

School ID:				

2014 AUSTRALIAN SCIENCE OLYMPIAD EXAMINATION

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 **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 2015).

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 2014 are not eligible to attend the 2015 Australian Science Olympiad Summer School.

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Examiners Use Only:									

2014 Australian Science Olympiad Examination

Time Allowed

Reading Time: 15 minutes

Exam Time: 120 minutes

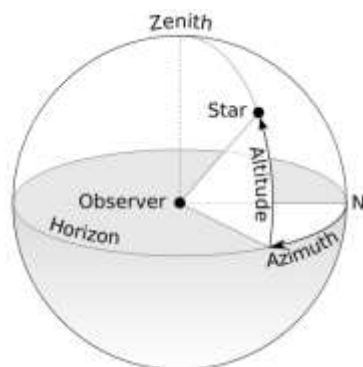
INSTRUCTIONS

- *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 51 to 52 of this booklet.
- Data that may be required for a question will be found on pages 3 to 4.
- Do NOT staple the multiple choice answer sheet to this booklet.

MARKS

SECTION A	25 multiple choice questions Each question worth one mark unless otherwise specified	27 marks
SECTION B	32 written answer questions Marks for each question are specified	93 marks
Total marks for the paper	120 marks	

DATA & DEFINITIONS



Azimuth is measured from the north point of the horizon around to the east. An azimuth of 90° is due East.

Altitude is the angle above the horizon.

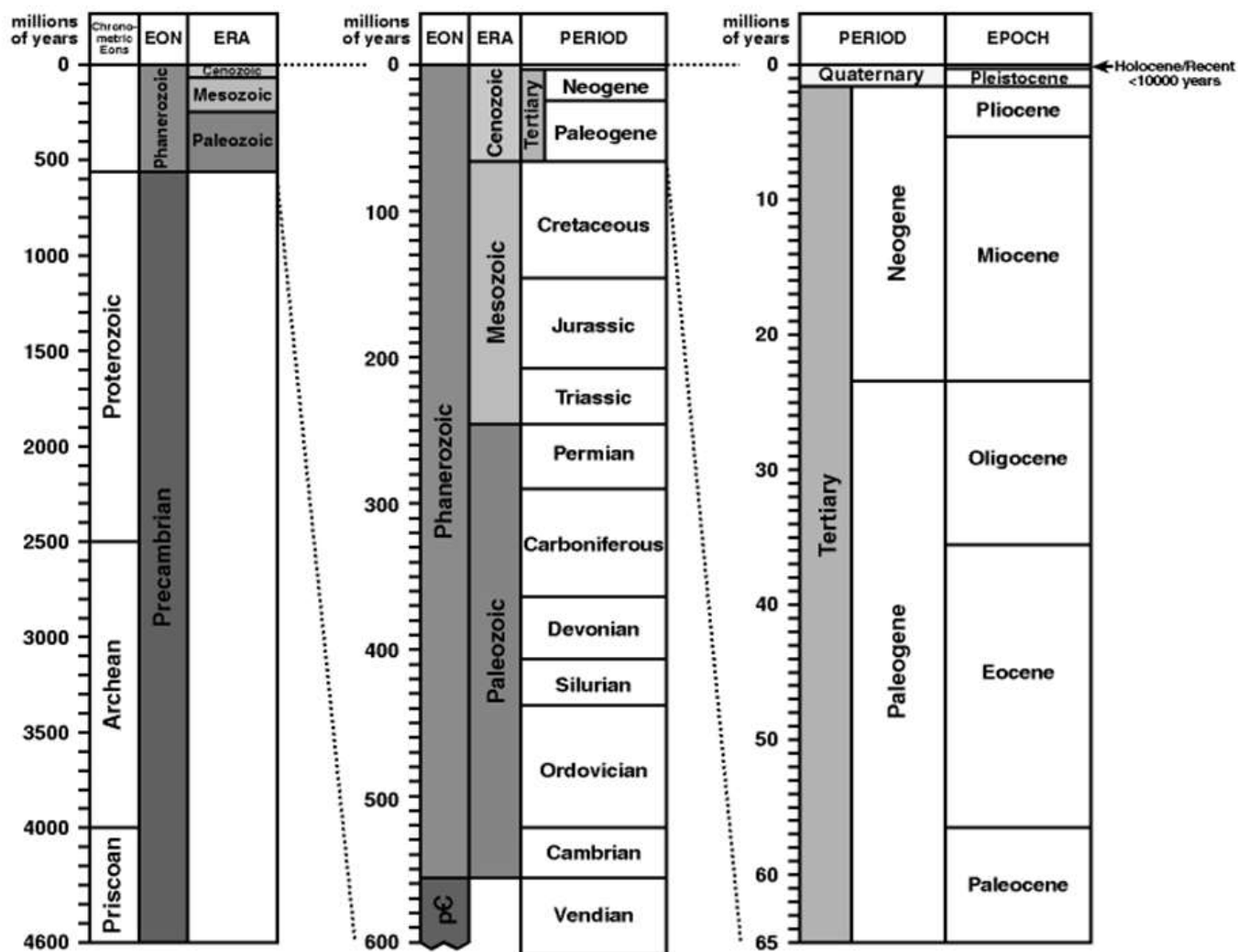
Source: Adapted from http://en.wikipedia.org/wiki/Horizontal_coordinate_system

Table of constants and units

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

Periodic Table of the Elements																		2			
1 IA 11A		2 IIA 2A																18 VIIIA 8A			
1 H Hydrogen 1.008				3 Li Lithium 6.941	4 Be Beryllium 9.012															10 Ne Neon 20.180	
		Atomic number		Atomic mass																	
		1		H Hydrogen 1.008																	
																				</	

GEOLOGICAL TIME SCALE



SECTION A : MULTIPLE CHOICE

USE THE ANSWER SHEET PROVIDED

1. Amphibolite is an Intermediate Grade metamorphic rock. On a mapping field trip to the famous mining region of Shattered Knoll, well known for its metamorphic rocks, student Wade Beachley thinks it is possible to see the true nature of the parent rocks at the very edge of the mapping area. If he is correct, what two rocks (parent & low grade equivalent) would he need to find to confirm his hypothesis as he maps the amphibolite towards the edge of the mapping area?
 - a. Basalt & Gabbro
 - b. Granulite & Greenschist
 - c. Basalt & Granulite
 - d. Anthracite & Greenschist
 - e. Basalt & Greenschist

2. On the same mapping field trip Wade's mapping partner, Roxanne Stone, collected numerous rock samples for identification. Using her field notes below, which rock is most likely to be an amphibolite?
 - a. A medium to coarse grained dark green to black rock, the only clearly visible mineral being hornblende. Some outcrops appear to have a very weak foliation.
 - b. A coarse grained rock with visible quartz, feldspar, hornblende & mica showing foliation and alternating bands of light and dark minerals.
 - c. A dark, shiny, strongly foliated, medium to coarse grained rock dominated by biotite with a random scattering of large garnet crystals.
 - d. A fine grained dark grey to black rock with a distinct cleavage that breaks the rock into large, thin, flat sheets.
 - e. A shiny rock with a distinct silky lustre and platy texture but mineral grains a little too small to see. Indistinct cleavage can be identified. Foliation visible.

3. Prior to their field mapping trip to Shattered Knoll, students have been studying minerals and rocks. One of the interesting things they learned was that some chemical compounds can form more than one type of mineral. Kyanite, Andalusite and Sillimanite are all made of the same aluminium silicate compound (Al_2SiO_5) but have different crystalline structures. What is the correct mineralogical term to describe these groups of minerals?

- a. Pseudomorphs.
- b. Polymorphs.
- c. Polyhedra.
- d. Nanomorphs.
- e. Polyploidy.

4. Wade Beachley's parents have recently installed a new kitchen with a polished granite bench top. Wade's teacher says stonemasons and kitchen bench top salespersons call any hard rock that takes a polish *Granite*. Wade thinks the bench top is actually made of gabbro if the correct geological name was used. If he is correct which description would best suit the Beachley household's new bench top?

- a. A dark green to black rock composed mostly of medium to coarse white feldspar crystals (plagioclase) and dark pyroxene crystals with lesser amounts of olivine and hornblende and no quartz.
- b. A dark green to black rock composed mostly of medium to coarse whitish quartz crystals and dark pyroxene crystals with lesser amounts of olivine and hornblende and no plagioclase feldspar.
- c. A dark green to black rock composed mostly of medium to coarse white feldspar crystals (plagioclase) and white calcite crystals with lesser amounts of olivine and pyroxene and no quartz.
- d. A dark green to black rock composed mostly of medium to coarse white feldspar crystals (plagioclase), pink feldspar crystals (potassium feldspar) and dark mica crystals (biotite) with lesser amounts of olivine and pyroxene and no quartz.
- e. A dark green to black rock composed mostly of medium to coarse white feldspar crystals (plagioclase) and dark green malachite crystals with lesser amounts of biotite and pyroxene and no quartz.

5. Roxanne Stone can't believe her parents have done the same thing except that they chose a marble bench top! Their teacher says stonemasons and kitchen bench top salespersons call many soft rocks that take a polish *Marble* but in geology, *Marble* is used exclusively as the name of a type of non-foliated metamorphic rock. In her blog she wrote: *It is a boring grey. However, it is full of things - mainly Brachiopods and Rugose corals I think - and shows no sign of recrystallization. An off-cut fizzes like crazy in acid. There is no way it's a Marble!* Assuming Roxanne's description is correct what type of rock is the Stone household's bench top most likely made of?
- a. Fossiliferous marble.
 - b. Fossiliferous limestone.
 - c. Fossiliferous sandstone.
 - d. Fossiliferous mudstone.
 - e. Fossiliferous rhyolite.
6. A friend tweeted Roxanne back; *Mrble fzzes in acid 2!* Another tweeted; *Marbles r round!* Which one of these materials would not fizz in acid like Marble does?
- a. Aragonite crystals filling a vesicle in deeply weathered basalt found near a blue stone quarry.
 - b. The broken end of a stalactite found in a limestone quarry.
 - c. A sea urchin skeleton found at the beach.
 - d. Feedstock going into a kiln to make the primary ingredient in cement.
 - e. A beryl crystal found in a pegmatite quarry.
7. Wade and Roxanne mapped a pegmatite quarry as part of their field mapping trip to Shattered Knoll. They were amazed to discover how important the major mineral in pegmatite is to the ceramics industry and their kitchen crockery. Select the correct name of this mineral.
- a. Beryl.
 - b. Feldspar.
 - c. Quartz.
 - d. Tantalite.
 - e. Tourmaline.

8. The Kuiper Belt contains millions of small pieces of ice and rock. Where is the Kuiper belt?
- a. It is found at the point where the solar wind stops.
 - b. It is the same thing as the asteroid belt, found between the orbits of Mars and Jupiter.
 - c. It is between 4.5 and 7.5 billion km from the sun, extending beyond the orbit of Uranus.
 - d. It is between 4.5 and 7.5 billion km from the sun, extending beyond the orbit of Neptune.
 - e. It is between 4.5 and 7.5 billion km from the sun, extending beyond the orbit of Saturn.
9. Students Daytona Light & Vincent Knight went on a field trip to remote Burrumlingawee where they planned to make astronomical observations. They set up camp at 16:30, sunset was at about 17:45 and twilight ended about 18:10. They began observations at 19:00. 12 hours later, after they had finished their observations and were eating breakfast, they noticed the moon was rising. 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
10. Some meteorite impacts are so energetic that terrestrial rocks are not only fragmented and ejected from the impact site but are raised to melting point. Some molten blobs may even reach space before falling back to Earth. Most reach stratospheric altitudes. When found on Earth these once molten objects appear to have been solid long before landing. They are collectively known as Tektites. What difference might you expect to find between tektites and most meteorites?
- a. Tektites are finely crystalline objects. Meteorites are never crystalline.
 - b. Tektites are totally glassy objects. Meteorites are mostly glassy too.
 - c. Tektites are coarsely crystalline objects. Meteorites are usually glassy.
 - d. Tektites are totally glassy objects. Meteorites are rarely glassy.
 - e. Tektites are identical to meteorites so no difference should be expected.

11. At midnight, looking south, Daytona and Vincent observed the Southern Cross with alpha Crucis at an azimuth of $194^{\circ}56'$ and an altitude of $13^{\circ}09'$ above the flat expanse of the Gibberish Plain (Figure 1 provided below illustrates what they saw). If they resumed southerly observation of the night sky 2 hours 15 minutes later, where would they most likely observe alpha Crucis?

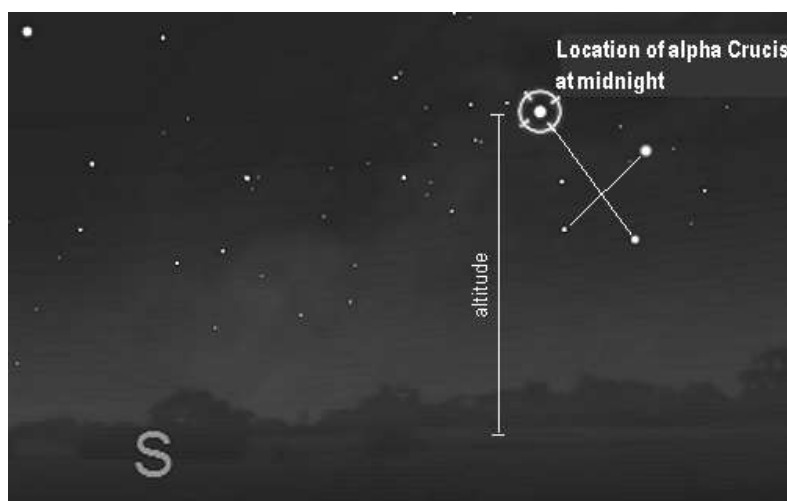


Figure 1.

