs	0			

45. The students are shocked to discover the data reveals a buried petrol tank has a major, long-lived leak contaminating the local aquifer system. Which tank do they identify when they contact Sandra Shore to discuss their report? Tank …

a. A
b. B
c. C
d. D
e. E
f. Sandra Shore corrected them, pointing out the data does not indicate that any of the buried tanks are leaking.

46. In addition, the students also identified a buried petrol tank that has a small or recently initiated leak contaminating the local aquifer system. Which tank was this?

a. A
b. B
c. C
d. D
e. E
f. Sandra Shore corrected them, pointing out the data does not indicate that any of the buried tanks are leaking.

47. The students also noted that one buried petrol tank is unable to be monitored by the existing wells. Which tank do they identify in the report as in need of monitoring?

a. A
b. B
c. C
d. D
e. E
f. Sandra Shore corrected them, pointing out the data does not indicate that any of the buried tanks are leaking or that any of them are beyond monitoring.

In a group discussion about the data the students identified elevated levels of lead, high concentrations of dissolved solids and very high levels of water hardness at some locations. In their report to Sandra Shore …

48. … what did they identify as the source of elevated lead (Pb) levels in the western CBD?

a. the underlying geology
b. groundwater flowing north from Lake Hurley Burley and
c. surface runoff from surrounding farmlands
d. a leak from buried gasoline tank B
e. a leak from buried gasoline tank C
f. old buried lead pipes beneath the city

49. … what did they point to as the most likely source of the unacceptably high concentrations of dissolved solids in some bores?

a. the underlying geology
b. groundwater flowing north from Lake Hurley Burley and
c. surface runoff from surrounding farmlands
d. sediments transported downstream in the Sullivan River
e. surface runoff from parking lots in the CBD
f. surface runoff from parks and golf courses in the suburbs

50. … what did they say is the most likely source of the very high water hardness observed at some locations?

a. the underlying geology
b. groundwater flowing north from Lake Hurley Burley and
c. surface runoff from surrounding farmlands
d. a leak from buried gasoline tank B
e. a leak from buried gasoline tank C
f. old buried lead pipes beneath the city

51. … what evidence did they see that the golf course near the western edge of Lake Hurley Burley has poor waste water management practices?

   a. low chlorine and fluorine levels
   b. elevated nitrate levels and pesticide levels
   c. moderate sulphate and hardness levels
   d. absence of lead and benzene
   e. low dissolved solid and VOC levels
   f. there is no evidence to indicate the golf course is not managing their waste water properly

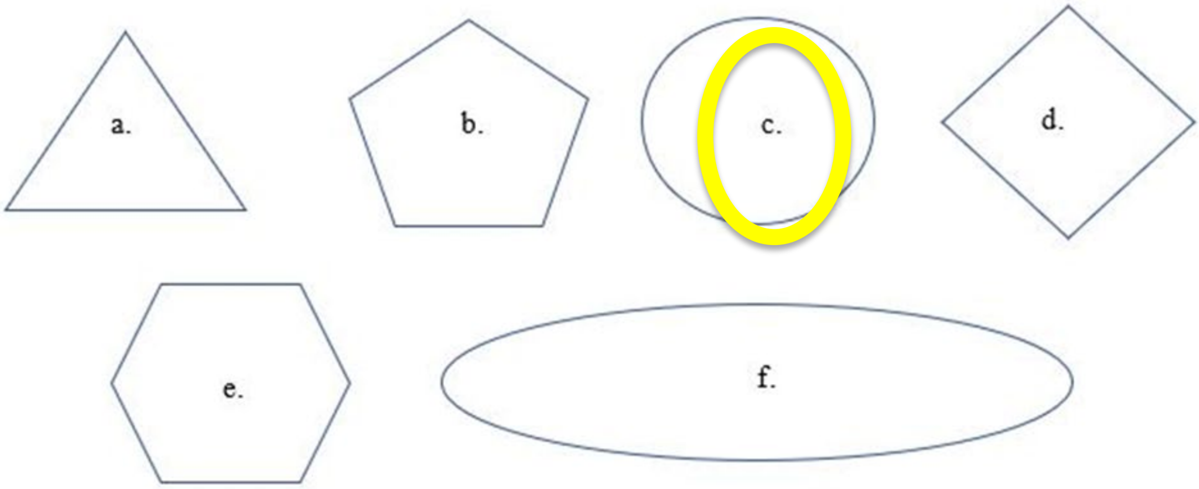
52. … which bores did the recommend as sources of groundwater that is safe to use as drinking water?

