School ID

2017 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 2018).

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

Please note - students in Year 12 in 2017 are not eligible to attend the 2018 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:

2017 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 pages 52 to 56 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	50 multiple choice questions Each question worth one mark	50 marks
SECTION B	11 written answer questions Marks for each question are specified	30 marks

Total marks for the paper 80 marks

DATA & DEFINITIONS

Material supplied:

- Mohs hardness scale – page 3
- Universal constants - 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

Universal constants

- Standard gravity: g = 9.8 m/s^2
- Density of water: ρ_{H2O} = 1 g/cm^3
- Density of acetic acid (vinegar): ρ_{aa} = 1.05 g/cm^3

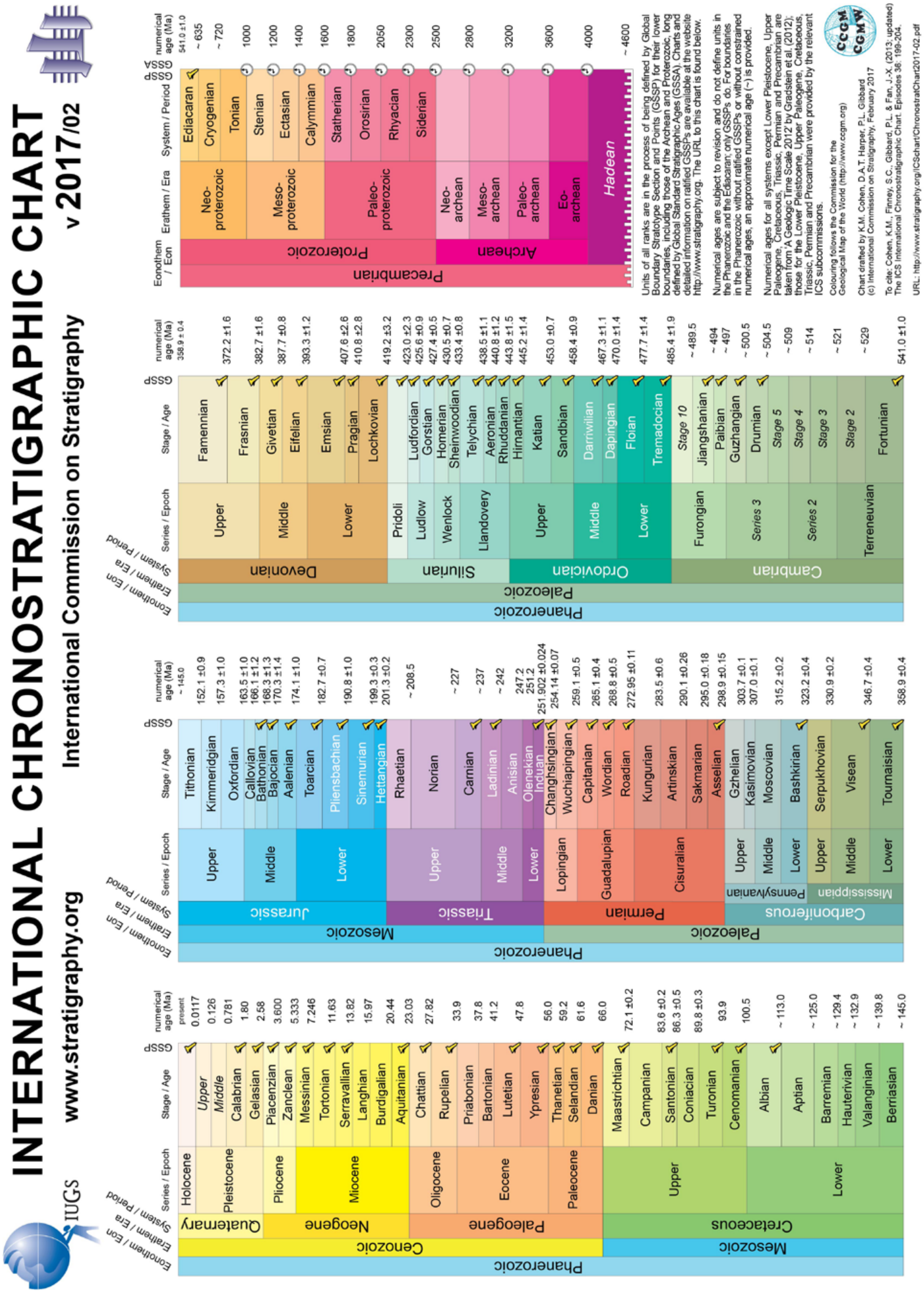
Periodic Table of the Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.01																	2 He Helium 4.00
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 51.99	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.63	33 As Arsenic 74.92	34 Se Selenium 78.97	35 Br Bromine 79.90	36 Kr Krypton 84.80
37 Rb Rubidium 84.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molibdenum 95.95	43 Tc Technetium 98.91	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.90	54 Xe Xenon 131.25
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.09	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium [208.98]	85 At Astatine 209.99	86 Rn Radon 222.02
87 Fr Francium 223.02	88 Ra Radium 226.03	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium 144.91	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.06	71 Lu Lutetium 174.97
89 Ac Actinium 227.03	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium 237.05	94 Pu Plutonium 244.06	95 Am Americium 243.06	96 Cm Curium 247.07	97 Bk Berkelium 247.07	98 Cf Californium 251.08	99 Es Einsteinium [254]	100 Fm Fermium 257.10	101 Md Mendelevium 258.1	102 No Nobelium 259.10	103 Lr Lawrencium [262]

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 …

The following information relates to questions 1 and 2.

Gabi Roe is a graduate geoscientist who has been invited back to help her former science teacher discuss minerals and rocks with the students. In reviewing her notes Gabi came across a strict definition of a mineral which read: *Minerals are naturally occurring inorganic crystalline solids. A crystalline solid is a solid material with atoms, molecules, or ions arranged in a highly ordered microscopic structure, forming a crystal lattice that extends in all directions.* She decided, as a way to start a class discussion, to create a list of materials found on Earth that meet this definition.
This is her list:

- $CaCO_3$
- H_2O
- Carbon
- NaCl
- SiO_2
- Mg_2SiO_4

1. Some students in the class thought one or more of these materials could not form an inorganic crystalline solid. Which student was correct?

   a. Jett was correct. He noted that carbon forms organic compounds that would rule out $CaCO_3$ and elemental carbon.
   b. Amber was correct. She noted salt dissolves in water and could not be a mineral.
   c. Jasper was correct. He claimed that all minerals contain silicon so only SiO_2 and Mg_2SiO_4 could be minerals
   d. Gemma was correct. She noted that all these materials form an inorganic crystalline solid somewhere on Earth.
   e. Gretal was correct. She noted that water is a liquid that can be found everywhere, so it cannot be a mineral.

2. Gabi pointed out that there are many exceptions to the strict definition of a mineral, often because not all inorganic solids found in rocks are crystalline. Sometimes the solid is amorphous; it has no highly ordered crystalline lattice. Gabi asked the students to suggest examples of materials they thought were minerals even though they were not crystalline. Which student used an example that really is a mineral that is not crystalline?

    a. Jett suggested opal; stating it was in fact an aggregate of non-crystalline spheres of hydrated silica.
    b. Amber proposed it was mica; stating that it breaks into microscopically thin sheets, so it cannot have a crystal structure.
    c. Jasper thought the iron and nickel in meteorites would not be crystalline because he thought they melted on the way down from space and cooled quickly when they landed.
    d. Gemma suggested bone because it is found as fossils in rocks but has an organic origin, proving that it cannot be crystalline.
    e. Gretal thought asbestos would be a good example because it forms as fibres and can be woven into a fabric so cannot be crystalline.

The following information relates to questions 3 and 4.

Expanding on her discussions with the class, Gabi also asked the class to think about rocks. Rocks are aggregates of minerals. Some rocks are made up of just one mineral; others contain more than one mineral. Gabi gave the students a list of rocks and asked them to divide the list into rocks that must have more than one mineral in them and rocks that can be made of just one mineral:

- Limestone
- Granite
- Sandstone
- Quartzite
- Marble
- Gneiss

3. Which student divided the above list of 6 rocks correctly?

   a. Jett divided them correctly into limestone and marble that are defined as single-mineral rocks that are easily cut and polished and granite, sandstone, quartzite and gneiss that are multi-mineral rocks that are hard to cut and polish.
   b. Amber divided them correctly into limestone and sandstone that are defined as single-mineral granular sedimentary rocks and granite, quartzite, marble and gneiss that are multi-mineral rocks composed entirely of interlocking crystals.
   c. Jasper divided them correctly into granite that is defined as a multi-mineral igneous rock and limestone, sandstone, quartzite, marble and gneiss that are single-mineral sedimentary rocks
   d. Gemma correctly divided them into granite and gneiss that are defined by the multiple minerals they contain and limestone, sandstone, quartzite and marble that can all be formed entirely from one type of mineral.
   e. Gretal divided them correctly into marble, quartzite and gneiss because they are all defined as single-mineral metamorphic rocks and limestone, sandstone and granite because they are all multi-mineral sedimentary rocks.

4. Gabi told the students some rocks in the list can form from the metamorphism of other rocks in the same list. Using A ➔ B to indicate metamorphism of A into B, she asked the students to group the six rocks into pairs. Which student's groups of pairs were totally correct?

   a. Jett listed 3 pairs:
      Sandstone ➔ quartzite, limestone ➔ marble & granite ➔ gneiss
   b. Amber listed 2 pairs:
      Granite ➔ gneiss & limestone ➔ quartzite
   c. Jasper listed 3 pairs:
      Gneiss ➔ granite, marble ➔ limestone & quartzite ➔ sandstone
   d. Gemma listed 2 pairs:
      Marble ➔ Limestone & sandstone ➔ granite
   e. Gretal listed 3 pairs:
      Sandstone ➔ quartzite, gneiss ➔ granite & limestone ➔ marble

The following information relates to questions 5 and 6.

Gabi was happy with how much the students enjoyed asking her questions. One tricky question was asked by Jett. He explained to her and the class that his grandfather works in a coal mine where the coal seams are known to be Permian in age. Sometimes his grandfather brings Jett interesting fossils that have been found in the mine. Jett wanted to know how it could be that between two layers of coal, which are formed from land-plant remains accumulating on the floor of a swamp, there was a layer of siltstone full of shells called brachiopods. In one large specimen, a group of brachiopods are clearly in their original life-position, along with some sea urchin and coral fossils. Before answering, Gabi gave each student the chance to propose an answer.

5. Gabi's answer requires no additional information for it to be a plausible explanation of how a layer of siltstone with brachiopods in it could be deposited between two layers of Permian period black coal. Which answer aligns with Gabi's solution?

   a. Jett thought it might be because some brachiopods live in freshwater. He suggested that during a brief change in climate the area became wetter, with the deeper river water drowning the land plants and providing a good environment for fresh-water brachiopods before once again drying out and returning to the swampy conditions that favoured the plants.
   b. Amber thought that brachiopods are only known to live in marine environments so the best explanation would be that a marine transgression occurred, drowning the swamp in sea water and allowing brachiopods to flourish before the sea regressed and the area returned to a plant-friendly swamp.
   c. Jasper suggested that the siltstone was the result of humans harvesting brachiopods from the near-by seashore and eating them in a swampy clearing. The discarded brachiopod shells were thrown in a pile and slowly buried in erosional silt from the human activity. After over-exploiting this resource the humans abandoned the area and it returned to being a plant dominated swamp.
   d. Gemma proposed that siltstone never occurs in the same sequence as coal, so the only possible explanation is a series of undocumented low angle thrust faults that have moved the siltstone into position between the coal seams. This would explain the unusual occurrence of siltstone and marine fossils with non-marine coal seams but extra mapping is needed to find the faults.
   e. Gretal thought the brachiopod rich siltstone might be the result of the erosion of a Cretaceous brachiopod-rich sediment in the highlands. A storm event washed the fossils and silt rapidly downslope and deposited both in the low-land swamp.

The following information relates to question 6.

Sometimes Permian period coal seams contain silty layers with beautiful fossil leaf impressions in them. Jett has also brought some of them to class. Gabi explained that these are *Glossopteris* leaves and that fossils of this group of woody seed-bearing trees and shrubs are found in Permian rocks in Australia, Antarctica, Africa, India and South America. She also challenged the students to explain why this group of plants can be found on all these continents given how far apart they are around the globe.

6. Which answer would receive Gabi's tick of approval, correctly explaining why these plants are found in Permian rocks in Australia, Antarctica, Africa, India and South America?

   a. Jett suggested all the continents were once joined up, allowing for easy seed dispersal across the landscape, but now the continents are spread across the globe due to plate tectonics.
   b. Amber proposed the seeds were dispersed by seed-eating birds that migrated between the continents.
   c. Jasper thought the seeds might have been dispersed in massive volcanic explosions sending ash and dust high into the atmosphere and drifting around the globe allowing the seeds to fall onto other continents.
   d. Gemma stated that sea floor spreading would have created a massive tsunami that washed lots of seeds into the ocean where they rafted from one land mass to the other.
   e. Gretal thought it more likely that the *Glossopteris* plants evolved independently on each continent and because they all lived in similar environments ended up looking the same, an example of convergent evolution.

7. The end of the Permian period is marked by the largest mass extinction event in Earth's history. Many lineages of plants and animals became extinct including ~96 % of all marine species and ~70 % of all terrestrial species. In the rock record all extinction events are always marked by:

   a. a thin iridium-rich sedimentary layer.
   b. the last occurrence of many species.
   c. a preceding increase in species diversity.
   d. massive volcanic eruptions.
   e. all of the above

8. Amber wanted to know what the yellow amber in her earring pendants really was. It looked like it had a little mosquito-like insect in it but she couldn't believe it was 50 million years old which is what the card that came with them said. What did Gabi correctly say?

   a. Gabi said yellow amber is really a kind of plastic first invented during the reign of Queen Victoria so that Prince Albert could amuse the queen with curious gifts appearing to contain the intact remains of whole animals that is, in reality, impossible.
   b. Gabi said yellow amber is formed by droplets of rapidly cooled basaltic magma, sometime known as Pele's tears. During some eruptions, small droplets of magma are thrown through the air and the resultant volcanic glass can trap insects it lands on. It is often clear enough to allow the insects to be seen.
   c. Gabi said the yellow amber in Amber's earrings is a wax material produced by sperm whales. When it washes up on the beach it is sticky enough to trap insects but then slowly hardens on exposure to the air.
   d. Gabi said yellow amber is fossilised tree resin or sap that sometimes traps insects and small animals in it before dropping into a swamp and being buried. Over time it slowly hardens due to chemical changes and preserves the whole insect or animal in the hard transparent material.
   e. Gabi said yellow amber is fossilised dinosaur blood. During fights to the death between large carnivores and herbivores of the Jurassic Period large clots of blood would sometimes land on insects and trap them in it before falling into a swamp. In the swamp, the iron in the blood would react to form yellow iron hydroxides. The blood would then solidify to preserve the trapped creatures.