- At an azimuth of $180^{\circ}00'$ and an altitude of more than $13^{\circ}09'$.
- At an azimuth of $280^{\circ}00'$ and an altitude $9^{\circ}35'$.
- At an azimuth of $180^{\circ}00'$ and an altitude $9^{\circ}35'$.
- At an azimuth of $200^{\circ}00'$ and an altitude $9^{\circ}35'$.
- At an azimuth of $195^{\circ}00'$ and an altitude $9^{\circ}35'$.

12. Figure 2 below is a Hertzsprung–Russell diagram, a scatter graph of stars showing the relationship between the stars' luminosities versus their spectral class (O, B, A, F, G, K & M) and effective temperatures. Which of the follow statements is correct?

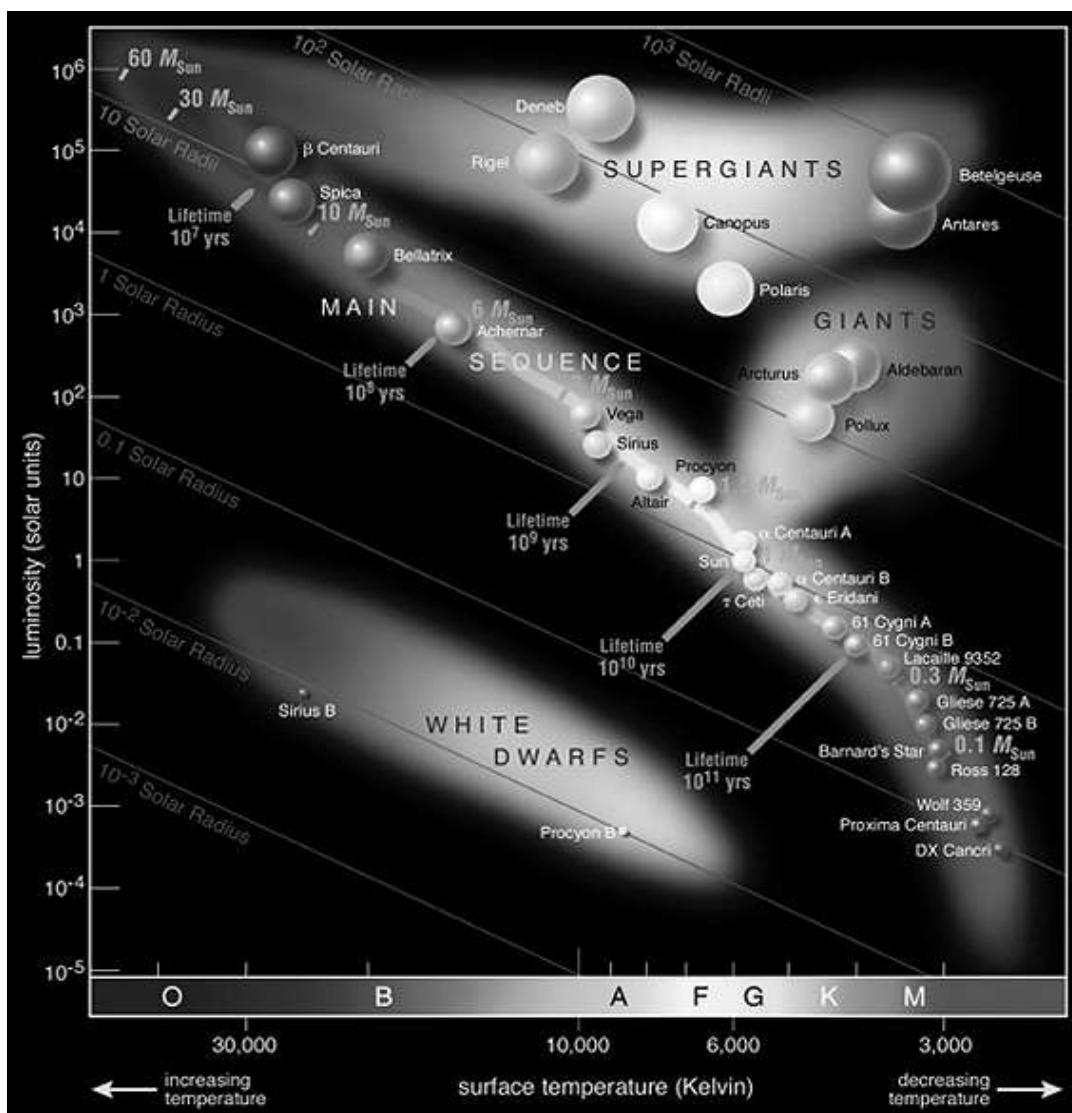


Figure 2. Source: http://en.wikipedia.org/wiki/File:Hertzsprung-Russel_StarData.png

- Sirius B is less than 100 times smaller than the Sun but it's luminosity is not 100 times less than the Sun
- The surface of Betelgeuse is several thousand Kelvin cooler than the Sun even though Betelgeuse is nearly 1000 times bigger than the Sun
- The Sun is an K-class star
- All White Dwarfs are A class stars
- Procyon and Polaris are both F-class stars but Polaris is 1000 times brighter than Procyon.

Use the following information and tables to answer questions 13, 14 & 15.

The Global Warming Potential (GWP) of greenhouse gases provides a means of combining the emissions of different greenhouse gases to calculate a total emissions figure expressed in terms of CO₂ equivalence (CO₂-e). According to a Victorian report* the GWP of some greenhouse gases over a 100 year timeframe relative to CO₂ (defined as having a GWP of 1) is:

Gas	GWP
Carbon dioxide - CO ₂	1
Methane - CH ₄	21
Nitrous oxide - N ₂ O	310
Carbon tetrachloride - CF ₄	6,500
The perfluorocarbon: C ₂ F ₆	9,200
The hydrofluorocarbon: HFC-23	11,700
Sulfur hexafluoride - SF ₆	23,900

Table 1. * Source: Report on Climate Change and Greenhouse Gas Emissions in Victoria, Victorian Department of Sustainability and Environment 2012

In 2006 one estimate of the greenhouse gas emissions for the state of Victoria was:

Gas	2006 emissions in kilotons (kt)
Carbon dioxide - CO ₂	96,938
Methane - CH ₄	834.4
Nitrous oxide - N ₂ O	14.72
Carbon tetrachloride - CF ₄	Detailed kt data for anthropogenic gases not available but for all these gases the total estimated CO ₂ -e is 1,277 kt.
The perfluorocarbon: C ₂ F ₆	
The hydrofluorocarbon: HFC-23	
Sulfur hexafluoride - SF ₆	

Table 2. * Source: Report on Climate Change and Greenhouse Gas Emissions in Victoria, Victorian Department of Sustainability and Environment 2012

13. What is the total 2006 estimated CO₂-e for Victoria? (2 Marks)

- Approximately 99014 kt
- Approximately 98215 kt
- Approximately 120300 kt
- Approximately 119023 kt
- Cannot be calculated because the data is incomplete.

14. Ariel Windlass and his laboratory partner Gayle Snowdon are concerned local pig farmers are creating too much greenhouse gas by wastefully burning off excess methane production from flare towers rather than venting the methane to the atmosphere. Their teacher has explained that water vapour is not counted as a greenhouse gas because it does not stay in the atmosphere for very long and over the long term its atmospheric concentration is in equilibrium. After studying the chemistry involved they correctly conclude:

- a. Burning methane is the least damaging option because farmers are creating CO₂ but at 21 times less greenhouse impact because $\text{CH}_4 + 2\text{O}_2 \Rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$
- b. Burning methane is the least damaging option because farmers are creating CO₂ but at 21 times more greenhouse impact because $\text{CH}_4 + 2\text{O}_2 \Rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$
- c. Venting methane is the least damaging option because farmers are creating CO₂ but at 21 times more greenhouse impact because $\text{CH}_4 + 2\text{O}_2 \Rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$
- d. Venting methane is the least damaging option because farmers are creating CO₂ but at 21 times less greenhouse impact because $\text{CH}_4 + 2\text{O}_2 \Rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$
- e. Burning methane makes no difference because farmers are creating CO₂ at the same rate as destroying CH₄ because $\text{CH}_4 + 2\text{O}_2 \Rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$

15. Ariel Windlass has decided to act local while thinking global by encouraging his local community to reduce greenhouse gas emissions. Living in Victoria, he has decided to use the Victorian data provided above as a reference. Of the options open to him, which one is most likely to reduce greenhouse emissions, in CO₂-e terms, the most? **(2 Marks)**

- a. Convincing his family and several others to install solar hot water, reducing CO₂ emissions by (at most) 3.0 t per year in total.
- b. Convincing his family and 60 others to install aerobic compost heaps, reducing CH₄ emissions by 0.0518 t per household per year.
- c. Convincing a local pig farmer to anaerobically produce 4 kt of CH₄ annually and burn it to make electricity to run the farm (saving an extra 25% of the CO₂-e produced in lower power bills).
- d. Convincing a local pig farmer to anaerobically produce 4 kt of CH₄ annually and burn it to keep the pigs warm (they have always been in cold pens until now).
- e. Convincing 10 local vegetable farmers to change fertilizer use and consequently each reduce N₂O production by 0.045 kt per year.

16. Wind is:

- a. Air moving to equalise variations in atmospheric pressure from regions of high pressure to regions of low pressure
- b. Air moving to equalise variations in atmospheric pressure from regions of high elevation to regions of low pressure
- c. Air moving to equalise variations in atmospheric pressure from regions of low elevation to regions of high pressure
- d. Air moving to equalise variations in atmospheric temperature from regions of high pressure to regions of low pressure
- e. Air moving to equalise variations in atmospheric pressure from regions of low pressure to regions of high pressure

17. Ozone in Earth's stratosphere filters out most dangerous ultraviolet radiation from light, protecting life on the surface from radiation damage. Ozone in the stratosphere is mostly formed by which process?

- a. Photochemical reactions producing ozone from methane
- b. Volcanic eruptions
- c. Photochemical reactions producing ozone from oxygen
- d. Photochemical reactions producing ozone from chlorofluorocarbons
- e. Photochemical reactions producing ozone from nitrogen

18. Banded Iron Formations are iron-oxide rich sedimentary rocks that formed around 2 billion years ago. One part of the explanation for these formations is that the ancient atmosphere contained no oxygen. This enabled Banded Iron Formations to develop because:

- a. Large amounts of Fe^{2+} could accumulate in the oceans prior to a precipitation event
- b. Large amounts of Fe^{3+} could accumulate in the oceans prior to a precipitation event
- c. Large amounts of O^{2+} dissolved in the oceans enabled a precipitation event
- d. Large amounts of Fe_2O_3 could accumulate in the oceans prior to a precipitation event
- e. Oxygen inhibits in the precipitation of Banded Iron Formations

19. Which sentence best describes an aquifer:

- a. A layer of soil or rock that has relatively higher porosity and lower permeability than the surrounding layers, enabling usable quantities of water to be extracted.
- b. A layer of soil or rock that has relatively higher porosity and permeability than the surrounding layers, enabling usable quantities of water to be extracted.
- c. A layer of soil or rock that has relatively lower porosity and/or permeability than the surrounding layers, limiting the movement of groundwater through it and the capacity to extract useable quantities of water.
- d. A layer of soil or rock that has relatively higher porosity and/or permeability than the surrounding layers, limiting the movement of groundwater through it and the capacity to extract useable quantities of water.
- e. A layer of soil or rock that has relatively lower porosity and higher permeability than the surrounding layers, enabling usable quantities of water to be extracted.

20. Choose the sentence that best summarises the role plants play in the water cycle:

- a. Plants take up water from the ground and aid in its storage in deep aquifers.
- b. Plants absorb as much water as they release so their role in the water cycle is neutral.
- c. Plants take in water from the rain and release it as vapour into the geosphere.
- d. Plants take up water from the ground and release it as vapour into the aquifer.
- e. Plants take up water from the ground and release it as vapour into the atmosphere.

21. In Figure 3 below the concentration of 3 groundwater pollutants is plotted over time at a point 5m from where they were introduced. If a relative concentration of 0.1 is a safe-use level for all 3 chemicals in the water, at what point in time would it be first safe for a farmer to use the water at the measurement location?