   a. all of the groundwater is safe for human consumption
   b. only bores 5, 9, 11, 12, 14, and 15
   c. only bores 7, 8, 10, 13, 16, 18, 19, and 20
   d. only bores 1, 2, and 3
   e. only bores 8, 13, 18, 19, and 20
   f. none of the bores contain groundwater that is safe for human consumption

Meanwhile, in another city and another school …

Newly graduated atmospheric scientists, Dr Gayle Snowdon, visited her old school as part of the Meteorological Action Dance troupe, a group taking atmospheric science to schools through interpretive dance. She was asked by student, Indigo Lightfoot, to explain how rainbows form. Her verbal answer was: *Rainbows form when sunlight is refracted – bent – slightly as it enters raindrops, reflects off the inside of the drops and then refracts again as it exits the raindrops. Blue light refracts at a greater angle than red light, separating the colours, and since you are looking up at the drops as they fall there are lots of raindrops along your line of sight that add their light together to make the familiar rainbow shape with the colours spread between blue and red.*

53. Trying to put Gayle to the test, Indigo asked what a rainbow looks like from a helicopter high in the sky. What shape did Gayle dance out on the floor of the class room while she shouted out R.O.Y.G.B.I.V?



54. Gayle's MAD answer saw other students keen to ask questions. Indigo's twin sister, Violet, wanted to know if rainbows happen when light shines through fog. Gayle wrote the options below on the board and then danced the shape of a letter (a – f) to indicate the correct answer. Which letter shape did she dance?

a. No, fog is not made of water droplets.
b. Yes, they look exactly the same only a bit foggy.
c. No, fog is made of droplets with a diameter small than the wavelengths of visible light so cannot refract light.
d. Yes, fog is made of tiny droplets that form rainbows but because the drops are tiny the light is less intense and the 'fogbow' looks washed out.
e. No, fog absorbs light, that is why you can't see through it.
f. Yes, but the 'fogbows' can be any shape because the fog droplets are suspended, not falling through the air as rain.

55. Gayle's dance partner, Ariel Windlass, did a solo performance to demonstrate the behaviour of a southern hemisphere cyclone. She was dizzy when she finished! What direction did she spin?

a. Clockwise.
b. Anticlockwise.
c. 50% of the time in each direction.
d. Clockwise in southern Australia and anticlockwise in northern Australia.
e. Anticlockwise in southern Australia and clockwise in northern Australia.
f. She didn't spin, she rolled on the ground, her head pointing north, from east to west.

56. Gayle and Ariel showed the students some of their interpretive moves.

1 - Rigid spread-hands moving from side to side = snowflakes
2 - Rigid body, spread eagled on the floor = ice formation on ground
3 - Rigid body going limp and wriggling across the floor = ice melt
4 - Body wriggling across the floor = flowing water
5 - Arms thrown quickly up into the air, spread wide = evaporation
6 - Arms curled slowly around head = condensation
7 - Fingers playing an air keyboard = precipitation
8 - Thrashing arms around wildly = wind
9 - Arms in a circle overhead = warm and sunny

and then challenged the students to solve their puzzle.
They danced 6, 1, 2, 5 and told the students they left a dance move out.
They challenged the students to complete the picture by inserting ONLY ONE more move into the sequence so that the process was a valid one, found in nature.
Only Violet got it right. What was her sequence?

a. 6, 1, 2, 9, 5
b. 6, 1, 2, 8, 5
c. 6, 1, 2, 5, 8
d. 6, 1, 2, 5, 9
e. 6, 1, 2, 4, 5
f. 6, 1, 2, 5, 4

57. Gayle and Ariel were keen to ensure the students could see the connections between the spheres, not merely from an Earth Systems Science perspective but from a Planetary Systems Science perspective as well. They pointed out that interactions between spheres and processes within systems has happened throughout time on Earth and on all other planets as well. This understanding is known as …

a. Planetarianism
b. Neptunism
c. Catastrophism
d. Uniformitarianism
e. Constantism
f. The Big Bang Theory

58. Indigo and Violet are twins and are fascinated by all things that are in some way twins. They know that Saturn's moon, Titan, is like Earth in some ways. Importantly, Titan is the only other place in the solar system that is known to have a planet-wide cycle that involves a solid, liquid and gas phase for the same compound. On Earth this is the water cycle. On Titan the same function is performed by methane. They asked Ariel what other aspects of Titan might make it even more like Earth. This was too hard for Ariel to dance an answer. Instead she drew some pictures on the board (some of Figure 20).

