



Mining Engineering Mineral Exploitation I (Geology)

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INTRODUCTION

What is MINERAL EXPLOITATION all about?

In this module, you will learn about the most important processes that are typically applied to exploit minerals in Southern Africa. These include exploration, mining, surveying and extraction metallurgy.

The module is subdivided into four sections: Geology, Mining, Surveying, and Metallurgy.

Mineral exploitation starts with GEOLOGY. This is because we need to apply geological knowledge to find the minerals that we will be mining. We also need to know the properties of these minerals in order to mine them effectively.

Once the mineral deposits have been located, they need to be mined. In the MINING section, we therefore deal with the phases involved in the development of a mine as well as the mining methods applied to different types of rock formations.

In the process, SURVEYING is applied to guide the operations. By this, we simply mean that surveying is used to direct the operations to the location of the deposit. Furthermore, the volume of rock that needs to be excavated should be determined. The size of the various excavations is also another important element covered in the SURVEYING section. That is why we will cover several geometric shapes and formulas relating to their areas and volumes.

Once minerals have been extracted, they need to be processed. The final section of this module, METALLURGY, deals with the processes that are typically undertaken at the metallurgical plant at a mine.

What teaching approach are we going to follow in this module?

The teaching in this module is based on the principle of “active learning”. We believe that the more **actively** you are involved in reading and learning, the more clearly you will understand what you are learning, and the more effectively you will be able to apply your knowledge and skills in real-life situations.

To help you work through this study guide actively – rather than just reading it passively – we have included many activities in the text during the course of every unit. By completing these activities you will ensure that what you are learning is meaningful to you, and you will start to develop the skills that will be required of you as a mining technician.

How should you go about studying this module?

To study this module, you will need the following materials:

- Tutorial Letter 101
- The four official study guides of the module MINERAL EXPLOITATION
- Other tutorial letters that you may receive during the course of the semester

You should start by reading Tutorial Letter 101, if you have not already done so. It will tell you more about the general arrangements relating to the module, and give you details about your assignments and assignment questions.

What is the structure of the study material in the module?

The module is made up of four study guides covering GEOLOGY, MINING, SURVEYING, and MINING.

The table below lists the structure of the study material and the number of study units of each section. It further gives a short statement on the purpose of each section of the module.

Section	Number of units	Purpose statement
Geology	7	Description of the earth's structure, the formation of rocks, the properties and types of minerals
Mining	8	Description of techniques of discovery of mineral deposits, methods of excavations of ore bodies, and safety issues associated with mining operations
Surveying	5	Description of geometric shapes and related formulas Study of basic surveying techniques used in the mine
Metallurgy	8	Description of techniques of treatment and concentration of mineral ore, extraction of metals, and environmental issues associated with the operations

In this Geology section, we will start out by looking at some aspects of physical geology, which deals with the natural processes that shape the surface structure of the earth. We are interested in the characteristics of the surface structure because these characteristics will affect our decisions about whether to excavate or not in certain areas, and how to extract the minerals. In the second study unit we will then examine the properties of minerals and ore bases that can

be exploited by mining; and in the third study unit we will look more closely at the nature of economic ore bodies that can be mined.

The properties of rocks are very important in mining because they determine the type of explosives, supports, and appropriate mining methods. In study units 4, 5, and 6, we will study the three main types of rock, namely igneous, sedimentary and metamorphic rocks. Finally, we will investigate the shapes in which sediments and rocks appear today, and the changes in these rock structures due to natural factors; this is known as structural geology.

What are the main features of the study guide?

You will see that at the beginning of every study unit there is a list of LEARNING OUTCOMES. These outcomes are like a checklist of the things you should be able to do once you have studied the unit. In other words, the outcomes provide you with the purpose and focus of your learning in that particular unit.

When you are reviewing the module, you should look back at the outcomes and check whether you have achieved them all. You should regard these outcomes as an overview of the knowledge and skills you should have acquired in the module.

In every unit there are some activities you need to complete as you work through the text. Completing the activities will help you to get to grips with the information that is presented in the unit. It will also make it easier for you to eventually apply the knowledge and skills you are learning in practice. The process of learning will thus not simply involve studying or memorising facts and procedures.

Acknowledgements

Where not otherwise indicated, the figures contained in this study material were sourced from Unisa Study Guides for Mineral Exploitation I (MEP171X), Second Edition, 2002.

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Physical geology

LEARNING OUTCOMES

On completion of this study unit, you should be able to do the following:

- Define the term PHYSICAL GEOLOGY
- Identify and describe the natural forces that change the surface structure of the earth
- Describe the effects of temperature on the crust
- Describe the effects of chemical and mechanical weathering
- Define “ground water” and “water table”
- Describe the effects of ground water and ice on the earth’s crust, and identify some implications of this for mining

1. INTRODUCTION

GEOLOGY can literally be defined as the science that studies the earth.

In a broader sense, geology as a science has evolved into becoming the discipline that studies the structure of the earth and the transformation it undergoes over time.

Now, the process by which the weather and other natural forces change the earth’s surface structure is referred to as **PHYSICAL GEOLOGY**. It embraces the continuous wearing down and eroding of rock, the transporting of rock and soil particles and their depositing elsewhere.

In this unit we will study the structure of the earth. We will then cover the natural factors that play an important role in shaping and reshaping the earth. It is important to have this knowledge so that we can determine the best and safest mining methods.

2. INTERNAL STRUCTURE OF THE EARTH

The diagram below shows the internal structure of the earth.

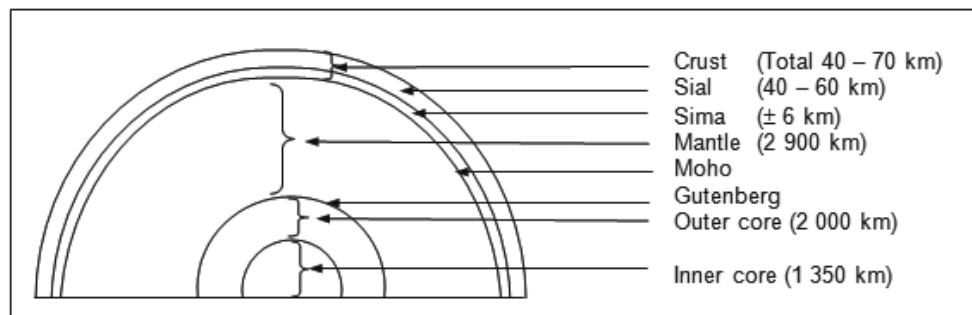


FIGURE 1.1

Internal structure of the earth

The earth is a sphere with a radius of about 6 370 km. It is flatter at the poles and bulges at the equator. Gravity is responsible for the densest material to sink to the centre and the lightest to float to the surface.

The crust consists of two parts: the continental crust and the oceanic crust.

- The **SIAL** (continental crust) averages up to 40 km in thickness and is composed mainly of silicon and aluminium (The word “SIAL” was formed by combining the first parts of the words **Silicon** and **Aluminium**). Its density is 2,7 on average. **Granite** is the common rock type.
- The **SIMA** (oceanic crust) averages up to 6 km in thickness and has silica and magnesium as its main composition; hence, the term “SIMA”. It is 10% denser than the Sial. **Basalt** is the main rock type. A discontinuity zone known as the **Moho** (for Mohorovicic) divides the crust from the mantle (the next layer of the earth). This zone offers resistance to the seismic waves travelling from the crust through to the mantle. Some of these waves are refracted, i.e. bent, others are reflected, i.e. bounced off.

The **MANTLE** measures about 2 900 km in thickness and in texture it is more like putty in the upper reaches and less viscous (less thick) in the lower. **Femic** material (iron and magnesium) is its main composition. The main rock type is **peridotite**.

The **OUTER CORE** is approximately 2 000 km thick and is a white-hot liquid. **Nife** (nickel and iron) is its main component.

The **INNER CORE** with a radius of about 1 350 km comprises the densest materials in the earth. Nife is again its main composition. The material is so compact that it is not liquid anymore. It is solid.

Activity 1.1

In which part of the earth's structure is mining typically conducted? To help you answer this question, consult a textbook or the internet and find out how deep the deepest mine on earth is.

3. NATURAL FORCES THAT CHANGE THE SURFACE STRUCTURE

Agents of weathering can be classified into three types according to their action: Atmospheric temperature, chemical action and mechanical forces.

3.1 Effects of atmospheric temperature

The alternating effects of the sun's warmth and the cold at night cause rock to expand and contract. Rock grains and minerals expand at different rates, and so **joints** occur and **cracks** appear. The **freeze and thaw** effect of water in cracks open cracks wider and wider. Warm temperate climates also encourage chemical action in the dissolving and decomposing of rock and organic material.

3.2 Effects of chemical action

Atmospheric water vapour and gases with their inherent chemical ingredients work on rock structures on the surface. Below the surface where ground water is the agent, chemical action and hydration are foremost in this action.

3.3 Effects of mechanical forces

Mechanical forces include all the physical eroding and transporting of material by wind, water, ice and the action of living creatures and natural causes.

- The **WIND** is a very effective method of transporting soil and sand. A good example of the effect of wind is the formation of **sand dunes** in deserts and the sandstone layering (Aeolian sandstone) of the massive Drakensberg's lower regions.
- **Ablation** is the action of removing soil particles by the wind and carrying it away. **Aeolian sandstone** is sedimentary rock that was laid as a result of wind-carried sand or soil.
- **Sandblasting** is another effect of wind whereby rock faces wear down as a result of wind-blow, e.g. the odd shapes of sandstone structures found in the Drakensberg and in Namibia.
- **WATER** in the form of **rain** is the main vehicle for atmospheric acids and gases which act on surface rocks as well as below surface as the rainwater percolates through the sub-soils. Torrential rain of course is the reason for flooded streams and rivers which cause massive soil erosion. In such river beds boulders are moved along by the action of **saltation** (the rolling and short lifts of large rock fragments), which in turn grind against other boulders by **attrition** and gouge the riverbeds. The vertical gouging is called **vertical corrasion** while the gouging of the banks is called **lateral corrasion**.

Activity 1.2

Complete the table below to summarise the effects of natural forces on the structure of the earth's surface.

Natural force	Actions on earth's surface	Final results
		Formation of cracks
Chemical action		
	Transport of soil and sand	

4. GROUND WATER AND WATER TABLE

Ground water is the water that seeps through the soil and rock beneath the surface after rain has fallen.

The **water table**, on the other hand, is the top most level of rock saturation below surface. Sometimes this level may intersect the surface in which case a spring develops and may form a marsh. If one drills a borehole for water, the water level in the hole is equal to the water table.

The diagram below shows examples of types of water table.