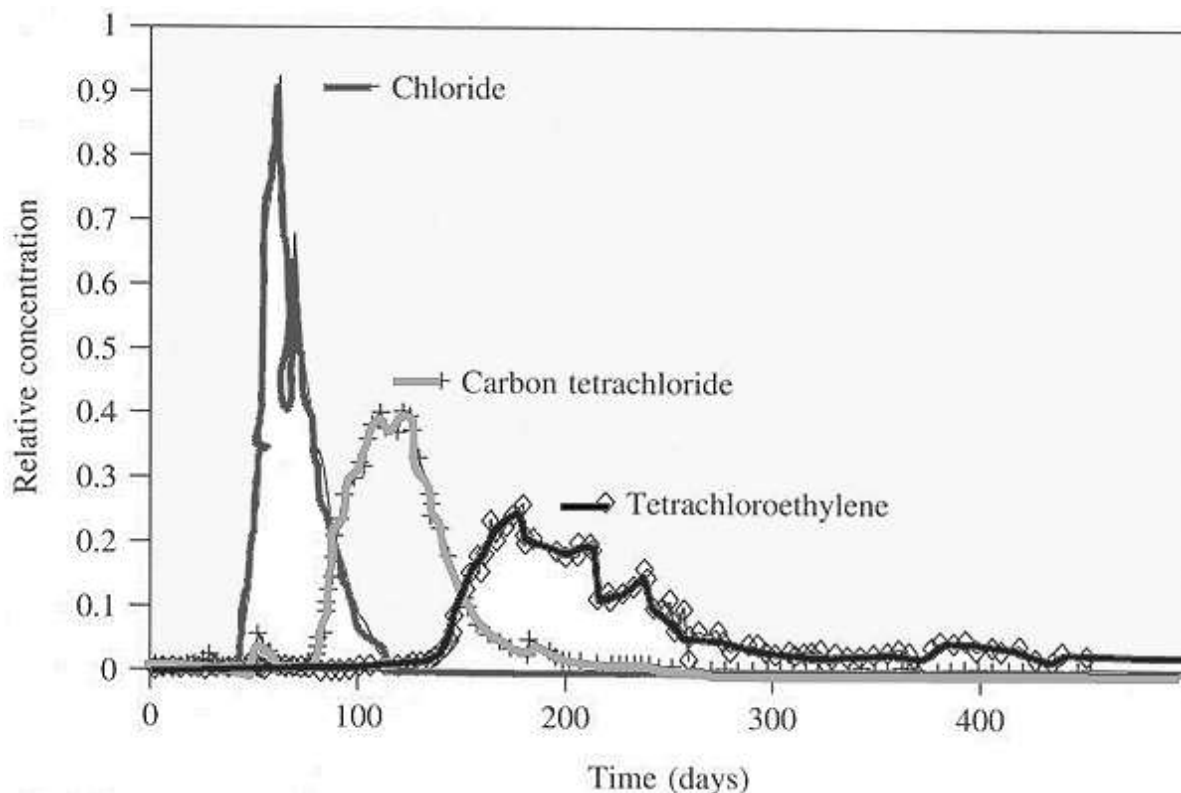


Figure 3. Source: Roberts, Goltz & Mackay, Water Resources Research 22:13, 1986

- a. 100 days
- b. 150 days
- c. 250 days
- d. 400 days
- e. Never

22. Saltation is a process of:

- a. Evaporation in a playa lake
- b. Moving sediment in a river with a bouncing motion off the bottom
- c. Windblown salt crystals causing abrasion of surface boulders to form ventifacts
- d. Faking a gold find by shooting gold dust into a mine's wall
- e. Sediment moving in a river by being rolled along the bottom

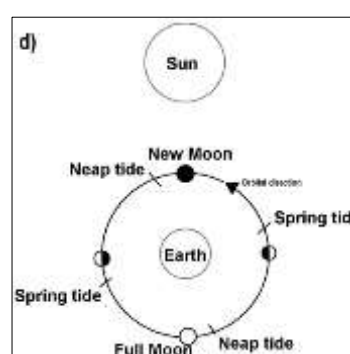
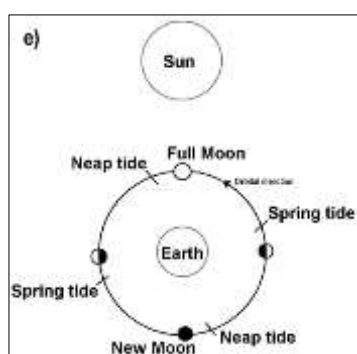
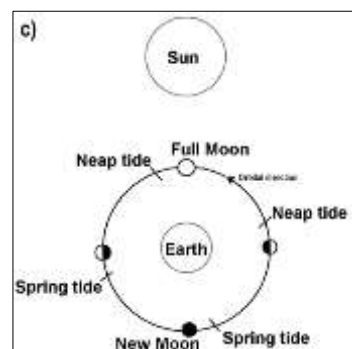
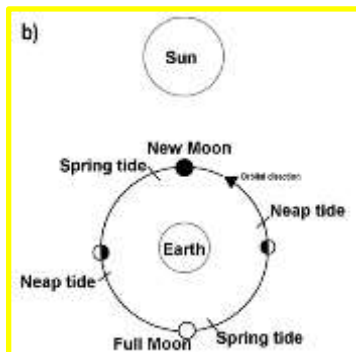
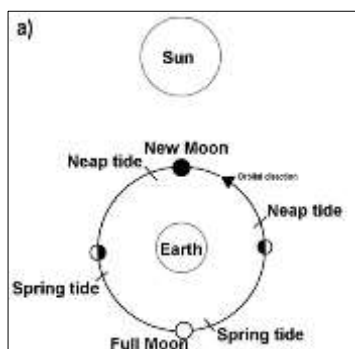
23. Limestone caves are spectacular spaces that have developed within layers of rock because of the interaction of water and limestone. Which sentence most correctly describes a chemical interaction that commonly leads to cave formation?

- a. Caves in limestone are the result of slightly alkaline water chemically dissolving the limestone.
- b. Caves in limestone are the result of the water table passing up and down through the limestone as the climate changes.
- c. Caves in limestone are the result of slightly acidic water chemically dissolving the limestone.
- d. Caves in limestone are the result of water mixing with bat guano to create a slurry that dissolves the limestone.
- e. Caves in limestone are the result of water flowing through aquifers, physically eroding the soft limestone rock and slowly hollowing out the landscape.

24. A common problem in modern Australia is Dryland salinity. This is often caused by the removal of deep rooted native plants so that shallow rooted crops can be planted. Why would replacing native plants with agricultural crops lead to Dryland salinity?

- a. Shallow rooted plants generate less evapotranspiration. This allows more rainfall to flush through the soil taking stored salt with it into the water table. The extra water passing through the soil causes the watertable to rise towards the surface, bringing the salt with it. The salt poisons the soil for plant growth and in some places reaches the surface where it creates salt scalds as the water evaporates.
- b. Dryland salinity is a misleading term as the salt scalds only develop in swampy ground where the watertable rises to the surface because deep rooted plants create a path to the surface with their roots. Shallow rooted plants make it easier for the water to evaporate and salt scalds to develop.
- c. Shallow rooted plants generate more evapotranspiration. This forces water towards the surface and flushes salt out of the soil and onto the surface. The watertable falls, leaving behind salt that poisons the soil for plant growth and in some places creates salt scalds in the soil profile.
- d. Shallow rooted plants generate more evapotranspiration. They also prevent water flushing salt out of the soil and into the water table. The watertable rises towards the surface as more water is lost to evapotranspiration, poisoning the soil for plant growth and in some places reaching the surface where it creates salt scalds as the water evaporates.
- e. Shallow rooted plants hold the soil together ineffectively. This allows the watertable to rise towards the surface, waterlogging the soil. In some places water reaches the surface where it creates salt scalds as the water evaporates.

25. High and low tides are caused mainly by the Moon. As the Moon orbits the Earth the rotation of the Earth combined with gravity produce tidal variations. Which diagram correctly shows the arrangement of the Earth, Moon and Sun and the timing of the Spring and Neap tides?



SECTION B: WRITTEN ANSWER QUESTIONS

ANSWER IN THE SPACES PROVIDED

Use the following information and diagram to answer questions 26 & 27.

High-resolution Galileo images of Jupiter's icy moon Europa show linear, curved, and wedge-shaped bands crisscrossing the surface. Europa is the sixth largest moon in the solar system and about the size of the Earth's Moon. Impact craters, like those all over Earth's Moon, are rarely seen on Europa.

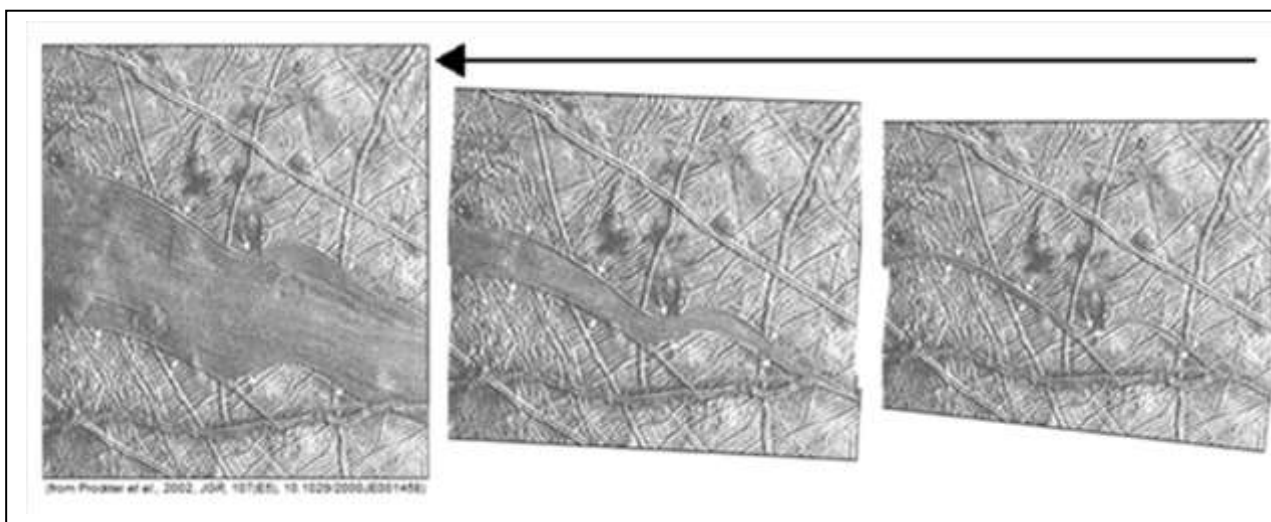


Figure 4. Based on images from Prockter, L. M., J. W. Head III, R. T. Pappalardo, R. J. Sullivan, A. E. Clifton, B. Giese, R. Wagner, and G. Neukum (2002) Morphology of European bands at high resolution, *Journal of Geophysical Research*, 107(E5), 10.1029/2000JE001458 and featured on the web at www.psrcd.hawaii.edu/Nov02/EuropeanBands.html

In Figure 4 above, the image on the left is how part of Europa's surface looks now. By aligning the various ridges across either side of the flatter looking broad band in the middle area researchers have concluded that the band has not always existed. The image on the right shows how Europa may have looked before the band began to develop. The middle image is how the area might have looked in transition.

While it is thought Europa is a rocky planet with an iron core it has a surface made of frozen water so solid that it behaves like granite on Earth (the surface temperature is -160°C to -220°C equator to poles). However, it is also thought to have an underlying mass of liquid water thanks to tidal heating of the interior caused by gravitational squeezing as Europa orbits Jupiter.

26. Select the scenario (a, b, c, d or e below) that best explains why impact craters are rare on the surface of Europa. Write the letter of your choice (a, b, c, d or e) in the box provided.

(1 Mark)

- a. Meteors always miss Europa because it has no magnetic field.
- b. Dynamic surface processes destroy the evidence of impacts over time.
- c. There are craters on Europa, they are just long and skinny for unknown reasons.
- d. Meteors are so hot they melt through the icy crust and leave no trace.
- e. Most meteors are made of ice so there should be no discernable difference before and after impact.

The scenario that best explains why impact craters are rare in the surface of Europa is:

B

27. Considering the images of Europa provided in Figure 4 on page 18, what dynamic Earth process (from a, b, c, d or e below) would best explain the change from Right to Left images in Figure 4 assuming such processes also operate on Europa? **(1Mark)**

- a. Subduction (driven by water convection in this case)
- b. Transverse faulting
- c. Hot spot volcanism (from water upwelling in this case)
- d. Magnetic reversal
- e. Mid-Ocean-Ridge sea-floor spreading (driven by water upwelling and convection in this case)

The dynamic Earth process that would best explain the change, assuming such processes also operate on Europa, is: **E**

28. In your own words and with the aid of a labelled diagram, explain what other dynamic Earth processes you would expect to find on Europa given your answer to question 27? Measurements indicate Europa is not expanding. **(4 Marks)**

Write your answer and draw your diagram here:

All of the answers should relate to Plate Tectonics. Diagrams that demonstrate and words to match that are acceptable are:

- ⇒ Subduction
- ⇒ Transverse faulting
- ⇒ MOR style spreading
- ⇒ Hot Spot volcanism trails
- ⇒ Subduction associated volcanism
- ⇒ Mantle / subcrustal convection

29. Roxanne and Wade have been studying minerals and mineral systems. On their field trip to Shattered Knoll they collected a large variety of minerals. They can identify many minerals in their collection but several are quite rare and they sought help from local mineral collector Ken Hill for correct identification. They created a table, based on their collection, and have challenged their peers – including you – to complete it.

Complete Table 3 below by writing the missing information in the eight grey areas. **(3 Marks)**

Table 3.

