2019 AUSTRALIAN SCIENCE OLYMPIAD EXAM

EARTH & ENVIRONMENTAL SCIENCE – SECTIONS A & B

TO BE COMPLETED BY THE STUDENT. USE CAPITAL LETTERS.

First Name: ……………….….………… **Last Name**………………………………….

Date of Birth: ……/…../….….

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

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

Examiners Use Only:

2019 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 60 of this booklet.
- Data that may be required for a question will be found on pages 3 to 9.
- Do NOT staple the Multiple Choice Answer Sheet to this booklet.

MARKS

SECTION A	55 multiple choice questions Each question worth one mark	55 marks
SECTION B	10 written answer questions Marks for each question are specified	25 marks

Total marks for the paper 80 marks

DATA & DEFINITIONS

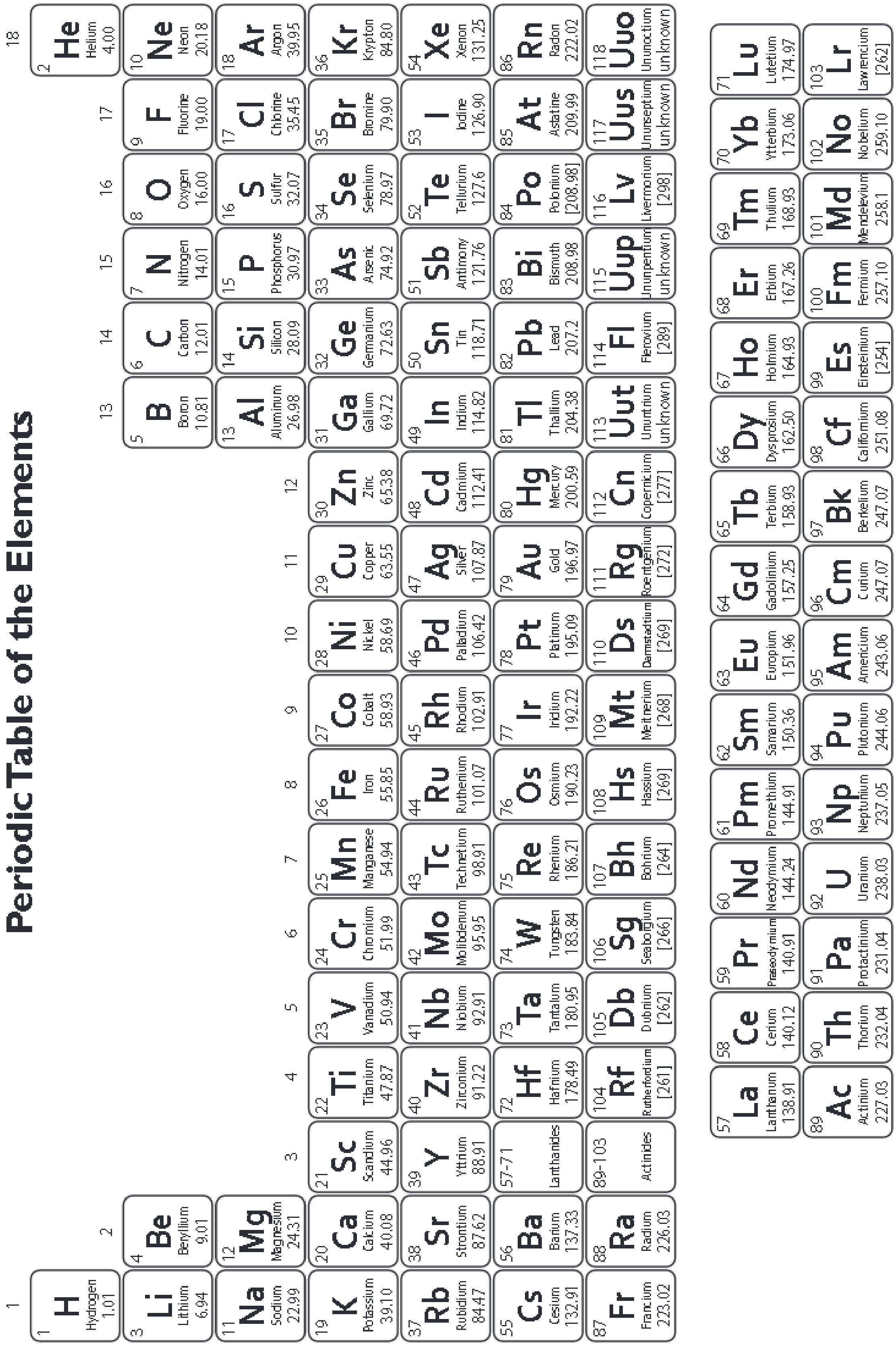
Material supplied:

- Mohs hardness scale – page 3
- Universal physical constants and useful facts - page 3
- Periodic Table of the Elements –page 4
- International Chronostratigraphic Chart 2018/08 – page 5
- Polar view of Earth with lines of longitude terminology – page 6
- Definition of hemispheres – page 6
- Some common minerals and their fluorescent properties under ultraviolet light – page 7
- Geologic features associated with modern and ancient igneous activity – page 7
- Major Tectonic Plates on Earth and sense of movement at plate boundaries. – page 8
- Igneous rock mineralogy chart – page 9
- Character disclaimer – page 9

Mohs Hardness	Example Minerals/materials
1	Talc
2	Gypsum
2.5	Fingernail, pure gold, silver, aluminium
3	Calcite, copper coin
4	Fluorite
4.5	Platinum, iron
5	Apatite, Pyroxene group (5 to 6)
6	Orthoclase feldspar, titanium, spectrolite, Pyroxene group (5 to 6)
6.5	Plagioclase feldspar, steel file, iron pyrite, glass, vitreous pure silica
7	Quartz, amethyst, citrine, agate, olivine, tridymite (high temp quartz)
7.5	Garnet, coesite (high pressure quartz)
8	Hardened steel, topaz, beryl, emerald, aquamarine
9	Corundum, ruby, sapphire
9.5	Carborundum
10	Diamond

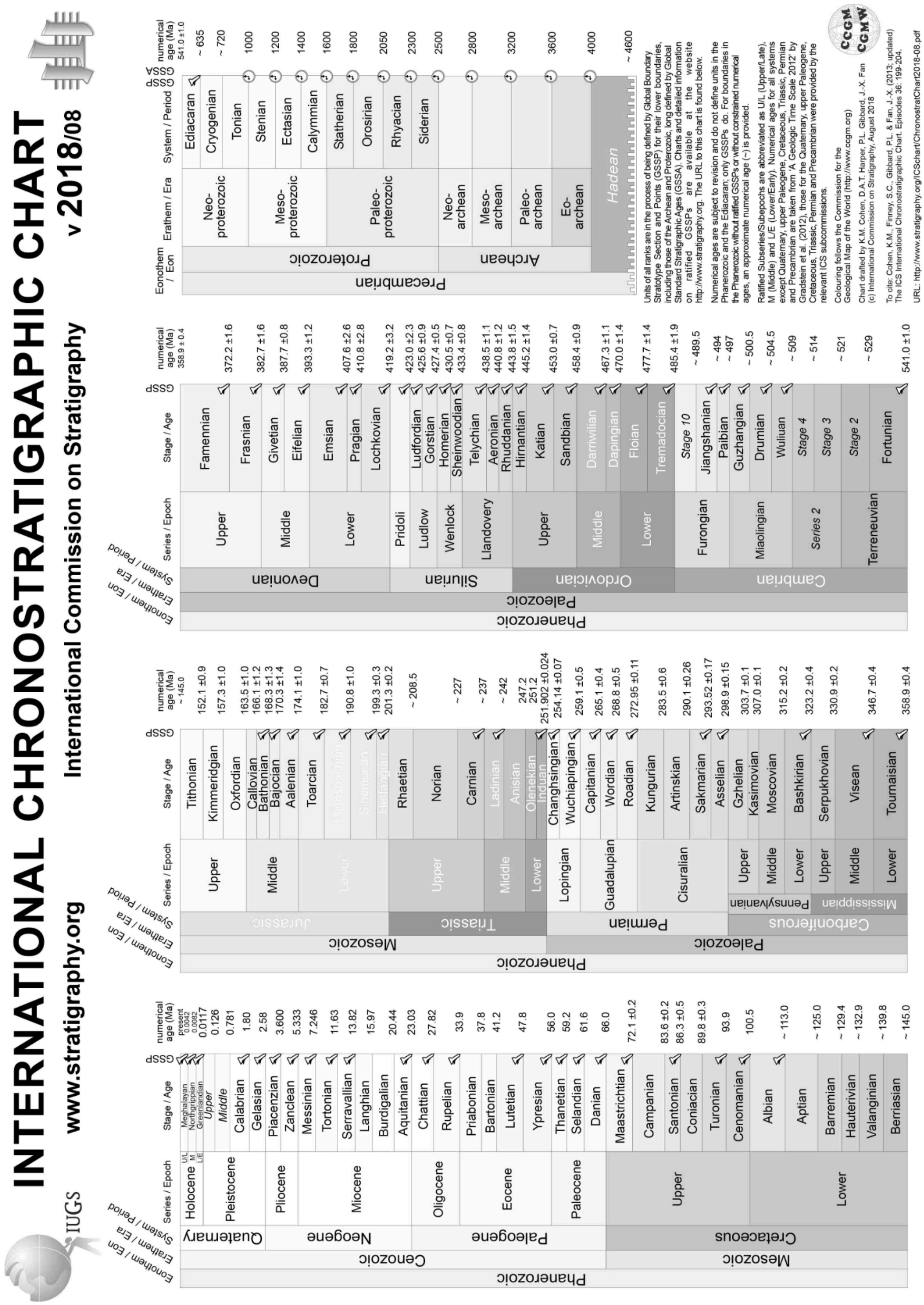
Universal physical constants and useful facts

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



Periodic Table of the Elements courtesy of

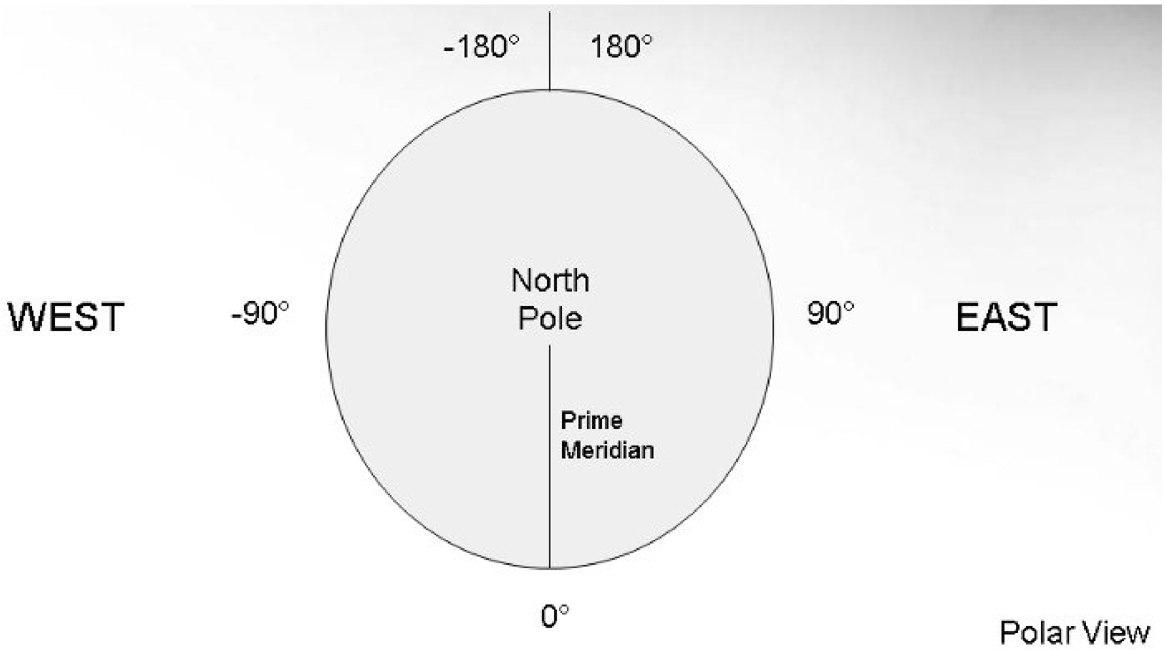
http://sciencenotes.org/category/chemistry/periodic-table-chemistry/



International Chronostratigraphic Chart 2018/08 courtesy of

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

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



Polar view of Earth showing the arrangement and terminology for lines of longitude also known as meridians. The Prime Meridian is also known as the Greenwich or Zero Meridian. The 180° meridian is sometimes called the antemeridian.

Definition of a hemispheres:

The **Eastern Hemisphere** is a geographical term for the half of Earth which is east of the prime meridian and west of the antemeridian.
The **Western Hemisphere** is a geographical term for the half of Earth which lies west of the prime and east of the antimeridian.
The **Northern Hemisphere** is a geographical term for the half of Earth that is north of the Equator.
The **Southern Hemisphere** is a geographical term for the half of Earth that is south of the Equator.

Some common minerals and their fluorescent properties under ultraviolet light

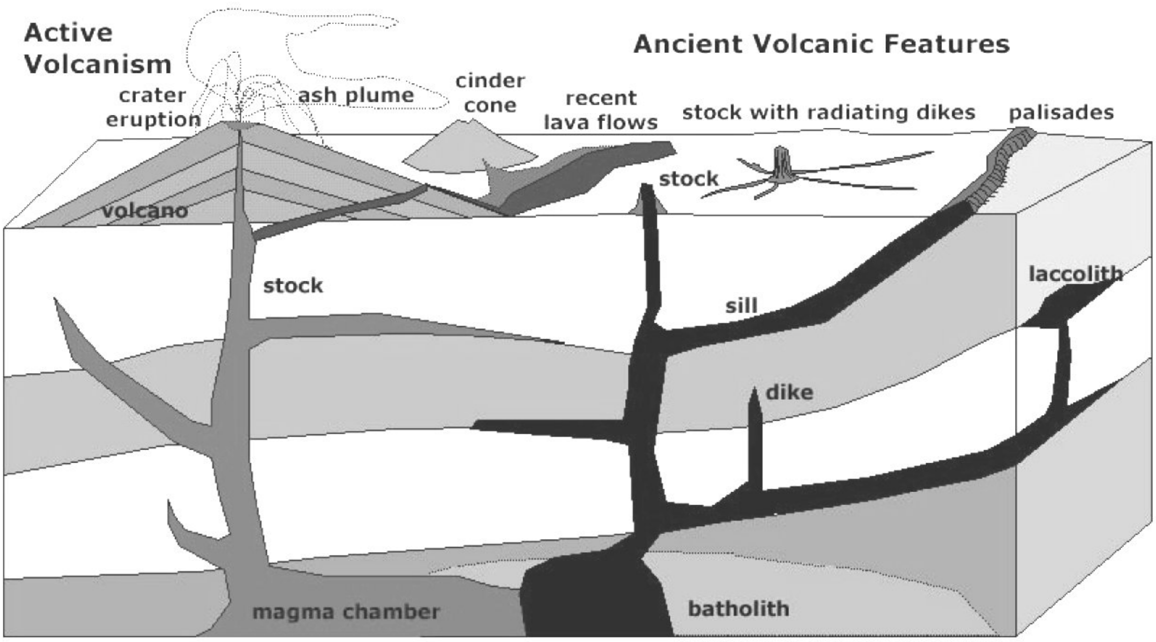
Longwave length ultraviolet light

Fluorescent colour	**Minerals**
White	Aragonite, Barite, Calcite, Fluorite, Gypsum, Halite, Smithsonite
Red	Barite, Calcite, Corundum, Halite, Sphalerite
Orange	Apatite, Barite, Calcite, Fluorite, Gypsum, Sphalerite, Talc, Zircon
Yellow	Apatite, Calcite, Sphalerite, Talc, Zircon
Green	Aragonite, Opal, Quartz, Willemite
Blue	Albite (feldspar), Apatite, Barite, Calcite, Fluorite, Gypsum, Magnesite

Shortwave length ultraviolet light

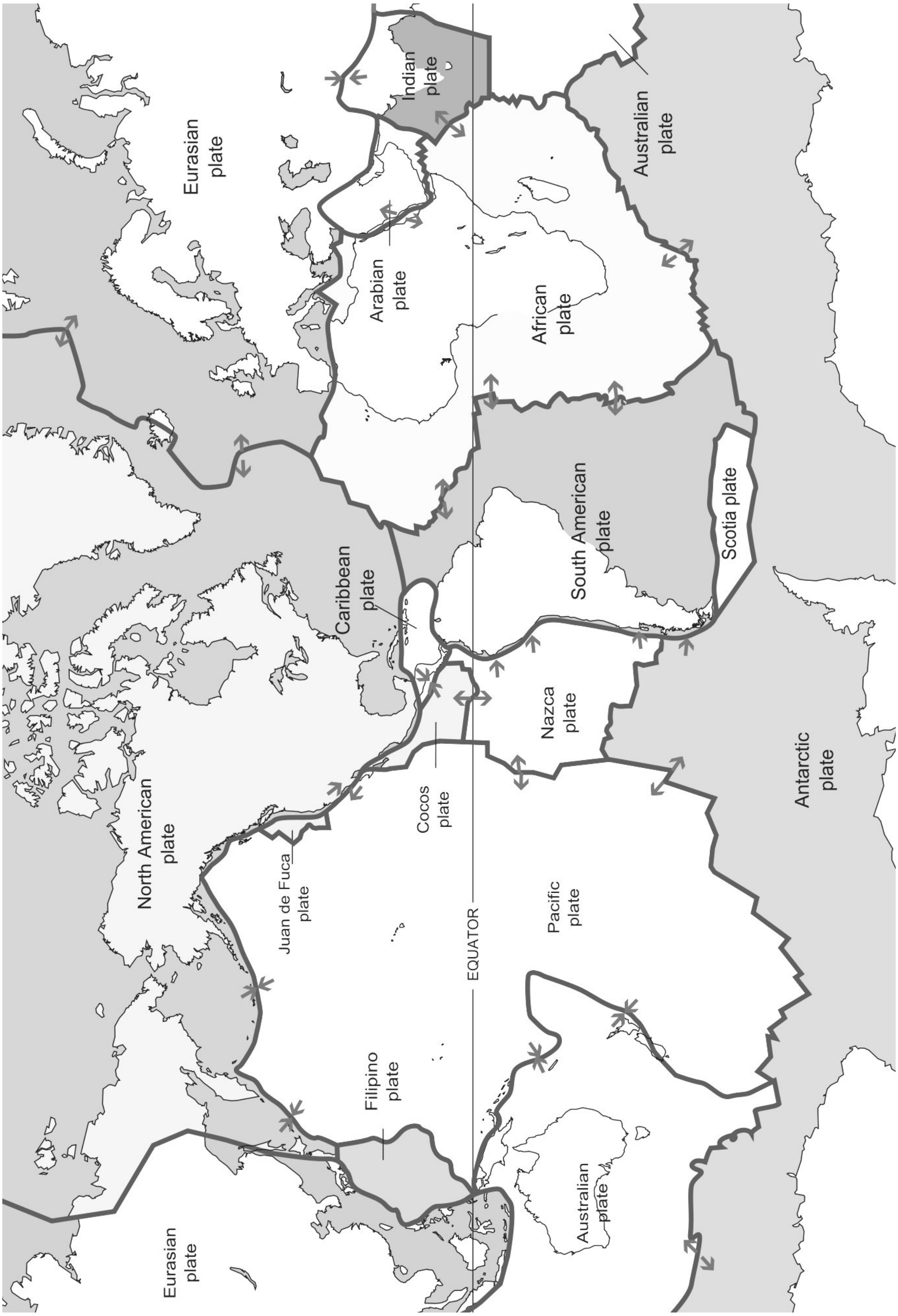
Fluorescent colour	**Minerals**
White	Aragonite, Barite, Calcite, Fluorite, Witherite
Red	Barite, Calcite, Halite, Microcline (feldspar), Ruby
Orange	Apatite, Amber, Sodalite, Sphalerite, Zircon
Yellow	Apatite, Aragonite, Barite, Calcite, Fluorite, Gypsum, Talc, Zircon
Green	Calcite, Diamond, Opal, Quartz (hyalite), Willemite
Blue	Albite, Barite, Calcite, Fluorite, Gypsum, Magnesite, Microcline