9. Gabi confirmed that Amber's mosquito-like fossil, trapped in her amber earring, really is 50 million years old. Amber was excited to think that her fossil might have lived amongst the dinosaurs. Gretal didn't think the insect could have lived amongst the dinosaurs but Jett argued that Amber was correct. Who was right and why?

   a. Jett was right because dinosaurs became extinct during the Paleocene-Eocene Thermal Maximum (PETM) event.
   b. Gretal was correct because dinosaurs became extinct at the end of the Cretaceous period.
   c. Jett was correct because mosquitoes evolved before dinosaurs became extinct.
   d. Gretal was correct because mosquitoes could not pierce the hide of dinosaurs.
   e. Gretal was correct because dinosaurs evolved before trees.

10. Jasper said he really liked red coloured minerals and rocks. He asked Gabi to explain why Mars is a red planet, explaining that he hoped to live on Mars one day. He was excited to hear that Gabi's friend, Roxanne Stone, is currently studying Mars. He was even more excited when he received an email from Roxanne with the answer. Her email explanation was:

    a. Mars is red for much the same reason that many landscapes in Australia are red. Zinc in the environment rapidly oxidises to form the pink variety of the mineral smithsonite ($ZnCO_3$). This mineral is very stable and accumulates as a colouring pigment on surface landscapes and is good for preventing sunburn.
    b. Mars is red for much the same reason that many landscapes in Australia are red. The landscape absorbs infrared radiation and bare rock and sand easily re-radiate this wavelength, giving the vegetation-free landscapes of a distinct red colour.
    c. Mars is not really red. The Martian rocks absorb green wavelengths so they look purple if standing on Mars but the Martian atmosphere absorbs yellow light meaning that all the reflected light seen from Earth looks red.
    d. Mars is red for much the same reason that many landscapes in Australia are red. Iron in the environment rapidly reduces to a suite of iron (II) minerals with a range of red colours. These minerals are very stable and accumulate as colouring pigments on surface landscapes.
    e. Mars is red for much the same reason that many landscapes in Australia are red. Iron in the environment rapidly oxidises to form the red mineral hematite (Fe_2O_3). This mineral is very stable and accumulates as a colouring pigment on surface landscapes.

11. Jasper hopes to live on Mars one day but Roxanne pointed out that all Martian colonies have to be contained within domes because Mars has a very thin CO_2 atmosphere; it is too cold for liquid water and is hostile to life in many other ways. Roxanne explained that the lack of a magnetic field and associated magnetosphere is the reason why …

    a. Mars is red and dusty. The solar wind (high energy particles from the sun) oxidises things and stirs the dust up.
    b. Mars only has a very thin atmosphere. The solar wind (high energy particles from the sun) strips the atmosphere away.
    c. navigation on Mars is so hard.
    d. Martian soils are mostly toxic at the surface. The solar wind (high energy particles from the sun) contaminates everything with radioactive particles.
    e. Martian gravity is only 38 % that of Earth's gravity.

12. Gemma was curious to know why her favourite mineral, diamond, is easily broken into pieces along planes of weakness, known as cleavage planes, when it is also known as the hardest of all the natural minerals (according to Mohs hardness scale which tests how difficult it is to scratch a material). Gabi's explanation to Gemma was:

    a. Diamond's carbon atoms are packed into a crystal lattice where they are covalently bonded to each other to form a very strong structure that resists scratching better than anything else in nature. However, because of the way the atoms are packed, along certain planes within the crystal, there are less covalent bonds than other planes and those with less bonds are a little weaker than the rest, allowing the crystal to be broken along them.
    b. Diamond's carbon atoms are packed into a crystal lattice where they are hydrogen bonded to each other to form a very strong structure that resists scratching better than anything else in nature. Cleavage in diamonds only happens when there are lots of impurities on planes known as *Jeweller's Friends*.
    c. Diamond's carbon atoms are packed into a crystal lattice where they are ionically bonded to each other to form a very strong structure that resists scratching better than anything else in nature. However, along certain planes within the crystal there are some covalent bonds and those with covalent bonds are a little weaker than the rest and allow the crystal to be broken along them.
    d. Pure-carbon diamonds don't break. However, carbon and silicon are in the same group on the periodic table so along certain planes within the crystal there are planes of ionically bonded silicon and carbon atoms in a 1:1 ratio and those planes with silicon atoms are a little weaker than the rest, allowing the crystal to be broken along them.
    e. Diamonds don't actually have cleavage. All the carbon atoms in a diamond are double-bonded to other carbon atoms, making diamond really hard. In some planes the double bonds are partially ionic, allowing the crystals to break along them.

The following information relates to questions 13, 14 and 15.

Gretal loves pearls, mother of pearl and all things pearly looking. She has found out that pearls are made mostly of the calcium carbonate mineral aragonite but can also contain some calcium carbonate in the form of the mineral calcite. Pearls also contain some low density (less than 2 g/cm^3) organic material. Gretal has a pearl necklace that she thinks might be a fake made of glass or plastic and was wondering how a pearl could be tested to prove it is made of the right material. Gabi was cautious to point out that some tests might prove what it is made of but destroy it in the process. Gabi helped Gretal find this information (Table 1) about aragonite, calcite and other substances that might be used to make fakes:

	Aragonite	**Calcite**	**Glass beads**	**Plastic beads**
Vinegar response	Dissolves & bubbles form	Dissolves & bubbles form	No reaction	No reaction
Density (g/cm^3)	2.94	2.71	2.4 – 2.8	1.2 – 2.1
Streak test colour	White or colourless	White	None/white	None/bead colour
Mohs hardness	3.5 – 4.0	3.0	5.0 – 6.5	NA

Table 1: Properties of aragonite, calcite, glass beads and plastic beads.

13. Gretal decided to test her necklace with the least destructive test first, even though she has a few spare pearls from when the necklace was shortened that she could destructively test. With careful measurement of their weight and water displacement she established that her pearls have a density of 2.78 g/cm^3.
What has Gretal proved with this test?

   a. Gretel has proved that the necklace is made of a mixture of aragonite and calcite with organic material.
   b. Gretel has proved that the necklace is probably made of glass since it is too dense to be a mixture of aragonite and calcite with organic material.
   c. Gretal has proved that the necklace is made of either aragonite or calcite but not both.
   d. Gretel has proved that the necklace is not made of plastic beads but could be glass or made of a mixture of aragonite and calcite with or without organic material.
   e. Gretal has not proved anything.

The following information relates to question 14.

Gretal purchased a pearl necklace that was falling apart at a garage sale for fifty cents. She placed two of the pearls in some vinegar and made careful observations for several hours. She later told her Facebook friends she that was amused to discover her new pearls were actually a mixture of both fake and real peals.

14. What did Gretal observe when she placed the pearls in the vinegar?

    a. Gretel observed that both pearls floated but one of them gently fizzed to produce bubbles.
    b. Gretal observed that both pearls gently fizzed to produce bubbles but only one of them floated.
    c. Gretal observed that one pearl gently fizzed to produce bubbles and neither of them floated.
    d. Gretal observed that no fizzing or bubbles were produced but one of the pearls floated.
    e. Gretal observed that no fizzing or bubbles were produced and neither pearl floated.

15. Gretal's friend, Hans, has a small sphere he found in the garden when he was looking for white pebbles to mark the edge of the garden path. He thinks it's a pearl. How did Gretal demonstrate to Hans that his 'pearl' is probably a marble made of glass?

    a. Gretal placed it in vinegar and it didn't dissolve, demonstrating it is probably made of glass because glass does not dissolve in vinegar.
    b. Gretal rubbed it on a streak plate. The white mark it left demonstrates it is probably made of glass, not calcium carbonate minerals.
    c. Gretal used water displacement to demonstrate it has a density of 2.75 g/cm^3, a value consistent with it probably being glass, not a mixed calcium carbonate minerals typical of pearls.
    d. Gretal scratched it with quartz but could not scratch it with fluorite, proving it has a hardness consistent with it probably being glass, not a calcium carbonate mineral.
    e. Gretal placed it in vinegar and it began to dissolve, demonstrating it is probably made of glass because glass is more likely to react with acid after a long time buried in garden soil.

The following information and Figure 1 relates to questions 16, 17 and 18.

Roxanne Stone graduated with a geoscience major and dreams of working on projects in deep space. She has already found work with the Martian colonists and is currently in orbit studying micro-quakes on Phobos while conducting remote sensing surveys of the Martian soil.

Analysis of the unconsolidated Martian surface materials (called regolith, not soil) was conducted by the pre-colonisation robots Spirit, Opportunity and Curiosity (Figure 1). Martian colonists now have confirmed these analyses are typical of most Martian regoliths. Since colonists must grow their own food in the regolith knowing what is in it is important. Roxanne's friend, Tracee LeMents, is an agronomist in the recently established farm dome designed to feed the new underground colony of New London. The regolith there is most like those analysed by the Spirit Rover. In addition, water in Martian regolith is found in hydrated minerals and as intergranular ice. Hydrated minerals are detected by different instruments but are present at all 3 sites. Water, as ice, is mostly present in the sub surface of the polar regions, not these 3 sites.

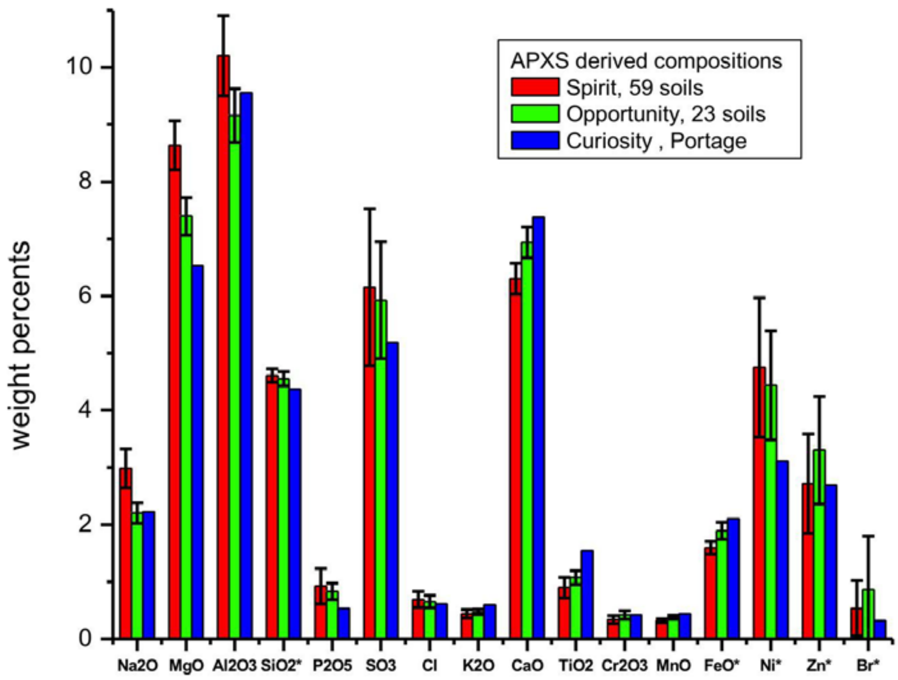


Figure 1: Elemental composition of typical Martian soils determined by Alpha Particle X-ray Spectrometer (APXS) at three landing regions on Mars: Spirit Rover at Gusev Crater, Opportunity Rover at Meridiani Planum, and Curiosity Rover at Gale Crater. Major elements are reported in weight percent as oxides. Error bars indicate the variations for the given number of soils measured by Spirit and Opportunity. Data from Curiosity is for only one site known as Portage.
Note: concentrations of silicon dioxide & iron oxide are divided by 10, and nickel, zinc & bromine levels are multiplied by 100 to enable ease of graphing. Image source: NASA/JPL-Caltech/University of Guelph 2012. https://photojournal.jpl.nasa.gov/catalog/PIA16572

The following information relates to question 16.

Roxanne and Tracee share a passion for old sci-fi movies. In one, called *The Martian,* potatoes grown in the soil – with the help of human excrement – keep the hero alive. Roxanne was curious to know if the movie had any scientific credibility and asked Tracee about it. Having grown up in Australia where the soils are phosphorus deficient she was especially interested in this element. Tracee told Roxanne potatoes need 25 parts per million (ppm) available elemental phosphorus for optimal productivity. They also need at least 10 ppm to avoid nutrient deficiency impediments to growth. She also noted that not all regolith phosphorus is bio-available.

16. Assuming there was no other fertiliser available, human or otherwise, would the regolith at New London be able to grow more than one crop of potatoes if only 1 % of its phosphorus is bio-available and each crop removes 10 ppm from the soil?

    a. The soil is ~1wt% P_2O_5 which is ~0.44 wt% elemental P or 4400 ppm. Given 1% is bio-available there is 44 ppm for potato growth. Assuming all other essential elements needed for growth are also present there is enough phosphorus at 1 % bio-availability to grow more than 1 crop of potatoes without deficiency.
    b. The soil is ~1wt% P_2O_5 which is ~0.44 wt% elemental phosphorus or 4400 ppm. Given 1% is bio-available there is only 4.4 ppm for potato growth. Even assuming all other essential elements needed for growth are also present there is not enough phosphorus at 1 % bio-availability to grow potatoes.
    c. The soil is ~1 wt% P_2O_5 which is ~0.22 wt% elemental P or 2200 ppm. Given 1 % is bio-available there is 22 ppm for potato growth. Assuming all other essential elements needed for growth are also present there is only enough phosphorus at 1 % bio-availability to grow one crop of potatoes.
    d. The soil is ~0.5 wt% P_2O_5 which is ~0.22 wt% elemental phosphorus or 2200 ppm. Given 1 % is bio-available there is only 4.4 ppm for potato growth. Even assuming all other essential elements needed for growth are also present there is not enough phosphorus at 1 % bio-availability to grow potatoes.
    e. It is impossible to calculate.

The following information and Figure 2 relates to question 17.

One of Roxanne's projects while working on Mars is to locate ore deposits or places where the regolith is enriched in elements suitable for extraction. If suitable materials can be found it should be possible to build machines capable of extracting resources from the atmosphere, regolith and rocks that can then be used to 3D print useful items. Polyproplene $(C_3H_6)_n$ and polyethylene $(C_2H_4)_n$ are plastic polymers used to make many common items that will be needed on Mars.

