School ID

2016 AUSTRALIAN SCIENCE OLYMPIAD EXAM

EARTH & ENVIRONMENTAL SCIENCE – SECTIONS A & B

TO BE COMPLETED BY THE STUDENT. USE CAPITAL LETTERS

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

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

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

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

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

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

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

To be eligible for selection for the Australian Science Olympiad Summer School, students must be able to hold an Australian passport by the time of team selection (March 2017).

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

Please note - students in Year 12 in 2016 are not eligible to attend the 2017 Australian Science Olympiad Summer School.

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

Examiners Use Only:

2016 AUSTRALIAN SCIENCE OLYMPIAD EXAM
EARTH & ENVIRONMENTAL SCIENCE

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

INSTRUCTIONS

- *Attempt ALL questions in ALL sections of this paper.*
- Permitted materials: Non-programmable, non-graphical calculator, pens, pencils, erasers and a ruler.
- Answer SECTION A on the Multiple Choice Answer Sheet provided**. Use a pencil.**
- Answer SECTION B in the spaces provided in this paper. Write in pen and use pencils only for annotating or making diagrams.
- Ensure that your diagrams are clear and labelled.
- All numerical answers must have correct units.
- Marks will not be deducted for incorrect answers.
- Rough working must be done only on pages 42 and 43 of this booklet.
- Data that may be required for a question will be found on pages 3 to 6.
- Do NOT staple the multiple choice answer sheet to this booklet.

MARKS

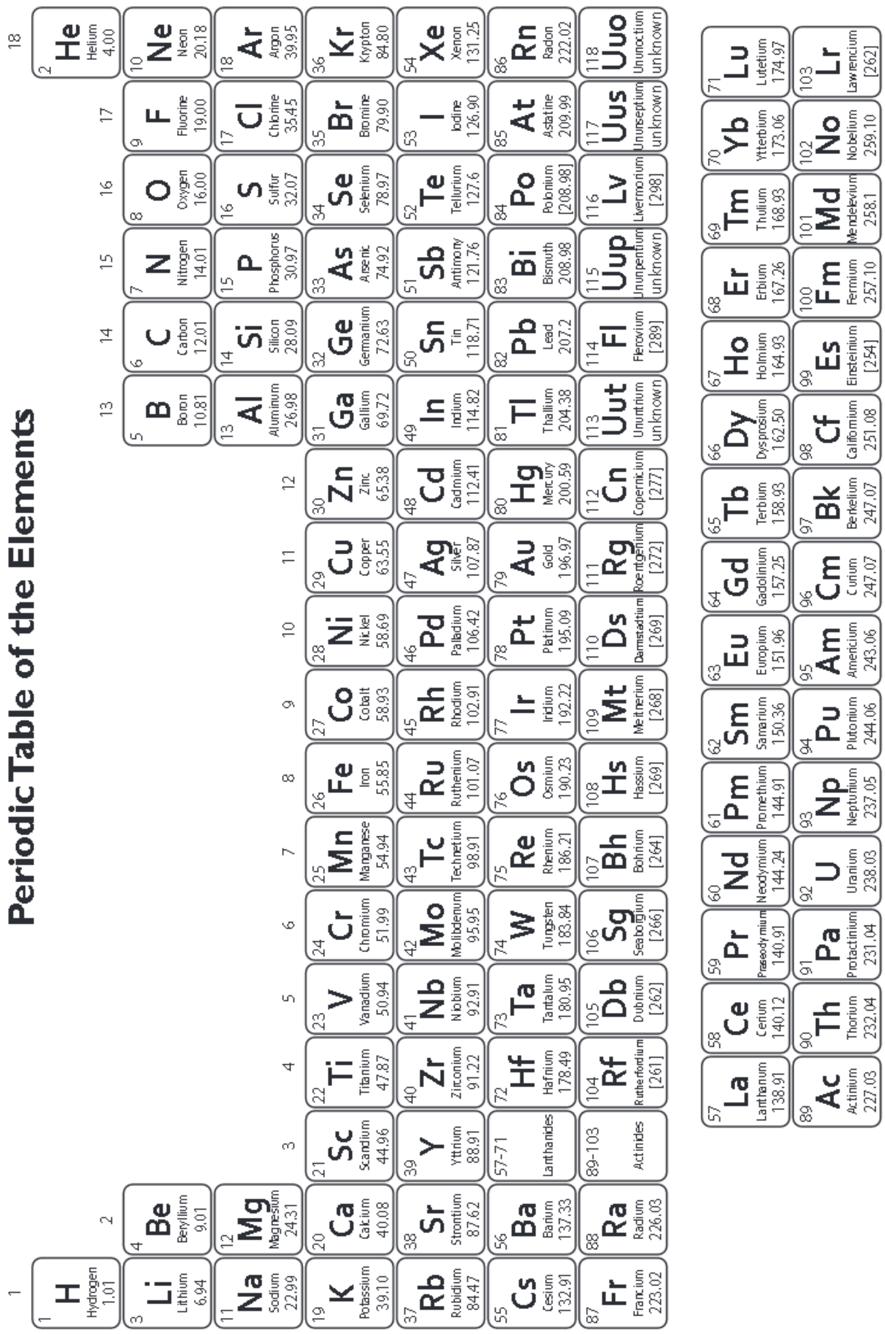
SECTION A	40 multiple choice questions Each question worth one mark	40 marks
SECTION B	16 written answer questions Marks for each question are specified	60 marks

Total marks for the paper 100 marks

DATA & DEFINITIONS

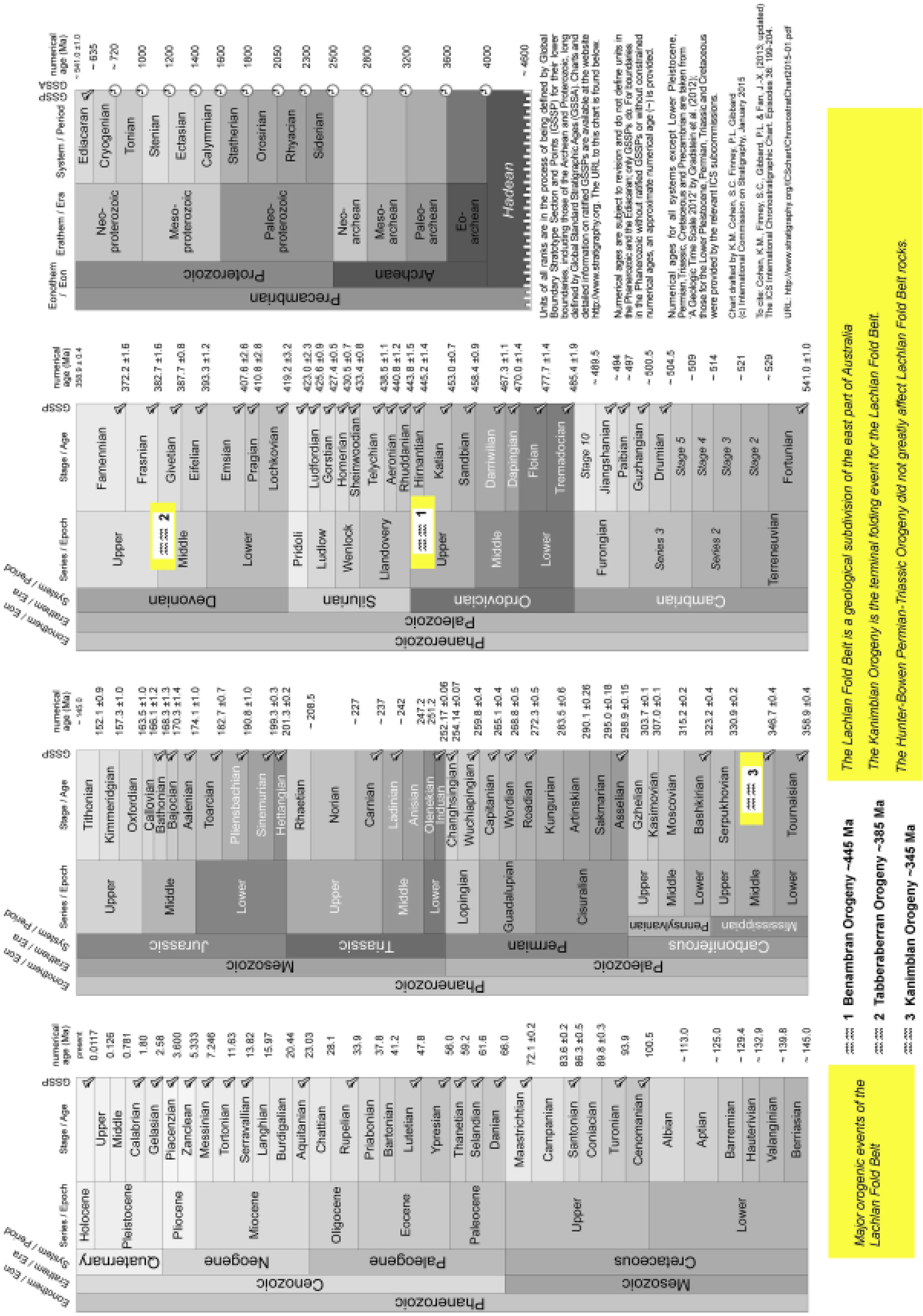
Material supplied:

- Periodic Table of the Elements: Page 3
- A Geological Timescale: Page 4
- Map of Earth's Major Plate Boundaries and sense of plate motions: Page 5
- Dip and Strike defined: Page 6
- Table of constants and units: Page 6



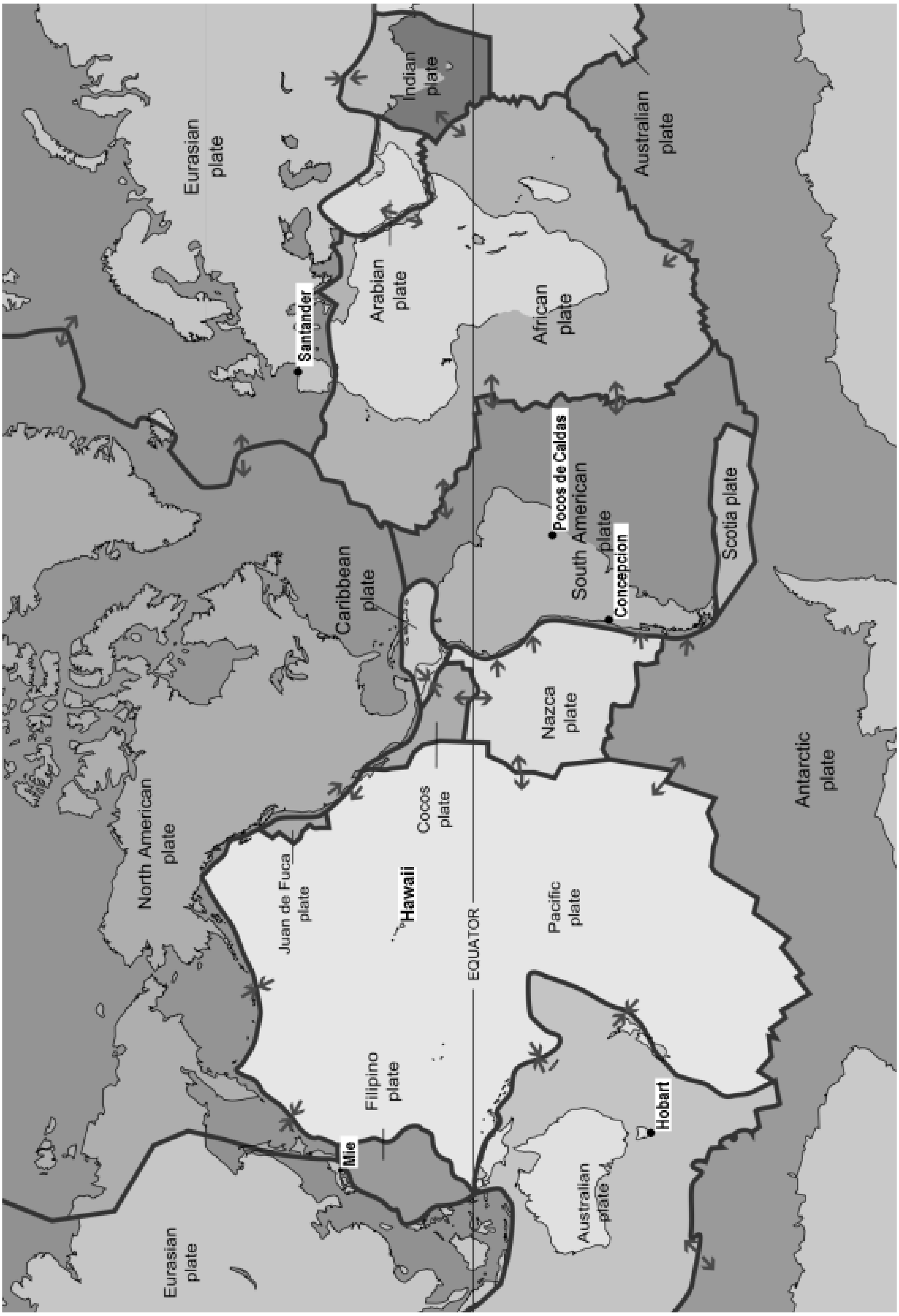
Periodic Table of the Elements courtesy of

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



A Geological Timescale.