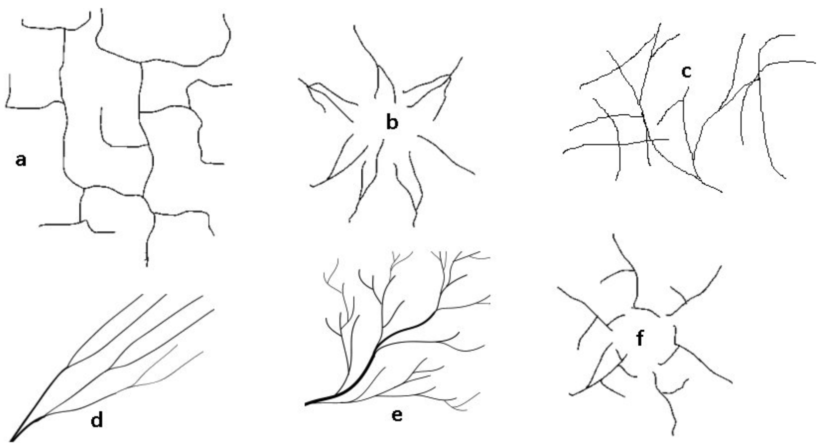


Figure 20: Which of these drawings did Ariel actually draw?

Of the six images shown in Figure 20, which ones, if any, did Ariel actually draw?

a. All except a and c
b. All except a
c. All except c
d. Only d and e
e. Only b and e
f. All of them

59. Gayle is an amateur astronomer and knows planetary scientists, Cameron Brian and Holland Listerfield, because she was in the same astronomy club as them at university. Indigo's classmate, Ellie Mints, had read about clouds of diamond nanoparticles being found in orbit around some stars. She asked Gayle where the diamonds came from and Gayle arranged a video message to be sent so to Cameron, who is working on Mars. Cameron's reply arrived about 35 minutes after the student's message was sent. Why did it take him so long to answer?

a. He is a busy scientist and doesn't prioritise school student enquiries.
b. Mars was behind the Sun so he didn't get the message straight away.
c. Radiowaves only travel at the speed of light in a vacuum so are slower in the solar system where there are lots of meteors, asteroids and comets.
d. Radiowaves travel at the speed of light in a vacuum and Mars is beyond Jupiter and it takes more than 35 minutes for messages to reach Jupiter.
e. Radiowaves travel at the speed of light in a vacuum and it takes about 14 minutes for messages to reach Mars.
f. Radiowaves travel at the speed of light in a vacuum and it takes about 35 minutes for messages to reach Mars.

60. What was Cameron's answer to the question: Where do the nano-diamonds come from?

a. They are left over from the Big Bang and are gravitationally attracted into the orbits of stars but it takes billions of years because they are so small.
b. Fusion in stars forms elements including carbon. Some carbon escapes into space during the turbulent end of life stages of low mass stars. Diamonds form from this carbon dust, possibly by grain-grain collisions in the interstellar medium although a low-pressure mechanism has not been ruled out.
c. Fisson in stars forms elements including carbon. Some carbon escapes into space during the turbulent end of life stages of low mass stars. Diamonds form from this carbon dust, possibly by grain-grain collisions in the interstellar medium although a low-pressure mechanism has not been ruled out.
d. Fusion in stars forms elements including lithium. Some lithium escapes into space during the turbulent end of life stages of low mass stars. Diamonds form from this lithium dust, possibly by grain-grain collisions in the interstellar medium although a low-pressure mechanism has not been ruled out.
e. The diamond dust is the residue of life on exoplanets orbiting stars that exploded.
f. The diamond dust is a misinterpretation of the data in 1967 by the astronomer John Lennon using the LUCY optical telescope.

SECTION B: WRITTEN ANSWER QUESTIONS
ANSWER IN THE SPACES PROVIDED

The following information relates to question 61

Cameron had been reading up on Europa, one of Jupiter's moons, in the hope of doing well in an upcoming interview for a crew position on the first human mission to the Jovian system.