Mineral	Cleavage	Industrial use	Chemical formula
Garnet (almandine)	None ALSO accept indistinct	Abrasive → or words that mean this NOT jewellery since it is to do with industrial uses	$\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$
Galena	3 perfect ALSO accept 3 forming cubes	Ore of lead	PbS
Sphalerite	Perfect in multiple directions	Primary modern day ore of zinc	ZnS (will also accept [Zn,Fe]S)
Amazonite (green lead-bearing microcline feldspar)	2, one perfect	None keeps mineral collectors happy	KAlSi_3O_8 with traces of Pb and H_2O
Raspite	1 perfect	None makes mineral collectors rich if they find a big one	PbWO_4

Use the following information and graph to help answer questions 30 to 34.

Mud rocks, where the dominant minerals are aluminium-rich clays, are often called Pelites. When metamorphosed these pelitic rocks produce a variety of minerals including aluminium-rich minerals. Researchers have conducted many laboratory experiments in which pelites were exposed to variable pressure and temperature conditions. Figure 5 below shows some key reactions in the metamorphism of pelitic rocks. The x-axis shows the temperature and the y-axis the pressure, which can be converted to depth of the rocks within the crust. In a stable continental crust, pressure and temperature both increase with increasing depth in a regular way as shown by the curve labelled *Average temperature in the crust*. The average thickness of continental crust in Australia is about 35 km and thus in areas that are not disturbed by any tectonic activity the temperature at the base of the continental crust is about 600°C. Pelitic rocks begin to melt in the presence of an aqueous fluid along the P-T curve labelled *initiation of partial melting*.

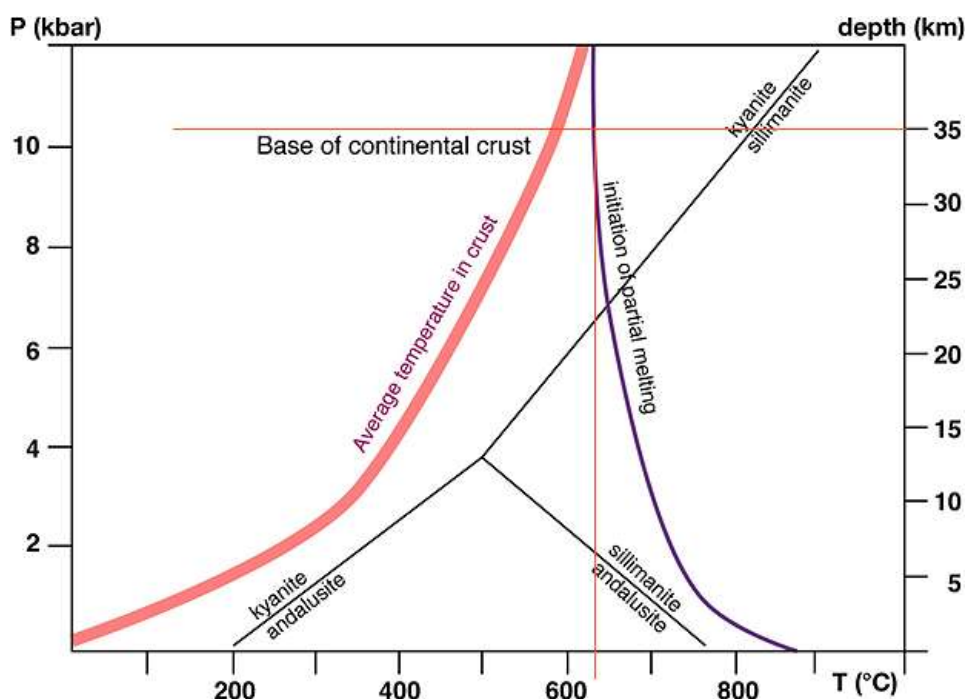


Figure 5. P-T graph for stable continental crust in eastern Australia together with the stability fields of kyanite, sillimanite and andalusite.

30. Using Figure 5 above for reference; at about what temperature does pelitic rock at the base of the continental crust in a stable crustal environment begin to melt? **(1 Mark)**

- a. approximately 600°C
- b. approximately 880°C
- c. approximately 640°C
- d. approximately 500°C
- e. it never melts at that depth

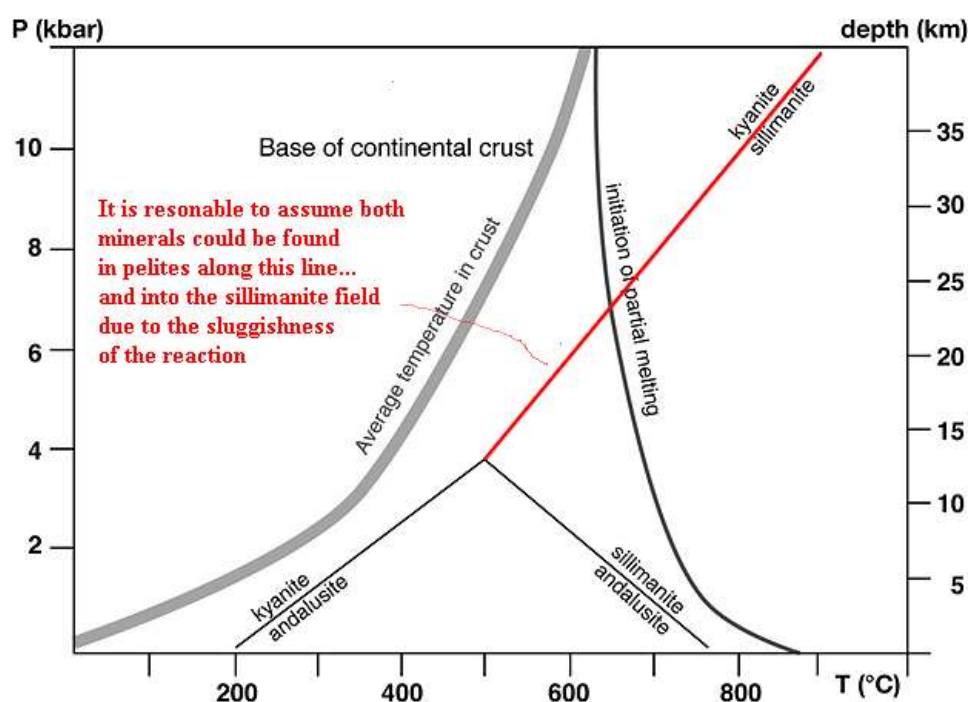
Write your choice (from a, b, c, d or e) here:

C

31. Using Figure 6 below for reference; is it possible to find pelitic rocks that contain both kyanite and sillimanite? If so, under what temperature-pressure conditions would this occur? Explain your answer with reference to the graph provided, marking the graph as you see fit [ensure all marks have words to explain their meaning]. **(4 Marks)**

Write your explanation here and annotate the graph in Figure 6 below as you see fit:

See answer in the diagram below



Use the following information and table to help answer questions 32 to 34.

Around the township of Kantmella, located in a stable area of eastern Australia, some of the rocks visible in outcrop appear to have undergone some melting. This is indicated by numerous small veins and dykes and an intensively interlayered rock comprising once molten parts and residual parts. This rock is called a migmatite. As part of a field trip, student Sandy Shore has also found a number of other metamorphic rocks, each with a characteristic mineralogy and texture. Mapping suggests they are all derived from the progressive metamorphism of mudstones and associated sandstones.

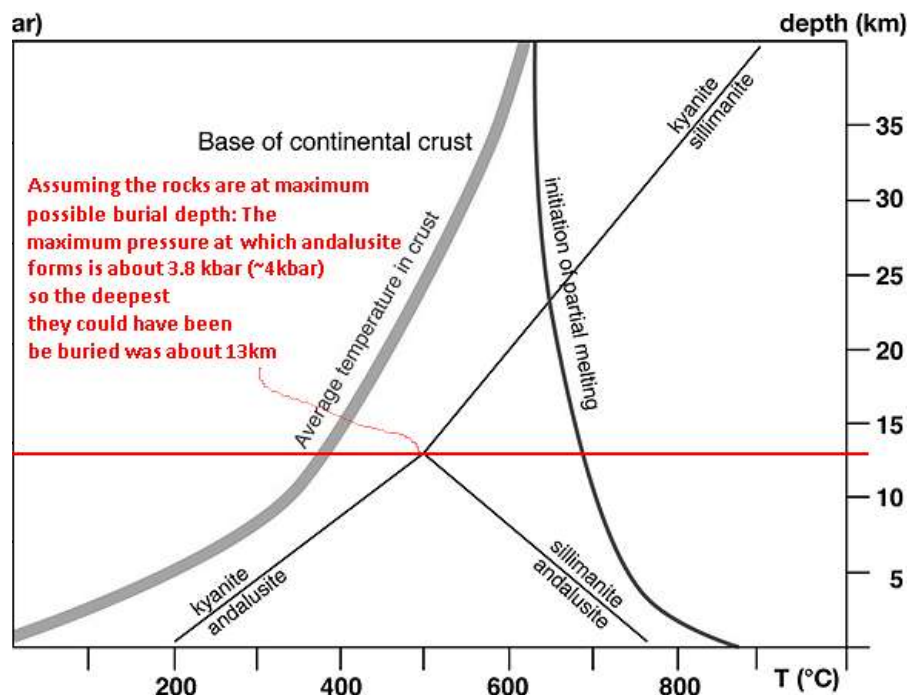
Rock type	Mineral assemblage	Key mineral	Texture
Slate	Chlorite Muscovite Quartz	Chlorite	Slaty cleavage.
Phyllite	Biotite Chlorite Muscovite Quartz	Biotite	Foliated.
Schist	Andalusite Biotite Cordierite Muscovite Quartz	Andalusite	Pronounced foliation.
Gneiss	Biotite Cordierite Potassium Feldspar Muscovite Quartz Sillimanite	Sillimanite	Segregation layering of light and dark minerals. Weak foliation
Migmatite	Biotite Cordierite Plagioclase Feldspar Potassium Feldspar Quartz Sillimanite		Veins, dykes and interlaying of melted and residual materials.
Granite	Biotite Cordierite Plagioclase Feldspar Potassium Feldspar Quartz Sillimanite		No foliation.

Table 4. Rocks and found in the Kantmella area.

The Kantmella rocks obtained their maximum burial depth when the schist formed.

32. Using the known mineralogy of the Kantmella metamorphic rocks with Table 4 on page 24 for reference; what is the maximum pressure the Kantmella pelitic rocks could have experienced during the formation of the schist (to the nearest whole number)? Explain your answer with reference to Figure 7 below, marking the graph as you see fit [ensure all marks have words to explain their meaning]. (3 Marks)

Write your explanation here and annotate the graph in Figure 7 below as you see fit:

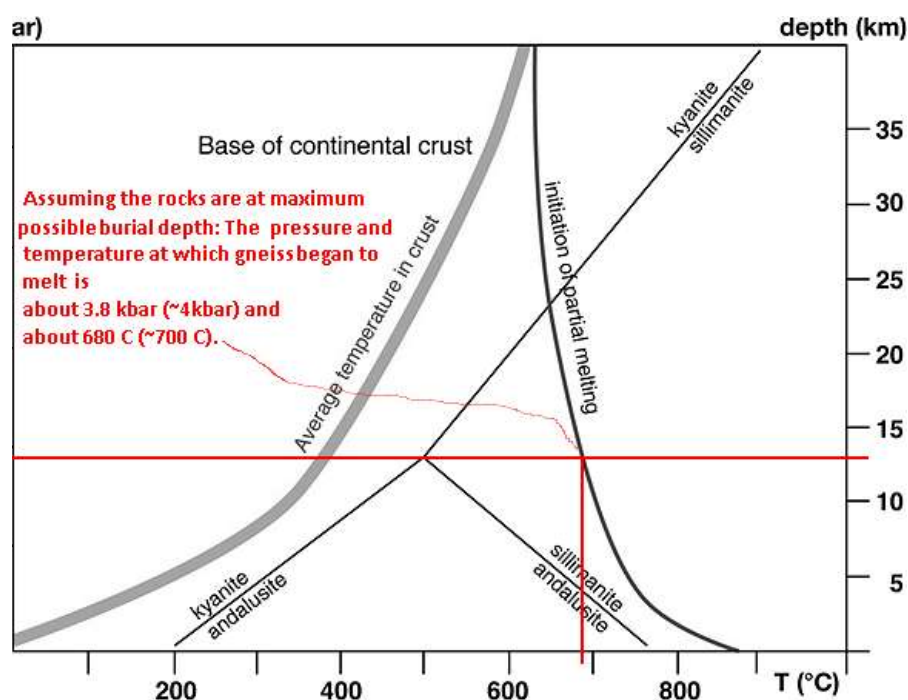


The schist contains andalusite, so it must have formed at pressures at or below the triple point. This limits the maximum possible pressure to 3.8 kbar – 4kbar to the nearest whole number – and thus to a depth of around 13km.