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



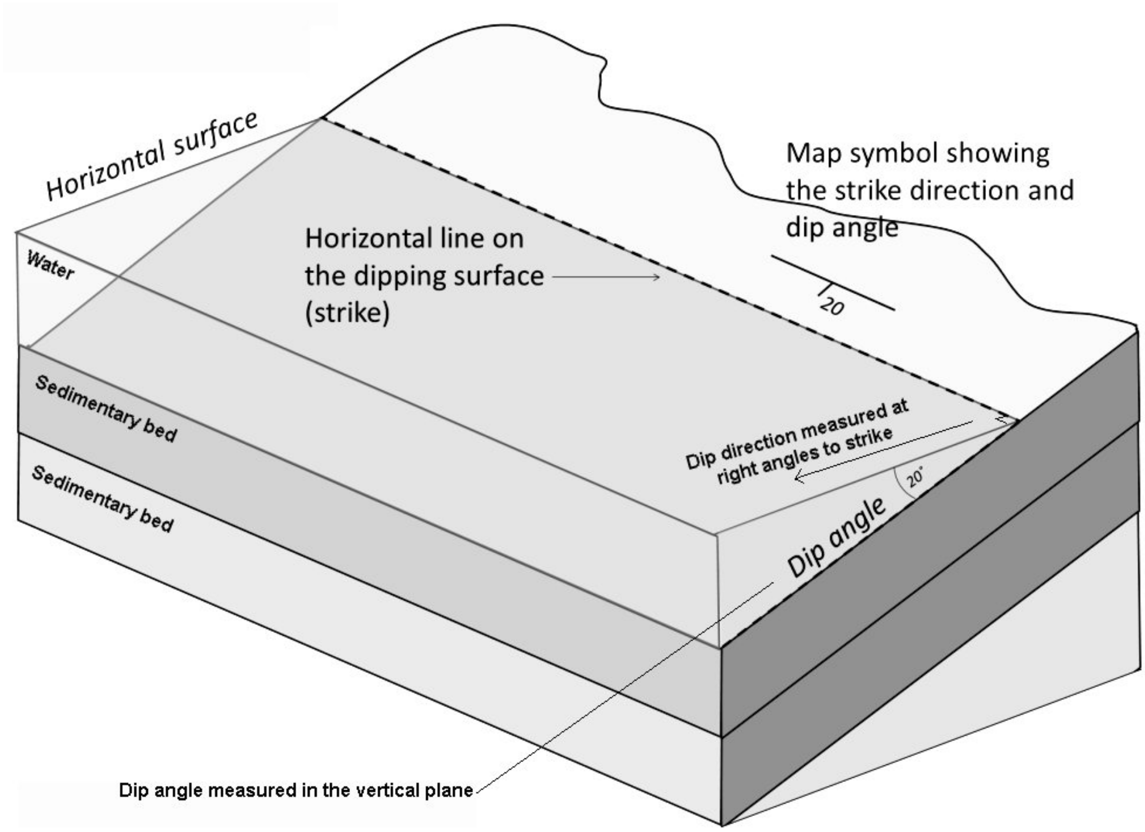
Major Tectonic Plates on Earth and sense of movement at plate boundaries.

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

Definition of Dip and Strike

Strike – the trend of a horizontal line contained in the surface of a planar structure such as a sedimentary bed, fault plane or planar intrusive body.

Dip – the angle between the horizontal and a planar structure such as a sedimentary bed, fault plane or planar intrusive body measured in the vertical plane perpendicular to strike.



A depiction of the strike and dip of some tilted sedimentary beds partially covered with water. The notation for expressing strike and dip on a map is shown. Modified from Figure 12.8, https://opentextbc.ca/geology/chapter/12-4-measuring-geological-structures/

Table of constants and units

Constants	Symbols	Values
Universal gravitational constant	G	6.67×10^{-11} Nm^2kg^{-2}
Earth's gravitational acceleration	g	9.8 ms^{-2}
Earth mass	$M_{\oplus}$	5.98×10^{24}kg
Earth radius	$R_{\oplus}$	6.37×10^{6} m

SECTION A: MULTIPLE CHOICE
USE THE ANSWER SHEET PROVIDED

The following information and Figure 1 relate to questions 1 to 7.

Earth Science students Roxanne Stone and Jade Montane are working on a mapping project on a farm in south eastern Australia known as Xavierland. They have spotted a linear outcrop with distinct edges on a high resolution satellite image and this has them intrigued. They have digitally combined the surface expression of the outcrop with a topographic map showing 100 metre interval contours for a portion of their mapping area that covers Pixie Spring and Toad Creek that it feeds (Figure 1). In planning for the field trip, they have proposed walking a traverse north from a drop-off point at the end of a four wheel drive track to an elevation of 600m before following the contour of the landscape to inspect Pixie Spring. They have included a north arrow and scale bar on their map as they know they will lose marks if they submit their assignment without them!

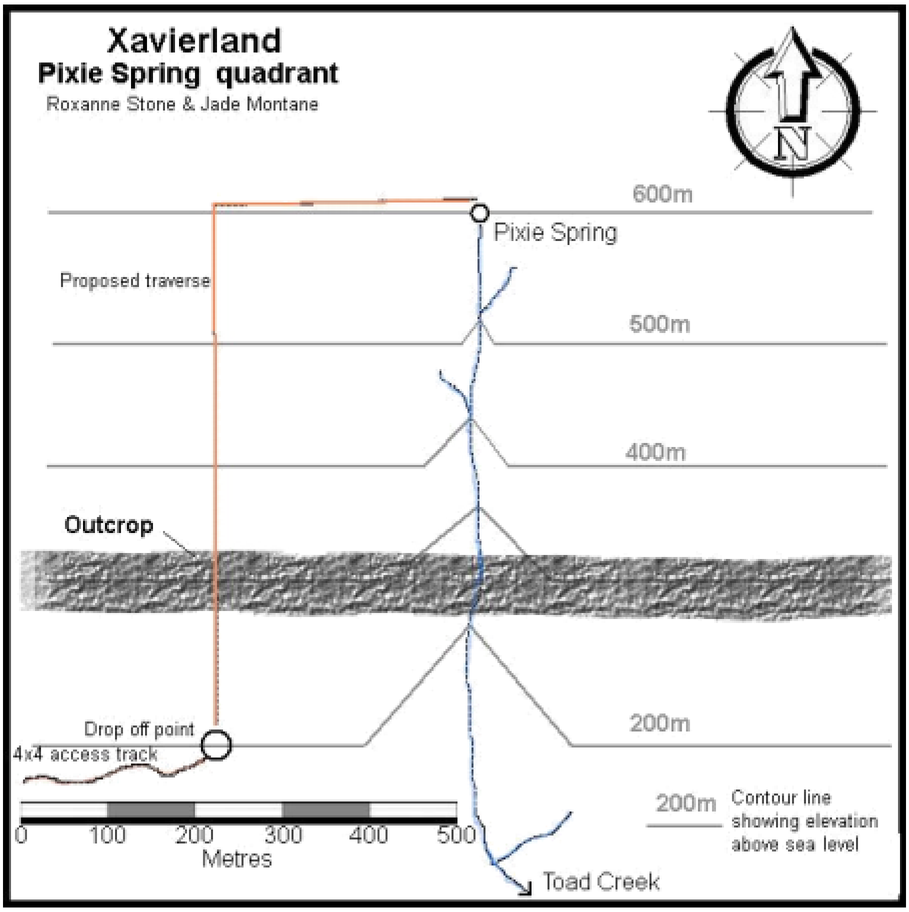


Figure 1: Pixie Spring quadrant, Xavierland. This map is a topographic contour map with 100m contour intervals. The students have overlain the map with the image of the distinctive linear outcrop so that it sits on the map exactly where it occurs in the topography. Composite map provided by Roxanne Stone and Jade Montane.

1. Roxanne and Jade are not looking forward to their traverse even though they will get to see the unusual outcrop and identify its lithology. When asked why they were not looking forward to the walk they gave accurate and plausible reasons which were:

   a. The gradient or slope angle of the hill is less than 12^{o} but the satellite image suggests most of the slope is covered in thick blackberries.
   b. The gradient or slope angle of the hill is more than 52^{o} and will be impossible!
   c. The gradient or slope angle of the hill is about 32^{o} and will be hard work.
   d. The gradient or slope angle of the hill is about 42^{o} and will be hard work.
   e. The gradient or slope angle of the hill is about 22^{o} and will be dangerously slippery because of the spring.

2. Classmate, Gabi Roe, correctly identified the strike and dip of the outcrop in her report without ever having seen it on the ground. What will the strike and dip of the outcrop be when Roxanne and Jade actually measure it?

   a. Strike 90^{o} and Dip 90^{o}
   b. Strike 90^{o} and Dip 0^{o}
   c. Strike 0^{o} and Dip 90^{o}
   d. Strike 0^{o} and Dip 0^{o}
   e. Strike 270^{o} and Dip 0^{o}

3. The top of the hill above Pixie Spring is an east-west ridge at 1200m above sea level (asl). On the other side of the ridge is another spring, Anole Seep. At 600m asl it is the headwaters of Indra Creek. Both springs flow all year but on cold winter nights the surfaces of ponds in both creeks freeze. However, only shaded ponds in Toad Creek are covered in ice during the middle of the winter days. The class have been asked to explain this observation. Tyson Snowdon received full marks for his response by correctly stating:

   a. In winter the rocks cool down and Pixie Spring rises to the surface at -2^{o}C.
   b. The winter sun is low in the sky and the south facing Toad Creek hillside is often in shadow. Ice in the shade never warms up enough to thaw on cold winter days.
   c. In winter the rocks cool down and Anole Seep rises to the surface at -0.5^{o}C, making ice on its ponds more likely to thaw during the day time.
   d. Anole Seep water is salty, raising the freezing point above winter temperatures.
   e. Pixie Spring water is salty, raising the freezing point above winter temperatures.

4. Roxanne and Jade noted in their field trip planning report that there is no other obvious outcrop on the hillside besides the one they copied onto their map. They suggested an explanation for this that could be tested when they map the area and examine any small outcrops they find in Toad Creek gully or under vegetation on the hillside that is not visible on the satellite image. Their explanation, which their teacher was pleased to see is correct, is:

   a. The outcrop is not natural but is the remains of a wall built by the Romans out of granite cobbles quarried elsewhere and cemented together to produce an outcrop-like appearance.
   b. The outcrop is composed of a lithology that is as resistant to weathering as all the surrounding rocks but contains lots of highly toxic minerals that prevent vegetation growth.
   c. The outcrop is composed of a lithology that is less resistant to weathering than the surrounding rocks allowing heavy rain to wash it clean of weathering products before vegetation gets a chance to grow.
   d. The outcrop is composed of a lithology that is more resistant to weathering than the surrounding rocks which weather faster and form soil more readily, allowing vegetation to easily grow on them.
   e. The outcrop is composed of a lithology that has only recently been intruded and vegetation has had little time to develop on it.

5. Pixie Spring is famous for its "pixie dust" which is a white crystalline substance that forms on the edges of pools associated with the spring. Contrary to popular belief it is not a mind altering magic powder but is actually a mineral deposit precipitating from the milky blue spring water. Gabi's field partner, Kimberley Piper, correctly identified this mineral as calcite with a hardness test, his magnifying glass, and his bottle of dilute HCl. His identification criteria were:

   a. 2 perfect cleavages at right angles and a hardness of 6. Fizzes in dilute HCl.
   b. 3 perfect cleavages, not at right angles, and a hardness of 7. Fizzes in dilute HCl.
   c. 2 perfect cleavages, not at right angles, and a hardness of 3. Fizzes in dilute HCl.
   d. 3 perfect cleavages at right angles and a hardness of 3. Fizzes in dilute HCl.
   e. 3 perfect cleavages, not at right angles, and a hardness of 3. Fizzes in dilute HCl.

6. Roxanne and Jade sampled the mysterious outcrop on their field trip traverse. They noted it was almost black in colour and fine grained but with some large, easily visible, white, rectangular crystals scattered through it. They also noted that it did not fizz in dilute HCl. Gabi also sampled the rock. She described it as a mafic feldspar porphyry. For both descriptions to be correct the outcropping rock must be

   a. an organic-carbon-rich limestone with numerous fossil crinoid skeletal blocks – each a single crystal of calcite - scattered throughout the black lime mud.
   b. an extrusive igneous rock containing more than 70% silica (SiO_2) that was emplaced after an eruption that produced rectangular fragments of volcanic glass.
   c. a contact metamorphic rock formed from a mudstone parent rock in which a porphyroblast of plagioclase feldspar has grown..
   d. an arkose sandstone derived from the weathering of a granite in a desert-like environment where the feldspar crystals do not chemically alter to clays.
   e. an intrusive igneous rock containing 45-55% silica (SiO_2) that cooled enough for plagioclase feldspar crystals to form prior to final emplacement.

7. Pixie Spring water is a milky blue colour and precipitates calcite on the edges of its pools. This suggests the

   a. groundwater is saturated in dissolved calcium carbonate derived from the dissolution of limestone by acidic groundwater and that caves might be forming in strata underlying Xavierland.
   b. groundwater is saturated in dissolved calcium sulfate derived from the dissolution of limestone by acidic groundwater and that giant gypsum crystals might be found in local caves.
   c. groundwater is saturated in dissolved calcium carbonate derived from the dissolution of limestone by alkaline groundwater and that caves might be forming in strata underlying Xavierland.
   d. groundwater is saturated in dissolved calcium sulfate derived from the dissolution of granite by acidic groundwater and that caves might be forming in strata underlying Xavierland.
   e. groundwater is saturated in dissolved sodium carbonate derived from the dissolution of limestone by acidic groundwater and that caves might be forming in strata underlying Xavierland.

8. Vertebrate fossils are often found in pieces (disarticulated). Where the bones of a skeleton are in the same relative position to each other as they were when the animal was alive they are called articulated skeletal remains. Articulated remains are more useful because they help palaeontologists understand what the animal looked like and allow otherwise hard to classify disarticulated pieces to be matched to a particular species. It is thought Xavierland's Graymalkin Cave fossil beds are the result of animals dying in the cave whereas Blindfold Cave fossil beds contain the remains of animals that died outside the cave. Which observations would support this hypothesis?

    a. Fossils found in Graymalkin Cave are mostly articulated skeletons and Blindfold Cave fossils are mostly disarticulated individual bones showing significant amounts of surface abrasion.
    b. Fossils found in Blindfold Cave are mostly articulated skeletons and Graymalkin Cave fossils are mostly disarticulated individual bones showing significant amounts of surface abrasion.
    c. Fossils found in Blindfold Cave are mostly articulated skeletons and Graymalkin Cave fossils are mostly disarticulated individual bones showing a significant number of tooth marks.
    d. Fossils found in Graymalkin Cave are mostly articulated skeletons. Blindfold Cave fossils are also mostly articulated skeletons but show lots of tooth marks.
    e. Fossils found in both caves are fully disarticulated remains but only Graymalkin Cave was a nursery den for *Thylacaleo carnifex*, a large marsupial carnivore.