He found out Europa's surface is striated by cracks and streaks. Analysis of data collected from Europa suggests the moon has a layer of liquid water beneath the frozen surface that is kept liquid by tidal flexing of the crust as Europa orbits Jupiter. When crustal movements crack the surface and blocks move apart, liquid water from below wells up to fill the gaps and freezes to form new crust. These crack-and-fill structures are seen as linear dual ridge-like features criss-crossing the surface. The surface of Europa is cold. It is ~50K at the poles and ~125K at the equator.

In his reading he also came across an interesting image (Figure 21a). In this region the surface temperature is around 90K but one area, marked by the oval on the left image, has a thermal anomaly with a central area up to 5K warmer (as shown on the right image).

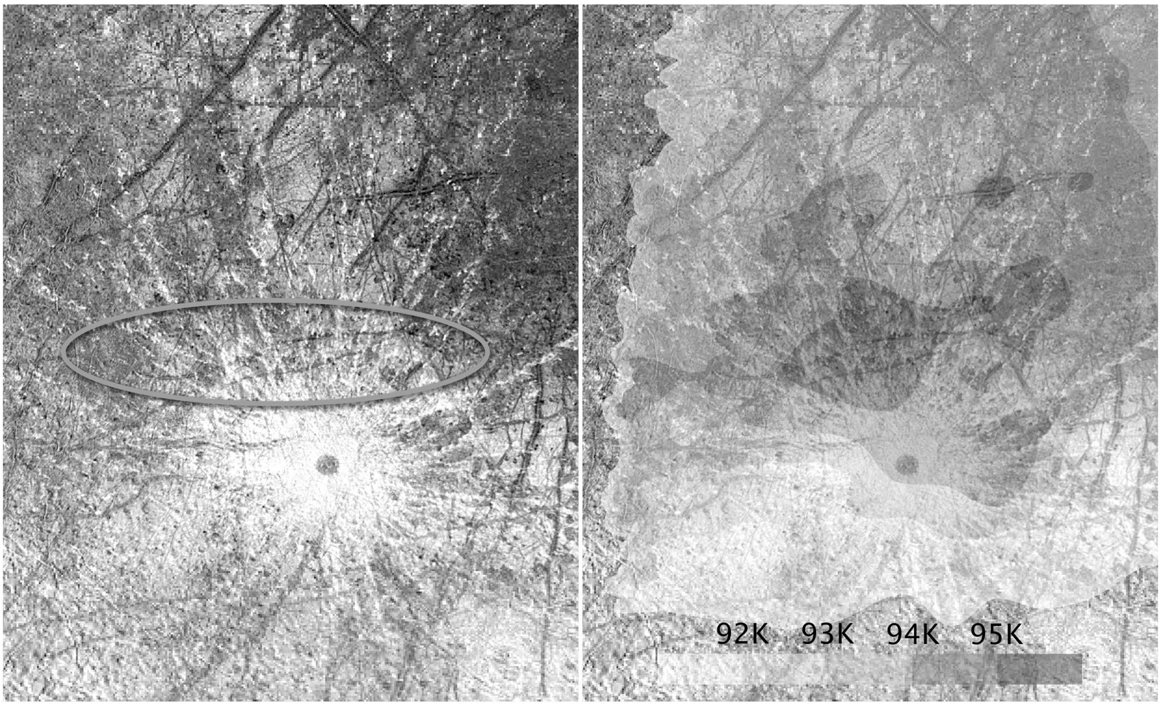


Figure 21a: Image of Europa's surface taken by NASA's Galileo spacecraft. The left image shows a region adjacent to an impact crater. The oval marks an area of interest based on thermal anomaly data shown in the right image. Modified from PIA21444.tiff courtesy of NASA/ESA/W. Sparks (STScI)/USGS Astrogeology Science Center.

A close up of the area is shown in Figure 21b.