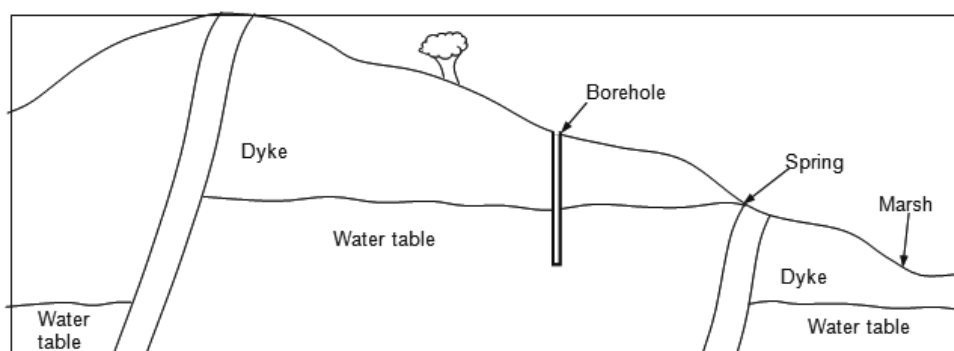


FIGURE 1.2

Illustration of different types of water table

5. EFFECTS OF GROUND WATER

Only a small amount of mechanical work is done by ground water, for instance in caves, in the so-called underground "rivers", and in soil where saturation can cause landslides. The greatest effect, however, is the chemical action of ground water.

The LEACHING of dolomites by **acidic water** takes place when raindrops pick up carbon dioxide (CO_2) from the atmosphere and take it below surface. The calcium carbonate in limestone (note that **dolomites** are composed of **calcium** and **magnesium**) is dissolved leaving open spaces which we refer to as caves, e.g. the Congo and Sterkfontein caves. In the case of sinkholes in the Carletonville area, man has induced the leaching of the dolomites by lowering the water table during mining operations. Acidic rainwater then seeps through the dolomites to replace the groundwater and thereby dissolves the dolomites. The caves forming below surface become so large that the roof collapses to form **sinkholes**.

Secondary sediments also form in the caves below the leached out rock to form **stalactites** and **stalagmites** which are carbonates.

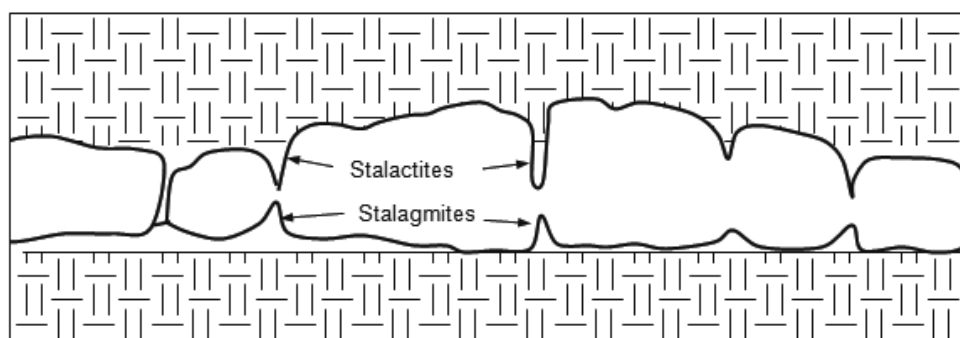


FIGURE 1.3

Stalactites and stalagmites in limestone caves

OXIDATION is the combining of oxygen and the chemical content of the mineral concerned, e.g. iron-bearing pyroxenes contain ferrous oxides which, if combined with oxygen, become ferric oxides, e.g. **haematite**, the main iron-bearing ore at Thabazimbi and Sishen.

HYDRATION (combining with water) of ferric oxides forms **limonite**, which is another important iron ore.

A quarry will always have water problems if the water table is in line with or above the bottom of the pit, apart from rainwater gushing into the pit. Often a stream running through the quarry boundaries becomes a problem if it floods over or breaks its banks so that the quarry or mining operation has to be constantly monitored. Spillage of chemicals/oils used in the quarry or mine must not make their way into streams unless neutralised.

Activity 1.3

1. Define in your own words the phrase "rock saturation" relating to water tables.
2. What do you think are the hazards in the following situations?
 - 2.1 A mine is established in an area where there is a large deposit of dolomite.

- 2.2 A quarry is mined to a depth where the water table is below the bottom of the pit.
 3. If mining operations lower the water table and acidic water leaches into the dolomite, it can cause sinkholes which may have devastating effects. If you have access to the internet, you will find some interesting information about the notorious Carletonville sinkholes if you search for “Blyvooruitzicht sinkholes”.
-

6. EFFECTS OF ICE

When water freezes in cracks of rocks, it expands; therefore it opens the crack a little more. **Scree**, the fragments that lie around the slopes of a rocky hill top or ridge, are broken down by **freeze and thaw**, which is constantly repeated between cold nights and warm days.

Glaciers, which are frozen rivers, maintain a forward motion of say 1 m/h and in the process break off portions of protruding boulders and sides of the valley (**lateral corrasion**), and gouge the bottom (**vertical corrasion**) with fragments of rock carried in the sole of the glacier. Deep scratch marks called **striated pavements** are produced on the bedrock. Examples of these signs of the glaciation period in South Africa can be seen today.

Moraine is the material deposited by a glacier.

Erratics is the name given to rock specimens left by glaciers in a place foreign to their place of origin. **Till** or **boulder clay** is formed as a result of the grinding action of glaciers which existed in Southern Africa about 200 million years ago. When the ice melted the till settled and was compacted.

The rock **tillite** found below the lowest coal seam on the Highveld is the result of this action. This points to the historical fact that no coal exists below the tillite because it was after the ice age that swamps developed throughout this region to set off the formation of coal seams.

Activity 1.4

1. Explain the effects of ground water and ice on the earth's crust in your own words. How is this responsible for the landscape of the earth as we know it today?
 2. Relate the effects of ground water and ice to the natural forces responsible to the change in structure on the earth's surface.
-

7. CONCLUSION

In this study unit we have seen that natural forces constantly reshape the surface of the earth.

Most importantly, we have seen how ground water and ice alter the nature of minerals buried underground by leaching, oxidation and hydration.

These phenomena have important implications for mining operations and also change the inherent properties of minerals. The next study unit covers these properties in detail and provides more information on the type of minerals that are generally mined.

Basic mineralogy and the nature of minerals

LEARNING OUTCOMES

On completion of this study unit, you should be able to do the following:

- Define the term “MINERAL”
- Name and describe six characteristics by which minerals are identified
- Define the term “SALIC MINERALS” and give an example
- Define the term “FEMIC MINERAL” and give an example
- Name and describe six other ore bases and give two mineral examples of each

1. INTRODUCTION

The mining industry is interested in the excavation of part of the earth’s crust. The regions of interest will contain materials from which commodities can be extracted for the benefit of humankind.

It is obvious that not all regions of the earth can be mined. The decision to exploit a certain region of the earth’s crust over another is dictated by what lies underground. However, this decision cannot be made if the nature of the material sought after is not known.

It is thus important to know what MINERALS are and what their nature is. We will therefore cover the classification, the properties and characteristics of minerals as well as associated types of minerals known as ore bases.

2. WHAT IS A MINERAL?

The standard definition of a mineral is as follows: “A mineral is a naturally occurring substance with a more-or-less definite chemical composition and a constant geometric arrangement of its atoms”.

3. CHARACTERISTICS OF MINERALS

Minerals may be identified and distinguished from one another by a number of the following characteristics:

COLOUR – This refers to the reflection of light, e.g. malachite is bright green, bornite is purple blue.

STREAK – The colour of the powdery form of the mineral when rubbed against a substance like unglazed porcelain, e.g. azurite which is light blue.

CRYSTAL SYSTEM – The geometric design in which the crystals forms repeatedly when magma cools slowly, e.g. hexagonal (quartz), cubic (galena).

COMPOSITION – The analytical chemistry of the mineral, e.g. diamond (carbon), cuprite (copper oxide).

HARDNESS – How hard the mineral is according to MOH's scale of hardness of 1 to 10 (softest to hardest). This scale is shown below:

MINERAL	HARDNESS	STANDARD OF TESTING
Talc	1	Marks cloth
Gypsum	2	Scratched by finger nail
Calcite	3	Scratched by copper – nickel coin
Fluorite	4	Scratched by copper coin
Apatite	5	Scratched by pen knife
Orthoclase	6	Scratched by steel file
Quartz	7	Harder than steel file
Topaz	8	
Corundum	9	Scratches hard metals
Diamond	10	Scratches all substances

DENSITY – The mass per unit volume of the mineral defined by g/cm^3 , e. g. gold is 19.3, quartz is 2.7, and coal is 1.5 (grams per cubic centimetre).

Activity 2.1

1. You are given the following names: Chalcopyrite, Salt, Smithsonite, Carbon, Copper. Determine which ones fit the definition of a mineral. You may need to go to the library or internet to find the answer.
2. Once you have determined which of the five names are minerals, list the characteristics of each one.

4. SALIC MINERALS

Salic minerals are a group of light coloured, low density minerals which, in the main, consist of **silica** and **aluminium**, hence the name SALIC.

Due to their relative low density they are formed in the top regions of the crust. Examples of salic minerals are quartzite and feldspars. Their main elements are potassium, sodium and calcium.

The best example of salic minerals is quartz which is a glassy looking mineral of 2.7 density. It often appears in veins along joints of rock as an opaque strip of intruding rock that is foreign to the surrounding material. The quartz concentrate at some stage exudes from the surrounding rock and forces its way along weak, stress joints. Where spaces in such veins occur quartz crystals with the familiar glassy hexagonal shape are found.

5. FEMIC MINERALS

Femic minerals are darker coloured and higher density minerals as compared to salic minerals. They are composed of iron (Fe) and magnesium (Mg); hence, FEMIC.

Due to their higher densities these minerals originate from deeper in the crust than salic minerals. Examples of these are micas, pyroxenes, olivines and garnets.

6. OTHER ORE BASES

There are hundreds of less common minerals and new ones are being discovered every year. But the most important ore bases from a mining engineering point of view are listed below:

6.1 **Native elements**

are the more common and primitive man's first discoveries. They include relatively pure samples of certain minerals like gold, silver, copper and platinum amongst the metallic ores and the carbon types of diamond and graphite. Sulphur is also a non-metallic native element. These may be found in the earth as considerably large, visible specimens of the mineral concentrate.

Gangue (pronounced gang) is the name given to worthless minerals found with economic minerals while carrying out mining operations.

Accessory minerals are valuable minerals that are found in association with an ore mineral which is the main focus of a mining operation.

6.2 **Oxides**

are the source of the most important iron ore minerals of haematite, magnetite and limonite. Oxides are also the source of chromite, cassiterite

(tin ore) and uraninite. Bauxite (aluminium ore) and laterite (hydrated aluminium and iron oxides) fall in this category.

6.3 Sulphides

are the source from which the copper ores of chalcopyrite, bornite and chalcocite are found. Other ore minerals such as galena (lead ore), sphalerite (zinc ore) and stibnite (antimony ore) are also sulphides. The iron sulphides of pyrite and pyrrhotite are not mined as iron ores but as a source for sulphur.

6.4 Carbonates

include calcite (stalactites and stalagmites), dolomite, malachite and azurite.

6.5 Sulphates and Phosphates

include gypsum (plaster of Paris) and apatite (fertiliser).

6.6 Silicates

include clay minerals and asbestos apart from the common rock-forming mineral silica discussed earlier.

