AGSC

Geoscience Education

Teachers Guide

Suggested answers to student activities from

Plate Tectonics (1995/8)
Earthquakes (1995/20)
Volcanoes (1995/24)
Climate Change (1995/21)
Time & Life (1995/14)
Silicate Chemisty (1995/19)

Gary B. Lewis
Susan M. Bilton

Record No. 1996/2

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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AGSO Geoscience Education
Further Information
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Australian Earthquake Slide Set
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Plate Tectonics

From AGSO Record 1995/8

Earthquake Boundaries!

10 000 earthquake epicentres have been recorded on a map of the world. Can you use this data to locate the Earth's crustal plates?

Earthquakes occur where slabs of rock grind past each other. This occurs at the boundaries of the Earth's crustal plates as the plates move past each other, move apart from each other or one plate slides over the top of another plate.

While some earthquakes occur away from plate boundaries, the majority occur in zones along the boundaries.

Like a huge "Join-the-dots" puzzle, trace around the locations of the earthquakes to mark out the plates. In some places this will be easy — in some places it will be difficult.

?

Compare your plates with those of a friend. Do you agree on the location of the plates? Do you have some plate boundaries in different locations?

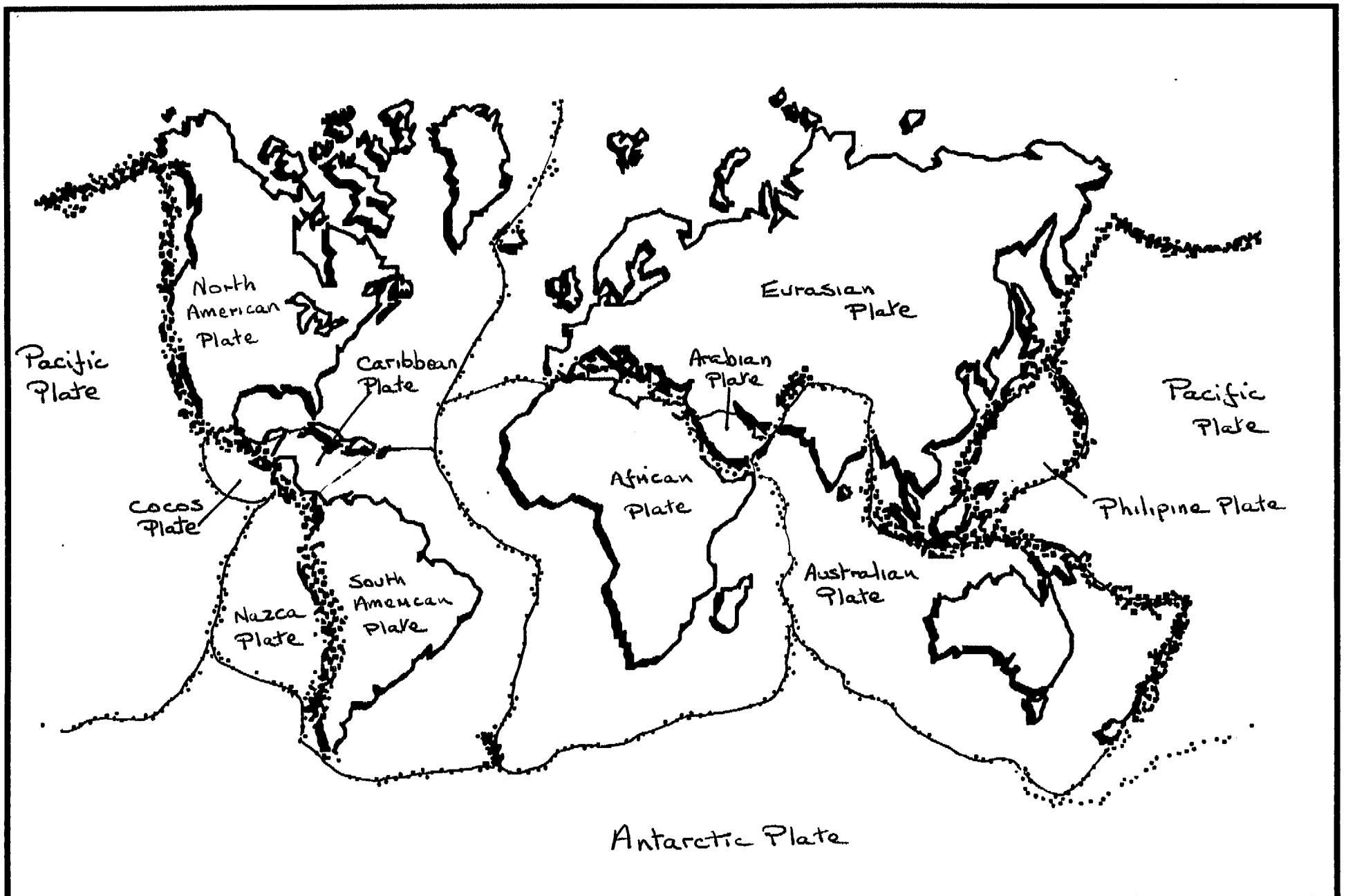
Geologists have identified the following major plates :

- Australian plate
- Antarctic Plate
- Pacific Plate
- North American Plate
- Cocos Plate
- Nazca Plate
- South American Plate
- African Plate
- Eurasian Plate
- Philippine Plate
- Caribbean Plate
- Arabian Plate

Try to identify these plates on your map. Use an atlas if you do not know where these places are located.

Some plate boundaries appear to be more active than others. Boundaries where one plate is being forced under another plate have a greater number of recorded earthquakes than the other types of boundaries.

Can you identify these plate boundaries. Mark them on your map with a different colour pencil.



Continent Movement

Tectonicland

It is the year 2153 and you are a geologist on a space mission to Tectonicland. Your main role is to study the continents of the planet and how they have been affected by plate tectonics. You will use the age of rocks to find if the continents have ever been joined together in the history of the planet.

On a previous mission your assistant collected 16 rock samples and had them analysed for radioactive elements. The location of each of the 16 samples is marked on the map.

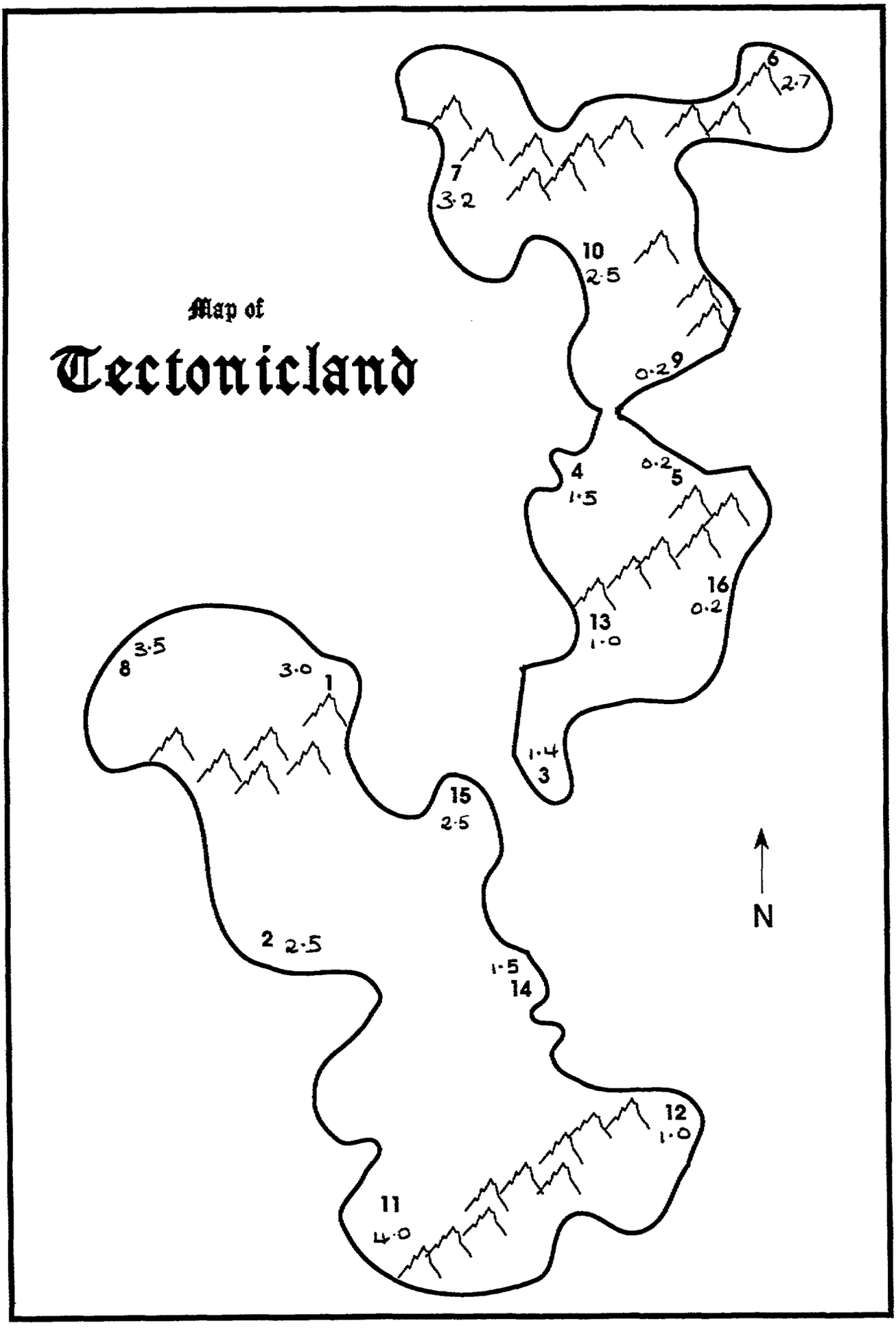
Sample	*Radioactive Element*	*% of original mass remaining*	*Age of rock*
1	U^{238}	67.5	3·0 billion years
2	Th^{232}	90	2·5 billion years
3	Th^{232}	95	1·4 billion years
4	U^{235}	26	1·5 billion years
5	U^{235}	95	0·2 billion years
6	U^{235}	7.5	2·7 billion years
7	U^{238}	66	3·2 billion years
8	Rb^{87}	96	3·5 billion years
9	U^{235}	94	0·2 billion years
10	U^{235}	10	2·5 billion years
11	U^{238}	57.5	4·0 billion years
12	U^{235}	40	1·0 billion years
13	U^{235}	40.5	1·0 billion years
14	U^{238}	85	1·5 billion years
15	Th^{232}	90	2·5 billion years
16	U^{238}	99	0·25 billion years

Using the radioactive decay curves, find the approximate age for each sample and complete the table. Also write the ages against the location numbers on the map.

Cut out both continents from the map and see if you can fit them together so that rocks of the same age match up between the two continents.

HINT : Locations 9 and 5 have rocks of the same age — try bending the continent to fit these together first.

Developed from "Imaginary Continents" Journal of Geological Education 1978 v26 p195



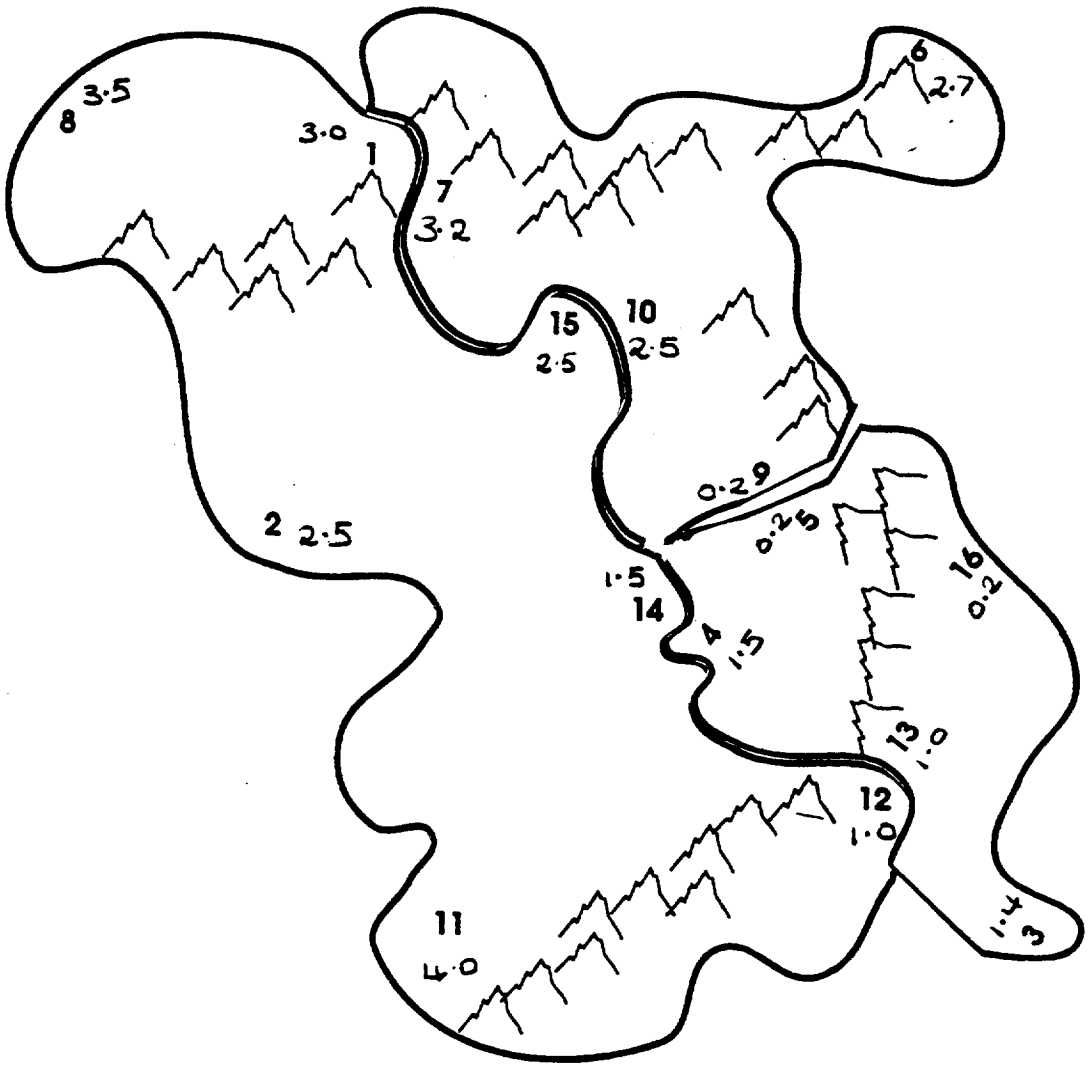
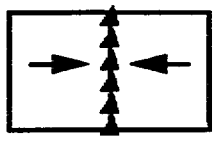
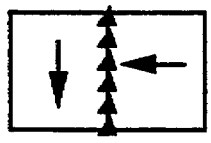

8
3·5
3·0
1
7
3·2
6
2·7
15
2·5
10
2·5
0·29
0·25
2
2·5
1·5
14
4
1·5
16
0·2
13
1·0
12
1·0
11
4·0
1·4
3

Plate Movement

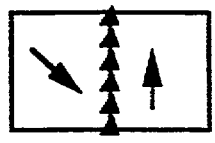
Using these simple diagrams, mark on the three diagrams below the type of boundaries which occur between the plates. You can use the same symbols, or use a different colour for each type of boundary.



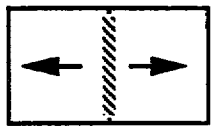
Subduction



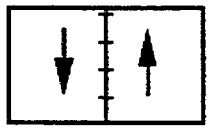
Subduction



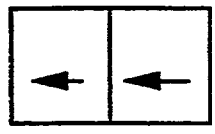
Subduction



Divergent

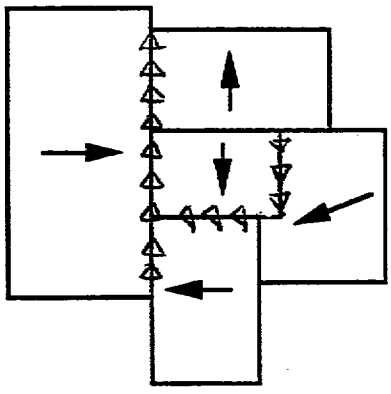


Transform fault



Dormant

1.



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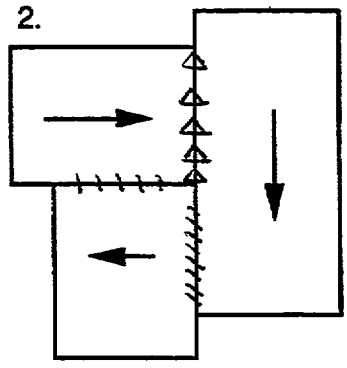
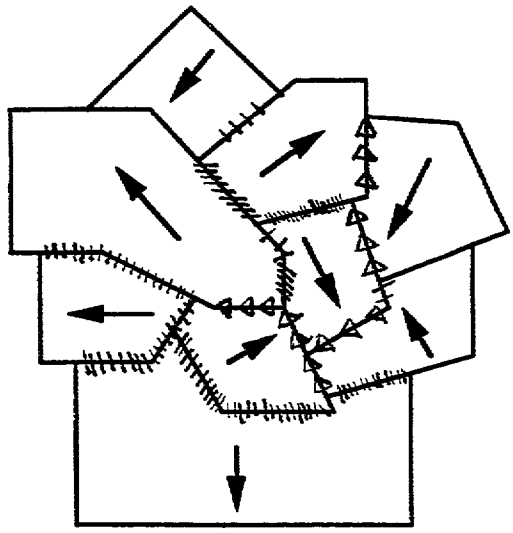


3.



Voyage of the "Tectonica"

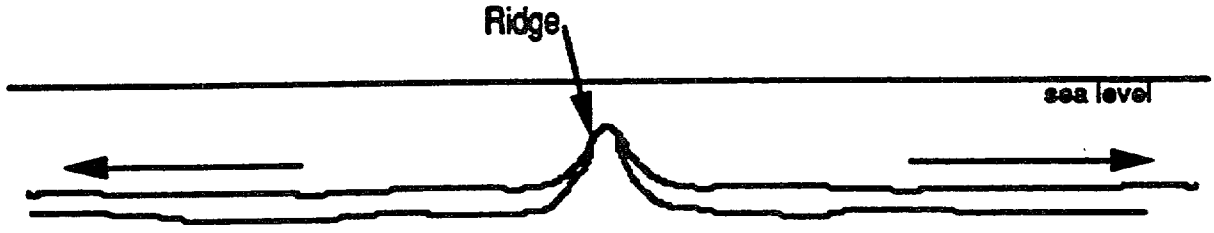
Background Information

The Earth has a natural magnetic field with a north and south pole, like a magnet. It is this field to which a compass needle aligns to point northwards (or in the southern hemisphere — southwards).

When rock is molten (such as lava) any magnetic minerals also align to this natural magnetic field. When the rock cools, these miniature "compasses" are frozen in that direction. Geoscientists can measure the direction that these minerals point using a device called a magnetometer.

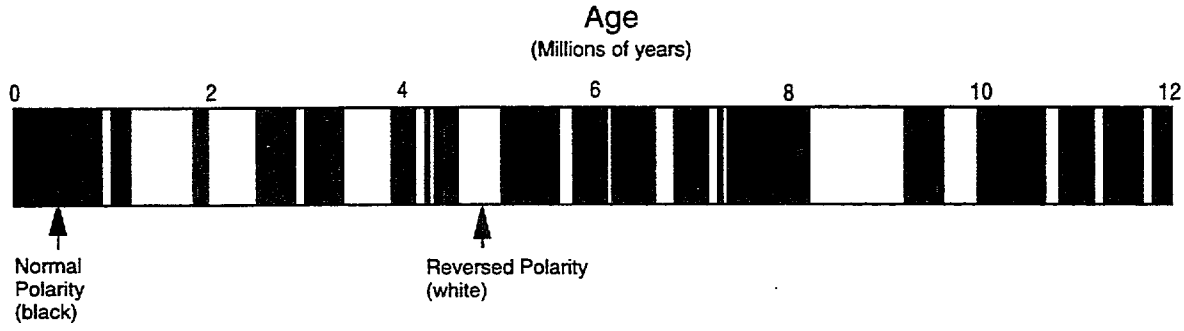
When geoscientists look at ancient igneous rocks, they find that some show that the Earth's magnetic field is opposite to what is found today. In these rocks the minerals show that the north magnetic pole was once at the south geographic pole, and the south magnetic pole at the north geographic pole. (Presently and north and south magnetic poles are located near the north and south geographic poles). This change in poles is known as Polar Reversal and has taken place many times over the age of the earth.

Where two oceanic plates are moving apart from each other, volcanoes along an underwater ridge create new ocean floor on both plates.



When a Polar Reversal occurs, the volcanic rocks record the change in their minerals. As you move away from the ridge the rocks display these Polar reversals as a series of magnetic stripes or anomalies.

Ocean Floor Magnetic Anomalies



The ages of the Polar Reversals are roughly known, so the rate that the plates are moving can be calculated by the thickness of the stripes in the pattern. Recognising the pattern of stripes is the first step in calculating the rate of spread.

Activity

The "Tectonica" is a survey ship which has instruments which can measure the change in polarity of volcanic rocks which make up the ocean floor. During a cruise in January 1994, four survey lines were taken across the plate boundary between the Australian Plate and the Antarctic Plate. It is you task to convert the raw data and calculate the rate of spread of these two plates.

As the ship moves along a survey line it records the distance at which any change in polarity is found.

The information you have been given :

i. "Survey Line Data" for the four survey lines (A,B,C and D).

ii. "Survey Lines of Southern Ocean" a map of the locations of the four lines.

Step 1. Convert to scale

The distances for each recording need to be converted into millimetres (mm) so you can plot them on the map. The conversion factor is 1/20. Divide each distance (km) by 20 and write the answer in the "Map mm" column. Note that survey lines B,C and D do not start at 0 km. You will need to adjust these by first subtracting the first recording.

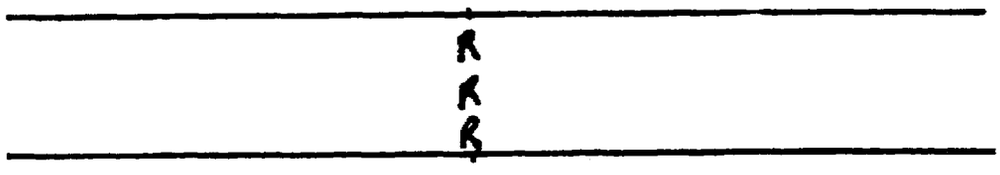
Example — Survey Line B

km	*Map mm*
800	*0*
920	*(920–800)/20 =6*
1000	*(1000–800)/20=10*

Do the conversions for all four survey lines.

Step 2. Mark the ridges.

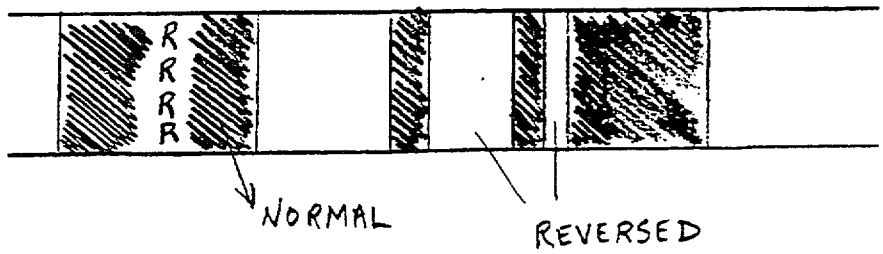
On the "Survey Lines for Southern Ocean map" measure the distance you calculated in mm from the left edge of the survey line A for the volcanic ridge and mark this location with a capital "R".



* Note: As photocopiers will change scales, the diagram of the survey lines will be slightly different.

Step 3. Mark the reversal points.

Start on the left side of Survey line A and mark each polar reversal with a line. Note that the ridge lies in the middle of a stripe. Once you have marked each polar reversal, colour those areas which have normal polarity in black. Leave those zones of reverse polarity white.



Step 4. Age the stripes.

Using the "Ocean Floor Magnetic Anomalies" data given at the start of this exercise, find the pattern of polar reversals on each side of the ridge in Survey Line A. Remember that the volcanic ridge is creating new materials and represents 0 millions of years ago. (You may have to turn one upside-down and the pattern is not exact.)

