DAEAREG A'R AMGYLCHEDD DYNOL

GEOLOGY AND THE HUMAN ENVIRONMENT

Diwrnod o sgyrsiau a thasgau i fyfyrwyr Daeareg y safon Uwch Atodol

A day of talks and tasks for students of Advanced Subsidiary level Geology

Awdur y tasgau / author of the tasks

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Gyda chydweithrediad staff adran addysg ac adran Ddaeareg Amgueddfa ac Oriel Genedlaethol - Caerdydd ac adran Ddaeareg Prifysgol Cymru - Caerdydd

With the co-operation of staff of the education and Geology departments of the National Museum & Gallery - Cardiff, and the Department of Geology of the University of Cardiff

AMGUEDDFEYDD AC ORIELAU CENEDLAETHOL CYMRU
NATIONAL MUSEUMS & GALLERIES OF WALES

The island of Nova Cambria is located in the southern Pacific Ocean (see map, figure 2). The small population has relied on energy production systems which use fossil fuels but this involves importing large quantities of coal and oil from abroad - a difficult and expensive process. The island government has decided to adopt nuclear power, using uranium ore found in the south of the island. A nuclear power station has been constructed but now a site is needed for the long term storage of radioactive waste.

Geology has two main influences on nuclear power. Firstly nuclear power stations depend on a source of nuclear fuel for their reactors. These may be a form of natural uranium or enriched uranium oxide and like any other natural mineral resource, geologists are responsible for locating the source.

The diagram below (figure 1) shows the basic layout of a nuclear power station.

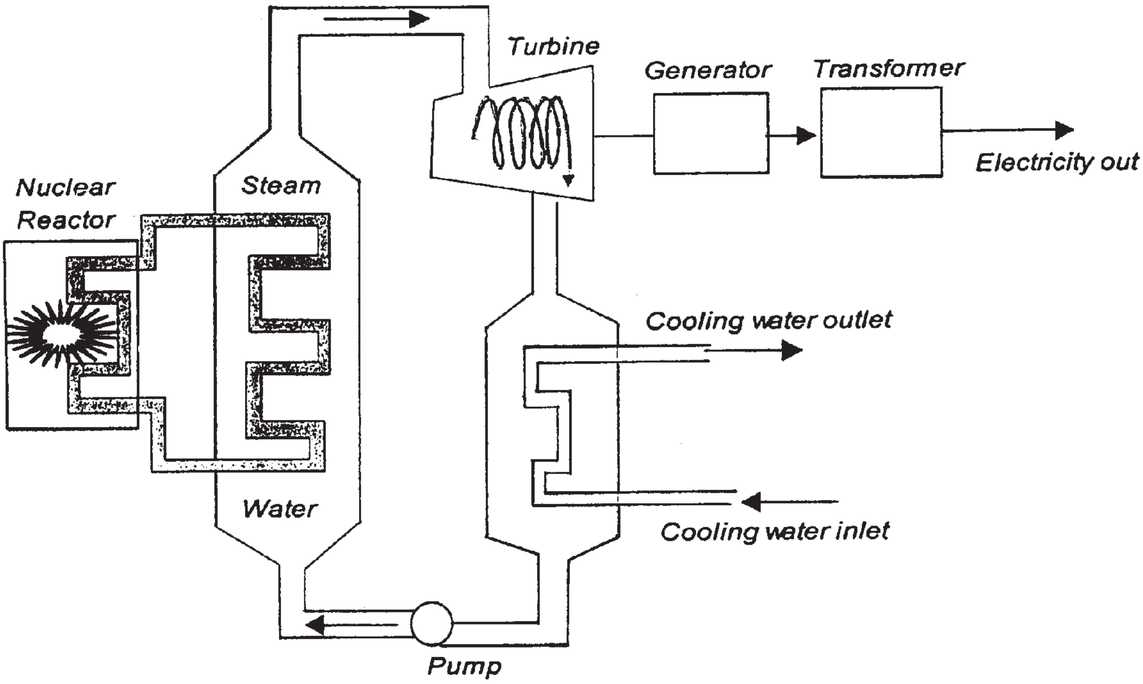


figure 1 - a nuclear power station

The second way in which geology plays a part in the nuclear power industry is in deciding on an appropriate site for the disposal of the waste. Nuclear power does not produce large quantities of waste but the waste that is produced will be radioactive and will remain so for a very long time. Special precautions need to be taken when disposing of nuclear waste to prevent the escape of any dangerous materials.

Nova Cambria Location Map

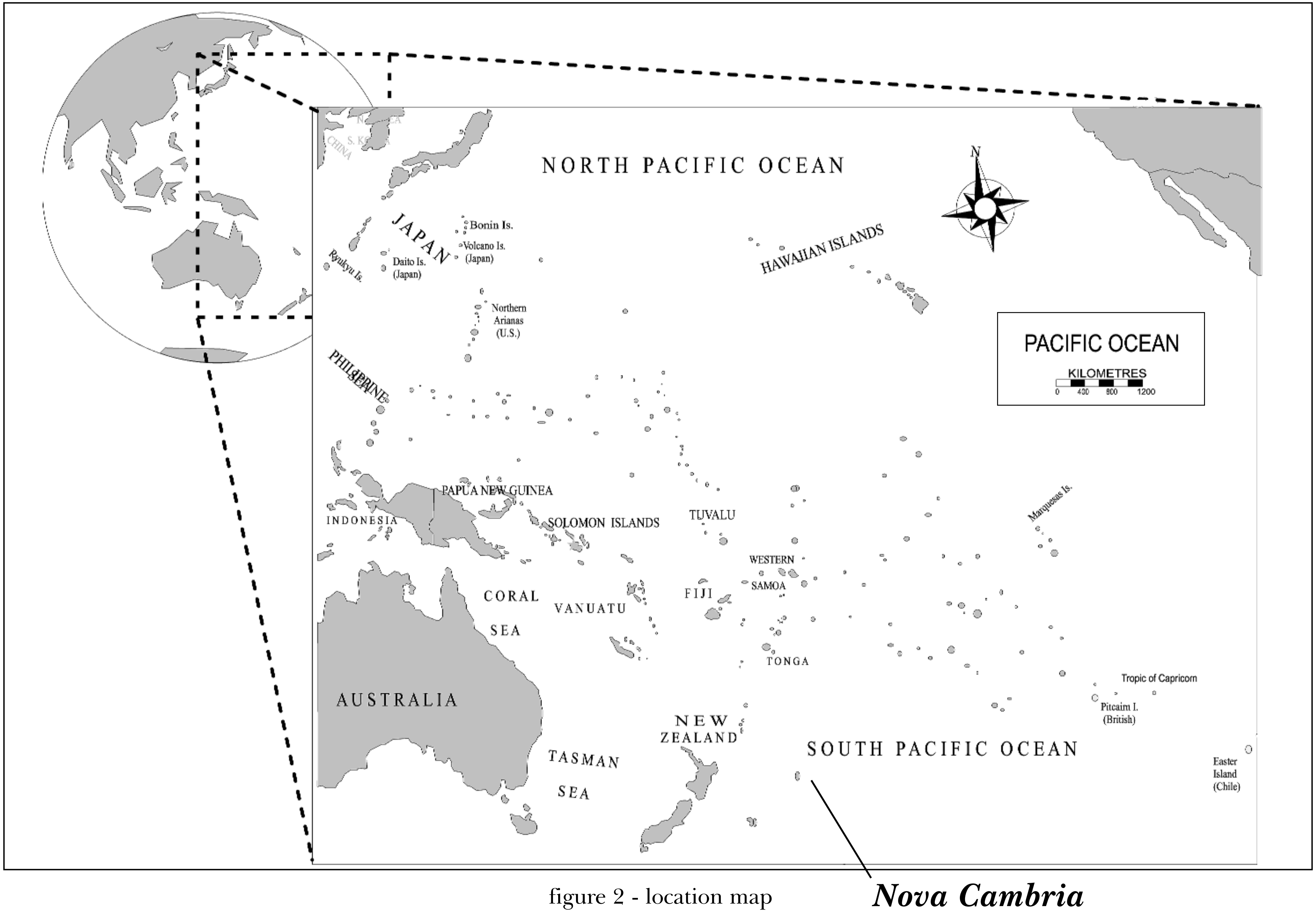
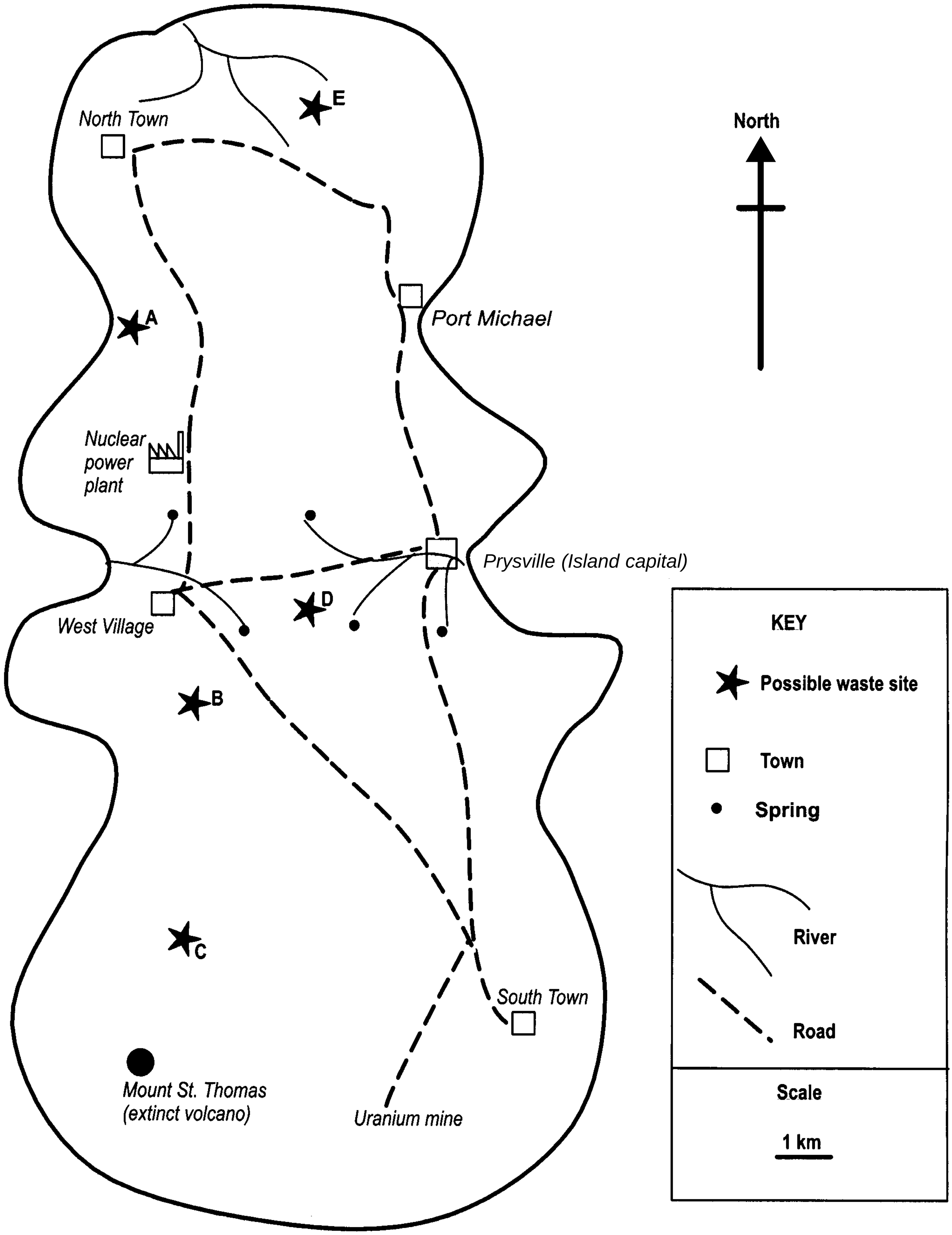