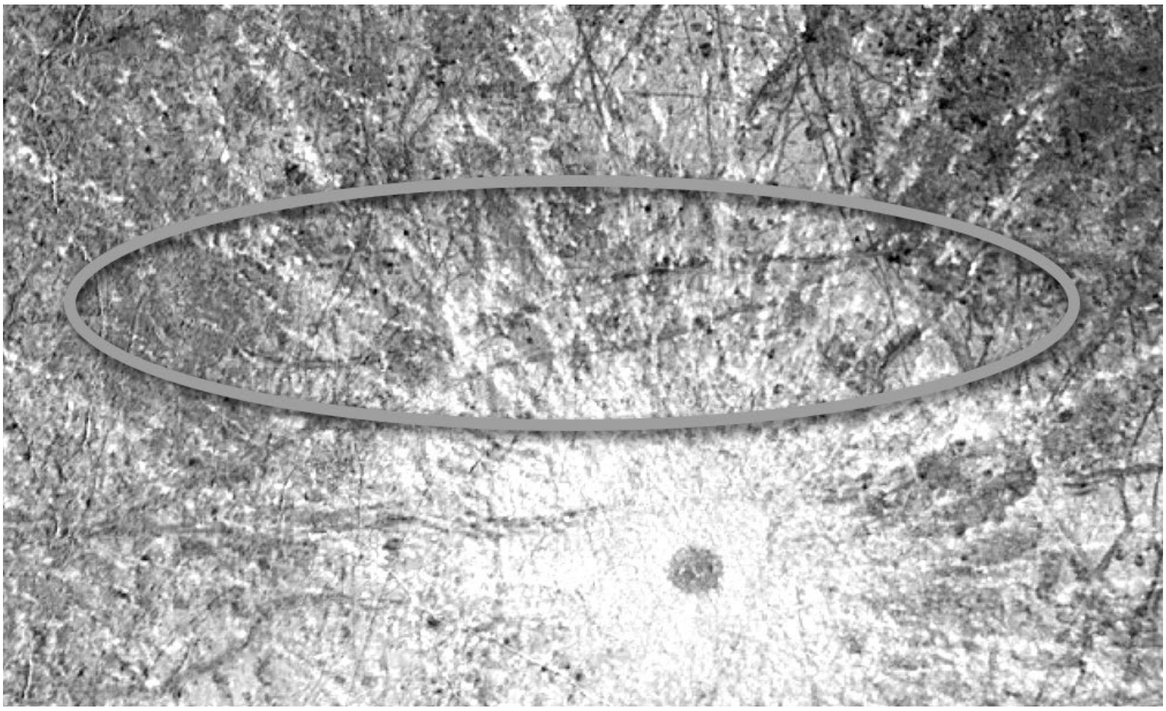


Figure 21b: Close up of the region showing anomalous thermal data.

Luckily for Cameron he got the interview. Even luckier, in the interview he was shown this set of images (Figures 21a and 21b) and asked to suggest a reason for the thermal anomaly. He has made it to the second round of interviews so his answer must have been good.

61. What did Cameron say in the interview to explain the thermal anomaly? **(5 Marks)**

- 1: Liquid water comes to surface, even with a high salt content it will be somewhere between 273K to 251K
- 2: Linear features inside the oval suggest a rift structure
- 3: The impact crater and its ejecta are not coincident with the thermal anomaly so are not directly involved – although it would be OK to speculate that this impact triggered the formation of the local rifts
- 4: Water emerging onto a 90K surface would cool and freeze quickly but raise the local area temperature slightly in the process
- 5: Liquid water unlikely to flow on the surface very far before freezing suggesting spread of the thermal anomaly across the wider area may be due to the water being rapidly ejected at the surface forming a plume that spreads out over a wider area as it cools

The following information relates to question 62

Cameron was also asked to evaluate an image of the Tyre multi-ring structure (T in Figure 22) on Europa and venture an explanation for the formation of the structure and the timing of its formation in relation to linear features L1, L2, L3 and L4.