? Find the stripe that represents the polar reversal that occurred 2 million years ago. How far is this from the volcanic ridge in km? (Every mm=20km)

18 mm = 18 x 20 km = 360 *km*

? How far does the ocean floor move from the ridge every year ? (show your calculations).

360 Km = 360.000 m = 36,000,000 cm

∴ ocean floor moves 36,000,000 cm every 2 million years

$$\therefore \quad \frac{360{,}000{,}000 \text{ cm}}{2{,}000{,}000} = 18 \text{ cm / year}$$

Step 5. Complete the Survey Lines B,C and D as in Steps 2 and 3.

? What observation can you make about the position of the Ridge in Survey Line B?

It is offset from the Ridge in Survey line A and Survey line C

? How far is the ridge in Survey Line B horizontally away from the Ridge in Survey Line A in km?

630 km

? What geological structure might occur between Survey Line A and Survey Line B to offset the Ridge?

Transform fault

As Tectonic moves along a survey line it only measures the polarity of the rocks directly below the ship. On the map lines you have drawn you have made the lines bigger than the ship can actually see. If you draw a line down the middle of the survey line box you will mark the actual position of the survey ships path.

Mark this line on Survey Line C.

Can you suggest why Survey Line D crosses the Ridge twice?

The ships route crossed a transform fault which has offset the ridge line

Is this further evidence for the same geological structure which offsets the Ridge in Survey Line B ?

Yes, although a different transform fault

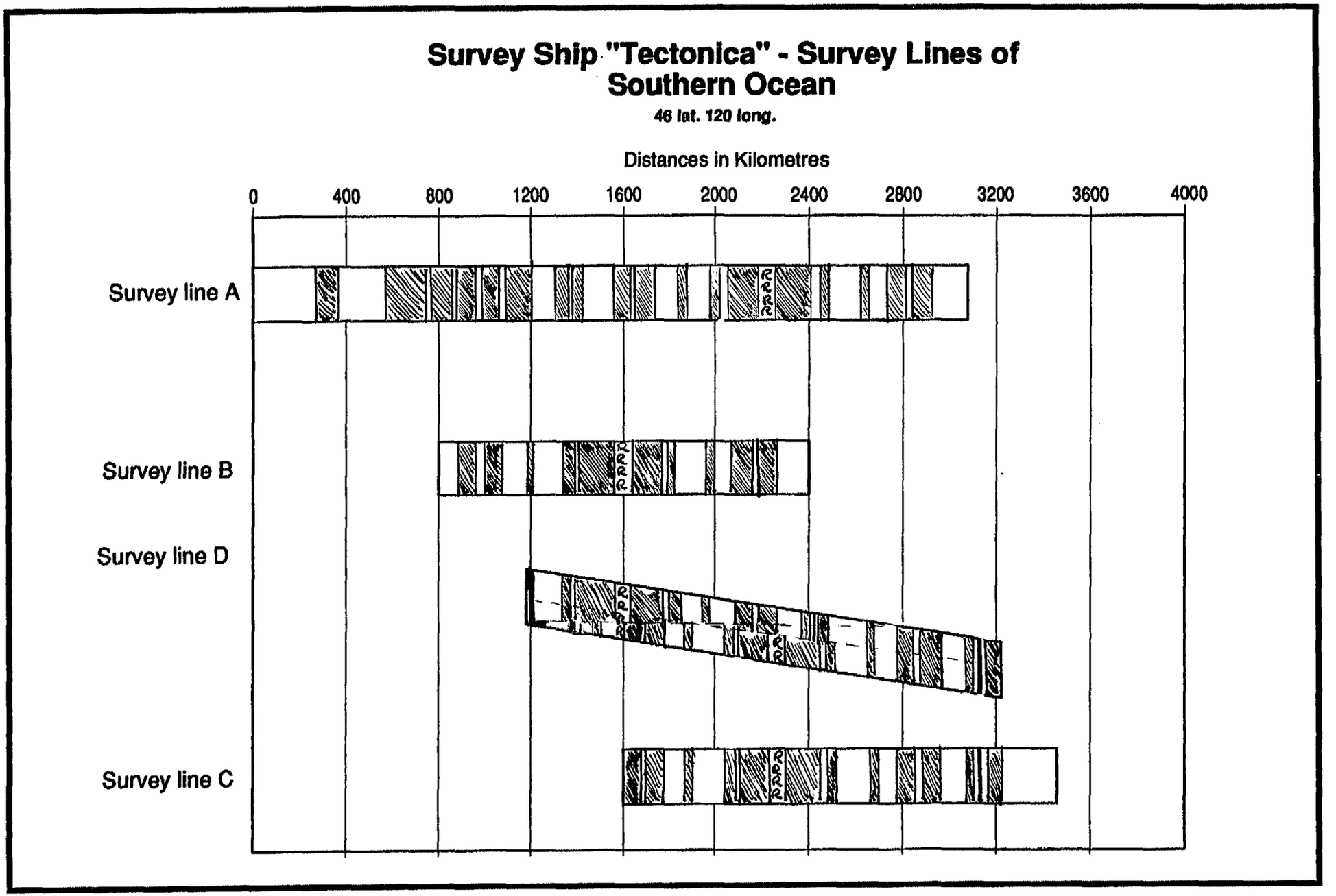
Survey Ship "Tectonica"
Survey Line Data

km	Map mm	Survey Line A
0	0	Normal
60	3	Reversed
80	4	Normal
220	11	Reversed
300	15	Normal
380	19	Reversed
580	29	Normal
780	39	Reversed
800	40	Normal
860	43	Reversed
920	46	Normal
1080	54	Reversed
1100	55	Normal
1240	62	Reversed
1320	66	Normal
1400	70	Reversed
1460	73	Normal
1640	82	Reversed
1680	84	Normal
1760	88	Reversed
1860	93	Normal
1900	95	Reversed
2020	101	Normal
2060	103	Reversed
2100	105	Normal
2280	114	RIDGE
2460	123	Reversed
2500	125	Normal
2540	127	Reversed
2660	133	Normal
2700	135	Reversed
2800	140	Normal
2860	143	Reversed
2900	145	Normal
2980	149	Reversed
3080	154	Normal
3100	155	END OF LINE

km	Map mm	Survey Line B
800	0	Reversed
920	6	Normal
1000	10	Reversed
1040	12	Normal
1100	15	Reversed
1200	20	Normal
1240	22	Reversed
1360	28	Normal
1420	31	Reversed
1440	32	Normal
1600	40	RIDGE
1780	49	Reversed
1800	50	Normal
1860	53	Reversed
1960	58	Normal
2020	61	Reversed
2120	66	Normal
2180	69	Reversed
2220	71	Normal
2300	75	Reversed
2380	79	Normal
2400	80	END OF LINE

km	Map mm	20 Survey Line C
1600	0	Reversed
1640	2	Normal
1720	6	Reversed
1760	8	Normal
1820	11	Reversed
1920	16	Normal
1960	18	Reversed
2080	24	Normal
2140	27	Reversed
2160	28	Normal
2300	35	RIDGE
2480	44	Reversed
2500	45	Normal
2560	48	Reversed
2680	54	Normal
2720	56	Reversed
2820	61	Normal
2900	65	Reversed
2940	67	Normal
3020	71	Reversed
3120	76	Normal
3180	79	Reversed
3200	80	Normal
3280	84	Reversed
3380	89	Normal
3460	93	END OF LINE

km	Map mm	Survey Line D
1200	0	Normal
1240	2	Reversed
1360	8	Normal
1400	10	Reversed
1420	11	Normal
1600	20	RIDGE
1780	29	Reversed
1800	30	Normal
1840	32	Reversed
2080	44	Normal
2120	46	Reversed
2140	47	Normal
2320	56	RIDGE
2500	65	Reversed
2520	66	Normal
2540	67	Reversed
2680	74	Normal
2720	76	Reversed
2820	81	Normal
2900	85	Reversed
2920	86	Normal
3020	91	Reversed
3100	95	Normal
3140	97	Reversed
3160	98	Normal
3240	102	END OF LINE



Earthquakes

From AGSO Record 1995/20

Find Detritus

Tracy walked home from school one day and found a message pinned to her front door. The message said:

> *"Tracy, Your dog Detritus has escaped your back yard and has run away. I saw it go at 3pm but I could not catch it. By the time you read this it would be 2km away! Sorry I can't help you find Detritus as I have a piano lesson. Rod"*

On the map you have been given, mark with a pencil where Tracy should go to look for Detritus. Tracy's house is marked and the scale is on the bottom of the map.

Hint : Assume the dog has stopped but while it travelled it could jump fences, swim creeks etc The dog could have travelled in any direction from Tracy's house.

? Describe the shape of the area where Tracy needs to look to find her dog : Circle

As Tracy leaves her front gate she spies another note in her mailbox. The note said :

> *"Hi Tracy, Detritus has escaped! As mum drove me home from Mr Jackson's house after my piano lesson we saw Detritus sitting alongside the road. We looked at the odometer and saw that we were exactly 4kms from Mr Jackson's house. We measured the distance we drove to our house from where we saw Detritus. It was 3km. I asked Dad to drop this note into your mailbox on his way to yoga. I hope you find Detritus soon. Joe"*

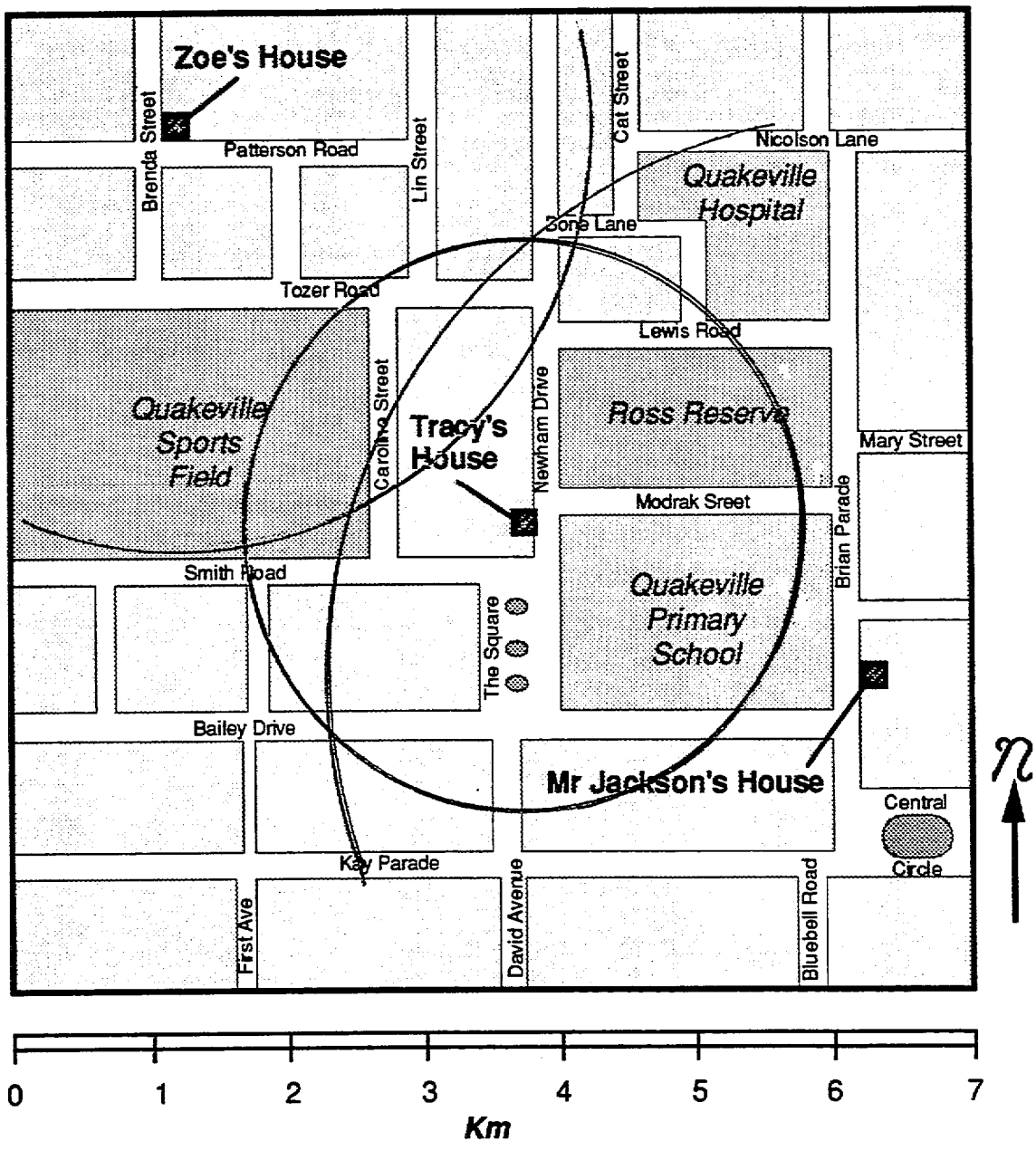
Use this information to help Tracy find Detritus.

? Where will Tracy find her escaped four-legged convict?

Corner of Bone Lane and Newham Drive

PS - Do you know what "Detritus" means? - Look it up in an encyclopaedia!

Map of Quakeville



When an earthquake occurs, seismographs in many locations measure the shaking of the earth. From the data they record, seismologists can calculate the distance from each seismograph the earthquake took place. They can then use the method that you have just used to find the epicentre of the earthquake, even if it's underwater!

Epicentre Hunt

While the people in the township and surrounding areas of Quakeville slept a small earthquake shook the area. The tremor was so small that it was not felt be any person, but was recorded by seismographs in the five seismic stations in the area. Similar small tremors had been recorded prior to more intense earthquakes in the past and they always occurred close to the epicentre of the following intense earthquake.

You have been sent the seismograms from the five stations. Can you predict where the epicentre of the next major earthquake may be?

Look at the Quakeville Station seismogram. The arrival of the P waves and the arrival of the S waves have been found and the number of seconds between them has been calculated (each mark represents one tenth of a second - so ten marks is one second).

Do the same procedure for the seismograms from the other four stations.

? The difference in the arrival time of the P and S waves for each Station are :

Quakeville Station	6.0 seconds
Pearsons Crossing Station	6.4 sec
Well Station	4.2 sec
Upper Valley Station	10.4 sec
Bucktown Station	4.1 sec

Using the Time/Distance Graph calculate the distance of the epicentre from each station.

HINT : To calculate the distance find the point on the graph where the line crosses the time for that station. Read straight down for the distance. You can use a rule and a pencil to get accurate readings. Quakeville Station's distance is 53km. Check to see if you agree.

? The distance each Station was from the epicentre was :

Quakeville Station	53 km
Pearsons Crossing Station	56 Km
Well Station	38 Km
Upper Valley Station	93 Km
Bucktown Station	37 Km

Using the map of the Quakeville Area, Draw circles from each station which represent the distance that station was from the epicentre.

Mark on the map where the epicentre was located with an X.

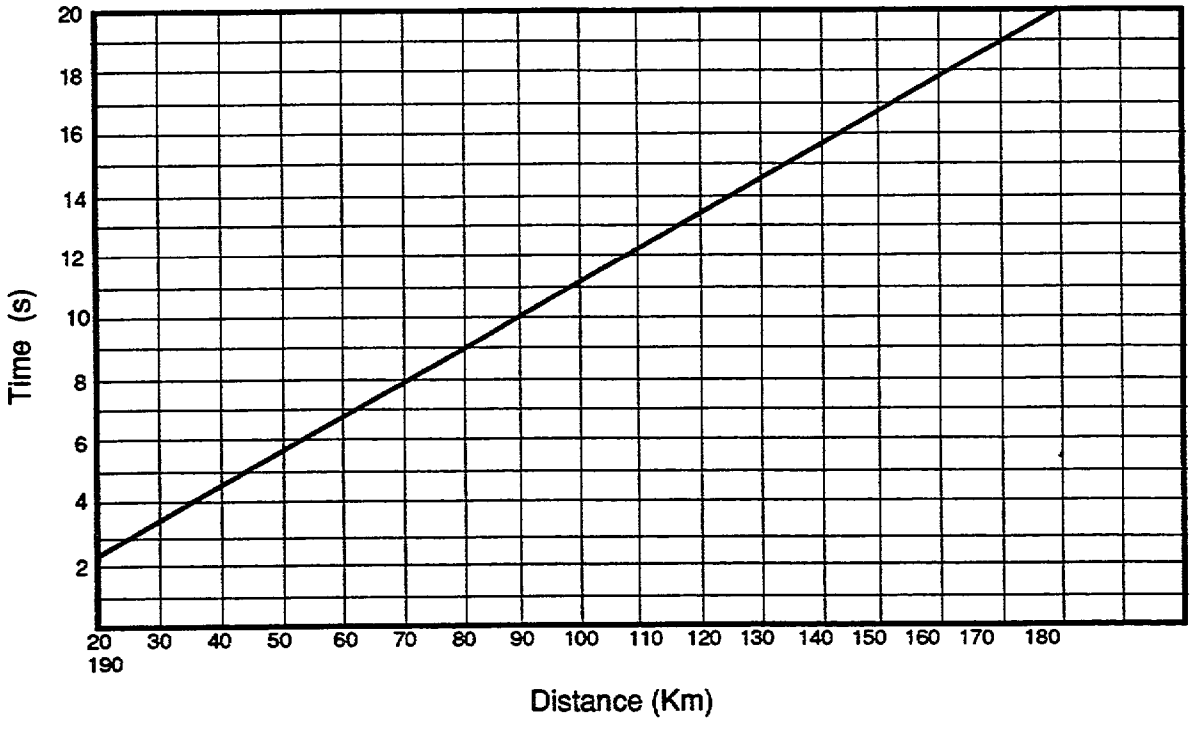
? Will any township or homesteads be affected if a more intense earthquake follows this tremor?

Two homesteads - one 15 Km one 22 Km away

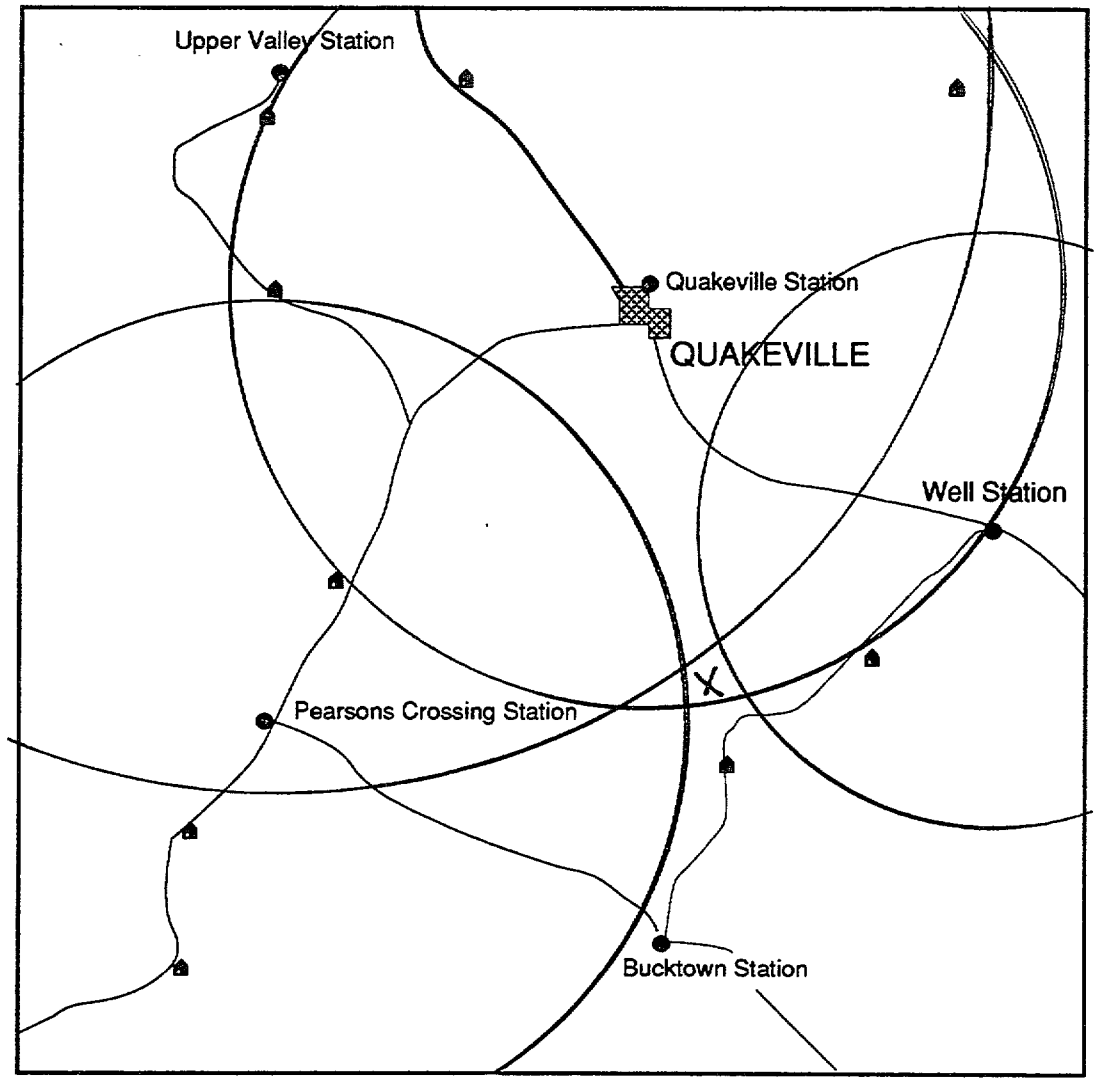
? What action could you take to warn people who may be affected without raising the alarm of other non-effected residents ?

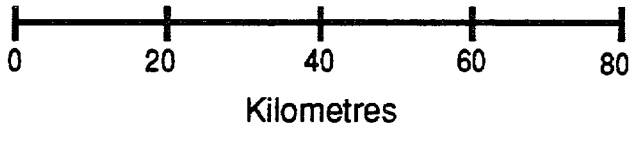
As there is only two homesteads, call them direct and advise them what action to take in case of an Earthquake

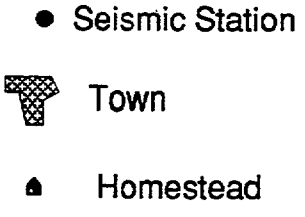
Time/Distance Graph
(Difference between the arrival of P and S waves)

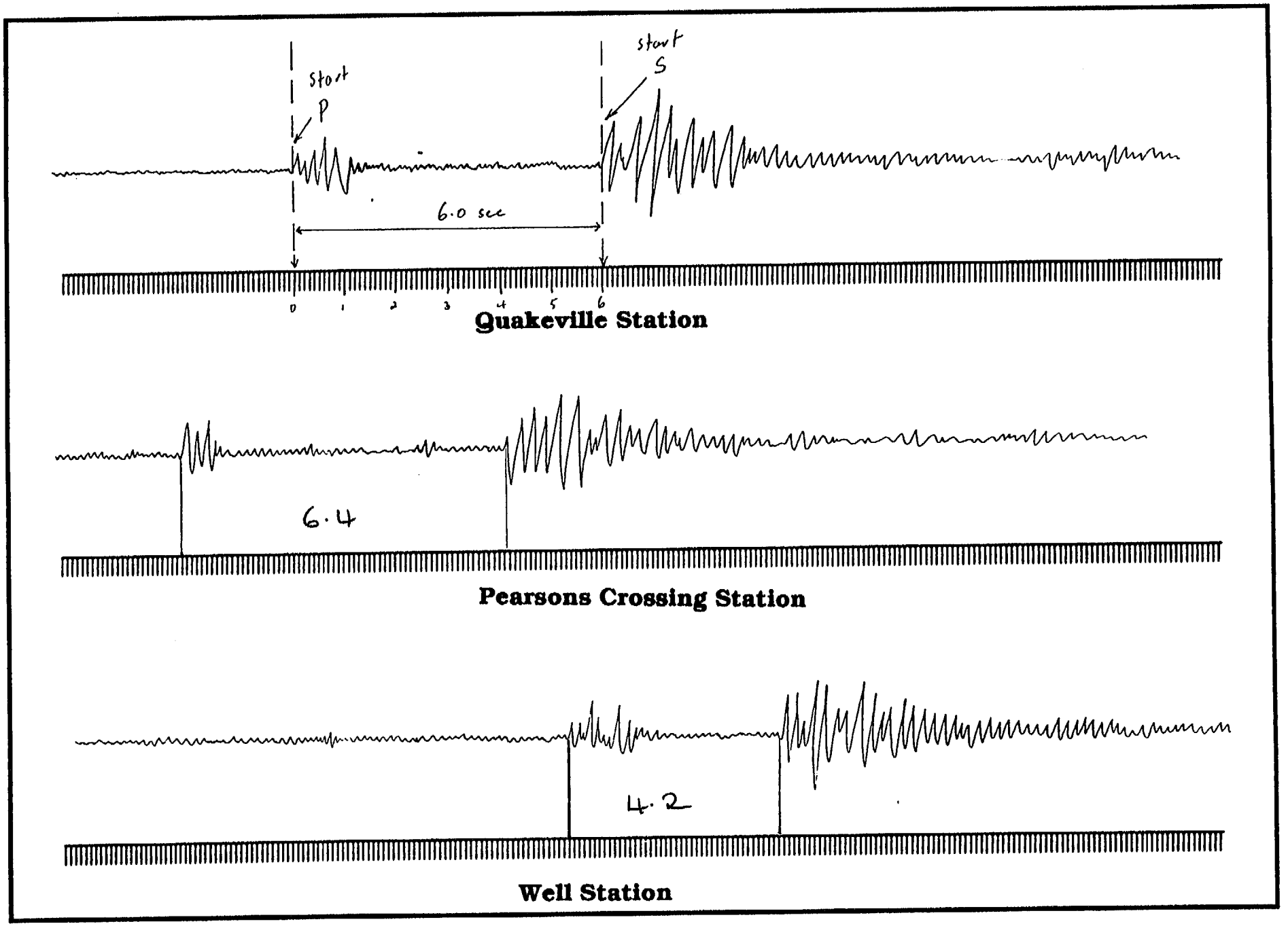


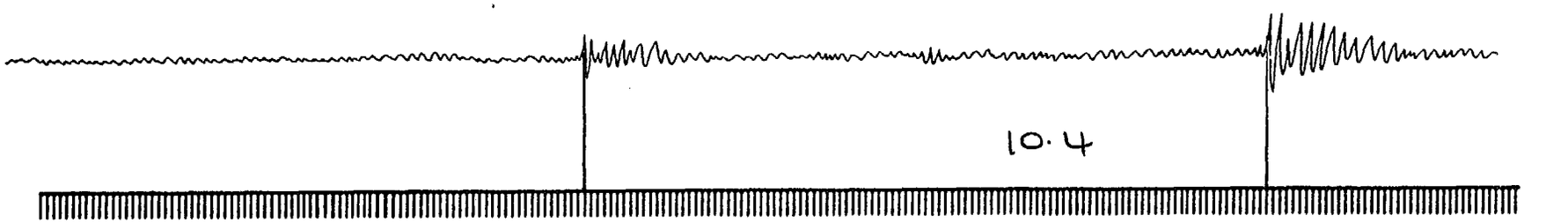
Quakeville Area Seismic Stations











Upper Valley Station

Bucktown Station

Each mark is 0.1 sec

Quakeville Earthquake

. NEWS FLASH . . NEWS FLASH . . NEWS FLASH .