9. The limestone in which the caves have formed was deposited at the end of the Givetian stage in the mid-Devonian but it is thought the caves did not start forming along limestone fractures hosting the water table until sometime in the Oligocene. Which observations made by Roxanne in her studies of the area would support this idea?

    a. Underlying volcanic rocks have been dated at 406.6 ± 2.6 million years
    b. An extinct type of primitive koala, *Litokoala sp*. fossil was found in the cave. It was previously only known from deposits in Queensland dated at 5.5 ± 0.2 million years
    c. A basalt lava flow, dated at 23.03 ± 0.02 million years, has filled the outer chamber of one of the caves
    d. Both b and c.
    e. None of these observations support the idea.

10. In Xavierland's Mimic Cave students on a volunteer fossil dig with the local museum unearthed the fragmentary remains of a megafaunal marsupial, *Phascolonas gigas* (a kind of giant wombat that was extinct by about 30,000 years ago). Stone tools and other human artefacts were found in a distinct layer above the bone bed. Charcoal in this layer was carbon dated and returned an age of 45,000 years. Charcoal from the bone bed was beyond the limits of radiocarbon dating. The surface of a buried stalagmite on the floor of the cave directly below the area of the bone bed returned a Uranium/Thorium date of 2.51± 0.05 million years. In what epoch did the giant wombat die?

   a. Holocene.
   b. Pleistocene.
   c. Pliocene.
   d. Miocene.
   e. Impossible to tell.

11. In the almost inaccessible Petra Cave researchers exploring Xavierland's diverse ecosystems have found some unique troglodytes, cave dwelling species of insects and arachnids, adapted to zero-light and low oxygen conditions. It is thought this cave has been isolated from the outside for several million years and as a result the inhabitants have evolved into new species unique to Petra Cave. In any ecosystem there must be certain inputs including nutrients and energy to sustain life. What is the most likely source of food and energy at the base of the Petra Cave ecosystem for consumer organisms?

   a. Algae using CO_2 found naturally in the cave air and solutes found naturally in the water.
   b. Chemosynthetic bacteria using CO_2 and CH_4 found naturally in the cave air, minerals in the rock substrate and solutes found naturally in the water.
   c. Hydrothermal water rich in sulfur and other solutes.
   d. Calcium carbonate saturated water.
   e. Photosynthetic cyanobacteria using CO_2 found naturally in the cave air and solutes found naturally in the water.

12. On Phoenix Farm, near Xavierland, cattle once roamed the bush eating native shrubs and grasses. However, several decades ago an attempt was made to increase the farm's productivity by clearing the scrub and ploughing the soil so that improved pastures could be grown. Unfortunately, the pastures died, strange rusty brown deposits formed in the on-farm swamps and many of the shrubs and trees also died. Water draining from the swamps developed a pH well below 4 and concrete and metal infrastructure dissolved and collapsed as a result. In chemical terms why did this happen?

    a. Ploughing exposed quartz grains in the soil to light. The quartz interacted with the sunlight and produced silicic acid that lowered the pH and killed plants.
    b. Ploughing exposed red clays in the soil. They absorbed more water into their structure, increasing the acid concentration in the remaining water, killing plants.
    c. When exposed to the air by ploughing, pyrite in the soil oxidised, producing sulfuric acid that lowered the pH as well as killing plants. Iron oxide precipitates also formed from the iron in the pyrite.
    d. When exposed to the air by ploughing, calcite in the soil oxidised, producing carbonic acid that lowered the pH as well as killing plants. Calcium oxide precipitates also formed from the calcium in the calcite.
    e. When exposed to the air by ploughing, anaerobic bacteria in the soil grew faster, producing brown organic acids that lowered the pH and killed plants.

13. Coastal and estuarine wetlands are home to mangroves, a type of plant that only thrives in this environment. The maze of aerial roots in mangroves forests are key nursery areas for many species of fish and other organisms. The roots also trap mud and other sediments which form a characteristic anaerobic ooze. The problematic soils on Phoenix Farm contain particular minerals and marine fossils that indicate they started out as mangrove muds. However, they currently sit several metres higher than maximum high tides and are never inundated with seawater. How did the problem sediments form?

    a. The sea-level was higher when they were deposited and has since dropped.
    b. Mangroves migrate inland by seed over time and create mud deposits as they go.
    c. The sediments formed at the current sea-level and were pushed higher by tsunami.
    d. The sediments formed when sea-level was much lower and have been moved up by thrust faulting.
    e. The sediments look like mangrove mud but are not. They are of unknown origin.

The following information and Figure2 relates to questions 14, 15, 16 and 18

NASA's Curiosity rover has been surveying the surface of Mars for 2 Martian years, almost 4 Earth years. It is based in Gale Crater, a little over 5^{o} south of the Martian equator. Each Martian day is called a sol. Each Martian sol lasts about 39.6 minutes longer than an Earth day, and a Martian year lasts 668.6 sols. Curiosity's weather station has now made measurements nearly every hour of every day for 2 full seasonal cycles (Figure 2). The Martian atmosphere is 95.97% CO_2, 1.93% Ar, 1.89% N_2 and 0.146% O_2 with traces of other gases including water vapour. Martian air is thin with its air pressure only about 0.6% that of mean sea level air pressure on Earth.

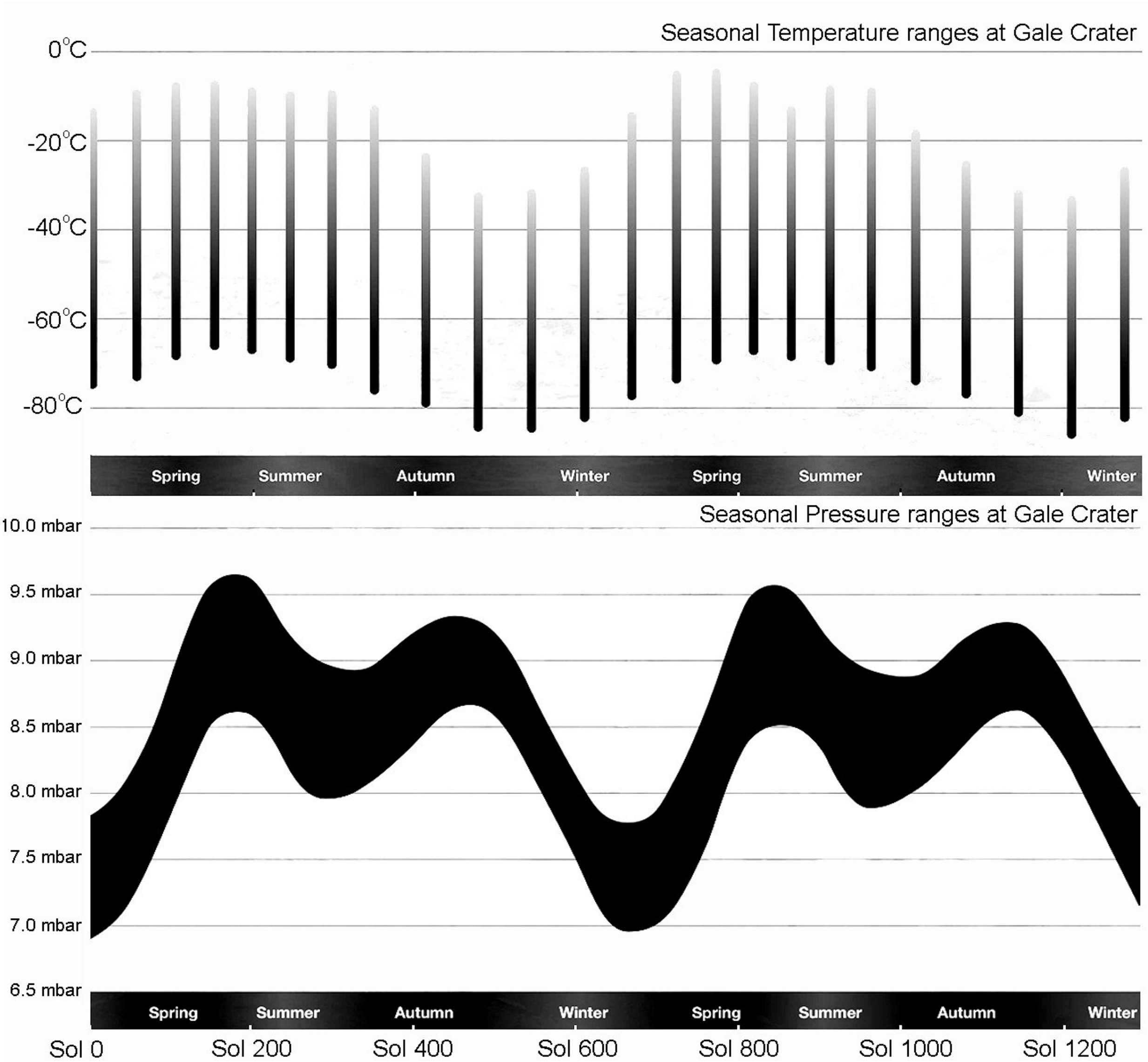


Figure 2: Two seasons of temperature and pressure readings at Gale Crater, Mars. Each bar on the temperature chart represents an average over one-twelfth of the planet's year. Some individual days have recorded higher or lower temperatures. The width of the pressure band is an indication of how the pressure varies throughout each sol. Modified from http://www.jpl.nasa.gov/spaceimages/details.php?id=pia20600 courtesy of NASA.

14. It is clear from the weather data for Gale Crater that Mars has seasons. This is partly explained by the fact that planet Mars has an axial tilt of 25^{o}, not that different to Earth's tilt. However, climatologists studying the data suggest that, unlike Earth, the southern hemisphere winters are much more severe than the northern hemisphere winters. What other factor could cause the Martian southern hemisphere winters to be much colder and longer than the Martian northern hemisphere winters?

   a. The Martian orbit is less elliptical than Earth's but because it is further from the Sun this still creates a bigger difference in the temperatures of the two Martian hemispheres' winters than is seen on Earth.
   b. During the Martian northern hemisphere summer the carbon dioxide icecap sublimes to produce a surge in extra CO_2 in the atmosphere which, as a greenhouse gas, makes the northern hemisphere summer warmer and the other hemisphere colder.
   c. The Martian orbit is much less elliptical than Earth's, placing it much closer to the Sun during its southern hemisphere winter and causing that season to be much more extreme than the same season in the northern hemisphere when the planet is much further from the Sun.
   d. The Martian orbit is much more elliptical than Earth's, placing it much further from than Sun during its southern hemisphere winter and causing that season to be much more extreme than the same season in the northern hemisphere when the planet is much closer to the Sun.
   e. During its southern hemisphere winter the orbit of Mars passes behind the planet Jupiter which shields it from sunlight and causes more extreme winter conditions, a situation that does not arise with Earth.

15. The southern hemisphere on Mars has short summers and long extremely cold winters. The extremely cold winter correlates with the lowest atmospheric pressures. Since Curiosity's data collection began which season has had the coldest nights according to the pressure data?

   a. The southern winter around sol 0.
   b. The northern winter around sol 180.
   c. The southern winter around sol 670.
   d. The northern winter around sol 1000.
   e. The southern winter around sol 1270.

16. Why does the atmospheric pressure drop in the Martian southern hemisphere winter and to a lesser extent in the southern hemisphere summer?

   a. The atmospheric pressure is inversely proportional to the intensity of the solar wind impacting the upper levels of the atmosphere. This is noticeable in the northern hemisphere winter when the pole receives the least incoming solar radiation but more so during the colder southern hemisphere winter.
   b. During both summers ultraviolet light forms extra CO_2 through interaction with quartz-rich rocks, increasing the atmospheric pressure. In winter the extra CO_2 freezes out at the poles dropping the pressure but more so during the colder southern hemisphere winter.
   c. During both winters adiabatic winds rushing off the poles towards the equator create planet-wide pole-to-equator Hadley-like cells that produce lower pressures either side of the equator but more pronounced over the southern hemisphere where the Curiosity rover is.
   d. During both winters the temperature at the poles drops below the freezing point of CO_2. The CO_2 is removed from the atmosphere as CO_2-ice, lowering the air pressure across the planet but the northern hemisphere winter is not as cold and not as long so the effect is not as marked. The CO_2 sublimes to gas in the summer.
   e. During both winters the temperature at the poles drops below the freezing point of water. The water vapour is removed from the atmosphere as snow, lowering the air pressure across the planet but the northern hemisphere winter is not as cold and not as long so the effect is not as marked.

17. There is a possibility that the Curiosity rover will find evidence of life on Mars but many scientists have argued that even if we find it we might not recognise it. The same could be said of aliens looking at Earth. If you were an alien on a nearby planet in another solar system looking at Earth what might make you suspicious that Earth hosts relatively smart life forms?

   a. Earth emits a variety of unnatural electromagnetic patterns.
   b. Earth's atmosphere contains CO_2
   c. The dominant gas in Earth's atmosphere is Nitrogen.
   d. Earth orbits the Sun in the goldilocks zone.
   e. Earth star is a G-type main-sequence "Yellow Dwarf", just right for life.

The following information and Figure 3 relates to questions 18, 19 and 20

Curiosity rover has discovered lots of evidence that confirms Mars once had lots of water on its surface. However, any water the surface of Mars now holds is frozen within the upper layers of the Martian lithosphere. On Earth water can occur as a solid, a liquid or a gas depending on local conditions. At 1 atmosphere (atm), approximately equivalent to 1 bar or 1000 millibar (mbar), water freezes at 0^{o}C (273.15 K) and boils at 100^{o}C (373.15 K) (Figure 3).