Geologic features associated with modern and ancient igneous activity



Geologic features associated with modern and ancient igneous activity

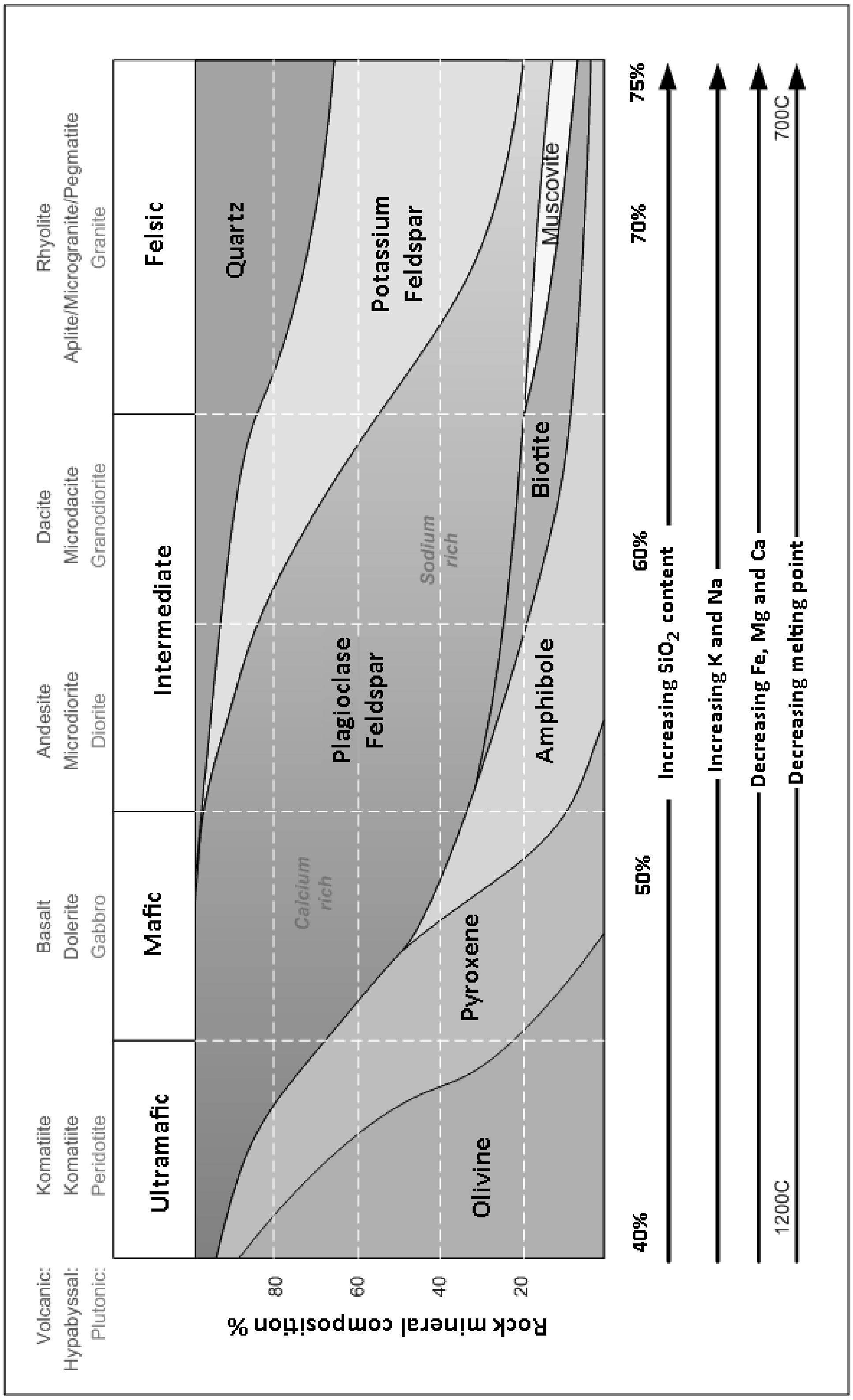
Modified from https://pubs.usgs.gov/bul/2195/b2195.pdf



Major Tectonic Plates on Earth and sense of movement at plate boundaries.

Modified from http://commons.wikimedia.org/wiki/File:Plates_tect2_en.svg

Igneous rock mineralogy



Characters

The names of characters, locations and events portrayed in this paper are fictitious (but fun). Enjoy!

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 …

Roxanne Stone has just returned to Earth from a stint on Mars as a planetary geologist, specialising in whole of planet motions. She was happy to be home and to catch up with family, especially her younger sister Gemma, who is also studying planetary geology as part of her Earth and Environmental Science course at school.

1. Roxanne found adjusting to life back on Earth a bit challenging. What did she tell Gemma that she found different about being home compared to being on Mars?

   a. Earth's Gravity. Mars is a rocky planet but only has about 38% of Earth's gravity so getting used to Earth's gravity again is an issue
   b. Earth's smell. Mars does not have a breathable atmosphere so residents only ever smell inside their habitats, so getting used to other smells again is novel
   c. Earth's water. Mars does not have liquid surface water so seeing open bodies of natural surface water again is great
   d. Mars is super dusty. The dust is so fine and abrasive it can cause serious, even fatal, lung damage. It is hard to get used to not having to worry about dust exposure
   e. Earth's protective atmosphere. Mars has a very thin atmosphere so even small meteors, that would burn up in Earth's atmosphere, hit the ground on Mars and pose a constant threat to habitat integrity. It is strange to be less alert to the danger
   f. All of the above

2. Gemma wanted to know what seasons are like on Mars. Roxanne explained that …

   a. … the orbit of Mars about the Sun is quite elliptical so it has extreme seasons
   b. … the axis of rotation of Mars is tilted at 25° so it has seasons just like Earth
   c. … a Martian year is almost twice as long as Earths so it has longer seasons
   d. … all of a, b and c
   e. … the orbit of Mars is circular so it does not have seasons
   f. … Mars is not tilted on its axis and it has a circular orbit so it does not have seasons

3. Gemma understands that Mars has an atmosphere that is 96% carbon dioxide (CO_2) but was puzzled when Roxanne said they could only go outside in space suits like the ones they wear when walking around on the Moon. When she asked Roxanne why she couldn't go outside in something like a wetsuit with an air tank attached Roxanne's answer was …

   a. … the Martian atmosphere is very thin, with a surface pressure less than 1% of Earth's, so if you went outside unprotected by a pressure suit your blood, which is mostly water at a body temperature of ~36.5° C, would boil at such a low pressure
   b. … even on a good day the air temperature can be quite cold but at night temperatures plunge to minus 60° C so you could very quickly freeze to death without a protective suit
   c. … Mars has so much more N_2 in the atmosphere than Earth that it causes nitrogen bubbles to form in the blood if you are exposed to it. The bubbles can cause brain damage and death
   d. … Mars has no magnetic field so it is not protected from cosmic radiation the way Earth is. Going outside without radiation protection in the form of a space suit is simply too dangerous
   e. Answers a, b and d
   f. The Martian Congressional Republic is just too safety conscious

4. Roxanne was happy that Gemma was so interested in Mars but was also happy to return to Earth and ask Gemma some questions too. She asked Gemma which gemstone from a list of Citrine (yellow quartz), Opal, Diamond, Ruby (a type of corundum) and Aquamarine (a type of beryl) she liked the most and why. Gemma had a good answer. Which one was it?

   a. Ruby, because she loved the amazing blue colour of this variety of corundum
   b. Citrine, because it is a pretty yellow colour and has the power to scratch diamond
   c. Opal, because it's Australia's national gemstone and it looks fantastic in a disco under UV light
   d. Diamond, because it is able to scratch any naturally occurring substance found on Earth and is impossible to break
   e. Aquamarine, because she loved the amazing pink colour of this variety of beryl
   f. None in Roxanne's list. She said she preferred Peridot (a type of olivine) because it is a pretty green, it's harder than Ruby or Aquamarine and is found only in the Earth's mantle, never on the surface of the Earth

5. Roxanne loved Gemma's answer to her gemstone question so she asked another one about rocks. Roxanne said her apartment on Earth was being refurbished, including the installation of a new kitchen with polished stone bench tops. She remembered their parents put in a new kitchen when she was at school. It was made of a really expensive rock the sales person said was marble. She explained to Gemma that, geologically speaking, marble is a non-foliated metamorphic rock formed by thermal metamorphism of limestone. Gemma grew up with that benchtop in the family home so she knew it well. She said … *it's full of fossils, it can't be marble!* Roxanne agreed but asked Gemma to suggest another rock type for her new kitchen if she didn't like the so-called marble. Gemma's reply was …

   a. Granite. It is a beautiful layered rock with segregated bands of light and dark minerals that will look really cool in a modern kitchen
   b. Sandstone. It is a really hard rock composed mostly of quartz that is totally impervious to water because the sand grains are packed together really tightly so beetroot stains will never be a problem
   c. Gabbro. It is a very hard rock composed mostly of medium to coarse white plagioclase feldspar crystals and dark greenish pyroxene crystals with lesser amounts of olivine and hornblende (amphibole) and no quartz
   d. Limestone. The fossils in it look really great and the mineralogy (almost entirely calcite) indicates it will resist scratching really well and food acids will never etch the beautifully polished surface
   e. Andesitic welded tuff. The rock is very hard because it contains more than 90% quartz and all the mineral grains are stuck together very tightly because they were so hot when they were deposited so beetroot stains won't be a problem
   f. Gneiss. It is beautiful rock and the one she liked was composed of quartz (25%), potassium feldspar (60%), plagioclase feldspar (6%) and a small percentage of muscovite, biotite and amphibole. It has no foliation and all the crystals are about the same size and randomly distributed throughout the rock

The following information relates to questions 6, 7, 8 & 10.

Roxanne Stone was cleaning up her apartment for the refurbishing and she found her old lecture notes. In them she has found a paper published in 2019, describing how the position of the Earth's rotational axis responded to changes in other dynamic systems. She thinks this might be an important reference to revisit as the Martian Congressional Republic plans to commence terraforming soon with the intention of returning liquid water to the surface of Mars sometime in the next millennium.

Roxanne knows that the Earth's spin axis position, relative to the crust, changes so that the actual location of the pole on the surface changes over time. This position change, relative to the crust, has been well documented since the year 1899. There is a well-known 25 to 35 year periodicity in the pole's movement (the Markowitz wobble) and also a 6 to14 year "quasi-decadal" periodicity (Figure 1). Roxanne can see that between 1976 and 2004 a linear trend is evident in the data. In her notes she had highlighted this trend with a dashed grey line (Figure 1). The pole position for 1976, relative to 1899 was also plotted in an assignment question she never completed (Figure 2, page 15).

6. Roxanne thought it would be fun to challenge her sister, Gemma, to indicate where the 1990 and 2004 data points should be plotted on the graph (Figure 2) but **only using the solid black smoothed line as the source**. Despite the poor figure resolution in Roxanne's notes (Figure 1) Gemma correctly worked out they should be plotted in positions …

   a. g (1990) and b (2004)
   b. d (1990) and c (2004)
   c. c (1990) and b (2004)
   d. d (1990) and g (2004)
   e. e (1990) and d (2004)
   f. f (1990) and g (2004)

on the graph (Figure 2).

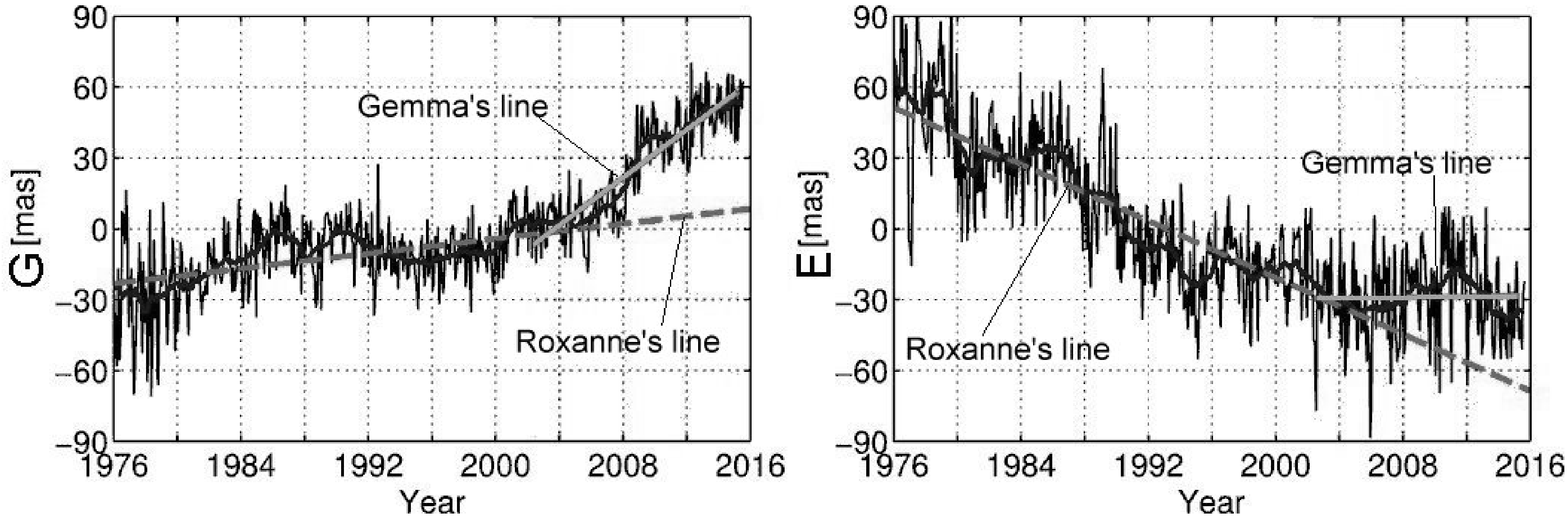


Figure 1: Observed pole position data. Pole positions are relative to the pole position in 1899. Mean monthly polar motion excitations (spiky black lines) derived from the observed daily values after removing semiannual, annual, and other wobbles. Smoothed solutions (solid black line) reveal quasi-decadal variability in the corresponding component of the 20th century. The Cartesian orthogonal vector positions of the pole, relative to the pole position in 1899, are described by G 0^o, the coordinate position along the Greenwich 0^o line of longitude (the Prime Meridian), and E, the coordinate position along the 90^o East line of longitude for each time, t. Units for movement along these longitudes are milliseconds of arc (mas) where 1 mas ≈ 3.09 cm.

Negative values (-ve) are for vectors along lines of longitude opposite to those for positive (+ve) G and E. Negative G for values along the 180^o line of longitude, negative E for values along the 90^o West line of longitude.

Raw data available to Roxanne indicates that G(t) and E(t) for 1976 are approximately -ve 50 mas from the 1899 pole and approximately +ve 90 mas East of the 1899 pole respectively. This data point is marked on Figure 2.

Graph modified from Figure 1 in Surendra Adhikari and Erik R. Ivins. Science Advances 2(4), e1501693.

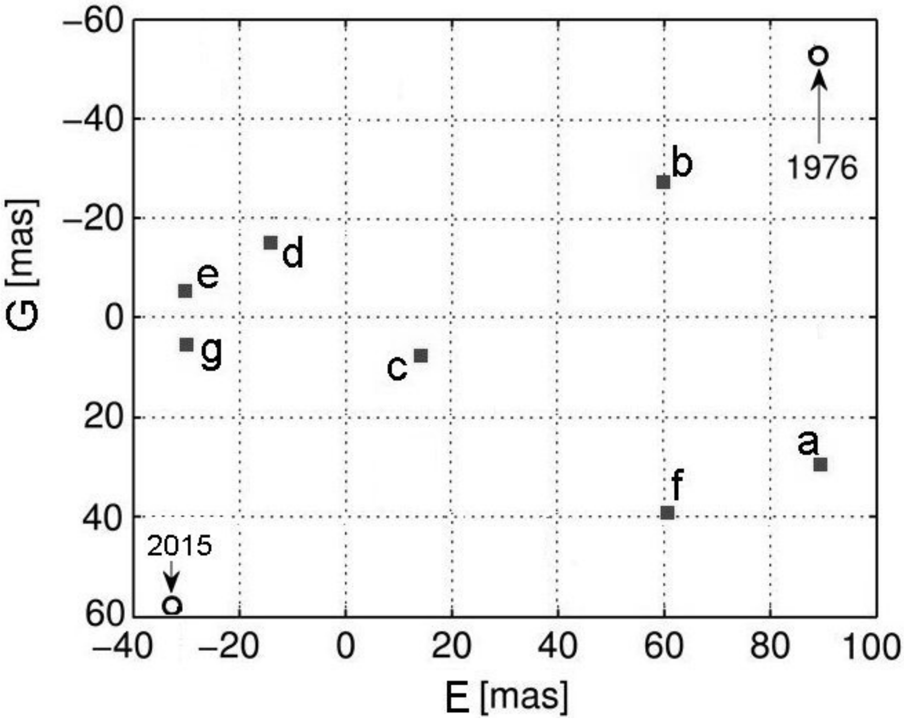


Figure 2. Data point for 1976 pole position, relative to 1899, plotted on a graph. Units are milliseconds of arc (mas) where 1 mas ≈ 3.09 cm. G(t) and E(t) coordinates for 1976 are -ve 50 mas from the 1899 pole and +ve 90 mas East of the 1899 pole respectively. Points a – g are possible locations for the 1990 and 2004 data points that Roxanne suggested Gemma consider.