33. Assuming the rocks were under the maximum possible pressure when rock melt began, at what temperature did this occur and which rock underwent melting? Explain your answer with reference to the Table 4 on page 24 above and Figure 8 below, marking the graph as you see fit [ensure all marks include a key to explain their meaning]. **(4 Marks)**

Write your explanation here and annotate the graph in Figure 8 below as you see fit:

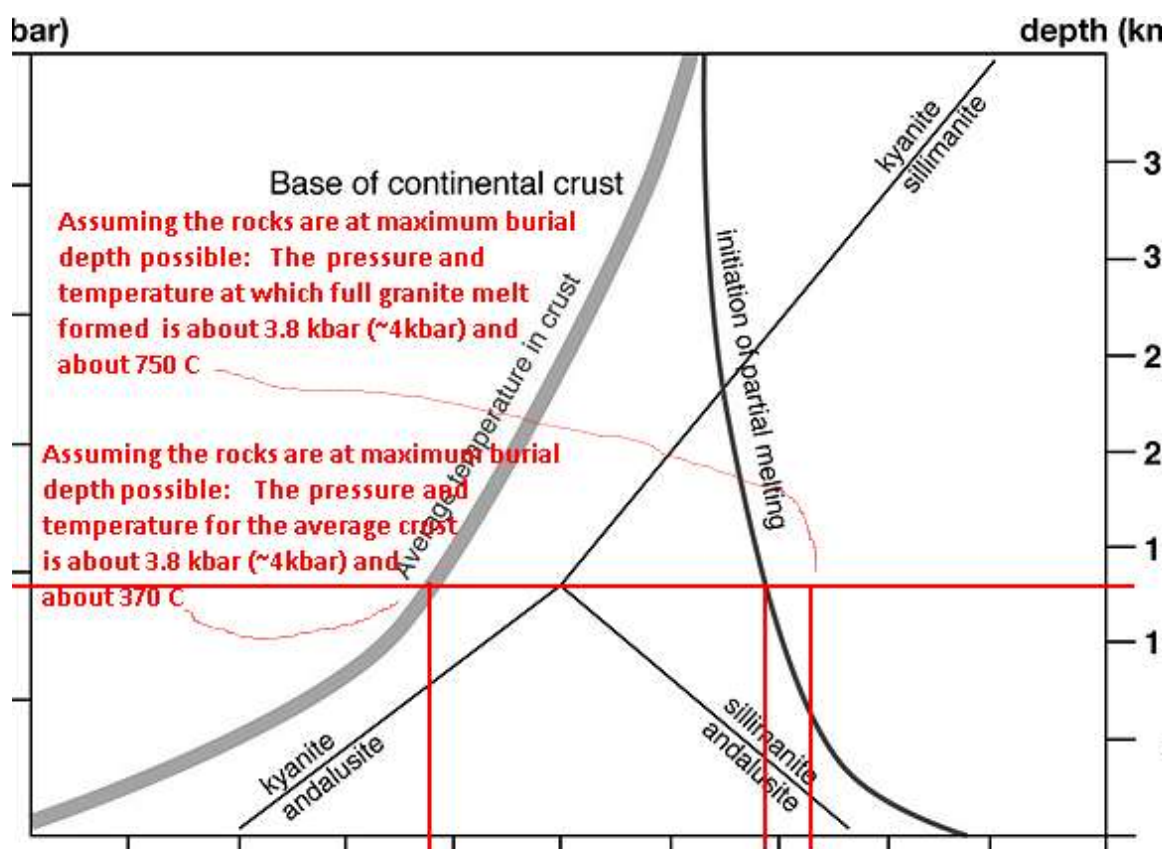
The rocks in the partial melting zone contain sillimanite, so the rock that underwent partial melting to form migmatite was the gneiss as it is the only metamorphic rock containing sillimanite. The gneiss contains sillimanite and therefore must have formed at temperatures greater than 500°C but since we are told the burial depth was at maximum during schist formation the pressure remains constant and at most 3.8 kbar so the maximum temperature at which partial melting could occur must be close to 700 °C, say 680°C.



34. The Kantmella granite has the same mineralogy as the gneiss. Mapping of all the rocks also suggests it formed from the total melting of the gneiss rather than from a foreign intrusion and was therefore not responsible for the metamorphism. Assuming the rocks are at maximum possible burial depth and total melt occurs about 70°C after partial melt begins; how does the temperature of full granite melt compare to the average temperature in the crust at that depth and what is the best explanation for any discrepancy between the two? **(5 Marks)**

Write your explanation here and annotate the graph in Figure 9 below as you see fit:

The most reasonable explanation for this large temperature difference is that the metamorphic terrain at the time must have been much hotter. The most likely scenario for a hotter crust, given it is not from an intrusion of the granite melt itself, is a regional metamorphic event. Such events might include involvement in subduction zone tectonics which are always much hotter than the crust in other areas.



Use the following information and map to help answer questions 35, 36, 37 & 39.

Students Roxanne Stone and Wade Beachley have also been on a field trip to the Kantmella region. They mapped the early Palaeozoic Kantmella Metamorphics but in one part of their field area the metamorphic basement rocks are overlain by younger rocks. The vertical relief on this area is too slight to show on this map. In this area they identified a folded terrain overlain by a more modern horizontally bedded suite of sediments. They found fossils in units B and J that are definitely Permian brachiopods, bryozoans and corals. The base of unit G contains sub-economic amounts of alluvial gold. There is no gold in Unit I. A literature search found reference to early Pleistocene fossils in Unit K and a Miocene kangaroo jaw unearthed in Unit I as well as other Miocene vertebrate fossils in Units D & A. The top of unit A contains cross-bedding that has been truncated by erosion. Elsewhere in the region there are dolerite intrusions that are mid-Carboniferous in age. Figure 10 below is a copy of the map they produced:

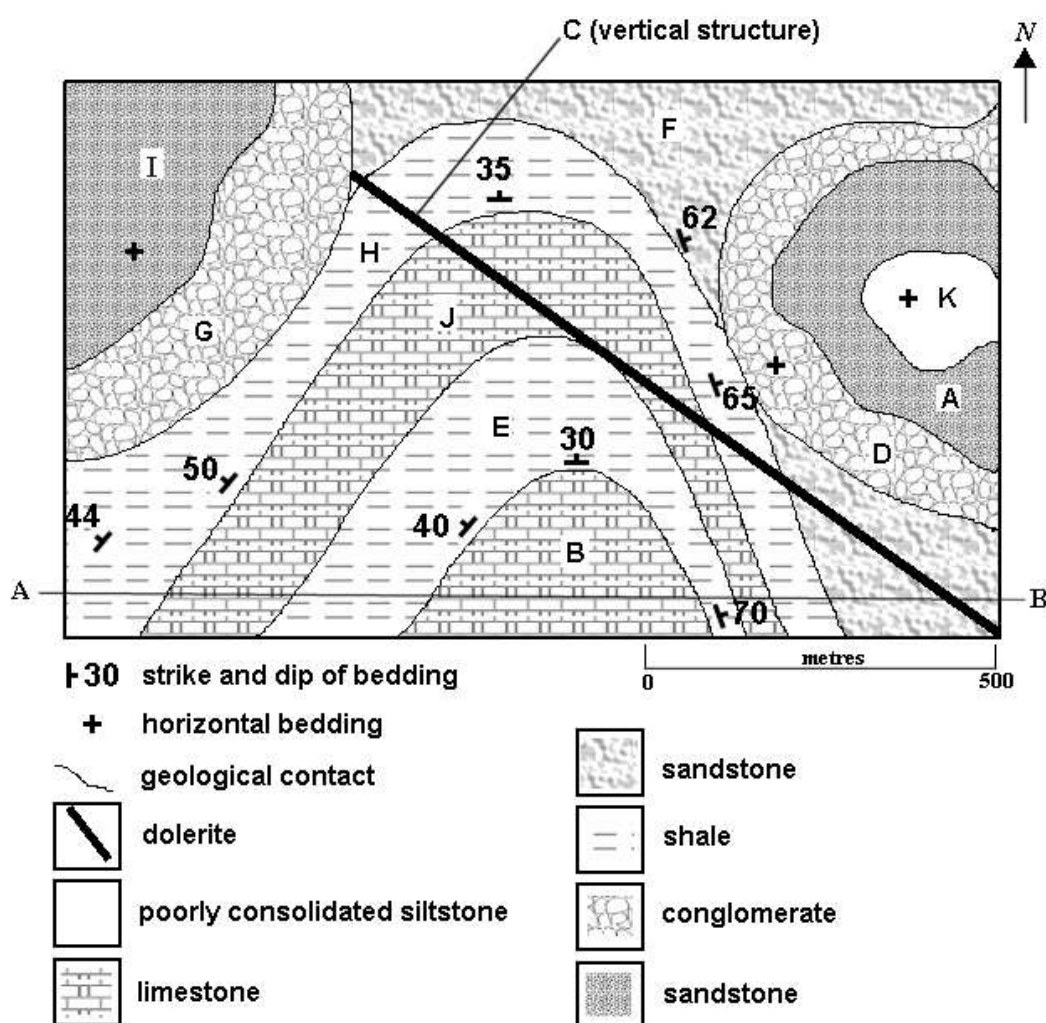


Figure 10.

35. Luckily, before they submitted their map for assessment, Roxanne realised they had omitted to mark in the unconformities they found. Using the map provided in Figure 11 below, mark in all the unconformities they left out, indicating for each whether they are a non-conformity, a disconformity or an angular unconformity. Explain your reason for naming each type of unconformity you marked on the map. (3 Marks)

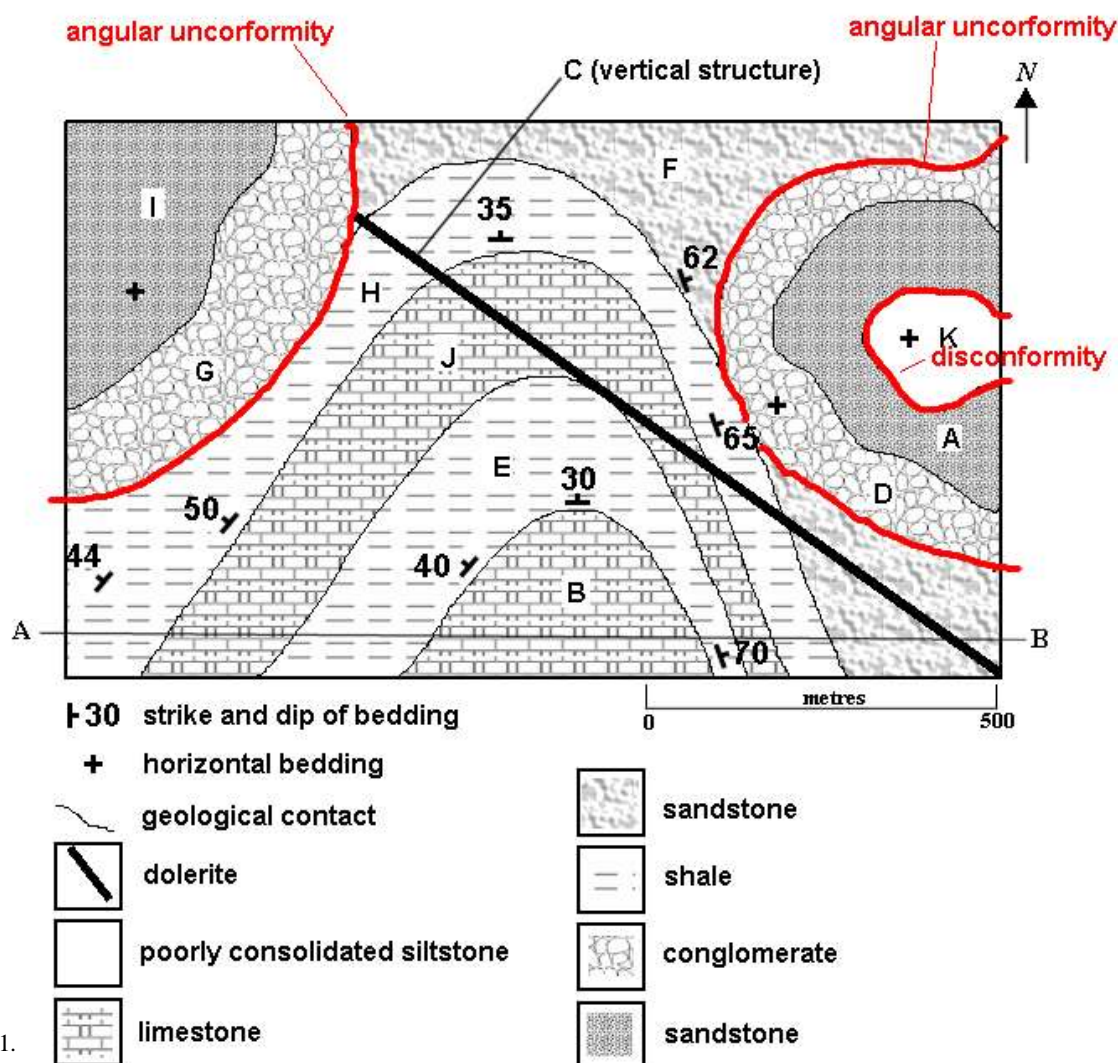


Figure 11.

Write your reasons here:

There is an angular discordance between the folded sequence of Permian rocks and the overlying horizontal sediments of Miocene age. This means the contact is an angular unconformity.

Units A and K do not have an angular discordance between them but unit A is Miocene and K is early Pleistocene so there is a large temporal gap. Unit A also has truncated cross-bedding at the top, indicating an erosion surface. This indicates the contact between these units is a disconformity.