figure 2 - location map


North Town
E
North
A
Port Michael
Nuclear
power
plant
Prysville (Island capital)
D
West Village
B
C
South Town
Mount St. Thomas
(extinct volcano)
Uranium mine
KEY
Possible waste site
Town
Spring
River
Road
Scale
1 km

An example from the UK

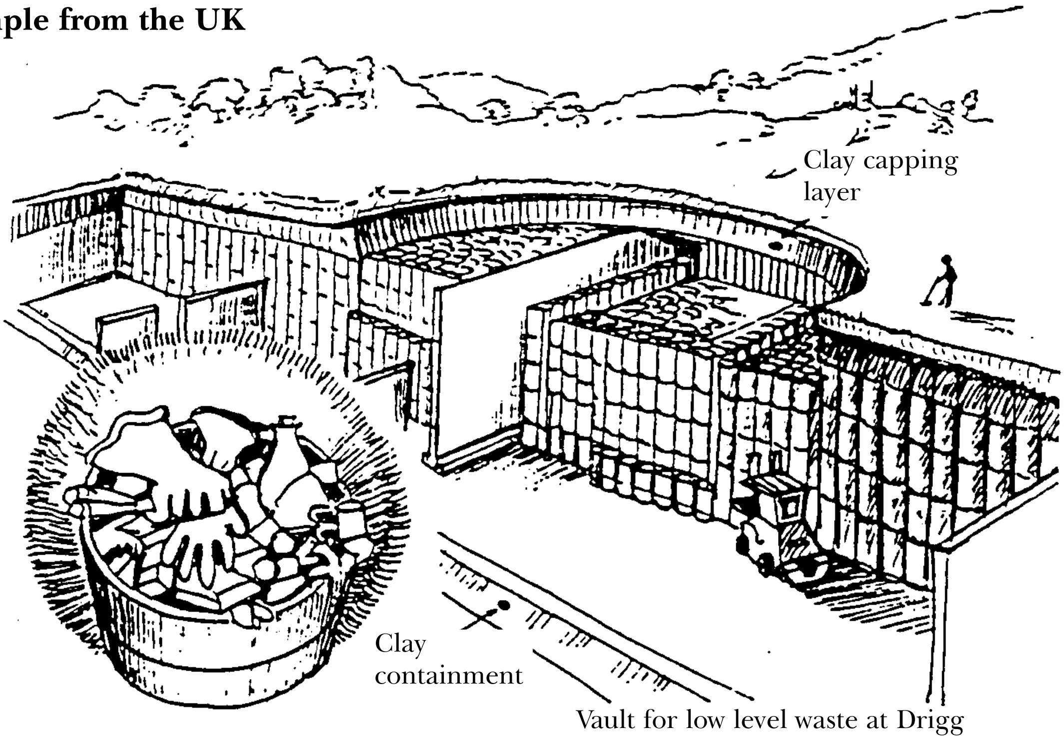


figure 4 - a nuclear waste dump in the UK

Five possible waste sites have been identified (A - E on the map, figure 3) but you will need to consider all factors before selecting which is the most suitable.

Activity 1
What are the social and economic factors associated with siting a nuclear waste dump? Think about how your community would respond if the local council proposed to site a dump near your house.

....
....
....
....
....
....

Activity 2
What geological factors will be important in selecting a suitable site?