Graph modified from Figure 5b in Surendra Adhikari and Erik R. Ivins. Science Advances 2(4), e1501693

7. Gemma asked Roxanne which way the pole was moving between 1976 and 2004 according to this analysis. Roxy's correct answer was:

   a. The pole isn't moving, the trend line shows the direction of ice movement in response to rapid wobbles in several directions
   b. The pole was moving in a general westerly direction into the 1899 western hemisphere
   c. The pole was moving in a general easterly direction into the 1899 eastern hemisphere
   d. The pole was moving parallel to the Prime meridian into the 1899 western hemisphere
   e. The pole was moving parallel to the 180 East meridian into the 1899 southern hemisphere
   f. The pole was moving exactly in an eastern direction into the 1899 western hemisphere

8. While studying the graph (Figure 1) Gemma noticed the linear trend Roxanne had marked on the graph in a dashed line deviated from the dataset radically after 2004. She drew another linear trend line on the graph, in a solid grey line (Figure 1), for data post-2004. Roxanne asked Gemma which way the pole was moving between 2004 and 2015 according to this analysis. Gemma's correct answer was:

   a. The pole isn't moving, the trend line shows the direction of ice movement in response to rapid wobbles in several directions
   b. The pole was moving parallel to the Prime meridian away from the 1899 pole position
   c. The pole was moving parallel to the Prime meridian towards the 1899 pole position
   d. The pole was moving parallel to the antimeridian towards the 1899 pole position
   e. The pole was moving parallel to the antimeridian away from the 1899 pole position
   f. The pole was moving parallel to the equator

9. Thinking about hemispheres Gemma consulted her globe to discover her home in Australia was situated at a longitude of $+148.3^{o}$ and a latitude of -37.1. Which sentence did she txt her friend Jade Montane?

   Hi J!
   I just found out I live in ….

   a. … 2 hemispheres, eastern and southern
   b. … 2 hemispheres, eastern and western
   c. … 2 hemisphere, western and southern
   d. … 2 hemispheres, western and northern
   e. … 2 hemispheres, eastern and northern
   f. … only 1 hemisphere, the eastern because my house is on the equator

   … what about you?

10. Gemma asked Roxanne to explain what this change in trend lines meant. Roxanne correctly explained that …

   a. … a rogue star had passed close to the solar system between 2005 and 2015. Its gravitational pull had shifted the Earth's axial tilt away from its usual trend and towards the passing star. Once a new trend is established the Earth will keep to it until another star passes close by
   b. … the Earth's magnetic field randomly flips and a flip in 2005 had caused the core to wobble so much that compasses didn't work for a while and the pole axis wobble changed and established a new trend when the magnetic field returned to normal
   c. … climate changes in the last 50 years have melted large amounts of ice in Greenland and Antarctica and have also caused large areas of the globe to dry out and other areas to get wetter. The resultant redistribution of water mass has altered the way the pole axis wobbles and established a new trend
   d. … as the Australian population grows more people living in the mega-cities along the East coast of Australia has resulted in significantly more mass in the area since 2005. This additional mass has altered the way the pole axis wobbles and established a new trend
   e. … in the last 20 years Plate Tectonics has moved the continents away from spreading centres by over 20 metres, causing a redistribution of continental mass that has altered the way the pole axis wobbles and established a new trend
   f. … the continuous bombardment of the Earth by meteorites, especially over areas of Russia since 2005, has seen so much additional mass added to these areas that it has altered the way the pole axis wobbles and established a new trend

11. In response to Gemma's txt about her location Jade sent a txt back the next day. She said:

Hi G!

I am currently on holidays (visiting family) and right now I have my left foot in one hemisphere and my right foot in another hemisphere.

Which txt did Gemma send back to Jade that was 100% correct and included Jade's actual location?

... I know you are visiting family so ...

a. That's only possible if you are somewhere on the equator. Are you visiting your extended Ecuadorian family in Ecuador? I know the capital Quito is very close to the equator
b. That's only possible if you are somewhere on the Prime Meridian, such as Greenwich in the United Kingdom, with one foot in the Eastern Hemisphere and the other foot in the Western Hemisphere
c. You are either in Quito, Ecuador (visiting family), having a holiday in the United Kingdom (visiting family in Greenwich) or having a holiday in Iceland
d. That's only possible if you are on a boat where the Prime Meridian crosses the Equator in the Atlantic Ocean, where there is a buoy jokingly called Null Island because it is where zero degrees latitude crosses zero degrees longitude
e. You are either in Quito, Ecuador (visiting family), having a holiday in the United Kingdom (visiting family in Greenwich) or on a cruise (with family) visiting Null Island
f. That's only possible if you are in Iceland with one foot on the North American tectonic plate and the other foot on the European tectonic plate

12. Gemma knew Jade could be many other places in the world, besides Iceland, where she could stand on two tectonic plates at once or at least get very close to doing so on dry land. She drew up a list of places but one was incorrect. Which one?

a. South Island of New Zealand – Pacific Plate & Australian Plate
b. Western United States (California) – Pacific Plate & North American Plate
c. East African Rift Valley – West African Plate & East African Plate
d. Morocco (north west Africa) – Eurasian Plate & African Plate
e. Himalayan mountains – Eurasian Plate & Indian Plate
f. Central America (Guatemala) – Caribbean Plate & North American Plate

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

Roxanne found more of her lecture notes and reading materials from her days as a student. She thought a 2019 scientific paper (published in the *Proceedings of the National Academy of Sciences*) that she still had would be of interest to her sister Gemma because her sister loves fossils (and has a collection of Ammonoids to prove it)! Before she showed Gemma the paper she asked Gemma to explain what an Ammonoid is. Gemma replied, showing Roxanne a picture (Figure 3) …

Ammonoids are an extinct group of marine molluscs that are well known from their shells which make excellent index fossils (fossils used to define geological periods of time) because they had a wide geographic distribution and evolved rapidly. Ammonoid shells have internal dividing walls called septa. The septa have complex shapes and, where they meet the external shell, form suture lines. The sutures have lobe (L) and saddle (S) patterns (Figure 3). The pattern of sutures evolved over time with goniatitic ammonoids found in Palaeozoic sedimentary rocks, ceratitic ammonoids typical of the Permian and Triassic periods and ammonitic ammonoids being found in all Permian and Mesozoic marine sedimentary rocks but very typical of the Jurassic and Cretaceous periods.

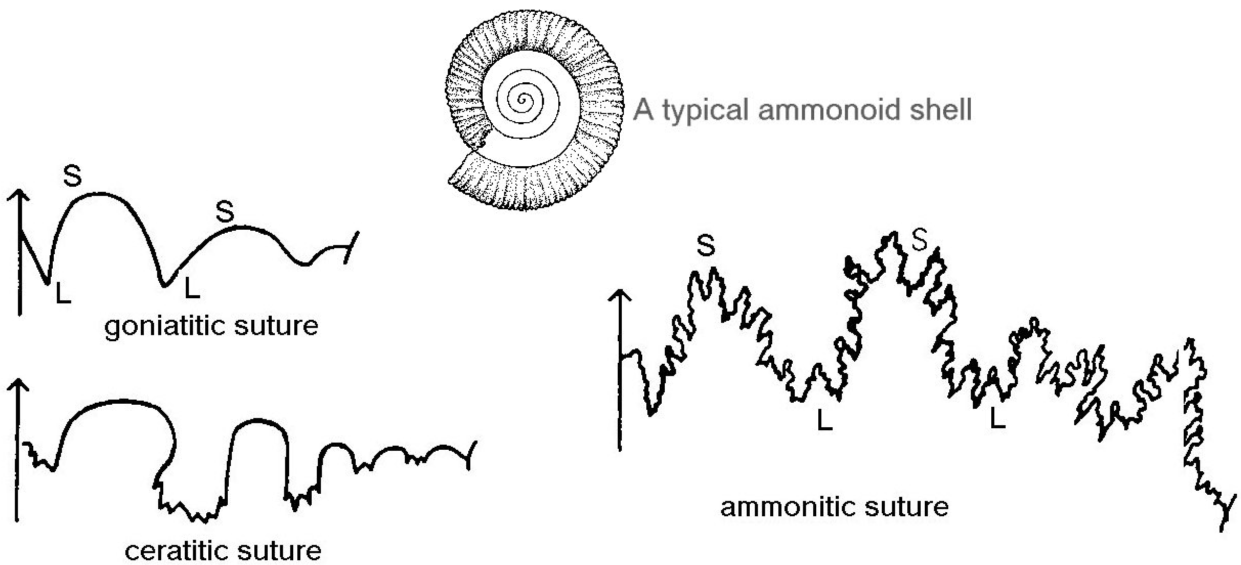


Figure 3: Ammonoid suture patterns. Goniatitic sutures have undivided lobes and saddles. Ceratititic sutures have lobes with divided, sawtooth-like, tips and undivided, rounded saddles. The sutures in ammonitic ammonoids have divided and subdivided lobes and saddles.

The paper describes a fossil Ammonite found in Amber. Roxanne has an amber necklace with a fossil insect in it. She pointed this out to Gemma and asked her ….

According to this paper the amber, which is fossilised tree resin, contains sand grains and the following fossils:

- 1 x ammonite (shell only, with tiny gastropod shells inside)
- 4 x marine isopods (a type of crustacean)
- 2 x terrestrial isopods (a type of crustacean often called a wood louse)
- 4 x marine gastropods (shells only, located within the ammonite shell as sand grains)
- 22 x oribatid mites (a type of arachnid that lives in soil and feeds on decaying matter)
- 1 x terrestrial spider (partly decayed, probably a fast-moving forest-floor predator species)
- 8 x true flies plus some midge larvae
- 2 x beetles
- 1 x parasitic wasp
- 1 x cockroach (partly decayed)
- 1 x millipede (a forest-floor detritus feeder)

… so how is it possible that the fossil tree resin, that originally flowed from a living tree, could have all these types of animals in it?

13. Gemma agreed it was a bit of a conundrum but suggested an answer. Which of the following is her correct answer that agrees with the original paper published in 2019?

    a. There was a sandy beach with resin-producing trees growing very close. Resin that trapped insects, spiders and mites on the trees dripped onto the beach, trapping marine animals and sand
    b. There was a tsunami that flooded the amber-producing forest, bringing marine debris into the forest and thus into contact with numerous blobs of resin
    c. The location of the amber is known to have been a tropical environment, so it could be assumed that tropical storms were fairly common and could therefore blow seashells and sand inland
    d. She suggested both a) and c) above are possible scenarios
    e. She suggested, in the absence of more information, it could be any of a), b) or c)
    f. She suggested b) above was the answer but only because the resin producing trees were relatively close to the beach

14. Roxanne was pleased to discover her younger sister enjoys Earth and Environmental Science and was keen to find out how much more she knew about fossils. In the paper about the ammonite in amber she read that it was definitely an ammonitic ammonoid. Roxanne asked Gemma to explain what that meant for the age of the fossil. Gemma was right when she said it means the fossil's age must be …

    a. … somewhere between the start of the Permian and the end of the Cretaceous because that is when ammonitic ammonoids have a fossil record
    b. … somewhere between the start of the Jurassic and the end of the Cretaceous because that is when ammonitic ammonoids were most abundant in the fossil record
    c. … any age after the end of the Palaeozoic when goniatitic ammonoids died out
    d. … Triassic because ammonitic ammonoids were not abundant then and there is only one of them in the amber so they were rare at the time the amber formed
    e. … unknowable without further information derived from the other fossils
    f. … somewhere between the early Palaeozoic and the end of the Mesozoic because that is the time span for rocks that have yielded ammonoid fossils

15. Gemma was aware Roxanne studied palaeontology and sedimentology at university before she graduated to become a planetary geoscientist. She asked her big sister to explain why the ammonite was not a whole animal, including the remains of soft tissues like tentacles, the way other animals in the sme bit of amber are whole. Roxanne's correct answer was …

    a. Marine Isopods are carnivorous. When the ammonite was trapped in the amber an isopod eating it was trapped too and it ate all the soft tissues before it died
    b. Marine amber does not have the same antibiotic properties as terrestrial amber and so the ammonite rotted away inside the amber
    c. The ammonite shell has the shells of tiny gastropods inside it so the animal must have died, rotted away and become an empty shell on a beach with tiny shells in the sand before it was trapped in the resin
    d. Ammonites are like hermit crabs. When they get too big they crawl out of their shell and find a bigger one so this shell must have been recently vacated by an animal looking for a bigger home
    e. The ammonite died long before the amber formed and was buried in shelly sand that became sandstone. It was eroded out of the sandstone, washed up onto a beach as a pebble and was then trapped in the amber
    f. Only Jurassic amber preserves whole animals, their internal organs and blood so the ammonite cannot be Jurassic in age

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

Roxanne and Gemma Stone were enjoying each other's company so much, after Roxanne had a long stint working on Mars, that they decided to go on a holiday to the beach. Mars has no surface water so Roxanne was keen to see the ocean up close again. One of Roxanne's favourite places is Cape Enterprise and nearby beaches that she visited on excursion when she was a student. Cape Enterprise is a rocky headland with the most southerly location called Kirk Point. The rocks at this point are interbedded sandstones and mudstones that have been folded and faulted. Roxanne showed Gemma a photograph she took as a student. She had printed out a copy with some features she had labelled with black lines (Figure 4) and kept it with her notes.

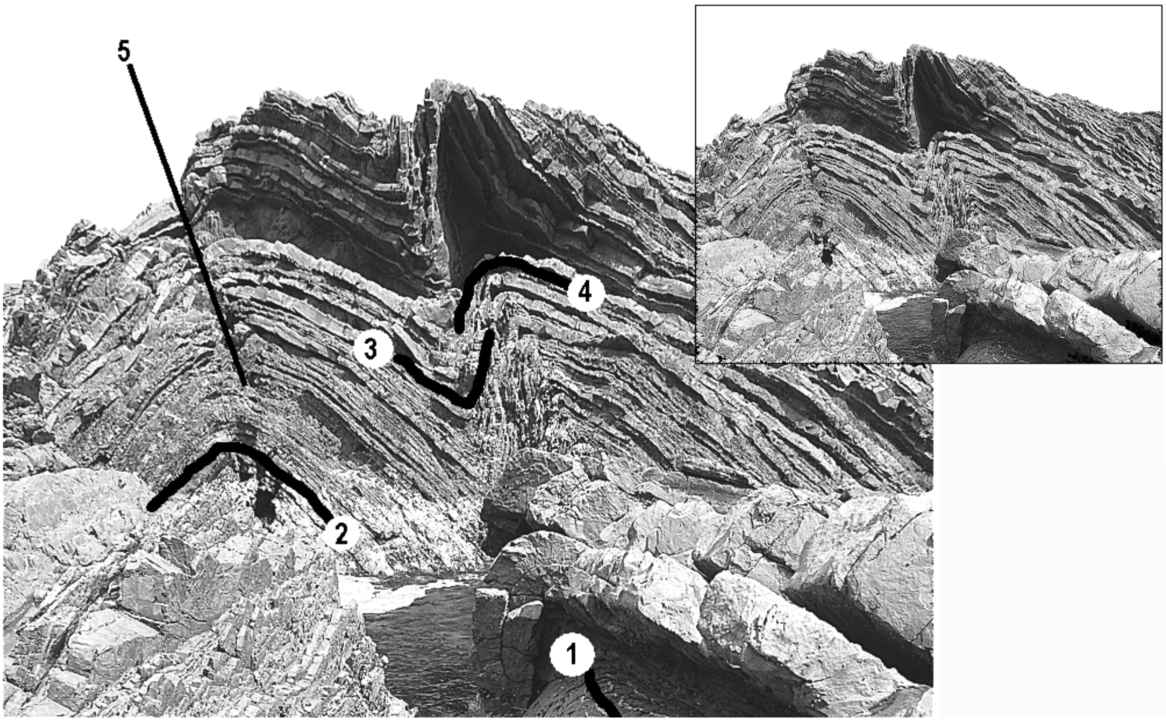


Figure 4: Five geological structures in one outcrop of interbedded sandstones and mudstones at Kirk Point, Cape Enterprise. The sandstone unit marked by the line labelled 4 is 20cm thick. The rock face displaying most of the structures is close to vertical. Image courtesy of Roxanne Stone.

Roxanne explained that the structures she labelled on the image are:

1: an anticline fold hinge

2: an anticline

3: a syncline

4: an anticline

5: a fault

Roxanne's old university friends, Philip Light, Gabi Roe, Daytona Light, Vincent Knight, Ariel Windlass, Sandra Shore and Gayle Snowdon joined them on the trip. They all remembered how much fun they had on the field trip and were keen to show Gemma all about the area.

16. Gemma wanted to know how the rocks could be folded when they are so hard. Which of Roxanne's friends gave her the correct answer?

   a. Philip said that rocks fold because they are made of soft minerals that are easily reshaped by metamorphism
   b. Gayle said that rocks fold when they are deeply buried, the higher pressures and temperatures buckle the rocks into folds because different rocks expand at different rates under higher temperatures
   c. Sandra said that rocks fold because when they are deeply buried the high pressures and temperatures weaken the rocks so they stop being brittle and become plastic. Gases released from the plastic rocks escape upwards forming anticlines by pushing the layered rocks upwards in some places resulting in synclines in the other places that were not pushed up
   d. Ariel said that rocks fold because when they are deeply buried the high pressures and temperatures weaken the rocks so they stop being brittle and become plastic. Tectonic forces in some areas slowly squeeze the rocks unevenly so they slowly buckle to form folds
   e. Vincent said that the folds were the result of really water-rich sediments being shaken in an earthquake, forming very regular folds as a result of sloshing about
   f. Gabi said that the folds were the result of brittle sediments being weakened by the heat of igneous intrusions. The hot plastic rocks buckled out of the way as the magma pushed through, creating regular folding in the sediments across the entire region

17. Gemma loved the way the sandstone layers stood out from the surface more than the mudstone layers (Figure 4). She thought it might be because the sandstone was harder than the mudstone but didn't know why that would be the case. Who had the best explanation?

   a. Daytona said the sandstone was mostly quartz grains held together by quartz cement and that it is a lot harder than feldspar that makes up mudstone
   b. Vincent agreed with Daytona about the quartz but insisted the mudstone is made of more easily eroded clay minerals
   c. Ariel thought that the bigger grains of sand would simply be harder to erode
   d. Philip agreed with Vincent about the clay but thought the hard mineral in the sandstone might be talc
   e. Gabi thought the sandstone was harder because it had no fossils in it
   f. Sandra said the rate of erosion is only dependent upon the angle of wave attack and at other places the mudstone probably weathers more slowly than sandstone

The following information relates to questions 18, 19, 20, 21 & 22.