36. Explain why the dolerite in the mapped area cannot be mid-Carboniferous in age despite the dolerites elsewhere in the region being that age. Could it be a Pleistocene intrusion? (3

Roxanne and Wade positively identified Permian fossils in the folded sediments. The dolerite dyke cross-cuts these sediments and the folding event so it is much younger than the Permian age of the sediments and therefore cannot be Carboniferous. It has been exposed by erosion and overlain by Miocene sediments so it must be of post-Permian and pre-Miocene age and thus cannot be as young as the Pleistocene.

Marks)

Use the following information to help answer questions 37.

Wade and Roxanne found further information relating to their map on page28:

- Units B & J contains fossil corals and fossils of other shallow water marine organisms
- Unit K contains trace fossils consistent with flood plain deposits
- Units E & H contain microfossils consistent with a deep marine environment
- Units D & G are both Miocene and further mapping reveals they are the same unit. The conglomerate pebbles are well rounded and have a Permian and early Palaeozoic provenance
- Units A & I contain cross-bedding consistent with deposition from a meandering river
- Unit F contains interbedded shales with fossils of coastal marine species and shales with abundant fossil leaves and other completely carbonised plant material
- Sedimentary structures in the Permian limestone indicate it is not overturned and the folds are upright.

37. Write a geological history of the mapped area, using the map (Figure 10 page 28) and other information provided by Roxanne and Wade to assist with telling the story. **(10 Marks)**

Starting with Unit B, the oldest in the sequence.

B: Deposition during the Permian of carbonate rich sediments in a shallow marine environment where corals, bryozoans and brachiopods thrive.

E: Marine transgression – water level deeper – deposition of mud, forming fossiliferous shale.

J: Marine regression – water level drops – return to shallow marine carbonate deposition.

H: Another transgression – return to deep water deposition of fossil rich muds

F: Marine transgression with transgression/regression forming coastal sediments rich in coastal marine species and plant materials typical of coastal marine swamps.

POST Permian folding event, forming a plunging anticline in this area

C: intrusion of vertical dolerite dyke

POST intrusion erosion event exposing folded bedding and dyke

Deposition of G-D conglomerate during the Miocene, most likely from a river with animals living dying on the banks and sourcing material from the folded Permian rocks and the Kantmella Metamorphics – including a source containing gold

Deposition from I-A from a meandering river with animals living dying on the banks

POST Miocene Erosion of I-A

Deposition of K on a flood plain during the Pleistocene

POST early Pleistocene erosion to the present day

38. In relation to the mapped area and assuming there are gold rich veins in the basement rocks of the region, why are there large grains and pebbles of gold in the Miocene conglomerate but not the Miocene sandstone? **(2 Marks)**

Gold is a heavy mineral and when eroded out of host rocks and moved by flowing water it tends to be entrained in very coarse sediments because hydro-dynamically it behaves like a larger grain of rock. When the water velocity needed to move the gold and large rock grains drops the gold falls to the bottom with the coarse sediments and is buried with those sediments. Only very tiny gold flecks might be expected in the sandstone.

39. Wade thinks they should label the folded structure in the mapped Permian rocks shown in Figure 10 on page 28. Of the choices a, b, c, d or e below which label should he use? **(1 Mark)**

- a. A syncline
- b. A plunging syncline
- c. An anticline
- d. A plunging anticline
- e. A fold belt

Write your choice (from a, b, c, d or e) here:

D

40. Wade and Roxanne also have to draw a cross-section through the map using the line marked A—B on the map in Figure 10 on page 28. Which of the rough draft options below is the closest to how their cross-section should look? Answer in the space on the following page giving at least one reason for accepting or rejecting each of the four options: **(4 Marks)**

Option A

Option B

Option C

Option D

Option a) is the most correct. It shows the dyke as vertical. It shows the fold as asymmetric with the west limb dipping steeper than the east limb. Unit B thickness is unknown.

Option d) is wrong because the fold is actually an anticline and the units have been joined to make a syncline in this cross-section.

Option c) is wrong because the limbs of the folds are not near vertical as shown in this cross-section (or it is not an isoclinal fold as implied by this cross-section).

Option b) is wrong because the dyke is vertical but in this cross-section it is shown with a distinct dip.

Use the following information to answer question 41.

Jupiter is 317.8 times more massive than the Earth with a radius 11.2 times that of Earth. When looking for exoplanets, researchers have found many planets as large as Jupiter or larger and often rate them in terms of the mass of Jupiter (M_{Jup}) and the radius of Jupiter (R_{Jup}). However, the aim of some research is to find Earth-like planets that may harbour life or that one day could be visited or even colonised by humans (assuming we one day develop some form of faster than light travel!). Based solely on size, four of the most interesting, found using the Kepler space observatory, are:

Planet	Mass (M_{Jup})	Radius (R_{Jup})	Period (day)
Kepler-92 c	0.0179	0.233	26.723
Kepler-138 c	0.00318	0.14364	23.008933
Kepler-307 c	0.0038	0.25	13.084
Kepler-78 b	0.00532	0.10706	0.35500745

Table 5.

Acceleration due to gravity, g , of a mass [in this case a planet] is directly proportional to the mass of the planet and inversely proportional to the square of the distance you are from the centre of the planet times G , the Universal gravitational constant.

41. Standing on the surface, on which of the four planets listed in Table 6 below would you weigh closest to what you weigh on Earth? Show your workings and explain your reasoning. Note: Table 6 is the same as Table 5 on page 34. **(4 Marks)**

Planet	Mass (M_{Jup})	Radius (R_{Jup})	Period (day)
Kepler-92 c	0.0179	0.233	26.723
Kepler-138 c	0.00318	0.14364	23.008933
Kepler-307 c	0.0038	0.25	13.084
Kepler-78 b	0.00532	0.10706	0.35500745

Table 6.

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

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

$$g_{\text{planet}} = G \times M_{\text{planet}} / R_{\text{planet}}^2$$

$$G = 6.67 \times 10^{-11} \text{ Nm}^2\text{kg}^{-2}$$

$$M_{\text{Earth}} = 5.98 \times 10^{24} \text{ kg}$$

$$R_{\text{Earth}} = 6.37 \times 10^6 \text{ m}$$

Using the facts that Jupiter is 317.8 times more massive than the Earth with a radius 11.2 times that of Earth we can calculate:

Kepler-92 c has a M_{Earth} of 5.689 and R_{Earth} of 2.612

Kepler-138 c has a M_{Earth} of 1.0106 and R_{Earth} of 1.609

Kepler-307 c has a M_{Earth} of 1.2077 and R_{Earth} of 2.8

Kepler-78 b has a M_{Earth} of 1.6907 and R_{Earth} of 1.1991

Thus

$$g_{\text{Kepler-92 c}} = G \times 5.689 \times 5.98 \times 10^{24} / (2.612 \times 6.37 \times 10^6)^2 = \sim 8.2$$

$$g_{\text{Kepler-138 c}} = G \times 1.0106 \times 5.98 \times 10^{24} / (1.609 \times 6.37 \times 10^6)^2 = \sim 3.8$$

$$g_{\text{Kepler-307 c}} = G \times 1.21 \times 5.98 \times 10^{24} / (2.8 \times 6.37 \times 10^6)^2 = \sim 1.5$$

$$g_{\text{Kepler-78 b}} = G \times 1.69 \times 5.98 \times 10^{24} / (1.2 \times 6.37 \times 10^6)^2 = \sim 11.56$$

Since Kepler-92 c has g closest to that of Earth it is the planet on which I would weigh the closest to my Earth weight.

42. In 1969 musician Joni Mitchell recorded the song *Woodstock*. In the song, two of the lines she sings are:

... *We are stardust*

Billion year old carbon ...

Are both lines correct in a scientific sense? Explain your answer with reference to the formation of the solar system, you carbon-based life form you. **(4 Marks)**

In the early universe the first stars were composed of Hydrogen and some Helium. Nuclear fusion in stars produces heavier elements over time, up to and including Iron. The collapse of a large star can cause a supernova, forming a neutron star in the process. During the supernova even heavier elements can be formed by the immense temperatures and forces involved and a dust and gas cloud results – aka a solar nebula. It is material in the solar nebula, together with other interstellar material, such as clouds of hydrogen, which forms the next star and planets in orbit around the star. This means that any material that makes up a planet – including us – is formed mostly from the recombination of solar nebula dust generated by a supernova. YES – we are (mostly) star dust, Joni Mitchell was correct.

Most of the carbon present on Earth was sourced from the solar nebula that provided materials to form the solar system as we know it. The solar system formed about 4.6 billion years ago. However, some Carbon (^{14}C) forms from the interaction of ^{14}N in the upper atmosphere with cosmic rays. This radioactive carbon has a half-life of about 5700 years and enters the food chain by combining with oxygen to form CO_2 so some carbon in us is very young! The carbon in us is mostly stardust that is over 4.6 billion years old, so Joni Mitchell was mostly correct as to the order of magnitude but would have been more accurate to sing ...*4.6+ billion year old carbon!*

43. One aim in the search for extra-solar planets or exoplanets (planets orbiting stars other than the sun) is to find Earth-like planets that might harbour life. In order for life as we know it to exist there are a number of pre-conditions. One of these pre-conditions is the presence of liquid water.

Let's assume an Earth-size planet is found that is orbiting a star identical to the Sun. It is at the same distance as Earth is from the Sun. It has the same global albedo as the Earth with the same amount of incident solar radiation coming in.

What atmospheric gases would need to be present to enable the surface to have liquid water given it is so similar to Earth ? Explain your answer. **(2 Marks)**

In order for a planet that is the same as Earth in every other respect to be warm enough for liquid water to be present greenhouse gases such as CO₂, CH₄ and N₂O need to be present. If an Earth-like planet in the same orbit around a similar star had no greenhouse gases its global average temperature is likely to be below the freezing point of water and life as we know it could not evolve.

44. We know from observing the sky that the Sun, Moon and stars appear to move from east to west because of the rotation of Earth. Most artificial satellites also orbit in the same direction as the moon but appear to move from west to east. Explain this contrary

The satellites mentioned here are moving in the same direction as the Moon but do so faster than the Earth rotates whereas the Moon moves slower than the Earth rotates, thus giving the appearance to a ground based observer of moving in the opposite direction to the Moon.

behaviour. **(2 Marks)**

Use the following information to help answer questions 45 & 46.

The Mauna Loa Observatory (Hawai'i) is an atmospheric baseline station of the Earth System Research Laboratory. It monitors atmospheric CO₂ levels and the levels of other key gases. In the graph below is CO₂ data for 2010 through to the present. The grey saw-tooth data set in Figure 12 represents the monthly mean values, centred on the middle of each month. The other line represents the same data set, after correction for the average seasonal cycle. The mean atmospheric CO₂ levels at Mauna Loa are corrected for volcanic emissions and other local sources of extraneous CO₂.

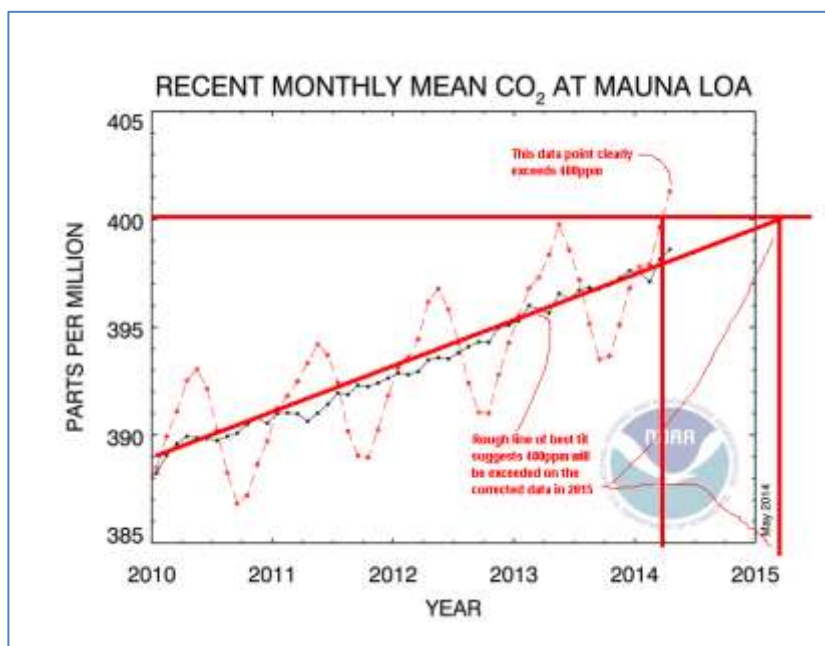


Figure 12. Data are reported as a dry air mole fraction defined as the number of molecules of carbon dioxide divided by the number of all molecules in air, including CO₂ itself, after water vapour has been removed. The mole fraction is expressed as parts per million (ppm). Example: 0.000400 is expressed as 400 ppm. NOTE: The last data point on this graph is for April 2014. Source: <http://www.esrl.noaa.gov/gmd/ccgg/trends/mlo.html>

45. Has the mean local atmospheric CO₂ level exceeded 400ppm at any time and if so when did it occur and if not when might it occur? Explain your reasoning. (2 Marks)

Monthly mean values indicate 400ppm was exceeded for April or March 2014

After correction for the average seasonal cycle, the CO₂ values are still below 400ppm. In roughly putting in a line of best fit to establish a trend line for the corrected values it is reasonable to say 400ppm will not be reached in 2014 but could be reached sometime in 2015

46. What is the likely cause of the seasonal variation seen in the CO₂ data set in Figure 13 below?

Hawai'i is in the central pacific but receives air via the trade winds from North America, Europe and Asia – all the northern hemisphere land masses. CO₂ values peak in May and are at a minimum in Sept-October. This corresponds to the peak being at the end of Spring and the minimums being at the end of Summer - beginning of Autumn.