....
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....
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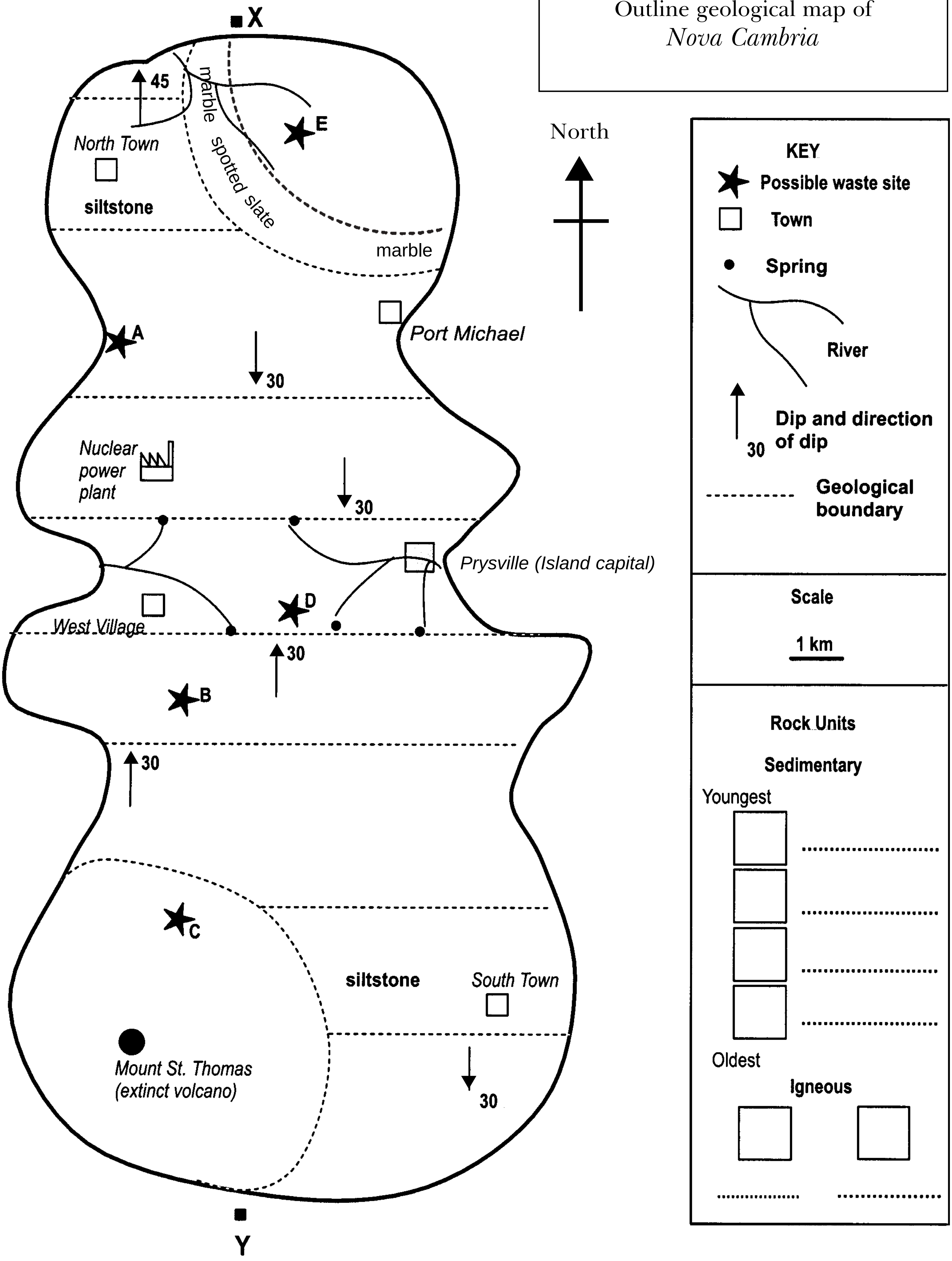
figure 5
Outline geological map of
Nova Cambria



Section 2 - The geology of the island

The geology of the island is the most important consideration in siting any waste facility. The rocks must be suitable for construction and they must also prevent any radioactive or toxic material from escaping. The outline geology map (figure 5) shows the boundaries of the different rock units.

Activity 3

In this exercise you will identify the five rock samples, one from each of the sites. You should examine them carefully, recording their colour, texture, reaction with acid (if any) and presence of fossils. You should use the fossils to try to work out the relative ages of the rocks.

Rock A

Colour ....
Texture ....
....
....
....
Reaction with acid ....
Fossils ....
Name ....
Age ....

Rock B

Colour ....
Texture ....
....
....
....
Reaction with acid ....
Fossils ....
Name ....
Age ....

Rock C

Colour ....
Texture ....
....
....
....
Reaction with acid ....
Fossils ....
Name ....
Age ....

Rock D
Colour ....
Texture ....
....
....
....
Reaction with acid ....
Fossils ....
Name ....
Age ....

Rock E
Colour ....
Texture ....
....
....
....
Reaction with acid ....
Fossils ....
Name ....
Age ....

Activity 4
Use your results to colour in the geology map (figure 5) and the key. Make sure you arrange the rocks in the correct order.

It is also important to know the structure that the rock layers form under the surface. To do this use the dip information from the map.

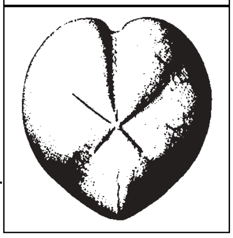
Activity 5
Complete the cross section on the outline (figure 6).

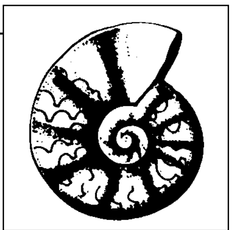
What geological structure is in the middle of the island? ....

THE STRATIGRAPHICAL COLUMN

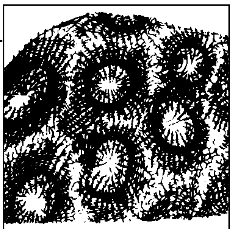
Eras **GEOLOGICAL PERIODS AND DURATIONS**
Cainozoic/Quaternary Present day to 2 million years ago
Cainozoic/Tertiary Pliocene 2 - 7 million years ago
Miocene 7 - 26 million years ago
Oligocene 26 - 38 million years ago
Eocene and Palaeocene 38 - 65 million years ago
Mesozoic Cretaceous 65 - 136 million years ago
Jurassic 136 - 190 million years ago
Triassic 190 - 225 million years ago
Palaeozoic/Upper Permian 225 - 280 million years ago
Carboniferous 280 - 345 million years ago
Devonian 345 - 395 million years ago
Palaeozoic/Lower Silurian 395 - 440 million years ago
Ordovician 440 - 500 million years ago
Cambrian 500 - 570 million years ago
Pre-Cambrian 570 - 4600 million years ago

Echinoid
(Micraster)

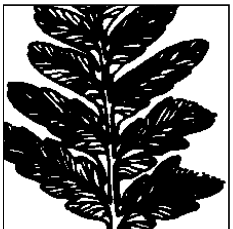




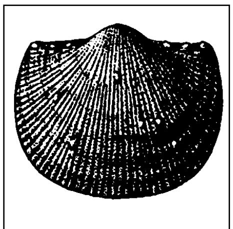
Ammonite
(Dactylioceras)



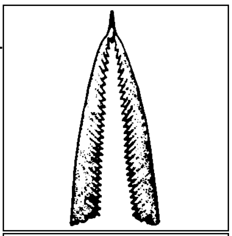
Coral
(Pachyphyllum)



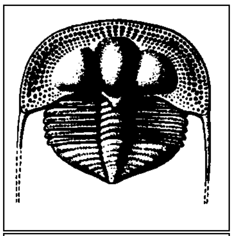
Plant
(Maryopteris)



Brachiopod
(Productus)

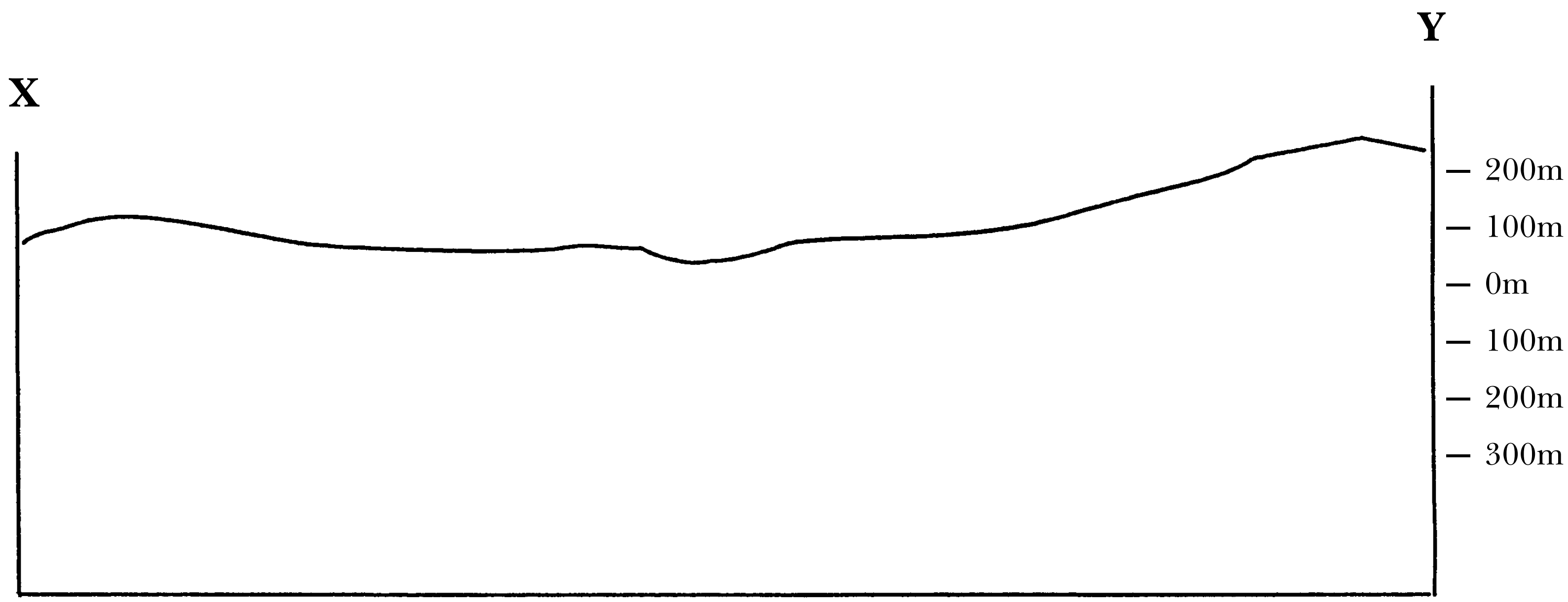


Graptolite
(Didymograptus)