8.35 pm . . .Reports have just come in that Quakeville has again been shaken by an earthquake. At this stage the extent of damage from the quake is unknown. Stay tuned for further reports throughout the evening. . . . .

You are the reporter for the local newspaper and your editor wants you to write an item and put a map into the next issue. You quickly pick up the telephone and call people you know around town and ask them what they felt and saw around 8.30pm on the evening of the earthquake. (These comments are on separate sheets). You also gather some background information about past earthquakes to include in your item.

Background information
Quakeville is often shaken by earthquakes. A large fault, known as the Crescent Fault, runs almost right under the town. The Crescent Fault is known to slip about once every ten years. The last earthquake was in 1985. No damage was done to any buildings. In 1942 an earthquake destroyed every brick house in town but no one was killed. It had a Modified Mercalli Intensity maximum of MM IX.

Using a Modified Mercalli Scale, work out the MM number for each of the eyewitness accounts you gathered and write it next to the comment .

? What was the greatest intensity (MM number) for this earthquake : VI

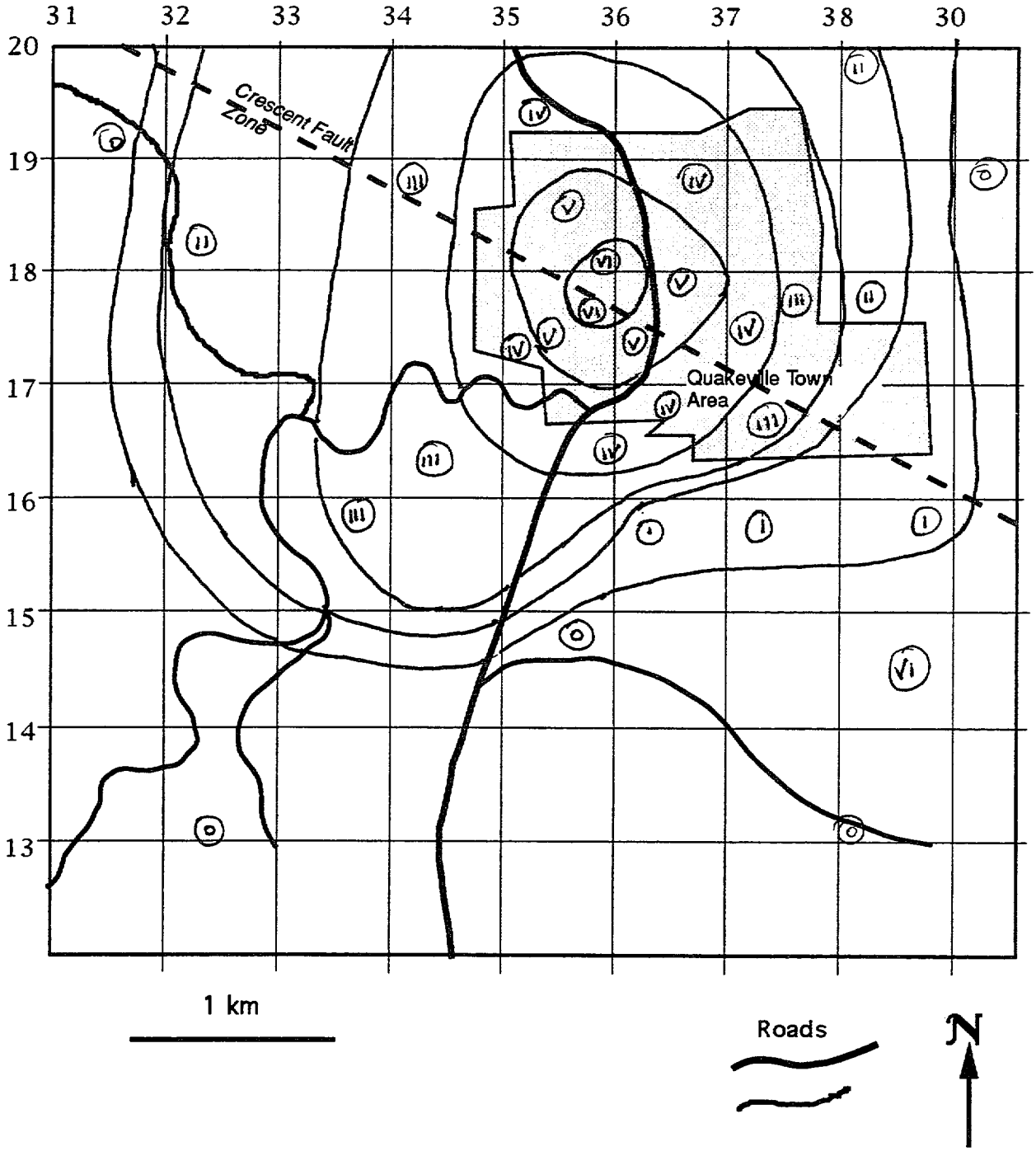
Using the map and grid references provided, find each location on the map and write on the MM number in a small circle.

Draw isoseismal lines (lines separating areas of equal intensity) on your map using the MM numbers you have plotted.

Hint : Draw a line so that no MM number falls inside it other than the highest MM number for the earthquake. Next, draw a lines so the next lowest MM numbers fall between it and the first line and so on.
Note that one person is very unreliable - you will have to ignore his information!

Write a brief item for the newspaper which contains the background information your map and an explanation of what your map shows. You should think of a headline which will get people to read your item The whole item should be less than 200 words.

Map of Quakeville Region



1993 Quakeville Earthquake Eyewitness Comments

Grid Ref	Comment	MM
355185	I was woken by my bedside clock falling off the table. When I sat up the mirror hanging on the wall at the foot of my bed was moving.	V
359180	I was making a cup of tea in the kitchen when I heard a crack and a great piece of plaster fell off the wall. Every cup in the house was broken. Later when I went outside I noticed that the chimney was also cracked.	VI
383178	I live on the top floor of a five storey apartment block. I was awake at the time and could feel a slight sway in the building. The people on the ground floor couldn't feel a thing.	II
372166	I don't know what all the fuss was about! My wife and I thought it was just a car passing in the street.	III
360165	I was walking the dog at the time and the whole row of cars parked in our street started to rock. I could not feel anything myself but the dog freaked out!	IV
325130	No one in our house felt anything, even Grandma and she is a very light sleeper.	0
367179	A was frightened. The whole house seemed to sway and the shutters on my bedroom window banged against the house. Later the only damage I could find was a cracked window.	V
374158	I was resting at home when I felt a slight movement. At the time I thought I was just giddy after a hard day at work. Then I found out that it was an earthquake!	I
391188	We did not feel a thing. We were both awake at the time watching TV.	0
379177	I said the my husband that it was strange for a bus to be travelling at that time of day down our street. He then noticed that the light fitting was very slightly swaying.	III

Grid Ref	Comment	MM
381198	I was on the roof of our two storey house fixing the TV aerial at the time. I could feel the house slightly swaying. My wife inside couldn't feel a thing.	II
357148	What earthquake? I was writing a letter at the time and didn't feel a thing.	0
357178	Dad ran around the house waking all us up. There was dust everywhere and big chunks of the ceiling had fallen down. The sofa had moved almost the whole way across the lounge room floor. Mum's favourite light stand had fallen over and was broken. The little bell in the clock was ringing.	VI
370174	I thought a car had hit the side of the house. I ran outside to see if there was any damage - but I could find none.	IV
363168	I had just driven home from work and was walking from the car when I heard a creaking sound like our house makes in a strong storm. The night was very still, and other than the sound I could not feel a thing.	IV
351172	I was driving at the time and didn't feel a thing. I could see some of he tall trees swaying as if someone was shaking them.	I
387157	My dog started barking and running around the house. She woke us all up but we couldn't work out what was worrying her.	I
367188	I knew we were having an earthquake. The glasses all rattled in the sideboard and the roller door on the garage make a loud noise like it was being shaken.	IV
362157	The only thing we noticed was the big light fitting which hangs above our stair well was slightly swaying.	I
339154	I always have trouble sleeping and the swaying of the house really gave me a start. Everyone else in the house slept on as if nothing had happened. There was no noise - it was so very quiet.	III
323182	Dad was in the barn loft moving hay when he felt the barn sway. We were in the house and couldn't feel a thing.	II

Grid Ref	Comment	MM
315192	We were playing cards with friends and none of us felt or heard anything.	O
353195	I thought it was a train passing by until I realised that while it felt like a train there was no sound.	IV
342187	We could all feel something but we did not know what it was. We were watching TV at the time.	III
371195	The whole hose rumbled like a number of cars were passing quickly down the street. We jumped up to look through the windows, but there were no cars in sight.	III
385143	The whole house shook and bricks cracked in the fireplace. Most windows in the house cracked and not one glass survived in the cupboards.	VI
361173	We had been away overnight but when we got home we found quite a few windows cracked and the good dinner set had most plates broken. The rest of the house seemed undamaged.	V
380131	The first we knew about it was that we heard it on the radio.	O
345165	We all felt it and then we spent the rest of the night arguing if it was an earthquake.	III
354175	It was the second quake we have felt since we moved here. Our old grandfather clock started chiming and we had to adjust the time in the morning. We even lost a few ornaments from the mantle piece.	V

MODIFIED MERCALLI (MM) SCALE OF EARTHQUAKE INTENSITY

MM I Not felt by humans, except in especially favourable circumstances, but birds and animals may be disturbed. Reported mainly from the upper floors of buildings more than ten storeys high. Dizziness or nausea may be experienced. Branches of trees, chandeliers, doors, and other suspended systems of long natural period may be seen to move slowly. Water in ponds, lakes, reservoirs, etc., may be set into seiche oscillation.

MM II Felt by a few persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long-period effects listed under MM I may be more noticeable.

MM III Felt indoors, but not identified as an earthquake by everyone. Vibrations may be likened to the passing of light traffic. It may be possible to estimate the duration, but not the direction. Hanging objects may swing slightly. Standing motorcars may rock slightly.

MM IV Generally noticed indoors, but not outside. Very light sleepers may be awakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building. Walls and frame of building are heard to creak. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock, and the shock can be felt by their occupants.

MM V Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people frightened. Direction of motion can be estimated. Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Some windows crack. A few earthenware toilet fixtures crack. Hanging pictures move. Doors and shutters swing. Pendulum clocks stop, start, or change rate.

MM VI Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily. Slight damage to masonry D. Some plaster cracks or falls. Isolated cases of chimney damage. Windows and crockery broken. Objects fall from shelves, and pictures from walls. Heavy furniture moves. Unstable furniture overturns. Small school bells ring. Trees and bushes shake, or are heard to rustle. Material may be dislodged from existing slips, talus slopes, or slides.

MM VII General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars. Trees and bushes strongly shaken. Large bells ring. Masonry D cracked and damaged. A few instances of damage to Masonry C. Loose brickwork and tiles dislodged. Unbraced parapets and architectural ornaments may fall. Stone walls crack. Weak chimneys break, usually at the roof-line. Domestic water tanks burst. Concrete irrigation ditches damaged. Waves seen on ponds and lakes. Water made turbid by stirred-up mud. Small slips, and caving-in of sand and gravel banks.

MM VIII Alarm may approach panic. Steering of motor cars affected. Masonry C damaged, with partial collapse. Masonry B damaged in some cases. Masonry A undamaged. Chimneys, factory stacks, monuments, towers, and elevated tanks twisted or brought down. Panel walls thrown out of frame structures. Some brick veneers damaged. Decayed wooden piles break. Frame houses not secured to the foundation may move. Cracks appear on steep slopes and in wet ground. Landslips in roadside cuttings and unsupported excavations. Some tree branches may be broken off.

MM IX General panic. Masonry D destroyed. Masonry C heavily damaged, sometimes collapsing completely. Masonry B seriously damaged. Frame structures racked and distorted. Damage to foundations general. Frame houses not secured to the foundations shift off. Brick veneers fall and expose frames. Cracking of the ground conspicuous. Minor damage to paths and roadways. Sand and mud ejected in alluviated areas, with the formation of earthquake fountains and sand craters. Underground pipes broken. Serious damage to reservoirs.

MM X Most masonry structures destroyed, together with their foundations. Some well-built wooden buildings and bridges seriously damaged. Dams, dykes, and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves. Large landslides on riverbanks and steep coasts. Sand and mud on beaches and flat land moved horizontally. Large and spectacular sand and mud fountains. Water from rivers, lakes, and canals thrown up on the banks.

MM XI Wooden frame structures destroyed. Great damage to railway lines. Great damage to underground pipes.

MM XII Damage virtually total. Practically all works of construction destroyed or greatly damaged. Large rock masses displaced. Lines of slight and level distorted. Visible wave-motion of the ground surface reported. Objects thrown upwards into the air.

Categories of non-wooden construction

Masonry A Structures designed to resist lateral forces of about 0.1 g. Typical buildings of this kind are well reinforced by means of steel or ferro-concrete bands, or are wholly of ferro- concrete construction. All mortar of good quality and the design and workmanship are good. Few buildings erected prior to 1935 can be regarded as Masonry A.

Masonry B Reinforced buildings of good workmanship and with sound mortar, but not designed in detail to resist lateral forces

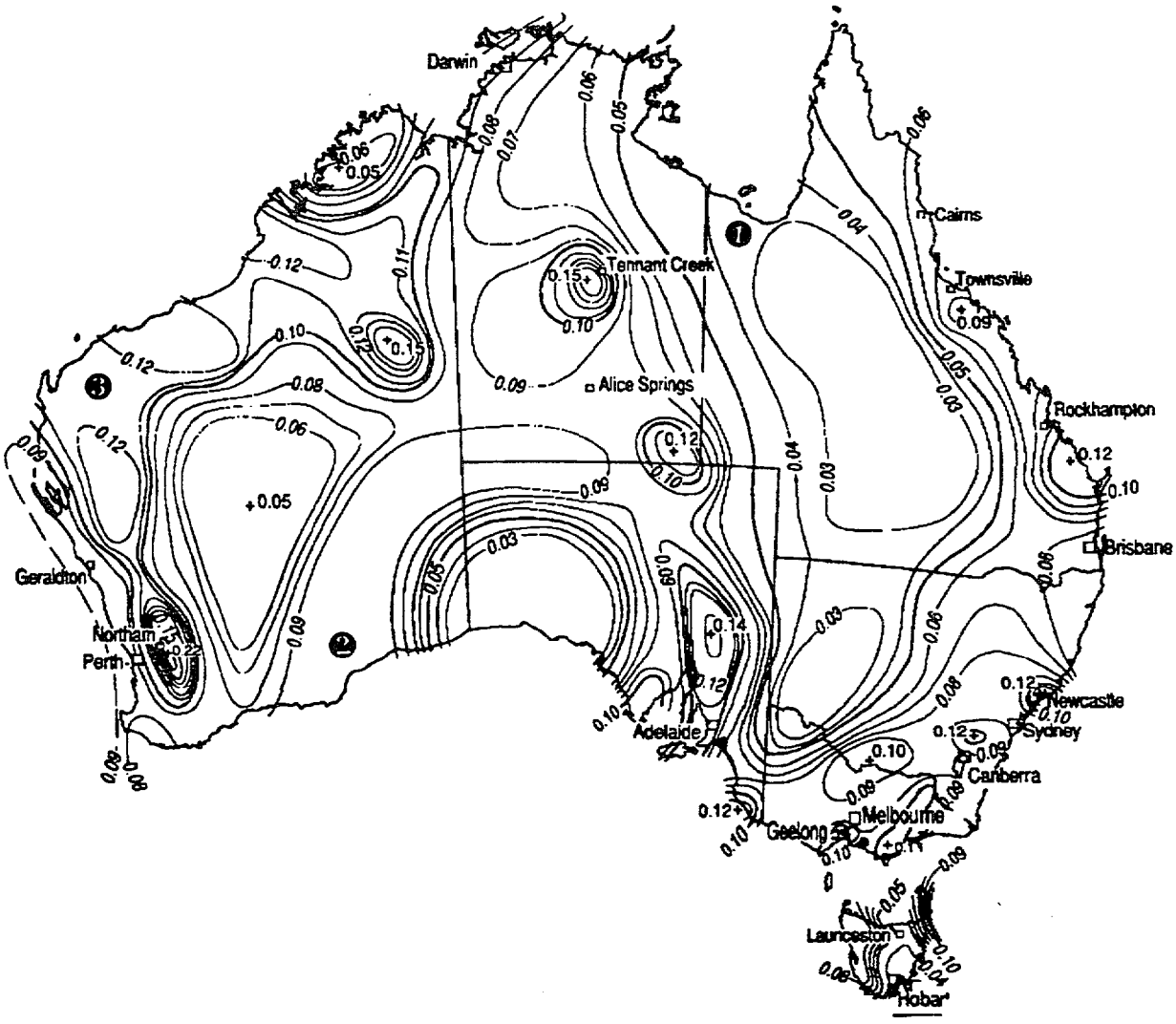
Masonry C Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces.

Masonry D Buildings with low standards of workmanship, poor mortar, or constructed of weak materials like mud brick and rammed earth. Weak horizontally.

Earthquake Hazard Map

After about 100 years of earthquake records, seismologists have been able to produce a map which shows the risk of any area having a damaging earthquake. The map below shows the possible maximum movement of the ground that could occur during earthquakes over the next 500 years. Damage will start to occur at the 0.05 level and increase as the number increases.

Seismic Hazard Map of Australia



The contours represent the estimated acceleration coefficient, which is equivalent to the acceleration due to gravity (approx. 9.8 m/ss)

? Locate where you live . What is the reading for your area ? _____

? What is the highest reading on the map and in what state or territory does this occur ?

0·22 Western Australia

Take three coloured pencils, red, orange and yellow would be best, and colour the map between the contours using the key below :

Colour	*Where*
Yellow	Between 0.09 and 0.11
Orange	Between 0.11 and 0.13
Red	Between 0.13 and greater

Your map now highlights those areas of high risk of being damaged by an earthquake in the next 500 years.

? Of all the capital cities, which would be the most prone to earthquake damage?

Adelaide

? Imagine you are a seismologist and have been asked for your advice on which of the locations marked ❶ ❷ ❸ on the map would be the best for a new city in which all the buildings were to be skyscrapers. Which would you suggest and why?

(1) lowest seismic hazard (0.035)

Scientists often use "contours" to show feature other than height above sea-level. Seismologists often use "contours" which show lines of equal earthquake intensity on a map. These lines are called isoseismal lines - "iso" means the same and "seismal" refers to earthquakes.

Climate Change

From AGSO Record 1995/21

Iceman

The Polar Ice Cap Expedition made a gruesome discovery yesterday on its return leg of a five week ice-core collection trip. Team leader, Dr Fiona Allen, sent a message to police that her team had come across some human remains while drilling an ice core. "The remains seemed old but well preserved" Dr Allen said. Scientists have been flown into the site to examine the remains. The expedition will continue to collect ice cores to provide the team with more information about past climates.

When Dr Fiona Allen returns to Australia she employs you to study the ice core she and her team extracted from the "Ice Man" site. Your job is to find out about the age of the remains and try to find out why a person would be so far north on the ice cap. She also tells you that she spoke with some of the native people of the area who said that it is common practice for hunters to journey onto the polar ice cap, but not as far as where the remains were found.

You notice that the core contains nine layers of volcanic ash from which you remove a small sample and send away for radiometric dating. The dating team returns you a range of dates for each sample - the youngest age and the oldest age of each volcanic layer You assume that there is always a error of 10 years in their dating, so that a range of less than ten years is probably one volcanic eruption of an age between the two dates (ie. VE1 was an eruption 3 705 years ago).

The information they provided is :

Volcanic Event number	Youngest age (years ago)	Oldest age (years ago)
VE1	3 700	3 710
VE2	4 702	4 710
VE3	5 295	5 300
VE4	8 715	8 722
VE5	8 932	8 935
VE6	13 885	13 891
VE7	19 420	19 427
VE8	19 610	20 343
VE9	20 717	20 726

On the ice core log provided, write the ages of each volcanic event on the right-hand side of the core.

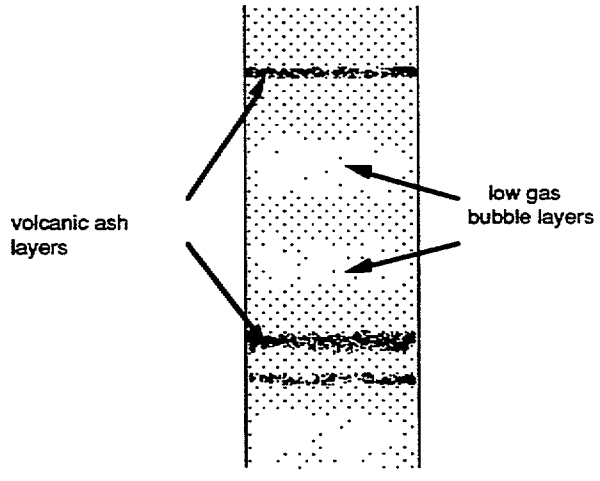
? How many years does this core represent? ≈ 23,200 years

Calculate the time scale of the ice core by measuring its length and dividing it by the total amount of years it represents.

1mm= 100 years

? What is the approximate age of the ice in which the Ice Man was found? 6750 years

You also know that areas in ice cores which are low in gas bubbles represent periods of time when the climate was slightly warmer and the ice melted releasing the gases.



These zones are marked a to e on the left-hand side of the ice core.

? What information does this tell you about the climate at the time the Ice Man lived?