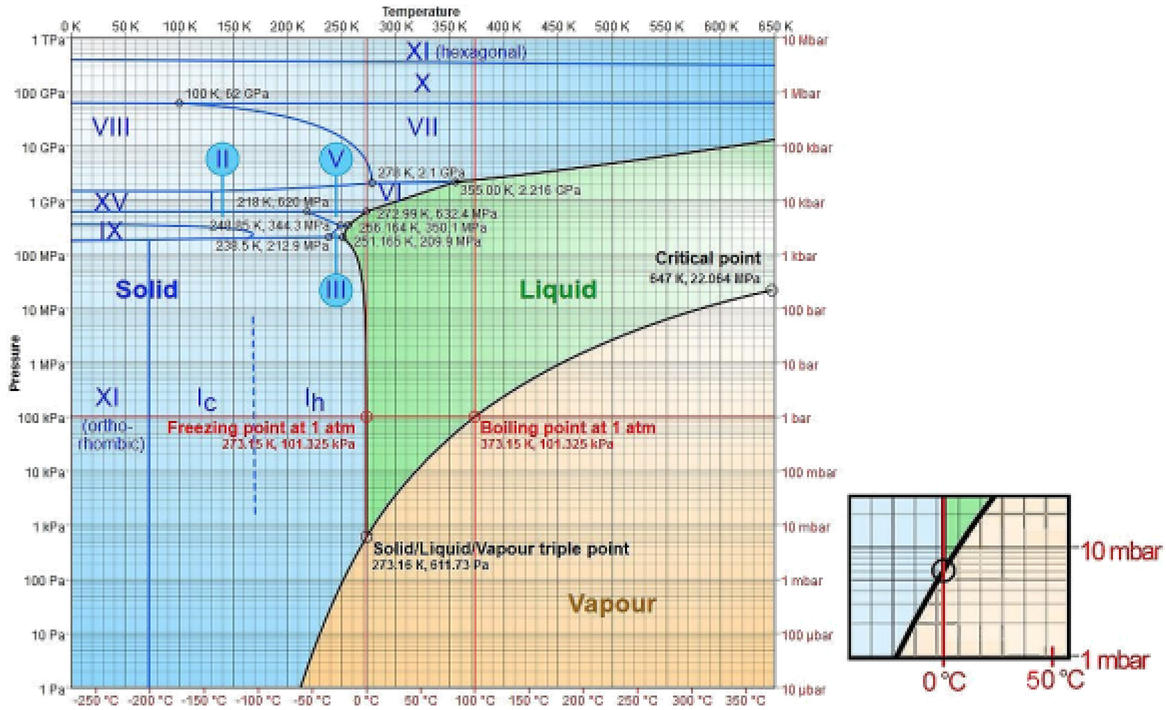


Figure 3: Log-lin pressure–temperature phase diagram of water. The Roman numerals indicate various ice phases. The graph in the small box is an enlargement of the triple point area in the Figure 3 graph. Modified from: https://commons.wikimedia.org/wiki/

18. Curiosity measures air temperature (Figure 2) from an instrument 1.5m above ground level. It also measures ground temperature via an infrared emissions detector. Ground temperatures during the warmer seasons peak at approximately 285 K. Air temperatures peak at approximately 293 K (not seen on average bars in the graph). Based solely on data collected by Curiosity could water ever be a liquid in Gale Crater under current conditions?

    a. No. The pressure is never above 10 mbar.

    b. Yes, but only at times when the ground temperature exceeds 0^{o}C.

    c. No. The pressure is never above 6.12 bar when the temperature exceeds 0^{o}C.

    d. Yes, but only at times when the pressure exceeds 10 mbar.

    e. Yes, but only at times when the air temperature exceeds 0^{o}C.

19. On average the atmospheric pressure at the top of Earth's Mt Everest in the Himalayas is only one third of a standard Earth atmosphere (atm) at sea-level. At what temperatures would water boil and freeze at the top of Mt Everest?

   a. The pressure is too low for water boil on Mt Everest. It is always frozen.
   b. Water will boil at approximately 70°C and freeze at 0°C.
   c. Water will still boil at approximately 100°C and freeze at 0°C.
   d. Water will boil at approximately 0°C and freeze at -30°C.
   e. It is impossible to get the temperature high enough on Mt Everest to boil water.

20. Titan is the largest moon of Saturn and the second largest moon in the solar system. It is larger than the planet Mercury and has a diameter 50% bigger than the Moon (Earth's moon). The Cassini space probe has confirmed the surface temperature of Titan is approximately -179°C (94K). However, Titan has liquid methane lakes and a thick atmosphere with a pressure at lake-level of 1.6 bars. Some rocks on Titan are undoubtedly made of water ice. What type of ice would be found in the rocky headlands on the shores of Kraken Mare, Titan's biggest lake?

   a. Ice X
   b. Ice IX
   c. Ice I_c
   d. Ice I_h
   e. Ice XI

21. Titan's atmosphere is made of nitrogen (98.4%), methane (1.4%) hydrogen (< 0.2%) and trace amounts of ethane, diacetylene, methylacetylene, acetylene, propane, cyanoacetylene, hydrogen cyanide, carbon dioxide, carbon monoxide, cyanogen, argon and helium. The Cassini space probe has observed methane clouds and methane rain on Titan. Cassini images have also revealed the numerous lakes on Titan are mostly composed of methane with some ethane. This means Titan must have

   a. a water cycle that carries the methane & ethane around.
   b. a nitrogen cycle analogous to the water cycle on Earth.
   c. a nitrogen cycle that carries the methane & ethane around.
   d. bushfires that are fuelled by flammable methane & ethane liquid, not put out by rain as on Earth.
   e. a methane & ethane cycle analogous to the water cycle on Earth.

22. Observations of Titan's surface have led to the identification of longitudinal dune systems in the equatorial region and extensive drainage systems in the region of the lakes. This has led observers to reasonably conclude that

a. Titan sometimes has winds capable of moving dry sediment grains and enough rain to run-off into the lakes and create erosional features in the process.
b. Titan has an ancient beach-dune system left behind as the lake levels fell with the drop in lake level creating drainage patterns back into the lake.
c. Titan's winds are so powerful that they create dunes and deep erosional gullies all over the planet.
d. Titan has a dynamic surface that creates Earth-like landforms by unknown means.
e. Titan has a sandy surface that absorbs rainfall and prevents run-off.

23. Studies in astrophysics inform us that the Sun was roughly 20 per cent less luminous 2.7 billion years ago. If Earth at that time, 2.7 billion years ago, had an atmosphere similar to today it would have been covered in ice. However, studies on rocks of that age indicate the climatic conditions at that time were not that different to today. New atmospheric information gleaned from rocks of that age demonstrates the atmosphere was a lot thinner than it is now and the air pressure at sea-level was only ~0.5 bar at most, half of what it is today. What is the most likely explanation for why the Earth was just as warm 2.7 billion years ago as it is today?

a. There is no good explanation, this is a scientific mystery.
b. The Earth was a lot closer to the Sun 2.7 billion years ago and this exactly compensated for the lower luminosity of Sun, allowing the Earth to warm up by the same amount as it does today.
c. The luminosity of the Sun is unrelated to the solar energy the Earth receives. The atmosphere 2.7 billion years ago would have heated up the same amount because the incoming solar energy was the same as today.
d. The atmosphere 2.7 billion years ago contained a lot less greenhouse gases such as methane and carbon dioxide than it does today and this difference compensated for the lower luminosity allowing the Earth to warm up by the same amount as it does today.
e. The atmosphere 2.7 billion years ago contained a lot more greenhouse gases such as methane and carbon dioxide than it does today and this difference compensated for the lower luminosity allowing the Earth to warm up by the same amount as it does today.

The following information and Figure 4 relates to questions 24, 25 and 26.

Students Roxanne Stone, Gabi Roe and Kimberley Piper worked together on mapping an area of Xavierland. They observed one rock unit that consisted of intensively layered rock comprising obviously once molten parts as well as residual parts that did not melt. Their teacher informed them that this rock is known as a migmatite. Nearby there are other metamorphic rocks. The students know that in stable crustal areas, like south eastern Australia, pressure and temperature increase with increasing depth in a regular way (Figure4). Figure 4 also shows some key reactions in the metamorphism of aluminium-rich clays that see the formation of andalusite, kyanite and sillimanite. These three minerals, polymorphs with the chemical formula Al_2SiO_5, have different pressure-temperature stability fields determined by laboratory experiments. If pressure and temperature conditions change to a new stability field, the Al_2O_5 minerals will readjust to form the stable polymorph.

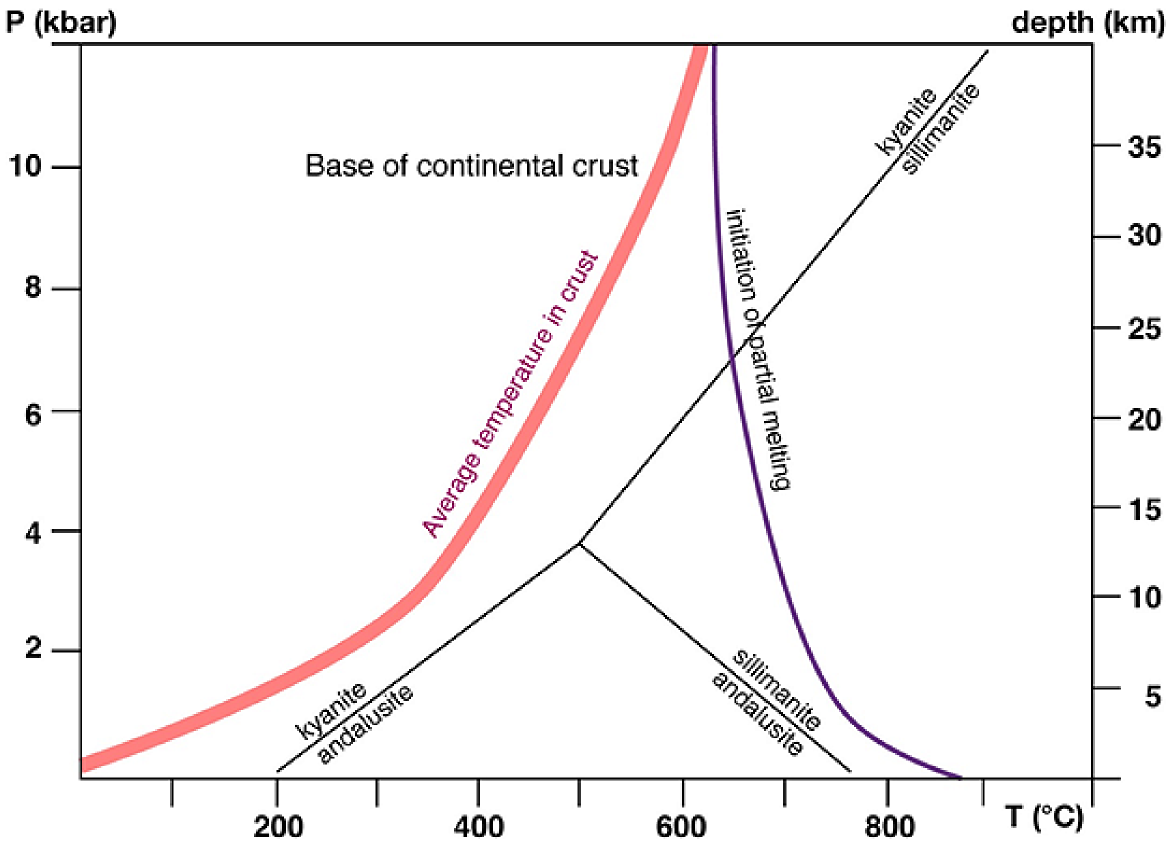


Figure 4: Pressure-Temperature graph for stable continental crust in south eastern Australia together with the stability fields of andalusite, kyanite and sillimanite.

24. In one of the metamorphic rocks they mapped (a schist) Kimberley found a typical suite of metamorphic minerals: andalusite, biotite, cordierite, muscovite and quartz. He thought these minerals indicated the rock had formed at the base of the continental crust but Roxanne and Gabi were not convinced. What maximum pressure for the formation of the schist should they propose in their field trip report in order to get full marks and what is the maximum temperature this would this involve?

   a. 10 kbar and 550°C. Kimberley is correct.
   b. 3.8 kbar and 500°C. Kimberly is not correct.
   c. 3.8 kbar and 550°C. Kimberly is not correct.
   d. 6.7 kbar and 500°C. Kimberly is not correct.
   e. 6.7 kbar and 650°C. Kimberly is not correct.

25. One of the rocks they mapped (a migmatite) appears to have formed from the partial melting of a metamorphic rock in the region (a gneiss). Roxanne found a typical suite of metamorphic minerals in the gneiss: biotite, cordierite, potassium feldspar, muscovite, quartz and sillimanite. She thought these minerals indicated the rock had begun to melt at 500°C. The students don't know the pressure at the time that partial melting began. In order to get full marks for their field trip report what temperature or temperatures for the onset of partial melting should they propose and what is the maximum pressure this partial melting could involve assuming the rocks were always buried deeper than 10km?

   a. 500°C and a maximum possible pressure of 3.8 kbar. Roxanne is correct.
   b. 550°C and a maximum possible pressure of 10kbar. Roxanne is not correct.
   c. 650°C to 700°C and a maximum possible pressure of 6.7 kbar. Roxanne is not correct.
   d. 650°C to 700°C and a maximum possible pressure of 10 kbar. Roxanne is not correct.
   e. 700°C and a maximum possible pressure of 3 kbar. Roxanne is not correct.