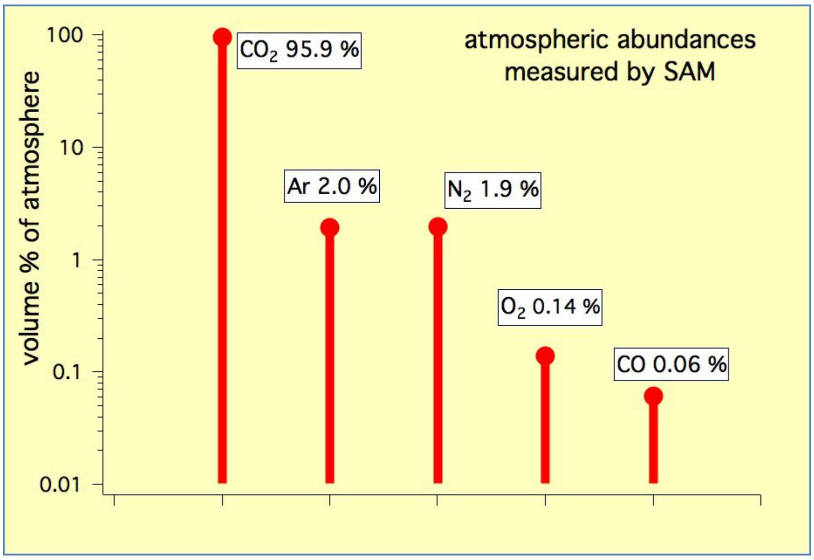


Figure 2: The percentage abundance of five gases in the atmosphere of Mars that may prove to be useful resources for Martian colonists. The concentrations were measured by the Quadrupole Mass Spectrometer instrument of the Sample Analysis at Mars (SAM) instrument suite on NASA's Mars rover in October 2012. The graph uses a logarithmic scale for volume percentage of the atmosphere so that these gases with very different concentrations can all be plotted. Any other gases present in the atmosphere are present at such low concentrations that they cannot be regarded as a useful resource for Martian colonists.
Image courtesy of NASA: https://photojournal.jpl.nasa.gov/catalog/PIA16460

17. If the data provided is typical of the atmosphere and all Martian regoliths where will the machines get the raw materials from on Mars to make plastic items in a 3D printer?

   a. Everything the machines will need is in the soil.
   b. The machines will need to extract carbon from the atmosphere and hydrogen from water imported from Earth.
   c. The machines will need to extract carbon from the atmosphere and hydrogen from hydrated minerals in the soil.
   d. The machines will need to extract carbon from carbonate minerals in the soil and hydrogen from water vapour in the atmosphere.
   e. The machines won't work because there is no carbon in the soil samples.

18. Magnesium is a very useful light weight metal. If machines could extract it from Martian soil, which site would be the best one to locate a processing plant at?

    a. The Spirit site.
    b. The Opportunity site.
    c. The Curiosity site.
    d. All sites are equally as good given the variations indicated by error bars.
    e. Magnesium is not present in Martian soils and will need to be imported.

The following information and Figure 3 relates to questions 19, 20, 21, 22 and 23.

Roxanne is 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. Roxanne shared this with Tracee which led to a conversation about another old movie; *Europa Report*. The movie was well received when released and was widely acclaimed as having put the science back in science fiction.

According to the latest data, Europa:

- is the 6^{th} largest moon in the Solar System and is only slightly smaller than Earth's Moon
- has a mean radius of 1560 km
- has a mass of 4.7998×10^{22} kg
- completes an orbit of Jupiter in 3.55 Earth-days
- has a tenuous oxygen atmosphere with a surface pressure of 10^{-12} bar
- has a surface temperature ranging from:
    - ~50 K at the poles to
    - ~125 K at the equator

Note: Water ice at these temperatures is as hard as granite.

19. In the movie *Europa Report*, one of the landing crew analysing the crust remarks that the surface ice-rocks appear to be made of a particular phase of ice. Roxanne was surprised that the script was accurate on this point but noted it was only accurate if they landed at one of the poles! What phase of ice did the script mention?

    a. The script must have mentioned Ice Ih.
    b. The script must have mentioned hexagonal Ice XI.
    c. The script must have mentioned orthorhombic Ice XI.
    d. The script must have mentioned Ice X.
    e. The script must have mentioned Ice XV.

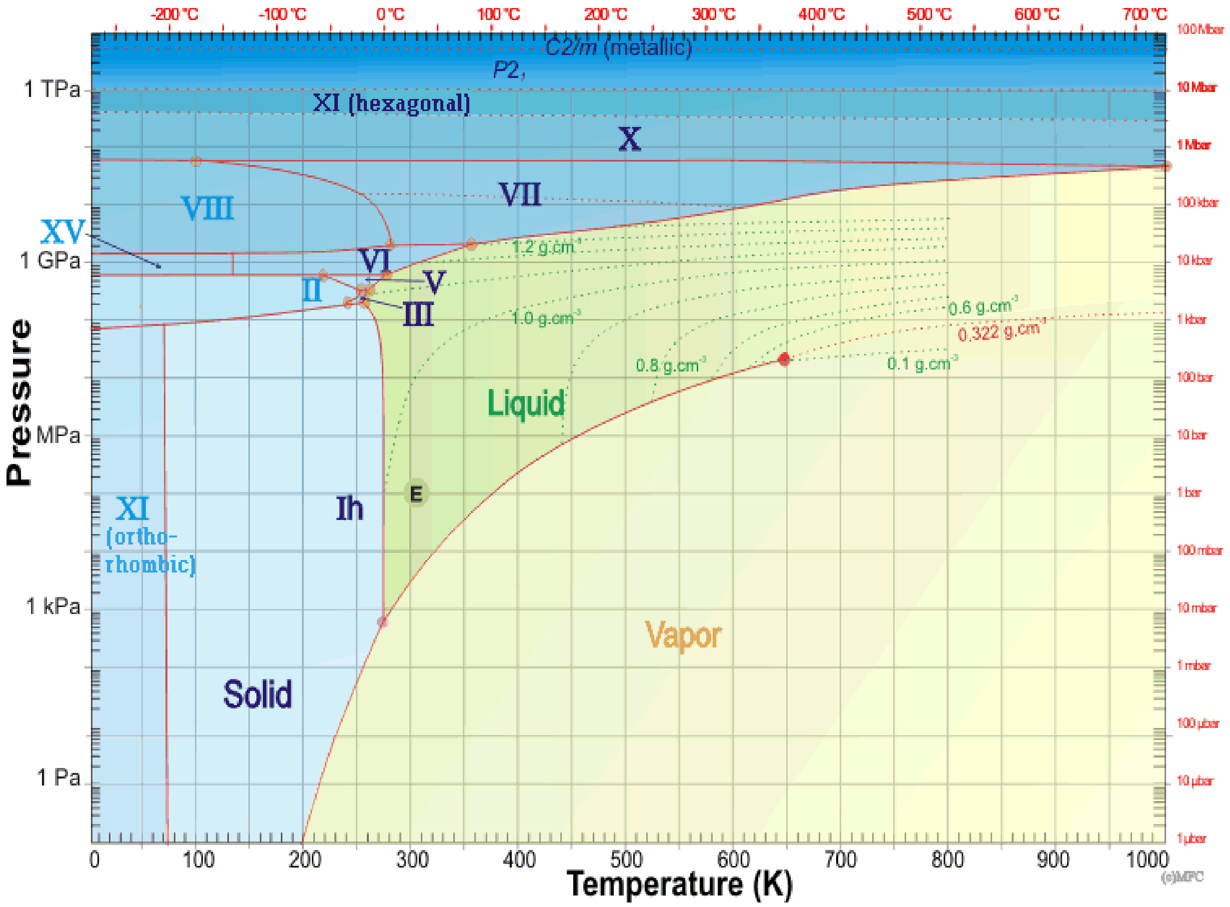


Figure 3: Log-lin pressure–temperature phase diagram of water.

The Roman numerals indicate various ice phases (Ice II, VII etc.).

The E on the graph represents Earth at a point on the surface where water is always a liquid.

Note 1: The gradients of phase boundaries present below 1 μbar do not change as the pressure approaches zero.

Note 2: 1 μbar = 10^{-6} bar.

Note 3: Water freezes at 0^{o}C (273.15 K) and boils at 100^{o}C (373.15 K) at a pressure of 1 bar.

Modified from: http://www1.lsbu.ac.uk/water/water_phase_diagram.html

20. In the movie *Europa Report*, the landing plan was to put down next to a chaotic region of surface blocks. The Rathmons Chaos and the Narbeth Chaos are 25^{o} north and south of Europa's equator respectively. Assuming a linear thermal gradient at the surface from the equator to the poles, what surface temperature ± 5 K would Roxanne expect to find if she is selected to crew the mission, land on Europa and explore the Narbeth Chaos?

   a. ~55 K
   b. ~75 K
   c. ~105 K
   d. ~115 K
   e. ~120 K

The following information and Figure 4 relates to questions 21 and 22.

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.

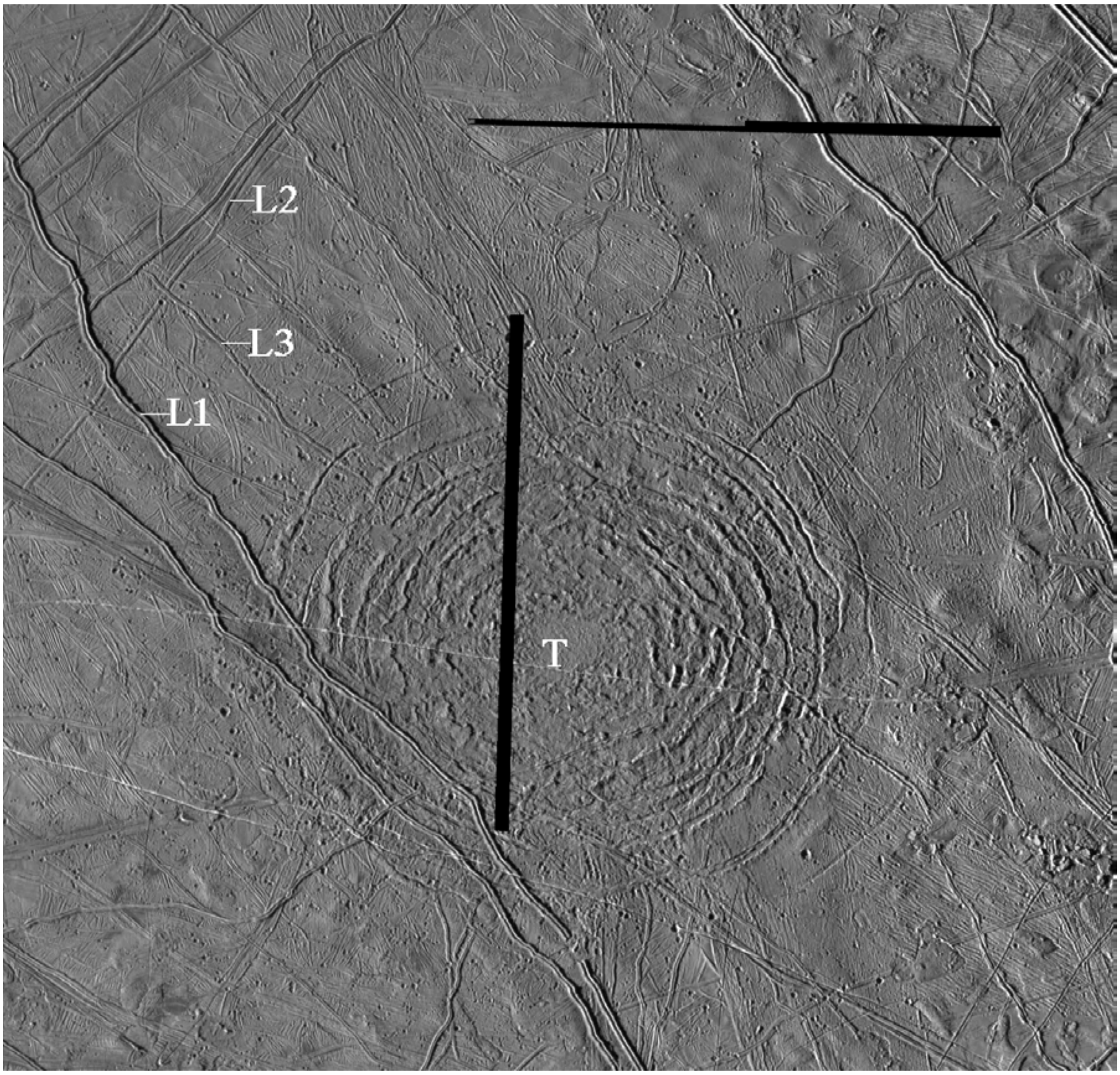


Figure 4: The Tyre multi-ring structure on Europa.

Note 1: Tyre multi-ring structure is marked with an T central to the rings in this image.

Note 2: Three linear features are marked L1, L2 and L3.

Note 3: The black lines are areas of missing data.

Image (modified) courtesy of NASA/JPL; http://ciclops.org/view.php?id=4245&js=1.

21. What is the most likely cause of the Tyre multi-ring structure (T)?

   a. It has most probably been formed by a hot spot volcano.
   b. It has most probably been caused by the landing blast of a rocket ship.
   c. It has most probably been caused by a granitic intrusion.
   d. It has most probably been formed by a cryo-volcano.
   e. It has most probably been caused by a meteorite impact.

22. What is the order of events, from oldest to youngest, that created structures L1, L2, L3 and T?

   a. L2, L3, T, L1
   b. L1, L2, L3, T
   c. L3, L1, T, L2
   d. T, L2, L3, L1
   e. T, L3, L2, L1

The following information relates to question 23.

Europa is the smallest of the four Galilean moons. In order of distance from Jupiter they are Io (the closest), Europa, Ganymede and Calisto. These moons are the largest moons of Jupiter and the inner three are in a 4:2:1 orbital resonance with each other with Io having the shortest orbital period.

23. If Roxanne is selected to crew the mission and land on Europa for a 10 Earth-day mission how many times will she see the volcanoes on Io up close when Io and Europa are in conjunction (the closest they can be), assuming the landing on Europa is timed so that the two moons are as far apart as they can be?

   a. She will see the volcanoes of Io once up close.
   b. She will see the volcanoes of Io twice up close.
   c. She will see the volcanoes of Io three times up close.
   d. She will see the volcanoes of Io four times up close.
   e. She will never see the volcanoes of Io up close.

The following image is Figure 5 and relates to questions 24, 25, 26 and 27.