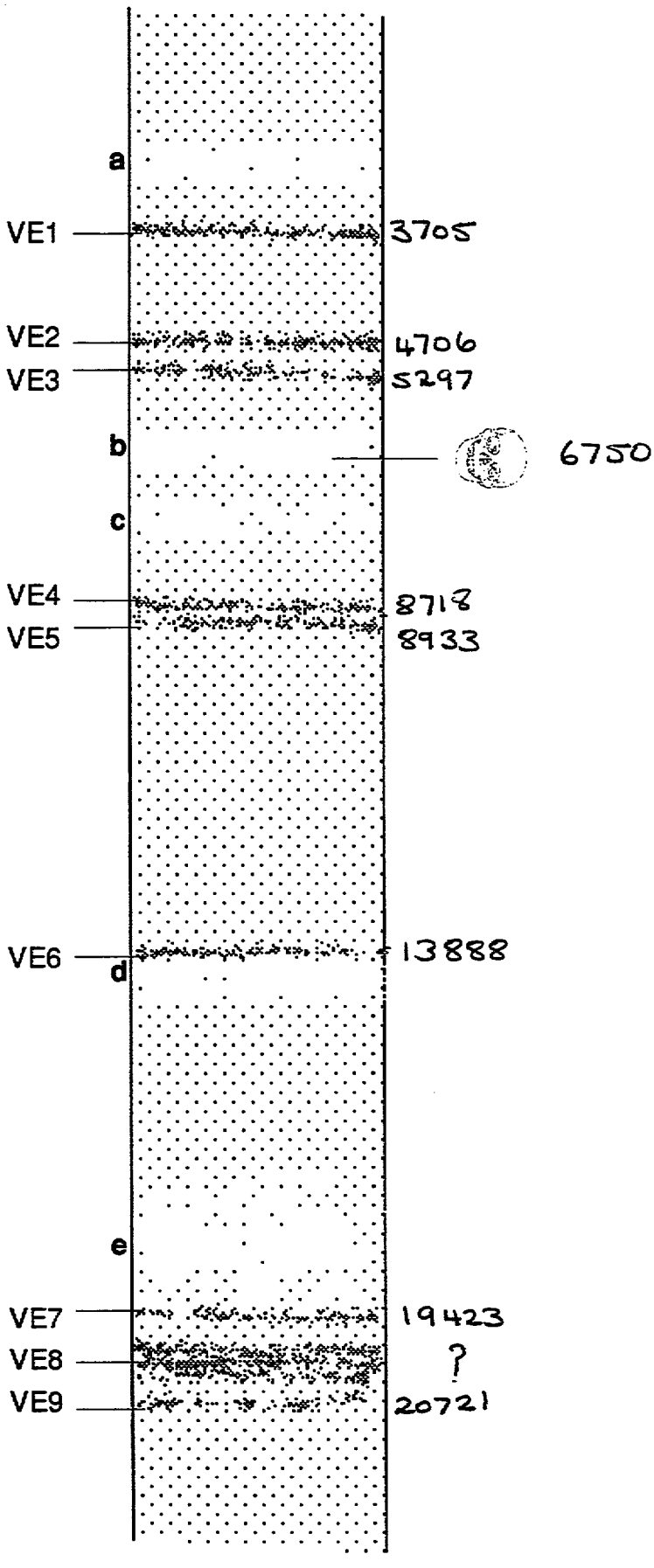
The 'Ice Man' lived in a period when the temperature was warmer

? Write a paragraph on the relationship, or lack of relationship, between the volcanic events and changes in climate.

Overall there appears to be no direct relationship between volcanic events and changes in climate. However it is possible that the VE6 may have ended a period of warm climate

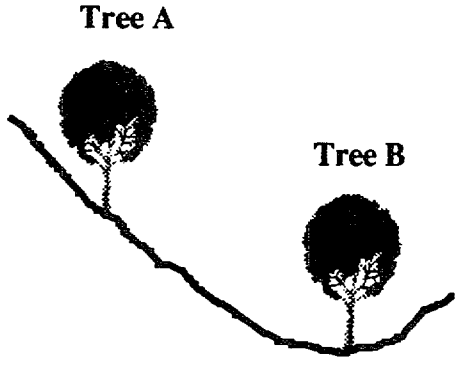
ICE MAN LOCATION
ICE CORE

Ice core log



Tree Ring Climates

Two field hands, Jayne Jones and Bart Smith, recently travelled into Mt Field National Park in central Tasmania to collect cores from some ancient trees for you to use in your study of past Australian climates. Using a special device, they removed small core sections from two living trees, A & B, in a small valley. Jayne recorded the position of the two trees in her field note book.



Back in the laboratory, Bart removed two small samples from each core (A1, A2 & B1, B2) and sent the samples away for radiocarbon dating. The results came back as :

Sample	Age in years*
A1	674
A2	641
B1	653
B2	644

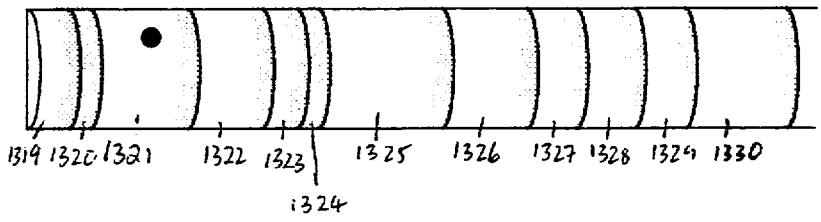
* based on 1995 standard

Calculate the year the tree produced the tree ring from which the four samples were taken by subtracting the age from 1995 (the radiocarbon date standard used) and complete the table below.

Sample	Year of each sample
A1	1995 - 674 = 1321AD
A2	1995-641 = 1354 AD
B1	1995-653 = 1342 AD
B2	1995-644 = 1351 AD

Jayne prepared the core samples for you and marked from which tree rings Bart removed the dating sample. Write the year below these tree rings and fill in the years in between. ie.

A1



The amount that a tree grows during its growing season, normally summer, depends on the amount of water available to the tree and the warmth of the sun. A dry summer may result in a narrow growth ring, while a wet summer a wider growth ring.

? In what year did the two trees grow the least (narrowest growth rings) ?

Tree A : 1335 Tree B : 1334

? In what year did the two trees grow the most (widest growth rings) ?

Tree A : 1355 Tree B : 1324

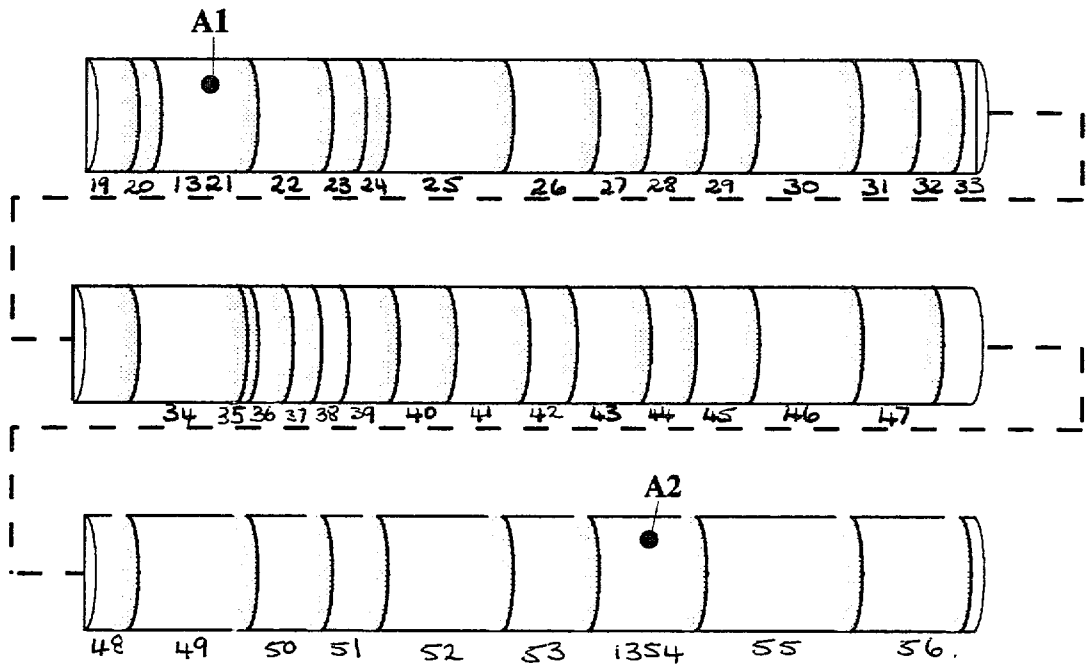
? What climatic feature, typical in Australian climate history, may have happened from 1335 to 1347? Drought

? During what other years did this climatic feature occur? 1323-1324 1326-1329

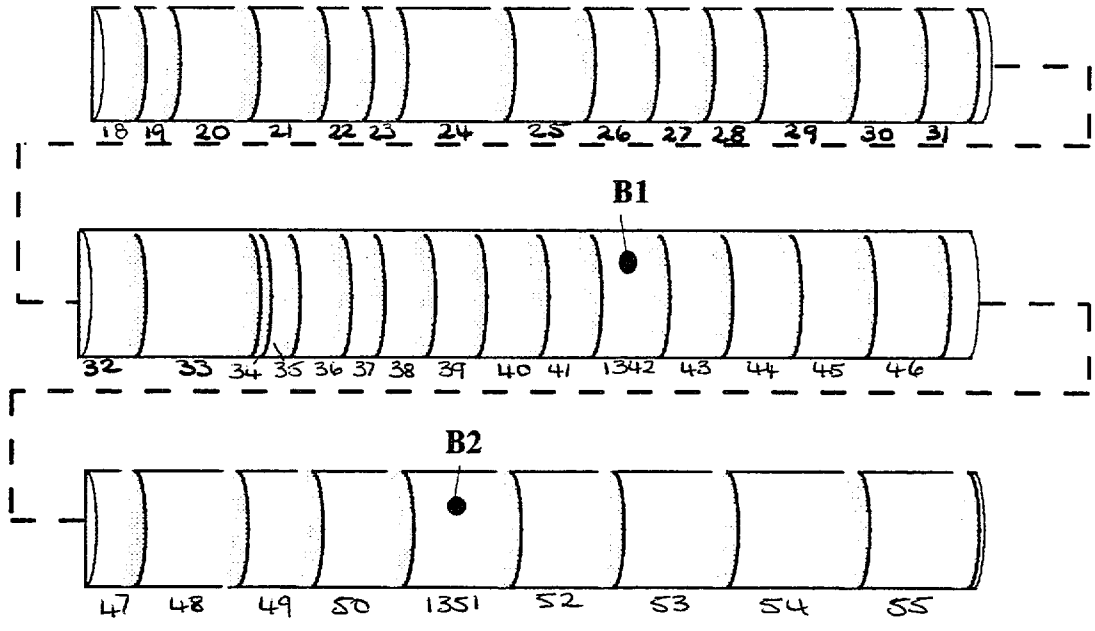
? The growth rings of Tree A and Tree B do not appear to be exactly the same. What environmental factors may differ between the two trees? Tree A is on a slope. Tree B is in a valley - ie affect is on available water - valley is wet/slope drier. This causes a one year delay in the affect of drought in the growth of trees

Which of the two trees would you select to provide more detailed climatic information and why? A - as it provides a greater variation between wet and dry periods

Core from Tree A

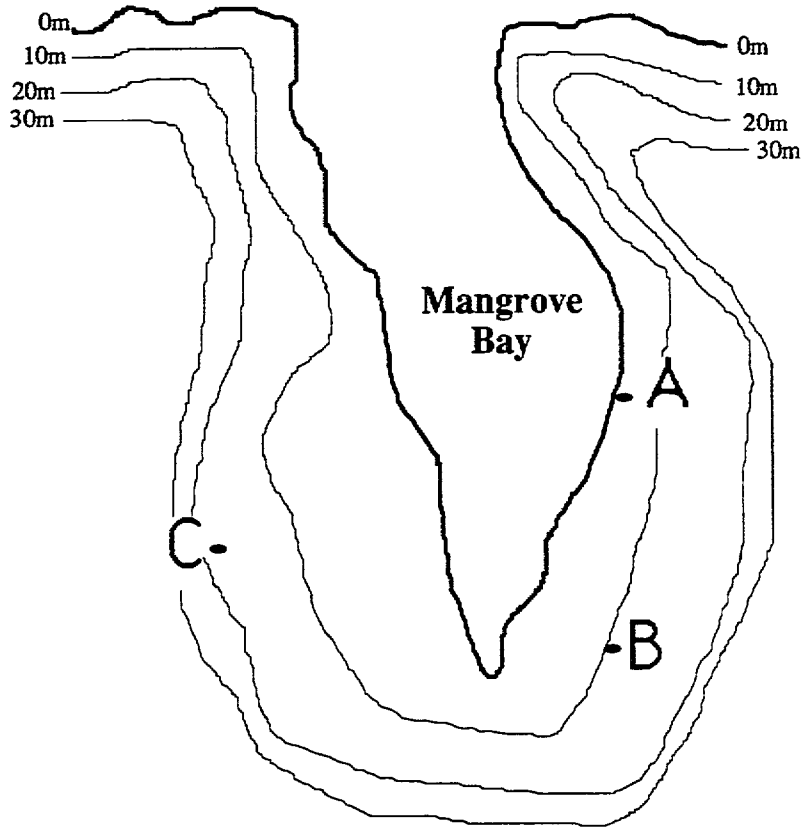


Core from Tree B



Terrace Temperatures

In a small bay in southern Queensland, geologist Abdul Theca discovered sand deposits on "terraces" above the current sea level. Abdul collected a small sand sample from each of the terraces at locations A, B and C and sent them to microfossil expert Sanja Leeverson for fossil identification.



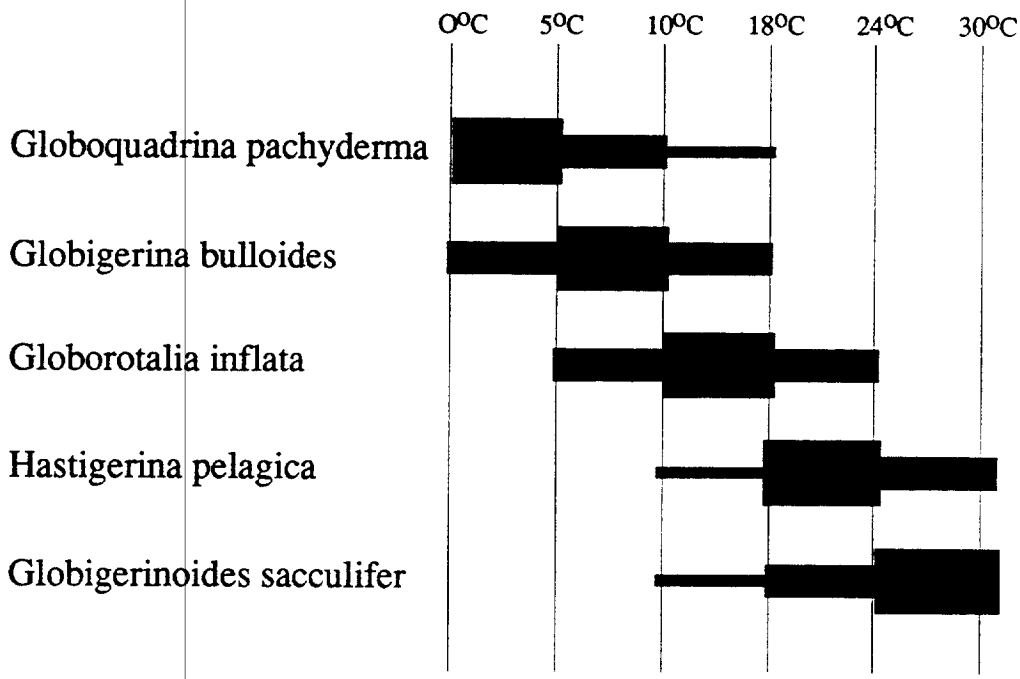
Location of samples taken from Mangrove Bay

Sanja recognised five different fossil foraminifera in the terraces and provided Abdul with the following information about their abundance.

Foram	Sample A	Sample B	Sample C
Globoquadrina pachyderma	10%	0%	0%
Globigerina bulloides	20%	0%	0%
Globorotalia inflata	40%	30%	0%
Hastigerina pelagica	15%	50%	30%
Globerinoides sacculifer	15%	20%	70%

Abdul has contacted you and asked if you could find out what may have caused the changes in sea level, as each of the terraces where deposited when the sea level was higher than present.

You come up with two possible explanations - either the sea level rose because of a period of climate change or the land surface is being uplifted out of the water because of some other factor. You find in a Foram reference book the following diagram which shows the relative abundance of the foram fossils recognised by Sanja plotted against sea water temperatures.



Using this information, at approximately what temperature was the sea when each of the three sand terraces was deposited?

Terrace A (sample A) : 10 - 18 °C

Terrace B (sample B) : 18 - 24°C

Terrace C (sample C) : 24 - 30°C

How high are these terraces above current sea level ?

Terrace A (sample A) : 2 m

Terrace B (sample B) : 12 m

Terrace C (sample C) : 18 m

What appears to be the relationship between the sea temperature and the height of the terraces?

As the sea temperature increases so does the height of the terraces. Therefore sea level has increased as a function of sea temperature. (The increase is about 1m/°C)

What further information could you seek to confirm that the sea level changes are related to the change in sea level temperatures ?

Stable isotope evidence from the fossils; evidence that no geological features ie fault had been active; additional foram information from other sites

Changes in climate, either warming or cooling, cause changes in ocean currents. As all of these fossils are planktonic (floating) they will have been brought into the bay by the prevailing ocean currents moving along the Queensland coast.

During an ice age, the cold waters from the southern Tasman sea move further up the east coast and may reach Mangrove Bay. If these waters are around 8-12°C, what proportion of foram fossils would be deposited in sands in the Bay and would these "terraces" be higher or lower than the present sea level?

Globoquadrina pachyderma 25%

Globigerina bulloides 50%

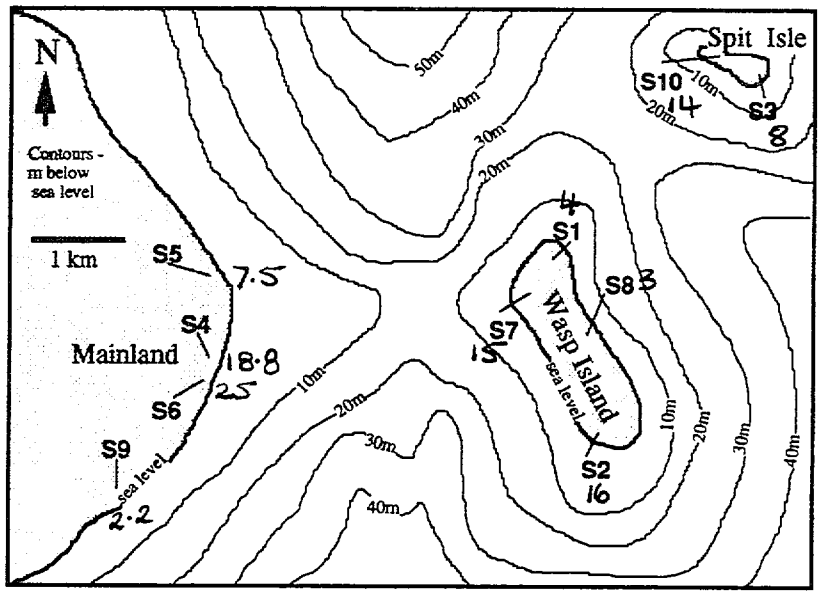
Globorotalia inflata 25%

The terraces would be lower than present sea level

Occupation Ages

You have been asked to gather evidence for aboriginal occupation of two islands, Wasp Island and Spit Isle, off the coast of northern Australia since the last Ice Age.

You visited the islands and the adjacent mainland with a member of the local Aboriginal community and collected charcoal samples from ancient fireplaces. It is known that the tribe which occupied this area did not build or use boats or rafts. The locations of your samples are marked on the map below.



Sample Locality Map

Each of the samples has been analysed for radioactive carbon 14. Use this information, and the Radiocarbon decay graph, to find the age of each of the samples and complete the table below.

Sample	Remaining C14	Age
S1	62%	4,000
S2	15%	16,000
S3	38%	8,000
S4	10%	18,800
S5	40%	7,500
S6	6%	25,000
S7	16%	15,000
S8	70%	3,000
S9	80%	2,200
S10	18%	14,000

? What is the age of the oldest sample from Wasp Island ? 16,000

? What is the age of the oldest sample from Spit Isle ? 14,000

? What is the age of the oldest sample from the Mainland ? 25,000

When does this suggest that Aboriginals were able to walk to the islands? 14,000

What must have happened for the tribal people to walk to these islands ?

The sea level had to be lower, due to lower temperatures such as an Ice Age

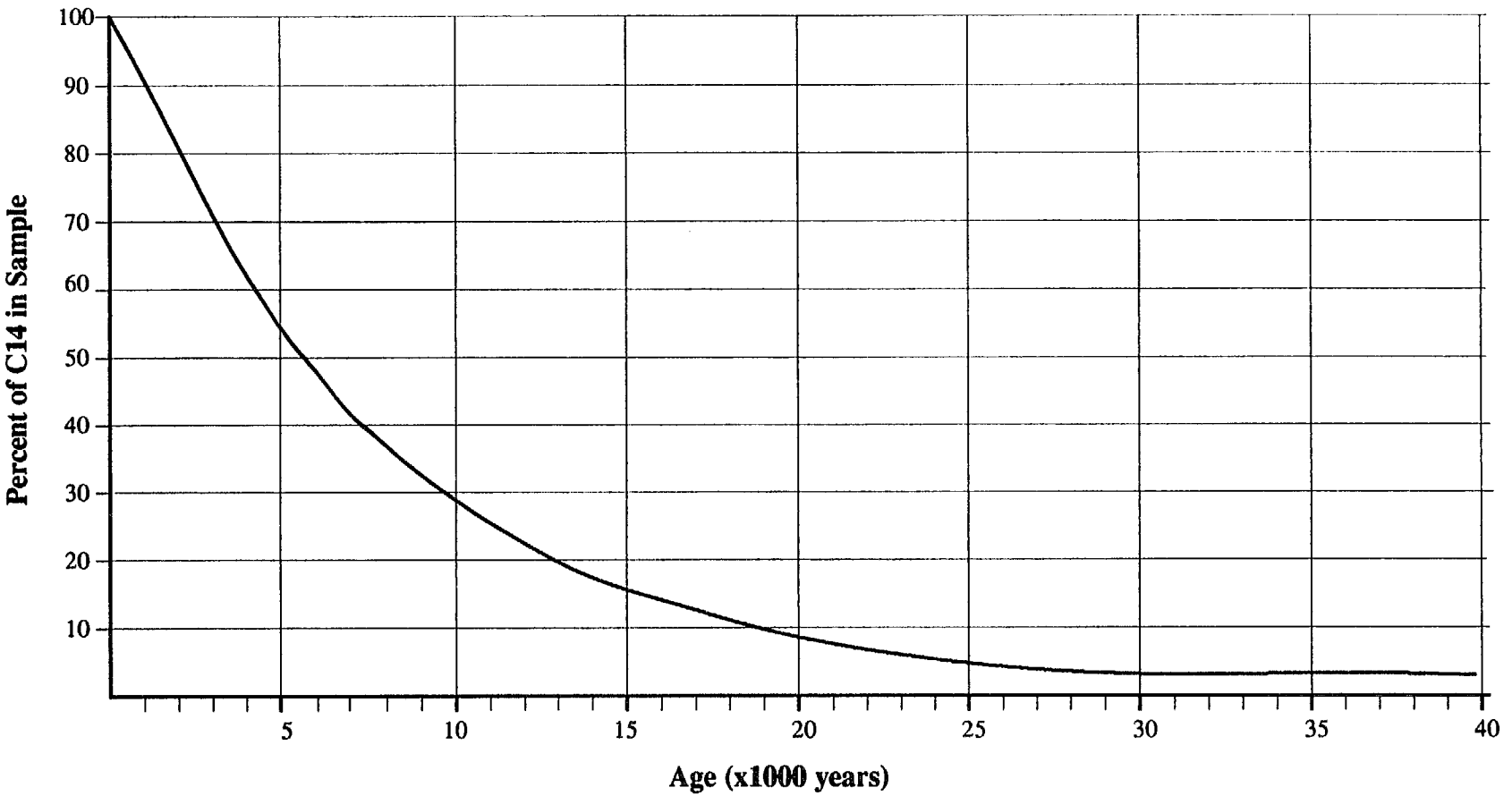
What evidence can you find to explain why the two islands were not initially occupied at the same time?