Activity 2.2

1. Draw up a table listing the differences between SALIC and FEMIC minerals.
2. Find two examples in the internet or the library of the six types of ore bases other than those mentioned in this study unit.
3. Suppose that you wanted to mine the minerals shown in the first column of the table below. Indicate in what compound form you would find them in the earth, and in which ore base. One example has been done for you.

Mineral	occurs in the earth as ...	in the ore base called ...
Copper	Chalcopyrite Bornite Chalcocite	Sulphides
Iron		
Sulphur		
Tin		
Lead		
Aluminium		

Mineral	occurs in the earth as ...	in the ore base called ...
Antimony		
Uranium		
Zinc		

7. CONCLUSION

We have learnt about the six properties or characteristics that differentiate minerals from each other. We have also reviewed the two classes of minerals and have covered the six types of ore bases that the mining industry is interested in.

In the next unit we will look at the ore bases with specific emphasis on the South African stratigraphy.

Nature of economic ore bodies – South African stratigraphy

LEARNING OUTCOMES

On completion of this study unit, you should be able to do the following:

- Describe the occurrence of the Bushveld Complex in terms of the phases in its eruption
- Identify the five zones of the Bushveld Complex and the minerals mined in it
- Give a brief description of the distribution of the Karoo Sequence
- Identify the groups of the Karoo Sequence
- Discuss the economic aspects of the Karoo Sequence
- Give a description of the most important minerals, their use and where they are mined in South Africa

1. INTRODUCTION

Alex du Toit, a South African geologist, theorised that the Southern hemisphere continents were once joined together to form one large continent – Gondwanaland. This theory is supported by the geological discoveries of plate tectonics, rift valleys, continental drift, fold mountains, deep sea trenches and lines of volcanic activity.

A journey back in time is necessary in order to understand how the minerals of economic value were formed and where they can be found in the Southern African region.

During geological history, various “erathems” were formed. An erathem is the total “layer” or stratigraphic unit that was deposited over a certain span of time. The chronological sequence of the formation of the erathems first started with CRATONS. Cratons were the first blocks of solid land to emerge on the earth, and formed the nuclei of most of our continents today. In the Southern African region, the Kaap Valley Craton, the Namibian Craton and the Zimbabwean Cratons are identified as examples (see Figure 3.1).

Geological rifts developed in sequence on the Kaap Valley Craton where water gathered to form large inland seas. This craton extends from Swaziland to Botswana and down to KwaZulu-Natal and the Northern Cape.

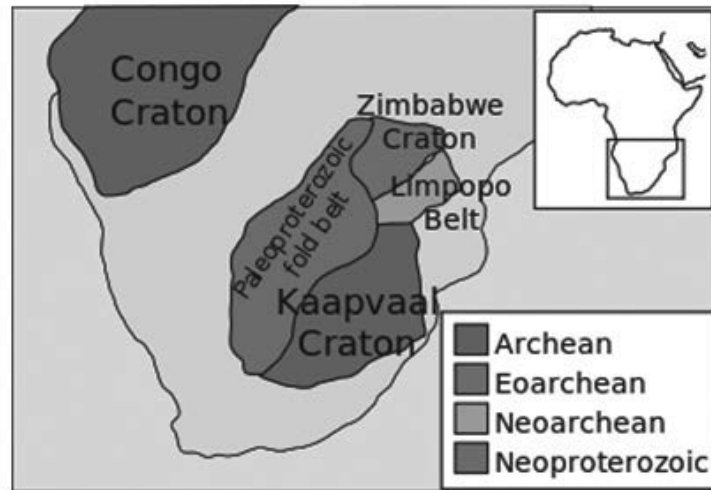


FIGURE 3.1

Example of cratons in the Southern African region

(Source: http://en.wikipedia.org/wiki/Limpopo_Belt#/media/File:Southern_African_Cratons.svg)

The earliest of these rifts was the SWAZIAN Erathem (3 300 million years ago) comprising the Barberton, Murchison and Pongola Sequences. A mixture of sedimentary, intrusive, volcanic and metamorphic rocks can be seen today. These types of rocks will be covered in the subsequent study units.

Then the RANDIAN Erathem was formed of which the Witwatersrand Supergroup was formed first (2 900 million years to 2 000 million years ago). It also comprises sedimentary, volcanic, intrusive and metamorphic rocks. It was followed by the Ventersdorp Supergroup.

The VAALIAN Erathem was formed next (2 000 million years to 1 350 million years ago). It comprises the Transvaal, Griqualand West and Olifantshoek Sequences. During this period the Bushveld Complex formed from massive volcanic activity (about 2 000 million years ago) which was accompanied by a number of individual volcanoes, e.g. Pilanesberg, Leeufontein, Spitskop and six other smaller ones.

The KAROO Sequence, 200 million years to the present day, is the youngest sequence and during its formation coal was formed (in the Ecca Group), when the ice age came to an end. Rock particles in suspension in the ice settled as tillite when the ice melted. Large marshy conditions followed producing vigorous vegetation growth which decayed in the marshes to form **coal seams**. Sediments of mud and sand appeared at varying intervals to form **shales** and **sandstone partings**.

The chronological sequence of formation of the erathems forms the basis for the concentration of minerals in certain places. A high concentration of minerals in the earth's crust that can be exploited economically and at a profit is referred to as an ORE BODY. In this study unit we will look at the two most important sequences of the South African stratigraphy, i.e. the Bushveld Complex and the

Karoo Sequence. They are the most important because South African mines are essentially organised around them.

2. THE BUSHVELD COMPLEX

About 2 000 million years ago, after the Transvaal Sequence had partly formed, massive volcanic activity took place from the present Botswana border in the west, to Ohrigstad in the east and from Villa Nora in the north to Bethal in the south. Five phases of volcanic activity have been identified, and together they formed a large lopolith shape, i.e. a V-shape, as illustrated in the sketch below.

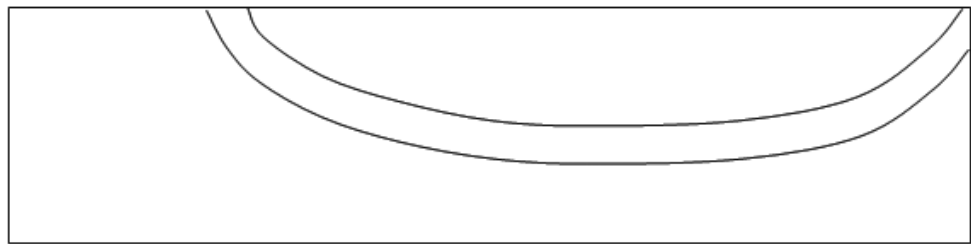


FIGURE 3.2

Lopolith shape characteristic of the Bushveld Complex

The diagram below shows the extent of the Bushveld Complex across the northern and central regions of South Africa. Various towns and cities are shown to give you an idea of where this complex is located.

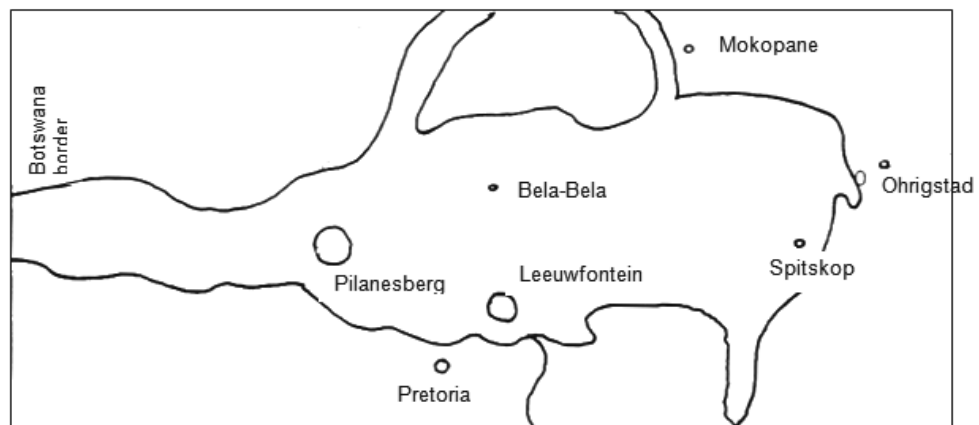


FIGURE 3.3

Shape in plan and cross-section of the Bushveld Complex

- PHASE 1: A basic volcanic phase which accompanied the forming of the Transvaal Sequence sediments.
- PHASE 2: A basic sill phase which was responsible for the appearance of basic sills in between the Pretoria Group of the Transvaal Sequence.
- PHASE 3: An acid volcanic phase which formed red felsites of the Rooiberg Group where tin is mined.

- PHASE 4: A basic plutonic lava phase which intruded the upper part of the Pretoria Group. These rocks have been dated at 2 098 million years.
- PHASE 5: An acid plutonic phase in which magma covered the basic rocks (1 920 million years).

3. MINERALS FOUND IN THE BUSHVELD COMPLEX

The Bushveld Complex consists of several zones or layers. From the bottom up we find the marginal, lower, critical, main and upper zones. Apart from the minerals that formed within the magmatic ores of the Bushveld Complex, metamorphic rocks such as hornfels, andalusite and slates were produced beyond the outer lip of this massive volcanic eruption in the metamorphic aureole.

4. THE KAROO SEQUENCE

Because the Karoo Sequence is the youngest, it appears to cover the greater part of Southern Africa. It spreads from the Cape Fold Belt in the south to the Witwatersrand in the north-east and Prieska in the north-west, and from the coastline of Natal in the east to beyond the Limpopo as far as Zambia and the Democratic Republic of Congo (formerly, Zaïre) in the form of outliers. See Figure 3.4 below.

4.1 Groups of the Karoo Sequence

The groups of the Karoo Sequence are shown in Figure 3.4 below.

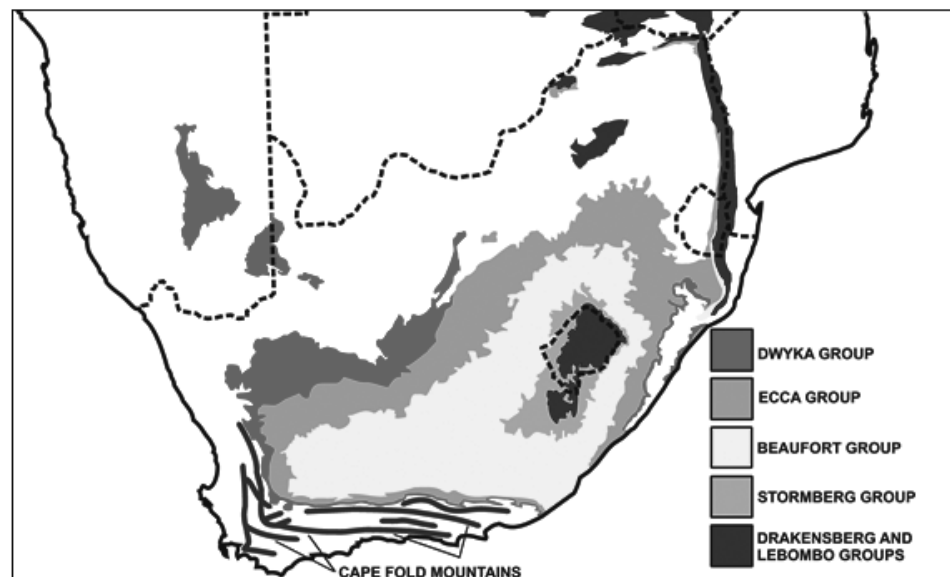


FIGURE 3.4

Groups of the Karoo Sequence

(Source: By Oggmus – own work. http://en.wikipedia.org/wiki/Karoo_Supergroup#/media/File:Geology_of_Karoo_Supergroup.png)

The **Dwyka Group** forms the base of the Karoo Sequence with **tillite** as its main rock type. The **Ecca Group** follows with the middle portion being the main coal-bearing layers. The **Beaufort Group** overlies the Ecca and this in turn is overlain by the **Lebombo Group** in which the Drakensberg mountains are the main feature.