Trilobite
(Onnia)

Outline for drawing geological cross-section X - Y



Part A - Plate tectonics

The outer part of the Earth is called the lithosphere, it comprises the crust and the rigid part of the upper mantle. The lithosphere is broken into plates which are constantly moving due to currents in the ductile mantle underneath. When plates move apart the mantle rock melts and this magma wells up between the plates, cools and forms new oceanic crust. This type of plate boundary is called constructive. A conservative plate boundary occurs when two plates attempt to slide past each other, generating massive earthquakes such as those experienced in California. Plates collide at destructive plate boundaries which involve one plate being forced down into the mantle in a process called subduction. Melting generates magma which rises through the crust to produce explosive volcanoes. Earthquakes also occur at this type of boundary, they are generated all along the subducting plate in a region called the Benioff Zone.

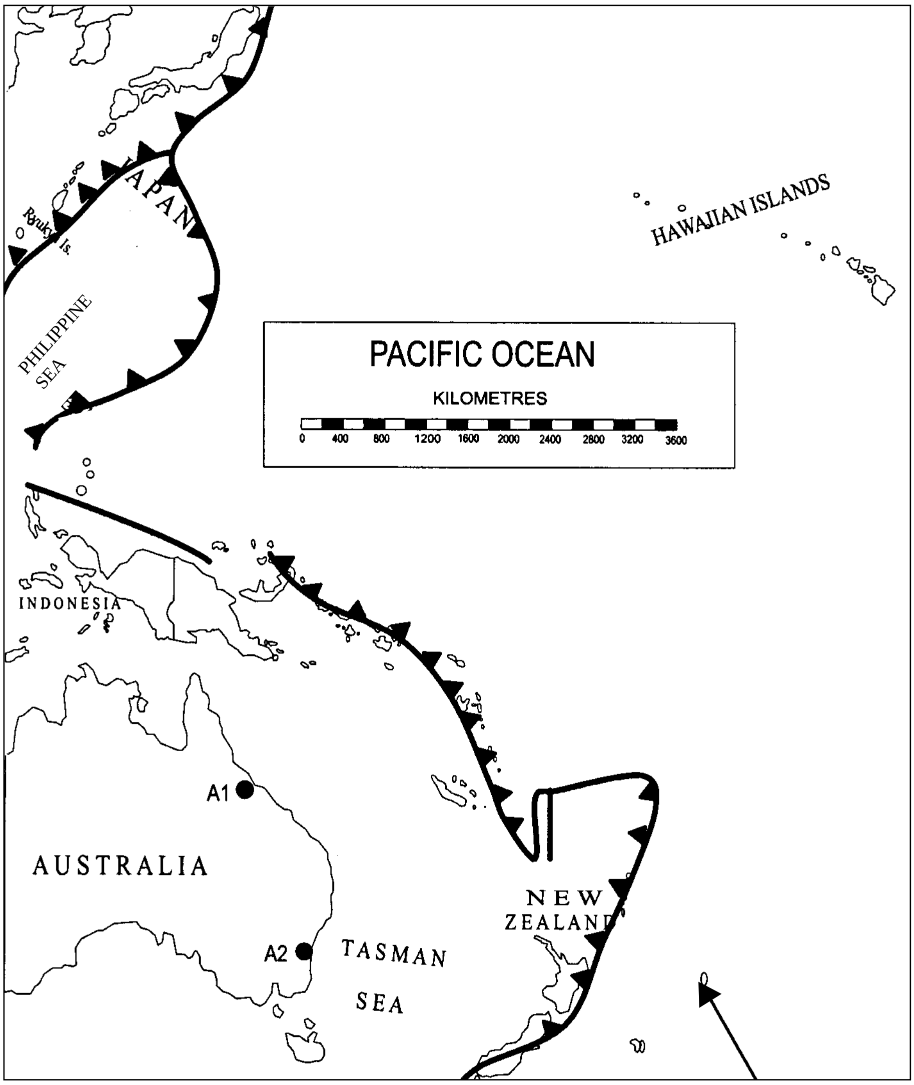


figure 7 - tectonics map for Nova Cambria and the west Pacific region

The nearest plate boundary to Nova Cambria is the destructive boundary at New Zealand (see the map above, figure 7).

Scientists can locate the epicentre of an earthquake by using seismograms. The first set of seismic waves to be recorded are the P waves, followed some time later by the S waves. The time delay between these two sets of waves is used to find the distance to the epicentre. Data from three seismograms is used to pinpoint the epicentre.

An example from the UK

On the 23rd September 2000, an earthquake occurred in England, its effects were felt across the Midlands. The British Geological Survey's network of seismometers recorded the event and their seismologists determined that the magnitude of the earthquake measured 4.2 on the Richter scale. Here are three seismograms which recorded the event.

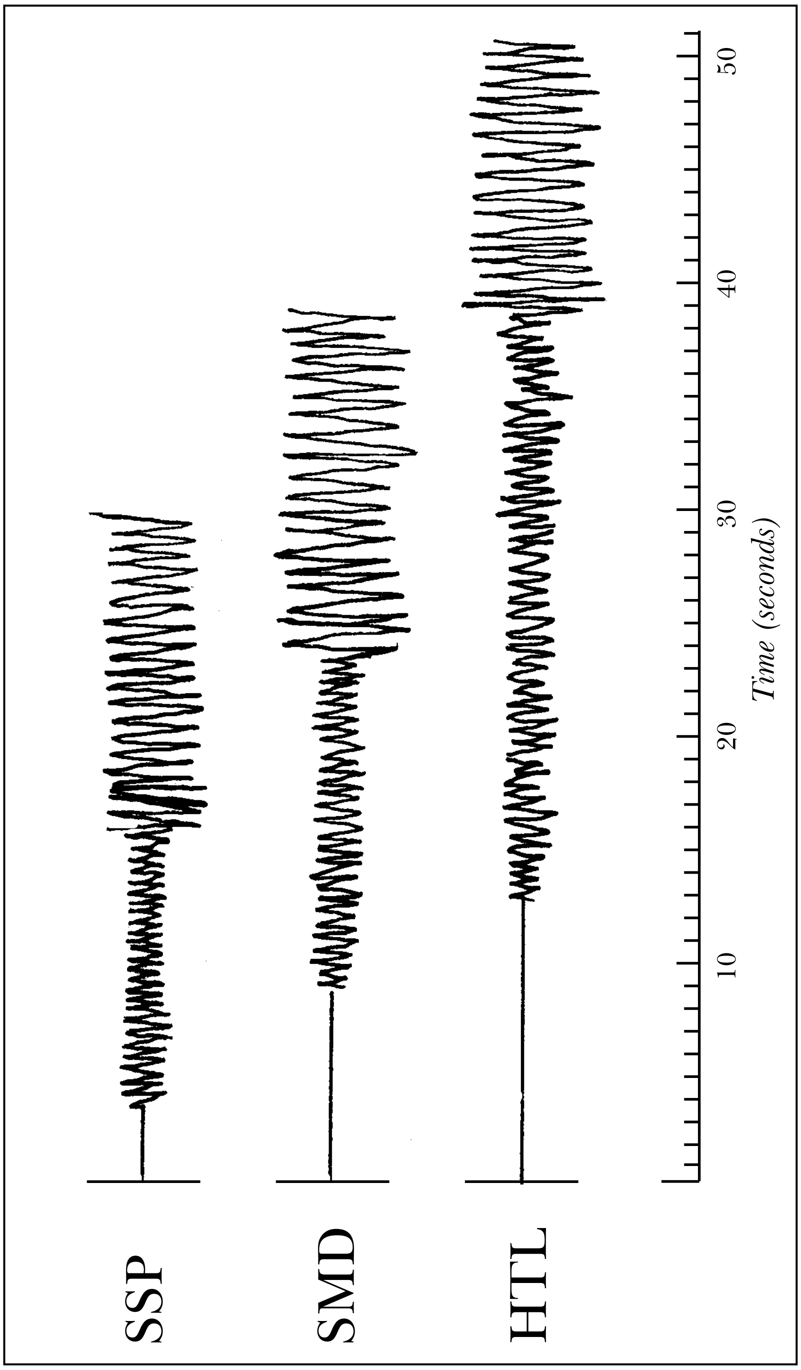


figure 8 - seismograms

Activity 6
On each seismogram above, label the first arrivals of the P and S waves.