The sea level would need to drop about 15m to walk to Wasp Island but about 25m to walk to Spit Isle

What other evidence might you be able to collect to prove your findings?

Sea water temperature through stable isotope evidence or fossil evidence to show sea level had dropped

Radiocarbon Decay Curve



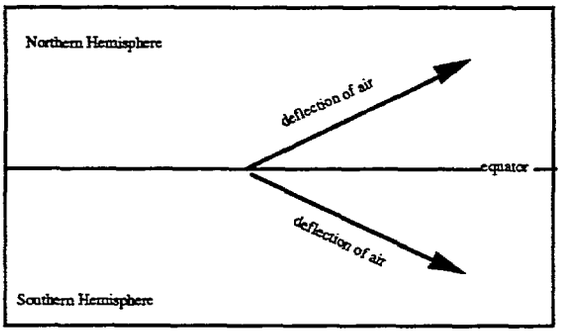
Eruption on Climeworld

It is the year 2025 and you, a trained climatologist, have travelled to the planet Climeworld. You have been asked by the Climeworld government to research the effect of volcanic eruptions on their planet's climate.

You know that every time a volcano erupts it puts many tonnes of volcanic aerosols into the atmosphere which block the solar energy reaching the planet's surface near the eruption. These areas are cooled and during large eruptions, crops fail and local inhabitants suffer famine.

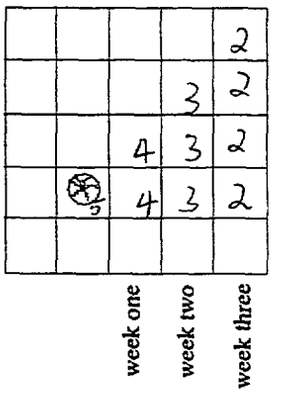
Background information on Climeworld

The atmosphere on Climeworld is very similar to Earth. However, the circulation of the Climeworld atmosphere is very simple. Air at the equator is heated and rises and moves towards the poles. Because of the circulation of the planet, the poleward moving air is deflected.

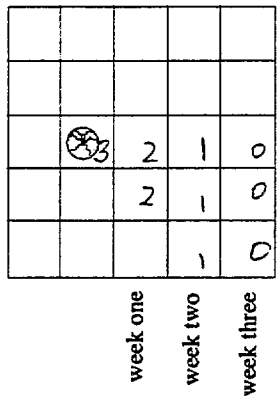


When a volcano erupts on Climeworld it is given an eruption magnitude number. (The largest recorded eruption was a 20). Every week after eruption the aerosol "cloud" spreads out in the atmosphere and decreases in intensity in the following way :

Northern Hemisphere - to the east one distance unit and north-east one unit. For example in an eruption of magnitude 5 -



Southern hemisphere - to the east one distance unit and south-east one unit. For example in an eruption of magnitude 3 -



The cloud continues to spread until it has completely dispersed (intensity=0)

The magnitude number is equivalent to the amount of solar radiation blocked from reaching the surface. Normally 25 units of solar radiation reach the surface of the planet. In an eruption of magnitude 10, directly under the eruption cloud only 15 units or solar radiation will reach the surface.

A magnitude 5 eruption is recorded from a volcano located at 24-06 (the Map of Climeworld has a grid reference system, the first number refers to the columns while the second number refers to the row). Note : this volcano is in the northern hemisphere of Climeworld. Plot the spread of the aerosol cloud until it is completely dispersed.

? How many weeks does it take for the eruption cloud to disperse? 5 weeks

A magnitude 9 eruption is recorded from a volcano located at 19-21 Plot the spread of the aerosol cloud until it is completely dispersed.

? How many weeks does it take for the eruption cloud to disperse? 9 weeks

? What is the smallest eruption magnitude which this volcano would need to erupt to cause some solar radiation blocking over the city of Icely (31-24)? magnitude 13

What would happen if a magnitude 20 eruption took place at the volcano located on the equator (marked V)? Because of the size of the eruption, assume that the four surrounding squares (29-13, 29-14, 30-13, 30-14) all receive the initial intensity 20.

? What cities would affected by this eruption and how long after the eruption would they record the effects? Doulton - start 7 weeks after
Loppo - start 6 weeks
Northtown - start 3 weeks

The growth of the planet's plants is related directly to the amount of solar radiation reaching the surface. The amount of plant activity against the solar radiation level is :

Solar radiation level	Plant activity
25	normal level
20	most plants survive
18	deciduous trees loose leaves, summer crops fail
16	winter crops fail
14	all crops fail
12 or less	all plants die

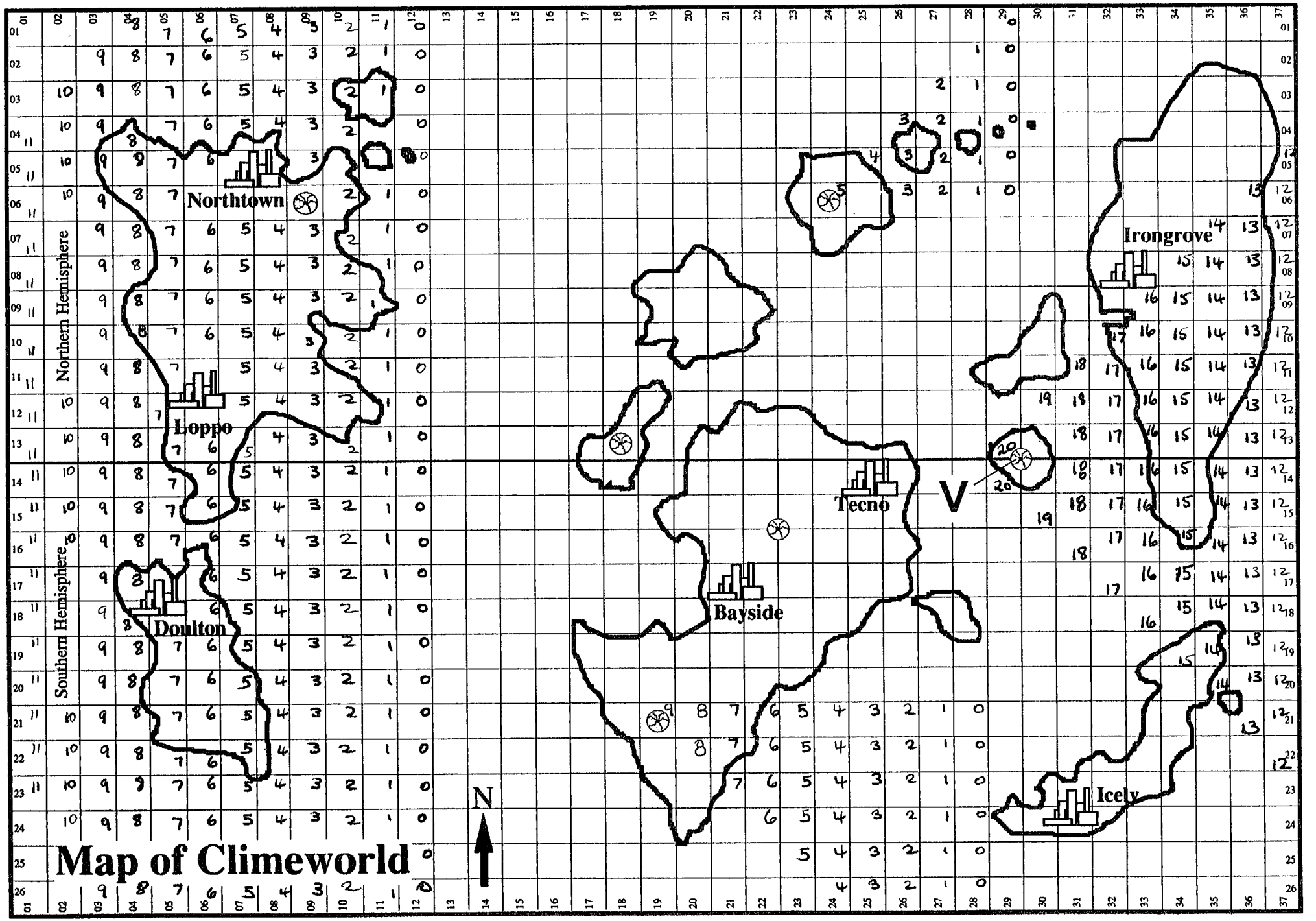
Using a coloured pencil, shade those zones in which all crops fail - which marks the area in which Climeworld inhabitants would be in famine.

? Why does this volcano have the potential to affect the entire planet's climate?

Because it is on the equator so the aerosols go into both N & S hemispheres

? Are there any other volcanoes on the planet which could cause such widespread famine?

Volcano at 18-13



Time & Life

From AGSO Record 1995/14

Geological Time

Getting it to scale

Geological time is so immense (geoscientists believe that the earth is 3,800,000,000 years old) that it is often difficult for us to understand the vast amounts of time over which our Earth has developed.

One way of representing geological time is to make a time line, in which every millimetre equals a number of years.

Calculate how long a piece of paper you would need to use to draw a time line for the ages of the Earth, using the following scales.

Hint : there are 1 million millimetres in a kilometre

				Length of paper
1mm =	10 years	3,800,000,00Ø ÷ 10 =	380,000,000mm =	380 km
1mm =	100 years	3,800,000,0ØØ ÷ =	38,000,000 mm =	38 km
1mm =	1,000 years	3,800,000,ØØØ ÷ =	3,800,000 mm =	3.8 km
1mm =	10,000 years	3,800,00Ø,ØØØ ÷ =	380,000 mm =	380 m
1mm =	100,000 years	3,800,0ØØ,ØØØ ÷ =	38,000 mm =	38 m
1mm =	1,000,000 years	3,800,ØØØ,ØØØ ÷ =	3800 mm =	3.8 m
1mm =	10,000,000 years	3,80Ø,ØØØ,ØØØ ÷ =	380 mm =	38 cm

Using the 1:10,000,000 scale and the 1:10,000 scale, calculate the distance from the present time to the various periods of geological time using the table below.

The Geological Time scale is used both as a relative time scale (comparing ages to each other) and an absolute time scale (giving an actual time in years before present). This activity is about absolute time.

Scale 1:10,000,000

(1mm=*10,000,000 years or 1 year=0.0000001mm)*

Era	Period	Start of period in years before present	Distance (mm)
	RECENT	15,000	0·0015 mm
CAINOZOIC	QUATERNARY	1,800,000	0·18 mm
	TERTIARY	65 million	6·5 mm
MESOZOIC	CRETACEOUS	141 million	14·1 mm
	JURASSIC	205 million	20·5 mm
	TRIASSIC	251 million	25·1 mm
PALAEOZOIC	PERMIAN	298 million	29·8 mm
	CARBONIFEROUS	354 million	35·4 mm
	DEVONIAN	410 million	41·0 mm
	SILURIAN	434 million	43·4 mm
	ORDOVICIAN	490 million	49·0 mm
	CAMBRIAN	545 million	54·5 mm
PRECAMBRIAN	PROTEROZOIC	2500 million	250·0 mm
	ARCHAEAN	3800 million	380·0 mm.

Scale 1:10,000

(1mm=*10,000 years or 1 year=0.0001)*

Era	Period	Start of period in years before present	Distance (mm)	Distance (m)
	RECENT	15,000	1·5	0·0015
CAINOZOIC	QUATERNARY	1,800,000	180	0·18
	TERTIARY	65 million	6500	6·5
MESOZOIC	CRETACEOUS	141 million	14100	14·1
	JURASSIC	205 million	20500	20·5
	TRIASSIC	251 million	25100	25·1
PALAEOZOIC	PERMIAN	298 million	29800	29·8
	CARBONIFEROUS	354 million	35400	35·4
	DEVONIAN	410 million	41000	41·0
	SILURIAN	434 million	43400	43·4
	ORDOVICIAN	490 million	49000	49·0
	CAMBRIAN	545 million	54500	54·5
PRECAMBRIAN	PROTEROZOIC	2500 million	250000	250·0
	ARCHAEAN	3800 million	380000	380·0

Find out the year (known or estimated) for the following events and then calculate the distance from the present time using the 1:10,000,000 scale and the 1:10,000 scale.

Event	Year	1:10,000,000 (mm)	1:10,000 (mm)
Birthday	–	1996 - date x 0.0000001	1996 - date x 0.0001
First Moon landing	1969	0.0000027	0.0027
First artificial satellite	1957	0.0000039	0.0039
First powered aircraft flight	1903	0.0000093	0.0093
Invention of the printing press	1795	0.0000201	0.0201
First motor car	1769	0.0000227	0.0227
Gold rushes	1850	0.0000146	0.0146.
Captain Cook discovers Eastern Australia	1770	0.0000226	0.0226
Birth of the Prophet Mohammed	570	0.0001426	0.0146
Birth of Christ	0AD or (4BC)	0.0002	0.2
Birth of Buddha	563 BC	0.0002559	0.2559
Birth of Confucius	551 BC	0.0002547	0.2547
Start of Aboriginal occupation	60,000	0.0061996	6.1996
Last Ice age	18,000	0.0019996	1.9996
Oldest known Homo sapien fossil	1.5 million	0.15	150
Extinction of Dinosaurs	65 million	6.5	6500
Oldest dinosaur fossil	≈245 million	24.5	24500
Oldest flowering plant fossil	≈100 million	10.0	10000
Oldest plant fossil	≈420 million	42.0	42000
Oldest fish fossil	≈400 million.	40.0	40000

Note
Before Christ (BC) make them negative numbers

With your teacher, select one scale and draw out the time line for the geological history of the Earth.

Hints :

1:10,000,000 Scale

You will be able to draw your time line on a piece of paper around 40cm long. However, it will be very hard to separate some of the dates as they will be in fractions of millimetres.

1:10,000 Scale

You will need to do this on a footpath alongside a straight road. You can use chalk to make the marks on the foot path. It will need to be around 400m long. This will allow you to separate more, but not all, dates.

Another Scale

An alternative is to calculate a different scale so as to fit a time line along one wall of the classroom. To calculate this scale, use the following formula :

L= length of wall (m)

1mm = 3,800,000,000 (L x 1000) years

e.g. A classroom wall of 11m

L=11

1mm = 3,800,000,000 (11 x 1000) years

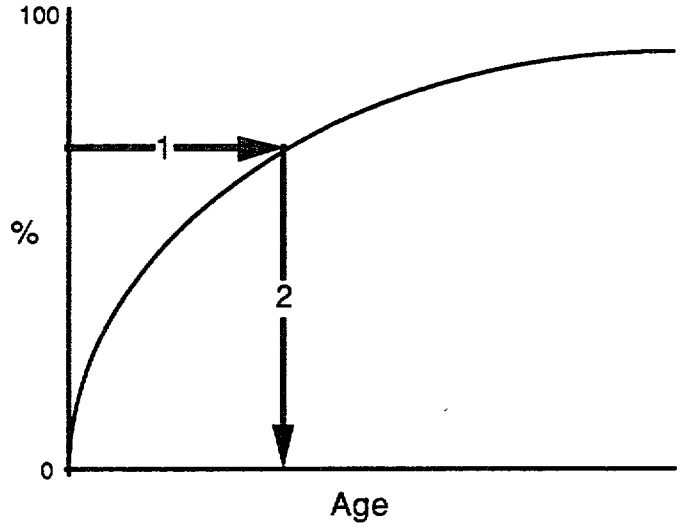
= 345,454 years

Reading Decay Product Curves

During the process of radioactive decay a "parent" radioactive atom decays to form a "daughter" atom over time. To calculate a radiometric age, geoscientists measure, using a mass spectrometer, the amount of daughter atoms that have accumulated in the sample through decay.

They then use known decay product curves to find the age of the sample.

To read the decay product curves, use the vertical (y-axis) to find the percent of decay product in the sample and read across (1) until you touch the curve representing that daughter atom. Then drop straight down (2) to find the age. Note that the scale on the decay curves is X 1,000,000,000 years.



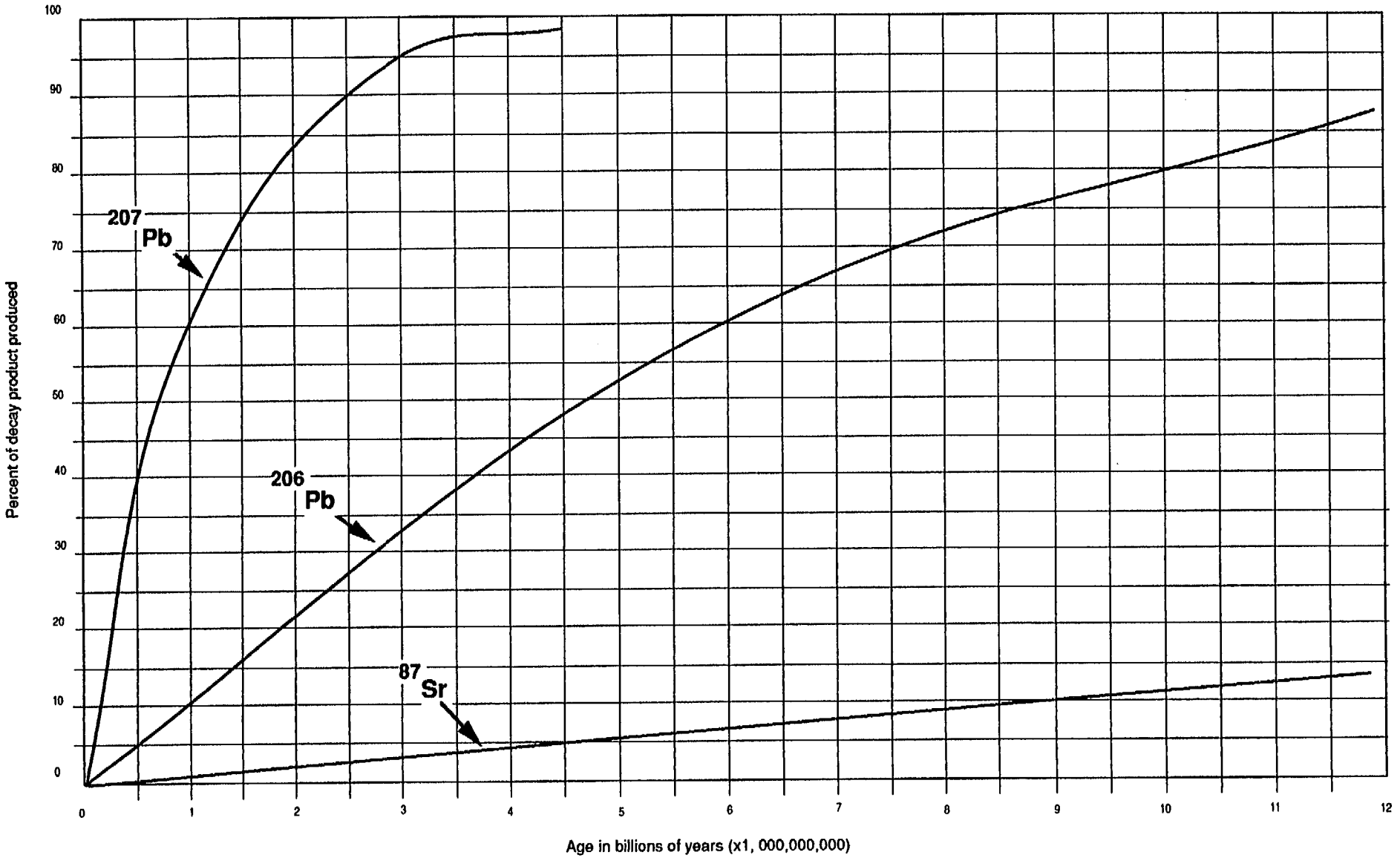
Find the ages of the following samples

Daughter Atom	% of daughter atom accumulated	Age (years)
^{207}Pb	60	1 billion years
^{207}Pb	40	0·5 billion years.
^{207}Pb	50	0·7 billion years
^{206}Pb	9	0·8 billion years.
^{206}Pb	50	4·75 billion years
^{87}Sr	5	4·5 billion years
^{87}Sr	4	3·5 billion years

If the age of the Earth is 4 600 000 years, what percentage of the daughter atoms will have accumulated .

^{207}Pb 98% ^{206}Pb 48% ^{87}Sr 5·5%

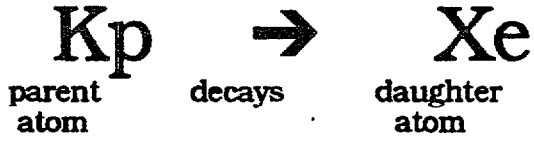
Radioactive decay product curves



Radioactive Ages

You have discovered a new radioactive element, which you have called Kryptonite (after Superman's home planet). You have given it the chemical symbol Kp.

You have found that Kryptonite decays to Xenon (a noble gas) after a period of time.



You want to use Kryptonite to date rocks found in Australia. Unfortunately, you do not know the half-life of Kryptonite — that is the period of time it takes for one half of Kp to decay to Xe. However, using other radiometric dating elements such as Uranium 235, you do know the ages of some rocks containing Kp. You have summarised these in the table below.

Rock no.	U^{235} age	% Kp	% Xe
1	5,000,000	23	77
2	500,000	75	25
3	2,350,000	40	60
4	4,475,000	25	75
5	7,200,000	14	86
6	300,000	82	18
7	1,250,000	56	44
8	3,150,000	33	67
9	9,900,000	9	91
10	11,400,000	7	93
11	1,800,000	47	53
12	5,750,000	18	82

On the blank graph, plot the twelve points then draw a curve of best fit.

?

What is the half-life of Kp (how long does it take for 50% to decay to Xe?)

1,700,000 years

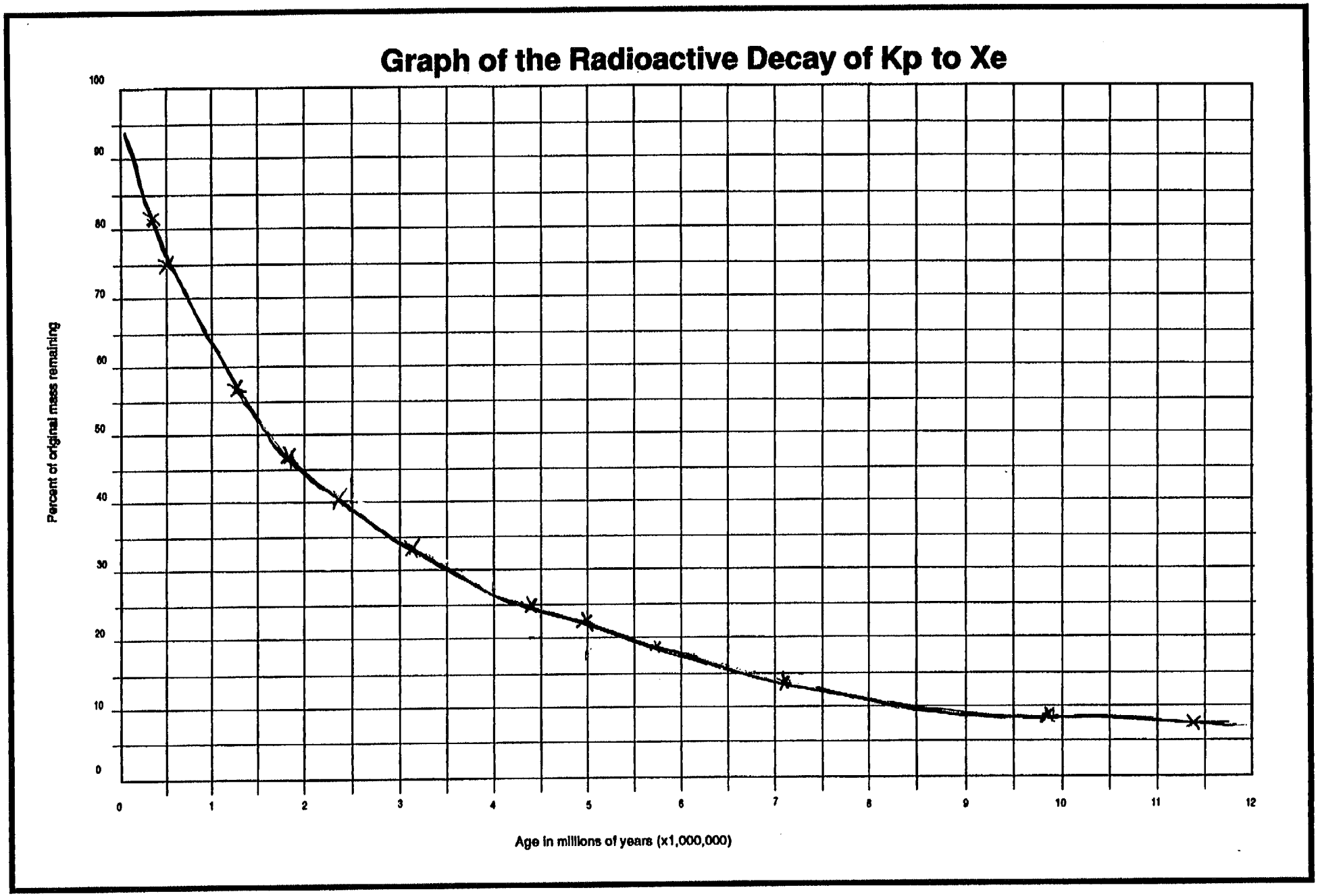
?