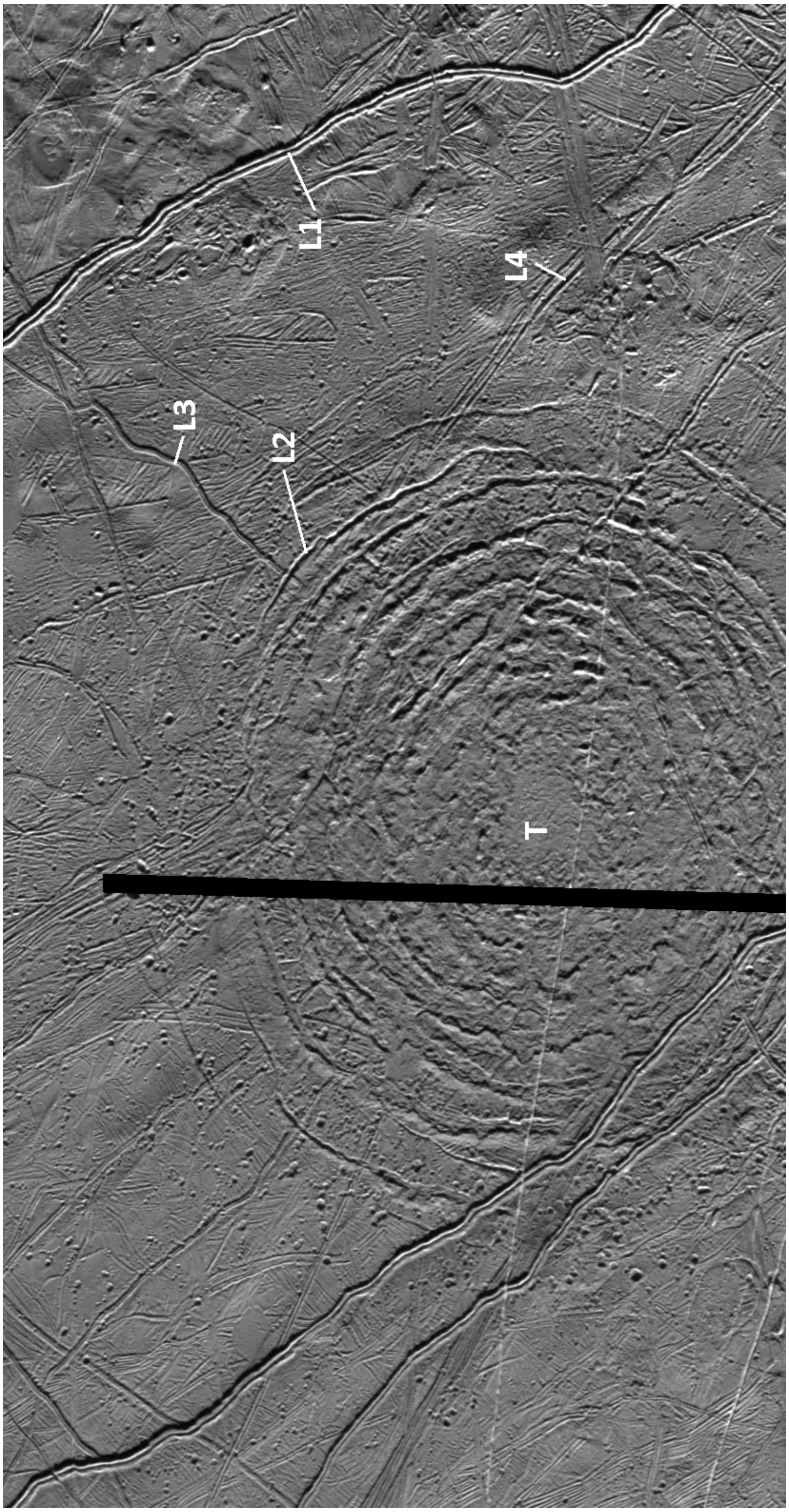


Figure 22: Tyre multiring structure on Europa. The solid black area is caused by missing data.

62. What did Cameron say when asked for an explanation for the formation of the structure T and the timing of its formation and the timing of formation of the linear features L1, L2, L3 and L4? **(5 marks)**

- Structure T is a series of concentric ring fractures, most likely caused by a meteorite impact - 1 mark – other ideas maybe 0.5 mark
- L2 appears to cut across L3 - 0.5 mark
- L3 appears to fork and at least one prong is cut by L1 - 0.5 mark
- L4 appears to be cut across by a ring fracture the same age as L2 - 0.5 mark
- L4 is cut and offset by a series of faint linear features that are cut by L1 - 0.5 mark
- Over all timing
    - T before L2
    - L3 before L2
    - L4 before L2
    - L4 before L1
- L3 before L1
- No way to know if L3 was before L4 or vice versa

Back on Earth …

The following information relates to question 63

When Darcy and Florence looked at samples of the rocks from below the surface in Kantmella to gather more information about the local geology they made some notes about each rock type identified in the cross-section (Figure 17 as well as Figure 23 below).

