STUDENT GUIDE

INTRODUCTION

In this unit you will find out about:

- how rocks deform to form a variety of features and how these features are identified on maps and in section
- the analysis of geological maps
- how certain aspects of physics can aid the interpretation of Earth structure and major Earth movements
- the theory of plate tectonics and how it unifies a number of geological processes.

What is provided?

You will have:

- a set of student activity sheets which ask you questions on a variety of topics including interpreting diagrams and maps, and drawing conclusions from various sources of information. Do not write on these sheets but keep your work in a notebook or folder. Sometimes there are printed worksheets to be completed. Keep these at the appropriate points in your folder.

  Also in the activity sheets are extension questions, boxed and identified by the letter E with the question number. Your teacher/lecturer will guide you on which of these should be attempted. Some of these extension exercises are helpful if you are taking the full Higher Geology course.

  At intervals in the activity sheets there are checkpoints and quick quizzes. At a checkpoint check your answers to the preceding section/s of the activity sheets. Please ensure that your work is correct as it is your record for revision purposes. If you are in doubt about any question, ask your teacher/lecturer for help.

  Before doing a set of questions called a Quick Quiz, look back over the relevant sections of the Information Book and Activity Sheets. When you have finished the Quiz, ask your teacher/lecturer to check your answers or provide you with the answers for self-checking. Ask your teacher/lecturer about any question you got badly wrong or that you do not understand.

- an information book which gives most of the information you require for the activities. Please do not write on this book.

Also available for use are:

- answer sheets for the checkpoints and quick quizzes in the activity sheets. Your teacher/lecturer will decide with you how these are to be used and at which points your work will be checked by him/her.
- other resources in your school/college such as rocks, minerals, slides, maps, block models, computer programs to which your teacher/lecturer will direct you. In particular you may use a computer program to assist you with aspects of structural geology.

How you will be assessed

You will be assessed in two main ways.

1. When you have finished the unit you will sit a test with two parts. Part A will test what you know and understand and part B will test how well you can solve problems. If you fail the test you can have a further attempt to pass a similar test.
2. As part of this unit you will undertake fieldwork and write a report on it. You will be given help in preparing for and undertaking the fieldwork and in reporting on your findings and conclusions. If your report is not of an acceptable standard you will be given advice and then be able to re-draft it. If necessary you may be asked to undertake a second fieldwork and report.

STUDENT ACTIVITY SHEETS

STRUCTURAL GEOLOGY

Introduction

Once rocks are buried in the crust they are subjected to increasing pressures and temperatures and this can affect them not only by the kind of metamorphism, studied in the unit: *Minerals and Rocks*, but also by deformation. In this unit you are introduced to some of the effects of deformation, such as folding and faulting, most of which are linked to mountain building events or orogenies. This unit also introduces you to geological mapping, where you will learn to recognise geological structures and how to interpret them.

By the end of this unit you should:

- know how rock deforms
- be able to construct structure contours on geological maps and use them to complete rock outcrops and calculate dips and dip directions
- identify the different types of faults on maps and sections
- identify the different types of fold on maps and sections
- identify igneous bodies and unconformities on maps and sections
- explain how lineation, joints and foliation form
- be able to analyse geological maps and construct sections from them.

SECTION 1: ROCK DEFORMATION

There are enormous forces acting inside the Earth which over a period of time will break and bend even a material as apparently strong as rock.

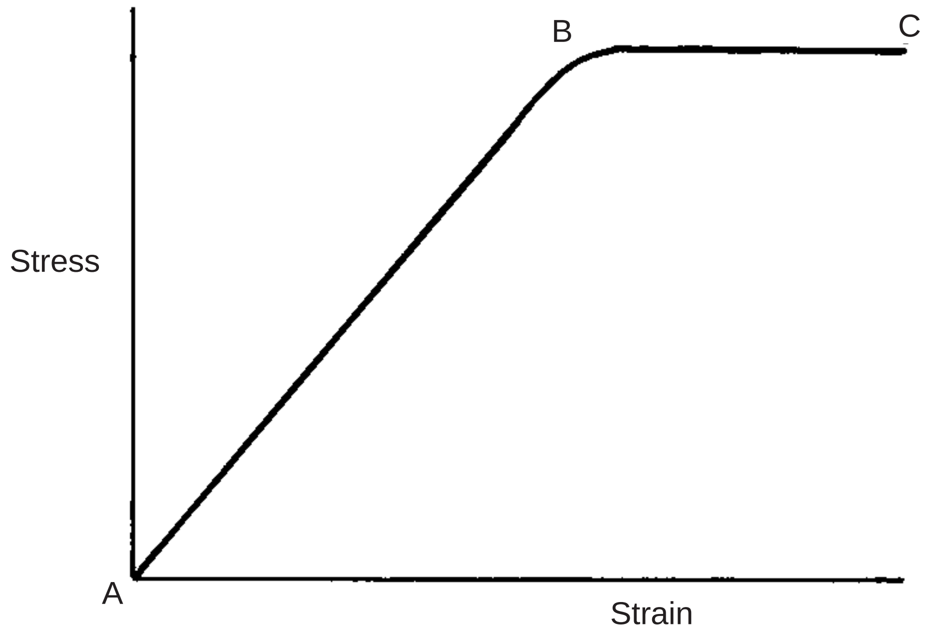
Read - Information Book Section 1: Rock Deformation

1. Write down a one sentence definition for each of the following items:
   (a) deformation
   (b) strain
   (c) elastic strain
   (d) plastic strain
   (e) ductile and brittle strain (behaviour)
   (f) stress
   (g) compressive, tensile and shear forces
   (h) creep.

2. For each of the following materials state whether they tend to display elastic or plastic strain and whether they follow brittle or ductile behaviour. You may find it helpful to try deforming some of the materials.
   (a) cold toffee
   (b) a rubber
   (c) plasticine
   (d) hot toffee
   (e) blackboard chalk
   (f) chewing gum.

3. (a) Plot the graph of stress against strain for the material in table 1.2.
   (b) Mark in the elastic limit and identify the stress at this elastic limit.
   (c) Label the graph with an area of elastic deformation and another where plastic deformation is occurring.
   (d) Mark on the fracture point.

4. Use the letters from this graph for sandstone to complete the sentences below:



(i) Elastic behaviour is taking place between point ___ and point ___ .
(ii) The rock is near the surface of the Earth at point ___ .
(iii) Plastic behaviour is taking place between point ___ and point ___ .
(iv) The rock is broken at point ___ .
(v) The rock will recover its original shape if the stress is removed between point ___ and point ___ .

5. Mudstone is a much more ductile rock type. Sketch the form of the stress/strain graph for mudstone.

Extension Exercise

E1 Using other sources of information read further on rock deformation. Write notes on any extra information that you think is relevant.

SECTION 2: THINKING IN THREE DIMENSIONS

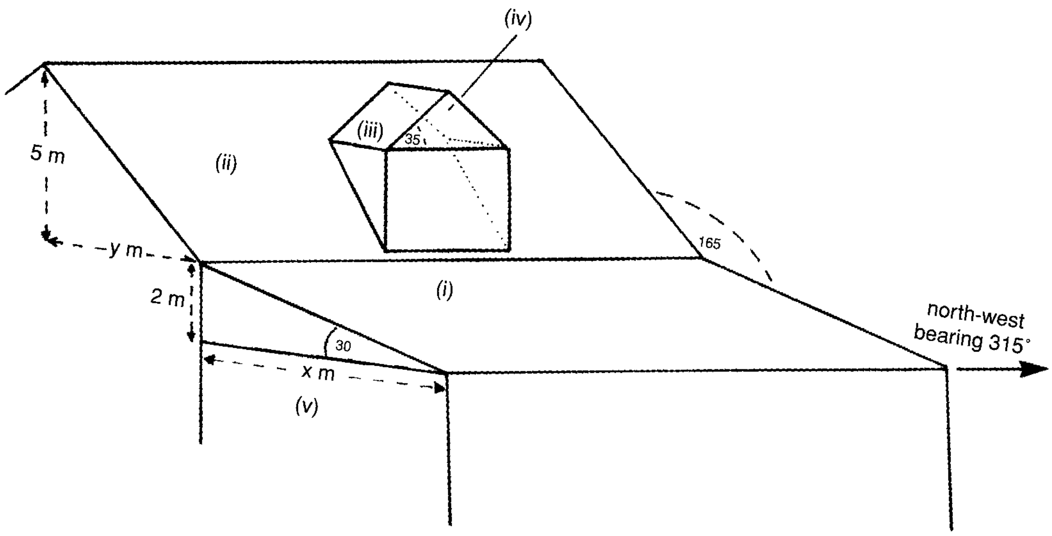
When rock layers are observed at the Earth's surface they are normally only seen in two dimensions such as in a road cutting or on the shore. At best only a few metres of the third dimension is seen.

To understand what is happening under the surface (a factor often as much of economic interest as academic) it is necessary to be able to measure the amount and direction of slope of rocks. This is achieved by measuring two quantities referred to as the strike and dip.

Read - *Geology: The Study of the Earth*
Student Information Book: Section 10 The Moving Earth

Read - Information Book Section 2: Dip and Strike

1. Worksheet 2.1 (not drawn to scale) shows the roof of the house below. Mark on the worksheet, using the correct symbols, the direction of dip and strike. State the strike and dip for each of the parts of the roof and walls that are numbered (i) – (v).



2. The idea of dip and strike is difficult to fully understand until you are able to measure them correctly for yourself. This will have to be demonstrated to you. If you have access to a compass and a clinometer you could practise for yourself on a tilted wooden board or propped up book. You will need to be able to measure these yourself during the fieldwork that is required as part of the unit assessment.

CHECKPOINT 1

SECTION 3: STRUCTURE CONTOURS

Structure contours are sometimes called strike lines and are used so that dipping planar features such as beds, foliation or fault planes can be treated geometrically. The two names used should give you an idea of what a structure contour is. You will probably be familiar with a topographic contour which is a line on the land surface connecting points of equal height above sea level. These lines are never straight as the land surface is always irregular.

A structure contour is a line on the surface of a structure such as a bedding plane, foliation surface or fault plane connecting points of equal height above sea level and hence are horizontal lines in the strike direction.

Read - Information Book Section 3: Structure Contours

1. (a) Worksheet 3.1 shows the roof in question 1 of Section 2 without the small window. Now treat the two areas of roof as dipping structures and draw structure contours for each part of the roof. Start with the lowest part of the roof at a height of three metres above the ground. Once the lower part is complete, progress to the upper section again drawing them every metre.
   (b) When viewed from above, on which part of the roof will the structure contours be closest together?
   (c) Using $\tan\theta = \dfrac{\text{opposite}}{\text{adjacent}}$ calculate the two distances x and y

2. Work your way through the computer program on structure contours. (You will need a computer with Hypercard Application. A paper copy is provided if these facilities are not available.)
   Worksheet 3.2 provides you with help in running the program.
   Worksheet 3.3 is to be completed whilst you are working on the computer program.

3. Complete the map on Worksheet 3.4. If you need help or wish to check the final map at the end of this exercise, this is covered in the exercise section of this part of the computer program.
   (a) First construct all the structure contours for boundary B.
   (b) Relabel the structure contours for boundary C.
   (c) Use these structure contours to construct boundary C on the map.
   (d) Now repeat for boundary A.
   (e) Draw a section.
   (f) Calculate the dip.

CHECKPOINT 2

Extension Exercise
E1 Now try any further examples of structure contour problems provided by your teacher/lecturer.

Quick Quiz 1

Try to complete the quiz from memory, only using reference material when you have to. You will be expected to complete similar questions for unit and course assessment without the aid of books.