What are the ages of the rocks listed in the table below

Rock no.	% Kp	% Kp	AGE
13	30	70	3,600,000
14	15	85	6,800,000

?

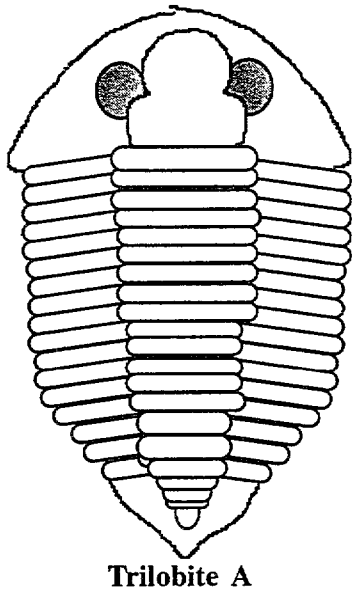
Another geoscientist dated Rock 13 using U^{235} and found an age of 8,500,00 years. What may have happened to the rock to give you an incorrect answer? Release of daughter element as it is a gas!!



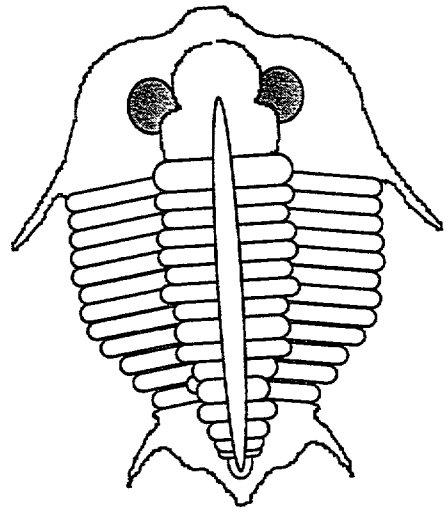
Critter Identification

A geologist, Sally Welsh, has returned from a field trip with rock samples containing two unknown trilobites. Your job, as a trilobite palaeontologist, is to describe the two trilobites so that other palaeontologists will be able to recognise them in the field.

Below are diagrams you have had drawn of the two trilobites. They are life-size in these drawings.

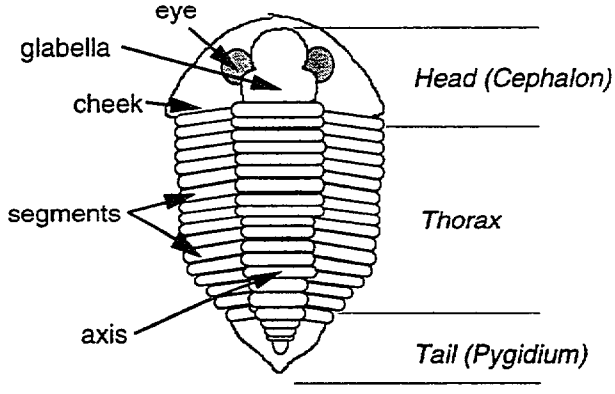


Trilobite A



Trilobite B

When you describe the trilobites, you should use the correct names for each of the trilobite parts. The correct parts



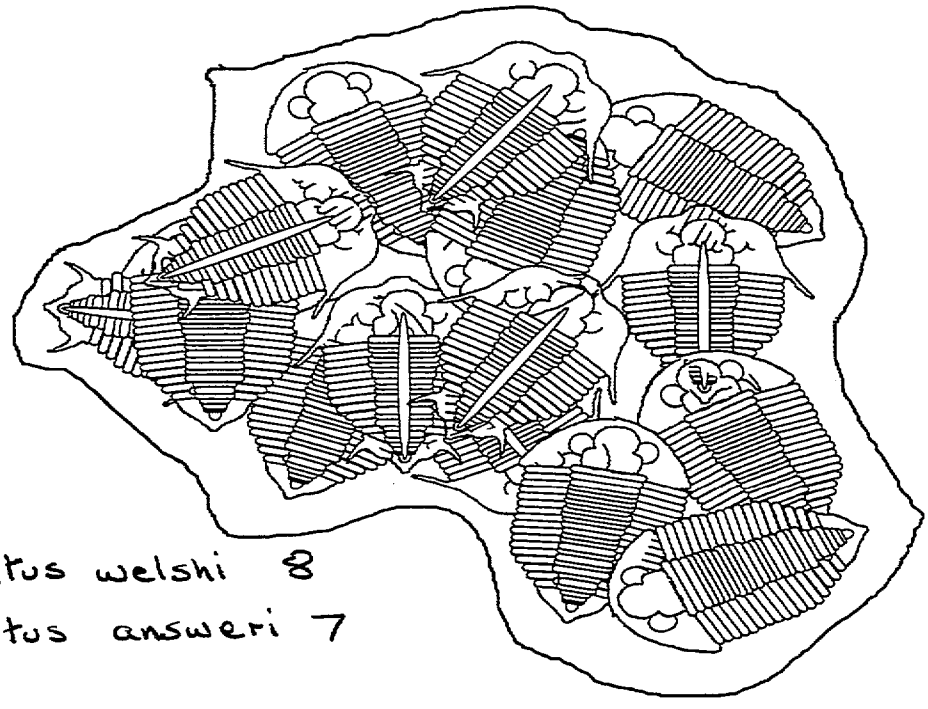
You have already completed the description of the Trilobite A and have named it after the geologist who found it. Your description reads :

Trilobitus welshi is 67mm long and up to 43mm wide. Its thorax and axis have 17 segments. It does not have a ridge running along its axis. It has smooth rounded cheeks with no cheek spines. Its glabella is smooth and it has two eyes each of 6mm diameter.

Write a description and name Trilobite B.

Trilobitus answeri is 67 mm long and 57 mm wide at its cheek spines. Its thorax has 12 segments. It has a central ridge running down its axis from the Head to the Tail. It has cheek and tail spines. The spines point backwards between 7mm - 10 mm from the body. It has two eyes 6 mm diameter

On the next field trip, Sally brought back a rock containing a number of trilobites which you have described. How many of each type are there?

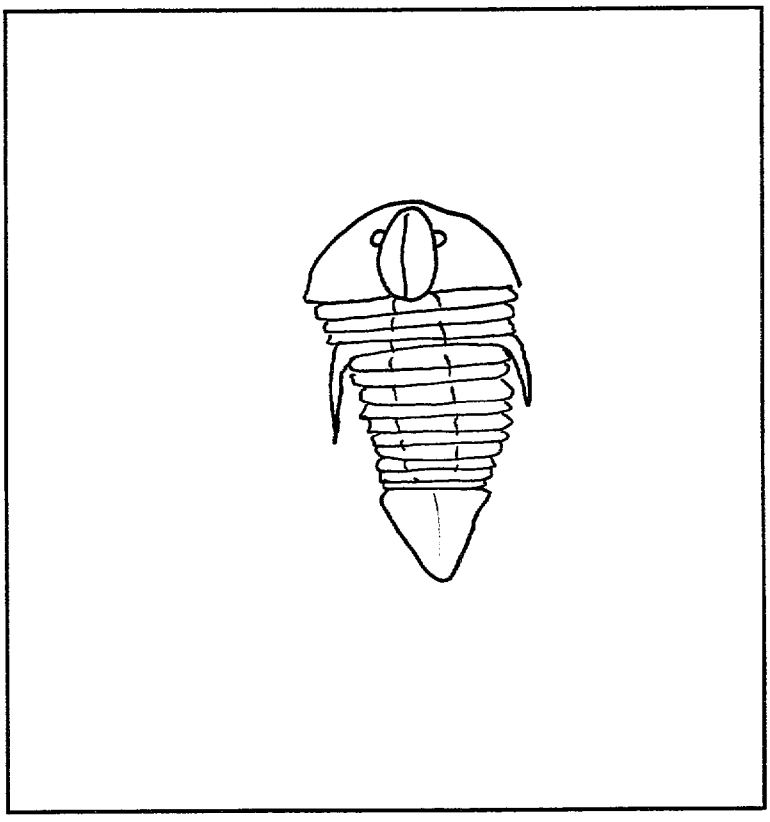


Trilobitus welshi 8

Trilobitus answeri 7

While you are looking through the old papers of a long dead trilobite expert you come across a description of a trilobite he had described. From his description, can you sketch what the trilobite might have looked like?

"Trilobitus lewisi is 50mm long. Its widest part is at the boundary of the cephalon and thorax where it is 27mm. The cephalon is a perfect semi-circle with a perfect oval glabellar. It has small (2mm) eyes. The thorax has 12 segments. The four segment from the head has a spine which points towards the tail. The axis also has twelve segments. The pygidium is 20mm long."



Fossil Frazzle

On the way back from her last field camp, Caroline had to drive her four-wheel drive through a flooded creek. All her fossils samples became wet and the labels washed off. Caroline quickly put new labels on the samples (A,B,C,D). Can you help Caroline by identifying the fossils and working out the ages for her samples?

What to do.

1. Examine the pictures of the eight fossil types which Caroline had researched before going into the field. Examine each of Caroline's samples and identify the fossils they contain.
Note : Some fossils are incomplete! Write the name and number of the fossil in the space provided below :

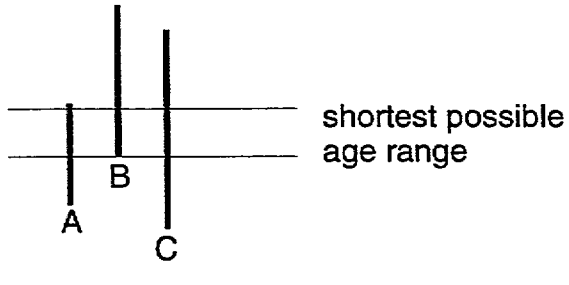
Sample A : Magellania (3) Obovithyis (8) Heliolites (4)

Sample B : Cyrtograptidae (7) Trinucleina (2) Heliolites (4)

Sample C : Magellania (3) Trinucleina (2) Agnostina (5) Sinograptidae (1)

Sample D : Magellania (3) Agnostina (5) Asaphina (6)

2. Using the Geological Time scale (with fossils groups), give a shortest relative age range for each of Caroline's samples using the Epoh/Period names. Each of the fossils is shown on the time scale with a line repesenting the period that they existed on Earth. This age range for the sample will correspond to the ages where all the fossils in the sample existed.



eg. Range from : Llandeilo Ordovician to Ashgill Ordovician

Sample A : Range From :	Early Devonian	**to**	Middle Devonian
Sample B : Range From :	Llandovery	**to**	Pridoli
Sample C : Range From :	Arenig	**to**	Llandeilo
Sample D : Range From :	Late Proterozoic	**to**	Late Cambrian

3. Place the samples in order, from oldest to youngest

Oldest **Youngest**

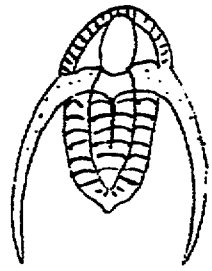
D C B A

Fossil Types

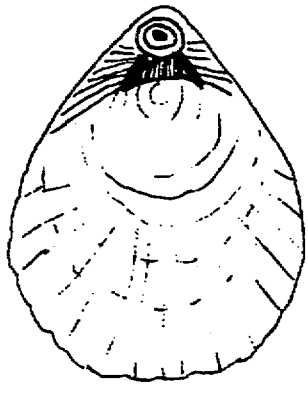
Researched by Caroline

1. Fossil group : Graptolite
"Sinograptidae"

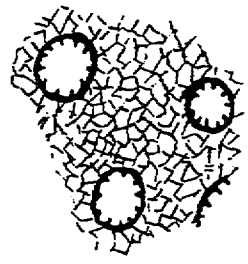
2. Fossil group : Trilobite
"Trinucleina"



3. Fossil group : Brachiopod
"Magellania"

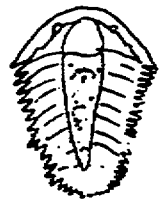


4. Fossil group : Tabulate Coral
"Heliolites"



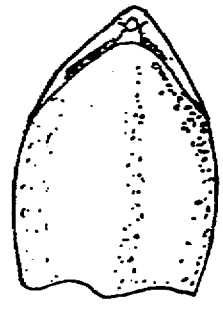
5. Fossil group : Trilobite
"Agnostina"

6. Fossil group : Trilobite
"Asaphina"



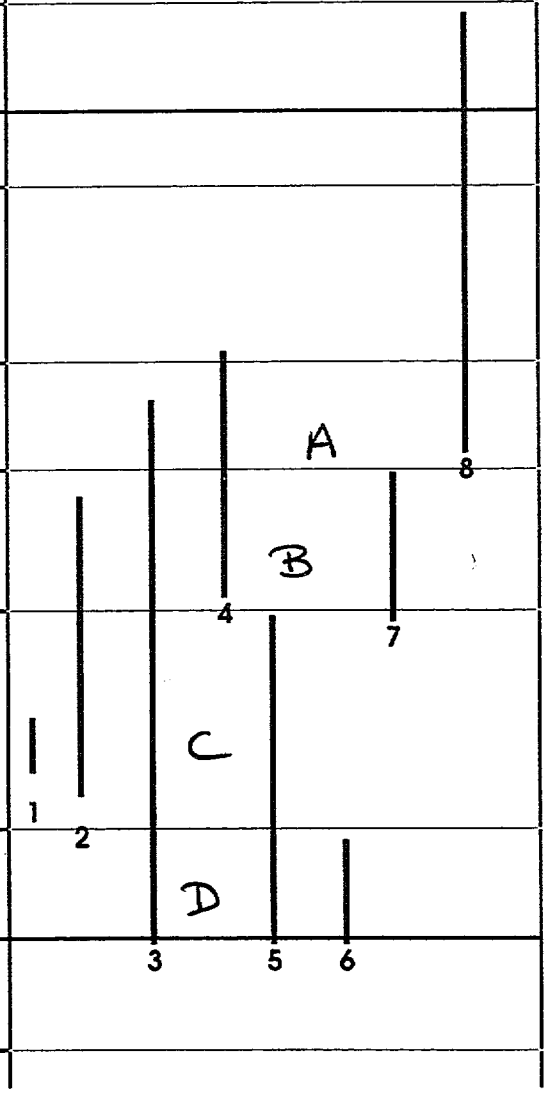
7. Fossil group : Graptolite
"Cyrtograptidae"

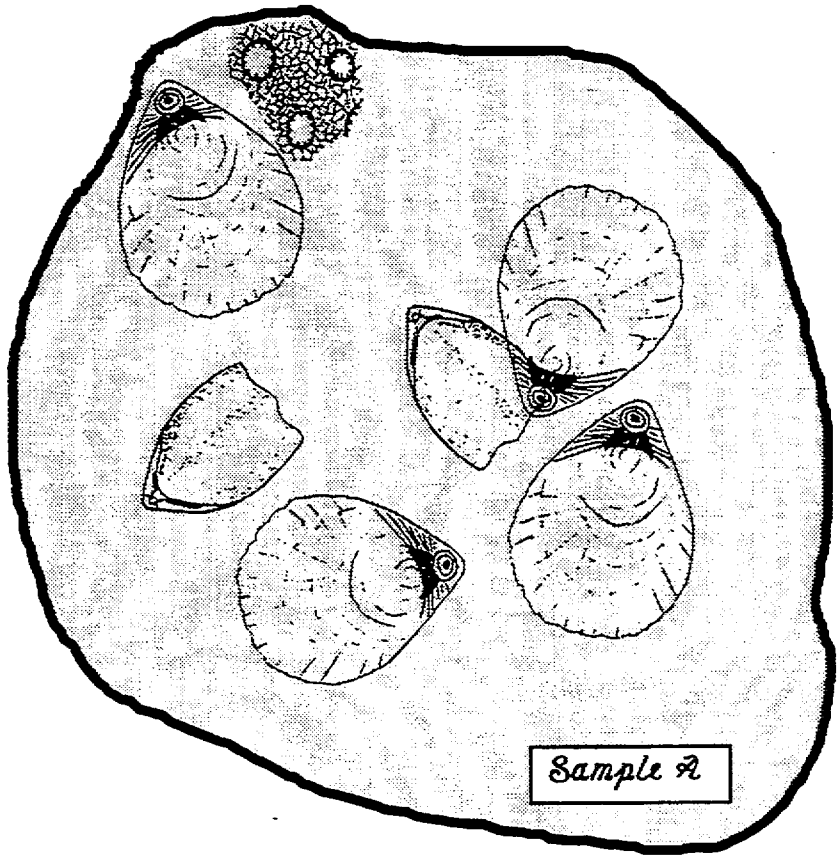
8. Fossil group : Brachiopod
"Obovithyris"

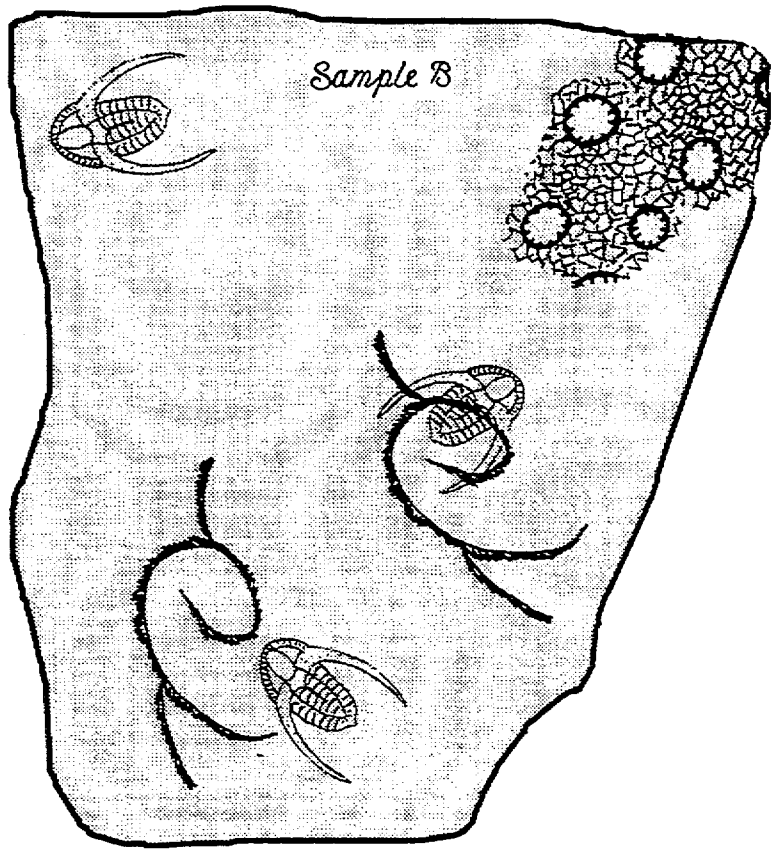


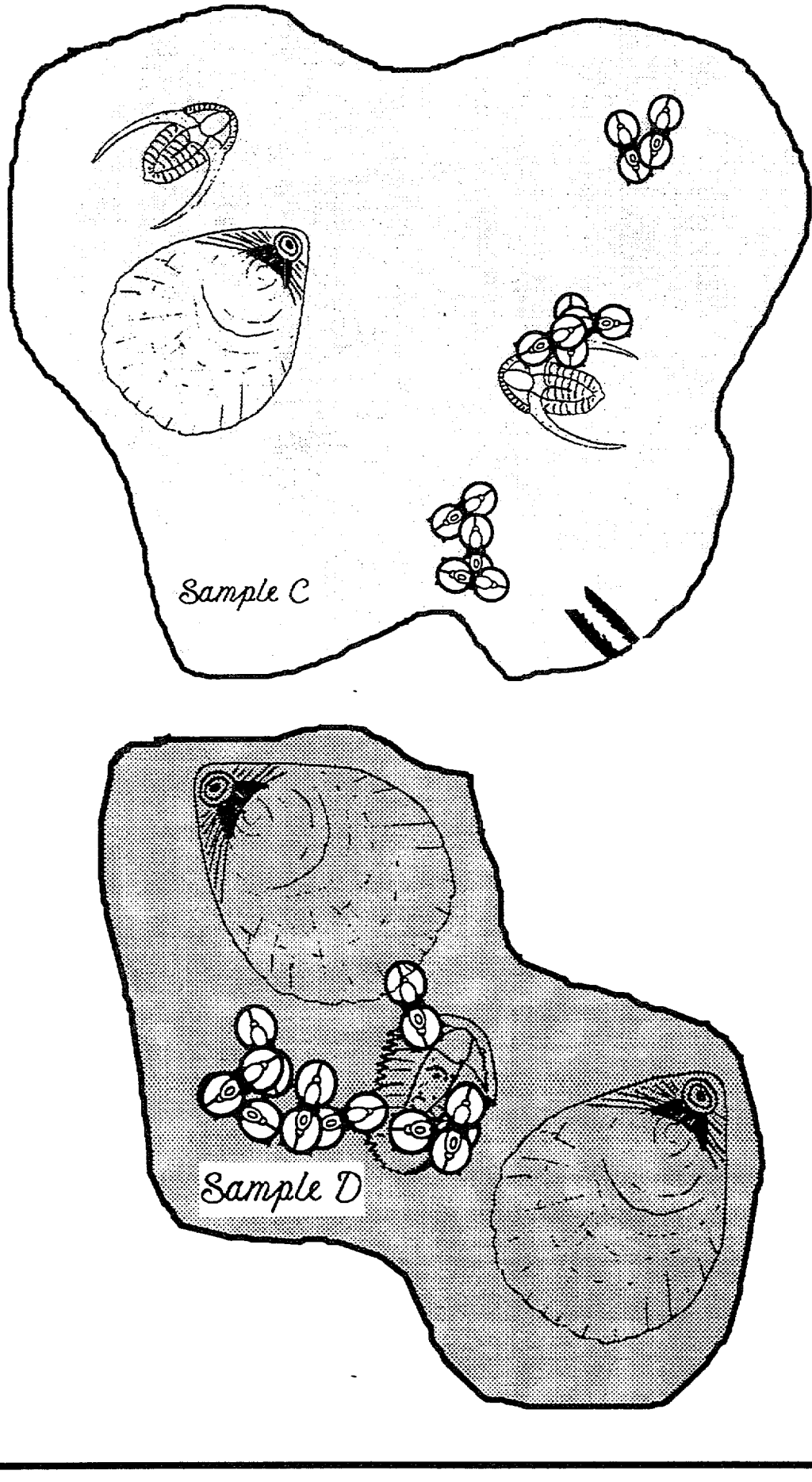
Geological Time Scale with Fossil Groups

Era	*Period*	*Epoch*	*Fossil Types*
CAINOZOIC	QUATERNARY	Holocene (recent) Pleistocene	
	TERTIARY	Pliocene Miocene Oligocene Eocene Paleocene	
MESOZOIC	CRETACEOUS	Late Early	
	JURASSIC	Late Middle Early	
	TRIASSIC	Late Middle Early	
PALAEOZOIC	PERMIAN	Late Early	
	CARBONIFEROUS	Stephanian Westphalian Namurian Visean Tournaisian	
	DEVONIAN	Late Middle Early	
	SILURIAN	Pridoli Ludlow Wenlock Llandovery	
	ORDOVICIAN	Ashgill Caradoc Llandeilo Llanvirn Arenig Tremadoc	
	CAMBRIAN	Late Middle Early	
PRECAMBRIAN	PROTEROZOIC	Late Middle Early	
	ARCHAEAN		





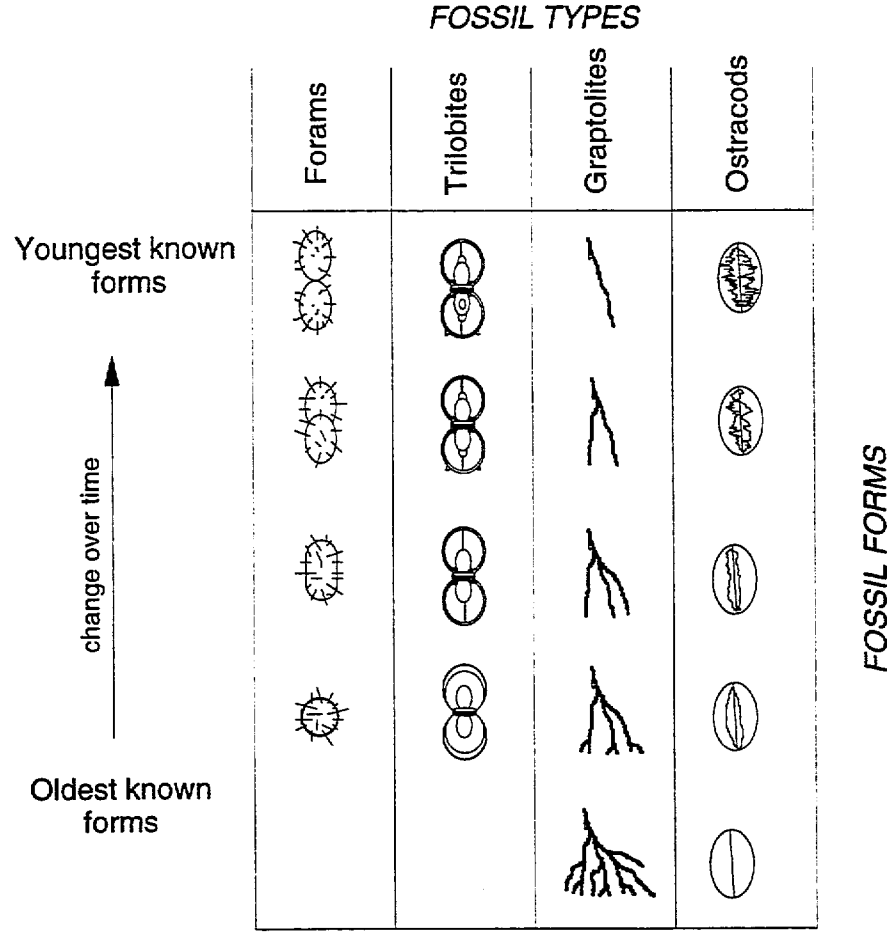




Drill Hole Stratigraphy

A petroleum exploration company has drilled a number of drill holes on the ocean floor to find out the relative ages of the rock layers in their hunt for oil. They have had a geologist identify the fossils, but they have not been able to work out the relative ages of all the rock layers. Can you do it?