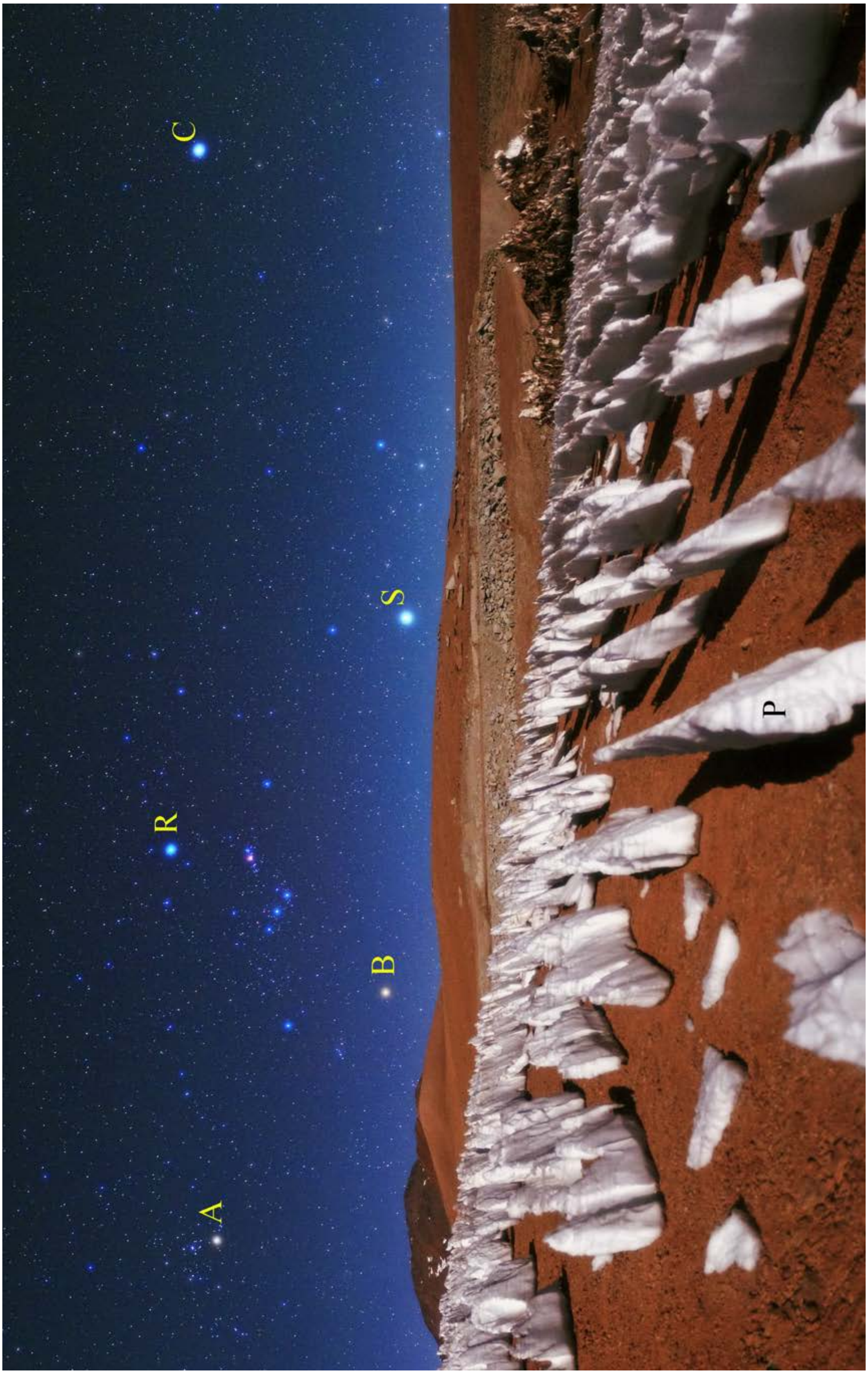


Figure 5: *Nieve penitentes* (P) photographed in the Atacama Desert, looking directly East, from a location with latitude S 23°01′09″ & longitude W 67°45′12″ on the Chajnantor plateau, ~60 km east of San Pedro de Atacama, Chile.

The photograph was taken in 2011.

Modified photograph courtesy of Babak A. Tafreshi.

Note 1: A number of bright stars are clearly visible: C=Canopus, S=Sirius, R=Rigel, B=Betelgeuse & A=Aldebaran.

Note 2: The Atacama Desert is the driest non-polar desert on Earth, precipitation of any kind is rare.

Note 3: The Chajnantor plateau is approximately 5000 metres above sea level and is home to the Llano de Chajnantor Observatory complex.

The following information and Figure 5 relates to questions 24 and 27

Roxanne's friend, Kimberley Piper, has also applied for the Europa mission. He is an expert on ice and especially ice structures found in some places on Earth called *nieve penitentes*. They are the result of physical processes acting on ice packs formed from snowfall (Figure 5).

24. What physical process has acted on the ice pack to form the *nieve penitentes*?

    a. The icy snow has melted in the sunshine but areas under shadows cast by speckled clouds didn't warm up enough to melt and have been left behind as pinnacles of ice. The water has rapidly run-off down slope with no infiltration.
    b. The icy snow has sublimated (evaporated without melting) on the peaks in the sunshine under high altitude conditions where the air is very cold, dry and at low pressure. Meltwater in the troughs infiltrated without runoff.
    c. The icy snow has been recycled from within the soil by magnetic termites, well known for building pinnacle structures aligned with the movement of the sun.
    d. The icy snow has melted because this location is in the South American Andes, a mountain range built by active volcanism. The pinnacles are areas where the ice didn't warm up as fast because of boulders in the soil. The water has rapidly run-off down slope with little to no infiltration.
    e. The icy snow melted to form pinnacles after herds of llama trampled the fresh snow pack, forming dense areas that melt slower than untrampled areas. The water has rapidly run-off down slope with no infiltration.

25. The Queensland town of Emerald is located in semi-arid country at latitude S 23°31′0″ and longitude E 148°09′0″. Assuming the night sky was clear, did the residents of Emerald have an opportunity to see the same arrangement of bright stars in the night sky as the photographer did in the Atacama Desert on the same evening in 2011?

    a. Yes, because the latitude of the two locations are similar so they should have seen the same arrangement of stars on the same evening thanks to the planet's rotation.
    b. No, because the longitudes of the two locations are too different for the same arrangement to be seen on the same evening even if the latitudes are similar.
    c. Yes, but only if they climbed to an altitude of ~5000 metres above sea level and looked west.
    d. No. People on different continents always see a different arrangement of stars.
    e. Yes, because the longitude difference allows for the same view to be seen from different continents.

26. Sirius is the brightest star in the night sky. It has a luminosity ($L_\odot$) 25 times that of the Sun ($L_\odot = 1$). However, astronomical measurements show that Aldebaran has a $L_\odot$ of 518, Canopus a $L_\odot$ of 14,800, Rigel a $L_\odot$ of 40,000 and Betelgeuse a $L_\odot$ of 55,000. Why is Sirius the brightest star in the night sky when other stars are much more luminous?

   a. Sirius was far more luminous but has since burnt up all its hydrogen fuel. We are still seeing this as massive brightness even though its luminosity has now diminished.
   b. Sirius is not really a star but a planet with a highly reflective surface just like Venus.
   c. The other stars all have large numbers of exoplanets in orbit around them that cause them to look dimmer than they really are. The $L_\odot$ is measured by instruments that ignore the dimming effect that we see.
   d. Sirius is generally less luminous except in those wavelengths humans can see. In those wavelengths it is brighter than other stars and so is perceived as the brightest star in the night sky when it really isn't.
   e. Sirius is only 8.6 light years from Earth so the combination of its luminosity and proximity makes it look brighter than the more luminous but much more distant stars.

27. The long axis of the *nieve penitentes* pinnacles is orientated East-West. Given the photograph in Figure 5 is taken looking directly east, what time of year was the photograph probably taken?

   a. At Autumn Equinox, March 21.
   b. After Autumn Equinox but before Spring Equinox, around May-June.
   c. At Spring Equinox, September 23.
   d. After Spring Equinox but before Autumn Equinox, around October-November.
   e. Summer Solstice, December 22, or Winter Solstice, June 22, because the photograph would look the same at either time.

Meanwhile, back on Earth …

The following information and Figure 6 relates to questions 28 to 37 inclusive.

A group of keen students have volunteered to help their lecturer and renowned tephrochronologist, Professor Lois Underhill, with deep sea drilling sample collection, data logging, and interpretation. Andy Syght, Ashleigh Hammer, and Ellie Mints are excited to help her analyse volcanic ash geochemistry with the aim of correlating tephra layers across the region and reconstructing the 200,000 year eruptive history of the volcanic arc. Their friends, Shelley Waters and Wade Beachly, plan to help them constrain the stratigraphy using fossil shells of microfauna and any other useful fossils found in the drill cores.

Before they set sail from Swedish Harbour, Captain Seymour Wistas provided them with a map of their intended route and drill target positions (Figure 6). They also collected an ancient ash sample, which they note is the only fine ash-fall deposit exposed, from the cliffs near the harbour to practice using their equipment. Professor Underhill informed them that their analysis was an excellent match for the key regional marker bed, the Old Scarecrow tephra (OSCt), which is well studied and known to cover the entire area of their cruise. It has a $^{40}Ar/^{39}Ar$ radiometric date of 95,000 ± 900 years. They logged this data in Table 2 (page 31).

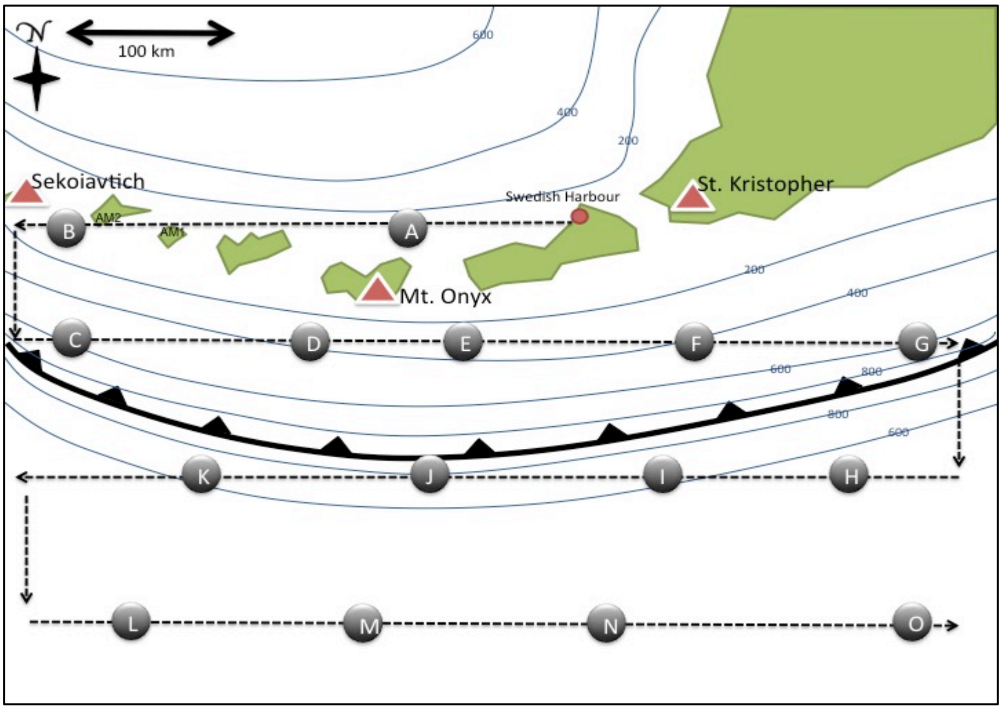


Figure 6: Map of the Ash Mountains Arc and scientific cruise route with targeted deep sea drilling locations (A to O) and onshore sample sites AM1 and AM2. The entire arc is built from active stratovolcanoes, all of which have erupted within the last 10,000 years. Holocene Plinian eruptions are marked with labelled triangles. The sawtooth pattern denotes the subduction zone and indicates the dip direction of the down-going plate. The thin numbered lines show bathymetry with water depth in metres below sea level.

The following information relates to questions 28.

Prior to embarking on their scientific cruise from Swedish Harbour, Andy and Ashleigh did some background reading about the volcanic arc they were heading out to study. They discovered that although the entire chain of islands is composed of active volcanoes, only three have had Plinian eruptions (explosive eruptions with gas and ash columns that extend into the Stratosphere) during the Holocene. They marked these on their map (Figure 6) with labelled triangles.

28. Why would this information be important for their voyage?

    a. Explosive volcanoes are extremely dangerous and they feel it is important to show the captain that he should chart a different course.
    b. Volcanoes that haven't erupted explosively during the Holocene are an even greater potential threat than those that have and they fear the entire journey may be threatened.
    c. These are the only volcanoes in the region that are of interest on this voyage as only the highly explosive eruptions eject ash to elevations high enough to create wind-blown ash deposits far off-shore.
    d. Only volcanoes that erupt explosively form high peaks, therefore these three mountains will provide the best landmarks for triangulating their position when drilling the sediment cores.
    e. Volcanic explosions create giant craters which trap fresh water and make excellent habitat for fish, which would be invaluable resources should they become stranded on one of the islands.

29. What physical structure would you expect to find between the 800 metre bathymetry lines as shown on the Map (Figure 6)?

    a. A long narrow depression known as a trench that marks the subduction zone.
    b. A chain of hot spot volcanoes marking the subduction zone.
    c. A ridge like structure marking the subduction zone with a central depression of upwelling magma forming pillow lava on the sea floor.
    d. A massive vertical fissure marking the subduction zone that is glowing red-hot thousands of meters below the 800 metre ledge.
    e. A featureless plain, disguising the subduction zone, that is covered in fine mud and populated by benthic (bottom dwelling) marine animals such as brittle stars.

30. Ashleigh was concerned about the planned route for the voyage as there is only a single targeted sample site to the north of the arc. Captain Wistas informed her that the waters are simply too rough to hold steady and complete deep water drilling any further north. She raised this concern with Professor Underhill who has more extensive knowledge of the geologic setting and regional conditions.

What did Professor Underhill tell Ashleigh to ease her mind?

a. Subduction would have carried all sediments from the north under the volcanic arc anyway, so there's no point in wasting time and money sampling there
b. The turbulent waters to the north would prevent ash from settling to the ocean floor, so there's no point in looking for them there.
c. The very cold waters to the north are completely frozen over in winter, therefore ash fall would only be recorded from the few warmer months each year and would confuse their data set.
d. The strong regional wind direction is towards the south, therefore very little ash has been deposited to the north.
e. Geologic sampling is never ideal and interpolation is always necessary.

The following information relates to question 31.