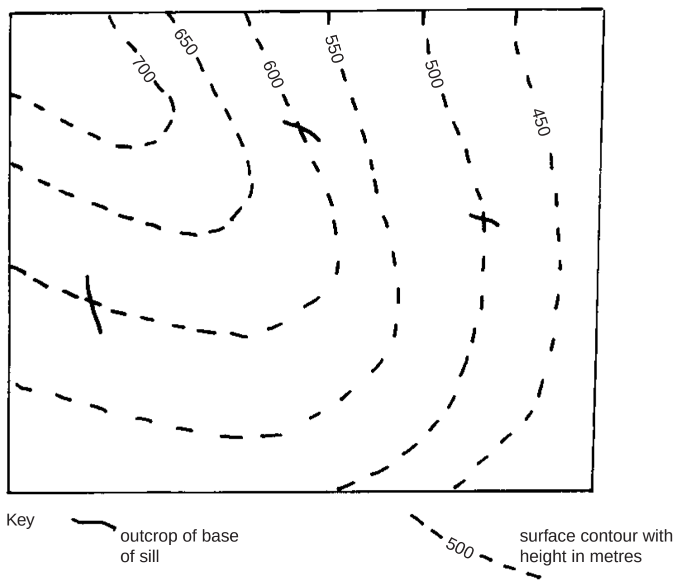
1. Explain the meaning of the following terms:
   stress; strain; elastic strain; plastic strain; brittle behaviour; ductile behaviour; elastic limit; creep. (8)

2. (i) State the meaning of the term strike and explain how it is measured. (2)

   (ii) State the meaning of the term true dip and explain how it is measured. (2)

   (iii) How does true dip differ from apparent dip? (2)

3.



The diagram above is also shown on worksheet QQ1. On the worksheet

(i) Draw the structure contours for the base of the sill over the whole area of the map and label them. (3)

(ii) Mark in the outcrop of the bottom of the sill. (3)

(iii) If the sill is 50 metres thick relabel the structure contours and mark in the top of the sill. Shade in the area of outcrop of the sill. (3)

(iv) Calculate the dip of the sill. (2)

(25)

SECTION 4: FAULTS AND FOLDS

When rock is placed under stress it may behave in a plastic manner and folds can be produced or it may behave in a brittle manner when faults occur. The types of folds and faults that develop depend on a range of factors including:
(a) the type of force
(b) how quickly the force is applied
(c) the rock types involved.

Introduction to faults and folds
If you have not successfully completed Intermediate 1 unit *Geology: The Study of the Earth* start at question 1.

If you have completed that unit but not completed Intermediate 2 unit *Earth Physics and Earth Movements* start at question 2.

If you have successfully completed the unit *Earth Physics and Earth Movements* revise by rereading the information sheets from that unit and then go on to Quick Quiz 2.

1. If you have not undertaken the Intermediate 1 unit *Geology: Study of the Earth* you should start by reading the student information book section 10 The Moving Earth and trying quiz 6. The block models and maps on the activity sheets are also worth trying.

2. Having successfully completed the structural geology part of *Geology: Study of the Earth* move on to the Intermediate 2 unit: *Earth Physics and Earth Movements*. From the Short Course materials, read the information sheets:
   - unit 13 More on Folds
   - unit 14 Igneous Bodies
   - unit 15 The Unconformity
   - unit 16 More on Faults
   - unit 17 Age Relationships.

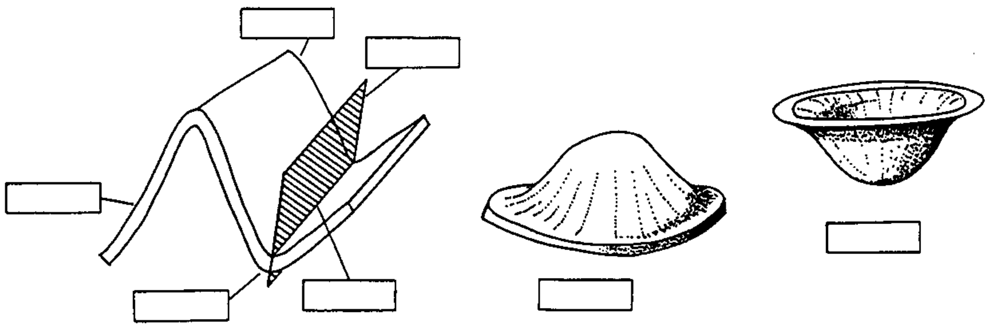
   Try the block models and maps on the activity sheets.

Now go on to do Quick Quiz 2

Quick Quiz 2

Try and complete the quiz from memory, only use reference material when you have to. You will be expected to complete similar questions for unit and course assessment without the aid of books.

1. Use the following terms to label the diagrams below:
   dome; anticline; fold axis; fold limb; basin; axial surface; syncline.



(7)

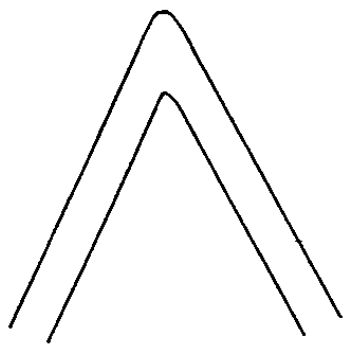
2. (a) State the symmetry of the fold in the diagram.

   ____ (1)

   (b) (i) Measure the inter-limb angle of the fold _________ degrees. (1)

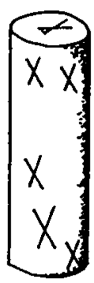
   (ii) The fold can be described as
   (a) open
   (b) closed
   (c) tight
   (d) isoclinal

   Answer: ___________ (1)

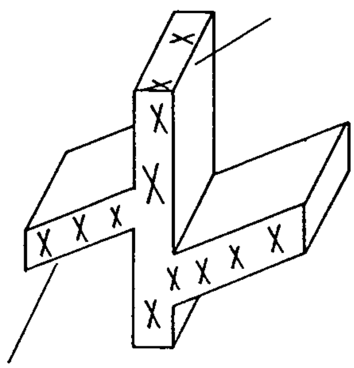


3. Name the following igneous bodies

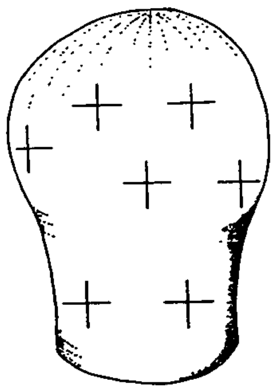
(i)



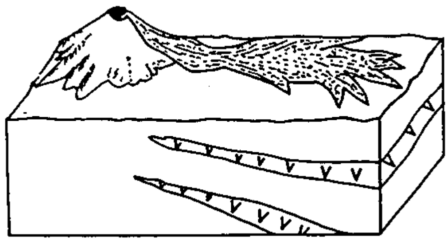
(ii)



(iii)



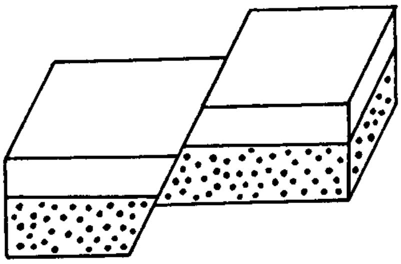
(iv)



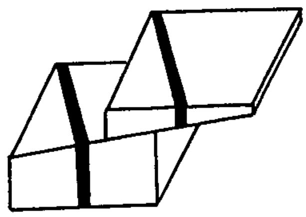
(5)

4. Name the 4 types of fault

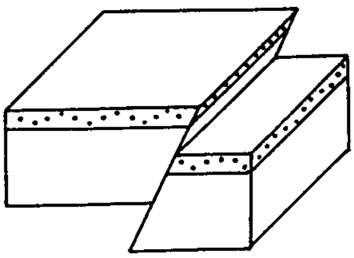
(i)



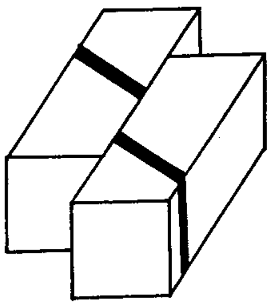
(ii)



(iii)

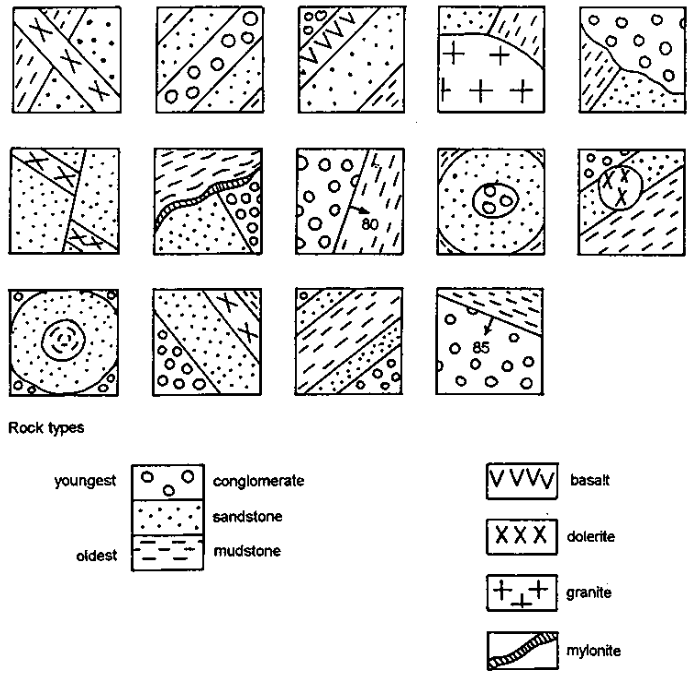


(iv)



(4)

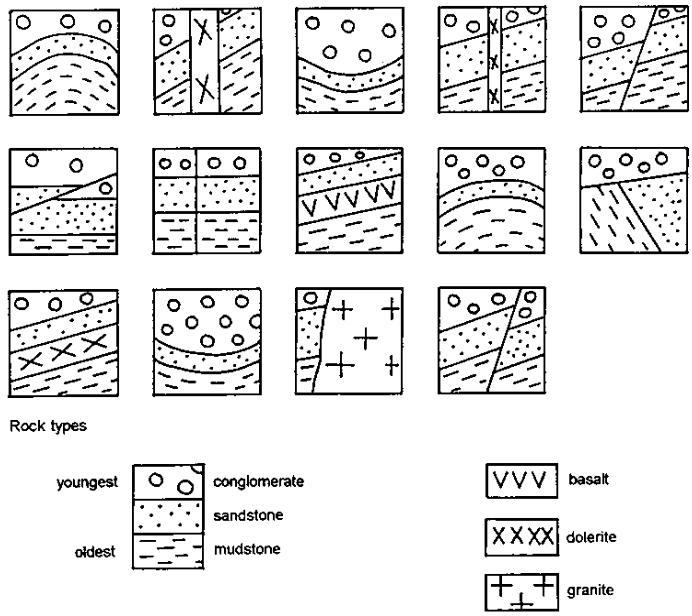
Use the diagrams below to complete the table showing each structure in plan (as it appears on a map).



anticline		dyke			
syncline		sill		normal fault	
dome		batholith		reverse fault	
basin		plug		thrust fault	
unconformity		lava flow		tear fault	

(14)

6. Use the diagrams below to complete the table showing each structure in section (as on the side of a block).



anticline		dyke			
syncline		sill		normal fault	
dome		batholith		reverse fault	
basin		plug		thrust fault	
unconformity		lava flow		tear fault	

(14)

Even more on faults

Further fault features must now be considered.