4.2 Economic aspects of the Karoo Sequence

Coal is the main economic mineral product. **Iron ore, clay and flagstones** are mined too. The presence of reptilian and other fossils in the Beaufort Group provides a major source for equipping our museums and those of the world with fossil specimens.

Activity 3.1

1. The SWAZIAN Erathem comprises the Barberton, Murchison and Pongola Sequences. Define in your words what “sequence” means in geological terms.
 2. Define the following words: sills, metamorphic aureole.
 3. Draw up a table to show the structure of the Bushveld Complex. Include the following columns: Phase; Description of the Phase; Minerals found in the Phase.
 4. Tabulate the groups forming the Karoo Sequence. Indicate roughly where each group occurs and which rocks or minerals it contains (where applicable).
 5. In your opinion, what is the importance of the Karoo Sequence as far as the South African economy is concerned?
-

5. ECONOMIC ORE BODIES

In this section we will describe the most important mineral products, where they are mined in South Africa and what they are used for.

ALLUVIALS (DIAMONDS) – Minerals that have been carried by rivers and deposited as a sediment in the river bed or in the flood plain are termed alluvials. Diamonds were washed away from pipes and carried downstream by rivers. In some cases the rivers carried the diamonds into the sea, e.g. the mouth of the Orange River. Gold was found in riverbeds in the same way, e.g. Pilgrims Rest.

ANDALUSITE – Contact metamorphism causes argillaceous (i.e. clay-containing) material to form andalusite crystals. These crystals were formed mainly in the aureole of the Bushveld Complex and washed down riverbeds where they are mined as alluvials. They are used for refractories such as high voltage insulators seen on overland high tension cables.

BUILDING SAND – An ideal concrete mix has a ratio of crushed stone, sand and cement in the ratio of 5:3:1. Therefore, wherever concrete construction takes place, a convenient source of sand (as well as stone) must be available.

Sand dunes, mine dumps, river beds and other alluvial deposits provide a source for the production of building sand. A blend of varying sizes of coarse, jagged grain is preferred by building contractors to well-rounded, polished, regular grain size. Therefore crushed sand may be preferred to river sand in concrete work.

CEMENT – The use of cement as a building agent in concrete structures is common knowledge. Cement is produced from limestone and limestone deposits such as Lime Acres near Kimberley are a source for the production of cement. In the earlier days, stalactites and stalacmites were cannibalised from caves, e.g. Sterkfontein, to produce cement.

COAL DEPOSITS – Seams of coal were laid down after the ice age in the Southern Hemisphere (Gondwanaland). They are found in the Ecca Group of the Karoo System. No. 1 seam (lowest) to No. 5 seam are mined in the Witbank area, whereas the Dundas and Alfred seams are mined in the Natal region. Coal is used for electric power generation and production of liquid fuel; coking coal is used in steel foundries and for domestic heating.

CHROMIUM – This is found in BIC (Bushveld Igneous Complex) which includes Brits, Rustenburg, and Steelpoort. It is used for all chrome plating.

CLAY – This refers to hydrated aluminium silicates (kaoline) which are used for brick making, ceramics, chinaware, tiles, etc. There are kaoline deposits on Chapman's Peak (Cape Peninsula), in Saldanha Bay, Vanryhnsdorp, Belfast, Hammanskraal and Middelburg.

CLAY PRODUCTS – Hydrated aluminium silicates form the bulk of clay products in South Africa. They are generally mixed with other fine clay minerals. They are used in the ceramic industry for the manufacture of chinaware, tiles, bricks, porcelain, pottery, toilet bowls, cisterns, wash basins, baths, sewer pipes and refractory bricks. Bone chinaware has bone powder added to clay. There are the following different types of clay:

MONTMORILLONITE which forms the base of fuller's earth and bentonite and has a swelling factor. Deposits are found in the Koppies area of the Free State and in the Knysna district.

KAOLINITE which is the main constituent of chinaware and pottery. A large deposit occurs in the Chapman's peak area of the Cape Peninsula where recently a lease to mine the deposit has been granted. Other kaolinite deposits occur in granites near Durban.

COPPER – In the Phalaborwa pipe, copper was formed in carbonatites by ascending fluids. It is the largest opencast mine in South Africa. Other copper deposits are found in the Messina (in a pipe and a fault) and O'Kiep districts. Electric cables are the main product of copper. Copper is used to mainly manufacture electric conductors. It is also used as an alloy to produce bronze (Cu + Sn) and brass (Cu + Zn).

CRUSHED STONE – This is used as an aggregate for concrete work and in the construction of roadways and railways. The source may be granite, dyke,

sandstone or dolomite. The main desirable feature is its cohesive strength and low water absorption. Quarry sites are located as close as possible to the customer (i.e. towns). The material mined may be dolomite, dolerite, granite, etc.

DIMENSION STONES – Slabs of stone are cut out in quarries for building facings. Granite is quarried for building blocks, table tops and plaques. Norite (black granite) is quarried for plaques and tombstones. Sandstone is cut out for building blocks.

Norite is quarried in the Bushveld Complex, granite slabs in Mpumalanga and sandstone blocks in Natal and the Western Cape.

DOLOMITES – This is a variety of limestone in which the carbonates of calcium and carbonates of magnesium are present. Dolomites are quarried for aggregate in the West Rand area.

FLUORITE – Calcium is the main composition of fluorite which is used mainly as a flux in metal foundries. It is mined in dolomites associated with the Bushveld Complex and often appears in pipes. Used as a flux in steel making, and in the production of glasses and enamels.

GOLD – This is found mainly in the Witwatersrand and Black reef. There are also in hydrothermal deposits in Barberton and in other areas. It is used as a precious metal for monetary exchange, jewellery, etc.

IRON – Magmatic iron ores in the Bushveld Complex are the source of many mining ventures at Brits, Rustenburg and Roossenekal. The enriched sedimentary deposit of Thabazimbi has vast quantities of haematite and limonite (important iron ores). The Sishen deposit in the Northern Cape is a major iron producing opencast mine which also evolved from enriched sedimentary deposits. Uses of steel are vast in the modern age of construction and civil engineering.

LIMESTONE – As discussed in section 5, limestone consists essentially of carbonates of calcium. The term “dolomite” as a rock refers to rocks that have both carbonate of calcium and carbonate of magnesium. Limestone is mined for the production of aggregate, cement, for agricultural purposes to neutralise acid soils and for the production of “stone dust” for the dilution of coal dust in coal mines. Apart from Lime Acres, quarries are found on the Rand for production of lime. Marble Hall produces limestone as well as marble dimension stone which is a metamorphosed limestone.

LOESS – Fine calcareous particles between 1/16 mm and 1/32 mm derived from the grinding action of glaciers and deposited by wind form a good clay for making chinaware.

NICKEL – mined in the BIC and is used for nickel plating and coin minting.

NORITE – see dimension stone.

PGMs – are mined in the Merensky Reef of the Bushveld Complex. Small quantities are found as accessory minerals in the Witwatersrand Supergroup.

PLATINUM GROUP METALS (PGM) – These include palladium, ruthenium, rhodium, platinum, iridium, osmium.

PALLADIUM – Alloy mixed with gold to make “white gold” and used in electronics.

IRIDIUM - Alloyed with platinum.

OSMIUM – Alloyed to make fountain pen nibs.

RHODIUM – For electro-plating.

PLATINUM – Electrical contacts, as a catalyst for petrol engine exhausts and for jewellery.

PYRITE – A by-product of gold and copper mining operations. It is used for production of sulphuric acid.

SILVER – Most of the world's silver is obtained as a by-product from gold, zinc, copper, nickel and tin operations. It is used in the manufacture of jewellery, coins and silverware.

SLATES AND SLASTO – Slate is formed from argillaceous sediments (mudstones) which have undergone dynamic pressure. The laminations appear at right angles (or near so) to the layerings. They have perfect parallel cleavage and therefore lend themselves favourably for production of roof slates. Slate quarries are found in the Pretoria Group at Swaruggens. Slasto is also formed from argillaceous sediments, but unlike slates, the cleavage of slasto lies parallel to the layers. Slasto is used as a paving stone or flagstone and is not as durable as slate. It is quarried in the Pretoria Group and in the shales of the Karoo System.

TIN – Mined at Rooiberg in the BIC. Cassiterite is the main ore. Tin plates and pots are made from tin.

TITANIUM – Is obtained from the ores ilmenite and rutile found in the beach sands at Richards Bay where it is mined. Its main use is to provide white pigment in ceramics. As a hard metal it is used in industry, golf clubs, etc.

URANIUM – extracted from the gold-bearing conglomerate reefs of the Witwatersrand, Ventersdorp and Black Reefs. It has more than 3 million times more energy potential per unit volume than coal. It is used for nuclear arms and nuclear power stations.

VANADIUM – High melting-point metal (1900 °C) for strengthening steel. It is mined in the BIC.

VERMICULITE – A non-metallic product of mica mined in the Palabora pipe. It is chemically inert and fireproof. It is used as an insulator, for sound-proofing walls and for hydroponics.

ZINC and LEAD – Mined in Aggenys and Black Mountain. Zinc is used to galvanise iron and steel. Lead is used for batteries, piping and wrapping foil.

ZIRCONIUM – It is found alongside titanium in the eastern coast beach sands. Its use is in the nuclear, ceramic and refractory fields.

Activity 3.2

Diamond, building sand, coal, copper, stones, gold and PGMs are some of the minerals which you are most likely to encounter in your career. Compile a table showing these minerals, where they are found, and what they are used for.

6. CONCLUSION

In this unit, we have seen that the Bushveld complex and the Karoo sequence are very important to the South African economy. This is because both the platinum and coal industries are organised around them.

We have also covered the most important ore bodies defining the South African mining industry as well as the commodities that are produced as a result.

In the next three units we will focus on the rocks in which these ore bodies are found. We will cover the formation and transformation of these rocks.