Wade and Shelley also did some background reading about marine microfauna and discovered that there are two species of planktonic foraminifera (open ocean single-celled organisms that are only found floating in waters greater than 200 meters deep) worth keeping a trained eye out for because their shells do end up in some deep sea sediments after they die: *Globorotalia crassaformis*, which disappears at 0.1 Ma (million years before present) and *Globigerinoides ruber* which has its first appearance at 0.12 Ma.

31. What time period are Wade and Shelly able to delimit using these two species?

a. Only events older than 120,000 years.
b. Only events younger than 100,000 years.
c. Only events that occurred during the Neogene.
d. Only events that occurred between 120,000 – 100,000 years ago.
e. They will not be able to constrain the timing of any volcanic events because the ash would wipe out all benthic (bottom dwelling) microfauna.

The following information relates to question 32.

Captain Wistas has no background in Earth Science, so he was very curious about the work the students were doing and peppered them with questions every evening. Before they reached the first drill site, he asked Ellie how she could identify which volcano each ash layer erupted from. She explained that every volcanic event has a unique chemical composition that can be used like a fingerprint to identify and correlate samples found at far distant locations. He found this fact fascinating and wondered if there is a way to tell how far the ash travelled from the volcano.

32. What is the correct answer she gave him?

    a. Every volcanic event ejects a mixture of ash and larger particles (collectively called tephra) with a unique mineralogy. Each mineral falls out of the ash cloud at a known distance from the source.
    b. Tephra is dispersed primarily by the wind, therefore the thickness of the ash fall deposits and size of the tephra particles decreases rapidly with distance from the vent.
    c. Tephra is dispersed primarily by the wind, therefore the thickness of the ash fall deposits and size of the tephra particles increases rapidly with distance from the vent.
    d. Tephra is dispersed primarily by the wind, therefore the thickness of the ash fall deposits decreases while the size of the tephra particles increases rapidly with distance from the vent.
    e. There is no scientifically valid method to do so, but she thinks she will be able to guess based on visual observations.

33. What geological hazards would residents of Swedish Harbour potentially be subjected to?

    a. Earthquakes.
    b. Volcanic eruptions and ash fall.
    c. Tsunami.
    d. Landslides.
    e. All of the above.

The following information, Figure 7 and Table 2 relates to question 34.

The cruise passed close enough to the two islands directly east of Sekoiavitch for the students and Professor Underhill to visit via a small boat. They found cliffs along the margin of each island built of layered lava flows, lahars (volcanic mudflows), and coarse block and ash deposits. They also discovered and sampled a series of fine ash layers within these deposits. Andy was not very confident in his drawing skills, but Professor Underhill encouraged him to make detailed geologic sketches of the two sites from the boat while Ashleigh and Ellie collected ash samples (Figure 7). Based on colour, character and thickness of the ash layers, he presumes that the Old Scarecrow tephra is present at both sites.

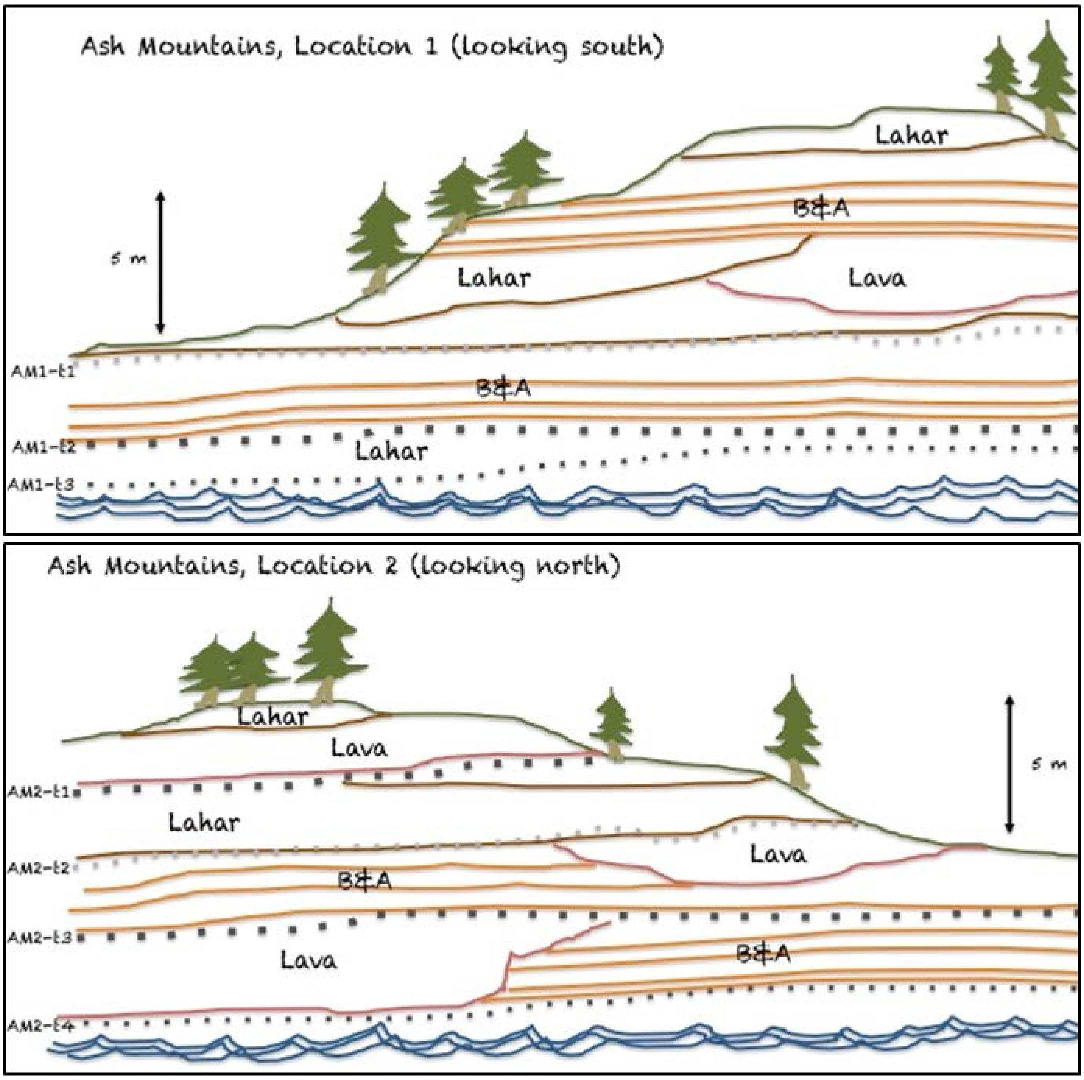


Figure 7: Andy Syght's field notebook sketches of onshore locations AM1 and AM2. Tephra layers are denoted with dashed lines, the colour and thickness of which are representative of his field observations. B&A stands for block and ash deposit.

Onshore samples	SiO_2	TiO_2	Al_2O_3	FeO_{TOT}	MnO	MgO	CaO	Na_2O	K_2O
Swedish Harbour (OSCt)	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
AM1-t1	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
AM1-t2	60.96	0.78	17.71	5.49	0.16	1.50	3.90	5.36	3.81
AM1-t3	60.06	0.81	17.83	5.94	0.16	1.81	4.34	5.14	3.56
AM2-t1	52.71	0.92	19.43	8.28	0.17	3.84	8.87	3.55	1.88
AM2-t2	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
AM2-t3	60.96	0.78	17.71	5.49	0.16	1.50	3.90	5.36	3.81
AM2-t4	60.06	0.81	17.83	5.94	0.16	1.81	4.34	5.14	3.56

Table 2: Major element geochemistry from onshore tephra samples in weight percent. (FeO_{TOT} is the total weight percent of iron oxides in all oxidation states.)

34. Do Andy's sketches (Figure 7) and the analyses in Table 2 confirm or contradict his hypothesis that the Old Scarecrow tephra is present at both sites?

a. They confirm his hypothesis as the top ash layer at each site must be the OSCt.
b. They confirm his hypothesis as layers AM1-t1 and AM2-t2 are geochemically identical to the OSCt.
c. They contradict his hypothesis because the top ash layer at each site looks different.
d. They contradict his hypothesis because there are different numbers of ash layers at each location.
e. They can neither confirm nor contradict his hypothesis because there is too much variability in the data at AM2 to draw any valid conclusions.

The following information, Figure 8 and Table 3 relates to questions 35, 36 and 37.

After weeks of seafaring and drilling, the crew amassed a significant data set. They tabulated and plotted their data as shown in Table 3 and Figure 8. Ashleigh and Andy were particularly happy to note that their marker bed, the Old Scarecrow tephra, was present in every drill core as expected, but Captain Wistas was perplexed as to why it wasn't present at the same depth in all cores if it represents a geologically instantaneous event.

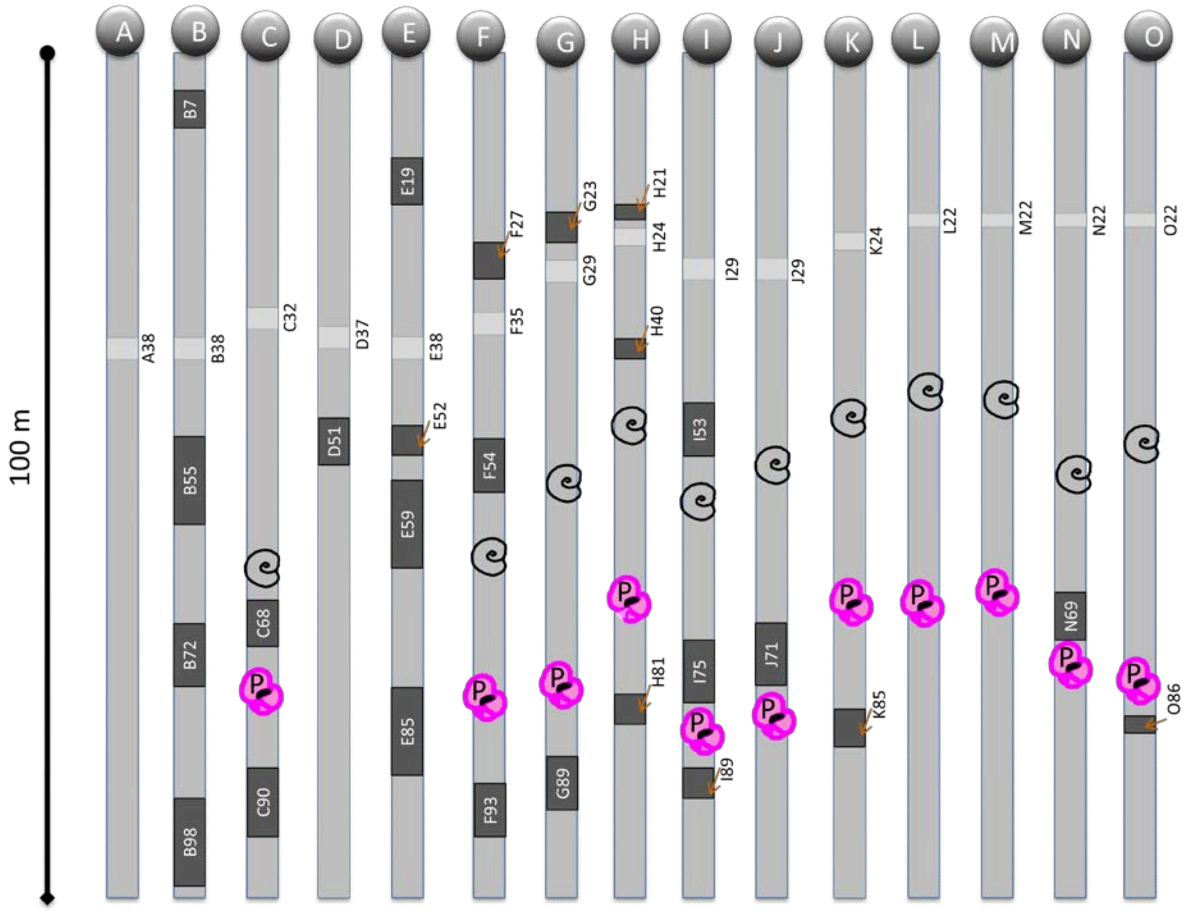


Figure 8: Scaled diagram of drill core sediments recovered from 15 holes. The circled letters at the top of each column correspond to the drill site in Figure 6. The labelled regions within each column denote the hole (letter) depth (number) and relative thickness (width of coloured bar) of ash layers and correspond directly to geochemistry data in Table 3. The spirals indicate the last appearance of *Globorotalia crassaformis* within the column and the pink spirals (marked with a P) denote the first appearance of *Globigerinoides ruber* within the column.
Note: *Globorotalia crassaformis* and *Globigerinoides ruber* are planktonic foraminifera found floating in open ocean in waters greater than 200 meters deep.

Core	Sample ID	SiO_2	TiO_2	Al_2O_3	FeO_{TOT}	MnO	MgO	CaO	Na_2O	K_2O
A	A38	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
B	B7	52.71	0.92	19.43	8.28	0.17	3.84	8.87	3.55	1.88
	B38	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	B55	60.96	0.78	17.71	5.49	0.16	1.50	3.90	5.36	3.81
	B72	60.06	0.81	17.83	5.94	0.16	1.81	4.34	5.14	3.56
	B98	62.61	0.46	17.47	4.69	0.12	2.33	6.32	4.44	1.39
C	C32	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	C68	60.06	0.81	17.83	5.94	0.16	1.81	4.34	5.14	3.56
	C90	62.61	0.46	17.47	4.69	0.12	2.33	6.32	4.44	1.39
D	D37	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	D51	60.96	0.78	17.71	5.49	0.16	1.50	3.90	5.36	3.81
E	E19	65.63	0.92	15.99	4.65	0.17	1.36	3.65	4.86	2.49
	E38	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	E52	60.96	0.78	17.71	5.49	0.16	1.50	3.90	5.36	3.81
	E59	67.09	0.78	15.97	3.63	0.17	1.16	3.32	5.29	2.37
	E58	70.40	0.54	14.92	2.63	0.14	0.59	1.98	5.74	2.96
F	F27	61.60	0.59	17.00	5.44	0.13	3.48	6.95	3.74	0.94
	F35	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	F54	67.09	0.78	15.97	3.63	0.17	1.16	3.32	5.29	2.37
	F93	63.36	0.56	16.52	5.20	0.13	3.04	6.25	3.81	0.99
G	G23	61.60	0.59	17.00	5.44	0.13	3.48	6.95	3.74	0.94
	G29	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	G89	63.36	0.56	16.52	5.20	0.13	3.04	6.25	3.81	0.99
H	H21	61.60	0.59	17.00	5.44	0.13	3.48	6.95	3.74	0.94
	H24	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	H40	67.09	0.78	15.97	3.63	0.17	1.16	3.32	5.29	2.37
	H81	63.36	0.56	16.52	5.20	0.13	3.04	6.25	3.81	0.99
I	I29	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	I53	67.09	0.78	15.97	3.63	0.17	1.16	3.32	5.29	2.37
	I75	70.40	0.54	14.92	2.63	0.14	0.59	1.98	5.74	2.96
	I89	63.36	0.56	16.52	5.20	0.13	3.04	6.25	3.81	0.99
J	J29	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	J71	70.40	0.54	14.92	2.63	0.14	0.59	1.98	5.74	2.96
K	K24	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	K85	62.61	0.46	17.47	4.69	0.12	2.33	6.32	4.44	1.39
L	L22	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
M	M22	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
N	N22	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	N69	70.40	0.54	14.92	2.63	0.14	0.59	1.98	5.74	2.96
O	O22	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	O86	63.36	0.56	16.52	5.20	0.13	3.04	6.25	3.81	0.99

Table 3: Major element geochemistry from each ash layer found within the drill cores.