The fossil types identified by the geologist are trilobites, graptolites, forams and ostrocods. Each of these types have a number of different forms, which have evolved over time. Research you have already undertaken gives the relative ages of each member of the fossils types. You have summarised these in a table :



Your table does not compare fossils types, only the known ages between different forms of the same fossil i.e.. the form of graptolite at the bottom is older than the form of graptolite above it, but it may be older or younger than the form of ostracod at the bottom.

What to do.

1. You have been given information about the fossils contained in four drill holes (A, B, C, D and E). Cut out each of the drill holes into strips (do not cut between the fossil layers). In each drill hole, the fossils at the bottom are older than the fossils at the top.

2. Line up like fossils. *Note* that in some cases fossils of different types will have the same age. You may have to swap the strips around so you get the best amount of information you can from each drill hole.

3. Give each layer of the same age a number, the youngest layer at the top being 1 with the layer below being 2 and so on until you find the layer containing the oldest fossil. These number represent relative ages for the layers

4. Use the layer numbers to give each fossil in the table above a relative age.

Describe the youngest fossils.

The youngest fossil is a foram. It has two oval segments to its shell with spines which are slightly wriggly

How does this form differ from other forms of the same fossil type?

The other forms have straight spines and while the next youngest has two segments, they are much closer together. Older forms have only one segment

Describe the oldest fossil form.

Two fossils are equally the oldest

(A) Ostracod is a simple oval with a line running from across the widest point

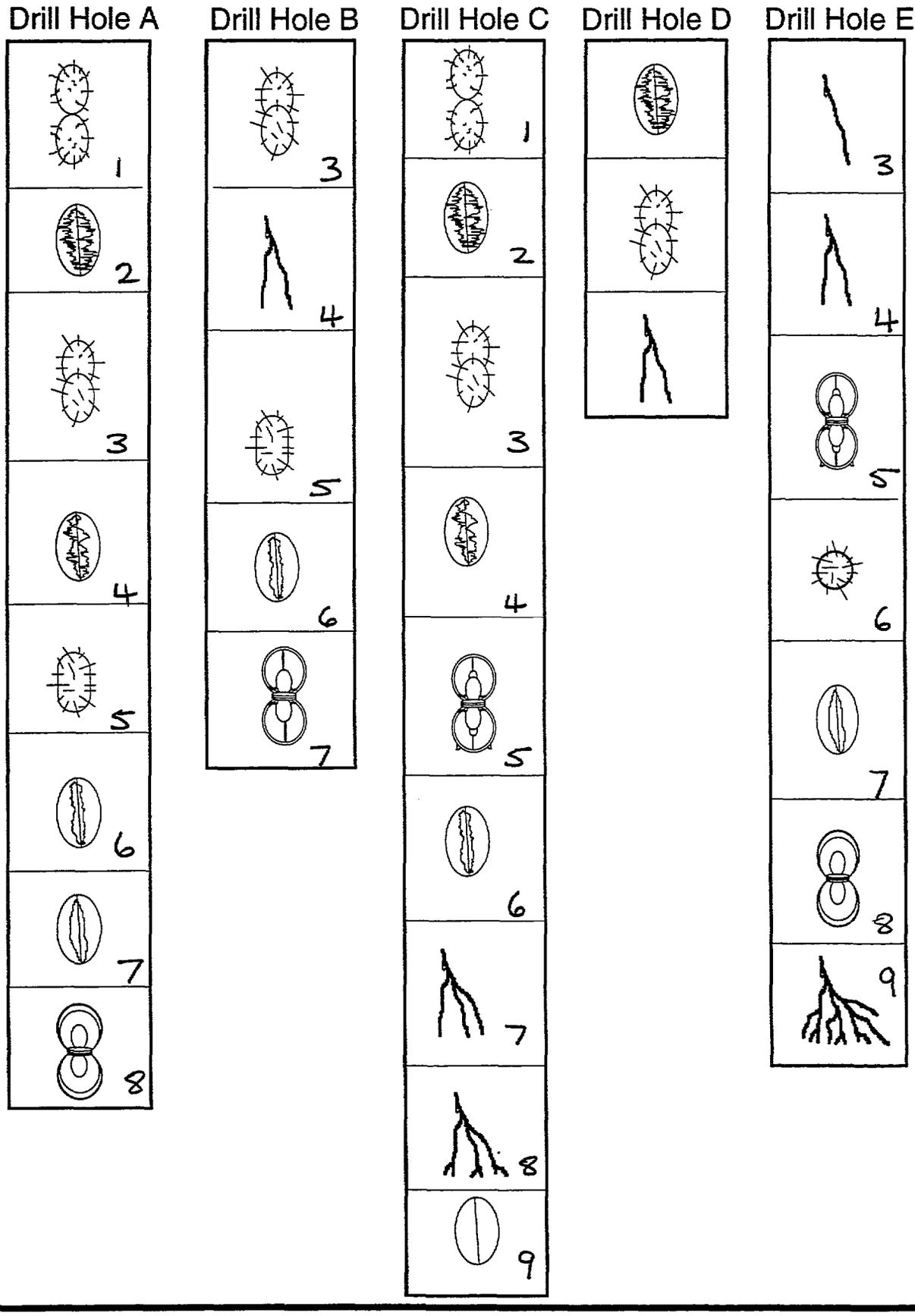
(B) The graptolite has numerous (10) branches

How does this form differ from other forms of the same fossil type.

(A) The ostracods evolved with an ever increasingly complex set of lines between the widest point

(B) The graptolites evolved with younger forms having fewer branches

OCEAN FLOOR DRILL HOLES



Silicate Chemistry

From AGSO Record 1995/19

Crustal Elements

On the Periodic Table blank sheet, summarise the information in the "Elements in the Earth's Crust Table" using the following steps.

With a black pen, write the element symbol and ionic radii in the correct square.

Using the following colours, lightly colour the squares to show the abundance of the elements in the Earth's crust.

Red	greater than 25.0%
Yellow	less than 25.0% but greater than 1.0%
Blue	less than 1.0% but greater (or equal to) than 0.01%

Leave blank (white) all those elements which are less than 0.01%

? How many elements are red 2

? How many elements are yellow 6

? How many elements are blue 13

? How many elements are white 82

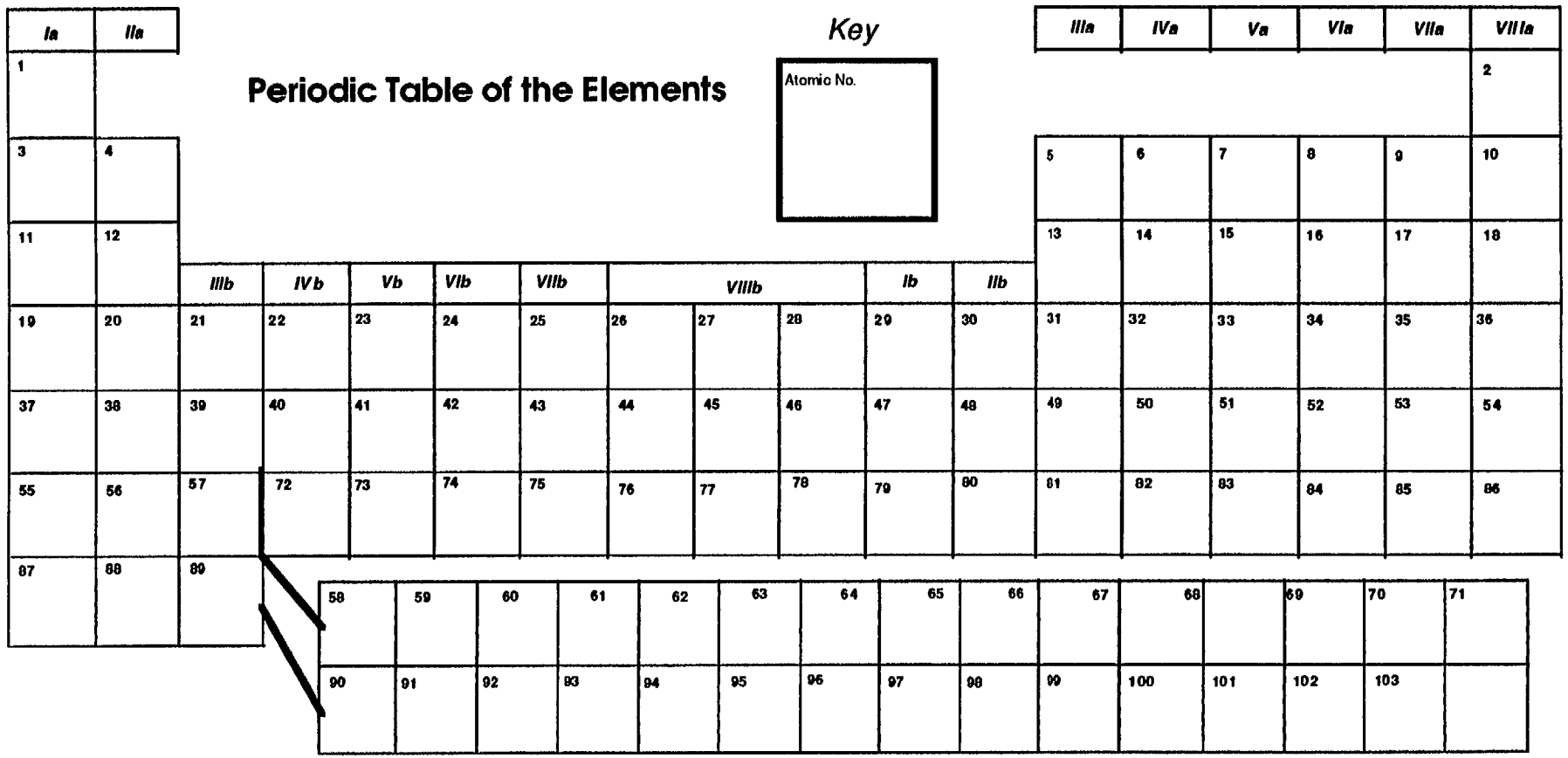
Elements in the Earths Crust

(Percent by weight/Ionic Radii of most common ion)

Atomic Number		g/t	%	Ionic Radii Angstrom units
1	H	1400	0.140000%	0.46
3	Li	20	0.002000%	0.68
4	Be	2.8	0.000280%	0.35
5	B	10	0.001000%	0.23
6	C	200	0.020000%	0.16
7	N	20	0.002000%	0.16
8	O	466000	46.600000%	1.40
9	F	625	0.062500%	1.33
11	Na	28300	2.830000%	0.97
12	Mg	20900	2.090000%	0.66
13	Al	81300	8.130000%	0.51
14	Si	277200	27.720000%	0.39
15	P	1050	0.105000%	0.44
16	S	260	0.026000%	1.74
17	Cl	130	0.013000%	1.81
19	K	25900	2.590000%	1.33
20	Ca	36300	3.630000%	0.99
21	Sc	22	0.002200%	0.81
22	Ti	4400	0.440000%	0.76
23	V	135	0.013500%	0.88
24	Cr	100	0.010000%	0.63
25	Mn	950	0.095000%	0.80
26	Fe	50000	5.000000%	++ 0.74 +++ 0.64
27	Co	25	0.002500%	0.72
28	Ni	75	0.007500%	0.69
29	Cu	55	0.005500%	0.96
30	Zn	70	0.007000%	0.74
31	Ga	15	0.001500%	0.62
32	Ge	1.5	0.000150%	0.73
33	As	1.8	0.000180%	0.58
34	Se	0.05	0.000005%	1.93
35	Br	2.5	0.000250%	1.96
37	Rb	90	0.009000%	1.47
38	Sr	375	0.037500%	1.12
39	Y	33	0.003300%	0.92
40	Zr	165	0.016500%	0.79
41	Nb	20	0.002000%	0.74
42	Mo	1.5	0.000150%	0.70
44	Ru	0.01	0.000001%	0.67

Atomic Number		g/t	%	Ionic Radii Angstrom units
45	Rh	0.005	0.000001%	0.68
46	Pd	0.01	0.000001%	0.80
47	Ag	0.07	0.000007%	1.26
48	Cd	0.2	0.000020%	0.97
49	In	0.1	0.000010%	0.81
50	Sn	2	0.000200%	0.93
51	Sb	0.2	0.000020%	0.76
52	Te	0.01	0.000001%	2.11
53	I	0.5	0.000050%	2.20
55	Cs	3	0.000300%	1.67
56	Ba	425	0.042500%	1.34
57	La	30	0.003000%	1.14
58	Ce	60	0.006000%	1.07
59	Pr	8.2	0.000820%	1.06
60	Nd	28	0.002800%	1.04
62	Sm	6	0.000600%	1.00
63	Eu	1.2	0.000120%	0.98
64	Gd	5.4	0.000540%	0.97
65	Tb	0.9	0.000090%	0.93
66	Dy	3	0.000300%	0.92
67	Ho	1.2	0.000120%	0.91
68	Er	2.8	0.000280%	0.89
69	Tm	0.5	0.000050%	0.87
70	Yb	3.4	0.000340%	0.86
71	Lu	0.5	0.000050%	0.85
72	Hf	3	0.000300%	0.78
73	Ta	2	0.000200%	0.68
74	W	1.5	0.000150%	0.70
75	Re	0.001	0.000000%	0.72
76	Os	0.005	0.000001%	0.69
77	Ir	0.001	0.000000%	0.68
78	Pt	0.01	0.000001%	0.80
79	Au	0.004	0.000000%	1.37
80	Hg	0.08	0.000008%	1.10
81	Tl	0.5	0.000050%	1.47
82	Pb	13	0.001300%	1.20
83	Bi	0.2	0.000020%	0.96
90	Th	7.2	0.000720%	1.02
92	U	1.8	0.000180%	0.97

Periodic Table of the Elements



Chemical Weathering of Feldspar

Orthoclase Feldspar, a potassium- aluminium tectosilicate, chemically alters to form clay minerals. This is due to the reaction of the mineral with carbonic acid disolved in rainwater.

The inputs are :

Orthoclase feldspar	$KAlSi_3O_8$
Carbonic acid	H_2CO_3
Water	H_2O

The outputs are :

Clay mineral	$Al_2Si_2O_5(OH)_4$
Potassium carbonate	K_2CO_3
Silica	SiO_2

Write a balanced equation for the reaction :

$$2KAlSi_3O_8 + H_2CO_3 + H_2O \rightarrow Al_2Si_2O_5(OH)_4 + K_2CO_3 + 4SiO_2$$

Other members of the feldspar group include Albite ($NaAlSi_3O_8$) and Anorthite ($CaAl_2Si_2O_8$). Write chemical equations for the chemical weathering of these minerals.

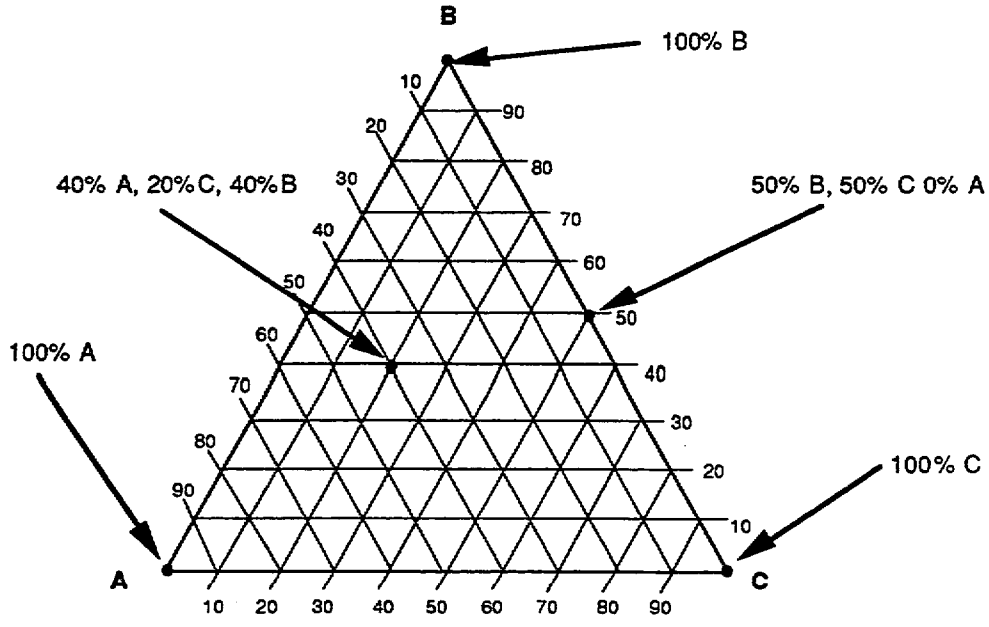
$NaAlSi_3O_8$

$$2NaAlSi_3O_8 + H_2CO_3 + H_2O \rightarrow Al_2Si_2O_5(OH)_4 + Na_2CO_3 + 4SiO_2$$

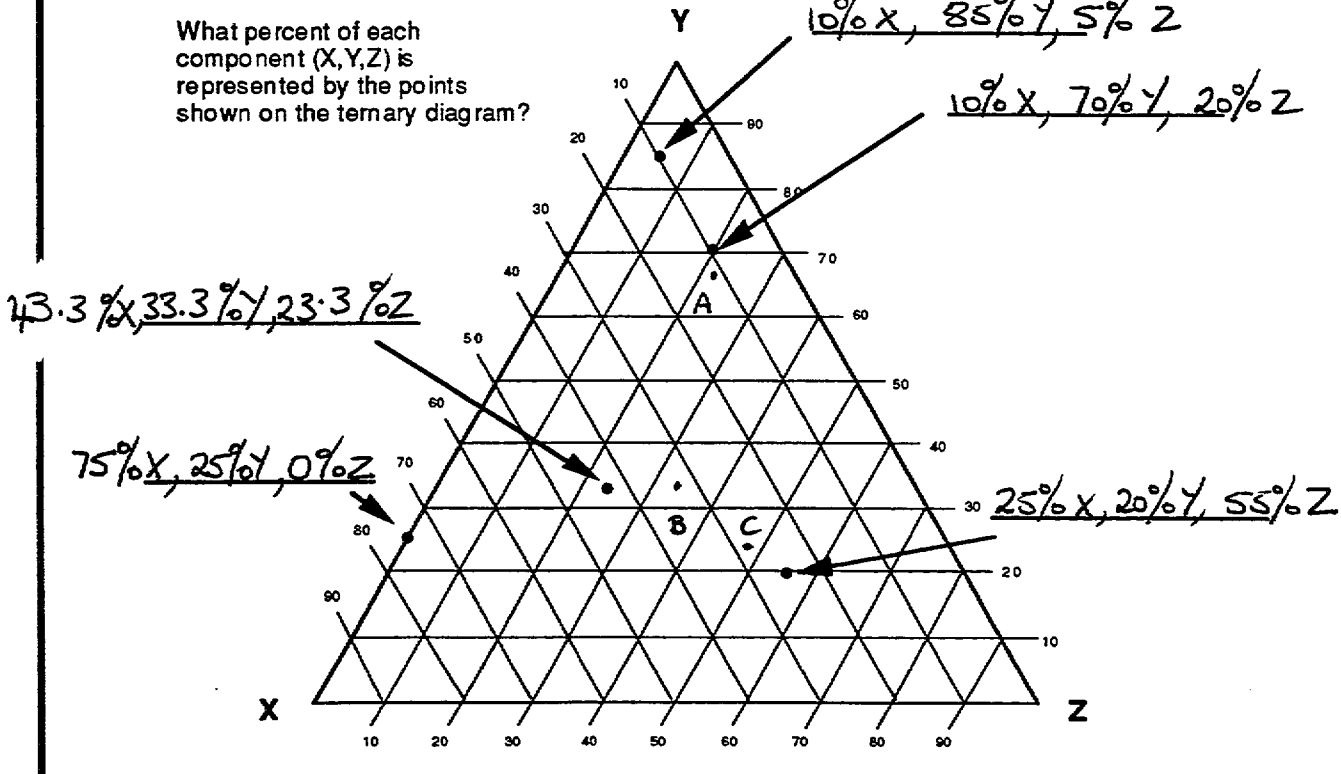
$CaAl_2Si_2O_8$ Note : Silica is not formed in this reaction.

$$CaAl_2Si_2O_8 + H_2CO_3 + H_2O \rightarrow Al_2Si_2O_5(OH)_4 + CaCO_3$$

Reading Ternary Diagrams



What percent of each component (X,Y,Z) is represented by the points shown on the ternary diagram?



Plot the following points

A 12%X, 66%Y, 22% Z

B 33%X, 33%Y, 33%Z

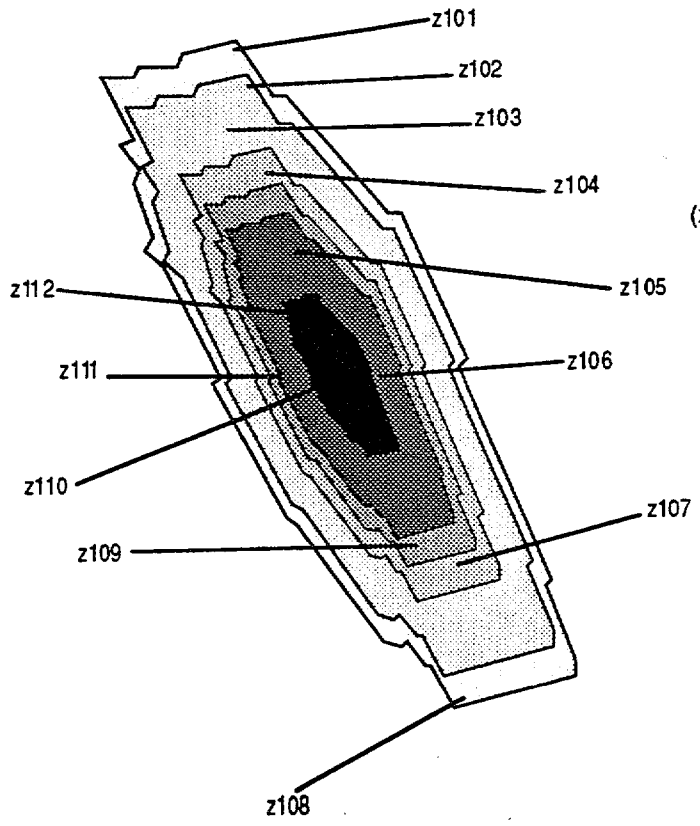
C 28%X, 24%Y, 48%Z

Chemical Zones

A geologist collected a sample of a rock containing the mineral feldspar (a tectosilicate) and noticed that the feldspars were zoned. Zonation occurs when a mineral crystallises from a solution, in this case molten rock, which changes composition over time.