Further along the rocky platform at Cape Enterprise the friends showed Gemma a plunging fold (Figure 5a) in more interbedded sandstone and mudstones. Gemma's careful observations revealed the sandstones have cross-bedding structures in them and the mudstones don't. The mudstones are very finely laminated and show low grade metamorphism, having become slate. When the slate is broken open it reveals strange marks on the bedding planes. Roxanne explained that these are actually fossils of marine planktonic animals called graptolites (Figure 5b).

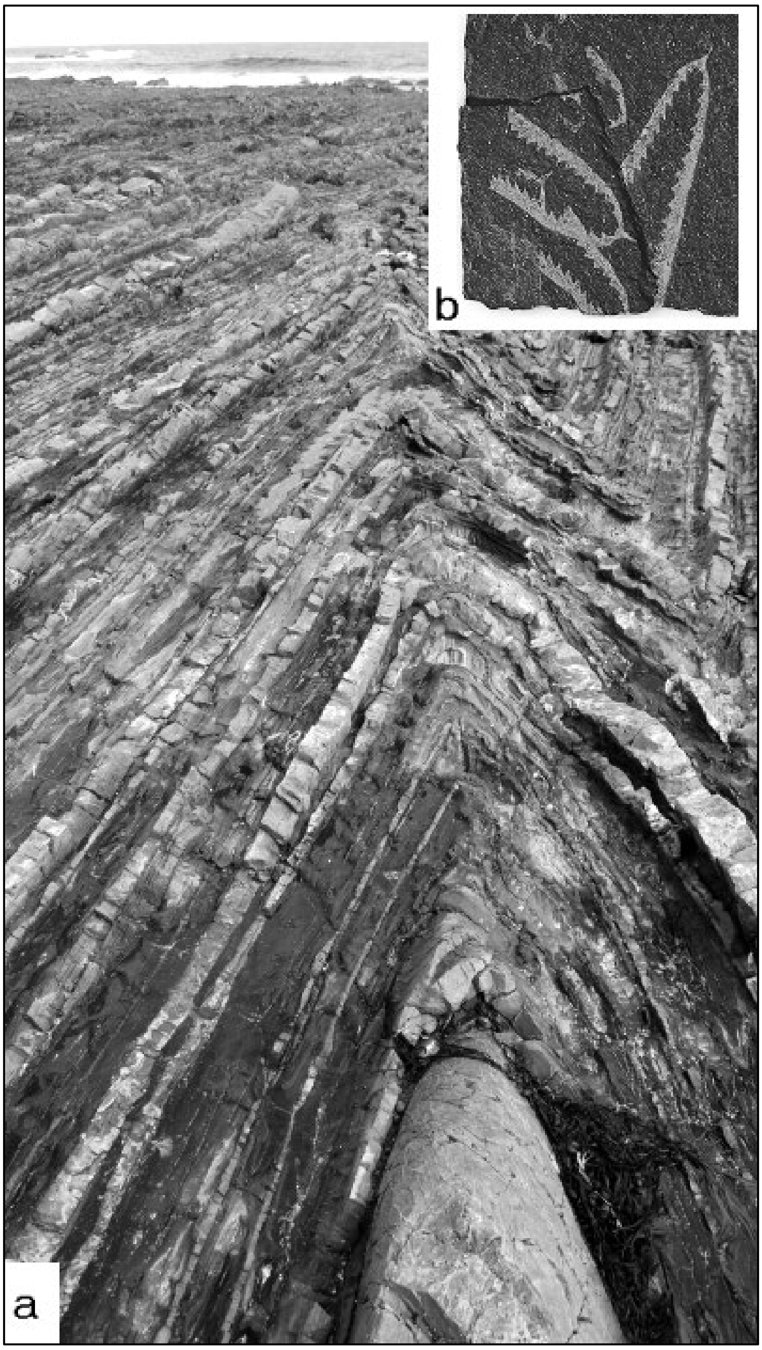


Figure 5: Cape Enterprise.
5a - Shore platform adjacent to Kirk Point,
Cape Enterprise, looking south towards the ocean.
Photograph courtesy of Vincent Knight.
5b – Graptolite fossils on the bedding plane of a black slate.
Image courtesy of the British Geological Survey,
http://tinyurl.com/y5z4b68l

18. Gabi didn't pay much attention in palaeontology classes so was intrigued by the graptolites. *They look just like graphite pencils marks,* she exclaimed! She asked her friends how there could be fossils of marine planktonic animals in the layers when cross-bedding in the sandstone is typical of fast flowing water that moves sand in ripples and dunes. Who gave the correct answer?

    a. Ariel. She said the sandstones were deposits formed when packets of sand rushed down the edge continental shelf and came to rest on the floor of the abyssal plain. The fast flowing, turbulent but mono-directional movement of the water formed the cross-bedding. The mudstones were deposited in the quiet times in-between the flows with both mud and the dead remains of planktonic animals gently settling out of the water column onto the sea floor
    b. Daytona. She agreed with Ariel about the packets of sand but said the mudstones were also deposited as turbulent flows off the edge of the continental shelf. Planktonic animals live in shallow seas so their remains could not be deposited from deep water. The laminations the fossils lie on are examples of very high energy laminar flow structures that entrain flat objects like the graptolites
    c. Philip. He agreed with Daytona about the laminar flow in the mudstones entraining the graptolites but said it was because high-energy deep-sea currents moved abyssal plain mud deposits around to form the layers mixed in with layers of sand (also moved by deep-sea currents)
    d. Vincent. He says he recalls his lecture notes saying metamorphic rocks like schist and gneiss don't contain fossils because, if they are metamorphosed fossil-rich sedimentary rocks, the metamorphic process destroys any fossils. Since the slate is a low-grade metamorphic rock the graptolites must be some kind of post-depositional artefact introduced into the slate by much later biological activity such as some kind of previously unknown rock boring graptolite
    e. Sandra. She was very confident the graptolites attached their bodies to clay grains in suspension and only get deposited on the sea floor when enough of them stick together in groups called flocculants. She agreed with Ariel about the deposition of the sand layers
    f. No-one was correct. Mud and the dead remains of planktonic animals never gently settle out of the water column onto the sea floor but remain permanently in suspension because sea water is so turbulent. The organic material and clay minerals must be reduced to carbon-rich materials in the digestive systems of placoderm fish first. These are known as Jeffites, named after well-known entrepreneur and amateur vertebrate palaeontologist Jeff Gnathostomes

19. Roxanne showed Gemma a page from her old notes (Figure 6). She asked Gemma if she could tell from her observations and this information how old the rocks at Cape Enterprise were. Gemma smiled, saying; *Of course I can*! What age did Gemma give the rocks?

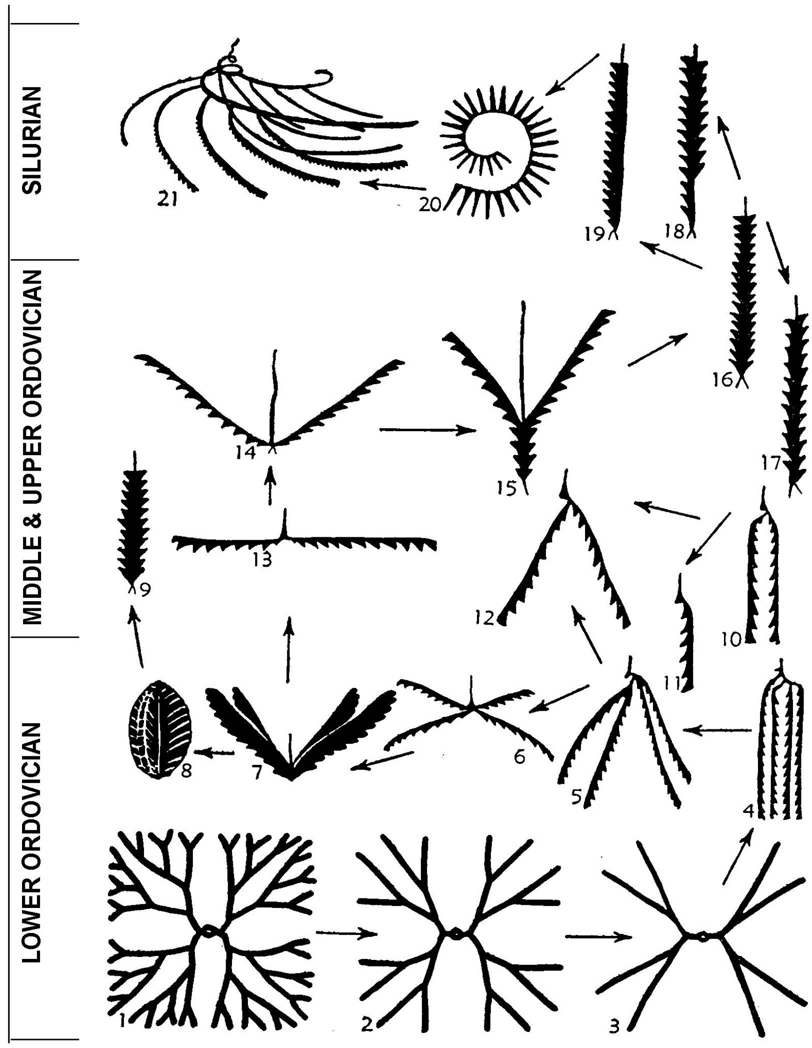


Figure 6: Evolution of graptolite shapes through time. Shapes in this graphic indicate when graptolites of this shape first appeared in the rock record but do not indicate when they went extinct. However, multibranched graptolites did not survive a late Ordovician extinction event and all graptolites were extinct by the end of the Middle Devonian.
Image modified from Moore, Lalicker & Fischer, Invertebrate fossils. (1952), Figure 22-7

a. Silurian
b. Upper Ordovician and Silurian
c. No older than Lower Ordovician, not Silurian
d. Lower Ordovician and Middle Ordovician only
e. Middle Ordovician
f. No older than Middle Ordovician, not Silurian

20. In an outcrop of tightly folded sandstone nearby, a series of small fractures (tension gashes) in the rock are filled with a white opaque mineral. A couple of pieces were loose, enabling the friends to look at them with their hand lenses (which they always carry with them). Gemma observed that it was quite hard, it scratched her finger nail and the metal on the handle of Roxanne's G-pick. Gabi declared it was quartz. What would help confirm she was correct?

    a. 3 good cleavages, vitreous lustre, scratches orthoclase feldspar
    b. 3 good cleavages, earthy lustre, scratches orthoclase feldspar
    c. 1 perfect cleavage, 1 good cleavage, earthy lustre, scratches orthoclase feldspar
    d. 1 perfect cleavage, 1 good cleavage, vitreous lustre, scratches orthoclase feldspar
    e. No cleavage, vitreous lustre, scratches orthoclase feldspar
    f. No cleavage, earthy lustre, scratches orthoclase feldspar

21. In discussing the opaque white mineral around the camp fire that night the friends asked Gemma what her favourite mineral was and why. Gemma, who had thought about this a lot, had discussed it with her teacher Ms Luciana Day so she was sure her reasons were correct. What answer did she give?

    a. Quartz, because it has amazing healing properties and it's found all over Earth
    b. Opal, because the crystals can grow to any size and it's found on Mars
    c. Ice, because it is part of life when it melts and it's found on the Moon
    d. Calcite, because it makes our skeletons and it's found on Mars
    e. Diamond, because you cannot break it with anything and it's found on the Moon
    f. Amber, because it can contain fossils (even ammonites) and it's found all over Earth

22. Well-known entrepreneur and amateur vertebrate palaeontologist Jeff Gnathostomes is friends with Roxanne. He arrived at the camp late in the evening in time for the favourite mineral conversations around the camp fire so naturally the group asked him to name his favourite type of fossil and why. His authoritative answer was:

    a. Fish, because they're vertebrates, great mascots and the best flavour for ice-cream
    b. Ammonoids, because they're Gemma's favourite and they evolved in the pre-Cambrian where all good life began
    c. Graptolites, because they're great index fossils up to the Permian extinction event
    d. Starfish, because with five-fold body symmetry they must be interstellar visitors
    e. Carbon isotope ratios in old sedimentary rocks, because even without solid remains we can tell when life evolved and started to alter the pre-life isotope ratio
    f. Dinosaurs, because they lived side-by-side with humans until their extinction

The following information relates to questions 23, 24 & 25.

The next morning the whole group headed for the beach. They explored both beaches either side of Cape Greyjoy (Figure 7). Jeff went swimming. Everybody else walked from Arya Beach, across the Cape and over Yara Point to Balon Beach (Figure 7). Sandra had great fun on Arya Beach, picking up shells and other flotsam and jetsam. Jeff swam out to Stark Reef. The others explored the rock platform at Yara Point. They all met up on Balon Beach and had a picnic lunch at the point where Blackwater Estuary meets the open ocean.

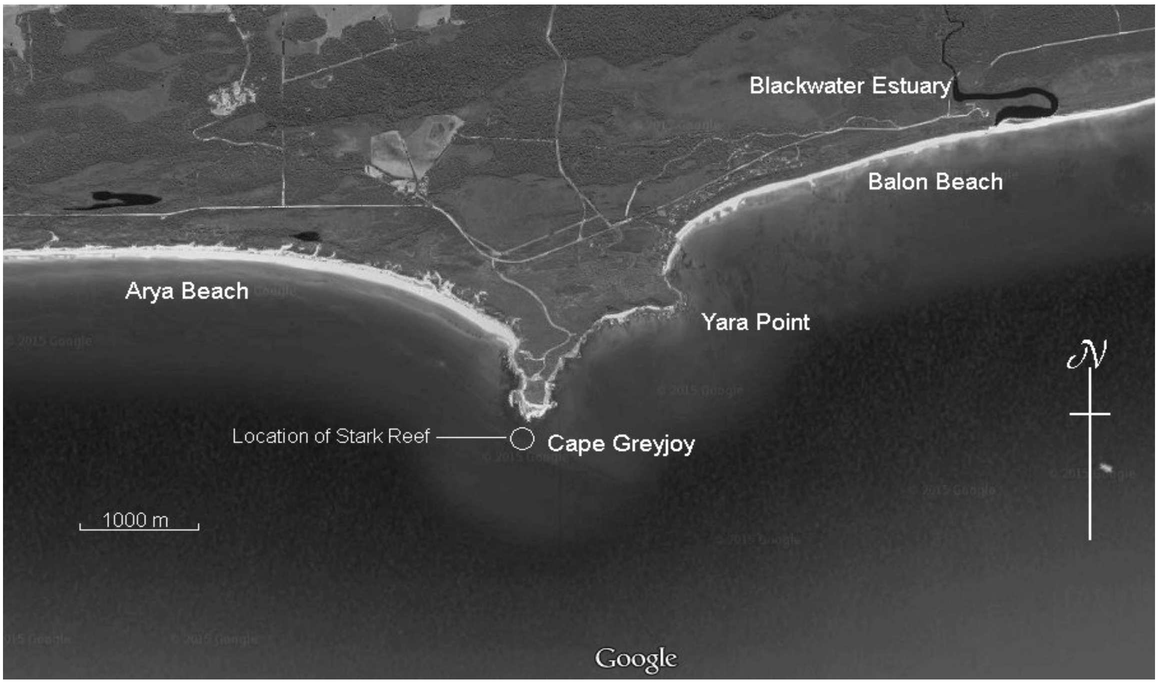


Figure 7: Geography of the Cape Greyjoy area.
Modified image courtesy of Google Maps.

At the picnic site the friends were puzzled to find the estuary was not flowing out to sea. Where the estuary should have been there was just a beach. On the beach was an unusual variety of blue, white, grey, brown, spotty and orange pebbles scattered randomly on the sand (Figure 8).

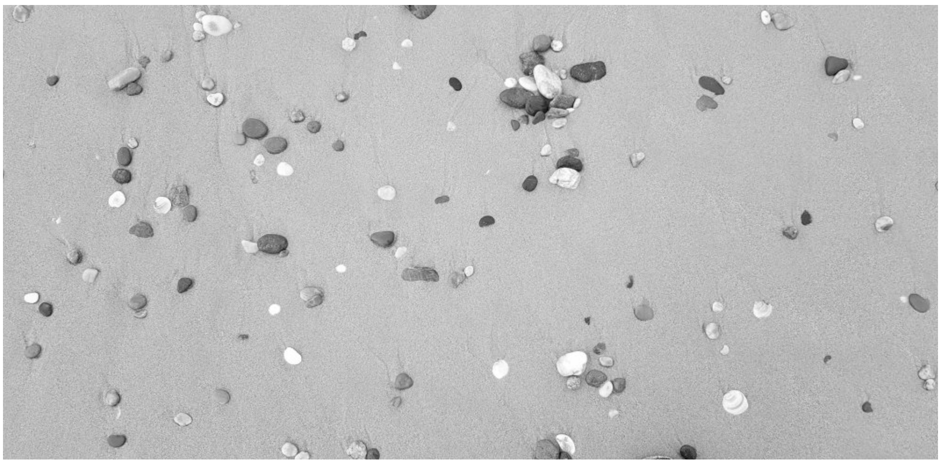


Figure 8: Pebbles on the beach at the estuary. Pebbles are between 20 mm and 45mm in diameter. Image Courtesy of Gemma Stone.