Plant photosynthesis uses up CO₂ so during the growing season [mostly Summer]. CO₂ use by photosynthesis exceeds CO₂ production by respiration at this time so CO₂ values should decline over summer.

In the northern hemisphere photosynthesis dramatically reduces over winter but plant and animal respiration continues to produce CO₂ so during autumn and winter CO₂ values should rise until warm weather returns and use exceeds production again which happens around the end of Spring.

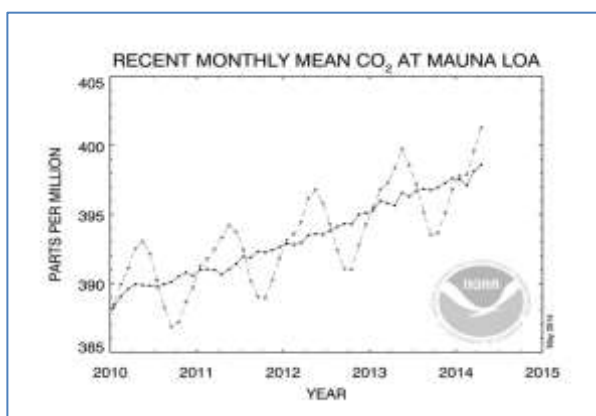


Figure 13. Data are reported as a dry air mole fraction defined as the number of molecules of carbon dioxide divided by the number of all molecules in air, including CO₂ itself, after water vapour has been removed. The mole fraction is expressed as parts per million (ppm). Example: 0.000400 is expressed as 400 ppm. NOTE: The last data point on this graph is for April 2014. Source: <http://www.esrl.noaa.gov/gmd/ccgg/trends/mlo.html>

Note: Figure 13 inset below is the same as Figure 12 on page 38. **(3 Marks)**

Use the following information to answer questions 47 to 50.

Gayle Snowden was lucky enough to score a holiday to Hawai'i, otherwise known as the Big Island. Her parents, amateur volcanologists, took her to the Big Island to see the active volcano, play with lava and visit the various observatories on Mauna Loa and Mauna Kea (see the Figure 14 map provided below).

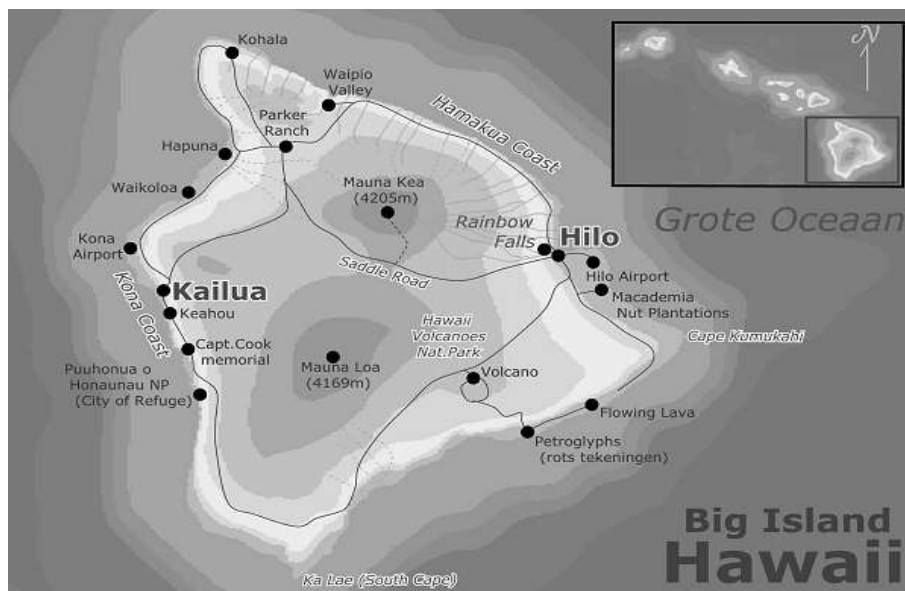


Figure 14. Source: <http://www.jolytravel.be/>

Driving around the Big Island at close to sea level she was amazed to find it is not all covered with tropical vegetation. She was also curious to know why Mauna Kea was such a good choice for optical telescopes since she expected that it would be like other tall mountains she knew, covered in fog and snow far too often for astronomy. Hilo, the island's capital, is one of the wettest cities in the United States of America and has a tropical climate.

When visiting Hawai'i Volcanoes National Park Visitor Information Centre she learned that the uplift of moist air is stopped at about 2200m above sea level by a layer of warm air known as an inversion. This forces the rising air to travel around the mountains at this elevation instead of going over them (see Figure 15 below).

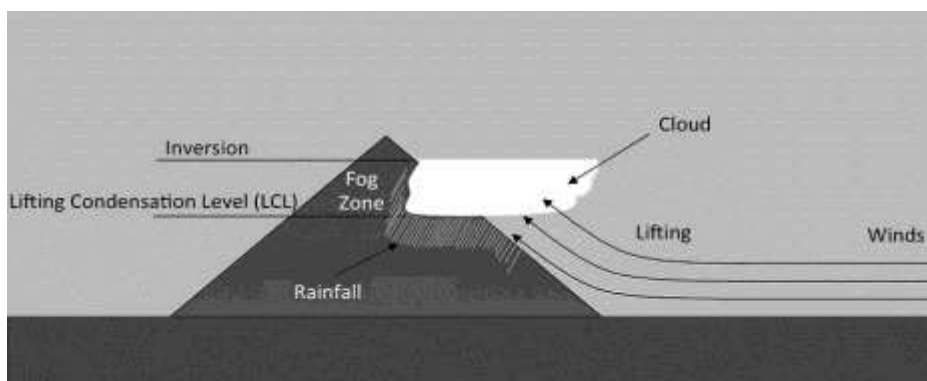


Figure 15. Modified from an image at <http://rainfall.geography.hawaii.edu/rainfall.html>

Use the following information to answer questions 47 to 50.

The mean annual rainfall of Hawai'i is provided in the Figure 16 map below:

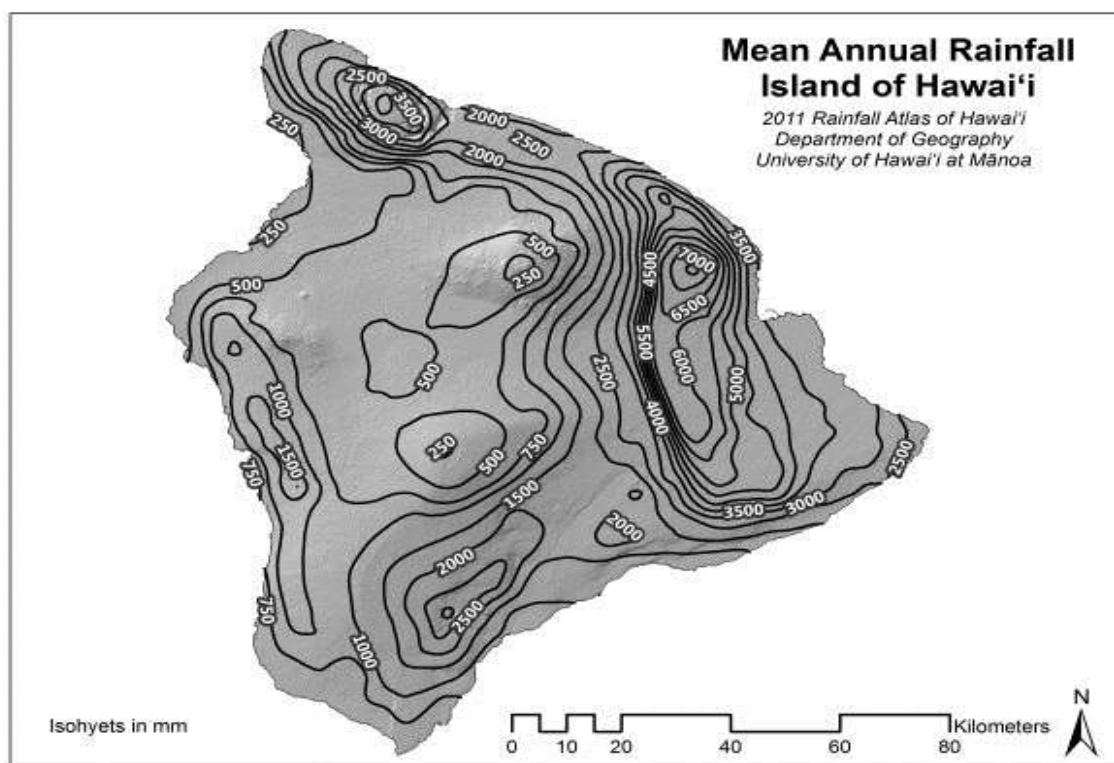


Figure 16. Source: <http://rainfall.geography.hawaii.edu/downloads.html>

47. Hilo has a high mean annual rainfall although there are many locations (unnamed on the Figure 14 map provided on page 40) on the Big Island that have a higher mean annual rainfall. Using the maps provided (Figures 14 and 16) identify the named town or towns with the lowest mean annual rainfall. (1 Mark)

The driest location named on the map is Hapuna although one could accept Waikoloa or both as they both could be interpreted as appearing to fall on or below the 250mm Isohyet.

48. In reference to the town or towns identified in the previous question, explain why the area where they are located is so dry that many local maps refer to it as a desert. **(3 Marks)**

To produce wet eastern shores and dry western shores winds must normally blow from east to west across the islands. Mauna Loa, being so tall, must affect the climate through orographic uplift and rain shadow effects. Moist air, coming off the sea, rises as it meets the island's tall volcanoes and results in the eastern (windward) side of the volcanoes getting very wet with heavy rain because the air will cool as it rises and at dew point and below condenses water into clouds producing lots of orographic rain. The western (leeward) side will have a drier climate because the air that reaches that side will normally have dropped its moisture as rain on the eastern side first. The air deflected around the volcano due to the presence of the inversion may be responsible for wetter areas on the south-westerly and north-westerly flanks but the area at Hapuna is in a true rain shadow thanks to the presence of Mauna Loa and Mauna Kea.

49. Why is Mauna Kea such a good location for optical astronomy? **(3 Marks)**

Mauna Kea is at a high altitude [over 4000m] but it is also very dry – demonstrated by the fact that it is inside the 250mm Isoheyt. It is so dry because it is well above the inversion layer that prevents the moist onshore winds from rising to that elevation, instead forcing them and the moisture they carry to pass around the islands at or below 2200m. This means the atmosphere most nights will be cool, dry and [at this altitude] relatively thin compared to coastal locations with most nights cloud free. It is also a long way from any towns [both horizontally and vertically] meaning light pollution levels are low.

Use the following information to help answer question 50.

Petroglyphs found on the coast of the Big Island south-east of the township of Volcano (marked on the map provided in Figures 14 and 17) are ancient rock carvings made by the first peoples to occupy the island. The entire island is composed of basalt, mostly lava flows. At any location on the island, the rocks have the same composition and have the same capacity to weather and erode. The coastal regions adjacent to Hilo are famous for agricultural products such as sugar cane and macadamia nuts because of the deep fertile soils created by the decomposition of the basalts. Where the petroglyphs are found there are lots of exposed solid rock surfaces. It can be assumed all petroglyphs are the same age and carved into rocks of a similar age and modern lava flows have not buried any known petroglyph sites.

Apart from visiting the cold, dry and inhospitable mountain tops to see the observatories, Gayle Snowdon's family plans to visit Hilo, Waipio Valley, Waikoloa, Kona and Keahou during a circum-island drive.

50. Where else on her coastal trip might Gayle Snowdon find petroglyphs, given the one marked on the map in Figure 17 has survived weathering so far? Note: Figure 17 inset below is the same as Figure 14 on page 40. **(3 Marks)**

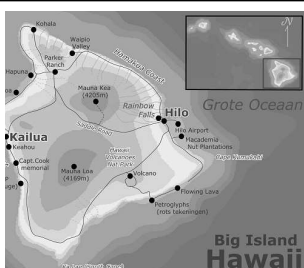


Figure 17.

The mountain tops are not part of the coastal trip as per the question so can be ignored. Besides they are inhospitable and unlikely to be a site people visited. However, the petroglyphs marked on the map are in a rainfall zone of less than 1500mm per year. This means anywhere with rainfall less than 1500mm per year is likely to allow for the preservation of petroglyphs because all the rocks are basalt and will weather at much the same rate under much the same climatic conditions. Waikoloa, Kona and Keahou are all in regions with annual rainfall well below 1500mm per year and thus even more likely to preserve petroglyphs than the area marked on the map, everything else being equal.

Use the following information to help answer questions 51 to 54.