Read - Information Book Section 4A: Fault Movements

3. Take notes on:
   a) the slip and throw movements on a fault
   b) a rift valley or graben
   c) nappes

Read - Information Book Section 4 B: Effects of Fault Movements

4. Take notes on:
   (a) Fault breccia
   (b) Slickensides.

5.

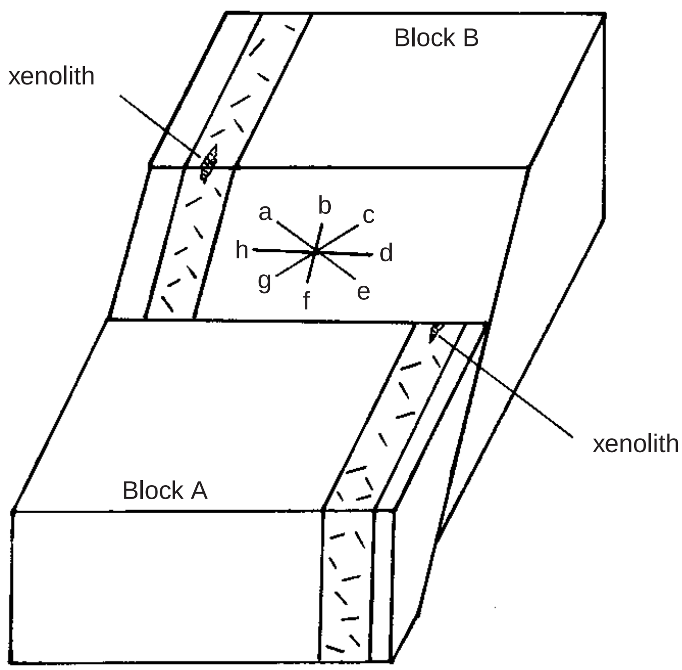


Figure 4.1

(a) Is the slip on the fault in fig. 4.1
   (i) dip slip
   (ii) strike slip
   (iii) oblique slip?

(b) In which direction (a) – (h) would slickensides be observed on the face of the fault in fig 4.1?

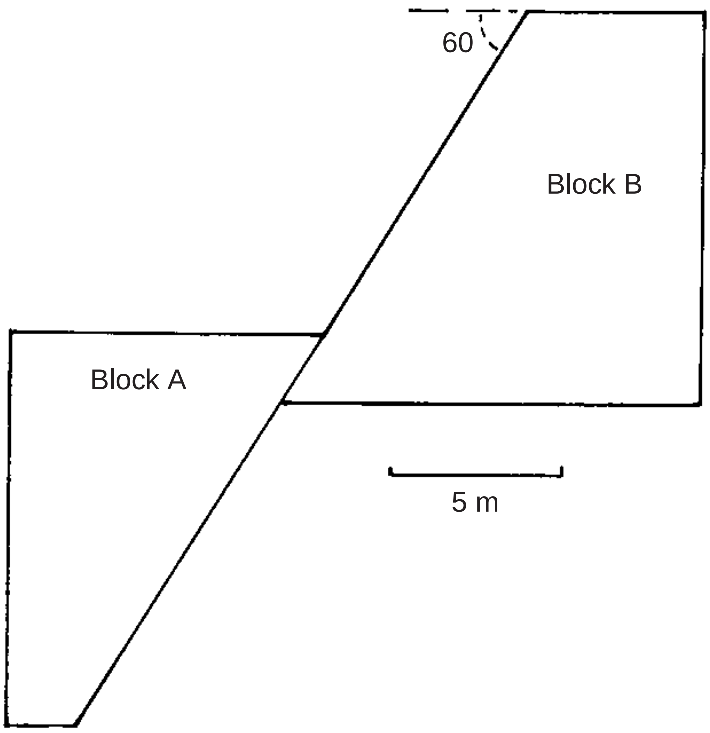
(c) If you were to run your finger from the centre of the circle toward the letter of your choice in part (b) what would you feel if there were steps present in the grooves?

(d) What type of fault is it
 (i) normal
 (ii) reverse
 (iii) thrust
 (iv) tear?

(e) Which block A or B contains the hanging wall?

Extension Exercise

E1 If the fault plane dips at 60° calculate the amount of throw. First measure the vertical component of the movement along the fault plane and then use trigonometry to calculate the vertical movement.



E2 Using other sources of information, read further on faults. Write notes on any extra information that you think is relevant.

CHECKPOINT 3

SECTION 5: FOLD TYPES

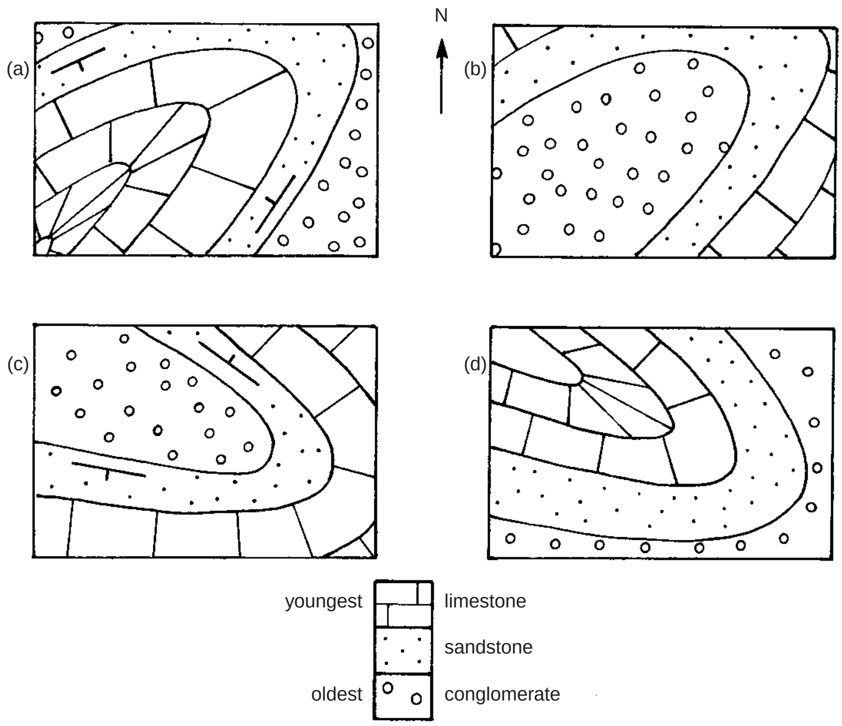
Further fold features must now be considered for Higher level.

Read **–** Information Book Section 5: Fold Types

1. Take notes on:
   (a) Antiform and synform.
   (b) Similar and parallel folds.
   (c) Plunge.

2. Carry out the exercise on Work Sheet 5.1 by classifying the folds as similar or parallel. You might find that the real life situation does not fit this simple two way classification in all cases. For each fold you must measure and record thicknesses parallel to the axial surface and at right angles to the bedding. Record these measurements in a table.

3. State whether the following are anticlines or synclines and give the direction of plunge.



Extension Exercise

E1 Using other sources of information, read further on folds. Write notes on any extra information that you think is relevant.

SECTION 6: IGNEOUS BODIES AND UNCONFORMITY

Read again - Unit 14 on Igneous Bodies and Unit 15 on the Unconformity from *Earth Physics and Earth Movements*

If you have already studied the Higher unit *Minerals and Rocks* you may be familiar with the appearance of other igneous bodies on a map. If not read Information Book Section 6: Igneous Bodies.

Extension Exercise

E1 Draw for yourself an unconformity in section and as it might appear on a map.

E2 Draw the following igneous bodies as they appear on a map and in section:
- (i) batholith
- (ii) stock
- (iii) ring dyke
- (iv) cone sheet.

E3 Using other sources of information, read further on igneous bodies and unconformity. Write notes on any extra information that you think is relevant.

CHECKPOINT 4

SECTION 7: ANALYSING GEOLOGICAL MAPS

Most of the structures that you have just been studying occur on a wide range of scales. Some you can see in hand specimens or in outcrops but others are on a much larger scale and require a map to identify them. A map will also allow you to work out a geological history for an area by placing geological events into order. To fully appreciate all of this it is often necessary to draw and study geological sections taken across the map area, as well as the map itself.

Both unit and course assessment require that you can draw a section from a map and analyse the section, map and construct a geological history for the area. Having examined the sorts of features to be found individually it is now time to look at them in combination as they appear in a field area.

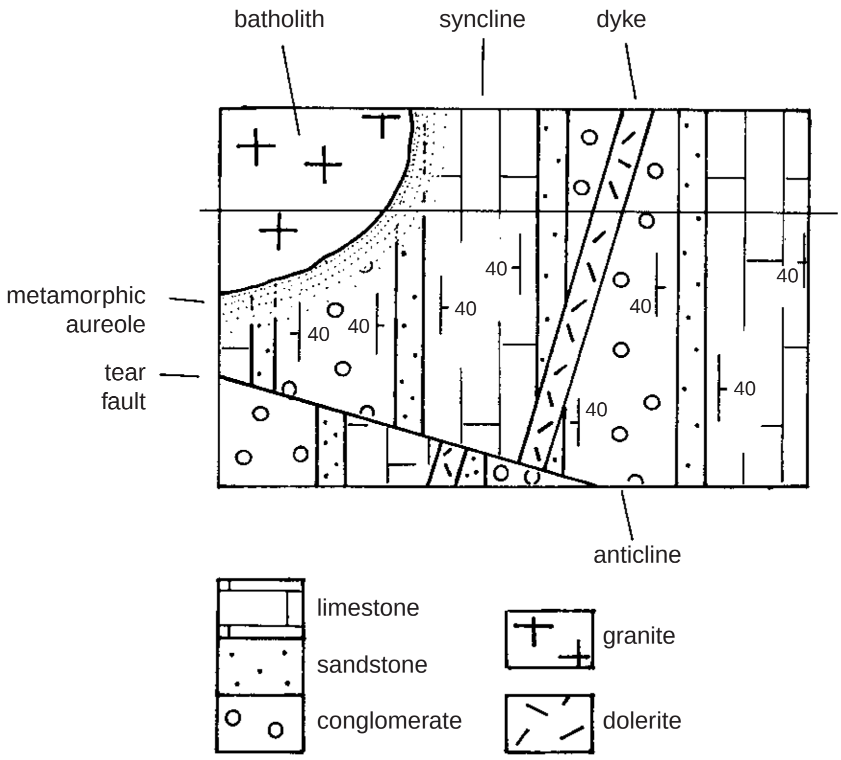
Read – Information Book Section 7: Analysing Geological Maps

Drawing a section

Following maps 1 and 2 on structure contours you should be able to draw the topographic profile of a landscape if contours are given. In fact in unit and course assessment this is always done for you to help save some time. What you have to do is to draw sections of the structures on to the topographic profile.

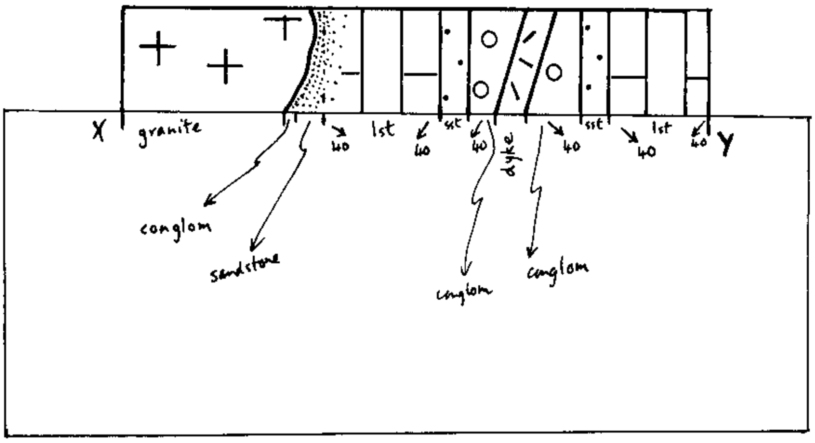
Before drawing the structures:

(a) Look at the map carefully for faults, folds, intrusions and, above all, unconformities. Look too for the dip directions of the strata, as this will give you clues as to the type of folding present, if any.