23. Jeff joined them on the beach after swimming from Stark Reef. He was happy to see them but exclaimed …*where is the estuary? I wanted some freshwater to flush out my gills!* Everyone laughed but Gemma thought she knew the answer. Her correct solution to this conundrum was …

   a. The word estuary is a misnomer. It is just a pond behind some sand dunes
   b. The Blackwater River has a small catchment area. In times of low rainfall it simply does not have enough river flow to push the beach sand out of the way so it backs up behind the sand dunes (being constantly built by wave action) in the estuary as a lake
   c. The process, known as long shore drift, pushes sand along the beach and builds beach dunes in the area so fast that the river never has a chance to push through them so there never is an estuary opening to the sea
   d. The beach sand is so porous that the estuary water flows through it out to sea extremely effectively so there never an actual river mouth opening to the sea
   e. The forest around the estuary has been cleared, increasing evapotranspiration so much that there is never enough water reaching the bottom of the estuary to actually flow out to sea
   f. The estuary only opens to the sea at high tide when waves break over the dunes, adding enough water to the estuary lake to allow a flow back out to sea

Jeff spent some time collecting pebbles from the beach. He was particularly taken with the fact they were all nicely rounded and very smooth to touch. Jeff and Roxanne drew a table in the beach sand (Table 1) and had a fun time filling it with data!

Pebble	Origin and/or Parent rock
Orange quartz	Vein quartz, probably metamorphic
Blue – black with lots of tiny laminations	Slate, metamorphic (metamorphosed mudstone or shale)
Spotty. Crystals 1-4mm in size, randomly interlocking.	Igneous, intrusive
Brown, not granular but ghosts of grains of sand visible. Very hard.	Quartzite, metamorphic (metamorphosed sandstone)
Black with spots of red crystal and some tiny white crystals	Igneous, volcanic

Table 1: Jeff and Roxanne's beach table

24. Gemma wanted to know where the pebbles came from and everyone at the picnic was intrigued. What did it all mean? Who got it right when it came time to suggest an answer?

    a. Jeff knew Stark Reef was a submerged outcrop of granite. He proposed all the pebbles came from Stark Reef
    b. Gabi thought it more likely that the granite had intruded some basalts that outcrop at Yara Point and the pebbles were metamorphosed basalts that had washed along the beach because of long shore drift
    c. Sandra thought the pebbles were more local, washed out of sand dunes during storm erosion and were probably from the same place as the pumice pebbles she found in the sand dunes
    d. Daytona suggested the pebbles arrived on the beach as the result of a tsunami ripping up rocks from the sea floor and throwing them up on the beach
    e. Vincent said the rocks were nice and rounded despite being hard so they must have been washed to the location from a long way up stream where lots of sedimentary and igneous rocks occur in cliffs and other outcrops
    f. Philip agreed with Vincent but suggested the upstream environment must have igneous and metamorphic rock outcrops, not sedimentary rock outcrops

Jeff had a fun time with Roxanne and her friends. That evening it was a cold clear night so sitting around the camp fire again they could do a bit of star gazing. The conversations soon turned to the likelihood of life being found elsewhere in the solar system or elsewhere in the universe. Jeff suggested life was not possible without the presence of liquid water; after all, fish need water! Gabi agreed that all life as we know it does need water so any life that evolves with a liquid that is not water might be so weird that we would never recognise it. Gemma agreed with both of them but then went on to say that liquid water can occur in places that are not at all Earth-like.

25. Which of the places she listed might potentially harbour life albeit not life as we know it?

    a. In salty lakes of water trapped within the Antarctic ice sheet
    b. The methane-ethane lakes of Saturn’s moon, Titan
    c. The subsurface of Saturn’s moon Enceladus that erupts geysers that form chains of water-ice crystal mountains on the surface
    d. The subsurface of Jupiter’s moon Europa that has a form of plate tectonics in its icy crust driven up upwelling salty water
    e. Beneath the Martian permafrost in sedimentary aquifers
    f. All of the above

The following information relates to questions 26 and 27.

Daytona and Vincent revealed their interest in astronomy during this star gazing session. Daytona pointed out the star cluster known as the Pleiades, also known as the Seven Sisters. She explained it is an open cluster of stars about 17.5 light years across and 444.2 light years from Earth and the one most easily seen with the naked eye. Six stars are easily seen by eye but 14 can be seen by eye if conditions are good and in 1610 Galileo used his telescope to count 36 stars. Modern observations have revealed lots of less bright objects in the cluster totalling about 800 solar masses. Jeff was certain he saw colours in the stars, mainly blue. The others agreed. Vincent confirmed their observations. Using the Hertzsprung-Russel diagram (Figure 9) he always carries with him, Vincent noted that the bright blue stars are all main sequence B-types.

26. Gemma asked him to explain. His actual reply was *The Sun is a G-type main sequence star. Main sequence B-Type stars are ….*

    a. … very hot and orders of magnitude more massive than the Sun
    b. …very hot, and orders of magnitude less massive than the Sun
    c. … like white dwarves only blue
    d. …very hot, usually 3-10 times more massive than the Sun
    e. … like brown dwarves, which are too cool for the Hertzsprung-Russel diagram, only blue and hotter
    f. …not much hotter but usually 3-10 times more massive than the Sun

27. Ariel said she loves the Pleiades but wanted to know if they could host planets suitable for life. Daytona said *I've got this!* Her answer was *… Stars in the Pleiades are too young to have planets but, assuming liquid water is a precondition for life, …*

    a. … any planet that orbits a star at a distance that allows liquid water to exist on its surface could potentially host life of some sort
    b. … only planets that orbit G-type stars could potentially host life of some sort
    c. … planets that orbit B-type stars could never host life because their light is blue
    d. … only planets that orbit K, G or F-type main sequence stars could potentially host life
    e. … only planets with greenhouse atmospheric gases could potentially host life
    f. … any planet that orbits a star or another planet could potentially host life if the water on its surface has the right nutrients irrespective of its phase (solid, liquid, gas)

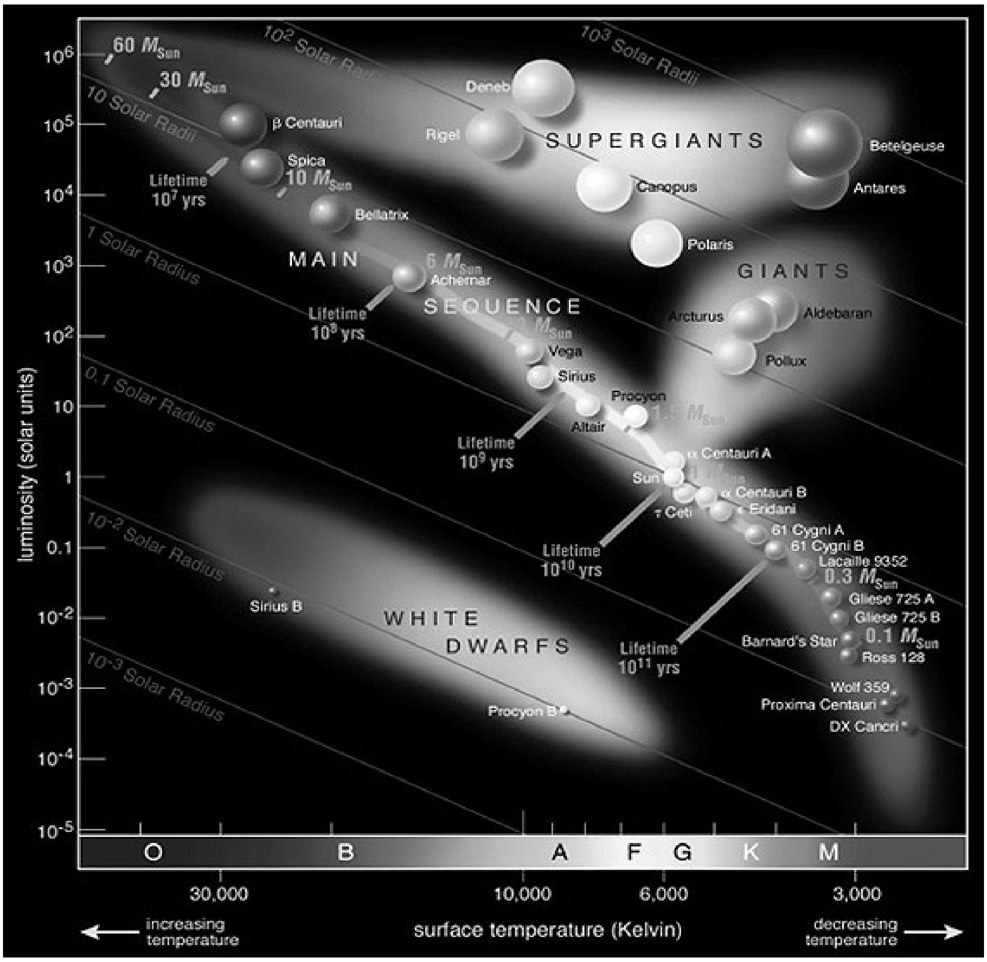


Figure 9. The Hertzsprung-Russel diagram used by Vincent.

Modified from *The Cosmic Perspective*. O. Bennett, J. Donahue, M. Scneider & N. Voit 7th edition.

The friends sat around the camp fire all night star gazing and satellite spotting. They even saw the International Space Station #2 pass overhead!

28. A bleary-eyed Gemma noticed the Moon was rising as she fell asleep while Jeff was cooking breakfast at sunrise. She managed to ask Vincent why it was so before she faded. His unheard answer was … *It is the Moon's phase which describes Moon rise and Moon set. The Moon rises and sets with the Sun when the phase is …*

a. … a Blood Blue Moon
b. … a Third Quarter Moon
c. … a Second Quarter Moon
d. … a First Quarter Moon
e. … a Full Moon
f. … a New Moon

On their way back home after breakfast, the friends stopped at Yara Point to admire the flood basalts that outcrop there. They form a prominent shore platform popular with fisher people.

29. Amber wanted to know how they knew it was a basalt rather than some other type of igneous rock. Roxanne replied … *Basalt is ...*

   a. … a volcanic igneous rock that is black despite being full of quartz and feldspar and other light-coloured minerals because the volcanic glass gives it a dark appearance
   b. … a black rock that forms horizontal layers because of the way it intrudes sediments
   c. … both a and b
   d. … a volcanic igneous rock that typically forms from lavas that cool to form a black rock because a large amount of the minerals that form it are dark coloured and together with the dark glassy matrix give an overall black appearance
   e. … a rock that forms from a lava that lets lots of gases escape from it as it is erupting. As the lava cools some of the gases are trapped as bubbles in the rock which are obvious in outcrop
   f. … both d and e

At Cape Greyjoy they did some whale watching and watched the surf break on the rocks of Stark Reef. Jeff was adamant the rocks at Stark Reef were granite but a sample he found on the rock platform courtesy of a lump kelp washed up during a storm had Roxanne thinking otherwise.

30. Why did Roxanne think it was a dolerite?

   a. She remembered from her student report
   b. The rock is light coloured, completely crystalline and shows about 20% to be clear glassy quartz
   c. The rock is composed entirely of black crystals 2-5mm in length
   d. The rock is dark coloured, foliated and shows abundant trapped gas bubbles
   e. The rock is dark coloured, very fine grained except for large, visible white opaque slightly rectangular crystals several millimetres long making up about 15% of the rock
   f. The rock is dark coloured, very fine grained except for large, visible pink opaque slightly pyramidal crystals several millimetres long making up about 35% of the rock

The following information relates to questions 31, 32 and 33.

After they returned to their mini-bus they said farewell to Jeff, who was intent on finding a fish-flavoured ice-cream, and headed home. On the way they stopped at a road cutting they had visited as students because the rocks were so easy to see and the geology was so interesting (Figure 10).

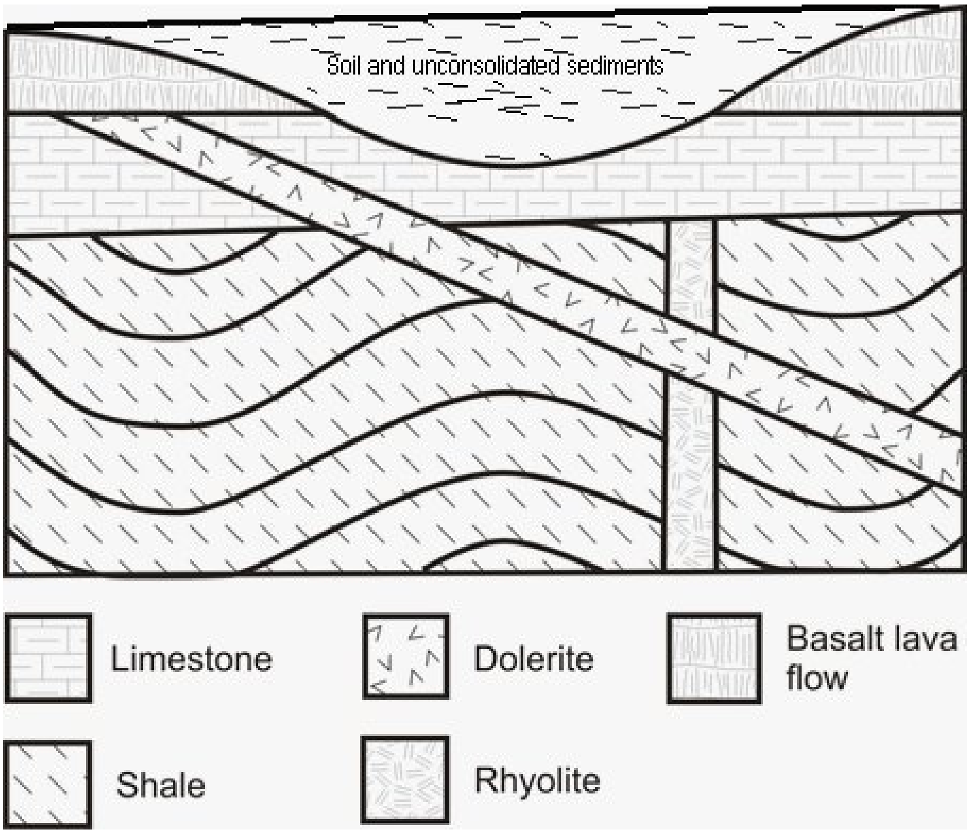


Figure 10: Road cutting outcrop near Cape Enterprise.
Drawing courtesy of Gemma Stone.

31. Roxanne challenged Gemma to list the rocks from oldest to youngest, ignoring all the events that deposited or created them. Gemma correctly listed them. What did she say?

   a. Shale, Rhyolite dyke, Limestone, Dolerite dyke, Basalt lava flow
   b. Basalt lava flow, Dolerite dyke, Limestone, Rhyolite dyke, Shale
   c. Shale, Rhyolite dyke, Limestone, Basalt lava flow, Dolerite dyke
   d. Dolerite dyke, Basalt lava flow, Limestone, Rhyolite dyke, Shale
   e. Dolerite dyke, Rhyolite dyke, Basalt lava flow, Limestone, Shale
   f. None of the above

Roxanne pointed out to Gemma that the dolerite intrusion (Figure 10) is thought to be a feeder dyke from a larger magma source several thousand metres below this outcrop. The dyke may have fed a volcano which has long since been eroded away. However, the slow cooling rock at depth may still be hot enough to be a source of geothermal energy.

32. Gemma wanted to know what rock type they would find if a geothermal exploration company drilled down to the slowly cooling crystalline material that was also the source of the dolerite in the outcrop. Roxanne carefully replied that ... *as long as there has been no magmatic fractionation between the time of the intrusion of the dolerite and the final intrusion of the large magma body at depth the rock they would find* is a …

a. Gabbro
b. Granite
c. Rhyolite
d. Hornfels
e. Dolerite
f. Andesite

33. Roxanne remembered that the soil and unconsolidated sediments at the top of the road cutting had revealed a fossil megafaunal marsupial, *Protemnodon anak* (a kind of giant wallaby). Their friend, Ariel Windlass, found the bones while on the student field trip they did together years ago. Gemma knew the Australian megafauna has a fossil history dating back many millions of years so she asked Roxanne to explain why she called it a Pleistocene fossil when it could also have been Pliocene or Miocene in age.
Roxanne's answer was … *In all probability it is a Pleistocene aged fossil because ...*

a. … identical fossils have been found in sediments underlain by a basalt lava flow dated at 2.01 ± 0.05 million years
b. … identical fossils have been found in sediments capped by a basalt lava flow dated at 0.16 ± 0.01 million years
c. … identical fossils have been found with cut marks on them consistent with having been butchered by human hunters
d. … identical fossils have been found in sediments in association with fossil wood with an Accelerator Mass Spectrometry ^{14}C date of approximately 47,500 years
e. … identical fossils have not been found in sediments of Holocene, Pliocene or Miocene age
f. All of the above

The following information and Tables 2 and 3 relate to questions 34, 35 and 36.

On the way home the friends kept each other entertained with a word game based on the Earth Systems Science studies they did when they were students.

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.

As they drove along Amber adjudicated the game. She read out a list of 30 words or phrases that the others wrote down (Table 3) (Roxanne was driving so she couldn't play).

Amber said the rules were simple!

She would choose six of the words from the list and nominate which two spheres the words chosen show an interaction between.

However, one of the six words will be incorrect and they must identify the incorrect word and replace it with another one from the list that is correct!

Weathering	Slate	Sedimentation	Longshore drift	Lava flow
Hot spring	Chalk	Amber pebbles	Andesite	Stalactite
Schist	Brown coal	Limestone	Tsunami	Sand dune
Fog	Tornado	Earthquake	Soil	Siltstone
Mudstone	Erosion	Aquifer	Graptolite fossil	Tar
Delta	Rainbow	Quartz crystal	Meteorite	Magma

Table 3: Amber's list

34. In Amber's first challenge, she shouted out the 6 choices, from the 30 she provided earlier (Table 3). They were:

Stalactite, Lava flow, Erosion, Hot spring, Long shore drift, Sedimentation

She said they were examples of interactions between the **geosphere** and the **hydrosphere** but one of them was actually wrong. Only one person got it; who was it?

a. Sandra. She replaced Longshore drift with Weathering
b. Gabi. She replaced Lava flow with Weathering
c. Vincent. He replaced Lava flow with Tar
d. Ariel. She replaced Erosion with Aquifer
e. Philip. He replaced Sedimentation with Rainbow
f. Gemma. She replaced Erosion with Delta

35. Amber issued a second challenge once everyone had finished arguing about who was right! Her next 6 choices were:

Chalk, Amber pebbles, Limestone, Andesite, Brown coal, Tar

She said they were examples of interactions between the **biosphere** and the **hydrosphere** but one of them was actually wrong. Who got it right?

a. Sandra and Gabi. They both replaced Tar with Graptolite fossil
b. Gabi. She replaced Chalk with Mudstone
c. Daytona and Vincent. They replaced Andesite with Graptolite fossil
d. Ariel. She replaced Andesite with Siltstone
e. Philip. He replaced Amber pebbles with Rainbow
f. Gemma. She replaced Limestone with Sedimentation

36. Vincent wanted to know what spheres were involved with the emplacement of iron-nickel meteorites. Who gave the best answer?

a. Gabi. She said meteorites are just rocks so they are just geosphere materials
b. Ariel agreed with Gabi but that said geosphere and hydrosphere because they are space rocks that get wet when they hit the ground
c. Gemma said geosphere and atmosphere because they are space rocks that are slowed and shaped a bit by friction with the air before they hit the ground
d. Daytona agreed with both Gabi and Ariel
e. Philip argued they are space rocks so no spheres are involved
f. Sandra thought all of the spheres were involved

At the end of the trip they all agreed they would do it again sometime but Roxanne said she was returning to Mars and was hopeful of getting a job on the next exploration mission to Europa.