26. Roxanne, Gabi and Kimberley are all puzzled by the fact that none of the metamorphic rocks in their mapping area contain kyanite despite evidence that all the original sedimentary rocks in the area contained plenty of aluminium-rich clays that could form kyanite. Students in another mapping group, Phillip Light, Daytona Light and Gayle Snowdon, think they know why. What do they need to put in their field trip report in order to get full marks?

   a. Even though stable today the area was subjected to regional metamorphism associated with subduction zone tectonics that elevated the regional crustal temperatures well above the average crustal temperature. This led to all the rocks in the region being in the stability fields of andalusite and sillimanite and any kyanite that may have formed initially has changed into one of the other polymorphs.
   b. Even though stable today the area was subjected to contact metamorphism associated with small granite intrusions that elevated the regional crustal temperatures well above the average crustal temperature. This led to all the rocks in the region being in the stability fields of andalusite and sillimanite and any kyanite that may have formed initially has changed into one of the other polymorphs.
   c. Even though stable today the area was subjected to regional metamorphism associated with subduction zone tectonics that elevated the regional crustal temperatures well above the average crustal temperature. This led to all the rocks in the region being in the stability fields of andalusite and sillimanite and any kyanite that may have formed initially has changed into quartz.
   d. Even though stable today the area was subjected to contact metamorphism associated with igneous intrusions that elevated the regional crustal temperatures well above the average crustal temperature. This led to all the rocks in the region being in the stability fields of andalusite and sillimanite and any kyanite that may have formed initially has changed into quartz.
   e. Even though stable today the area was subjected to regional metamorphism associated with sea-floor spreading tectonics that created ideal conditions for the formation of all three polymorphs but in this region the kyanite bearing rocks do not outcrop.

The following information and Figure 5 relates to questions 27, 28, 29 and 30.

Students Phillip Light, Daytona Light and Gayle Snowdon, worked together on mapping an area of Xavierland known as Stryker Valley. Their high quality map was matched by an equally good cross-section (Figure 5). In their field notes they observed the following:

1) The Dolerite [literature search] has not been successfully dated
2) Rb-Sr radiometric date on the Gabbro [literature search]: 1660 ± 12 million years.
3) Sandstone contains vertebrate fossils (fish): Identified as Upper Devonian (Frasnian) placoderms
4) Mudstone and Coal contains plant fossils: Identified as Permian *Glossopteris* species
5) Limestone contains numerous invertebrate species: Identified as Middle Jurassic corals and bivalves
6) Limestone has caves within it

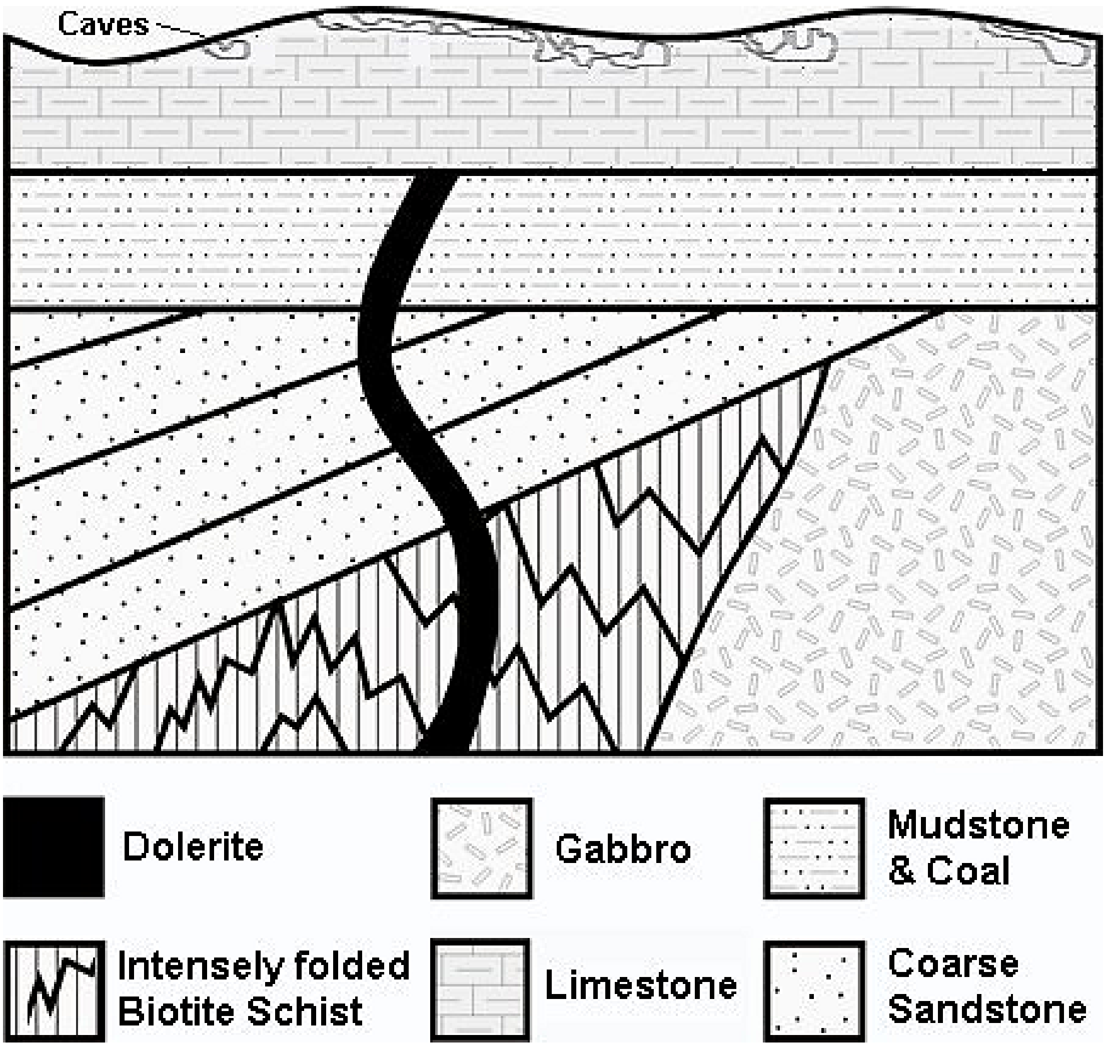


Figure 5: Stryker valley schematic cross-section compiled by Phillip Light, Daytona Light and Gayle Snowdon.

27. When in the field Phillip observed that the Schist is not contact metamorphosed by the Gabbro. Daytona and Gayle agreed with this observation and correctly concluded that

   a. the contact between the Schist and the Gabbro is an angular unconformity.
   b. the Gabbro intruded the Schist.
   c. the Gabbro is sourced from the same magma chamber as the Dolerite.
   d. the contact between the Schist and the Gabbro is a disconformity.
   e. the contact between the Schist and the Gabbro is a fault.

28. Daytona was intrigued by the Dolerite because it is weathered to the point where the minerals that would normally be used to K-Ar date it have broken down and allowed the loss of Ar. However, in her fieldtrip report she is still insistent on providing an estimate of its date. Which statement would get her full marks?

   a. the Dolerite post-dates the Permian but pre-dates the Jurassic.
   b. the Dolerite is Permian.
   c. the Dolerite pre-dates the middle Jurassic.
   d. the Dolerite is the oldest rock in the mapped area.
   e. the Dolerite is the youngest rock in the mapped area.

29. Gayle was having trouble writing part of her fieldtrip report because she wasn't sure what to call the contact between the dipping Sandstone beds and both the Gabbro and the Schist units. In the end she correctly decided

   a. the contact between the dipping Sandstone beds and both the Gabbro and the Schist is an angular unconformity.
   b. the contact between the dipping Sandstone beds and the Gabbro is a disconformity and between the Sandstone and Schist it is a nonconformity.
   c. the contact between the dipping Sandstone beds and both the Gabbro and the Schist is a nonconformity.
   d. the contact between the dipping Sandstone beds and the Gabbro is a fault and between the Sandstone and Schist it is a nonconformity.
   e. the contact between the dipping Sandstone beds and the Gabbro is conformable and between the Sandstone and Schist it is a nonconformity.

30. Student Sandra Shore has been reading about the geological history of the Stryker Valley and greater Xavierland area. She thinks the dipping Sandstone beds might actually be part of the limb of a very large regional syncline that formed during one of three major orogenic events in eastern Australia's Lachlan Fold Belt that folded vast swathes of Palaeozoic rocks. These events are marked on the Geological Timescale provided on page 4. Her field mapping partner, Vincent Knight, agrees but they disagree about which event it actually was. The correct conclusion is

   a. Sandra is mistaken because the evidence indicates the dipping beds are post-orogenic.
   b. the folding is part of the Benambran Orogeny because the dipping beds post-date the folding of the Precambrian Schist.
   c. the folding event was the Tabberaberran Orogeny because the dipping Devonian beds were in their current position prior to the Permian but post-date the Ordovician Benambran Orogeny.
   d. the folding event was the Kanimblan Orogeny because the dipping Devonian beds were in their current position prior to the Permian but post-date the Ordovician Benambran Orogeny.
   e. the folding event was either the Kanimblan Orogeny or the Tabberaberran Orogeny because the dipping Devonian beds were in their current position prior to the Permian but post-date the Ordovician Benambran Orogeny.

31. Tsunami are as amazing as they are frightening. In the Pacific region earthquake motions sometimes trigger tsunami that travel from one side of the ocean basin to the other. They are also renowned for reaching incredible heights as they enter shallow water. The increase of the tsunami's wave height as it enters shallow water is given by:

$\frac{h_s}{h_d} = \left(\frac{H_d}{H_s}\right)^{\frac{1}{4}}$ where h_s and h_d are wave heights in shallow and deep water and H_s and H_d are the depths of the shallow and deep water. If a tsunami with a wave height of 1.0 m in the open ocean where the water depth is 4000m approaches the coast what would the wave height be in water 1.0m deep?

   a. close to 0.8m high.
   b. close to 8.0m high.
   c. close to 18m high.
   d. close to 80m high.
   e. Insufficient information available to calculate the height.

The following information and Figure 6 relates to questions 32 and 33.

Tsunami have wavelengths ranging from 10 to 500 km and because the wavelength is very large compared to the water depth they act as shallow-water waves. Shallow-water waves move at a speed, *c*, that is dependent upon the water depth and is given by the formula:

$c = \sqrt{gH}$ where *g* is the acceleration due to gravity and *H* is the depth of water in metres. In the deep ocean, the typical water depth is around 4,200 m. In 1960, the largest earthquake ever recorded occurred near the Chilean city of Valdivia (Figure 6). It triggered a damaging Pacific-wide tsunami. In 1975, the largest earthquake ever recorded in Hawaii occurred just off the western shore of the Big Island. It triggered a damaging local tsunami that also impacted the Pacific Rim. Valdivia is approximately 10,700 kilometres from the Big Island.

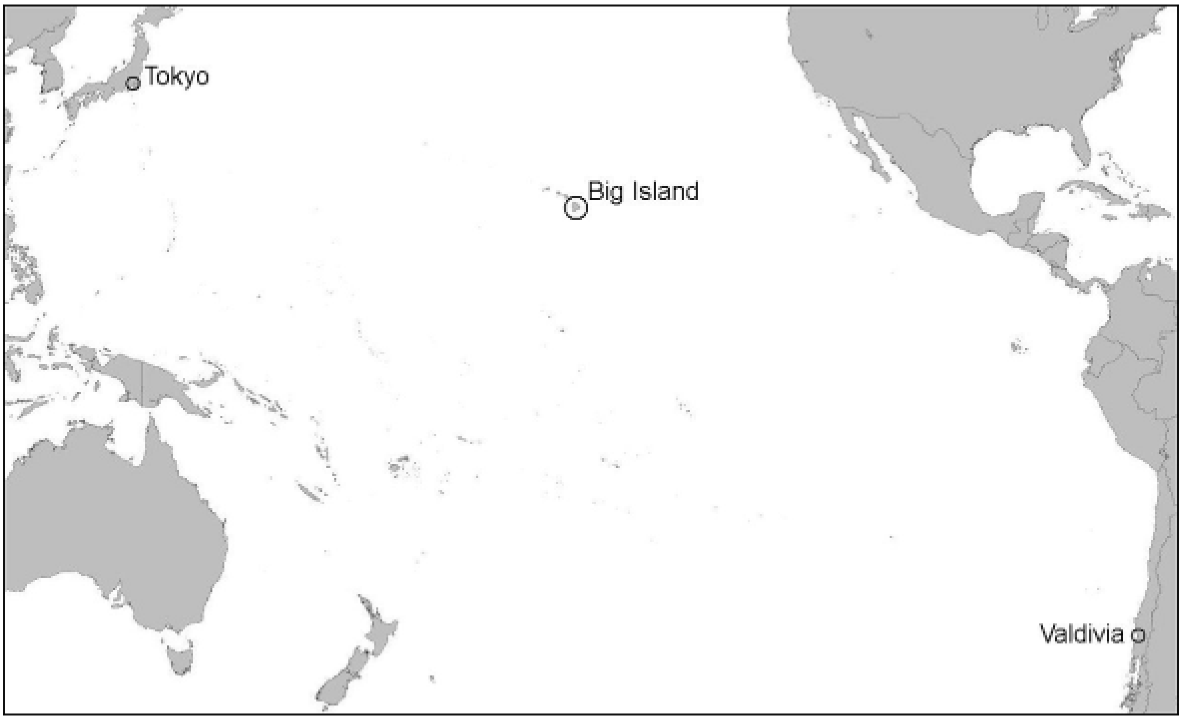


Figure 6: Map of the Pacific Rim showing the location of Valdivia in Chile, the Big Island of Hawaii and the capital of Japan. Modified image courtesy of http://tinyurl.com/gn8slcn

32. How long did it take the 1960 tsunami to reach the Big Island?

   a. The 1960 tsunami took ~15 hours to reach Hawaii.
   b. The 1960 tsunami took ~5.0 hours to reach Hawaii..
   c. The 1960 tsunami took ~7.0 hours to reach Hawaii.
   d. 1960 tsunami took ~17 hours to reach Hawaii.
   e. Insufficient information available to calculate the time.