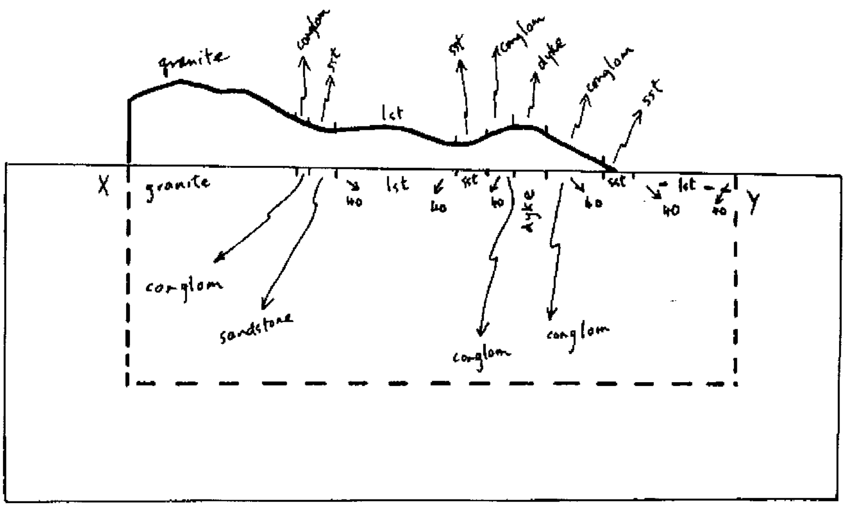


When drawing the structures:

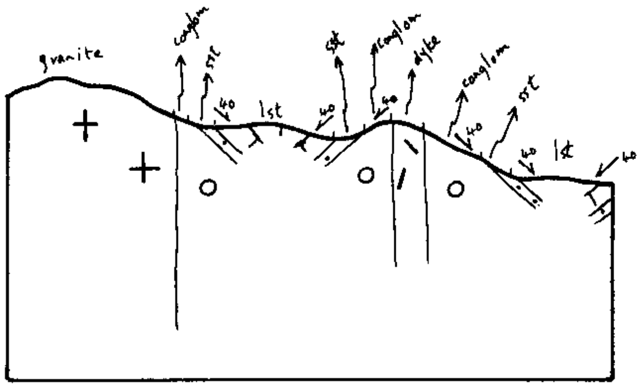
(b) To transfer information from the map to the section place a sheet of paper along the line of the section of the map. Mark the two ends of the section and the position of intersection of each bedding plane and structure (e.g. fault planes and the edges of intrusions) with the surface along the line of section. Label all points marked on the sheet including information on rock types and the amount and direction of dip.



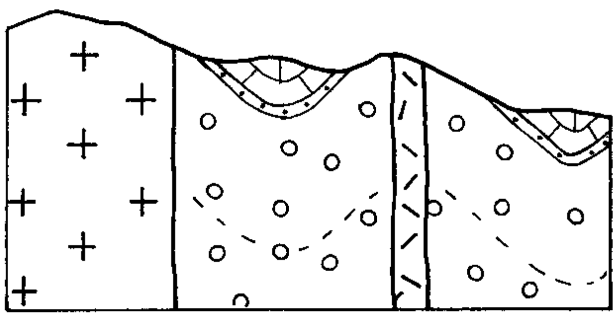
(c) Make sure the sheet is then placed the correct way round on the section. Using a pencil, transfer all these intersection points to the land surface of the topographic profile. To make the transfer as accurate as possible the sheet can be slid up and down to place the marks directly onto the surface.



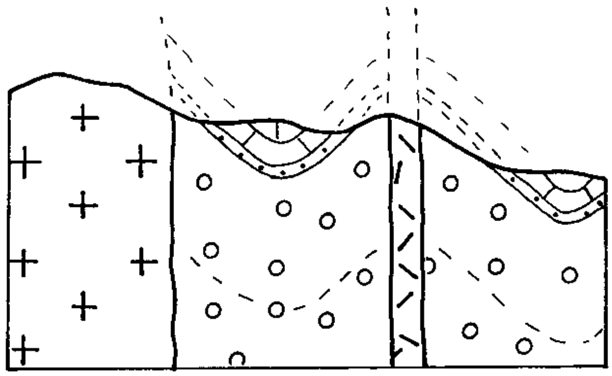
(d) Using a protractor, mark in the correct dips below the land surface. It is better to start with the more recent beds/structures, if you can quickly work those out, as these will cut across any older beds/structures. This saves a lot of rubbing out! The dip is always measured from the horizontal and not the land's surface. You may therefore find it easier to draw a short horizontal line at the marked point on the surface before measuring the angle of dip. The names of the rock types should also be added at the surface.



(e) You may have to interpret what is happening below the surface, for example by connecting up the two limbs of a syncline as they meet. Put in the ornamentation or symbols used for each rock type.



(f) It may well make the whole structure clearer if you interpret what previously existed above the present land surface before erosion took place. This is normally done using a dashed line rather than a solid one.



Writing a Geological History

At Higher you must be able to write a geological history as a structured account. (It may be worth rereading *Earth Physics and Earth Movements* information sheets on unit 17 before you go any further).

Start by noting down all geological events in a rough list, e.g. deposition of sandstone, intrusion of dyke. Then using the two simple principles mentioned in unit 17 of *Earth Physics and Earth Movements*, start to number them from the oldest (1) to the youngest event (n). Rewrite your list with the oldest event at the bottom and the youngest at the top. This may be written directly onto the paper in the unit or course assessment.

Then start your written account with the oldest event explaining each in turn. Such detail as the following should be considered:

(a) a very brief consideration of the environment of a sediment, often this cannot be precisely established
(b) a brief consideration of the origin of a magma
(c) the type of forces required to produce a fault
(d) the series of events which led to the formation of the unconformity
(e) the plate tectonic setting (which type of margin, if any) - there is further study of plate tectonics later in this unit
(f) the geometry of folding.

1. Worksheet 7.1 is an actual map from the Higher Grade examination of 1994. Answer the questions, draw the section and write a geological history.

SECTION 8: FOLIATION AND LINEATION

Rocks that have been folded and deformed often develop new planar and linear structures known as foliation and lineation. A foliation is a planar feature, which penetrates right through the rock and is the result of planar minerals such as micas being orientated in one direction as a consequence of deformational stresses. Another type of planar feature that you have already come across is bedding. A lineation is a line, running across the surface of a bedding or foliation plane or running through the body of a rock.

Read **–** Information Book Section 8: Foliation and Lineation

1. Take notes on:
   (a) Foliation and its different types
   (b) Lineation and its different types.

2. Now try another map on Worksheet 8.1.

SECTION 9: JOINTS

Joints are very common in all types of rocks. They are cracks along which there has been no movement, whereas a fault is a crack along which there has been movement.

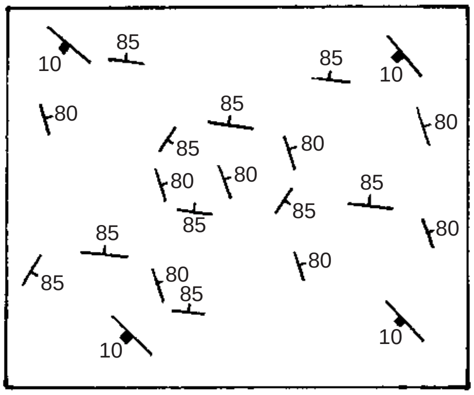
Read – Information Book Section 9: Joints

1. Take notes on the different ways in which joints can form.

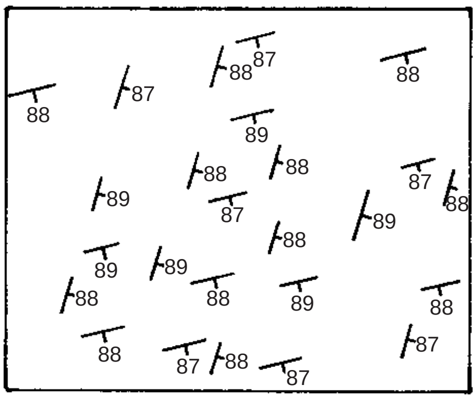
2. (a) For each of the maps (i), (ii) and (iii) describe the joint patterns from their dip and strikes.

   (b) Explain how each joint pattern may have been formed.

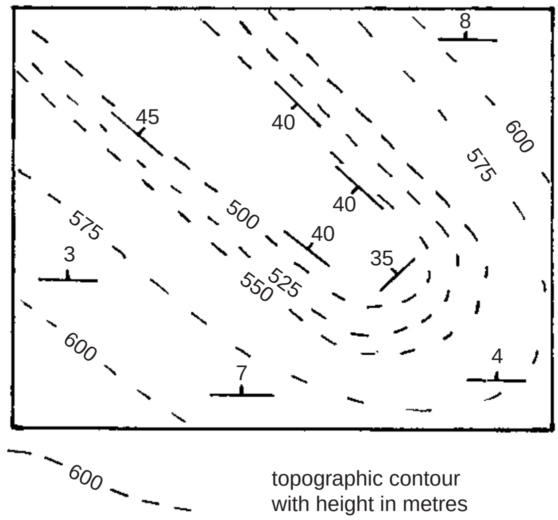
Map (i) Rock type basalt



Map (ii) Rock type sandstone



Map (iii) Rock type granite



Extension Exercise

E1 Using other sources of information read further on foliation, lineation and joints. Write notes on any extra information that you think is relevant.

CHECKPOINT 5

SECTION 10: MORE ON STRUCTURE CONTOURS

You have already seen how structure contours can be used to complete the outcrop of a particular rock. They can even be used for a structure or rock above or below the original one provided that the structure contours are renumbered.

For example if you need them for a bedding plane 100m above the original one just add 100m to all the original structure contour labels. This relabelling technique can also be used if there has been vertical movement on a fault plane.

Before you go any further it is important to be sure that you can carry out these procedures successfully.

Structure contours can also be constructed using a method of triangulation provided that you have height data on the structure from three separate points.

1. Work your way through the computer program on three-point problems. You can use Worksheet 10.1 with pencil and ruler to do the construction for yourself step by step.

   When doing this type of problem:
   (a) check that the structure height values at the three points are in height above sea level (not in depth below the surface as given, for example, in boreholes)
   (b) draw a triangle connecting the three points
   (c) taking each side of the triangle in turn divide it into sufficient equal divisions to allow for all planned heights between each corner. The heights used are usually at the same intervals as the topographic contours on the map.

2. Complete the map which is on Worksheet 10.2. If you need help, or wish to check it this exercise is the second part of the computer program.
   (a) Construct the triangle and divide the sides as needed.
   (b) Draw in the structure contours.
   (c) Use the structure contours to draw in the outcrop pattern.
   (d) Work out the dip.

CHECKPOINT 6

Extension Exercise

E1 Now try other examples of structure contour problems supplied by your teacher/lecturer.

Quick Quiz 3

Try to complete the quiz from memory, only use reference material when you have to. You will be expected to complete similar questions for unit and course assessment without the aid of books.

For all answers take the top of the page as north.