A week or so later Gemma and her friends, Kimberly Piper, Jade Montane, Amber Gris and Ruby Novenary got together for a movie night to test their understanding of what they're learning in their Earth and Environmental Science class. They spent the evening watching a series of movies and challenging each other to prove certain scenes true or false.

They started their evening with *Journey to the Center of the Earth*, wherein the main characters find themselves falling through a lava tube for just over a minute below a very deep mine shaft, eventually landing on a platform somewhere in the Earth's crust (the time spent falling would place them about 40 km below the surface). The walls are covered in fist-sized sparkling colourful jewels of feldspar ($KAlSi_3O_8$), diamond (C), emerald - a variety of beryl ($Be_3Al_2(SiO_3)_6$), ruby and sapphire (both varieties of corundum, Al_2O_3) and the floor is identified as "a thin type of rock formation" called "Muscovite" ($KAl_2(Si_3AlO_{10})(OH)_2$). They paused the film and discussed how preposterous it is after they all stopped laughing. Each offered up one thing that's wrong with the scene and then the others tried to explain why it is wrong.

37. Amber thinks it's preposterous that the characters are supposed to be falling through a vertical "lava tube" ~40 km below the surface. Who gave the best explanation of the problem in the scene Amber was critical of?

    a. Jade agreed because lava does not flow freely beneath the surface
    b. Gemma agreed because high pressure will close large cavities deep below the surface
    c. Ruby agreed because ground water circulating beneath the surface will deposit soluble minerals in any cavities
    d. Kimberly pointed out that lava tubes are predominantly horizontal features, not vertical shafts, forming as low-viscosity lava flows across the ground, cooling around the exterior quickly while insulating a river of lava inside
    e. All four friends provided correct explanations for the problem with this scene
    f. None of the friends managed to correctly explain this problem with the scene

38. Jade claimed that feldspar, diamond, emerald, ruby and sapphire cannot form in the same environment. Who gave the best explanation of the problem in the scene Jade was critical of?

a. Ruby pointed out that corundum only forms under extreme metamorphic conditions within mountain fold belts at depths greater than 30km
b. Gemma explained that sapphires and ruby are the same mineral with different trace impurities, therefore they must form separately
c. Amber pointed out that large crystals of feldspar and beryl only form in the upper parts of granitic magma chambers at approximately 15km depth
d. Kimberly used a diagram (Figure 11) to show why diamonds could not form in the crust at a depth of approximately 40km
e. All of the friends provided excellent explanations for the error in this scene
f. Only Kimberly and Ruby's explanations shed light on what is wrong about this aspect of the scene

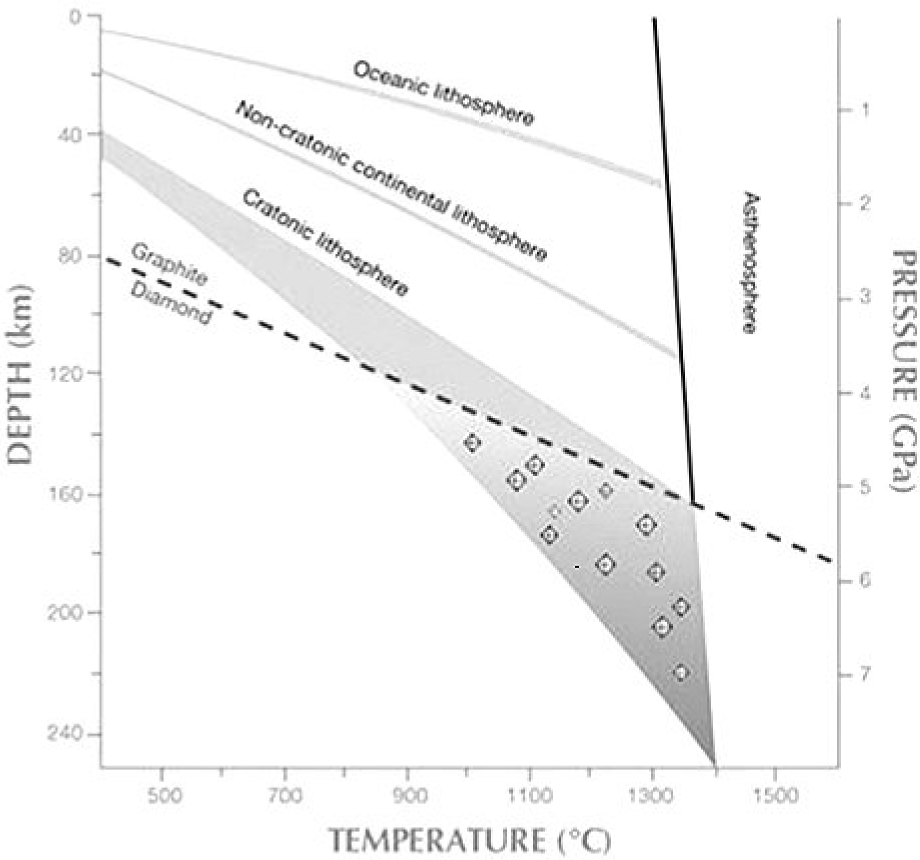


Figure 11: The diagram Kimberley used to make his case.

39. Gemma was flabbergasted by both the presence and description of Muscovite in the scene, which rigidly holds the weight of the three explorers until a 'diamond' is dropped on it and shatters it like ice. Who gave the best explanation of the problem in the scene Gemma was critical of?

a. Ruby explained that Muscovite is a mineral (also known as white mica) that easily peels off into thin layers and is <u>not</u> a "thin type of rock formation".
b. Kimberly pointed out that lava tubes only form from basalt, therefore Muscovite cannot form here.
c. Jade pointed out that Muscovite is a flexible mineral and therefore should bend significantly before shattering.
d. Amber noted that clusters of Muscovite do form in hydrothermal deposits, so perhaps a hydrothermal origin is acceptable
e. All the friends came up with amazing explanations for this issue!
f. All the friends need to review their basic mineralogy notes.

40. Kimberly suspected that all the sparkling "jewels" in this cavern are actually just different coloured common void-filling minerals like calcite and fluorite. He challenged his friends to suggest one simple test they could perform to see if they'd discovered great riches or just lots of pretty minerals. Who had the best approach to Kimberley's challenge?

a. Amber suggests testing with HCl as that will react vigorously with calcite ($CaCO_3$) and fluorite (CaF_2), but not with the gemstones
b. Jade suggested trying to scratch the minerals with her fingernails, as they should only scratch calcite and fluorite
c. Ruby thought shining a UV light on them might help, arguing that only calcite and fluorite will fluoresce under ultraviolet light
d. Gemma suggested scratch testing each mineral with a piece of glass. This test would separate calcite, fluorite and feldspar from the precious gemstones
e. Kimberly thought smashing them with a hammer would work, with the gemstones resisting breaking while the common minerals would disintegrate
f. None of the suggested tests will work

They resumed watching the film, laughing uproariously at some of the incredible physics-defying events, then pausing again when the main character tells everyone that the cute little birds they find in the world within the world have been extinct on the Earth's surface for 150 million years. They argued for a while about whether or not this could be correct. In the end Gemma found a bird evolution chart she thought might settle the matter (Figure 12).

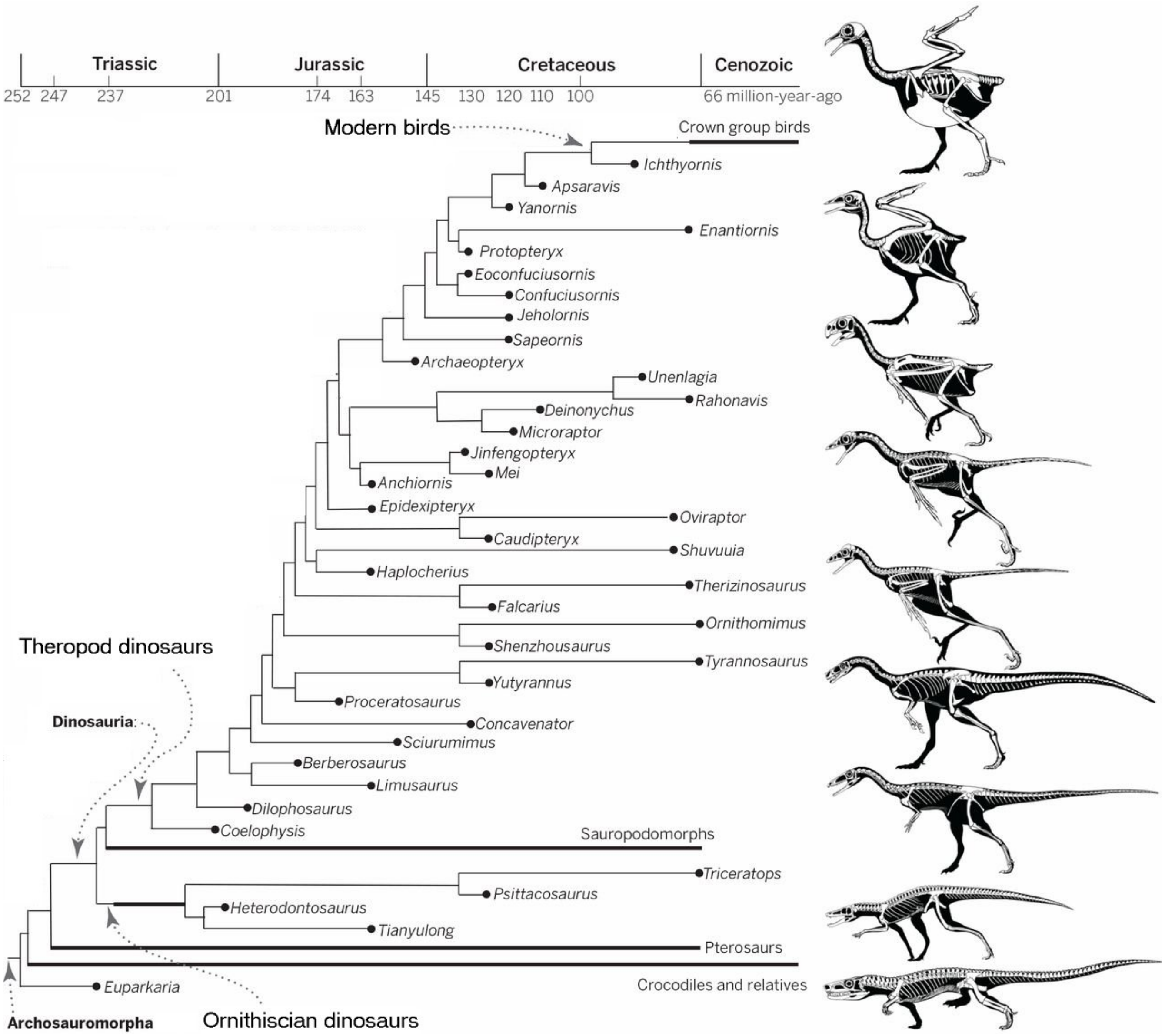


Figure 12: Evolution of birds.

Modified from Xu et al 2014. *An integrative approach to understanding bird origins.* Science V346, 6215, 1253293

41. Gemma said the diagram (Figure 12) could help them decide if a bird with all the characteristics of a modern bird could have gone extinct 150 million years ago. What did they collectively decide was the correct answer?

   a. Yes, it is possible, because that's when Archaeopteryx went extinct
   b. Yes, it is possible because species like modern birds co-existed with dinosaurs and bird-like dinosaurs have been around since 145 million years ago
   c. No, it's not possible because modern birds evolved directly from Archaeopteryx
   d. No, it's not possible because Apsaravis went extinct at the end of the Cretaceous.
   e. No, it's not possible because the earliest modern bird did not exist before 100 million years ago
   f. They decided the diagram was of no help whatsoever

42. They all thought Gemma's diagram (Figure 12) was pretty cool but for different reasons. Unfortunately, evolutionary biology was not their strongest point. Whose reason was the only truly valid one?

   a. Kimberley's. He loved the idea that birds evolved from crocodiles
   b. Ruby's. She loved the idea that birds evolved from Ornithischian dinosaurs
   c. Amber's. She loved the idea that birds evolved from Pterosaurs
   d. Jade's. She loved the idea that birds evolved from Theropod dinosaurs
   e. Gemma's. She loved the idea that all dinosaurs must have had feathers
   f. None of their reasons were truly valid

After their hilarious journey to the centre of the Earth, the friends were inspired to watch another adventure along the same trajectory via more technologically advanced methods in *The Core*. Again, they found many of the same glaring misconceptions about the time required to cover the incredible expanse of the Earth's radius and the immense pressures experienced at such depths, but one scene in particular made them smack their heads in utter geologic disbelief. After drilling diligently through the mantle, which is composed of peridotite (a dense, coarse-grained igneous rock consisting mostly of the minerals olivine and pyroxene), for an extended time, putting the protagonist somewhere between 1,000-2,000 km below the Earth's surface, his vessel suddenly bursts into a massive void encrusted in enormous purple crystals, which he identifies as 'amethyst' (a variety of quartz).

Kimberley found a copy of Bowen's Reaction Series he thought might help them pin down why the scene was so wrong (Figure 13).

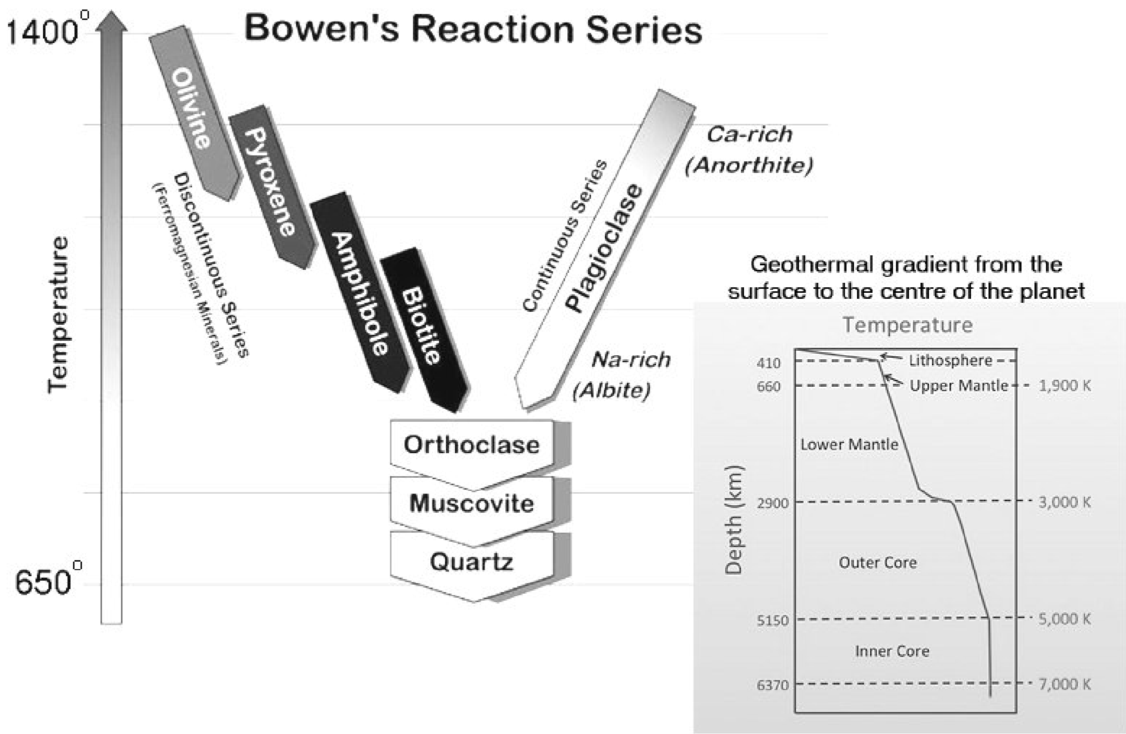


Figure 13: Bowen's Reaction Series with the Earth's Geothermal Gradient inset.
The reaction series shows that, when a natural magma cools, certain minerals crystallize earlier and at higher temperatures than others. The common igneous rock-forming minerals form in a regular sequence, with olivine and calcium-rich plagioclase crystallising first as magma temperature falls.
Modified from https://www.saddleback.edu/faculty/jrepka/notes/GEOigneousLAB.pdf

43. After studying the Bowen's Reaction Series diagram (Figure 13) what did the friends decide was the real problem with the scene?

    a. Quartz can only be solid below about 1,000 °C and the entire mantle is hotter than that
    b. Quartz does not co-exist with peridotite
    c. Quartz is not hard enough to exist at such high pressures
    d. There is no problem, quartz is found everywhere on and within the Earth
    e. Answers a and b are correct
    f. Answers a, b, and c are correct.

44. The friends continued finding problems. In the following scene the hero is in a panic, worried that his ship will be pierced by the sharp points of the giant amethyst crystals. Kimberley thought this was preposterous but Amber thought it was plausible. What evidence did they use to pick apart this plot twist in order to verify or refute it?

   a. They decided the hero's concern **was not valid** because he entered the crust through the Marianas Trench, cutting first through basaltic oceanic crust. This is primarily composed of minerals that are harder than quartz, so the vessel has proven to be hardy enough to get through these and won't be pierced by amethyst points
   b. They decided the hero's concern **was not valid** because the vessel navigated through the mantle, where diamonds are present, so if it can't be pierced by these, quartz is no issue
   c. They decided the hero's concern **was valid** because quartz becomes much harder at higher temperature and pressure experienced within the mantle
   d. They decided the hero's concern **was valid** concern because the purple colour of amethyst signifies that it is much harder than normal quartz
   e. They decided the hero's concern **was not valid** for both reasons a and b
   f. They decided the hero's concern **was valid** for both reasons c and d

Although it was getting very late, the friends decide to watch one final classic geo-action film, Dante's Peak. They had mixed reactions watching the film because some aspects of it seemed so geologically sound, whereas others appeared to be pure Hollywood. They had a debrief at the end to sort out the facts from the fiction.