33. When the 1975 tsunami generated by the Hawaiian earthquake impacted the coast near Tokyo it took 7.7 hours to arrive. Given the Japanese coast is approximately 6,400 kilometres from the epicentre of the Hawaiian earthquake, what does this mean for the average depth of the ocean between Hawaii and Japan?

a. The average ocean depth must vary a lot.
b. The average ocean depth must be about 4,200 metres.
c. The average ocean depth must be less than 4,200 metres.
d. The average ocean depth must be greater than 4,200 metres.
e. Insufficient information to calculate the ocean depth.

34. Tsunami have occurred in many places throughout recorded history and the rock record also contains evidence of tsunami in the ancient past. What events can cause a tsunami?

a. Only an earthquake can cause a tsunami.
b. Some earthquakes and all landslides can cause a tsunami.
c. All earthquakes, some landslides and some volcanic eruptions can cause a tsunami.
d. All earthquakes, landslides, volcanic eruptions and meteorites can cause a tsunami.
e. Some earthquakes, landslides, volcanic eruptions and meteorites can cause a tsunami.

35. A major earthquake occurred near Concepción, a coastal city in Chile, in 2010. Concepción is 200 kilometres north of Valdivia. This earthquake was caused by energy released during

a. a slow westerly movement of the South American Plate subducting under the Nazca Plate .
b. a sudden westerly movement of the Nazca Plate subducting under the Pacific Plate
c. a sudden movement of the Nazca Plate northwards and roughly parallel to the South American Plate
d. a sudden movement of the Nazca Plate subducting under the South American Plate.
e. a sudden north easterly movement of the Antarctic Plate subducting under the South American and Nazca Plates

The following information and Figure 7 relates to questions 36 and 37.

Figure 7 shows atmospheric CO_2 mole fraction (in ppm by volume) at the Mauna Loa Observatory, Hawaii (top red line). It also shows the surface ocean partial pressure of CO_2 (pCO_2; middle green data points), and surface ocean pH (bottom blue data points) at Station ALOHA in the subtropical North Pacific north of Hawaii.

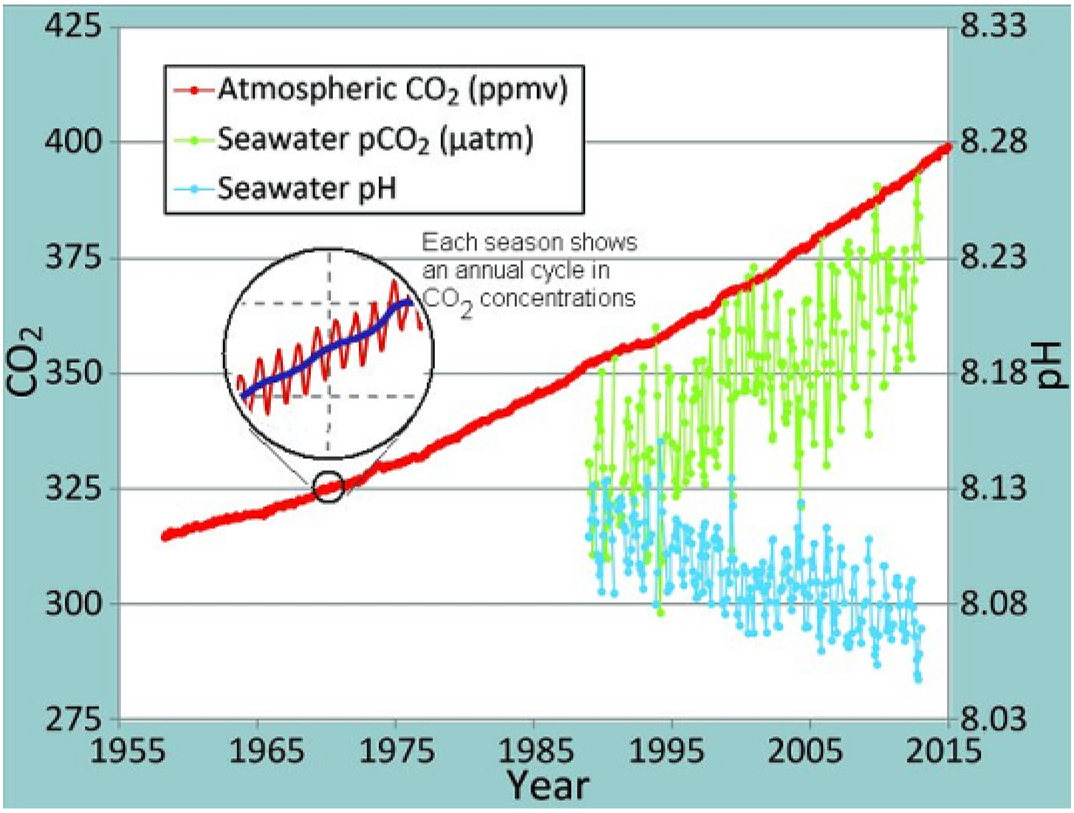


Figure 7: Atmospheric CO_2 measured at Mauna Loa Observatory, Hawaii. Oceanic CO_2 and pH measured at ALOHA Station, Hawaii. Image (modified) courtesy of NOAA: http://tinyurl.com/3kfsons

36. Why is the pH of the Pacific Ocean dropping?

   a. Plastic pollution in the oceans is increasing. It is acidic so the more plastic in the ocean the lower the pH of the water.
   b. Atmospheric CO_2 is increasing. The extra CO_2 dissolves in the water. It then fosters algae growth which oxygenates the water and lowers the pH as a result.
   c. The pH is not dropping. The data points show the pH just goes up and down over time.
   d. CO_2 in the atmosphere is increasing. The more CO_2 in the atmosphere the more CO_2 dissolves in the water forming carbonic acid that lowers the ocean's pH.
   e. The information supplied cannot help answer this question.

37. Why are the data points for the seawater pCO_2 so variable when the atmospheric CO_2 appears less variable?

a. Atmospheric CO_2 concentration does change with the seasons but the mixing of the CO_2 with ocean waters is also dependent upon the turbulance of the ocean surface. Each year the turbulence is very different to the next, producing a very big variation in the amount of mixing.
b. Atmospheric CO_2 concentration does change with the seasons, producing a similar variation in the mixing of the CO_2 with ocean waters. However, the pCO_2 recorded in the water is then further varied by the amount of plankton in the water.
c. Submarine volcanic eruptions at subduction zones produce this variability in the data recorded at ALOHA Station, Hawaii.
d. Atmospheric CO_2 concentration does change with the seasons which produces a similar variation in the mixing of the CO_2 with ocean waters. However, the pCO_2 recorded in the water is then further varied by the amount of plastic rubbish in the water which breaks down to CO_2 and SiO_2 in ultraviolet light.
e. The equipment used to record pCO_2 has a large uncertainty. This produces an apparent variability which is not real.

38. Students Daytona Light and Vincent Knight hoped to make some observations of the night sky while on their field trip to Xavierland's high country where there is no light pollution. They set up camp at 16:10, sunset was at about 17:00 and twilight ended about 18:30. They began observations at 18:50. 12 hours later, after they had finished their observations and were eating breakfast, they watched the moon setting. Which phase of the moon had they chosen to work through?

a. Full Moon.
b. First quarter.
c. New Moon.
d. Third quarter.
e. Blue Moon.

39. While making their observations Daytona and Vincent discussed their favourite music with an astronomical flavour. This led to a discussion about the dark side of the Moon. Both students understood that the expression derived from the fact that the Moon is tidally locked to Earth so we only ever see one side of the Moon. It rotates about its axis as it orbits Earth so that the same side is always facing Earth. However, they were uncertain about whether the side we never see is actually dark. What is the answer to this late night puzzle they gave themselves?

   a. The dark side of the Moon is only completely devoid of sunlight during the first quarter.
   b. The dark side of the Moon is only completely devoid of sunlight during a Full Moon.
   c. The dark side of the Moon is only completely devoid of sunlight during a New Moon.
   d. The dark side of the Moon is only completely devoid of sunlight during the winter solstice.
   e. The dark side of the Moon is always dark.

40. Daytona and Vincent know that they cannot see the dwarf planet Pluto with their eyes or even with their nice but relatively small telescope. However, data from the New Horizons space probe has recently revealed that a large section of Pluto's surface appears to be made of nitrogen ice. Curiously, this area has no impact craters. In their late night discussions they postulated some reasons for this. Which one is the most likely reason?

   a. The interior of Pluto contains enough radioactive material to generate heat which causes thick deposits of nitrogen ice to slowly convect, destroying all evidence of impact craters in the process.
   b. The surface of Pluto is constantly reworked by a steady bombardment of nitrogen ice fragments from the Oort cloud. This bombardment leaves no craters because it is all nitrogen ice.
   c. What appears to be nitrogen ice is in fact liquid H_2O which simply flows back over any impacts so they appear to have never happened.
   d. The orbit of Pluto crosses the orbits of Uranus, Neptune, Saturn and Jupiter bringing it closer to the Sun at which time its surface melts, destroying all evidence of impact craters.
   e. The thrusters of the New Horizons probe have melted the ice which destroyed all evidence of impact craters before it refroze to a smooth surface.

SECTION B: WRITTEN ANSWER QUESTIONS

ANSWER IN THE SPACES PROVIDED

The following information relates to question 41.

Roxanne Stone really likes vertebrate fossils and was one of the students who found the giant wombat bones in Xavierland's Mimic Cave. Some of the charcoal in this cave was radiocarbon dated to 45,000 years old. She also really likes astrophysics. She thinks that one of the neat things about the formation of solar systems is that they must have been preceded by earlier stars that exploded in a supernova. The elements made during the life of the stars and during the supernova form the 'star dust' from which the next generation stars and their solar systems (and you) are built. This includes the stable isotopes of carbon. Roxanne knows ^{14}C has a half-life of about 5,700 years and that it undergoes radioactive decay in which one neutron converts to a proton, changing from unstable ^{14}C to stable ^{14}N in the process. However, Roxanne has always been unclear about where the ^{14}C comes from in the first place since its short half-life means it cannot have formed in stars or a supernova.

41. In the space provided below write some dot points to help Roxanne understand the origin of ^{14}C and how it comes to be in the charcoal that is used to date archaeological sites and some fossil sites. **(5 Marks)**

- ^{14}C is formed in the upper atmosphere
    - Incoming cosmic rays hitting the atmospheric gases generate free neutrons
- Some free neutrons impact ^{14}N atoms and replace a proton, turning ^{14}N into ^{14}C

  $n + {}^{14}_{7}N \rightarrow {}^{14}_{6}C + p$
- ^{14}C rapidly reacts with O_2 in the atmosphere to form CO_2
    - Atmospheric movements rapidly disperse CO_2 throughout the air and into the oceans as well
- Plants take up the CO_2 via photosynthesis and the ^{14}C in some CO_2 is incorporated into plant tissues.
- Plant tissues, mainly wood, that is burned is reduced to pure carbon forming charcoal where it is chemically stable and biologically inaccessible (including any ^{14}C in the tissues).
    - From the time the plant tissue died no new ^{14}C was being added and the 'decay clock started ticking'.

The following information and Figure 8 relate to question 42, 43 and 45.

Before the Huygens probe (dropped from the Cassini space probe) landed on Titan, the largest moon of Saturn, it photographed a mountainous terrain with peaks and gullies as well as flatter low lands. When it landed it took this photograph (Figure 8). This is the only image taken on the surface of Titan before the probe's batteries ran out. Subsequent analysis of the land surface of Titan indicates the rounded objects in the image are probably made of water ice. At -179°C (94K) water ice is as hard as quartzite. Cassini radar images also reveal that it rains liquid methane on Titan and that it flows over the surface and into lakes, just like water does on Earth.

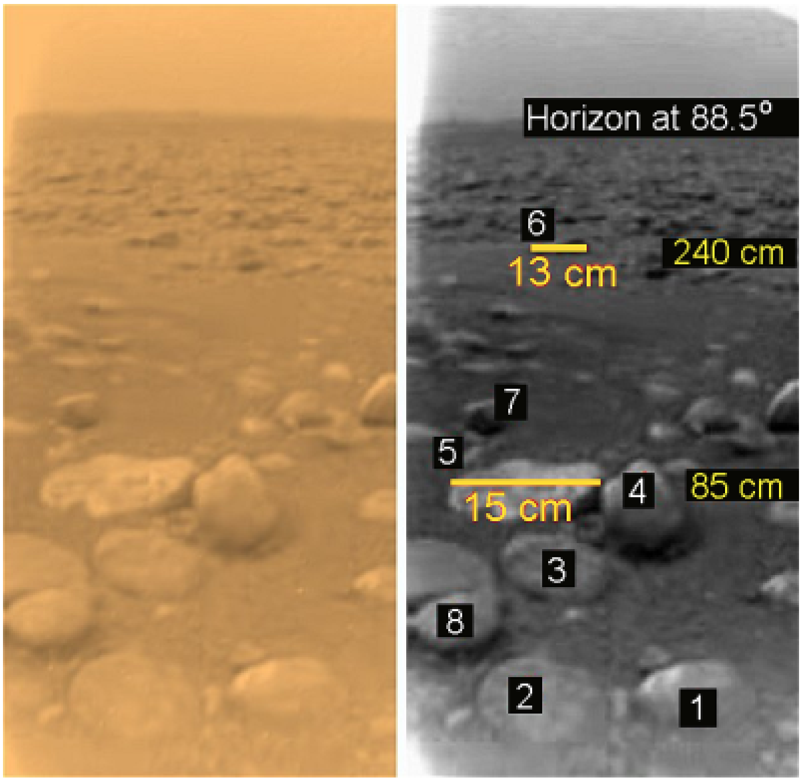


Figure 8: Left image: Colour view, following processing to add reflection spectra data, which gives a better indication of the actual colour of the surface. Right image: Raw image with eight rock-like objects numbered. Object 5 at 85 centimetres from the Huygens probe camera is 15 centimetres across. Object 6 at 240 centimetres from the camera is 13 centimetres across. Image (modified) courtesy of ESA/NASA/JPL/University of Arizona - http://photojournal.jpl.nasa.gov/jpeg/PIA07232.jpg and http://science.nasa.gov/science-news/science-at-nasa/2005/16jan_titan/

42. In the space provided on the following page explain (using diagrams as you see fit) where these ice-pebbles might have originated, how they came to be where they are and look the way they do in this rather flat landscape that scientists have interpreted to be part of a huge flood plain.