(FeO_{TOT} is the total weight percent of iron oxides in all oxidation states.)

35. How did the students correctly explain to Captain Wistas why the Old Scarecrow tephra wasn't present at the same depth in all cores?

a. The sea floor is a high energy sedimentary environment; therefore rates of erosion will be extremely high in some places.
b. Rates of sedimentation across the sea floor are highly variable as a function of the productivity and mortality rate of sea life in the water column above any given point.
c. The proximity to a subduction zone parallel to the volcanic arc means that the sediments are being destroyed at variable rates as a function of their distance from the trench.
d. Mass flows, in the form of turbidites, transfer significant volumes of sediments from the shelf to the abyssal plain, leading to much higher rates of sedimentation further offshore.
e. Erosion from the landmasses provides significantly more sediment at a higher rate to the locations closest to the eruptions than the most distant locations, which are predominantly composed of benthic microorganism remains (*biogenic ooze*).

36. Ashleigh and Andy plotted all of their data onto their map to better constrain the spatial distribution of the ash fall deposits. What did they determine is the prevailing wind direction in the region (the direction towards which the wind is blowing) <u>and</u> does this confirm, contradict, or modify what their professor told them?

a. The prevailing wind direction is towards the south, confirming what their professor told them.
b. The prevailing wind direction is towards the south-west, modifying what their professor told them
c. The prevailing wind direction is towards the south-east, modifying what their professor told them
d. The prevailing wind is towards the west, contradicting what their professor told them.
e. It is not possible to determine from the available data.

37. Based on the geochemical analyses in Table 3 which word best describes the composition of ash A38?

a. Ultramafic.
b. Mafic.
c. Intermediate.
d. Felsic.
e. None of the above.

The following information and Figures 9 & 10 relates to questions 38-48 inclusive.

Darcy Law and Brooke d'Chargé have been hired by water company Rio de Agua Limpa (RAL) as summer interns to help map an area of interest for developing drinking water wells and contribute recommendations for a final report. While both students have strong backgrounds in Earth science, they have a lot to learn about groundwater resources. Before they headed into the field, Darcy suggested they first determine what types of rocks would be the best sources of drinking water. They found the following depictions of porosity and hydraulic conductivity to study:

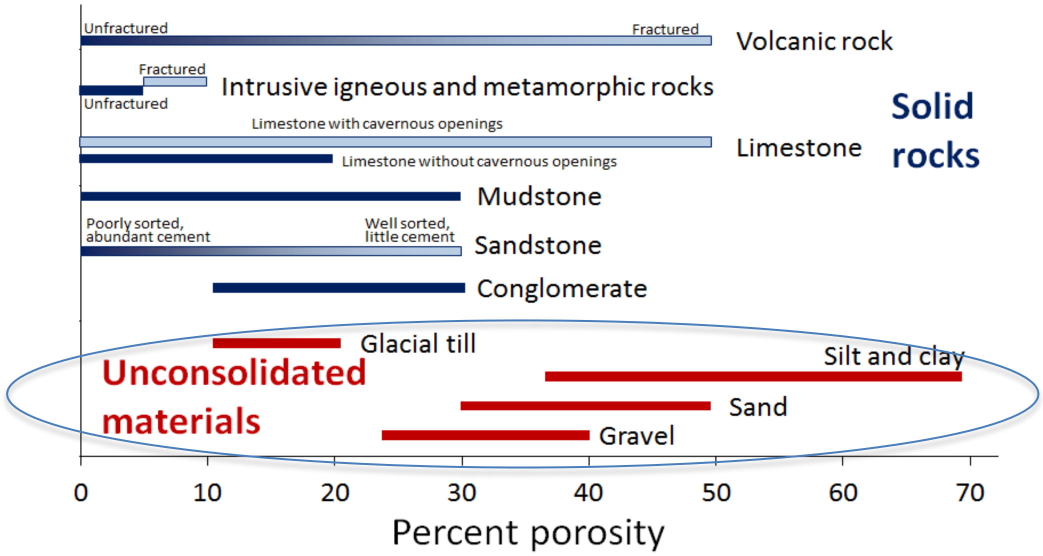


Figure 9: Variations in porosity of unconsolidated materials (circled red bars) and rocks (blue bars).

Note: Porosity is the void-space portion of a rock as a percentage of the total volume of the rock.

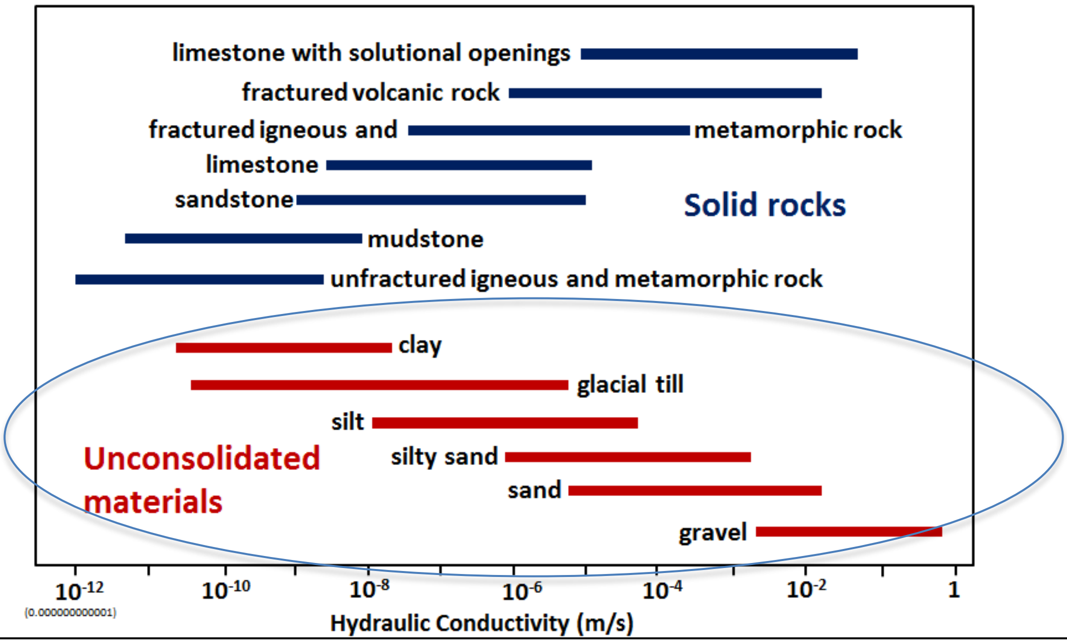


Figure 10: Variations in hydraulic conductivity (how quickly a fluid flows through the material in meters/second) of unconsolidated materials (circled) and rocks.

Note: Solutional opening means the same thing as Cavernous opening = there are caves in the limestone.

38. Darcy noticed something that struck him as odd. While unconsolidated silt and clay have very high porosity, greater than nearly all other materials, it appears to loose most of that porosity when it is lithified (turned to mudstone). However, sand and gravel undergo a smaller percentage change when lithified to sandstone and conglomerate respectively and yet end up with a greater porosity than mudstone.
How does Brooke 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 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.
    e. 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.

39. 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 is Brooke'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 where 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. Silt and clay bake to hardpan when exposed to heat, making them completely impenetrable to fluid flow beneath the surface.

The following information and Figures 11 & 12 relates to questions 40-48.

Brooke and Darcy discovered through their reading that the best rock formations for water production have both high porosity and high hydraulic conductivity. This initially made them very excited to use fractured volcanic rocks, until their supervisor provided them with a geologic map and cross section of their field area (Figures 11 and 12) that shows there are only sedimentary rock types present above an igneous basement.

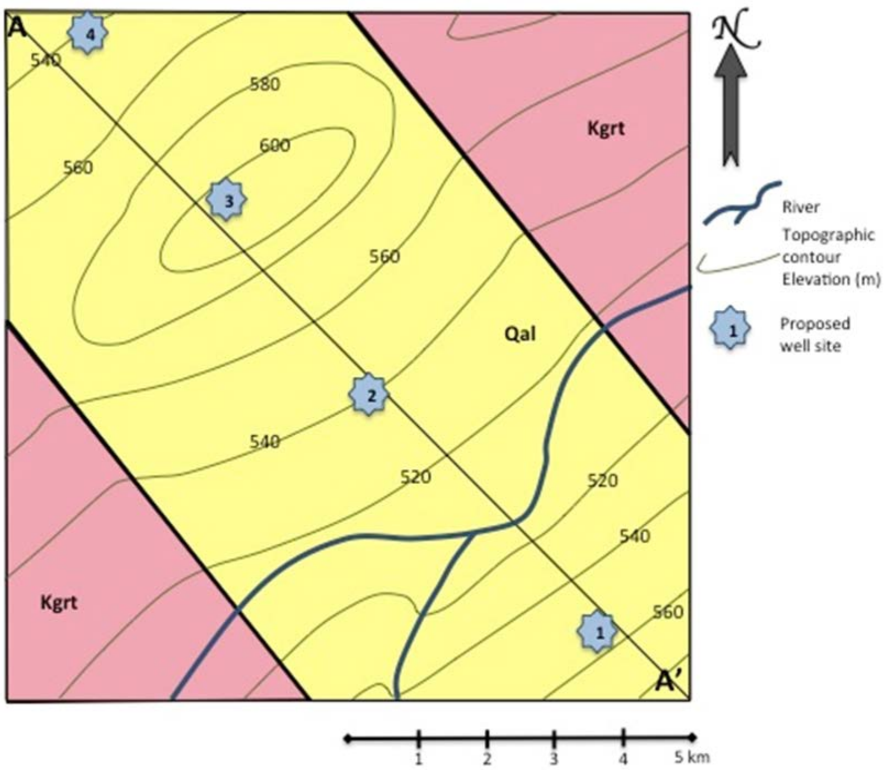


Figure 11: Geologic map of the RAL drinking water development plan. Lithologies are explained in Figure 12. Thick black lines separate distinct geologic units; the thin black line A-A' is the transect for the cross section shown in Figure 12.

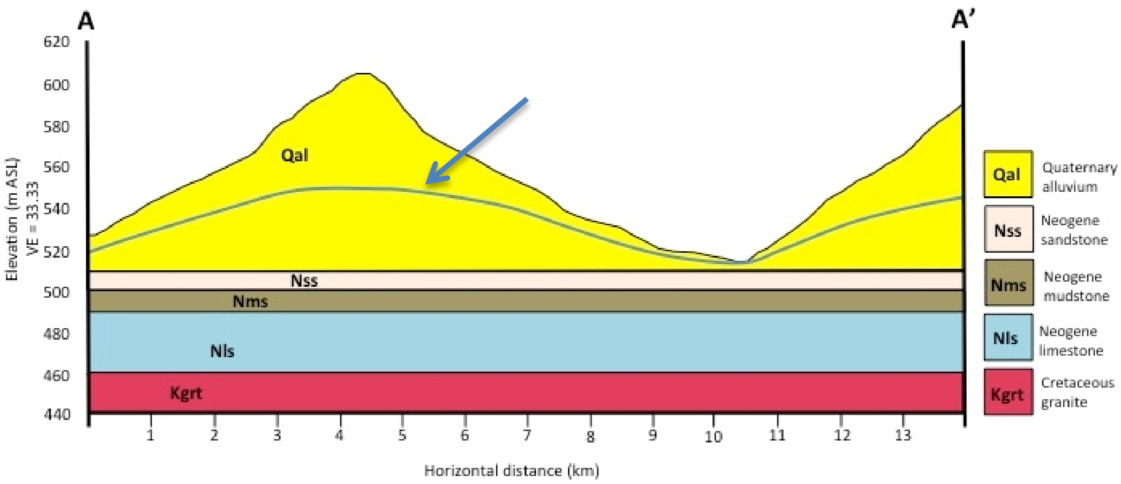


Figure 12: Geologic cross section of the RAL drinking water development plan. Groundwater elevation is marked by a thin blue indicated by the arrow. (m ASL = metres above sea level; VE = vertical exaggeration).

40. On their geologic map, Darcy noticed that there is something very unusual going on. The material in the central portion of the map is labelled **Qal**, which he remembers is used for loose, unconsolidated materials eroded and deposited in a non-marine setting during the Quaternary period. But on either side of this, bounded by very straight contacts, are rocks labelled **Kgrt**, which he deciphers to mean granite of Cretaceous age.
What does he correctly interpret has happened here?

a. The intrusive igneous rocks have moved up relative to the sedimentary rocks along normal faults to form a graben (a depressed block of the Earth's crust bordered by parallel faults). The sedimentary rocks on the up-thrown sides of the graben (the horsts) have been eroded by a subsequent event (possibly glaciation) that deposited sediments in the graben.
b. The granites were formed by stratovolcanoes that erupted and spread lava on top of the unconsolidated sediments in very straight lines along either side.
c. The unconsolidated sediments were dropped by a river that flowed between two parallel lava flows sitting on the surface of the sedimentary rocks.
d. The region was fractured by a meteor impact that created two parallel faults and threw fragmented material into the air when it hit the Earth. The unconsolidated sediments represent the fall back of fragmented material. It landed mostly in the horst (the depressed block of the Earth's crust bordered by the parallel faults).
e. The intrusive igneous rocks formed deep in the roots of two parallel volcanic chains (probably hot spot chains), which were then eroded to form sedimentary rocks and sediments between them. The sediments were deposited in a basin (possibly a giant U-shaped valley caused by glaciation).

41. Which two rock types would make the best aquifers (rock or sediment layers with enough permeability to be used for groundwater storage and transport) in their field area?

a. Unconsolidated glacial till and gravel.
b. Well sorted sandstone and limestone with solutional openings.
c. Mudstone and poorly sorted sandstone.
d. Mudstone and limestone with solutional openings.
e. Fractured and unfractured volcanic rocks.