Their first order of business was to define what is meant by a pyroclastic flow. Jade found a good definition online that read:

A pyroclastic flow (also known as a pyroclastic density current or a pyroclastic cloud) is a fast-moving current of hot gas and volcanic matter that rapidly moves away from a volcano, often as a result of a collapsing eruption column. The gases can reach temperatures of about 1,000 °C and the volcanic ejecta can be sometimes be so hot it 'welds' itself back together when it stops flowing. Pyroclastic flows with a low particle concentration can move so fast and fluidly that they travel up and over ridges rather than always travel downhill.

45. Having agreed on the meaning of pyroclastic flow they started to argue about the film's use of various forms of eruption. In the film, the volcano - for which the film is named - is shown as a steep-sided stratovolcano in the Cascade mountain range, which runs parallel to the subduction zone between the Juan de Fuca and North American plates (west coast, North America). The eruption is depicted as a mixed event with huge ash explosions, fast-moving pyroclastic flows, and rapidly spreading, thin, runny, effusive lava flows. Who gave the best assessment of the film's use of these eruption styles?

  a. Amber. She claimed this is all Hollywood nonsense because stratovolcanoes don't form near subduction zones or have explosive eruptions and pyroclastic flows. She says it should be a shield volcano and only have basaltic lava flows
  b. Jade. She thought it was incorrect because there are only large earthquakes on subduction zones and that no volcanoes of any kind should form near them
  c. Kimberly. He said the depiction is partially correct in having a stratovolcano near a subduction zone, but that it should only erupt the thin, runny basaltic lava
  d. Gemma. She thought the film-makers nearly got it right with the correct type of volcano for the tectonic setting and the mixture of explosive and effusive volcanic activity, but that the lava flows should be incredibly viscous (resistant to flow) and slow moving
  e. Ruby. She said it is a massive Hollywood success story accurately depicting every aspect of this volcano and its eruption
  f. None of them were correct; their Earth Science teacher would be disappointed

46. A side argument erupted, with Jade and Kimberly trying to decide what gases would be present in a pyroclastic flow. The others also gave their opinions. Who was closest to the mark?

  a. Jade. She maintained it would only be hot air caught in the eruption cloud
  b. Amber. She was positive all eruptions let out CO_2 and not much else
  c. Ruby. She was sure most of the gas is SO_2 which is why volcanoes smell bad, adding it could also form H_2SO_4 when it mixes with the water vapour
  d. Kimberley. He maintained H_2O is the only volatile, released as super-hot steam
  e. Gemma. She decided all of them came up with a correct piece of the puzzle but added that Cl_2 could be present too, forming HCl when it mixes with the water vapour
  f. None of them were close to the mark even if they were each a bit right

47. In the film there are many geophysicists listening intently to ever increasing numbers of earthquakes as the eruption becomes more imminent. They claimed they could predict when the eruption would occur based on the timing and type of seismic events. The friends argued over whether or not this was realistic and why. Who won the argument?

a. Amber. She said it was correct because magma pushing through the crust would cause it to fracture, triggering many small earthquakes at ever shallower depths
b. Jade. She agreed with Amber but said there is no way for the geophysicists to determine when the eruption might actually occur
c. Kimberly. He was sure seismology is only useful for detecting really large earthquakes and that the little tremors caused by micro-fracturing rock around a slowly rising magma body would not be detectable
d. Gemma. She thought it was possible to detect seismic waves in the liquid magma as it rises because is sloshes around in the Earth like water in a bucket
e. Ruby. She was convinced that seismic waves would be completely dampened by the presence of magma, so the seismometers wouldn't pick up anything
f. No one won the argument; they could not agree on the best solution so they all went to bed.

48. In the morning, over breakfast, the friends discussed which disastrously bad Earth Science-based film to watch next. They wanted to choose the one with the most preposterous and least verifiable scientific premise but didn't immediately agree on which movie fitted the bill. What did they decide on watching in the end?

a. *Volcano*. It's about a small cinder cone volcano that suddenly appears in Los Angeles, California, near the infamous San Andreas Fault (a 1,300-km transform fault), and inundates the city with fast moving lava flows
b. *The Day After Tomorrow.* In it, climate change shuts down the thermohaline circulation system in the oceans, generating massive super-storms, flooding coastal cities, then plunging the Earth into a deep freeze within a matter of days
c. *2012*, wherein cataclysmic events, such as California's coast plunging into the ocean, mega tsunamis in the middle of the ocean, world-wide volcanic eruptions, etc are caused by solar flare neutrinos heating the Earth's core
d. *10.0 Earthquake*. It's about a super-quake, triggered by deep fracking activities, that is going to drop the entire city of Los Angeles into a lava-filled chasm
e. Ruby said they should watch all of them except *2012*, saying its premise was plausible even if the details were debatable
f. They decided to watch them all because they all had preposterous premises

The following information relates to question 49.

After their great movie binge the friends all went their various ways. Gemma heard from Roxanne who was on her way back to Mars via Moon Base Alpha. Roxanne wrote: *Hi Gemma! Moon Base Alpha is awesome since the new expansion pods have been installed. I have been asked to help explore the Moon's South Pole. It is exciting because back in 2019 we discovered a major gravitational anomaly in the South Pole-Aitken (SPA) Basin and we still don't know what causes the increased gravity in the area. The anomaly shows up in the topographic low (Figure 14) of the SPA Basin.*

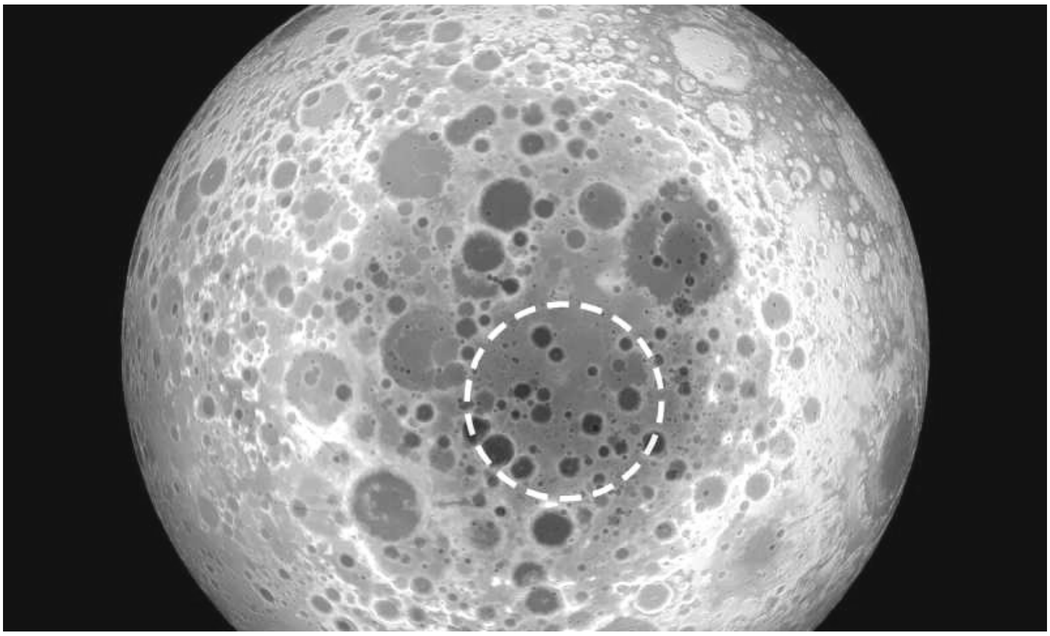


Figure 14: The darker tones in the centre of the picture represent topographically lower areas with lighter tones representing higher areas. The dashed circle shows the area of the anomaly under the SPA Basin. It is approximately 2000 kilometres across. This anomaly has a minimum mass of 2.18×10^{18} kg and likely extends to depths of more than 300 km.
Modified from an image supplied by NASA/Goddard Space Flight Center/University of Arizona

49. Gemma asked Roxanne what the possible causes of the anomaly were. Roxanne said that something had to provide the extra mass needed to generate a gravitational anomaly and the best idea so far was …

    a. … a deep sedimentary aquifer with the water providing the extra mass
    b. … that the SPA Basin is the impact site of an ice and carbon dust comet
    c. … that the SPA Basin is the impact site of an iron-nickel asteroid
    d. … that the SPA Basin is the impact site of a gas giant planet known as Theatica
    e. … that the SPA Basin is a giant collapse caldera and the core is solid, very dense basaltic rock
    f. … the moon is mostly made of cheese but the SPA Basin is made of denser basaltic rock

The following information relates to question 50.

Eventually Roxanne finished her exploration work after she'd found some really interesting rocks in the SPA Basis and headed back to Mars. After she docked at her research base on Phobos (one of two moons of Mars – the other being Deimos) she contacted Gemma to say hello and included an image (Figure 15). She wrote: *Hi Sis! Check this out. Can you guess from the data (Table 4) which of the eclipse shadows is caused by my home base?*

	PHOBOS (fear)	DEIMOS (panic)
Mean distance from Mars (km)	9,377	23,436
Orbital period (Mars days)	0.31891	1.26244
Major axis (km)	26	16
Minor axis (km)	18	10
Mass (x 10^{15} kg)	10.8	1.8
Mean density (kg/m^3)	1,900	1,750

Table 4: Data for Phobos and Deimos.
Data supplied by https://mars.nasa.gov/all-about-mars/moons/summary/

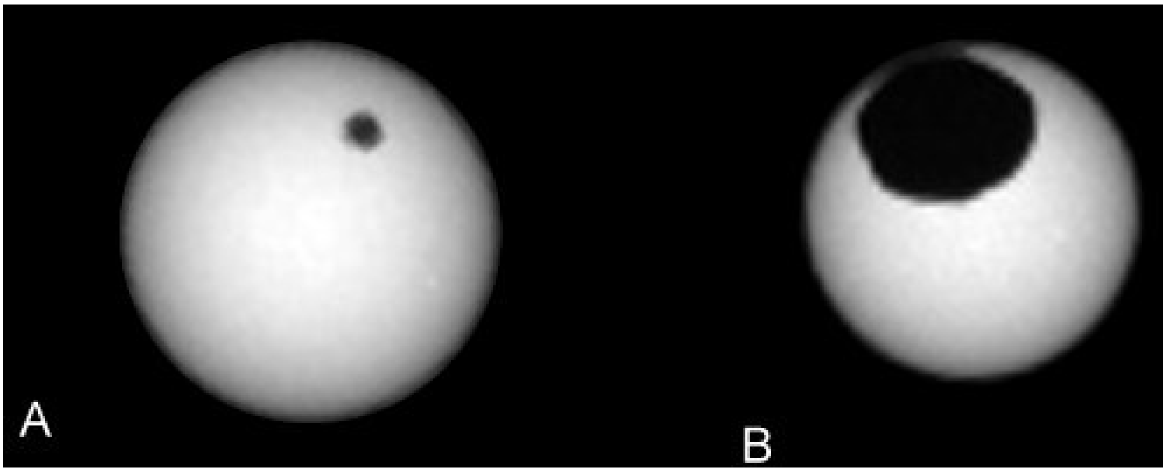


Figure 15: Two views of the Sun from the same location on the surface of Mars (A & B), each with a Martian moon crossing in front of it.
Image courtesy of NASA/JPL-Caltech/MSSS.

50. Gemma studied the images and the data carefully. Which imaged did she decide was the shadow of Phobos and why?

a. She reasoned Phobos was A because it orbited faster than Deimos so it had to appear as a smaller eclipse shadow
b. She reasoned Phobos was A because it was physically bigger than Deimos and closer to Mars so it had to appear as a smaller eclipse shadow
c. She reasoned Phobos was A because it was the denser than Deimos so it had to appear as a smaller eclipse shadow
d. She reasoned Phobos was B because it orbited faster than Deimos so it had to appear as a bigger eclipse shadow
e. She reasoned Phobos was B because it was physically bigger than Deimos and closer to Mars so it had to appear as a bigger eclipse shadow
f. She reasoned Phobos was B because it was the denser than Deimos so it had to appear as a bigger eclipse shadow

The following information relates to question 51.

Roxanne wrote to Gemma again later, explaining that she had recently visited the Ares3 base on the Martian surface and got to eat some home-grown potatoes. She said she also had a chance to explore a fair bit of the surface since she was part of a team that went out to service the famous Insight Lander that touched down on Mars in 2018 and has been sending weather reports and seismic data back to Earth ever since. She also sent Gemma another photograph (Figure 16).

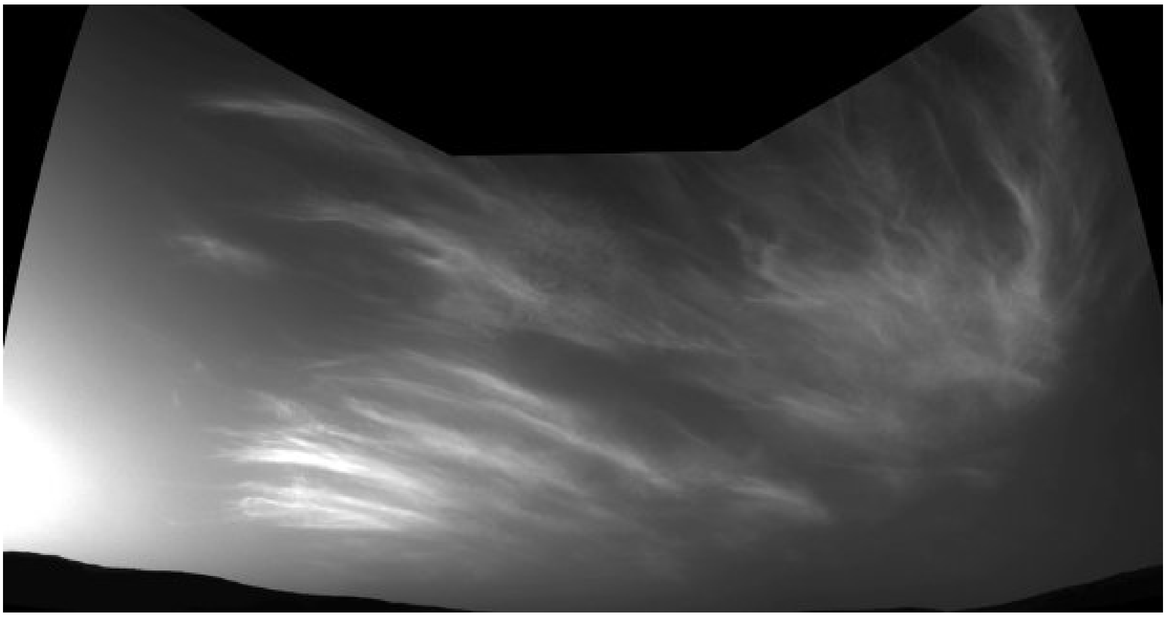


Figure 16: Water-ice clouds approximately 31 km above the surface of Mars.
image courtesy of NASA/JPL-Caltech.

Roxanne explained that the clouds look fantastic because they often glow brightly, even when it is night time on the surface. Gemma was puzzled by this.

51. What did Gemma's research reveal about this phenomenon?

    a. Water ice stores sunlight and re-radiates it at night contributing to global warming and causing the interior of the cloud to glow
    b. Ice crystals have a high albedo and reflect a lot of sunlight. Any clouds on Mars will exhibit this phenomenon if it is a sunny day on Mars
    c. Water ice clouds reflect sunlight. To see this reflection from the ground the cloud must be over the observer's horizon so that sunlight grazing the surface of the planet passes through the cloud from below
    d. This phenomenon is only visible if the sky is dark enough for sunlit clouds to be seen behind the foreground of the twilight sky
    e. Both c and d
    f. Both b and d

52. Roxanne also said the sunsets on Mars were both weird and wonderful because they were blue! Again Gemma was puzzled by this and did some more research. What did she discover about the reason for blue sunsets?

    a. The Martian atmosphere contains a lot of water vapour that absorbs the red wavelengths more for the long travel path through the atmosphere at sunset providing a greater blue hue to the evening sky
    b. The ultra-fine dust in the atmosphere scatters the sunlight such that blue light penetrates the atmosphere more efficiently during long travel path through the atmosphere at sunset providing a greater blue hue to the evening sky
    c. Mars has the largest volcano in the solar system. Volcanic ash is blue and it colours the atmosphere more for the long travel path through the atmosphere at sunset providing a greater blue hue to the evening sky
    d. Mars has about 38% the amount of gravity of the Earth so more of the red wavelengths of light are turned towards the ground for the long travel path through the atmosphere at sunset providing a greater blue hue to the evening sky
    e. The average temperatures on Mars is -63 ^{o}C. The cold air allows blue light to travel through it more easily providing a greater blue hue to the evening sky
    f. The red rocks of Mars re-radiate blue wavelength light at night

The following information relates to questions 53 and 54.

In her next message to Gemma, Roxanne said she was very excited to visit the famous Clay-Bearing Unit, first explored by the Curiosity Rover in 2019. This unit sits in a topographic low between a ridge and Mount Sharp and in May 2019 drilling revealed the highest amounts of clay minerals ever found in Martian rock to that date. Roxanne said this was very important because, together with the outcrop of a layer of other sediments found inside the Clay-Bearing Unit close to the drill site (Figure 17) it said a lot about the climate history of Mars.