Igneous rocks

LEARNING OUTCOMES

On completion of this study unit, you should be able to do the following:

- Define the term IGNEOUS ROCK
- Describe the nature of magma
- Give the classification of igneous rocks
- Name and describe five common igneous rocks

1. INTRODUCTION

The study of rock is referred to as PETROLOGY. It includes the study of three types of rock: **igneous**, **sedimentary** and **metamorphic rocks**. In this study unit, we will cover the IGNEOUS ROCKS. What this means is that this type of rock is formed from the solidification of the mantle into the earth's crust.

Recall from Study Unit 1 that the MANTLE forms part of the internal structure of the earth as shown in the diagram below. It measures about 2 900 km in thickness and in texture. The mantle is more like putty in the upper reaches and less viscous (less thick) in the lower reaches.

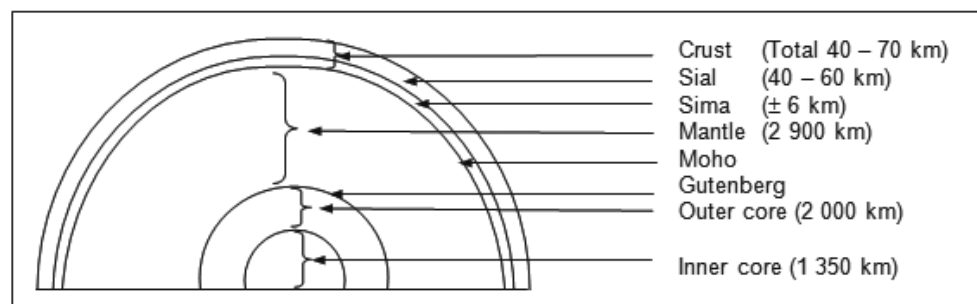


FIGURE 4.1

Internal structure of the earth

The mantle basically consists of hot, dense, and molten rock known as semisolid rock.

The occurrence of igneous rocks is the result of semisolid rock travelling from the mantle through the cracks of the earth's crust. This is illustrated in the diagram below.

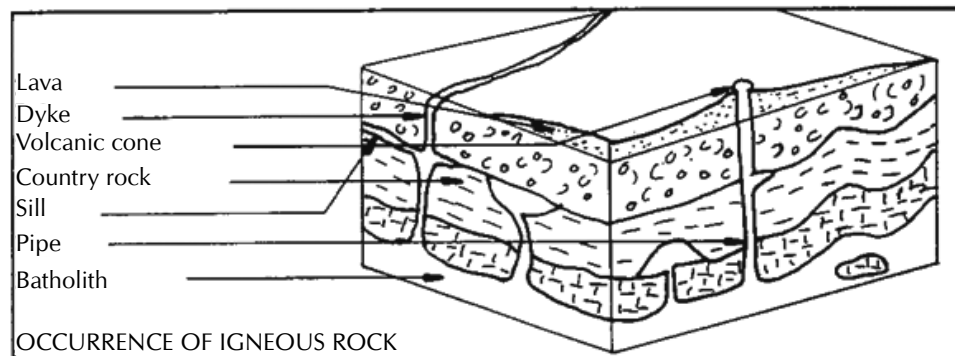


FIGURE 4.2

Occurrence of igneous rock

As the semisolid rock travels through the crust, it loses progressively its heat into the crust, cools down and eventually solidifies. The end result is the formation of a hard rock called IGNEOUS ROCK.

We will describe the most common igneous rocks and where they can be found in South Africa.

2. IGNEOUS ROCK: DEFINITION

Igneous rock is rock that forms when magma cools down and solidifies, e.g. dykes, sills and lavas.

3. NATURE OF THE MAGMA

Magma is a white-hot liquefied rock found below the earth's crust at temperatures of between 800 °C and 1 500 °C. It comprises a mixture of the nine main elements in order of abundance: oxygen, silicon, aluminium, iron, calcium, sodium, potassium, magnesium and titanium.

The solvent is silica and the solutes are the other elements mentioned above.

Magma is discharged on the surface through volcanoes and it is then referred to as lava. Some eruptions are in the form of fissures and others are central (i.e. occur in the centre of volcanoes). The central variety may be conical (high off the ground) or shield shape, i.e. flatter, with gentle slopes.

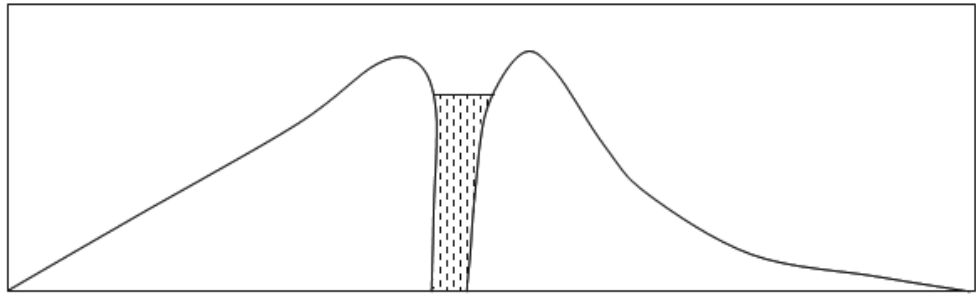


FIGURE 4.3
Cone-type volcano

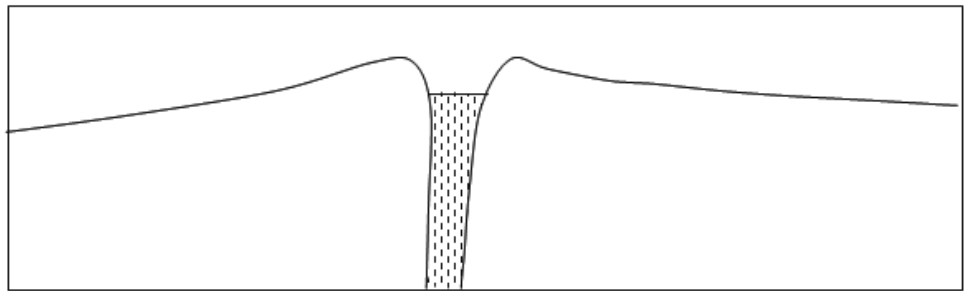


FIGURE 4.4
Shield-type volcano

Viscous acid lava (thicker) produces cones whereas fluid basic lava produces the shield shape. Acid lava has a high percentage of silica and is formed from the upper regions of the crust. Rocks formed from acid lava like **rhyolite**, which is found in the Lebombo mountains, are lighter in colour and less dense than those that form from basic lava, e.g. the **basalts** of the Drakensberg.

Activity 4.1

1. Explain the term "igneous rock".
2. Draw your own diagram or mind map to summarise the most important facts about magma and lava. You may consult this link to see how this can be done: http://en.wikipedia.org/wiki/Lopolith#/media/File:Intrusion_types.svg

4. CLASSIFICATION OF IGNEOUS ROCKS

The table below indicates that the deeper into the earth's crust the rock is located, the less silica it contains and the denser it will be.

	Silica %	Extrusive	Intrusive	Density
ACID	63	RHYOLITE	GRANITE 2,6	2,6
INTERMEDIATE	52	TRACHITE ANDESITE	SYENITE DIORITE	TO
BASIC		BASALT	DOLERITE/GABRO	
ULTRA BASIC	45	KIMBERLITE	PERIDOTITE	3,3

5. COMMON IGNEOUS ROCKS

Below are listed the five most common igneous rocks and an example of places where they may be found in South Africa:

- i) **GRANITE** – Coarse grained and composed of **quartz** and **alkali feldspars**. These rocks underlie large areas of South Africa and are freely found exposed in the Nelspruit area.
- ii) **SYENITE** – Coarse to medium grained and composed of **alkali feldspars** and very little if any quartz. These rocks are found in the Phalaborwa and Pilanesberg regions.
- iii) **DIORITE** – Medium to coarse grained and composed of **hornblende** and **plagioclase**. The basic phase of the Bushveld Complex contains these rocks.
- iv) **GABBRO** – Medium to coarse grained and composed of **augite** and **plagioclase**. Norite is a family member of Gabbro.
- v) **PERIDOTITE** – Medium or coarse grained, composed of **olivine** and some **pyroxene**. Volcanic pipes and dykes contain forms of this rock, e.g. **kimberlite**.

Activity 4.2

Draw up a table to summarise the common igneous rocks, their composition, and where they can be found.

6. CONCLUSION

We have seen in this study unit that igneous rocks are the result of magmatic and volcanic activities. We have also covered the five most common igneous rocks and places where they may be found in South Africa.

In the next study unit we will see how igneous rocks undergo transformations through the geological ages in order to lead to the formation of sedimentary rocks.

Sedimentary rocks

LEARNING OUTCOMES

On completing this study unit, you will be able to do the following:

- Define the term “SEDIMENTARY ROCK”
- Describe the formation of the following:
 - Continental deposits, marine sediments and glacial deposits
 - Mechanically formed (clastic) rocks, organically formed rocks, chemically formed rocks, and residual rocks
 - Common sedimentary rocks

1. INTRODUCTION

In Study Unit 4, we looked at igneous rock. Recall that the molten mantle found a way through the earth’s crust and later solidified into an igneous rock.

Now, if you look at the diagram below, you will notice that the cycle starts off with the magma from the mantle that becomes an igneous rock.

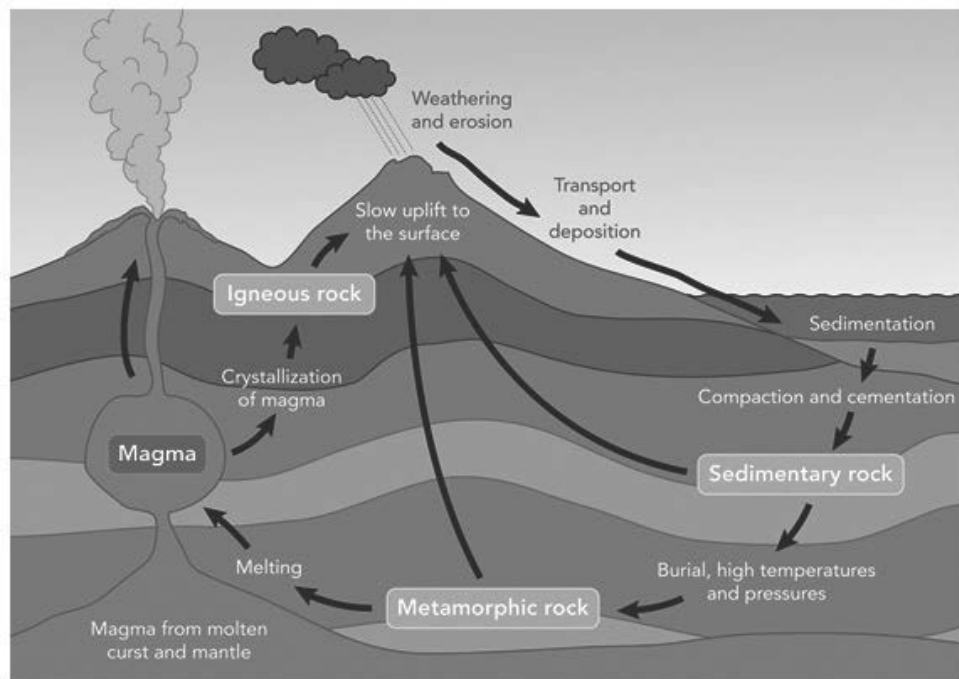


FIGURE 5.1

Schematic representation of the rock cycle

(Source: <https://www.flickr.com/photos/121935927@N06/13581730833/>)

The igneous rock will not stay in place forever. A quick reference back to Study Unit 1 reveals that there are some natural forces that constantly shape the surface of the earth. The natural forces will change the structure of the igneous rock by weathering and erosion. Then the eroded material is transported and deposited into a shallow valley which by compaction becomes a **SEDIMENTARY ROCK**. This is what we will cover in this study unit.