Activity 7
Look carefully at the seismograms. Measure the time difference between the first arrivals of the P waves and the S waves on each.

Seismogram 1 = ...seconds
Seismogram 2 = ...seconds
Seismogram 3 = ...seconds

Activity 8
Now we will find how far each seismometer was from the epicentre. Compare each time lag with the table below.

km	S-P sec	km	S-P sec	km	S-P sec	km	S-P sec
1	0.21	30	3.96	135	16.21	240	26.31
2	0.34	35	4.60	140	16.78	245	26.77
3	0.47	40	5.25	145	17.34	250	27.23
4	0.60	45	5.90	150	17.91	260	28.14
5	0.73	50	6.54	155	18.48	270	29.05
6	0.86	55	7.16	160	19.01	280	29.96
7	0.99	60	7.72	165	19.47	290	30.88
8	1.12	65	8.29	170	19.93	300	31.79
9	1.25	70	8.86	175	20.38	310	32.70
10	1.37	75	9.42	180	20.84	320	33.61
11	1.50	80	9.99	185	21.30	330	34.53
12	1.63	85	10.55	190	21.75	340	35.44
13	1.76	90	11.12	195	22.21	350	36.35
14	1.89	95	11.69	200	22.66		
15	2.02	100	12.25	205	23.12		
16	2.15	105	12.82	210	23.58		
17	2.28	110	13.38	215	24.03		
18	2.41	115	13.95	220	24.49		
19	2.54	120	14.52	225	24.95		
20	2.67	125	15.08	230	25.40		
25	3.31	130	15.65	235	25.86		

figure 10

Seismogram 1 = ...km
Seismogram 2 = ...km
Seismogram 3 = ...km

Activity 9

On the map below, use a pair of compasses to draw circles around each of the seismometer locations. The circles should have the same radius as the distance to the epicentre.

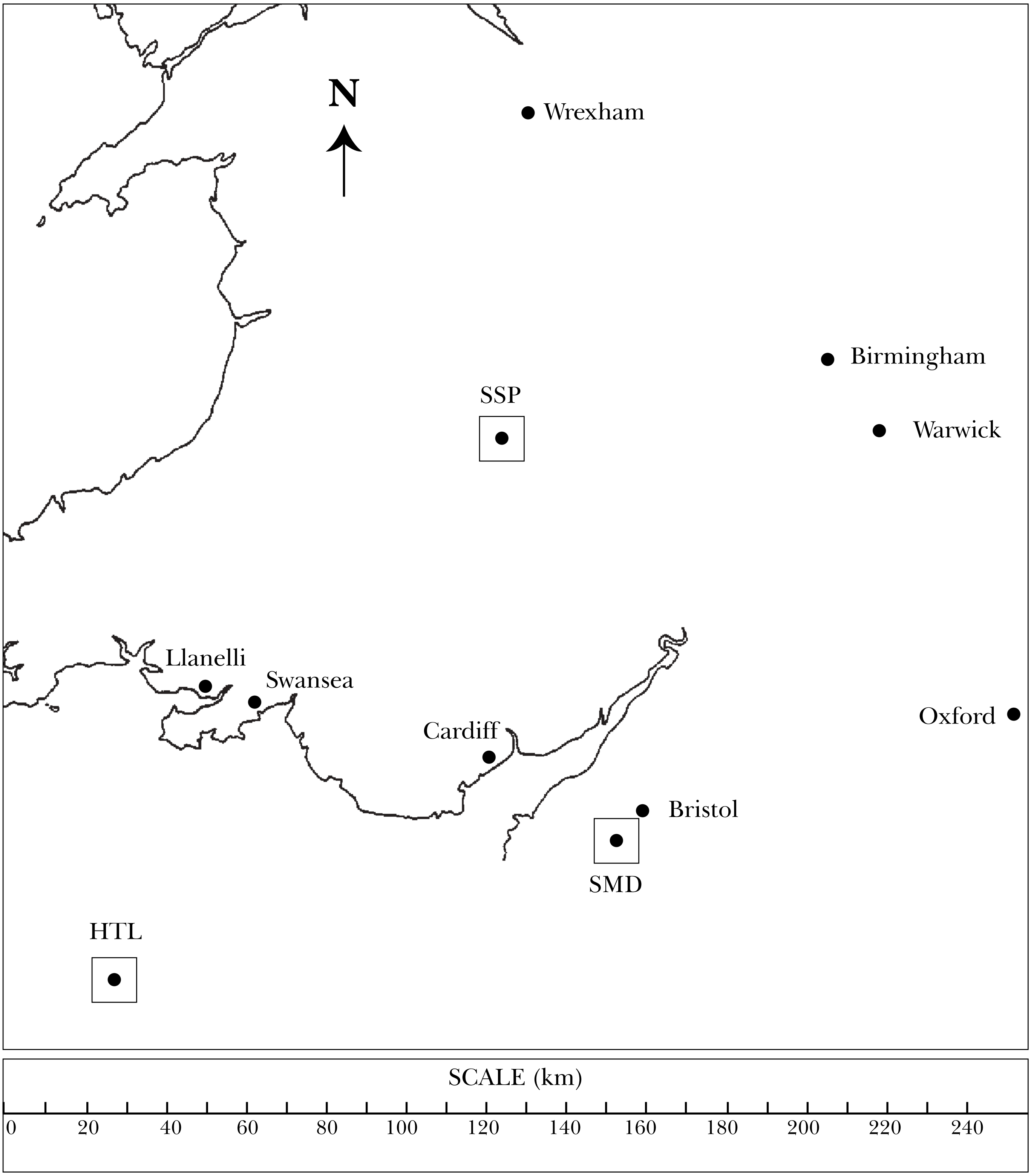


figure 11 - map of part of the Uk

We need to assess the risks of a major earthquake affecting the island of Nova Cambria.

Activity 10

The seismograms below show a magnitude 7 earthquake which occurred along the subduction zone in the South Pacific. Use the same method to locate the epicentre of the earthquake.

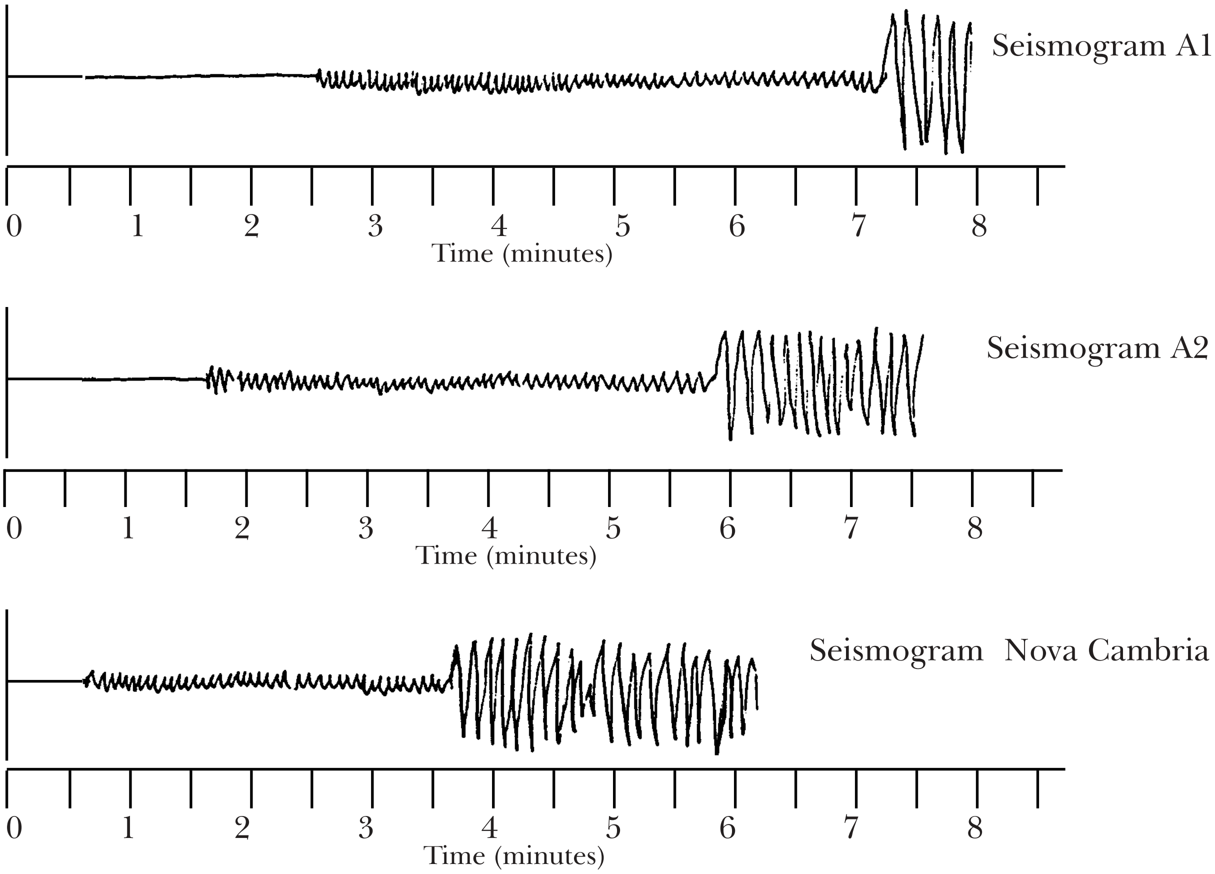


fig 12

S-P time differences:

Seismogram A1 = ...minutes
Seismogram A2 = ...minutes
Seismogram NC = ...minutes

Now work out the distances from the epicentre to each station. Use the table below:

S-P time lag (min)	Distance (km)
1.75	1000
3	1800
3.25	2000
4.3	3000
4.8	3400
5	3800

fig 13

Distances to epicentre:

Seismogram A1 = ...km
Seismogram A2 = ...km
Seismogram NC = ...km

Use the tectonics map, figure 7 to plot the epicentre of the earthquake.

We have seen from the tectonics map that the nearest plate boundary is destructive and this is characterised by explosive volcanic eruptions. Lava is just one hazard of such volcanoes, greater risks come from the gases and pyroclastic material produced by these eruptions.

An example from the USA

Mount St. Helens is located in the Cascades Range of mountains in Washington State. On the 18th May 1980, at 8.32 am, the volcano erupted explosively creating widespread destruction across the region. The main agent of destruction was a pyroclastic flow - a cloud of hot gas and dust which rolled down the side of the mountain. This was accompanied by debris avalanches and lahars (mud flows). The initial blast moved at speeds of approximately 500 km/hr.

By 5.30 pm 57 people had been killed, 250 homes, seven bridges and 300 km of roads were destroyed.

Despite the devastation, relatively few people lost their lives because the US Geological Survey were able to warn people of the imminent eruption. There were a number of indicators of an eruption. Most notably the side of the volcano was seen to inflate like a balloon being blown up, this was accompanied by many shallow focus earthquakes.

Following the 1980 eruption, the USGS established a monitoring system for Mount St. Helens. The graph below shows their results for monitoring the tilt of the volcano. Notice how the tilt increases rapidly before each eruption.

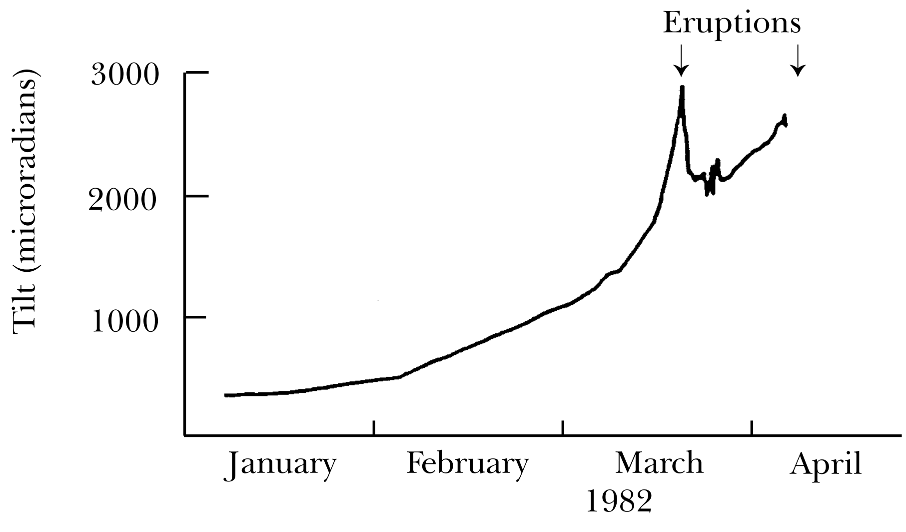


figure 9 - tiltmeter readings for Mount St. Helens during 1982

Monitoring indicators of activity is a very important way of assessing the hazard posed by a volcano. Monitoring techniques include measuring the angle of tilt of the lava dome, sampling gas emissions and measuring temperature changes.

Nova Cambria has its own volcano, Mount St. Thomas in the southern part of the island. It is thought to be extinct, but could it erupt again?

Activity 11

The data below show tiltmeter readings (measured in microradians) for Mount St. Thomas during 1995 - 2000.

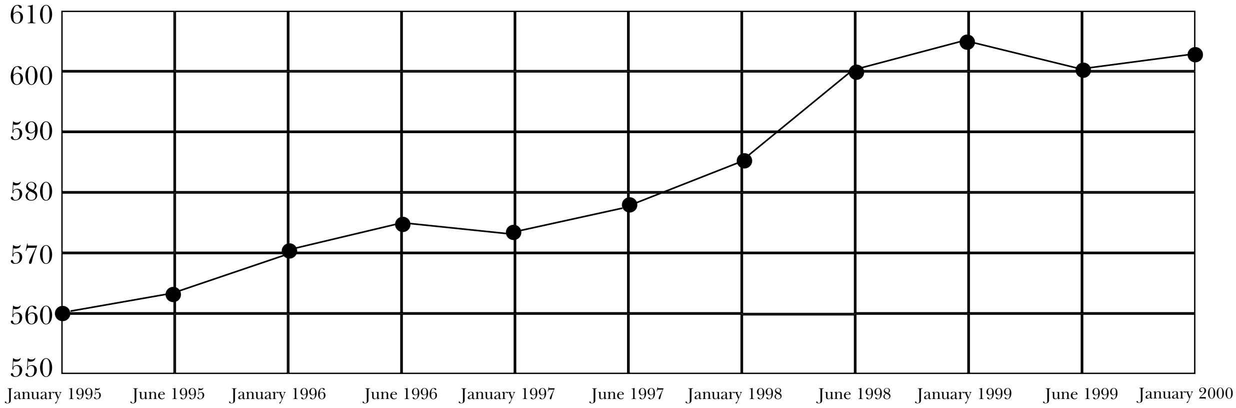


figure 14

Is there any evidence for renewed volcanic activity?

....
....
....

Section 4 - Coastal problems

If you live on an island, you are never far from the sea. The dominant agent of erosion at the coast is wave action and the most powerful and destructive waves are those which have travelled the greatest distance. Such waves are said to have a long "fetch". Waves are able to exploit weaknesses in cliffs such as joints, faults and softer rock types. This may lead to a "notch" which undercuts the cliffs, eventually causing cliff fall or landslides. As the waves reach shallower water, their directions change in a process called refraction.

Under certain conditions, 'wave refraction' the swash of the waves is greater than the backwash. This leads to deposition of beach material derived from erosion. Beaches are natural defences against wave attack. Where waves reach the beach at an angle, there is a tendency for sediment to be transported along a coast in a process called 'longshore drift'.

Activity 12

Fig. 16 shows a map of the island with the surrounding water depths labelled. A wind rose is also shown
On the map, draw an arrow to show the prevailing wind direction.
Using arrows, show the probable longshore drift direction along the west coast of the island.
If you have a sample of sand from the coast of site A, examine it carefully.
How does this support your ideas about longshore drift?

....

....

In some places wave erosion is so pronounced that it poses a significant threat to human activity. It may be necessary to use artificial sea defences to try to prevent further erosion or loss of sediment from the beach, but these schemes tend to be expensive and interfere with the natural processes occurring at the coast. Nova Cambria is in a tectonically active region so it may be in danger from tsunami generated far offshore.

Activity 13

The map below shows part of the coast of Nova Cambria, the region around site A. It also shows historical positions of the coastline. Use these data to calculate the rate at which the sea is eroding this part of the island.