The following information relates to question 42.

Brooke is interested in determining how quickly water can flow through an aquifer. In her reading she found the following equations related to water transmission in a pipe, which she thinks she can use to approximate the flow through the aquifer(s) in their field area. She reads that hydraulic head is a measurement of liquid pressure above a specific level, usually measured as a liquid surface elevation in a specialised water well. There must be a difference in hydraulic head between two points (hydraulic gradient Δh/L) for flow to occur.

$Q = Ak\frac{\Delta h}{L}$ $\quad$ $h = \left(\frac{p}{\rho g}\right) + z$

Q: volumetric flow rate (m^3/s)

L: path length between two points (m)

A: flow area cross section perpendicular to **L** (m^2)

k: hydraulic conductivity (m/s)

h: hydraulic head at a specific point (m)

Δ**h**: change in **h** over path **L** (m)

p: water pressure (N/m^2)

ρ: water density (kg/m^3)

g: acceleration of gravity (m/s^2)

z: elevation (m)

42. Brooke thinks she can use the information from Figure 10 and then determine all of the other variables from the field map and cross section (Figures 11 and 12) to solve for the flow rate. Is she correct?

    a. No, she is not correct, the field area is too complex to model fluid flow rates with a simple equation.
    b. No, she is not correct, the cross section **A** cannot be determined because there is no way to determine the size and shape of the aquifer.
    c. No, she is not correct because the path length **L** cannot be measured directly.
    d. No, she is not correct because the hydraulic head **h** cannot be determined without gathering direct measurements of water elevation within a test well in the field.
    e. Yes, she is correct. All of the variables are measurable from the map and cross section.

43. Looking closely at their cross section (Figure 12), Brooke and Darcy determined the number and type of aquifers in their field area. What did they write in their report?

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

The following information relates to questions 44, 45 and 46.

Before heading to their field site, Darcy and Brooke visited the core shed to look at samples of the rocks from below the surface to gather more information about the geology in the area. They took with them their handy Geoscience Australia sedimentary rock card (Figure 13).

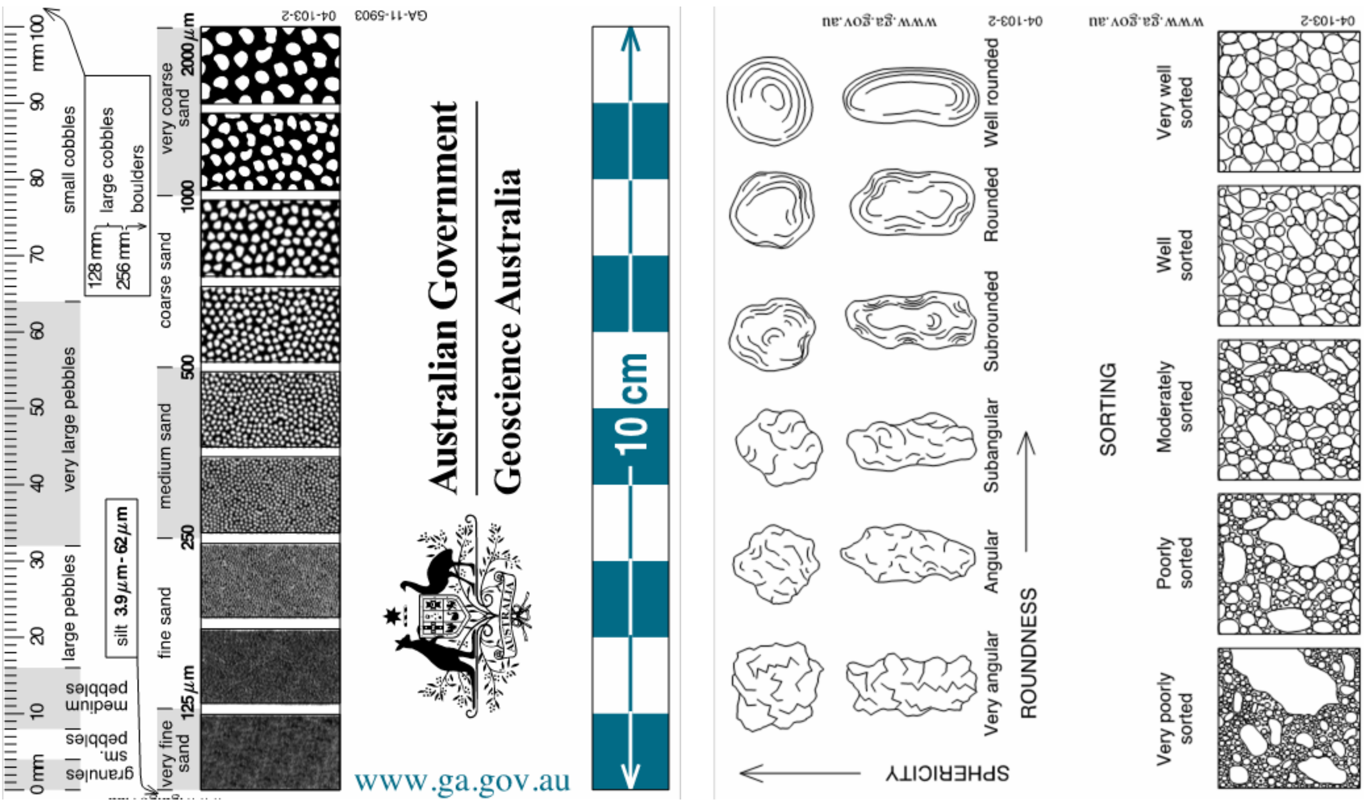


Figure 13: Sand grain size, shape and sorting field card (front and back). Card courtesy of Geoscience Australia.

44. Based on their observations they estimate that both the sandstone and the limestone have hydraulic conductivities of $\sim 10^{-5}$ m/s. What did they observe that led them to this conclusion?

   a. The angular sand grains range from 0.06 mm to 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 is full of holes ranging from 2 mm to 15 mm diameter.
   b. The subrounded sand grains range from 0.25 mm to 0.66 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 mm to 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 mm to 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 0.25 mm to 0.66 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.

45. Why does limestone most often develop cavernous openings?

   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.

46. Further observations led them to estimate that the mudstone and unconsolidated sediments on top of the sedimentary rocks have hydraulic conductivities of $\sim 10^{-10}$ m/s. What did they observe that led them to this conclusion?

a. The mudstone grains are not visible without a magnifying lens, but a drop of HCl placed on the sample slowly seeps into it. The unconsolidated sediments are angular sand grains ranging from 0.06-1.5 mm and composed of at least three different minerals.
b. The mudstone grains are not visible without a magnifying lens, but a drop of HCl placed on the sample slowly seeps into it. The unconsolidated sediments are angular gravels ranging from 2-6 mm and composed of several rock types.
c. The mudstone grains are not visible without a magnifying lens, but a drop of HCl placed on the sample slowly seeps into it. The unconsolidated sediments are a very poorly sorted mix of angular cobbles and gravel suspended in a matrix of fine clay and silt particles composed of a several rock types and minerals.
d. The mudstone grains are not visible without a magnifying lens. A drop of HCl placed on the sample fails to seep into it even after several hours. The unconsolidated sediments are a very poorly sorted mix of angular rocks >6 mm suspended in a matrix of fine mud to sand particles composed of a several rock types and minerals.
e. The mudstone grains are not visible without a magnifying lens. A drop of HCl placed on the sample fails to seep into it even after several hours. The unconsolidated sediments are angular gravels ranging from 2-6 mm and composed of several rock types.

47. Brooke and Darcy headed out to their field site armed with plenty of ideas about where to locate the company's water wells. The wells are required to be at least 2 km away from any surface water sources and at least 4 km away from any other well to avoid interference with pumping. In the field, Brooke and Darcy got into a debate over the recommended sites, which are plotted on Figure 11.
Which site(s) is/are controversial and why?

a. Site 1, because it is too close to a stream.
b. Site 4, because it is too far from a stream.
c. Sites 1 and 2, because they are too close to a stream.
d. Site 3, because it will not penetrate into an aquifer.
e. Site 3, because it would be pumping from the recharge area for wells at sites 2 and 4.

48. Darcy and Brooke decided to settle their disagreement over the proposed well sites by thinking more carefully about the direction of groundwater flow in their field area. Just as surface water always flows from high to low potential, so too does groundwater. Using their map and cross section (Figures 11 and 12) they determined…

    a. All water in the area must be flowing to the southeast.
    b. All water to the west of the stream must be flowing to the southeast, whereas water on the eastern side of the stream must be flowing northwest.
    c. All water to the west of the stream must be flowing to the northwest, whereas water on the eastern side of the stream must be flowing southeast.
    d. Water between site 1 and the stream, and water between sites 3-4 must be flowing northwest, whereas water between site 3-2 and the stream must be flowing southeast.
    e. Water between site 1 and the stream, and water between sites 3-4 must be flowing southeast, whereas water between site 3-2 and the stream must be flowing northwest.

Meanwhile, back in space ….

49. Ceres is the largest object in the asteroid belt between Mars and Jupiter and is being considered as a forward base for exploration of Europa and the Jovian system and also as a base in the asteroid belt. It has a rotation period of 9.074 Earth hours (a Cerian day) and an orbital period of 4.60 Earth years (a Cerian year).
    How many Cerian days will the first Cerian colonists experience in a Cerian year?

    a. 3,330
    b. 4,440
    c. 5,550
    d. 6,660
    e. 8,880

50. Why won't Ceres be a great base for exploring Europa and the Jovian system?

    a. Ceres rotates so fast it will be impossible to colonise.
    b. Ceres is in the asteroid belt and is constantly bombarded by asteroids.
    c. A colony on Ceres will only be focussed on mining asteroids.
    d. A colony on Ceres will be too far from Earth for humans to survive.
    e. Jupiter has an orbital period of 11.8618 Earth years so won't always be close enough to Ceres to make regular trips practical.

SECTION B: WRITTEN ANSWER QUESTIONS
ANSWER IN THE SPACES PROVIDED

Back on Earth …
The following information, Table 4 and Figures 14 & 15 relate to questions 51 to 58 inclusive.

Back in the comfort of her university dorm, Ellie decided to review the field trip geochemical data (Table 4 page 46 – same as Table 3 on page 33) collected on the sea voyage through the Ash Mountains Arc (Figure 14 – same as Figure 6 on page 26). She has looked very carefully at the geochemical data, the drill core locations and drill core logs (Figure 15 page 45 – same as Figure 8 on page 32) and came to several conclusions about the volcanic eruptions in the region.

She also decided she like volcanology so much she would apply for the next mission to any planet or moon with active volcanism, even if it is cryovolcanism!

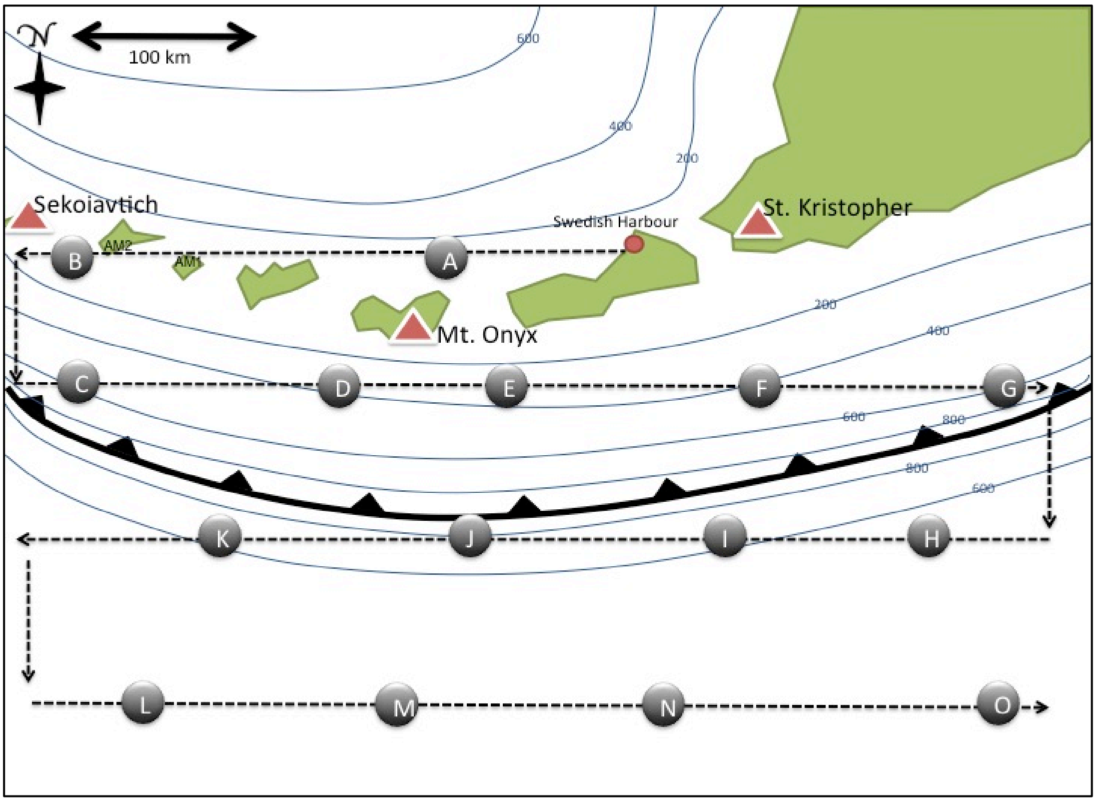


Figure 14: Map of the Ash Mountains Arc and scientific cruise route with targeted deep sea drilling locations (A to O) and onshore sample sites AM1 and AM2. The entire arc is built from active stratovolcanoes, all of which have erupted within the last 10,000 years. Holocene Plinian eruptions are marked with labelled triangles. The sawtooth pattern denotes the subduction zone and indicates the dip direction of the down-going plate. The thin numbered lines show bathymetry with water depth in metres below sea level.