With the continuous formation of sedimentary layers, the old layers buried underneath will start experiencing high temperature and pressure. The result of the combined effects of temperature and pressure gives birth to a **METAMORPHIC ROCK**. This type of rock will be covered in the next study unit.

2. SEDIMENTARY ROCK: DEFINITION

A sedimentary rock is material that has consolidated and solidified after being eroded elsewhere, transported and then deposited.

3. SEDIMENTARY DEPOSITS

Sedimentary rocks are generally found in valleys or lower regions of the surface of the earth as deposits. The most common types of sedimentary deposits are continental deposits, marine deposits and glacial deposits.

3.1 Continental deposits

After the cooling down of the earth the crust (which obviously must have been igneous) was subjected to constant erosion by water in the form of rain, rivers and sea, and the loosened material carried by river water or seawater and deposited elsewhere.

Rivers deposited their suspended soil particles in lakes or inland seas like the famous Witwatersrand deposit where the material solidified in layers.

Winds have in the past bombarded solid rock structures with suspended sand particles and worn down these structures to various grotesque shapes of remnants like the former God's Finger in Namibia (it was finally blown down towards the end of 1989). Such particles that have been sandblasted off these rock structures and other desert sand particles are carried away by the wind and deposited elsewhere, e.g. the sandstone underlying the basalt in the Drakensberg.

3.2 Marine deposits

Rivers emptying into the sea bring loads of material in suspension when they are in flood and such particles gravitate and settle down when the velocity of the water is reduced. The heaviest particles settle down first. Some of the finest particles are carried far out to sea to settle in the deepest parts. The seabed is a source of numerous mineral deposits.

The sea itself constantly bombards the coastline with waves and erodes it as shown in the diagram below. Sand particles are carried down the coastline by the waves or out to sea by the currents and are deposited there.

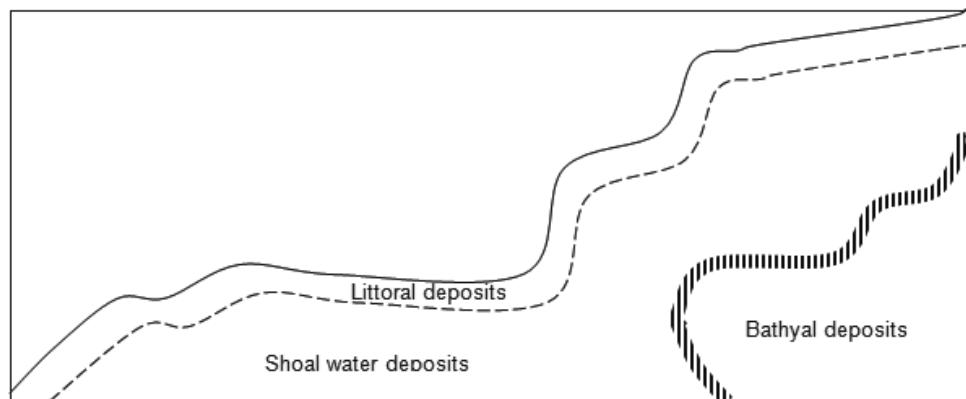


FIGURE 5.2

Formation of different types of marine deposits

LITTORAL deposits are those laid down between high and low tide. They include boulders and pebbles which consolidate to form **conglomerates**.

SHOAL WATER deposits are those that are permanently submerged between low tide and 200 m below sea level. Here in the continental shelf shells, mud and sand are laid down.

BATHYAL deposits are laid down at great depths farther out to sea. Mud and oozes from marine organisms form the bulk of the materials here. Sunken ships that are found submerged in silts give evidence of this.

3.3 Glacial deposits

Glaciers pluck off pieces of rock from small fragments to large boulders from the edges of the glacial valley and carry these in suspension until thawing takes place. When this happens, these jagged chippings which remain unaltered when in suspension gravitate to the bottom of the valley and are known as **ground moraine**.

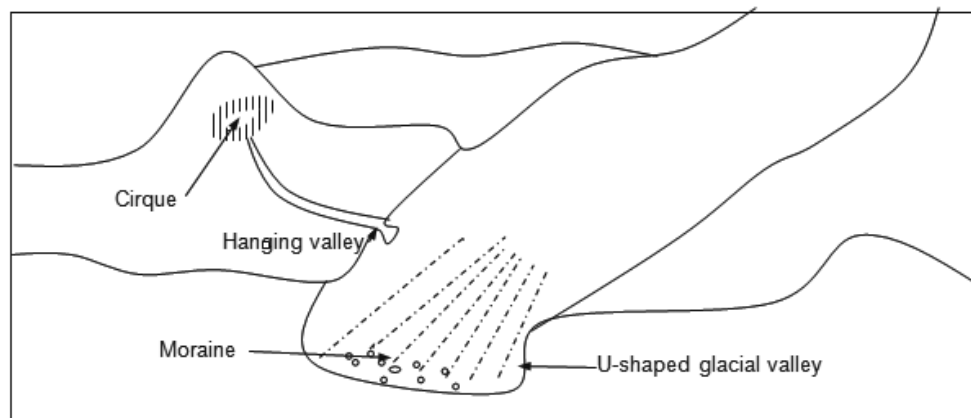


FIGURE 5.3

Formation of a ground moraine

Erratics are boulders that have been dropped by glaciers in foreign surroundings from where they were removed.

Boulder clay (or till) is the finely ground rock material formed by the grinding action of the glacier while in motion. It forms the rock **tillite**.

Striated pavements are the scratch marks found on bedrock. They were caused by boulders being dragged along by glaciers.

4. CLASSIFICATION OF SEDIMENTARY ROCKS

Cementation is the process by which loose soil particles are fixed together by a fluid that seeps through them, e.g. siliceous fluids, calcareous, ferruginous or argillaceous (mud) fluids. They bind sandy soil together to form **siliceous sandstone, calcareous sandstone, ferruginous sandstone and argillaceous sandstone**. As you can probably gather, siliceous fluids are composed of silica, calcareous fluids of calcium, and ferruginous fluids of iron.

Compaction, on the other hand, is the process by which loose sediments will solidify by sheer pressure of the overlying mass of sedimentary material. Mudstone is an example of material formed by compaction.

Sedimentary rocks are classified into four groupings according to how they were formed. The process of formation entails cementation and compaction. The four groupings are as follows: mechanically, organically, chemically and residually formed.

4.1 Mechanically formed rocks

MECHANICALLY formed (clastic) rocks are fragments derived from other rocklike **boulders**, **pebbles** and **breccias** (rudaceous), **sands** (arenaceous), **mud** and **shales** (argillaceous).

Pebbles are rounded off during transportation, whereas **breccias** are jagged due to the fact that they do not move from where they are formed. For example, such jagged fragments are formed when, at a fault, the parting zones grind and chip the material between them.

Volcanic breccias (**pyroclastic**) are the fragments ejected from a volcano when it bursts through the plug of solid material at the start of an eruption. These fragments consolidate where they land and do not travel therefore they remain jagged and angular.

4.2 Organically formed rocks

ORGANICALLY formed rocks are those that form from living creatures. Among these are the following:

Calcareous deposits – Those that form from shelly sea creatures like the White Cliffs of Dover and coral islands.

Siliceous rocks – Formed from organisms that had hard silica bodies, e.g. microscopic radiolaria congregated at death to form such rocks.

Carbonaceous deposits – Carbon rich organic material that is formed from plants, e.g. the **coal family** of **peat**, **lignite**, **bituminous coal** and **anthracite**, and those that are formed from minute organisms, e.g. **petroleum** and **asphalt**.

Phosphatic deposits – Remains of animals, mainly skeletons and excreta, e.g. **bone beds** and **guano**.

4.3 Chemically formed rocks

CHEMICALLY formed rocks are those that have resulted from chemical precipitation or chemical action. **Stalagmites** and **stalactites** form from limestone in caves (calcareous); **bog iron** ore in swamps and **banded ironstones** in marine conditions (ferruginous), **flint** from **chert** which is a siliceous hard deposit. **Evaporites** like **silcrete**, **calcrete** and **ferricrete** are formed when evaporation takes place leaving a sediment of rich mineralisation in a pan. **Salt** is also a good example of evaporites.

4.4 Residual rocks

RESIDUAL deposits – As the word indicates, the material left behind after water has leached minerals away from the soil is referred to as residual deposits, e.g. laterite that is used in the construction of roads.

Activity 5.1

1. Name the three types of sedimentary deposits and describe in your own words what makes them different from each other.
2. Complete the table below:

Rock type	Formation process	Examples of rocks
		Boulders
	formed as a result of chemical precipitation or chemical action	
Residual		

5. COMMON SEDIMENTARY ROCKS

The most common sedimentary rocks are formed as described below.

5.1 Sandstones –

medium grained sand particles cemented together are referred to as **sandstones**. These particles may be rounded or angular and usually are fragments of quartz. They were deposited by winds generally, some two to three hundred million years ago. Remnants of these are the sandstone caves below the Drakensberg lavas and the weird rock shapes in the Golden Gate areas of the Free State.

They are classified according to the cementing material; namely **siliceous sandstone, calcareous sandstone, ferruginous sandstone and argillaceous sandstone**. Siliceous sandstone is in fact quartzites due to the abundance of silica cementing the grains. The water-deposited beds of the Magaliesberg range laid down 2 000 million years ago are examples. Sandstone laid down by water after the ice age between 100 and 200 million years ago forms the parting between the coal seams and also formed the so-called **floating stones** and rolling stones encountered in coal seams.

5.2 Mudstones and Shales –

These argillaceous (mud) deposits were deposited by water as a silt and are therefore fine-grained. They differ from each other in that shales are well bedded with visible planes while mudstones are massive, i.e. no layering or special shapes.