The extreme south west peninsula of England is a place known as Cornwall. The location of Cornwall is marked on Figure 18 below. This area has a mild, warm, sub-tropical climate that allows rich plant life to flourish in summer. This unexpected climate, fed by westerly winds coming in off the Atlantic Ocean in summer contrasts with other places at 50° North such as the Labrador region of Canada which has a much colder climate. The location of Labrador is also marked on Figure 18 below. Both coastal Cornwall and coastal Labrador are adjacent to sections of the global ocean circulation system known as the great ocean conveyor belt.

51. Using Figure 18 provided below: **(3 Marks)**

- Mark on Figure 18 three places where you would expect the conveyor belt waters to be warm and shallow.
- Mark on Figure 18 three places where you would expect the conveyor belt waters to be cold.
- Mark on Figure 18, using arrows, the direction of flow of conveyor belt waters in the Atlantic, Indian and Pacific Oceans.

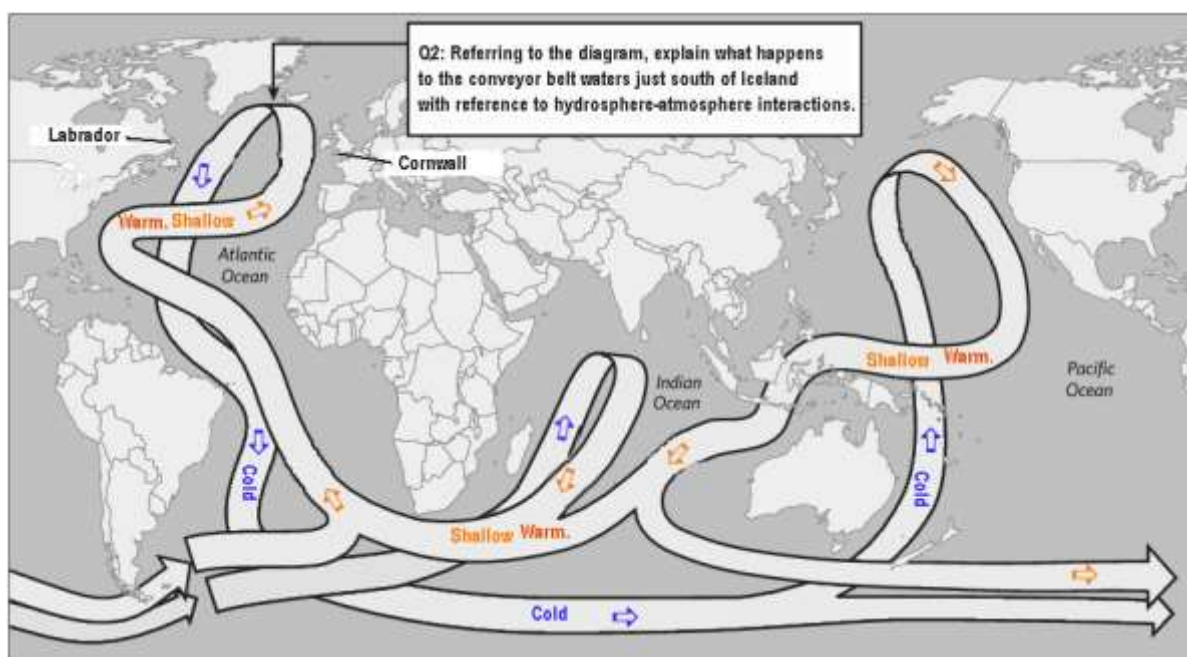


Figure 18. Modified from: <http://imgarcade.com/1/global-conveyor-belt/>

52. Referring to the conveyor belt diagram in Figure 18 on page 44, explain what happens to the conveyor belt waters just south of Iceland with reference to hydrosphere-atmosphere interactions. **(3 Marks)**

Warm surface waters loose heat to the atmosphere and become saltier as evaporation and arctic ice formation take place. Saltier cold water is denser so it sinks and in doing so heads south down the other side of the Atlantic.

53. Referring to the motions and conditions of the conveyor belt, explain what influence, if any, it might have on the climate of Cornwall. **(2 Marks)**

The warm surface waters of the conveyor belt loose heat to the atmosphere as they pass northwards close to the Cornwall coast. This warms the air and creates warm moist conditions for westerly winds blowing across the Atlantic to take on shore at Cornwall creating a warm moist climate on the Cornwall coast.

54. During the last ice age conditions in polar regions were so cold that massive amounts of water were locked away in ice. This resulted in a global sea level drop of 100 metres. This drop in sea level blocked the flow of the ocean conveyor belt between the Pacific and Indian Oceans. Referring to your answers in Question 52, would this blockage have provided negative or positive feedback to the global cooling happening at the time? **(2**

Marks)

A blockage of the conveyor belt in the Asian region would prevent warm tropical waters flowing out of the Pacific towards colder latitudes. This in turn would reduce the warming of the colder latitudes closer to the poles creating a situation of never ending cooling. Therefore, this would be a positive feedback loop into global cooling.

Use the following information to answer questions 55 to 57.

Captain Cook's final voyage was a failed attempt to locate the Northwest Passage, an ice-free sea route thought to link the Atlantic to the Pacific. The Northwest Passage was first successfully navigated by Roald Amundsen in 1906 but the Arctic ice pack has prevented regular shipping using this route. This route could be economically important as it is a much shorter route between the north Atlantic and the north Pacific for the shipping of trade goods.

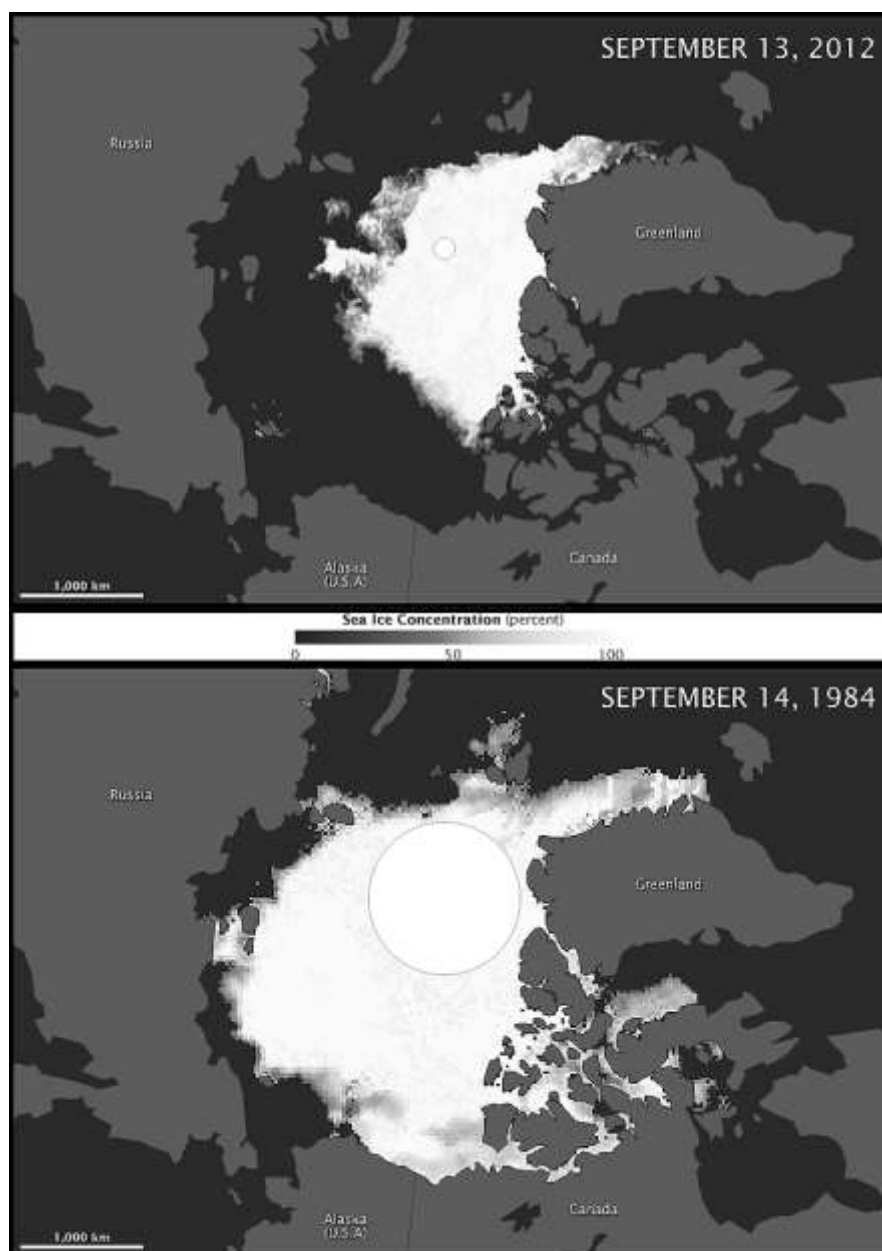


Figure 19: Arctic sea ice grows through the winter and melts through the summer, usually reaching its minimum extent sometime in September. The maps above compare the Arctic ice minimum extents from 2012 (top) and 1984 (bottom). The 1984 observations are considered close to average for Arctic ice minimums for the period 1979 – 2000 and can be used as a reference point for that reason. On each map the circle over the pole represents an area unobserved by satellites but reasonably interpreted as ice covered as confirmed by surface observations.

Source: http://en.wikipedia.org/wiki/File:Arctic_Sea_Ice_Minimum_Comparison.png

55. In reference to the 1984 and 2012 sea ice maps provided in Figure 19 on page 47, explain why Captain Cook, or at least the people who commissioned him to find the Northwest Passage, would have preferred to have explored for the Northwest Passage in 2012 rather than 1778. **(2 Marks)**

The ice pack as per 1984 usually does not allow for an ice free route even at the ice pack minimum in September. This means prior to recent times it was not possible to travel by ship through the Northwest passage because it was usually still full of ice and either too dangerous or impossible in summer and absolutely impossible in winter.

Now the extent of sea ice in summer has reduced to the point where the Northwest passage is open in summer and much safer/easier to navigate. Had it been like this in 1778 Captain Cook may well have found it and consequently not returned to Hawai'i where he was killed!

Use the following information to help answer question 56.



Figure 20. This map shows the routes thought to be best for a northwest passage through the Arctic and the location of Barrow.

Source: http://en.wikipedia.org/wiki/Northwest_passage

Sea ice in the Arctic suppresses ocean swells. It also suppresses wave action completely where present and dampens it significantly in small open water areas adjacent to the sea ice. The Alaskan coastal community of Barrow (marked on the map in Figure 20 above) is built just a few metres above sea level on barely consolidated sediments mostly held together by frozen water.

Q56:

In reference to the sea ice maps and Northwest Passage map provided in Figures 19 and 20 on pages 47 and 48; discuss the likely hydrodynamic impact of the changes observed between 1984 and 2012 on the coastal community of Barrow, especially with respect to the material upon which the community is built. **(2 Marks)**

Barrow used to be hemmed in by sea ice almost all year [as shown by the minimum sea ice extent in 1984] and consequently would have had very little wave action on the coast. Now in summer Barrow has a large open ocean facing it on which large swells and waves can develop unhindered. When this occurs wave action on the shore at Barrow could result in severe erosion of the beach and the unconsolidated sediments upon which the community is built – potentially eroding the beach to the point where the community infrastructure starts to fall into the sea.

Some students might rightly note that the sediments are essentially permafrost and as it melts it will be more prone to erosion too. Note: the reduction in sea ice will have no impact on sea level. Sea level rises will also impact this community but are not a consequence of sea ice melting since the ice displaces much the same volume of water it turns into and thus the impact on sea level is practically neutral.

Use the following information to help answer question 57.

Shipping that moves goods from the cold northern Atlantic waters to the cold northern Pacific waters and back the other way must travel via the tropical to sub-tropical waters leading to and from the Suez Canal or the Panama Canal. The Panama Canal is a freshwater system. Ships loading and unloading cargo also carry water in their hulls as ballast. This water is sourced from or pumped into the sea where the ship loads, unloads or needs to adjust its displacement level.

A new report by the Smithsonian Environmental Research Center's Marine Invasions Research Lab reveals recent travel via the Northwest Passage has saved one ship 4 days travel time and over \$200,000 in operating costs. In reducing the fuel bill it also reduced the associated carbon emissions. However, the same report also indicated there is a much greater risk of severe ecological and economic damage from invasive cold water species being transported in ship's ballast water via the Northwest passage to the north Atlantic or the north Pacific. Some invasive species may also hitch a ride on a ship's hull.

57. Why would there be a greater risk of damage from invasive species if ships use the Northwest Passage compared with the same ships travelling to the same destinations via the Panama Canal or the Suez Canal? **(3 Marks)**

Cold water species in a ship's ballast are likely to die en route if they encounter warm tropical conditions or freshwater. Both the Panama Canal and the Suez Canal are in tropical environments so cold water invasive species are likely to be dead before the ships return to a suitable cold water environment. Ships that go via the Panama Canal also pass through freshwater which will also kill marine species. Both routes thus 'protect' cold water destinations from invasive species so long as the local tropical/fresh waters are used in ballast or if the invasive species is on the hull exposed to the changes in temperature and salinity.

If the ships go via a Northwest Passage they will never leave cold water or enter freshwater and thus any invasive species in their ballast water or on their hull will still be alive and ready to invade when they are discharged at the destination port.

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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