1. (a) Draw in section a sandstone bed which is part of an open symmetrical syncline. (1.5)

   (b) Draw a sandstone bed in a dome as it would appear on a map. Add dip and strike symbols. (1)

   (c) Draw in section a normal fault which has thrown a horizontal sandstone bed by 1 metre. Put the footwall block to the East and mark in the 1 metre throw. (1.5)

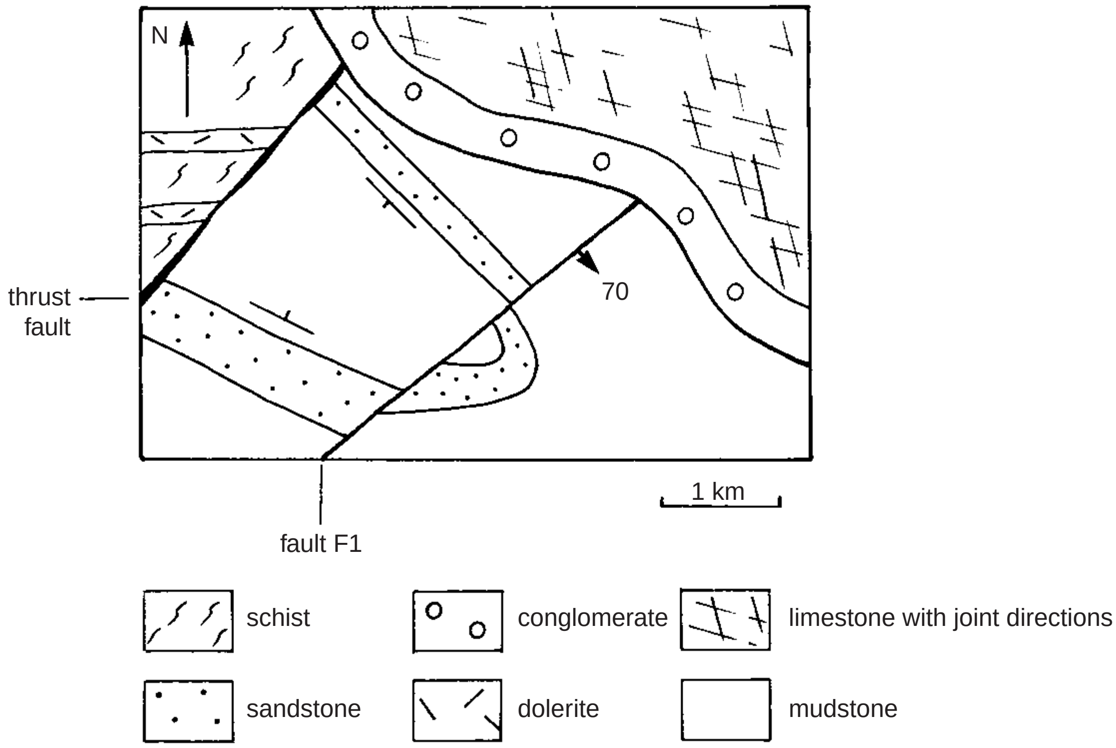
   (d) On a map draw a sandstone bed which is part of an antiform plunging east by 30°. Mark on dip and strike symbols including at the fold closure. (1.5)

   (e) A block showing both a ring dyke and a cone sheet. The top surface should show the map and the side surfaces show both structures in section. (2)

2. What is meant by the following items:
   (a) slickensides
   (b) fault breccia
   (c) a nappe
   (d) similar and parallel folds? (5)

3. How are the following formed:
   (a) columnar joints
   (b) lineation
   (c) shear joints
   (d) fracture cleavage
   (e) an unconformity? (5)

4.



(a) Using compass directions give the orientation of the minimum stress that existed when the dykes were intruded. (1)

(b) The fault F1 dips SE at 70°.
   (i) Which is the upthrown block?
   (ii) What type of fault is it? (1.5)

(c) Using compass directions give the orientation of the maximum stress when fault F1 was formed. (1)

(d) What suggests that the SW limb of the fold has a more gentle dip than the NE limb? (1)

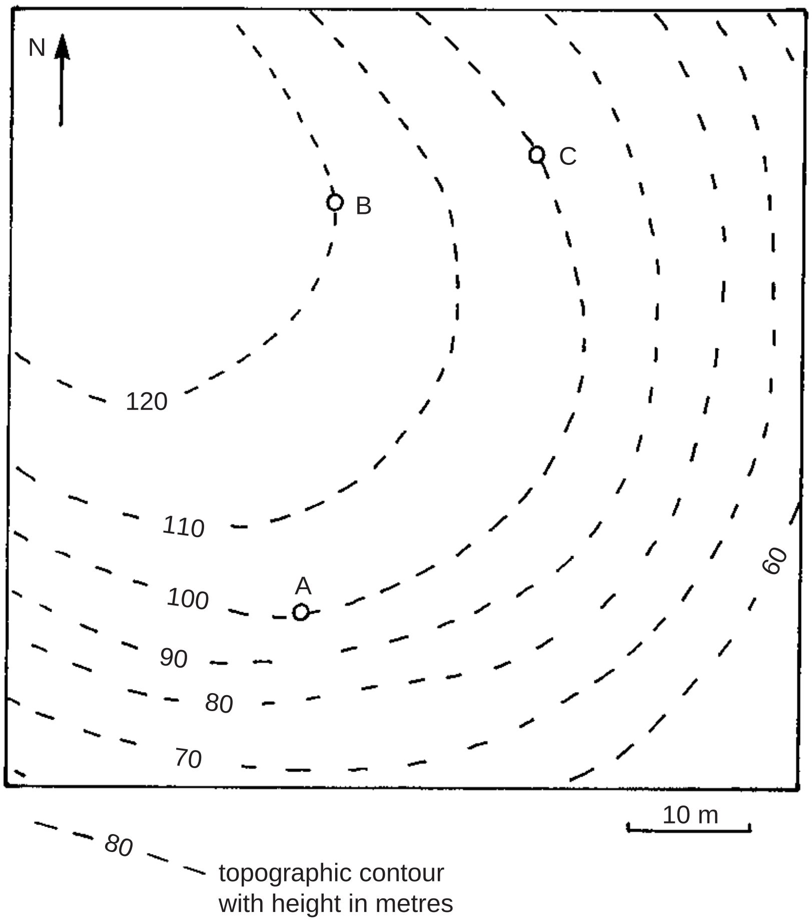
(e) Using compass directions give the orientation of the maximum stress direction when the thrust fault was formed. (1)

(f) The sandstone has a diamond shape pattern of joints. Using compass directions give the orientation of the maximum and minimum stress directions. (1)

(g) Write a geological history for the area of the map. (5)

5. A fault breccia is encountered in three boreholes at the following depths on the map shown:

    borehole A - 40 metres
    borehole B - 20 metres
    borehole C - 20 metres



The map is also given on worksheet QQ3. On the worksheet:

(i) Draw the structure contours for the fault over the whole area of the map and label them. (4)

(ii) Mark in the outcrop of the fault. (2)

(iii) Calculate the dip of the fault plane. (2)

(iv) If the rocks to the southeast of the fault are older than those to the northwest, state the type of fault. (1)

(v) State the type and orientation of stress that existed to form the fault. (2)

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PLATE TECTONICS & EARTH PHYSICS

Introduction

Plate tectonic theory makes a major contribution to an overall understanding of why geological processes occur where they do and when they do. The first ideas of moving continents date back to the middle of the 19th century. But it was 1915 before Alfred Wegener wrote a book setting out the evidence for moving continents. At that time no mechanism was known that could move the continents around, although convection in the mantle was suggested, and so his theory of continental drift was rejected by many geologists. Fifty years on in the 1960s such a mechanism was discovered and Wegener's ideas became accepted through the newly formulated Theory of Plate Tectonics. The breakthrough had come following advances in geophysics which allowed for more detailed examination of the Earth's interior.

By the end of this unit you should:

- understand the evidence which supports the theory of moving continents
- explain the formation of magnetic stripe anomalies during sea floor spreading
- identify the characteristics of lithosphere and asthenosphere
- explain the formation of apparent polar wandering curves
- describe the rocks and structures associated with different plate boundaries
- explain possible mechanisms of plate movements
- understand how earthquake waves are produced and how they behave
- be able to plot travel-time curves and epicentres
- describe the Earth's magnetic field
- explain magnetic reversals
- describe the Earth's internal structure quoting supporting evidence
- explain gravity anomalies
- describe the Earth's internal source of heat
- describe isostatic adjustments.

The plate tectonics and Earth physics sections have been interleaved as it is often necessary to consider a physics principle and its application to the Earth before the significance of some plate tectonic evidence can be fully appreciated.

SECTION 11: CONTINENTAL DRIFT

When the theory of moving continents was first put forward some geologists found it difficult to believe that something as large as a continent could move around, apparently on its own. It took many years for all the sources of evidence to be drawn together and appreciated. The evidence that eventually convinced most geologists that this had indeed been taking place consists of four main categories:

- the fit of present day continents into a super continent
- the matching geology across present continental boundaries
- matching past glaciations across present continental boundaries
- evidence for continental movement from the fossil record.

If you have not undertaken the Intermediate 2 unit *Earth Physics and Earth Movements* you should start by considering the evidence for the movement of continents from activity sheets Moving Continents and information sheets Unit 18: Moving Continents.

Read **–** Information Book Section 11: Further Evidence for Continental Movement

1. Why does the 1000 m submarine contour produce a better continental fit than the present day coastline when reassembling past major continents?

2. Explain how glacial striae can establish the direction of movement of a glacier.

SECTION 12: THE EARTH'S MAGNETIC FIELD

The existence of the Earth's magnetic field has been known of for many hundreds of years. Its shape is roughly the same as that which would be produced if a bar magnet was positioned at the centre of the Earth. The field is strong enough to magnetise iron-rich igneous rocks as they cool down.

Read **–** Information Book Section 12A: The Earth's Magnetic Field

1. Why is it certain that the Earth's magnetic field is not produced by a permanent magnet located within the Earth?

2. List the similarities and differences between the magnetic field of the Earth and that of a bar magnet.

3. Write a short note of about 100 words describing the Earth's magnetic field and its likely origin.

Read **–** Information Book Section 12B: Remanent Magnetism and Apparent Polar Wandering Curves

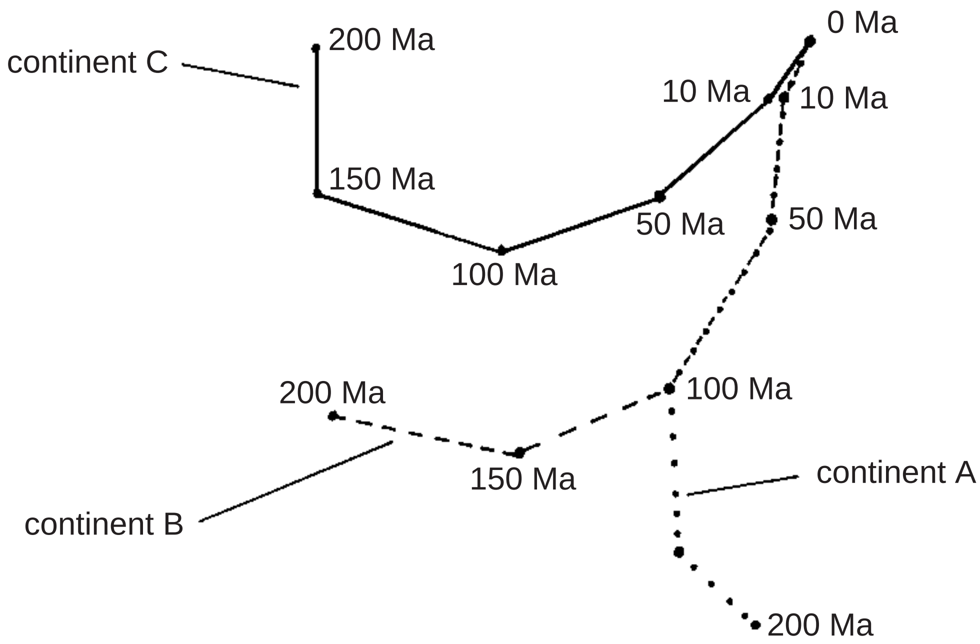
4. Carry out the exercise described in Section 12C: Drawing Apparent Polar Wandering Curves. Compare the two curves. The two curves should have identical sections when the continents were joined and differing sections when they were separated.