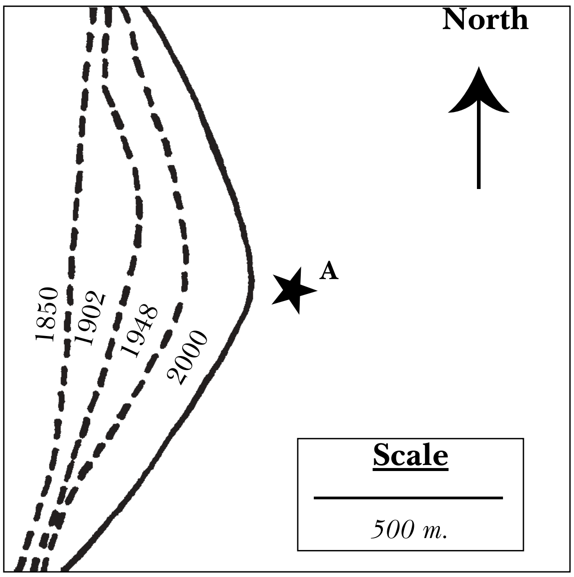
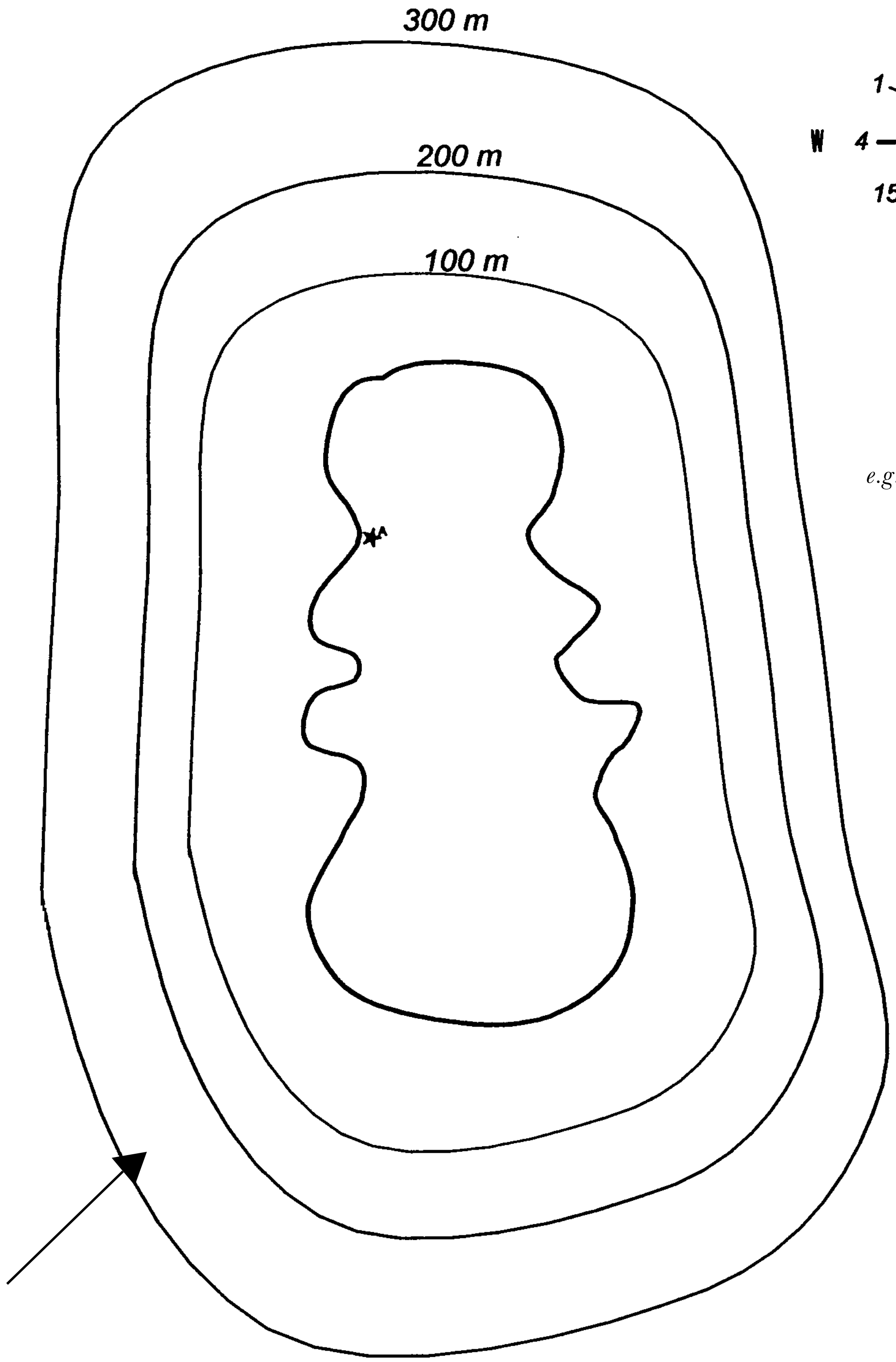
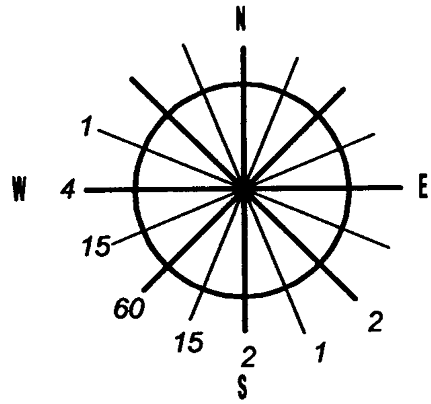


figure 15 - map of the coast near site A

....

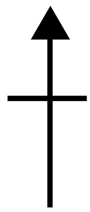
....





Wind direction data
(percentage of year)
e.g. wind blows from south west
for $60^{0}{}_{0}$ of the year

North



KEY

100m

Submarine depth contour

Scale
5km

figure 16
Bathymetric map of
Nova Cambria

Groundwater can move through rocks which are permeable. Porous rocks have spaces within them which contain fluids and if these spaces interconnect then the fluid can move through the rock and it is said to be permeable. This type of permeability is called primary permeability. Secondary permeability refers to the ability of fluids to move through cracks and fissures in the rock. Rocks containing water are called aquifers. Groundwater is the second largest supply of water after the oceans, and is much greater than rivers and lakes.

Where there are rocks of low permeability at the surface, such as clays or granites, or metamorphic rocks such as slates, only a little rain soaks into the ground, and rainwater flows straight into streams or rivers. Flooding is more likely in these areas. If the rocks are permeable water takes time to go through the aquifer before reaching the rivers, and the areas are less prone to flooding

Groundwater flow is related to surface water and can follow the general pattern of drainage in an area, with water flowing from high areas to low areas. Highly permeable rocks allow water to move more quickly than rocks of low permeability.

There is a downward limit to where water will usually permeate, but it varies with rock type. Generally however active circulation of water can be expected to a depth of 1 kilometre, but is exceptional below that level.

The problem pollution poses depends on how fast the groundwater moves through the aquifer, many substances breakdown naturally to harmless products, but radioactive material will remain harmful for a very long time. The groundwater may be able to transport radioactive material so you will need to know the way in which it moves through the rocks of the island.

For this exercise only a simple permeability test will be made on the rock samples. However it is also expected that consideration will be given to the likely movement of surface and groundwater on this island according to the distribution of the rock types and the shape of the landscape.

PERMEABILITY TEST 1 - DOES THE DROP DISAPPEAR ?

Although rocks may look very solid, some have small holes between the grains. Water will sink into these holes and pass through the rock. If water and other fluids can pass through the rock the rock is said to be **PERMEABLE**, but if there are no holes and the water cannot pass through the rock it is said to be **IMPERMEABLE**.

Activity 14

1. Use the rod or teat pipette to put a droplet of water onto a flat surface of the rock

(a) Does the droplet disappear into the rock straight away?
If so the rock is highly permeable.

(b) Or does it spread out as a damp patch and disappear slowly?
If so, the rock is slightly permeable

(c) Or does it remain on the surface?
If so the rock is impermeable

2. Try each of the rocks in turn

3. Complete the following table - one of the answers has already been inserted

Name of rock	Name of rock	Permeable or Impermeable
andesitic lava	igneous	impermeable
limestone		
sandstone		
shale		
granite		
siltstone		

figure 18

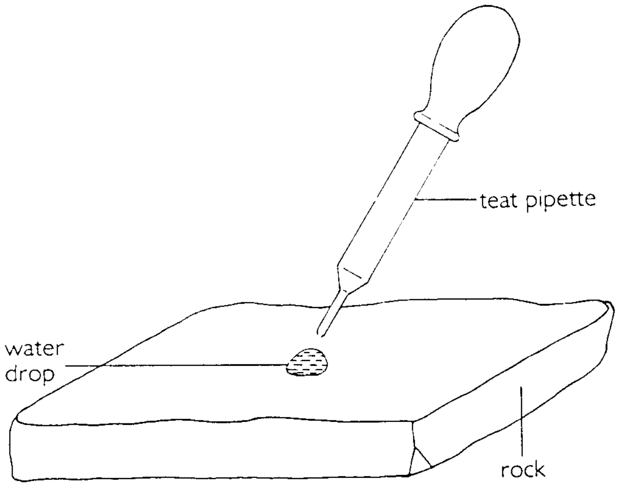


figure 17

To which major rock group do the permeable rocks belong? Give a reason for this

....
....
....