(5 Marks)

Use the space below to answer question 42.

- The ice rock pebbles must be sourced from outcrops of ice rock in the higher terrain of Titan some distance from this location since they appear to have had a long transport history
- Fragments have been eroded out of the ice rock in the higher terrain and have been washed into drainage channels during heavy rain
- Fragments in drainage channels have been moved by fast flowing liquid, gradually rounding the edges of the rock by the tumbling action in the movement which chips off the angular edges to produce rounded pebbles
    - Flash flood during heavy downpour events the most likely scenario
- Large amounts of distance and time are involved in rounding such hard materials
- Flooding out across the lower plains, the flash-flooding liquid would lose energy and drop the heavier particles – such as these pebbles – on the floor of the flood plain
    - Pebbles show signs of erosion around their bases suggesting liquid (or wind) has flowed/blown around them at a lower velocity that could not move the pebbles but could erode the fines around their bases.

43. When humans establish a colony on Titan they will need raw materials, such as liquid methane, to use as starting chemicals for the synthesis of building materials, fuel and food. At the landing site of the Huygens probe (Figure 8) colonists may find liquid methane, even when the stream bed is dry, by sinking a well into the surface. For liquid methane to flow into the well what two physical characteristics must the sediments possess in this region and which one is most important?
(3 Marks)

- Porosity: The sediments must contain pore spaces that can be filled by liquid.
- Permeability: The pore spaces must be interconnected so that the liquid can flow through the sediment.
- The higher the porosity and permeability the better the flow of liquid will be.

The following information relates to question 44.

Despite the hostile conditions on Titan the thick atmosphere, weather systems, lakes of methane, unusual geology and varied topography make Titan an attractive place to establish a human colony once people start to live in the Solar System beyond Earth. However, the Moon is the most likely place people will first establish a permanent colony beyond Earth.

The Moon has a diameter of 3,474 km and a bulk (average) density of 3.34 g/cm^3.
Titan has a diameter of 5,152 km and a bulk (average) density of 1.88 g/cm^3.

44. We know that the acceleration due to gravity, g, of a mass [in this case a moon] is equal to the mass of the moon divided by the square of the distance you are from the centre of the moon all multiplied by G, the Universal gravitational constant. Assuming both moons are spherical, on which moon would you weigh the most? Show your workings and explain your reasoning with reference to 'g' for the Moon and for Titan. **(5 Marks)**

Many ways of answering this. This way is the least elegant!

Weight of an object = Mass of the object {ie: me!} x acceleration due to gravity.

$g_{planet} = G \times M_{planet}/R^2_{planet}$ and we know $G = 6.67 \times 10^{-11}$ Nm^{2}kg^{-2}

M_{Moon} = Density x Volume = 3.34 g/cm^3 x 4/3π(1737km)^3 = 3.34 g/cm^3 x 4/3π(1.737 x 10^{8}cm)^3

- = 7.33 x 10^{22} kg ➔ 1 mark for the correct Moon mass

R_{Moon} = 1.737 x 10^6 m

g_{Moon} = 6.67 x 10^{-11} Nm^{2}kg^{-2} x 7.33 x 10^{22} kg /(1.737 x 10^6 m)^2 = 4.8 x 10^{12}/3.02 x 10^{12}

- = 1.59
- M_{Titan} = Density x Volume = 1.88 g/cm^3 x 4/3π(2576km)^3 = 1.88 g/cm^3 x 4/3π(2.576 x 10^{8}cm)^3

= 1.34 x 10^{23} kg

R_{Titan} = 2.576 x 10^6 m

g_{Titan} = 6.67 x 10^{-11} Nm^{2}kg^{-2} x 1.34 x 10^{23} kg /(2.576 x 10^6 m)^2 = 8.94 x 10^{12}/6.64 x 10^{12}

- = 1.34

Thus

- $g_{Moon} > g_{Titan}$ and I would weigh more on the Moon than I would on Titan since my mass would be the same on both moons because the weight of an object = Mass of the object {ie: me!} x g - acceleration due to gravity.

The following information and Figure 9 relates to question 45.

Titan is very Earth-like despite its size and alien atmosphere. There is evidence of rain on Titan and the radar images of the surface of Titan clearly show drainage patterns (Figure 9). These indicate flowing liquids have eroded the surface and formed dendritic patterns very much like water does on Earth. Dendritic patterns typically form where the fluid follows the slope of the land over impervious (non-porous) substrates and leads to the erosion of V-shaped valleys.

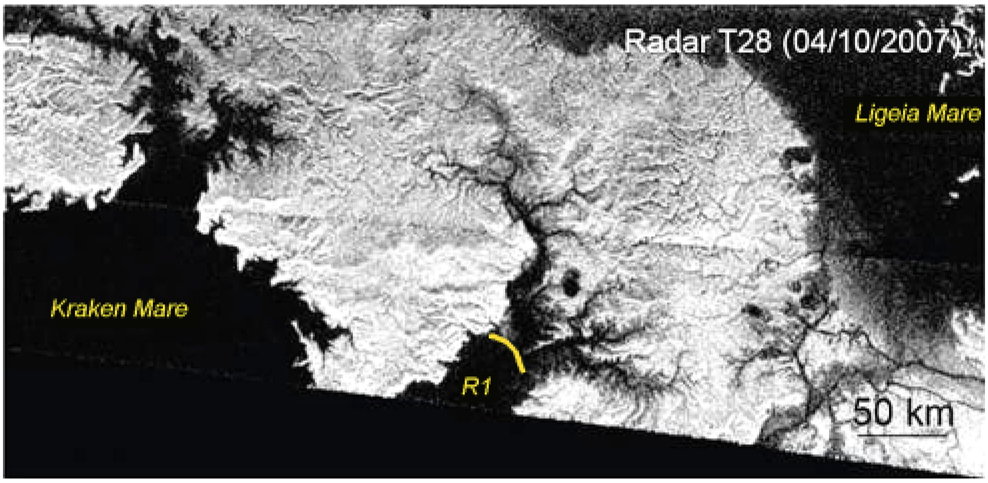


Figure 9: The north polar region of Titan. The dark areas are either lakes or channels transporting liquid while the light areas are dry land. Two lakes, Kraken Mare and Ligeia Mare, are in view. The edge of Kraken Mare is very clear as are the river channels flowing into the lake. Radar image courtesy of Cassini Radar Team/ESA/JPL/NASA

45. Examine the river system R1 that flows into Kraken Mare (Figure 9). The line across the head of the embayment represents the point where the river system meets the lake at lake-level. When we send a semi-submersible robot to explore Kraken Mare what type of sedimentary deposits are we likely to find in the region of this line? Give your reasons for your conclusions.**(3 Marks)**

    - The river is a river of flowing liquid methane. Like water on Earth, it is flowing across the landscape and eroding it, forming V-shaped valleys. This erosion generates sediments.
    - The river moves sediment downstream when the velocity of flow is sufficient to suspend, bounce (saltate) or roll the sediment grains.
    - When the flow reaches the lake it loses velocity and is unable to move the unsuspended sediments any further. This forms a river mouth delta with crossbedding a major feature of the structure of a delta.

The following information and Figure 10 relates to questions 46 to 53.

Students Daytona Light, Roxanne Stone and Vincent Knight mapped Longshotland, an area north of Xavierland (Figure 10). The vertical relief on this area is too slight to show on this map. In this area they identified a complex terrain overlain by a thin layer of fluvial sediments which in turn is buried by a 5 metre thick basalt lava flow. The sediments beneath the basalt are sandy silts and show signs of soil development. In their notebooks they also observed:

1) The schist retains relic sedimentary structures from the parent rock indicating it was an alternating suite of sandstones and mudstones not unlike a deep-marine turbidite deposit.

2) The mudstone labelled A contains Silurian graptolite fossils.

3) The mudstone labelled B contains lower Ordovician graptolite fossils.

4) The sandstone labelled C contains numerous solitary coral fragments and brachiopod shells.

5) The quartz-rich sandstone labelled D contains numerous solitary coral fragments, brachiopod shells and other fragmentary calcium carbonate skeletons.

6) A literature search revealed the sub-basaltic soil has been carbon dated to 12,000 years ± 10.

7) A small metamorphic aureole, approximately 250 metres wide, surrounds the gabbro.

8) A white mineral is evident in the rock labelled D where it is in contact with the gabbro.

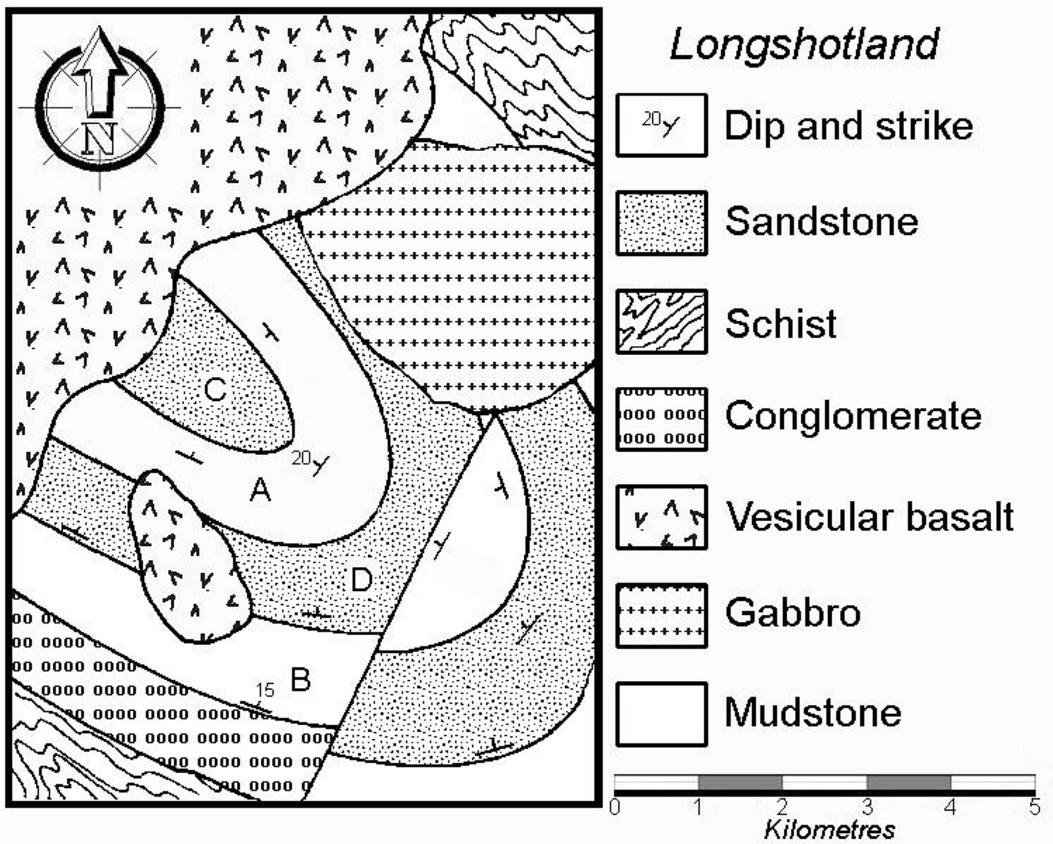


Figure 10: Map of Longshotland produced by Daytona Light, Roxanne Stone and Vincent Knight showing the distribution of rocks together with dips, strikes and other features identified or measured in the field.

46. In Figure 10, Rock type D is a quartz-rich sandstone containing fossils of invertebrates with calcium carbonate skeletons.

a) Assuming the rock is only composed of quartz grains and fossil fragments write out the chemical reaction that occurs during contact metamorphism.

b) What crystalline compound might be found in the metamorphic aureole as a result?

c) State the chemical formula of this compound.

d) What colour is this compound? **(2 Marks)**

$SiO_2 + CaCO_3 \leftrightarrows CaSiO_3 + CO_2$

The students all agree the mapped area contains some interesting structures but they disagree on a number of points. They need your help!

47. Mark on the map (Figure 10) where any unconformities occur. Use a bright colour to highlight their location/s. **(3 Marks) ➔ PINK on the inset map below**

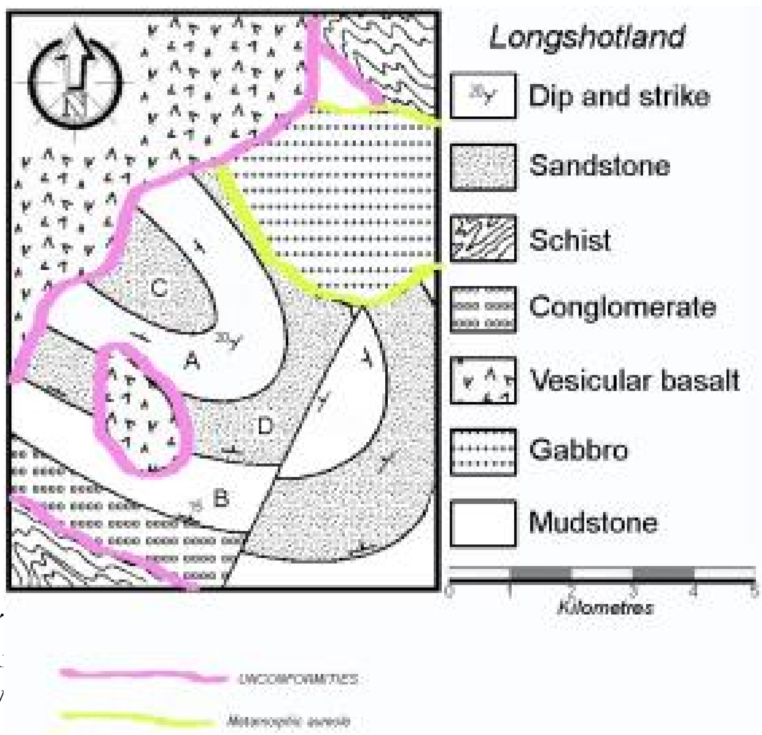
48. Using a different bright colour, mark on the map (Figure 10) where the metamorphic aureole should be found. **(1 Mark) ➔ YELLOW on the inset map below**

49. One big source of argument amongst the students is the fold in the sandstones and mudstones. What type of fold is it? **(1 Mark)**

- PLUNGING Syncline.