Extension Exercise

E1 Estimate the shape of the polar wandering curve from 450 Ma to present that you would expect for that part of continent A which breaks away after 300 Ma to remain attached to continent B. Do this by considering the two polar wandering curves already produced.

E2 Now actually produce the polar wandering curve for this shaded part of the continent using the same technique as in question 4. How close was it to your estimated polar wandering curve in E1?

5. Trace the three apparent polar wandering curves on separate pieces of tracing paper and by overlapping them interpret how the continents have moved through time. Write a short account that describes that movement.



6. Make short notes on apparent polar wandering curves by answering the following.

   (a) What is an apparent polar wandering curve?

   (b) What evidence do apparent polar wandering curves provide for continental movement?

Extension Exercise

Start by reading Information Book Section 12D: More on the Earth's Magnetic Field and then using other sources of information read further on the Earth's magnetic field.

E3 Write notes on any extra information concerning the Earth's magnetic field that you think is relevant.

E4 If a compass needle was suspended such that it could turn both horizontally and vertically. Which way would it point at:
(a) the north pole (b) the equator
(c) the south pole (d) Scotland (try measuring it yourself)?

E5 The Earth's magnetic field has changed considerably through time. List four ways in which it has changed.

SECTION 13: SEA FLOOR SPREADING

The theory of continental drift did not progress a great deal during the first half of this century as the mechanism for moving continents around remained elusive. Exploration of the sea floor in the 1950s and 60s began to raise questions and to provide some of the answers. Among the facts known at this time were that:

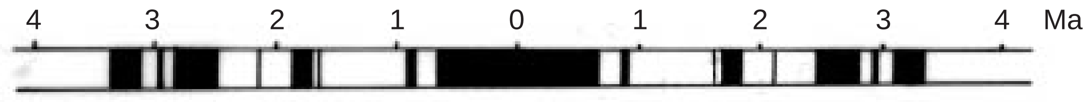
- there existed long volcanic ocean ridges, e.g. down the centre of the Atlantic.
- the ocean floor basalts were older at the edges of the oceans, e.g. adjoining the continental edge.
- deep ocean trenches existed in some parts of the oceans especially close to some of the continents and to island arcs.
- the oldest and thickest sediments were to be found at the edges of oceans.
- magnetic stripe anomalies existed in the basalts of the ocean floor.

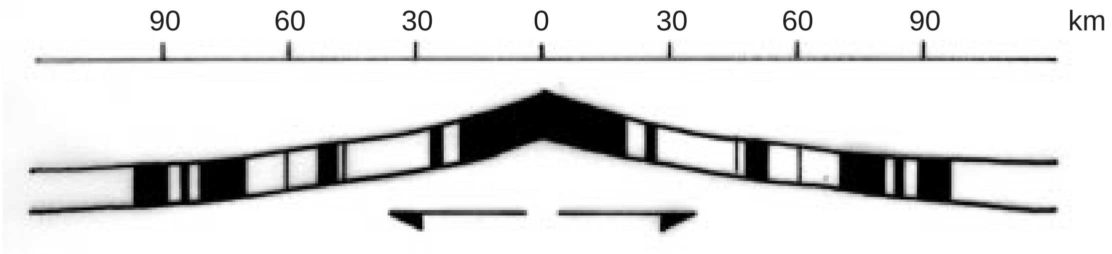
The theory which explained such observations has been termed sea floor spreading.

Read - *Earth Physics and Earth Movements* information sheets Units 19 and 20

1. If you have not successfully completed the Intermediate 2 unit*: Earth Physics and Earth Movements* carry out activity sheets:
    - How do continents move?
    - The basalts of the ocean floor
    - Basalt magnetisation
    - Sea floor spreading

2. The figure below shows the magnetic polarity either side of the Jaun de Fuca Ridge in the Pacific. The black stripes are normal polarity and the white stripes are reverse polarity.





(a) Calculate the spreading rates either side of the ridge.

(b) Does the spreading occur at the same rate either side of the ridge?

(c) Does the spreading rate remain constant through time?

Extension Exercise

E1 Redraw the magnetic stripe anomaly as it would have appeared if the left side of the ridge had been spreading at twice the rate of the right hand side.

E2 Now redraw the magnetic stripe anomaly pattern as it would have appeared on the right hand side if the spreading rate had been 5.6 cm/year for the period of time between 4 Ma and 2 Ma and then 1.4 cm/year between 2 Ma and the present.

CHECKPOINT 7

Quick Quiz 4

Evidence for drifting continents

1. Name two geological features which are continuous between the continents when Africa and South America are placed together. (2)

2. Give three other pieces of evidence that suggest Africa and South America were once joined. (3)

3. Give a piece of evidence for suggesting that North America, Europe and Greenland were once joined? (1)

The Earth's magnetic field

4. Which three of the following statements are correct concerning the Earth's magnetic field?

   (a) The Earth's magnetic field is produced by a permanent magnet located in the core.
   (b) The Earth's magnetic field is basically a dipole.
   (c) The Earth's magnetic field originates from the mantle by convecting rocks.
   (d) The Earth's magnetic field has reversed twice in the history of the Earth.
   (e) The Earth's magnetic field has reversed many times during the history of the Earth.
   (f) The magnetism detected by a compass at the Earth's surface is due to the magnetic basalt in the crust.
   (g) The Earth's magnetic field on average over a long period of time aligns with the axis of rotation.
   (h) The Earth's magnetic field attracts us to the Sun. (3)

5. State three ways in which the Earth's magnetic field changes. (3)

6. What is the likely origin of the Earth's magnetic field? (1)

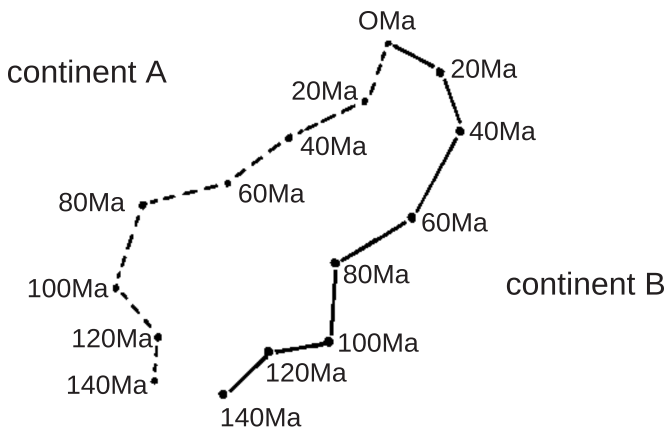
Apparent polar wandering

7. Which rock types are most likely to record the ancient magnetic field? (1)

8. Why are these rocks able to record the ancient magnetic field and others are not? (1)

9. Explain why the polar wandering curves are referred to as apparent. (1)

10. Describe the movement of the two continents whose polar wandering curves are shown. (2)



Sea floor spreading

11. Select the three correct statements
    (a) The oceanic crust is made of andesite.
    (b) Some oceans have a ridge running along their length.
    (c) Earthquakes are common all over the oceans.
    (d) The oceanic crust is moving apart in some places.
    (e) Oceanic crust is youngest at the ridges and becomes older away from the ridges.
    (f) The oceanic crust is mostly older than the continental crust.
    (g) The sediment on the oceanic crust is thicker at the ridges than nearer the coast.
    (h) In some oceans there are rift valleys close to their western coasts. (3)

12. Why are the rocks of the oceanic crust slightly magnetic? (2)

13. The magnetic stripes of the ocean floor reveal:
    (a) The Earth is not round
    (b) The Earth's magnetic field alternates in direction as you travel from west to east
    (c) The Earth does not have any magnetism of its own
    (d) The Earth's magnetic field has reversed many times during its history. (1)

THE EARTH'S STRUCTURE

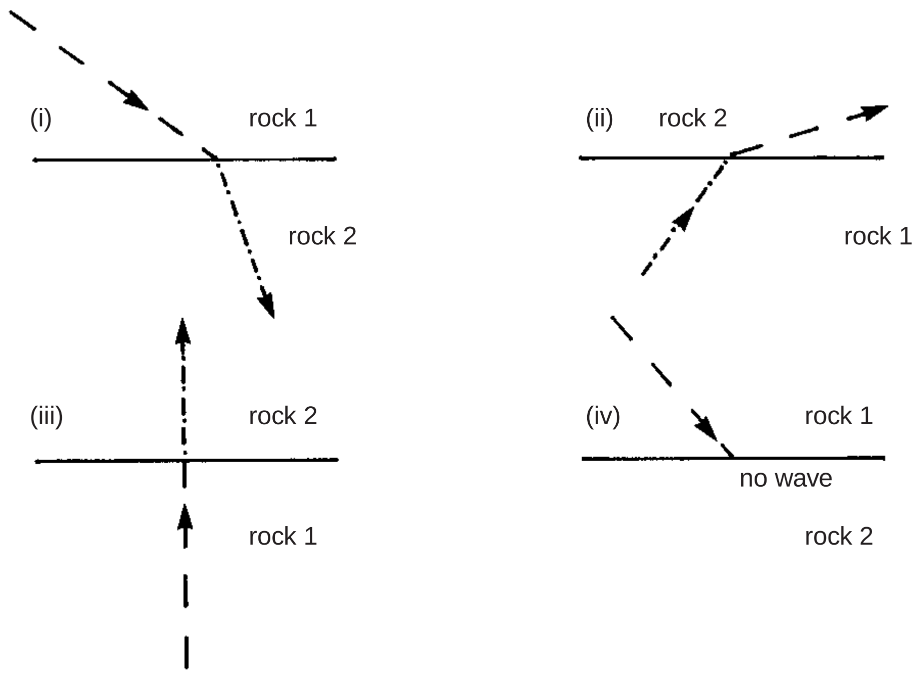
To fully understand how these massive slabs of rock called plates move around at the surface of the Earth it is necessary to consider the properties of the Earth's interior. As it has not been possible to take samples from very deep inside the Earth, it is necessary to depend on a remote sensing technique, namely by observing the behaviour of earthquake waves as they travel through the Earth.

SECTION 14: SEISMOLOGY

Read - *Earth Physics and Earth Movements* information sheets Units 1-11 and if you have not successfully completed the Intermediate 2 unit *Earth Physics and Earth Movements* then also undertake the activity sheets from the start up to and including quick quiz 2.

Read - Information Book Section 14 (a), (b) and (c): Seismology

1. (a) How much more energy is released by an earthquake with a magnitude of six than an earthquake of magnitude three?
   (b) Use figure 14.1 to establish the velocities of both the P- and S-waves by finding the gradients of the lines.
   (c) Explain the shapes of the P- and S-wave lines on figure 14.2.
   (d) Why is the L-wave line straight on figure 14.2?
   (e) What is the L-wave speed from figure 14.2?
   (f) For the following four examples explain whether the waves travel faster in rock 1 or rock 2.



(g) Using graph paper draw a graph to show distance against the time lag between P- and S- wave arrival.