Arrange the rocks on the island in order of permeability:

.... *most permeable*
....
....
....
....
.... *least permeable*

Which rocks are most unsuitable for siting the waste facility?

....
....

Are any of the sites near to surface water courses or on particularly permeable rocks?

....
....
....

Before any civil engineering project starts, the site must be assessed for its suitability, this is called a site investigation. The purpose of the site investigation is to cut down on overall costs by identifying "difficult ground" before construction begins.

The first part of the site investigation is called the desk study. The engineering geologist consults any available data about the site, this may include geological maps, old land use maps, historical records etc. Once this initial survey has been completed the ground conditions are examined directly by using a range of geological and geophysical techniques such as borehole logging, ground penetrating radar, magnetic field measurements etc.

Geophysical methods involve remote sensing of some physical property of the ground. Induction methods use a signal of some sort which is sent down through the ground and it is then received back at the surface where it is recorded. These techniques include seismic, electrical and radar equipment.

Passive techniques include measuring tiny variations in the strength of the Earth's gravitational and magnetic fields. Magnetic surveys are particularly useful for detecting the presence of linear vertical features such as mine shafts.

Activity 15

The map below shows the result of a magnetic survey carried out at site D (measurements are in 10^2 nanoteslars)

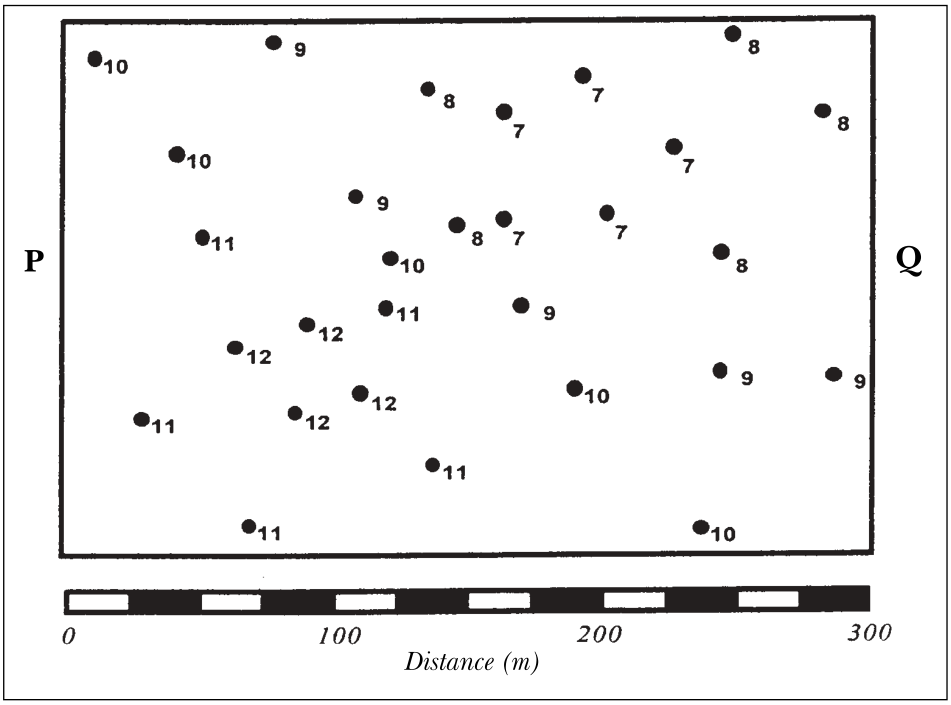


figure 20 - magnetic survey at site D

Complete the map using magnetic contours.

Mark on the map the probable location of an abandoned mine shaft.

Measurements of gravitational field strength can be used to find low density material under the surface. In site investigations, a negative anomaly can indicate underground cavities such as mining tunnels.

Activity 16

A gravity survey was also carried out across this site (from P to Q).

Distance (m)	Gravity reading (gu)	Distance (m)	Distance (m)
0	719.4	175	718.1
25	719.2	200	718.1
50	719.1	225	718.2
75	718.3	250	718.7
100	718.1	275	719.4
125	718.2	300	719.5
150	718		

figure 21

On the graph below, plot these data.

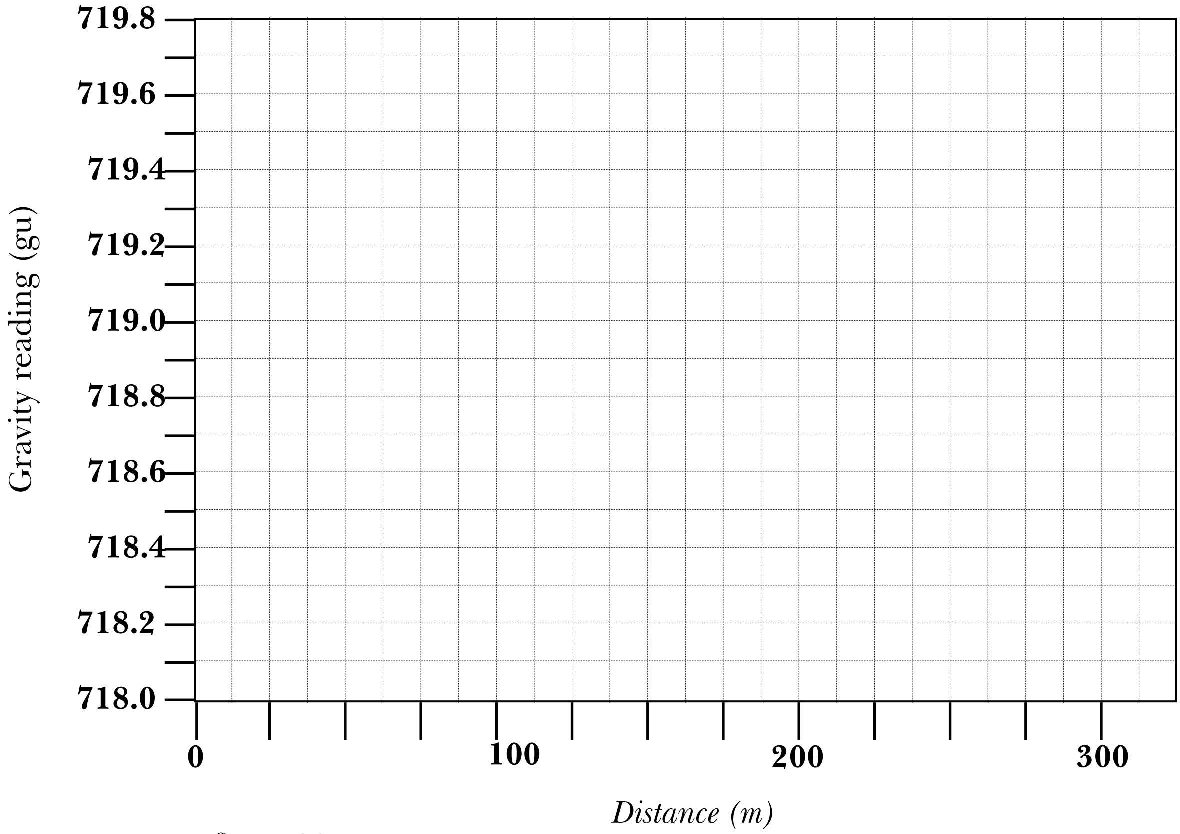


figure 22

Section 7 - Conclusions

By now you probably know which sites are unsuitable for the waste dump, but are there any sites which are suitable? Should the project go ahead, or should the islanders think again?

Activity 17

Complete the following form recommending which site the islanders should pick. Alternatively you could recommend that the whole project is abandoned. In each case it is important to give your reasons for rejecting the alternative sites.

To Nova Cambria Government

My recommendation is:

....
....
....

Reasons for rejecting alternative sites:

Site A
....
....

Site B
....
....

Site C
....
....

Site D
....
....

Site E
....
....

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Mr Geraint Price, NMGW (Collections and Education Division)
Dr Carolyn Heeps, NMGW (Collections and Education Division)

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