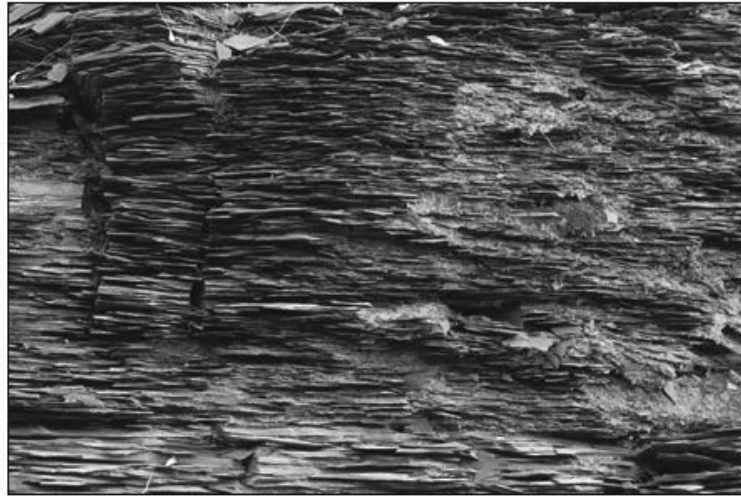


FIGURE 5.4

Example of well-bedded shale wall with visible planes

(Source: <http://smurfage.deviantart.com/art/Shale-Wall-208582121>)

Shale beds are the reason for the successive valleys lying between parallel quartzite ridges of the Hospital Hill and Orange Grove quartzites in the Witwatersrand ridges, and the Pretoria Group formations of the Magaliesburg, Daspoort and Timeball ridges (see sketch).

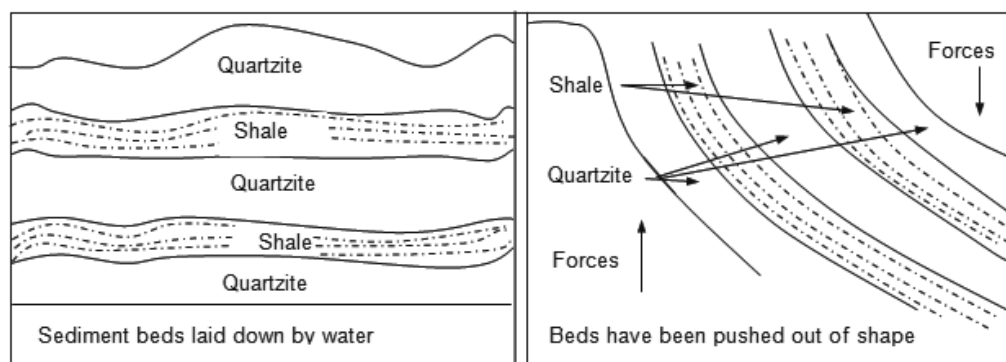


FIGURE 5.5

Valleys and ridges

Dwyka Tillite is a mudstone. Shales of the Karoo System (coal deposits are part of this) are rich in fossils of the dinosaur era of 60 to 150 million years ago.

5.3 Conglomerates and Breccias –

Rocks comprising medium to large fragments of classic (shattered) material form these sedimentary rocks. Those with rounded pebbles and boulders are known as **conglomerates**, whereas those with angular fragments are known as **breccias**.



FIGURE 5.6

Example of a boulder of conglomerate with cobble-sized clasts. The rock hammer is used for scale.

(Source: [http://en.wikipedia.org/wiki/Conglomerate_\(geology\)#/media/File:Lehigh_conglom.jpg](http://en.wikipedia.org/wiki/Conglomerate_(geology)#/media/File:Lehigh_conglom.jpg))

Conglomerates resulted from water-borne fragments that became rounded while being transported. They were then laid at the mouths of rivers where they were consolidated. A typical example are the fans of the Witwatersrand reefs. The pebbles are the remnants of large boulders of hard rock gradually ground down in the riverbeds.

Mineralisation of reefs is purely incidental. The gold example in reefs indicates that a solution of gold permeated the conglomerate deposit settling around the pebbles in the case of the Witwatersrand system. In numerous other cases conglomerates were invaded by solutions of other valueless mineral solutions.

5.4 Limestone

Calcium carbonate is the predominant mineral of limestones. Some limestone originated from the remains of marine organisms, e.g. **shelly limestones**. However, the majority of these sedimentary deposits are chemically precipitated. They are called dolomites if they have an equal amount of both calcium carbonate and magnesium carbonate. If there is less magnesium they are called magnesium limestone.

5.5 Coals

Vegetable matter that has decayed in the absence of oxygen is altered into coal, therefore coal is a **carbonaceous organic deposit**. The coal family consists of **peat, lignite, bituminous coal** and **anthracite**, according to the degree of alteration.

Peat is hacked out in fields in Europe in the form of lumps of soil. In South Africa it is found in Lichtenburg.

Lignite is brown in colour and originates mainly from the wood of the plants. It is found in Knysna.

Bituminous coal is jet black and forms the basis of our coal mining operations. It appears in the Ecca Group of the Karoo System where up to five seams are found in the northern Ecca regions.

Anthracite is coal that has been subjected to the highest degree of alteration. It is almost pure carbon. **Anthracite** in South Africa has come about by coal seams superimposed by hot lavas (or sills) which have devolatilised the seam leaving the carbon behind, as in Utrecht and Vryheid.

Activity 5.2

1. Coal is one of the most important sedimentary rocks in South Africa. Draw up a table listing the different types of coal, their distinctive characteristics and places where they may be found.
2. Do the same for the other common sedimentary rocks.
3. Complete the table provided below. The table gives an overview of the various types of the sedimentary rocks and how they were formed.

The table below provides a summarised classification of sedimentary rocks described in this study unit by use:

COMPOSITION	MECHANICALLY FORMED	ORGANICALLY FORMED	CHEMICALLY FORMED	RESIDUAL
Siliceous	Sandstone Quartzite	Radiolarian Chert	Sinter Chert Silcrete Flint	Sandy soil
Calcareous	Shelly-limestone	Shelly- Limestone Coral limestone	Limestone Dolomites Calcrete	
Ferruginous		Bog Iron ore	Banded Ironstone Ferricrete	
Aluminous	Mudstone Shale			Laterite "ouklip"

COMPOSITION	MECHANICALLY FORMED	ORGANICALLY FORMED	CHEMICALLY FORMED	RESIDUAL
Phosphatic		Bone bed Guano		
Sulphates Chlorides			Gypsum Rock salt	
Mixed	Conglomerates Breccia Tillite Agglomerate Tuff			

6. CONCLUSION

In this unit we have seen how igneous rocks are transformed into sedimentary rocks. We then classified sedimentary rocks on the basis of the formation process. We finally reviewed the most common sedimentary rocks and their formation, and provided examples.

In the next unit, we will study the type of natural forces acting on sedimentary rocks as well as the changes in structures and compositions that result from these. These last types of rocks are referred to as metamorphic rocks.

STUDY UNIT 6

Metamorphic rocks

LEARNING OUTCOMES

On completion of this study unit, you should be able to do the following:

- Define the term METAMORPHISM
- Describe the three types of metamorphism
- Describe how andalusite is formed
- State what type of rock the following metamorphic rocks were originally from, and name the type of metamorphism that was responsible for the change:
 - marble
 - slate
 - quartzite
 - gneiss
 - anthracite
 - phyllite
 - andalusite
 - schist
 - hornfels

1. INTRODUCTION

It is important to remember the figure below describing the rock cycle. The figure was first introduced in study unit 5.

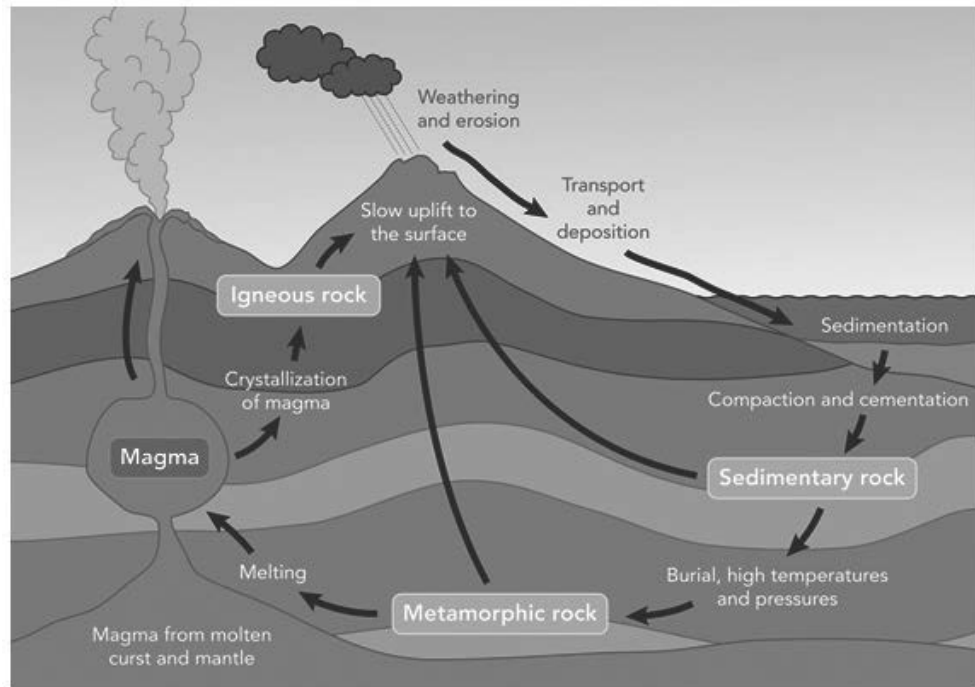


FIGURE 6.1

Schematic representation of the rock cycle

(Source: <https://www.flickr.com/photos/121935927@N06/13581730833/>)

We can see that rocks come from the magma and solidify into igneous rocks. Natural forces such as weather and erosion transport the igneous rocks and deposit them in shallow valleys. Compaction and cementation then turn the deposits into sedimentary rocks.

Recall that rocks formed from magma were covered in study unit 4. These rocks, better known as igneous rocks, were later eroded to become sedimentary rocks and which we spoke about in study unit 5.

Now, the progressive deposition of new layers of sediments makes the underlying layers undergo some transformation. This is what unit 6 is all about.

2. METAMORPHISM: DEFINITION

METAMORPHISM can be defined as the change in structure and/or composition of sedimentary or igneous rock which may be brought about by pressure (dynamic), heat (thermal) or both (dynamo-thermal), or by active fluids (chemical).

3. TYPES OF METAMORPHISM

THERMAL METAMORPHISM – Heat may be caused by volcanic action or by sheer depth of material below surface. Such heat may alter the structure and/or composition of material much in the same way as in a pottery where moulded forms of clay are baked in an oven.

DYNAMIC METAMORPHISM – Pressure is applied to lower lying material by sheer mass of the overlying substances whether they are land or water. Compaction takes place and the resultant metamorphism depends on the type of the material so affected.

DYNAMO-THERMAL METAMORPHISM – It is the combined effect of the above. The heat causes recrystallisation while the pressure causes restructuring or deformation.

CHEMICAL METAMORPHISM – Active fluids, mainly water, play a major role in chemical action on minerals. Such fluids may percolate through existing rock structures or along cracks. Tree trunks have been known to change in composition though not in structure as in petrified wood. **METASOMATISM** is the term used to describe the total replacement of the chemical composition of material by fluids of different chemical composition.

4. CONTACT METAMORPHISM

Contact metamorphism is brought about by a magmatic intrusion like a volcano or **dyke**. A magmatic intrusion occurs when magma “intrudes”, or is forced into, the surrounding rock. This rock in the immediate vicinity, also known as “country rock”, is altered by being in contact with hot magma. The composition of limestone is altered into **marble**, **siliceous sandstone** into **quartzite**, and **shales** (argillaceous rock) into **hornfels**.