Redraw and complete the table of data required by using figure 14.1 to establish the lag time between the P- and S-wave arrival times. Use this data to plot the graph.

Distance travelled in km	50	100	150	200	250	300	350	400
Lag in time between P-wave and S-wave arrivals in seconds.								

2. The diagram on worksheet 14.1 shows three seismograms recorded at the seismometers shown. To plot the position of the epicentre carry out the following:
   (a) Firstly assess the lag times recorded by each seismometer and estimate, if you can, where you think the epicentre is.
   (b) Use the graph for question 2 (g) to work out the distance of each seismometer from the epicentre.
   (c) On worksheet 14.1 use a pair of compasses to construct a circle at the epicentre distance from seismometer A. The epicentre is somewhere on the circle but it is not known where as the direction that the seismic waves took is unknown.
   (d) Now repeat the same exercise for seismometers B and C. Where the three circles intersect is the epicentre.

3. Explain the behaviour of P- and S-waves at a depth of 2900 km below the surface.

4. Explain the behaviour of P- and S-waves as they pass through the low velocity layer.

SECTION 15: THE EARTH'S COMPOSITION

We have already discussed the basic structure of the Earth as established by the study of the behaviour of earthquake waves in passing through the Earth. Difficulties exist in trying to be precise about the composition of each of the layers, as it is impossible to sample most of the Earth's interior directly. Obviously the main exception to this is the crust itself, where at least its upper part can easily be sampled. Some of the metamorphic rocks found at the surface today have been metamorphosed at great depths and therefore the composition of the greater part of the crust can be established.

The average composition of continental crust lies roughly between a granite and a diorite although there is a huge variation in rock type. Oceanic crust has been sampled directly by drilling. Also slices of it are sometimes caught up in the continental crust during mountain building episodes due to plate movements, as in the island of Cyprus. It is composed mostly of basalt underlain by dolerite dykes and then gabbro. Only a thin layer of sediment exists on the surface.

On occasions, pieces of peridotite, an ultrabasic rock, have been brought up by volcanoes. It is thought that these have been carried up from the upper mantle by rising magma. The partial melting of peridotite can produce basaltic magma, so it is not surprising that occasionally a piece of solid rock is brought up with the magma and erupted at the surface. Peridotite is also to be found on the island of Cyprus associated with the slice of oceanic crust.

***Read* –** Information Book Section 15: The Composition of the Earth

The Meteorites

1. Meteorites have come from broken up larger bodies in space. If those bodies also had a differentiated structure, complete the table to compare the layers of the Earth with meteorite falls. The data for the Earth is to be found in Figure 15.1 and Table 15.

EARTH			**SIMILAR METEORITES**		
Layer	**% Mass**	**Material**	**Type**	**% Falls**	**Material**
Core					
Mantle / Crust					

2. Could iron meteorites always have been small fragments moving through space? Explain your answer.

3. If the meteorite finds are a representative sample, what is the main difference between the Earth and the bodies that have broken up to form the meteorites?

4. Where could the stony iron meteorites have come from?

5. What evidence is to be found in the stony meteorites that melting is relatively rare after planets have formed?

6. If the average iron meteorites formed at a depth of 200 km below the surface estimate the size of the average body that produced these meteorites.

The Earth

7. (i) How thick is the continental crust?
   (ii) How thick is the oceanic crust?

8. What composition is the outer core?

9. How much faster do the P-waves travel in the inner core compared to the continental crust?

10. How deep below the surface does the low speed layer start and finish?

11. How much denser is the inner core compared to the continental crust?

12. Why is there a transition zone within the mantle?

CHECKPOINT 8

Quick Quiz 5

1. Rewrite Questions 1(a) and 1(c) and fill in the blank spaces.

   (a) The _______ which is measured on the ________ ______ is a measure of how much energy is released during an earthquake. (2)

   (b) How much more energy is released when an earthquake of seven occurs on this scale compared to an earthquake of three? (1)

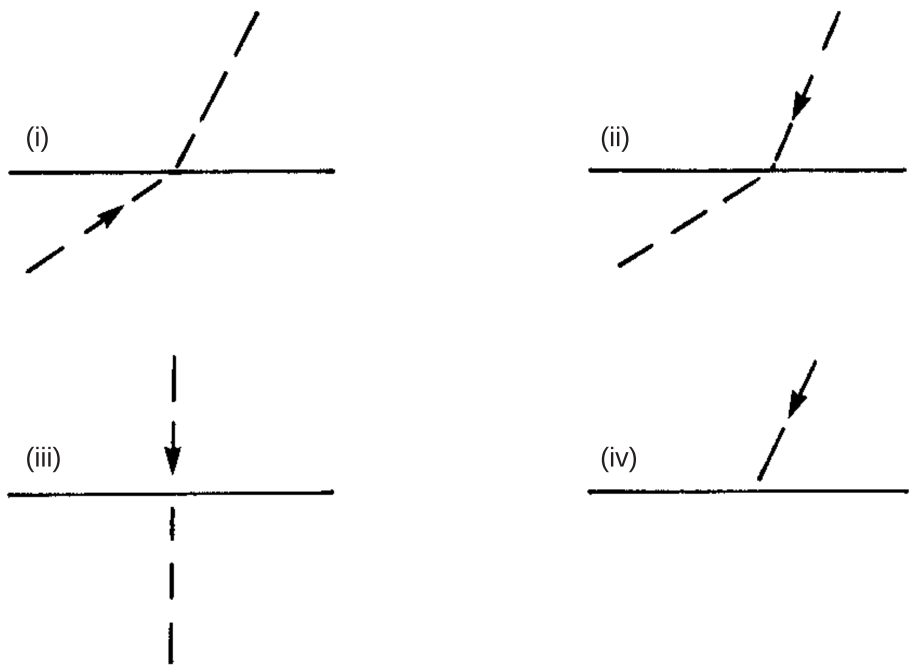
   (c) The ________ which is measured on the ___________ _________ is a measure of how much shaking occurs at the Earth's surface immediately following an earthquake. (2)

2. Why do P- and S- waves tend to follow a curved path as they penetrate into the mantle? (2)

3. Explain how the lag time between the P- and S -waves arrivals at a seismometer can be used to establish how far away the focus of the earthquake is. (2)

4. (a) On crossing a major discontinuity within the Earth P- and S -waves may change their behaviour radically. Why is this? (1.5)

   (b) Explain what is happening to an S-wave as it changes layers within the Earth in each of the examples shown.



(4)

5. Why do P- and S- waves slow up on passing through the low speed layer? (1)

6. Describe the composition of each of the major layers within the Earth.
   (a) Crust (4)
   (b) Mantle (1)
   (c) Outer core (1.5)
   (d) Inner core. (1.5)

7. Which layer within the Earth:
   (i) is on average 35 km thick
   (ii) is 200 km thick
   (iii) is a sphere of radius 1215 km
   (iv) has a P- wave speed averaging at 9.0 kms^{-1}
   (v) has a density of 2.7 kgm^{-3}
   (vi) has a density of 3.0 kgm^{-3}
   (vii) has a density between 3.3 and 5.4 kgm^{-3}? (3.5)

8. (i) What is the origin of stony meteorites?
   (ii) What is the origin of iron meteorites? (2)

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Extension Exercise

Read - Information Book Section 14(d): What P- and S- wave speeds depend upon.

E1 If the axial modulus of a layer is 3×10^{11} Nm^{-2} and the rigidity modulus is 8×10^{10} Nm^{-2}, which wave will travel faster through the layer, the P- or the S- wave?

E2 Calculate the actual speeds of the waves given the density of the layer as 10.5×10^{3} kgm^{-3}.

E3 The P- and S- waves then cross a discontinuity into a new layer which has a density of 13.5×10^{3} kgm^{-3}, an axial modulus of 17×10^{11} Nm^{-2} and a rigidity modulus of 0 Nm^{-2}. Describe what happens to the P- and S- waves.

E4 Using other sources of information read further on meteorites. Write a short note on carbonaceous chondrite meteorites.

SECTION 16: PLATE TECTONICS

The full Plate Tectonic Theory gradually took shape by combining the original continental drift theory with others, especially that of sea floor spreading. The resulting theory provides us with a method of explaining the association of so many geological processes at the margins of these great slabs of rock referred to as plates.

If you have not successfully completed Intermediate 2 unit *Earth Physics and Earth Movements* do question 1. If you have successfully completed that unit read the information sheets only as revision and proceed to question 2.

1. Read *Earth Physics and Earth Movements* information sheets Units 21 - 26 and all related activity sheets on Plate Tectonics.

2. Do quick quiz 6 of Intermediate 2 unit: *Earth Physics and Earth Movements*.

Extension Exercise

Using other sources of information read further on Plate Tectonic Theory.

E1 Write short notes on the types of volcanic activity found at each of the three main plate margins.

E2 The patterns of movement of plates is traceable back through some of geological time. Describe the formation of Pangaea about 300 Ma and its subsequent break up about 160 Ma.

E3 Explain the term ophiolite and state what type of ancient plate margin exists where an ophiolite occurs.

SECTION 17: THE EARTH'S GRAVITY

The force of gravity exerted by the Earth is roughly the same everywhere on its surface. Small variations do however occur. Some of these variations are due to the shape of the Earth and others due to the density of surface rocks or slow vertical movements that are taking place in the crustal rocks.

Read **–** Information Book Section 17: Gravity anomalies

1. Take brief notes on:
   (a) The Earth's gravity
   (b) Gravity anomalies at destructive plate margins
   (c) Any additional points not covered in *Earth Physics and Earth Movements*.

2. Explain why the force of gravity is less at the equator than at the poles. Remember that the Earth is not a perfect sphere.

3. To the northwest of the Isle of Lewis lie a number of gravity anomalies which are submerged beneath the sea. As there has been some oil exploration in these seas the structure is known and a few wells have been drilled.

   On the next page are shown a gravity anomaly map of such an area and a section across the area. A well was drilled at the position shown and after penetrating a few metres of sediment only basalt was found.

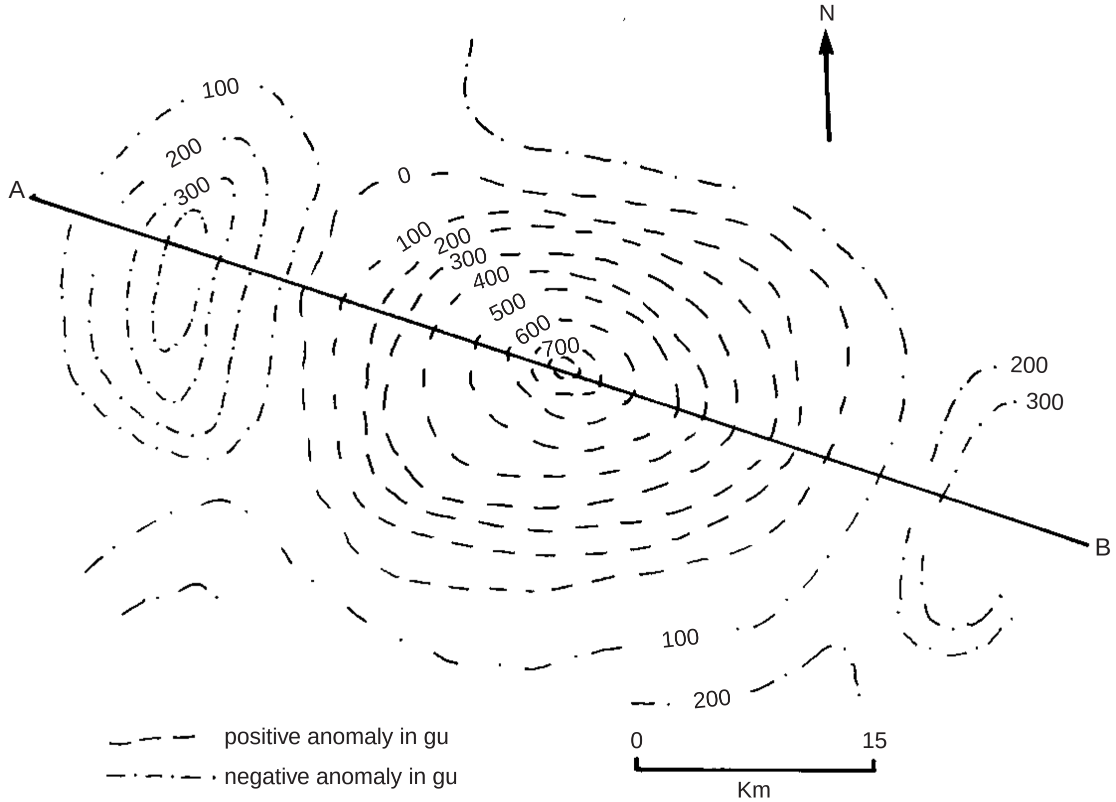
   (a) What does the unit gu represent?