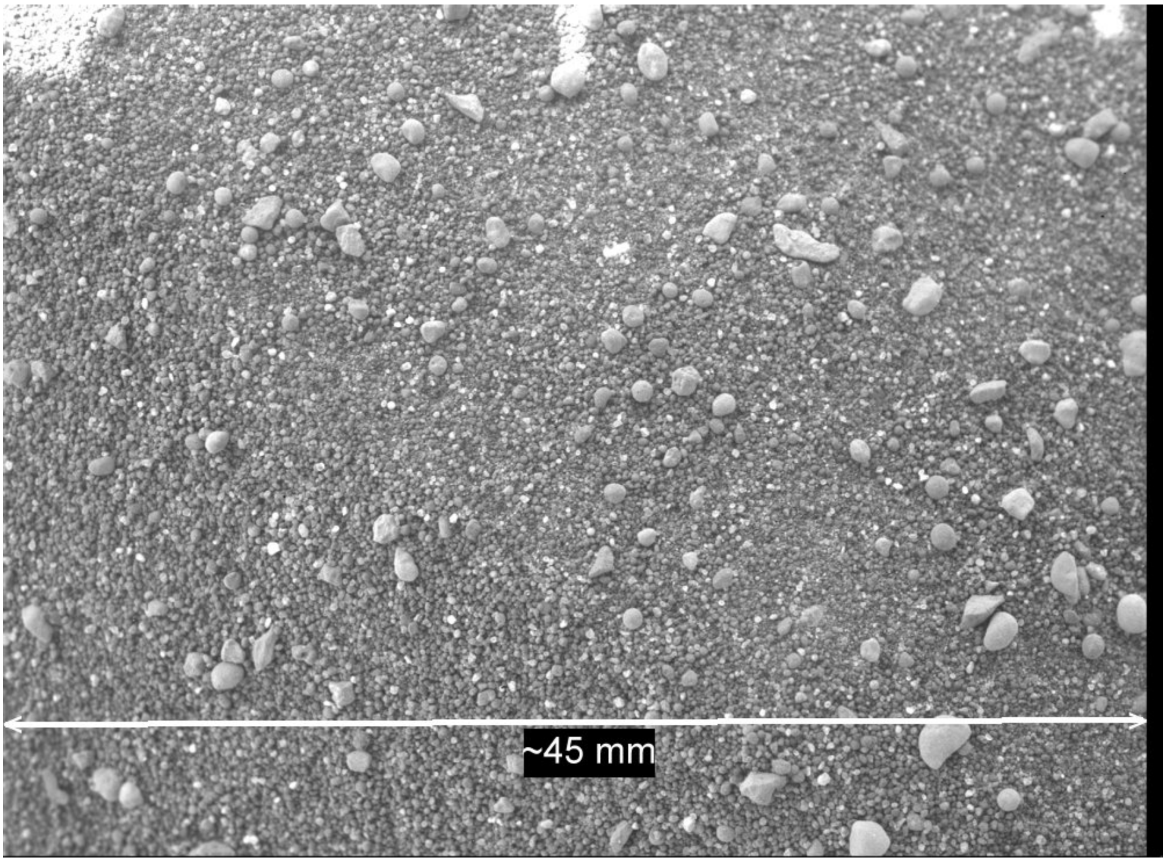


Figure 17: Sediments found within the Clay-Bearing Unit, May 2019, by Curiosity Rover

53. Gemma sent Roxanne a question in reply. She asked …*What is so special about clay on Mars; it's everywhere here on Earth?* What was Roxanne's reply, 20 minutes later?

    a. Clay is an igneous mineral, telling us there were once a lot of volcanoes on Mars
    b. Clay is a metamorphic mineral, telling us there was once Plate Tectonics on Mars
    c. Clay can be deposited as dust on Mars, telling us it was once very windy
    d. Clay can be a sedimentary material, telling us the area was once a lake
    e. Clay is a weathering material, telling us Mars was once wet enough to weather other minerals to clay
    f. Both d and e

The following information relates to question 54.

In doing some follow up research Gemma came across an interesting grainsize – fluid velocity chart (Figure 18).

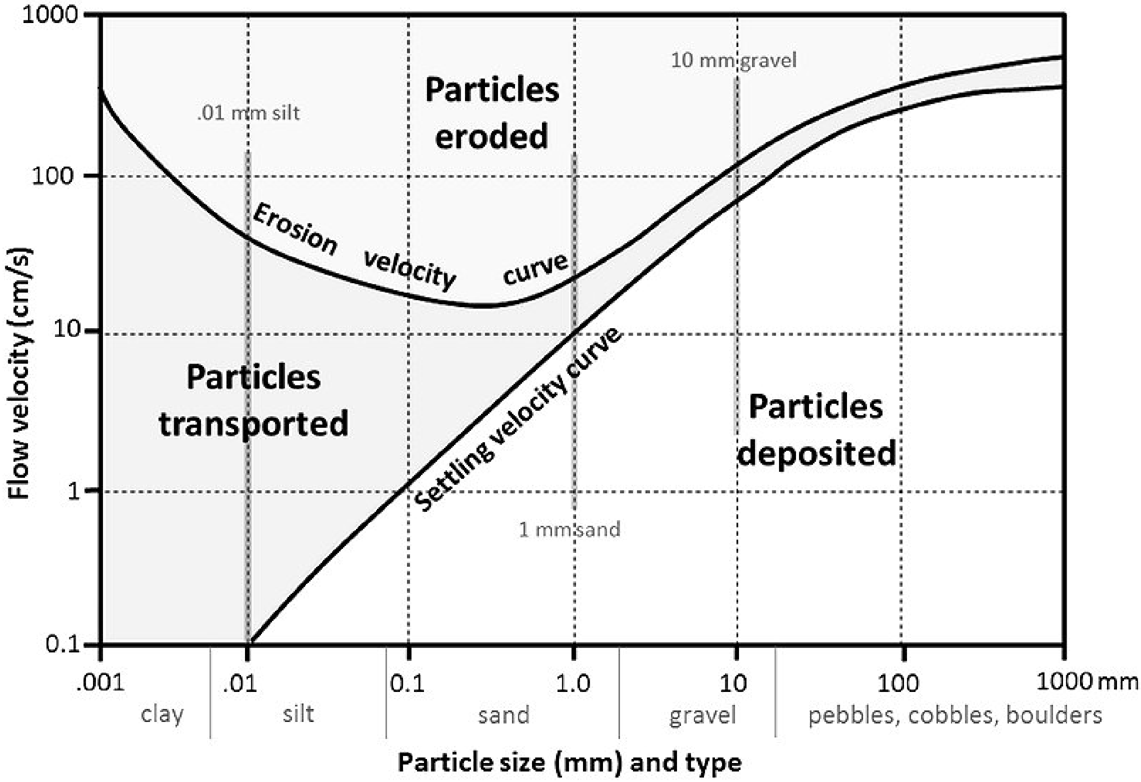


Figure 18: A Hulstom-Sunborg diagram showing the relationships between particle size and the tendency to be eroded, transported, or deposited at different current velocities.
Modified from https://opentextbc.ca/geology/chapter/13-3-stream-erosion-and-deposition/

She read that planetary geologists, like her sister Roxanne, think that Mount Sharp is a central peak within an impact crater called Gale Crater. It appears to be an enormous mound of eroded sedimentary layers.

54. What did the presence of the clay in the Clay-Bearing Unit, the diagram in Figure 18 and the image Roxanne sent (Figure 17) tell Gemma about the depositional history of this part of the Mount Sharp sequence?

   a. Lake waters must have sometimes been very still, moving at less than 0.1 cm/s
   b. Lake waters must have sometimes moved fast enough to transport silt and sand
   c. Lake waters must have sometimes moved fast enough to erode silt and sand
   d. Lake waters were always eroding and depositing particles of some size
   e. All of a, b, c and d
   f. Only a and b

55. Gemma was disappointed that even after all the exploration done since humans landed on Mars no signs of life, extinct or extant, had been found. While thinking about this she doodled a list of criteria she knew could be used to confirm life on Mars exists or once existed. What did her list include?

a. Actual fossils – like ammonoids, only Martian!
b. Actual living things – like bacteria, only distinctly Martian (not contamination)
c. Both a and b
d. Trace fossils – like footprints, only left by Martians
e. Organic molecules – like oil, only with a uniquely Martian chemistry
f. All of a, b, d and e

SECTION B: WRITTEN ANSWER QUESTIONS
ANSWER IN THE SPACES PROVIDED

The following information relates to question 56.

Roxanne 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 next human mission to the Jovian system. Roxanne's friend Cameron Brian was on the first Europa mission so she asked him for some tips. His advice was to learn as much about the Jovian moons as possible!

In her readings she discovered that Europa has an equatorial radius of 1,560.5 km, making it about 90% the size of Earth's Moon (with a radius of 1,737.5 km). However, Europa's surface is water ice so, if it were orbiting Earth, it would be a lot brighter since it would reflect 5.5 times more sunlight than the Moon's surface does. Europa has a density of 3.013 g/cm^3 and a total mass of 4.799 x 10^{22} kg while the Moon's density is 3.344 g/cm^3 and mass is 7.348 x 10^{22} kg. Since her mission to Europa might involve surface exploration and she has recently been exploring on the surface of the Moon, she wondered what the gravity would be like on Europa as compared with the Moon's. As an exercise in mindful maths she decided to calculate them using a table she doodled.

56. **Fill in the table** to see what Roxanne discovered about Europa's gravity. Show all your working calculations on the Blank Working Page at the back of the exam booklet. **(4 marks)**

Values	The Moon	Europa
Equatorial radius		
Average Density		
Mass		
To calculate g use (insert equation) where M is mass, R is radius and G = ……………………………………….		
Surface gravity (g)	g_{Moon} = ……………………..	g_{Europa} = ……………………...
From these calculations Roxanne was able to see that she would feel slightly Heavier / Lighter (cross out the wrong answer) on Europa's surface compared with her recent time on the surface of the Moon		

The following information relates to questions 57 and 58.

Roxanne spent a long time reviewing all the materials about Europa as she studied for her interview. She was particularly intrigued by data concerning the spectra obtained with the Hubble Space Telescope, which detected a 450-nm absorption line on the surface that is indicative of irradiated sodium chloride -NaCl (Figure 19).

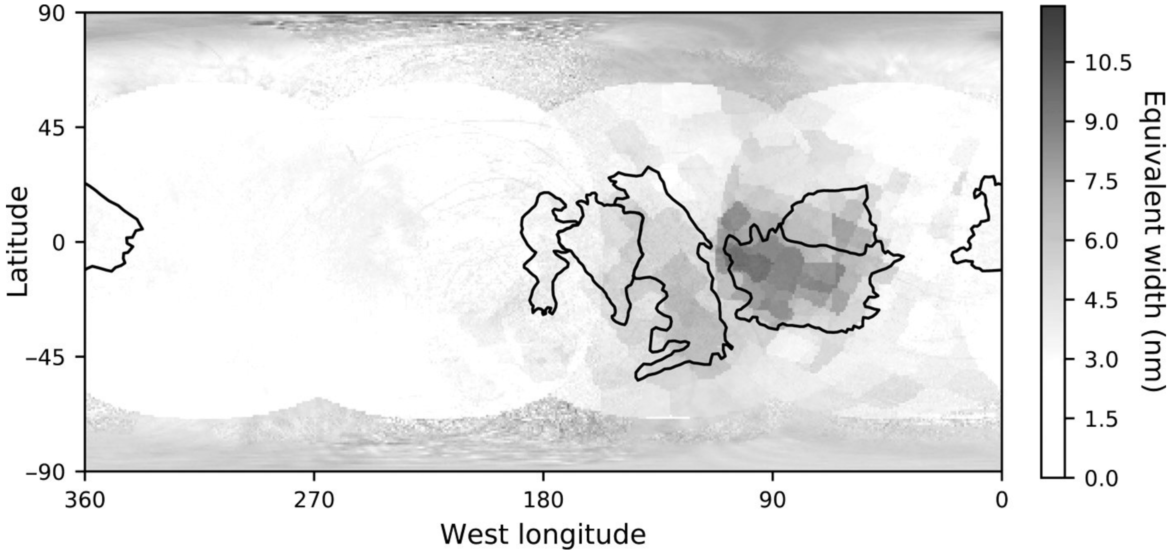


Figure 19: A map of Europa's surface. The black outlined areas are the large-scale chaos regions. The shaded regions show absorption at 450 nm with darker shades showing greater absorption.
Image modified from Trumbo et al 2019. Science Advances V5 (6) eaaw7123

The mission she is applying for intends to land in a chaos region. These regions are composed of fragments of the pre-existing ice crust tens of kilometres in diameter, or larger, separated by a chaotic, lumpy matrix of material of all sizes and shapes below about 1000m in diameter. The shape of the individual fragments varies from smoothly circular to polygonal blocks of ridged terrain. The matrix material can be either low lying or high standing relative to the surroundings. Some of the individual plates appear to have moved from their original position. Roxanne noted that there is a visual similarity between chaos terrain and Earth-ocean pack ice. Her working model being that the chaos regions are where subsurface liquid water has broken through a crustal shell of water ice, chaotically jumbling blocks of ice, followed by a refreezing of the crust.

57. What did the Hubble spectral data tell Roxanne about Europa?
    (2 marks)

58. Roxanne wondered where the NaCl could have come from, given Europa's crust is almost entirely water ice and yet the average density of Europa is more than 3 times that of water. What did she conclude?

(2 marks)

The following information relates to questions 59, 60, 61 and 62.

Studying Europa further, she examined an image of a proposed landing area for the mission. Landing at this spot would enable exploration of the dark pits and domes, which are an unusual feature not seen in most chaotic terrain (Figure 20).

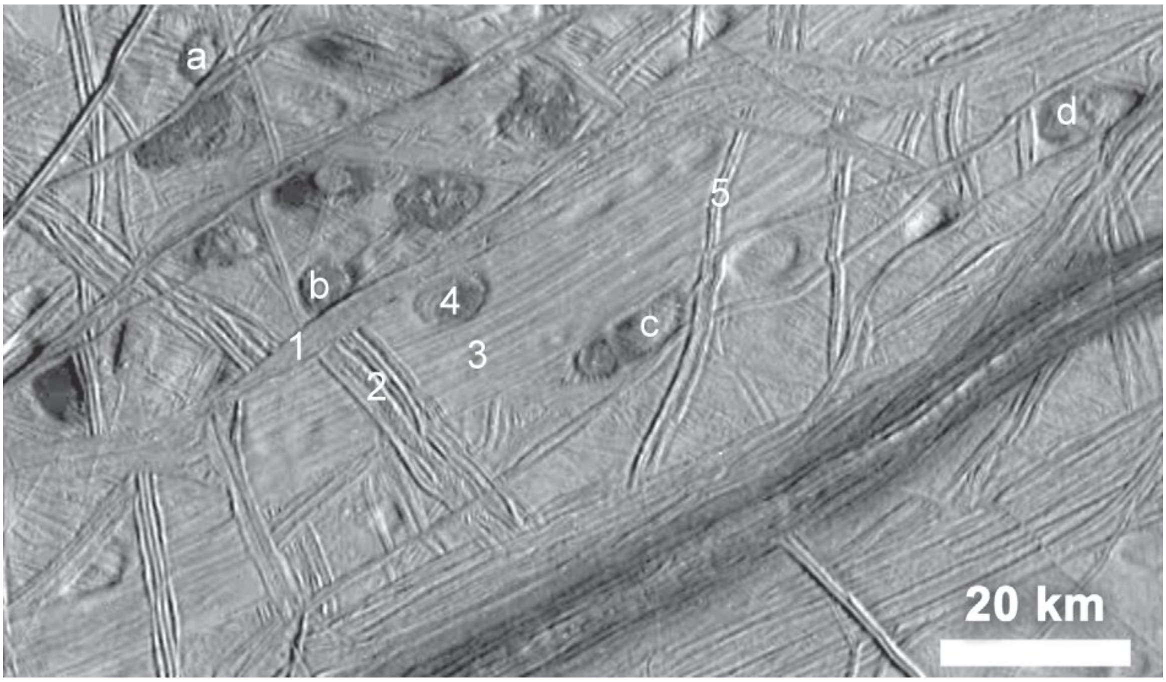


Figure 20: Chaotic terrain on Europa displaying blocks, ridges, pits and domes. Sites a, b, c and d are proposed landing sites for dome exploration.
Image modified from Collins and Nimmo 2009.

59. Background notes that Roxanne read about proposed landing sites a, b c and d suggested the dome structures were the youngest features within this chaotic terrain. She wasn't so sure about this. Why?

(1 mark)

60. Roxanne was intrigued by how much had happened to the surface in the chaotic regions. She tried to figure out what order the structures labelled 1, 2, 3, 4 and 5 occurred in. What did she conclude about the relationship between linear structures 1, 2, 3, and 5?

(5 marks)

The oldest linear structure is …. because … (2 marks of the 5)

The youngest linear structure is … because … (2 marks of the 5)

What additional comments would she add to help explain the age relationships between all the linear structures:

(1 mark of the 5)

61. What did Roxanne conclude about the age relationship between the linear structures and structure 4?

(2 marks)

62. Roxanne noted that the linear structures seemed to have formed a bit like Mid-Ocean-Ridges on Earth, with a linear fracture spreading apart and upwelling watery material from below, filling the widening gap to form parallel linear structures in the ice. What else did she notice to add weight to that idea?

(2 marks)

The following information relates to questions 63 and 64.

The next message Gemma received from Roxanne read:

Hi Sis! Guess what? I got the job … I'm going to Europa!!!!

Gemma was excited for her sister and more than a little envious. However, she knew that getting to Mars from Earth, even with the new Epstein Drive, takes a long time and Europa is even further away again. Gemma knows that on average Jupiter is 778.5 million km from the Sun with its closest point (perihelion) being 741 million km and its farthest point (aphelion) being 817 million km. Earth is 150 million km from the Sun on average with a perihelion of 147 million km and an aphelion of 152 million km. On average Mars is 228 million km from the Sun with a perihelion of 206.7 million km and an aphelion of 249.2 million

63. Gemma did the maths. If there was a time when Mars and Jupiter were as close together as possible <u>and</u> Mars was at aphelion <u>and</u> Jupiter was at perihelion they would still be

_______________________________________km apart (fill in the blank)

(1 mark)

64. A) Assuming the Epstein Drive results in an average speed of 10,000 m/s Gemma figured it would take Roxanne at least

____days to travel from Mars orbit to Jupiter orbit (ignoring all the complications of the planets constantly moving in their orbits).

(0.5 mark)

65. B) Gemma wrote back to Roxanne knowing her message would travel at approximately 300,000,000 m/s. She figured Roxanne's last message took 20 minutes to reach Earth so she must be about

___________ ___________________________km distant.

(0.5 mark)

66. Gemma sent her sister a special message that read:

Hi Roxy! Great news about your new job, it will be awesome, Looking forward to seeing more of you on the news and some amazing pictures from the Chaos Terrain on Europa. Make sure the outcome isn't like the scifi film please!

To keep you grounded I have included a few Down to Earth exercises for you to have a go at when you are bored on the long trips out and back. Send me your answers and I'll send you some more!

Time to fill in the table just like Roxy would! Thanks for playing along.

Word	Description or chemical formula
Quartz	
Cirrus	
	The void space fraction in sedimentary rock
	The amount of interconnectedness of void space in sedimentary rock
	An erosional or non-depositional surface separating two rock masses or strata of different ages
	Organic residue left behind in rocks after plankton and other organisms have decayed in anaerobic conditions and then broken down further under the elevated temperatures and pressures of deep burial
	Atmospheric air movement from a high-pressure region to a low-pressure region
Quartzite	
	$CaCO_3$
	High grade metamorphic rock derived from Mudstone

(0.5 mark per answer for a total of 5 marks)

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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.