50. How old are the fossils in sandstone D (Figure 10) if they are not the same age as the fossils in mudstone B? Explain your reasoning. **(3 Marks)**

- Mudstone B is lower Ordovician. Since D overlays B it must be younger. If not the same age as B then D must be middle Ordovician or younger.
- Mudstone A is Silurian. Since D underlies A it must be older BUT it could still be Silurian of some age.
- D must be middle Ordovician to Silurian in age



51. A rare coral fossil found in sandstone C (Figure 10) is an index marker species for the upper Devonian Frasnian Stage. What does this mean for the likely age of the folding event recorded in the Ordovician to Devonian rocks? **(2 Marks)**

- Sediments deposited BEFORE the folding. The top of the Frasnian Stage is 372.7 ± 1.6 Ma ➔ after the both the Tabberaberran Orogeny @ 385 Ma and the Benambran Orogeny @ 445 Ma.
- The Kanimblan Orogeny occurs after the Frasnian @ 345 MA and is thus the only likely orogenic event to have caused the folding post-Frasnian.

52. One of the students, Jade Montane, has been to Hawaii and has seen lava flows that are not all that old (you know, as in just cooled this morning not-old!). Jade knows that the Longshotland basalt looks a lot different to a very recent flow even though it is only 12,000 years old. Jade explained that the top of the flow is chemically weathered but not all the other students know what this means. You can help them by explaining

a) What chemical weathering does to basalt and

b) What this means for the appearance of the basalt which was once almost black in colour and very glassy on top with ropy lava features in many places. The colour is now different and the glassy features have disappeared.

(4 Marks)

- Chemical weathering involves minerals in the rock reacting chemically with water, oxygen, organic acids and other reactive agents in the environment.

- The minerals in the basalt are iron-rich olivine & pyroxene plus feldspar. All 3 minerals chemically weather to clays.

- This physically weakens the rock and allows physical agents to more easily break the rock apart, resulting in destruction of the original glassy surface and many of the ropy features on the top of the rock.

- In the process, the iron in the minerals is liberated and forms red-brown iron oxides that alter the colour of the rock and are the major colouring agent in basaltic soils.

53. Using the blank geological column (Figure 11)

a) Schematically draw in the rock units and geological events from oldest to youngest and

b) Write a note about each geological unit or event next to the column given what you know about this outcrop, the rock types present, the environment of formation and any other information revealed in the map or the student notes. NOTE: Full marks can only be awarded if the <u>entire sequence</u> of rocks and events is in the correct order.

(12 Marks)

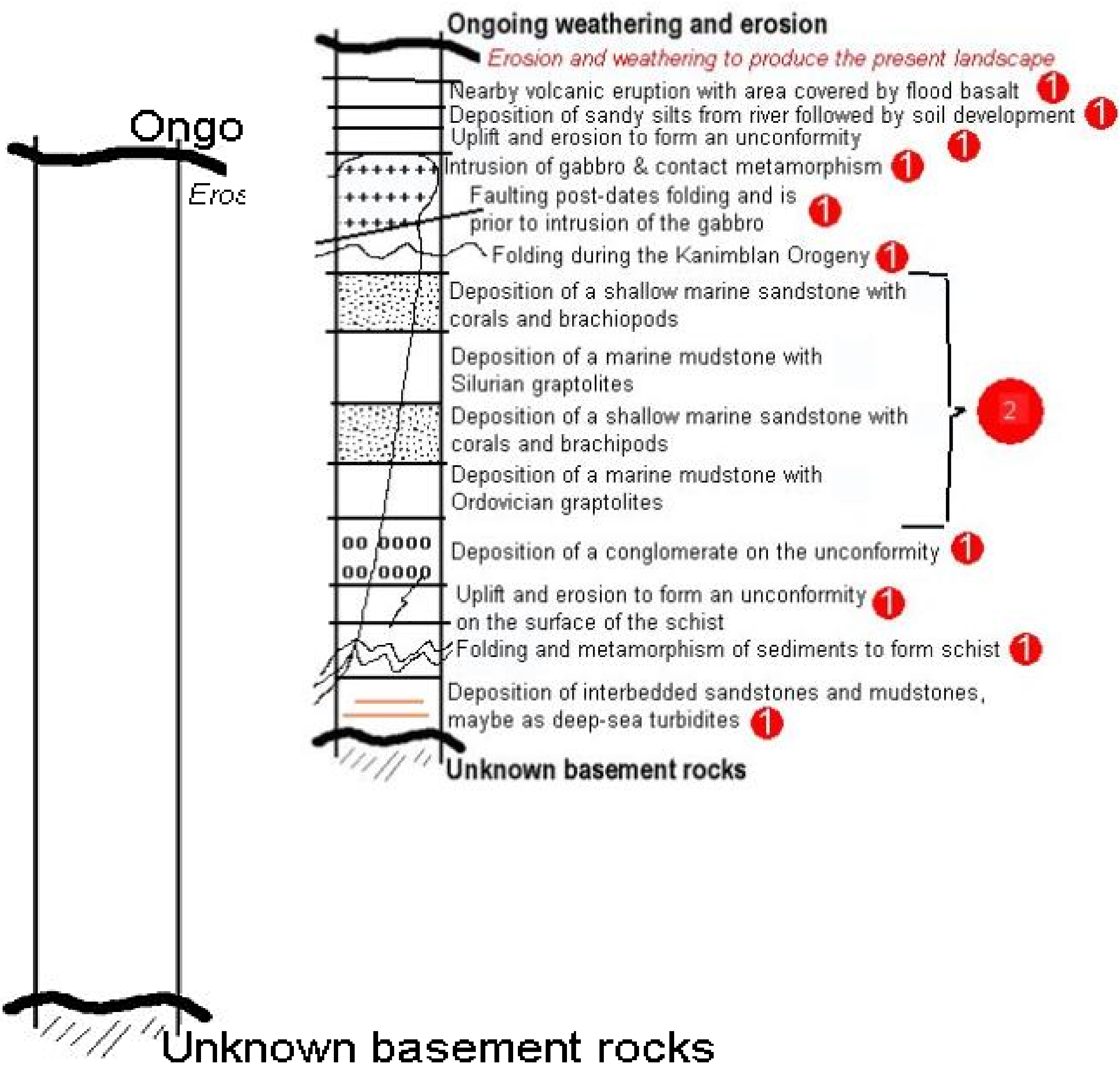


Figure 11: Blank geological column to be completed in answer to question 53.

The following information relates to question 54.

In 2011 a magnitude 9.0 earthquake occurred off the Pacific coast of Tōhoku, north of Tokyo in Japan. It triggered a devastating tsunami that severely impacted coastal Japan. Debris from the tsunami was washed out to sea, including large floating objects such as shipping containers. One such container, housing a Harley-Davidson motorbike, was found on the west coast of Graham Island, Canada. Other debris has washed up on Hawaiian beaches.

54. Using the map below (Figure 12), place one arrow head on each of the 12 surface current 'flow lines' to show the flow direction of the ocean currents.

    Use a bright coloured pen or pencil to show the path of the motorbike shipping container.

    Use a different coloured pen to show the path of other tsunami debris that has ended up in the North Pacific Garbage Patch (NPGP).

(5 Marks)

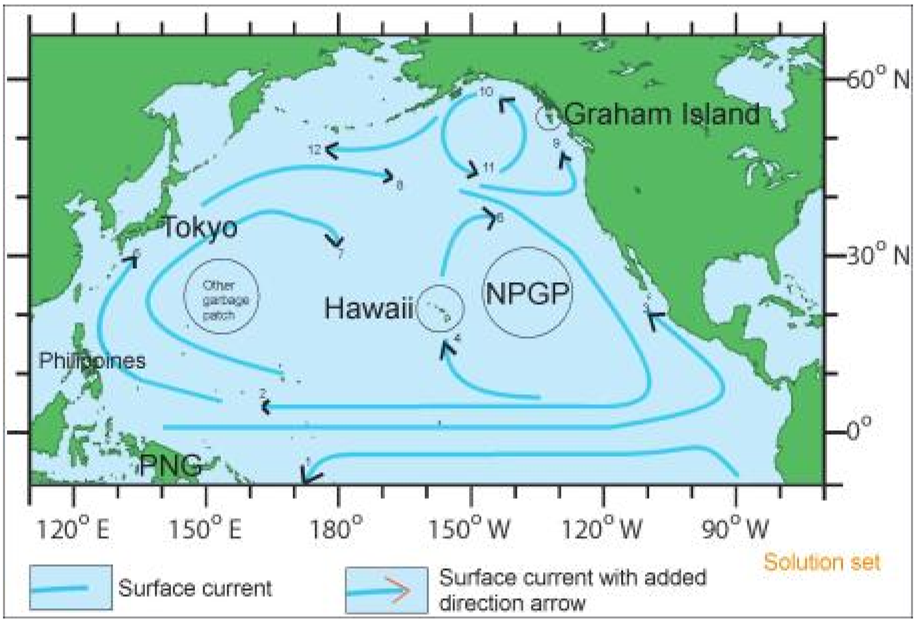


Figure 12: Simplified map showing some major surface current 'flow lines'. Use this map to answer question 54 and question 55.

55. Using the map above (Figure 12), place a coloured circle on the map where another Garbage Patch containing rubbish from Hawaii might be found. **(1 Mark)**

⇨ **The west north pacific gyre, not the Alaskan gyre**

The following information and Figure 13 relates to question 56

An intense low pressure system (996 hPa) formed off the coast of eastern Australia when students were field mapping (Figure 13). It rained so hard in Xavierland that it forced Roxanne and her classmates to abandon their field trip and seek shelter on higher ground.

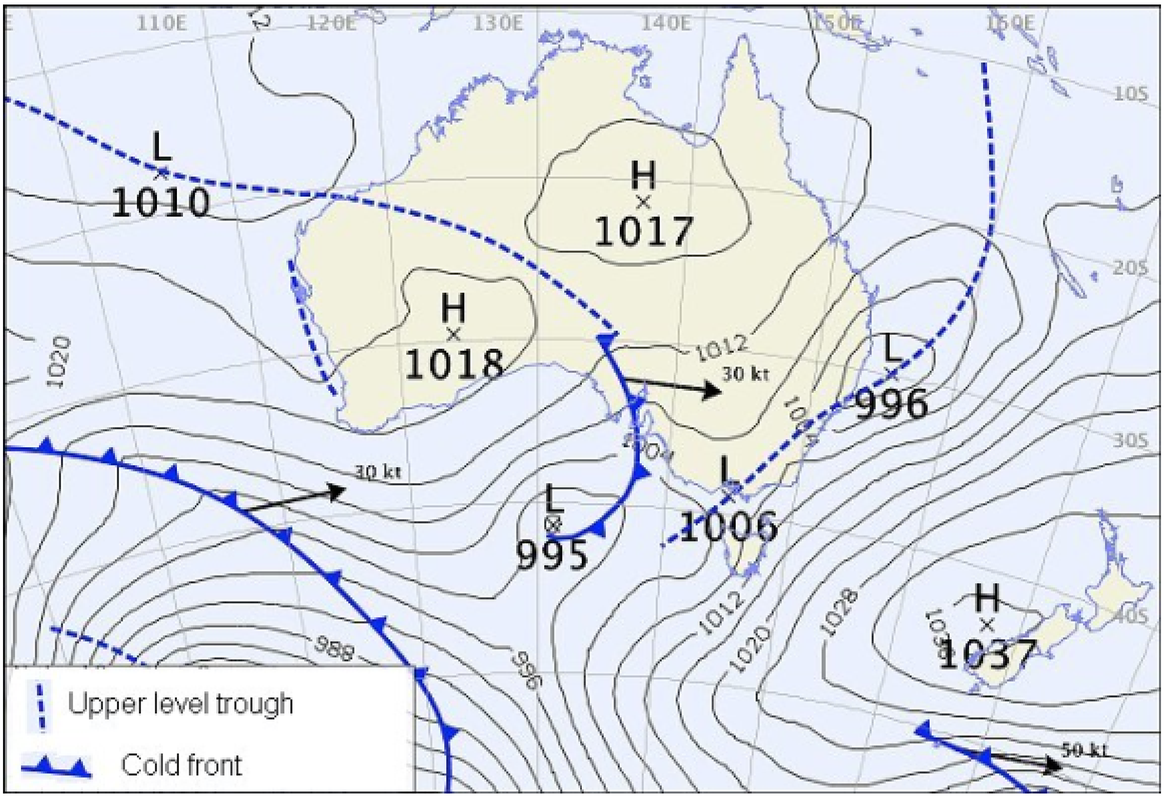


Figure 13: Synoptic chart (modified) courtesy of the Australian Bureau of Meteorology.

56. Why did eastern Australian coastal communities south of this low pressure system receive very heavy flooding rains while communities north of this system did not?
(4 Marks)

- Low pressure systems rotate in a CLOCKWISE direction
- When centred off-shore, this creates an ON-SHORE airflow SOUTH of the low. Coming from over the ocean the air mass is very moist.
- The on-shore maritime airstreams are forced to lift over mountain ranges, causing the air to cool and form clouds and heavy rain.
- Off-shore airstreams to the north of the low are relatively dry and cloud free and there is no orographic uplift affect to create clouds and rain.

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BLANK WORKING PAGE

Integrity of Competition

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