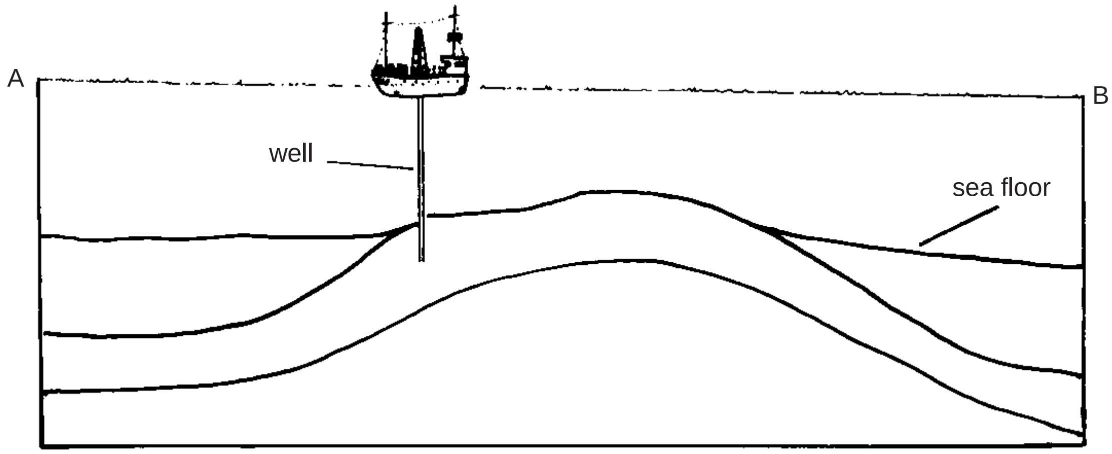
   (b) What is likely to be the main difference between the rocks underlying the negative and positive anomalies?

   (c) What is the shape of the rock body underlying the positive anomaly?

   (d) If the rock under the positive anomaly is an igneous rock what rock type is it likely to be?

   (e) What rock types are likely to be producing the negative anomalies to the northwest and southeast?


N
A
B
100
200
300
0
100
200
300
400
500
600
700
200
300
100
200
positive anomaly in gu
negative anomaly in gu
0
15
Km


A
B
well
sea floor

Extension Exercise

E1 Calculate the mass of the Earth and its average density as follows

Using $F = \frac{GM\,m}{r^2}$

Rearrange: M, the mass of the Earth = $\frac{F \times (\text{radius of Earth})^2}{G \times (\text{known mass at the surface})}$

Another formula for the force on a mass at the Earth's surface is

$F = ma$

For 1 kg mass F $= 1 \times 9.8$

$= 9.8\text{N}$

(a) Now use these formulae to calculate the mass of the Earth.

(b) Use the formula for a sphere to find the volume of the Earth.
volume = $4/3\ \pi\ r^3$ r - radius of the Earth

(c) Now find the average density of the Earth.

density = $\frac{\text{mass}}{\text{volume}}$

(d) If the average density of continental crust is 2.7×10^3 kgm^{-3} and that for oceanic crust is 3.0×10^3 kgm^{-3}, what conclusion can you draw about the density of the Earth's interior?

CHECKPOINT 9

SECTION 18: ISOSTASY

The theory of plate tectonics deals mostly with the horizontal movement of the crust and part of the upper mantle (lithosphere). Plate tectonics alone cannot account for all of the vertical movements that take place in the crust. The principle of isostasy should also be considered when explaining these observations.

If you have not successfully completed Intermediate 2 unit *Earth Physics and Earth Movements* do question 1. If you have successfully completed that unit reread those information sheets only as revision, read Section 18 and then go on to question 2.

Read - *Earth Physics and Earth Movements* information sheets Unit 12 and do the activity sheets on Isostasy.

1. Do quick quiz 3 of Intermediate 2 unit: *Earth Physics and Earth Movements*.

Read **–** Information Book Section 18: Isostasy and Gravity Anomalies.

2. Isostatic equilibrium exists in most of the crust. Why are isostatic adjustments so slow where equilibrium does not exist?

3. When ice rapidly builds up on a mountain range isostatic equilibrium is not maintained.

   (a) What type of gravity anomaly will exist over the mountain range?

   (b) What type of movement will take place in the crust over the coming years due to the build up of ice?

   (c) When the mountain range again reaches isostatic equilibrium what type of gravity anomaly will exist?

   (d) If the ice then melts what gravity anomaly will exist and what crustal movement will take place?

4. (a) How much uplift has there been at the Gulf of Bothnia since 6800 BC?

   (b) What has been the average rise per year of the Gulf of Bothnia since 6800 BC?

   (c) Is this faster or slower than at the present day? Explain why this should be the case.

   (d) Explain why a large gravity anomaly exists in the area at the present time.

Extension Exercise

E1 Using other sources of information read further on Isostasy. Make any notes that you think are useful.

SECTION 19: THE EARTH'S INTERNAL HEAT

One of the first methods of estimating the age of the Earth was carried out by Lord Kelvin, who worked out how long the Earth would have taken to cool down from being molten to its present state. The answer arrived at was between 20 and 40 million years, which is much shorter than now thought likely. The reason for this is that heat is being produced all the time within the Earth. The heat is produced by radioactive decay, a phenomenon unknown to Lord Kelvin.

Read – Information Book Section 19: The Earth's Internal Heat

1. Take notes on:
   - The source of heat inside the Earth.
   - The geothermal gradient.
   - Heat flow over the Earth.

2. The following information represents the inside of an imaginary planet.
   - The planet is 6000 km in radius and consists of two major layers separated by discontinuity at a depth of 4000 km.
   - In the upper layer the temperature increases by 500°C for every 1000 km of depth into the planet, the surface temperature is 0°C.
   - The melting point of the upper layer is 1000°C at the surface and increases by 100°C for the increase in pressure equivalent to a depth increase of 600 km.
   - In the lower layer the temperature is 2000°C at a depth of 4000 km and increases by 125°C for every 500 km increase in depth.
   - The rock of layer two melts at 2100°C at the depth of 4000 km and the melting point increases to 2250°C at a depth of 5500 km and then to 3000°C at a depth of 6000 km.

   (a) Plot on graph paper the thermal gradient within the planet. Mark in the discontinuity and the areas covered by layers one and two.

   (b) On the same set of axes plot in the melting point of the rocks in the two layers.

   (c) Identify on the graph paper which parts of the planet will be liquid and complete the following sentences:

   Layer one will be liquid between depth ____ km and _____ km
   Layer two will be liquid between depth _____km and ____ km.

3. Explain the effect on the melting points of rocks of:
   (a) pressure
   (b) the presence of water
   It may be useful to draw sketch graphs in your answer.

4. Explain how the heat generated inside the Earth acts as the source of energy which maintains the movement of plates.

CHECKPOINT 10

Quick Quiz 6

Plate tectonics

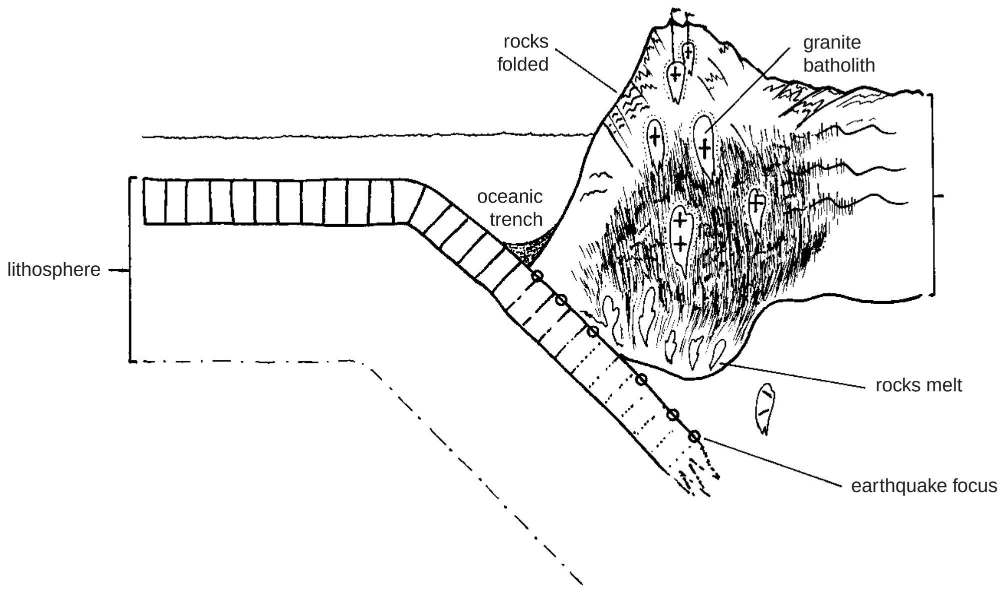
1. Why is plate tectonics theory so important in geology? (1)

2. State the three main types of plate margin. (1.5)

3. (i) At which margin is plate material produced?
   (ii) Explain briefly how this process takes place. (1.5)

4. How does a transform fault differ from a tear fault?
   Draw a diagram of each showing the movements that take place as part of your explanation. (2)

5. The diagram below is also given on Worksheet QQ6.



On the worksheet QQ6 mark in where:

(i) andesite volcanoes occur
(ii) the Wadati-Benioff zone occurs
(iii) thick layers of sediment will accumulate
(iv) regional metamorphism takes place
(v) thermal (contact) metamorphism takes place
(vi) the ocean crust, continental crust and mantle are located. (4)

Gravity anomalies

6. State what type of gravity anomaly, if any, will exist in each of the following examples:
   (i) a recently glaciated mountain range
   (ii) a stable piece of continental crust in isostatic equilibrium
   (iii) a magnetic ore body
   (iv) an area recently deglaciated
   (v) an area where rapid erosion is taking place. (5)

7. Draw the gravity anomaly pattern that exists across the margin shown in question 5 (2)

Isotasy

8. Using the principles of isostasy explain how a raised beach is formed in a recently deglaciated region. (3)

Earth's Heat

9. Name two sources of heat which make the interior of the Earth hotter than the surface rocks. (2)

10. Both pressure and water content can change the melting point of rocks.

    (i) State how pressure within the Earth can effect the melting point of peridotite and hence whether it is a solid or a liquid.

    (ii) Explain the existence of the partially molten low speed layer.

    (iii) Why is the inner core solid and the outer core liquid?

    (iv) State how the presence of water affects the melting point of rock. (6)

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