In their books they wrote:

Rock type	**Description and other notes**

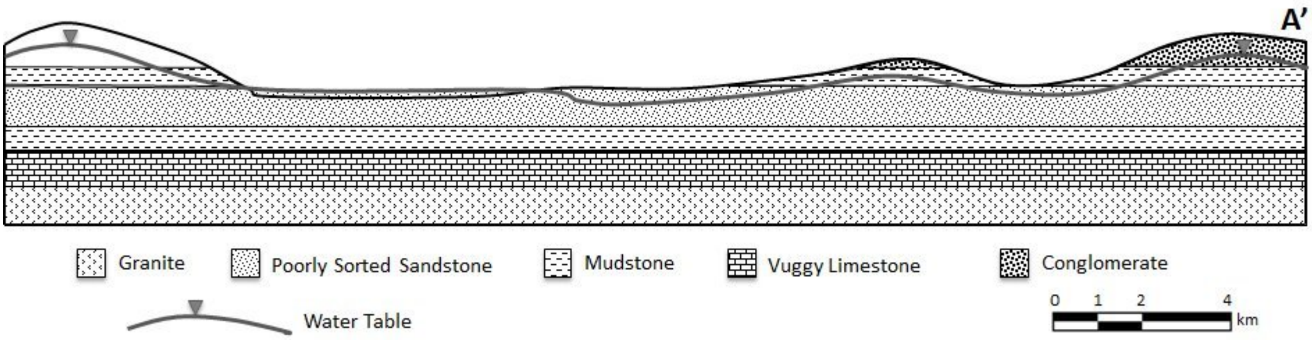


Figure 23: Cross-section through the Kantmella area, showing granite basement overlain by sedimentary rocks.

Conglomerate	Base of conglomerate on an erosional surface in the underlying mudstone. Pleistocene megafaunal kangaroo bones in the basal gravel horizons
Mudstone	Finely laminated. Carbonaceous horizons. Permian terrestrial plant fossils. Coal lenses.
Sandstone	Poorly sorted. Quartz and feldspar grains. Carbonate cement. Base of sandstone on an erosional surface in the underlying mudstone. Permian terrestrial plant and vertebrate fossils in lenses of finer sandstone.
Mudstone	Finely laminated. Late Ordovician – Silurian graptolite fossils.
Limestone	Vuggy, massive with some fossil rich horizons. Ordovician brachiopods, crinoids, corals and bryozoans.
Granite	Pink, porphyritic k-spar, no accessory minerals likely to cause groundwater contamination. Geological Survey age of 700 Ma

62. Using the stratigraphic column provided by their teacher, Darcy and Florence (Figure 24) marked in two other unconformities. Did they label them each as an angular unconformity, a disconformity or a nonconformity? **(1 mark)**