The geologist gave a piece of the rock to a geochemist who used an electron probe to obtain chemical data about each of the zones on one feldspar crystal. The sites on the crystal sampled, and the results, are shown below.

Feldspar crystal electron probe sites



Sample site	CaO	NaO	K2O
z101	12	67	21
z102	18	73	9
z103	27	71	2
z104	28	67	5
z105	63	29	8
z106	66	31	3
z107	32	65	3
z108	12	70	18
z109	69	29	2
z110	96	2	2
z111	68	26	6
z112	85	11	4

Note : Electron probe results are given as the percent of metallic oxide found in the sample. In this case, the probe only calculated the relative amounts of calcium, potassium and sodium. Any other metal oxides, such as aluminium oxide, were disregarded.

The Feldspar group of minerals differ in composition due to the type of metallic ions in their structure. As calcium, sodium and potassium can fit into the crystal structure there is a continuum of compositions with the end members being Orthoclase (100% potassium), Albite (100% sodium) and Anorthite (100% calcium).

What to Do

1. Using the Feldspar Composition Ternary diagram, plot the composition of each of the sites.

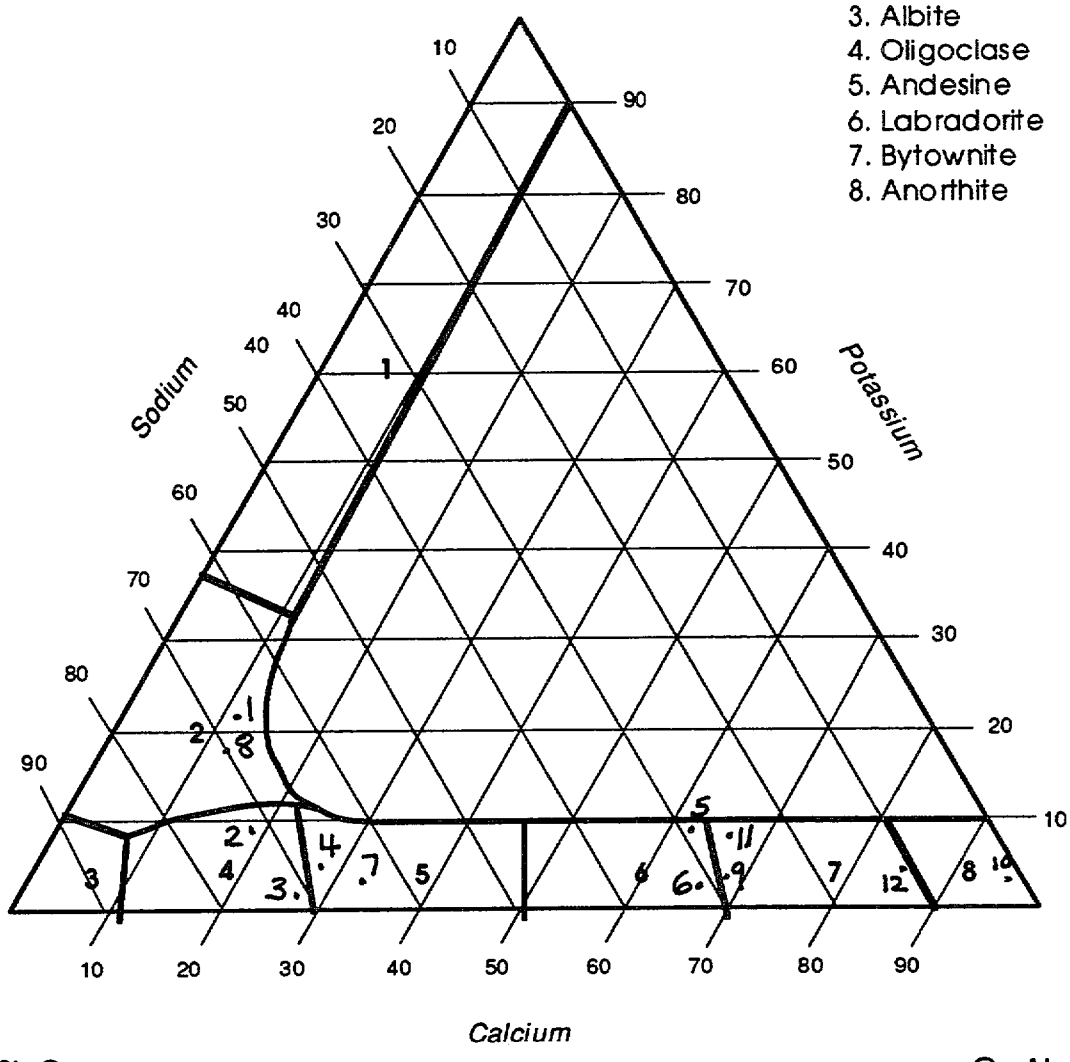
2. As a crystal adds layers to the outside, write the feldspar mineral sequence from the core to the outside of the crystal.
Anorthite → Bytownite → Labradorite → Bytownite → Labradorite → Bytownite → Andesine → Oligoclase → Anorthoclase

3. What happens to the composition of the solution that this crystal formed in over time and what may have caused the changes?
The solution becomes deprived of Ca, therefore feldspars richer in Na are formed. At the final stages of crystal development the Na starts to be depleted and a more K rich feldspar is formed. The process of crystalization removes elements from the solution

Feldspar Composition Ternary Diagram

$KAlSi_3O_8$

Mineral Names
1. Sanidine
2. Anorthoclase
3. Albite
4. Oligoclase
5. Andesine
6. Labradorite
7. Bytownite
8. Anorthite



$NaAlSi_3O_8$

$CaAl_2Si_2O_8$

Mineral Phases

The existence of a chemical in more than one structural form is known as *polymorphism*, with each of the different structures being *allotropes* of the chemical. Diamond and graphite, for example, are naturally occurring allotropes of carbon.
The chemical Al_2SiO_5 is found in nature as three allotropes. These are the minerals Andalusite, Kyanite and Sillimanite. Experiments have shown that the formation of these minerals is somehow dependant on the temperature and pressure of the environment in which they form. In mineralogy, these minerals are referred to as *phases*, and a diagram which represents the relationship between their "environment-of-formation" conditions and mineral phase is call a *Phase Diagram.*

What to do

A number of experiments have been undertaken in which Al_2SiO_5 was placed under different temperature and pressure conditions and the resultant mineral phase recorded. The table of results is below :

Pressure kb	Temperature C	Mineral
7	300	Andalusite
4	50	Andalusite
6	400	Andalusite
3	550	Andalusite
1	100	Andalusite
2	600	Andalusite
6	50	Kyanite
10	400	Kyanite
14	800	Kyanite
8	200	Kyanite
12	300	Kyanite
10	300	Kyanite
16	200	Kyanite
14	700	Kyanite
4	700	Sillimanite
6	500	Sillimanite
8	400	Sillimanite
10	700	Sillimanite
2	800	Sillimanite
12	800	Sillimanite
4	800	Sillimanite
15	900	Sillimanite
5	150	Andalusite
3	300	Andalusite
5	350	Andalusite
7	150	Kyanite
11	550	Kyanite
11	50	Kyanite
13	200	Kyanite
15	450	Kyanite
12	650	Kyanite
9	550	Sillmanite
5	600	Sillmanite
7	650	Sillmanite
7	850	Sillmanite

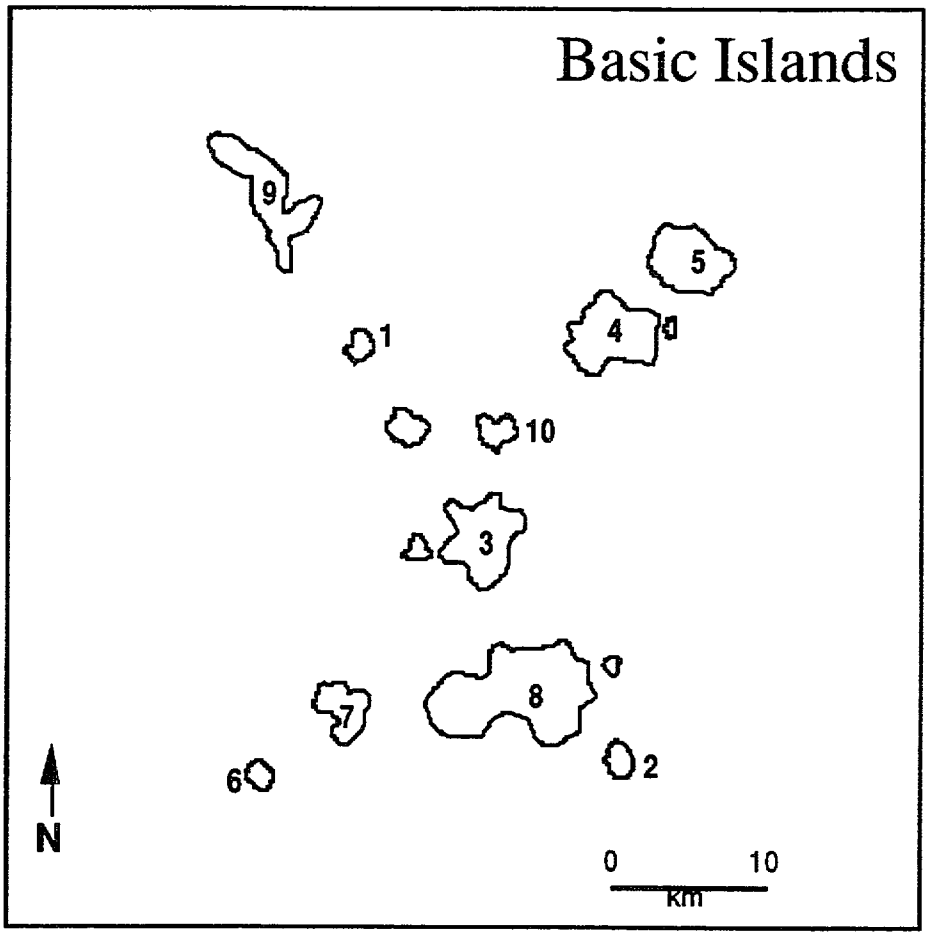
Volcanoes

From AGSO Record 1995/24

Basic Islands

A Hot Spot Problem

In the year 2010, a group of scientists start studying a planet not unlike earth. It was recognised that plate tectonics was active on the planet. A geologist collected a number of volcanic rock samples from 10 islands in the Basic Island Group. She developed a theory that the islands were all volcanoes which developed because the crustal plate they were sitting on moved over a hot spot which caused melting. Only the volcano from which she collected sample number 5 was still active.



To find evidence for her theory, she sent the samples back to Earth for analysis of their radioactive element composition, which would enable her to date each of the islands. This, she, hoped, would show that the islands became older as you moved towards the south.

Using the radioactive element composition and the radioactive decay curves, calculate the age for each of the islands and complete the table.

Island	Element	Percent of original mass remaining	Age
1	U^{238}	44.0	5·7 billion yrs
2	U^{238}	95.0	0·6 "
3	Rb^{87}	95.0	4·5 "
4	U^{235}	85.0	0·25 "
5	U^{235}	96.0	0·1 "
6	U^{235}	3.0	3·4 "
7	Th^{232}	85.0	3·8 "
8	U^{235}	61.0	0·5 "
9	Rb^{87}	93.0	7·0 "
10	U^{238}	48.0	4·9 "

? What is the order of islands from oldest to youngest?

9 - 1 - 10 - 3 - 7 - 6 - 2 - 8 - 4 - 5

The geologist recognised that the ages of the island seemed to fall into two age groups, those over 3 billion years and those under 2 billion years. She changed her theory to say that the islands formed by the movement of the plate over two hot spots at different periods of time.

For the islands which are all over 3 billion years old, play join the dots starting with the oldest island through to the youngest island. Using a different coloured pen, do the same with the islands which are all under 3 billion years old.. Describe the shape of these lines and think of a reason they might be this shape?

Islands over 3 billion → the line is a bend line (boomerang) shape with oldest at top (oldest → youngest)

Islands under 3 billion → the line is also a boomerang but bent in the opposite way with the oldest at bottom (youngest → oldest)

The plate on which these islands lay has moved northwards in a curve between 7.0 billion yrs & 3.4 billion, then southwards in the opposite curve from 0.6 billion to the present day

Magma Chamber Chemistry

A magma chamber full of molten rock has formed below the surface of the Earth. Over time it will slowly cool and some minerals will crystallise out of the magma and fall to the bottom of the chamber, leaving a residual pool of magma on the top. Every now and then this residual pool feeds a volcano on the earth's surface.

Your task is to work out what rock type will be extruded from this volcano over time as the magma chamber cools using the silica content data in the table below.

Silica Content	*Volcanic rock*
45-54%	basalt
54-62%	andesite
62-70%	dacite
70-78%	rhyolite

The original magma is made up from the following ;

Component	*Symbol*
Silica	Si
Magnesium	Mg
Iron	Fe
Calcium	Ca
Potassium	K
Aluminium	Al
Silver	Ag
Gold	Au
Copper	Cu

Using the diagram, count the number of each component in the magma chamber and calculate its percentage of the total number of components.

	Number	Percentage
Silica	101	58·38
Magnesium	22	12·71
Iron	22	12·71
Calcium	9	5·20
Potassium	6	3·47
Aluminium	7	4·04
Silver	2	1·15
Gold	2	1·15
Copper	2	1·15
Total	173	99·96

If the magma fed the volcano above, what volcanic rock would you expect to be extruded ?

Andesite

After a few thousand, the magma cooled and three different minerals crystallised and sunk to the bottom of the chamber. These minerals were olivine, pyroxene and amphibole and they removed the following components from the melt :

	Si	Mg	Fe	Ca	K	Al	Ag	Au	Cu
Olivine	5	5	5	0	0	0	0	0	0
Pyroxene	5	3	3	2	0	0	0	0	0
Amphibole	5	2	2	2	0	0	0	0	0

Using a pencil, colour over these components in the magma chamber as these have now been removed from the molten material which can feed the volcano. Count the remaining components left in the melt and calculate the percentage of each component to the new total number of components.

	Number	Percentage
Silica	86	64·18
Magnesium	12	8·95
Iron	12	8·95
Calcium	5	3·73
Potassium	6	4·47
Aluminium	7	5·22
Silver	2	1·49
Gold	2	1·49
Copper	2	1·49
Total	134	99.97

If the remaining magma fed the volcano above, what volcanic rock would you expect to be extruded ?

dacite

After another few thousand years, the magma cooled down and more minerals crystallised and sank to the bottom of the chamber. These minerals were more pyroxene and amphibole with a new mineral biotite mica. They removed the following components from the melt :

	Si	Mg	Fe	Ca	K	Al	Ag	Au	Cu
Pyroxene	5	3	3	2	0	0	0	0	0
Amphibole	5	2	2	2	0	0	0	0	0
Biotite	5	2	2	0	2	2	0	0	0

Using a pencil, colour over these components in the magma chamber as these have now been removed from the molten material which can feed the volcano. Count the remaining components left in the melt and calculate the percentage of each component to the new total number of components.

	Number	Percentage
Silica	71	73·19
Magnesium	5	5·15
Iron	4	4·12
Calcium	2	2·06
Potassium	4	4·12
Aluminium	5	5·15
Silver	2	2·06
Gold	2	2·06
Copper	2	2·06
Total	97	99·97

If the remaining magma fed the volcano above, what volcanic rock would you expect to be extruded ?

Rhyolite

Another few thousand years pass and the magma cools. More Amphibole and biotite crystallise as well as the mineral orthoclase feldspar. They removed the following components from the melt :

	Si	Mg	Fe	Ca	K	Al	Ag	Au	Cu
Amphibole	5	2	2	2	0	0	0	0	0
Biotite	5	2	2	0	2	2	0	0	0
Orthoclase	4	0	0	0	2	2	0	0	0

Using a pencil, colour over these components in the magma chamber as these have now been removed from the molten material which can feed the volcano. Count the remaining components left in the melt and calculate the percentage of each component to the new total number of components.

	Number	Percentage
Silica	57	87·69
Magnesium	1	1·53
Iron	0	0
Calcium	0	0
Potassium	0	0
Aluminium	1	1·53
Silver	2	3·07
Gold	2	3·07
Copper	2	3·07
Total	65	99·96

By this stage, the material in the volcanic vent has solidified and plugged the magma chamber so no more material can escape to the surface. The remaining magma gets squeezed into cracks in the surrounding rocks where it forms veins. What percentage of these veins is gold?

3·07%

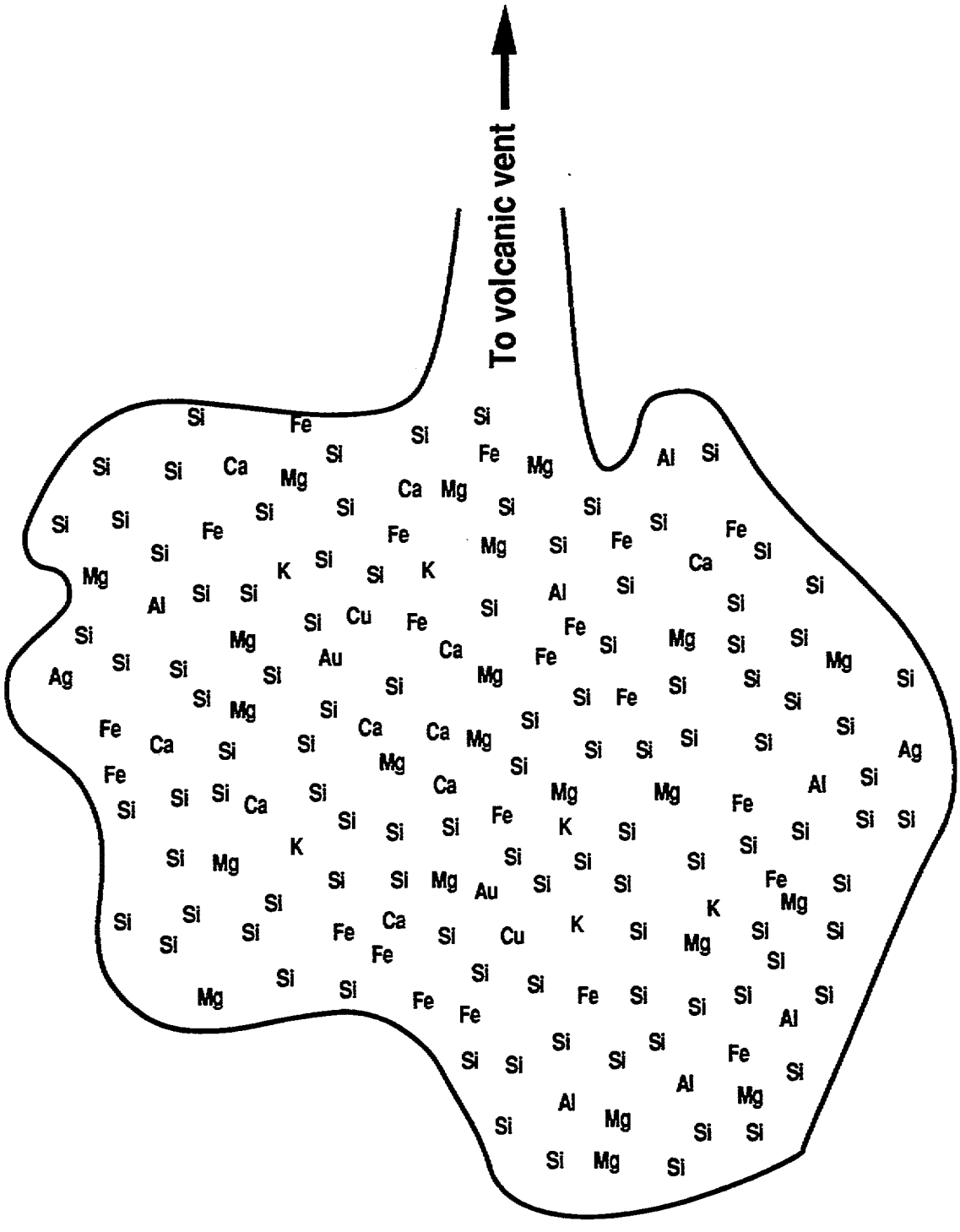
Gold is mined in Australia at around at 1 gram /tonne. What is this as a percentage? 0·0001 %

1,000 Kg = 1 tonne

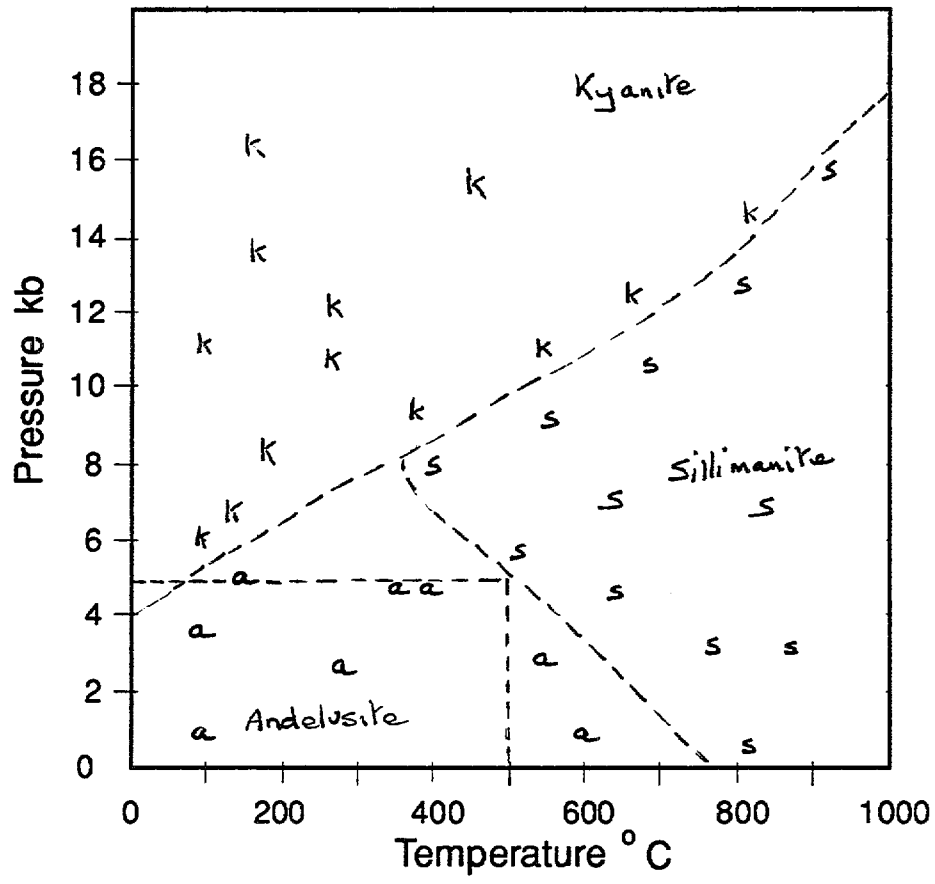
1,000 g = 1 Kg

1000 x 1000 g in a tonne = 1,000,000

Magma Chamber Chemistry



1. On the graph, plot each of the experiments results, using (a) for Andalusite, (k) Kyanite and (s) Sillimanite.



2. Draw lines on the graph which separate the mineral phases.

3. What mineral phase would you expect to form under the following temperature and pressure environments.

a. 20°C, 101.4 kPa (1 b=101.325 Pa) : Andelusite

b. 500°C, 8 kb: Sillimanite

c. 350°C, 350 kb : Kyanite

4. A rock containing the mineral Andalusite was close to a volcanic vent where the temperatures reached 500°C and the mineral phase did not change. What conclusion can you draw from the pressure environment for this location?

The pressure did not exceed 5 kb