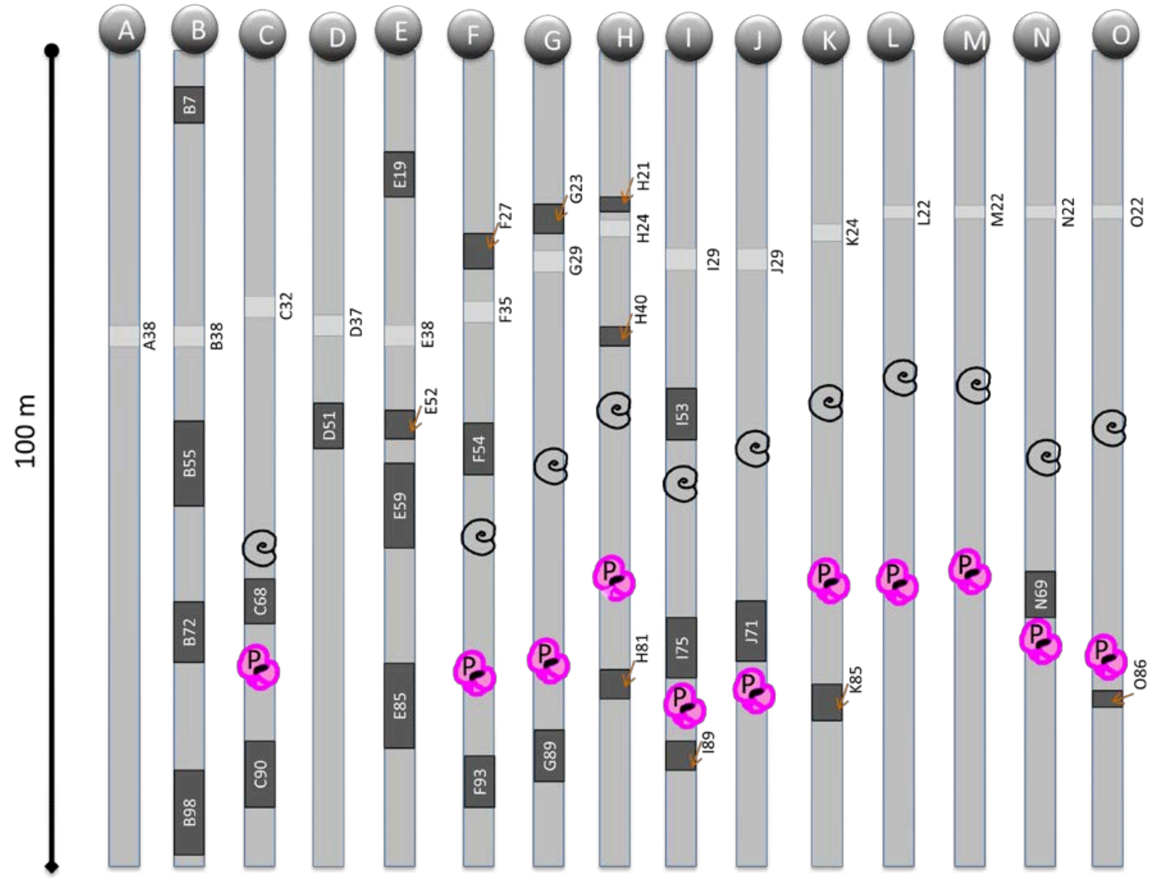


Figure 15: Scaled diagram of drill core sediments recovered from 15 holes. The circled letters at the top of each column correspond to the drill site in Figure 6. The labelled regions within each column denote the hole (letter) depth (number) and relative thickness (width of coloured bar) of ash layers and correspond directly to geochemistry data in Table 4. The spirals indicate the last appearance of *Globorotalia crassaformis* within the column and the pink spirals (marked with a P) denote the first appearance of *Globigerinoides ruber* within the column.

Note: *Globorotalia crassaformis* and *Globigerinoides ruber* are planktonic foraminifera found floating in open ocean in waters greater than 200 meters deep.

51. Ellie knew that her crew mates Wade and Shelly, who were logging the cores for fossils, were not expecting to find any useful foraminifera in cores A and B. Explain why.

(**1 mark**)

Core	Sample ID	SiO_2	TiO_2	Al_2O_3	FeO_{TOT}	MnO	MgO	CaO	Na_2O	K_2O
A	A38	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
B	B7	52.71	0.92	19.43	8.28	0.17	3.84	8.87	3.55	1.88
	B38	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	B55	60.96	0.78	17.71	5.49	0.16	1.50	3.90	5.36	3.81
	B72	60.06	0.81	17.83	5.94	0.16	1.81	4.34	5.14	3.56
	B98	62.61	0.46	17.47	4.69	0.12	2.33	6.32	4.44	1.39
C	C32	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	C68	60.06	0.81	17.83	5.94	0.16	1.81	4.34	5.14	3.56
	C90	62.61	0.46	17.47	4.69	0.12	2.33	6.32	4.44	1.39
D	D37	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	D51	60.96	0.78	17.71	5.49	0.16	1.50	3.90	5.36	3.81
E	E19	65.63	0.92	15.99	4.65	0.17	1.36	3.65	4.86	2.49
	E38	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	E52	60.96	0.78	17.71	5.49	0.16	1.50	3.90	5.36	3.81
	E59	67.09	0.78	15.97	3.63	0.17	1.16	3.32	5.29	2.37
	E58	70.40	0.54	14.92	2.63	0.14	0.59	1.98	5.74	2.96
F	F27	61.60	0.59	17.00	5.44	0.13	3.48	6.95	3.74	0.94
	F35	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	F54	67.09	0.78	15.97	3.63	0.17	1.16	3.32	5.29	2.37
	F93	63.36	0.56	16.52	5.20	0.13	3.04	6.25	3.81	0.99
G	G23	61.60	0.59	17.00	5.44	0.13	3.48	6.95	3.74	0.94
	G29	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	G89	63.36	0.56	16.52	5.20	0.13	3.04	6.25	3.81	0.99
H	H21	61.60	0.59	17.00	5.44	0.13	3.48	6.95	3.74	0.94
	H24	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	H40	67.09	0.78	15.97	3.63	0.17	1.16	3.32	5.29	2.37
	H81	63.36	0.56	16.52	5.20	0.13	3.04	6.25	3.81	0.99
I	I29	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	I53	67.09	0.78	15.97	3.63	0.17	1.16	3.32	5.29	2.37
	I75	70.40	0.54	14.92	2.63	0.14	0.59	1.98	5.74	2.96
	I89	63.36	0.56	16.52	5.20	0.13	3.04	6.25	3.81	0.99
J	J29	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	J71	70.40	0.54	14.92	2.63	0.14	0.59	1.98	5.74	2.96
K	K24	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	K85	62.61	0.46	17.47	4.69	0.12	2.33	6.32	4.44	1.39
L	L22	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
M	M22	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
N	N22	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	N69	70.40	0.54	14.92	2.63	0.14	0.59	1.98	5.74	2.96
O	O22	75.49	0.3	13.03	1.71	0.06	0.29	1.47	3.71	3.66
	O86	63.36	0.56	16.52	5.20	0.13	3.04	6.25	3.81	0.99

Table 4: Major element geochemistry from each ash layer found within the drill cores.

(FeO_{TOT} is the total weight percent of iron oxides in all oxidation states.)

52. Based on the geochemical analyses in Table 4, how many distinctive events did Ellie correctly conclude are recorded in cores in addition to the previously identified Old Scarecrow tephra?
(**1 mark**)

There are ____________________ distinctive eruption events in addition to the Old Scarecrow tephra.

53. How is Ellie able to determine the number of eruptive events that have deposited tephra across the sample region?
(**1 mark**)

54. How many Holocene Plinian eruption centres contributed to the deposits found in the cores and how many eruptive events are there from each of the Holocene Plinian eruption centres represented?
(**5 marks**)

55. Which volcano is responsible for the largest eruption (not considering the Old Scarecrow tephra)? How did you determine this?
(**2 marks**)

56. Determine the eruptive history of the events using the geochemistry (Table 4) and map (Figure 14). List the events from the oldest event to the youngest event, noting which is the first event, which is the last event and the evidence you used to place each unit in your chosen order.
E.g. Unit 3 is between unit 2 and unit 4 because …
(**8 marks**)

57. Are there any events that do not have age constraints that allow them to be unambiguously placed in order? If so, list them and explain why they cannot be easily ordered.
(**2marks**)

58. What principle did you use to determine the order of events?
Using an example from the sequence, demonstrate how you applied it.
(**2marks**)

The following information and Figures 16 & 17 relates to questions 59 to 61 inclusive.

The drill cores that Darcy and Brooke examined in the core shed were taken from locations very close to where they plotted proposed water extraction sites 2 and 3 (Figure 16 page 51, same as Figure 11 page 37). Their supervisor provided them with the bore data measurements taken before they were capped. Borehole geophysics is the science of recording and analysing measurements of physical properties made in wells or test holes and is used in groundwater and environmental investigations to obtain information on well construction, rock lithology and fractures, permeability and porosity as well as water quality. Probes that measure different properties are lowered into the borehole to collect continuous or point data. This creates multiple logs simultaneously to analyse collectively, providing more insight from a suite of logs than by the analysis of the same logs individually.

The borehole data supports their earlier predictions of hydraulic conductivity for the rock formations in their field area. It also includes two consecutive piezometric head (water height) measurements from each location, taken in sequence as the bore drilled deeper.

- Near site 2, these measurements are 55 m and 35 m, respectively.
- Near site 3, these measurements are 50 m and 25 m, respectively.

Darcy reasons that these can be used to estimate the flow rate within the aquifer(s) between the two sites.

$Q = Ak\frac{\Delta h}{L}$ $\qquad h = \left(\frac{p}{\rho g}\right) + z$

Q: volumetric flow rate (m^3/s)

L: path length between two points (m)

A: flow area cross section perpendicular to **L** (m^2)

k: hydraulic conductivity (m/s)

h: hydraulic head at a specific point (m)

Δh: change in **h** over path **L** (m)

p: water pressure (N/m^2)

ρ: water density (kg/m^3)

g: acceleration of gravity (m/s^2)

z: elevation (m)

59. Showing all work, calculate what this would be in m^3/year.

(**4 marks**)

60. Which geologic layer would make the most productive source of drinking water?

(**2 marks**)

61. How deep will each of the proposed wells need to be drilled to produce drinking water for Rio de Agua Limpa (RAL)?

(**2 marks**)

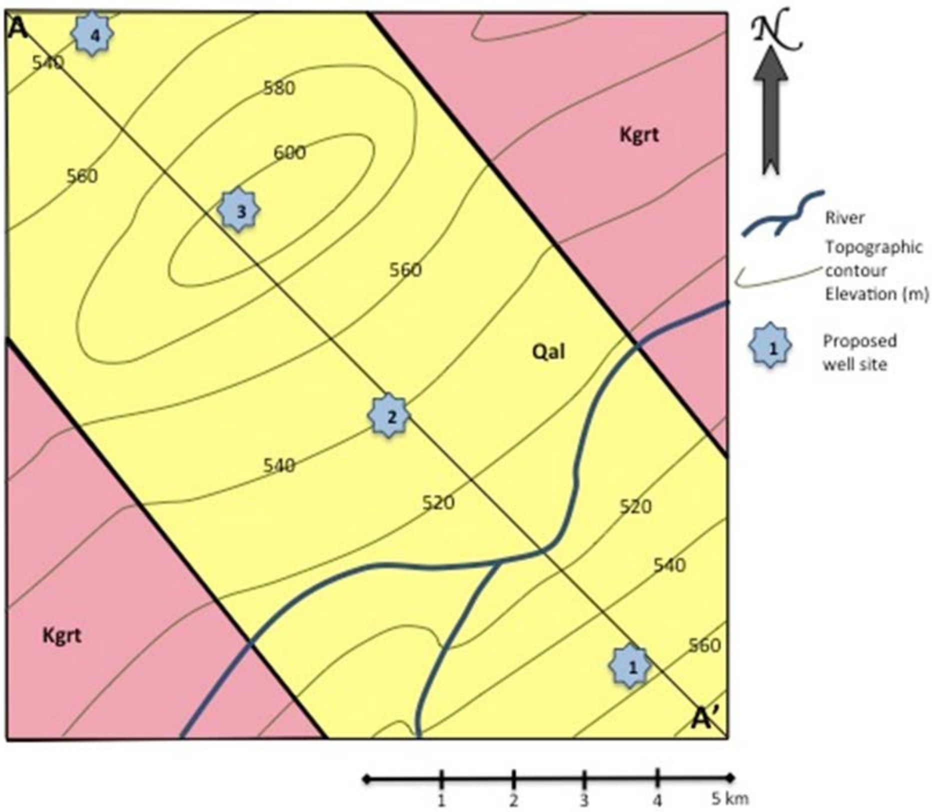


Figure 16: Geologic map of the RAL drinking water development plan. Lithologies are explained in Figure 17. Thick black lines separate distinct geologic units; the thin black line A-A' is the transect for the cross section shown in Figure 17.

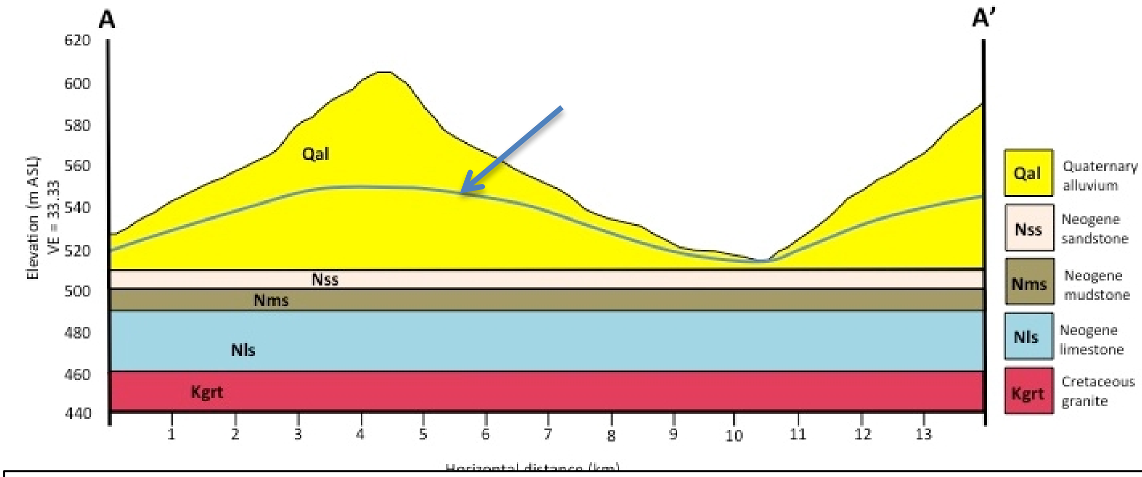


Figure 17: Geologic cross section of the RAL drinking water development plan. Groundwater elevation is marked by a thin blue indicated by the arrow. (m ASL = metres above sea level; VE = vertical exaggeration).

BLANK WORKING PAGE

BLANK WORKING PAGE

BLANK WORKING PAGE

BLANK WORKING PAGE

BLANK WORKING PAGE

Integrity of Competition

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