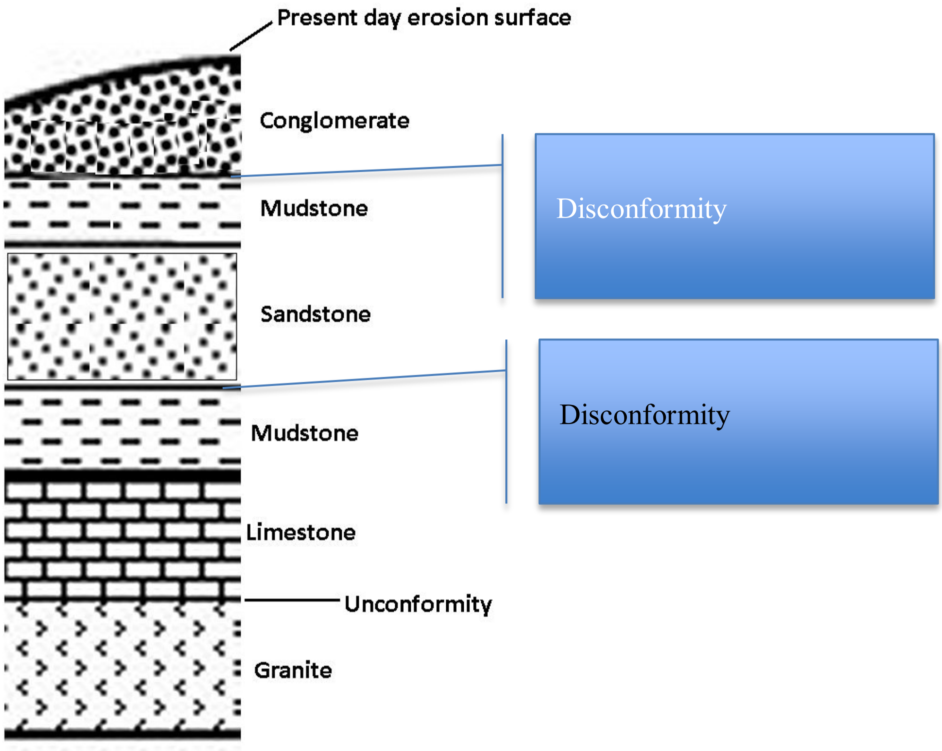


Figure 24: Stratigraphic column for Kantmella.

63. Using the stratigraphic column and their notes on the rocks and fossils, Darcy and Florence wrote a brief geological history of the area. Their report didn't print properly but you might be able to fill in the blanks for them. **(6 marks)**

Rock type	**Description and other notes**
	Ongoing erosion to the present day.
Conglomerate	D… eposition of conglomerates from high energy streams during the Pleistocene.
	Ongoing non-deposition and erosion post-Permian.
Mudstone	Basin deepening lead to a swampy environment where forest plants accumulated into peat. Ongoing burial led to diagenesis (not expecting this word) and the formation of coal form the peat.
Sand … stone	Basin formation led to the deposition of terrestrial sands on the erosion surface during the Permian. The terrestrial environment supported plants and vertebrate animals.
	… Uplift or relative sea level fall exposed the pre-Permian sequence to erosion and weathering.
Mudstone	Towards the end of the Ordovician relative sealevel rose and the shallow water carbonates were buried by deep water muds during the Silurian. Skeletons of planktonic graptolites rained down on the seabed and were fossilised in the mudstone.
Lime … stone	… During the Ordovician carbonate skeletons from marine invertebrates accumulated on the sea floor, packed down, lithified and became fossiliferous limestone.
	At the end of the Cambrian relative sea level rose and inundated the granite under a shallow sea in which Ordovician invertebrates thrived
	Uplift and erosion … removed the overlying crust and exposed the granite to weathering sometime prior to the Ordovician
Granite	A high silica magma intruded the crust approximately 700 million years ago, cooling slowly to form a coarsely crystalline granite porphyry.

Coming full circle …

The TRAPPIST-1 system might be a potential new home for humanity but medical science informs us that we have evolved on a planet with a gravitational acceleration of $9.8\ ms^{-2}$ and earthling bodies might not do well over the long term in higher or lower gravities. Planetary scientists, Cameron Brian and Holland Listerfield have presented data for TRAPPIST-1 but another system is also an attractive destination for would-be colonists: Proxima Centauri. It is less than 5 light years away, is our nearest star and has at least one planet in its orbit, Proxima Centauri b. Even though it looks like it might be a good candidate it has downsides. Unfortunately, because Proxima Centauri is a red dwarf star, the habitable zone is not a great distance from the star. This means habitable zone planets are likely to be hit by solar flares, that are common with red dwarf stars, and be tidally locked so that one side always faces the star.

64. To be truly attractive to colonist from Earth it is likely an exoplanet will need to have
    a) a gravity close to that of Earth, not too high, not too low
    b) a star with light similar to the Sun, not too red, not too blue
    c) be within range of a long haul colonist's ship
    d) no competition – no biosphere (no alien life forms to complicate colonisation)!

    Cameron and Holland have compiled a list of other criteria that could be used to make a short list for colonists to consider when the time comes to choose a destination.
    You can help them by adding two essential criteria for each sphere: **(3 marks)**

Sphere	**Essential criteria**
Exosphere	Stellar illumination suitable for an earthling friendly habitable zone
	Planetary gravity close to 1g, no nasty solar flares
Atmosphere	Oxygen / No toxic gases
	Ozone / Greenhouse gases
Hydrosphere	Water / Water cycle
	Potable water
Geosphere	Silicate rocks / No toxic minerals in abundance
	Easy to access ore bodies of essential elements Could be many others in this table, answers here indicative of best suggestions

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Integrity of Competition

If there is evidence of collusion or other academic dishonesty, students will be disqualified. Markers' decisions are final.