METAMORPHIC AUREOLE – The degree of change effected in contact metamorphism varies according to the distance of the country rock from the point of contact with hot magma. Consequently, rings of similar metamorphic rock form in concentric circles round a volcanic pipe. These rings are referred to as a metamorphic aureole. The Bushveld Complex has a very large metamorphic aureole extending some 400 km in diameter.

A good example of contact metamorphism is the alteration of **ARGILLACEOUS ROCK** to form **ANDALUSITE**.

In the Bushveld Complex crystals were formed in shales when the intrusion occurred. In some cases, these crystals have been freed by erosion and carried along riverbeds where they have concentrated to form andalusite. Andalusite is used to manufacture refractories, e.g. the ceramics of spark plugs and high-tension cable insulators. The quality that favours the use of andalusite is its ability not to deform or crack when subjected to very high temperatures.

Activity 6.1

1. Describe in a tabular format the four types of metamorphism and their respective effects on the rock structure and composition. Also give an example in each case of rock formed by the metamorphism.
2. Explain in your own words contact metamorphism and metamorphic aureole.

5. EXAMPLES OF METAMORPHISM

The table below gives examples of changes in rock structure as a result of some form of metamorphism. It lists the original rock, the type of metamorphism responsible for the change as well as the final rock formed from the metamorphism.

ORIGINAL ROCK	TYPE OF METAMORPHISM	METAMORPHIC ROCK
Calcite or limestone	Thermal	Marble
Argillaceous rocks	Dynamic	Slate
Siliceous sandstone	Thermal	Quartzite
Granite	Regional	Gneiss
Bituminous coal	Thermal	Anthracite
Argillaceous rock	Dynamo-thermal	Phyllite
Argillaceous rock	Thermal	Andalusite
Shales/mudstone	Dynamic/dynamo-thermal	Schist
Shales	Thermal	Hornfels

6. CONCLUSION

This study unit concludes the discussion of the three types of rocks that exist: igneous, sedimentary and metamorphic rocks.

In the next study unit, we are going to wrap up the GEOLOGY section with the different types of structures and formations in which we can find the various rocks in the earth's crust.

Structural geology

LEARNING OUTCOMES

On completion of this study unit, you should be able to do the following:

- Describe the natural process of sedimentation
- Define a number of important terms that relate to structural geology
- Draw sketches to illustrate the elements of a fold and a fault
- Draw diagrams to show the following fault structures:
 - normal dip fault
 - normal strike fault
 - oblique fault
 - reverse fault
 - graben
 - horst
- Describe the following structural formations:
 - conformable strata
 - unconformities
 - angular unconformity
 - disconformity
 - outlier
 - inlier
 - sub-outcrop

1. INTRODUCTION

Since the appearance of the first solid matter of the earth's crust and the surrounding masses of water, continuous erosion of material from higher ground and its depositing in lower regions has taken place for at least 3 500 million years (i.e. 3,5 billion years). Some of these new deposits have again been eroded away and redeposited in some other place. As an example, the sediments that formed the now grotesque shapes of Golden Gate in the Free State are steadily being worn away and deposited somewhere else. The topmost slice of the Highveld (at least 1 km) is known to have been eroded away since it was originally deposited. Included are portions of the Witwatersrand gold reefs which were eroded and deposited in the Ventersdorp areas where it is now mined as the Ventersdorp Contact Reef.

Structural geology is all about studying the shapes in which the layers of sediments appear today in association with intrusion of igneous rock. It also entails the study of changes in shape of these rock structures due to natural factors such as tectonic forces, erosion, transportation and deposition of soil.

2. THE PROCESS OF SEDIMENTATION

Sedimentation can be defined as the process of deposition and layering of eroded igneous rocks into sediments over a long period of time. The process of sedimentation is therefore the result of layering of sediments.

STRATIFICATION

The layering of sediments in sequence is referred to as **stratification**. Such layers are easily noticeable in road cuttings and quarries where they have been exposed. Parallel lines (**bedding planes**) may be visible showing a series of sequential layerings. You can refer to Figure 5.4 to see an example of layerings.

PSEUDO-STRATIFICATION

The prefix “pseudo” means unreal, therefore, **pseudo-stratification** stands for stratification which is not from layering of sediments but from lava sheets (igneous rock) that were spilt over a period of time and appear today as “layerings”. The caps of the Drakensbers and spills found freely on the tops of the Karoo “koppies” can be called pseudo-stratification because they are lava sheets that were laid down at intervals over a long period of time.

BEDDING-PLANE

When sediments were laid, the wind or water carrying them did so in periodic stages. These periods could have been a season or decade of strong winds or torrential rain for example. In a later season the action could have been repeated with a variation of the type of material carried. As a result the tabular division between the two layers appears very distinct today as there is not much cohesion between the layers. This tabular surface is known as a **bedding plane**.

LAMINA

Lamina (laminae, if more than one) is the thinnest layering of a **stratum** (see below). A single downpour of rain could have deposited a thin layer of sand or silt that may measure only a millimetre or two in thickness.

STRATUM

A stratum (strata, if more than one) is a collection of laminae of the same material. This may occur when erosion of material from the same source takes place for a few seasons until the source is exhausted or the river changes its course.

3. STRATIFICATION STRUCTURES

The following are the most important types of stratification structures:

CONFORMABLE STRATA – These are strata that appear to be lying in the same sequence as when they were laid irrespective of folding or tilting that may have taken place.

UNCONFORMABLE STRATA – Sometimes uppermost strata are eroded away and then new strata are laid over the remaining ones. The historical gap so created is referred to as an unconformity, or the strata are said to be lying unconformably.

ANGULAR UNCONFORMITY – Where the newer, upper strata are lying at a different angle to the older ones in an unconformity the feature is referred to as an angular unconformity. This occurs when conformable strata are tilted due to tectonic pressure followed by erosion of part of the strata and a subsequent deposition of younger material.

DISCONFORMITY – When the contact surface between older and younger strata in an unconformity shows that no tilting of strata took place between the original deposit and the second deposit, the structure is referred to as a disconformity.

OUTLIER – Where younger material is surrounded by older material **in plan**, the isolated block is referred to as an **outlier**.

INLIER – Where an old block of strata is surrounded by younger material **in plan**, the isolated block is called an **inlier**. Both structures come about due to erosion of part of the layerings.

SUBOUTCROP – Tilted or folded strata may cause a limb to protrude on the surface as an **outcrop**. Where such a surface feature is then overlain by newer material (as in an angular unconformity) this “outcrop” is now referred to as a **suboutcrop**.

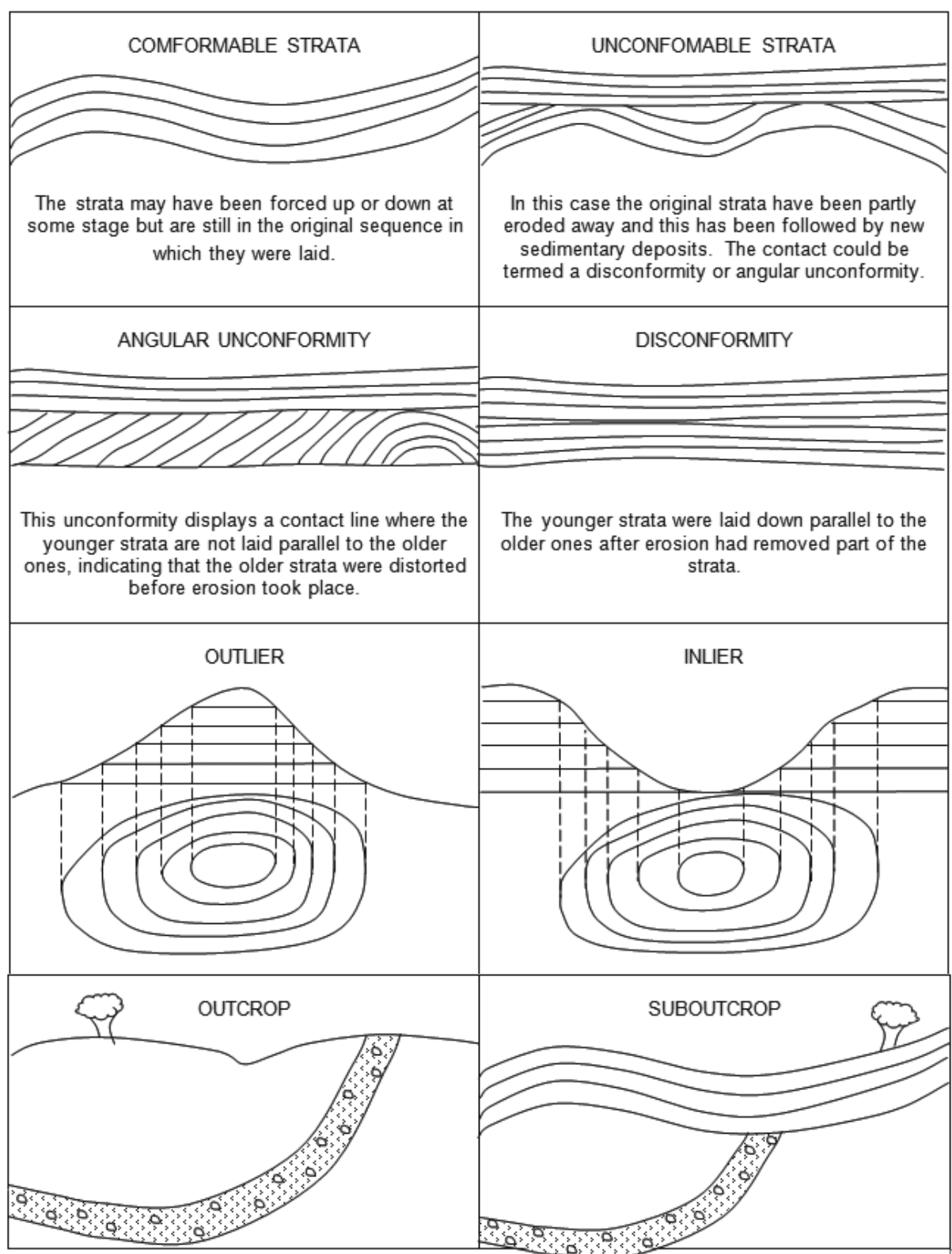


FIGURE 7.1
Examples of structures of stratification

Activity 7.1

1. Differentiate stratification from pseudo-stratification. Also discuss whether there are similarities in the bedding planes, lamina and strata between stratification and pseudo-stratification.
 2. Explain in your own words how an outcrop can become a suboutcrop and vice versa. You may need to use the library or internet to help you answer this question.
-

4. INCLINATION OF A STRATUM

All sediments are laid down flat by lakes or seas as a matter of course. The edges may be inclined slightly due to the action of waves. These strata may later be pushed up or down by the internal forces of the earth's crust causing them to be inclined.

STRIKE

It is a **compass direction** of a stratum obtained by drawing a line along the bedding plane where this line has 0° dip, i.e. perfectly horizontal. A compass is then placed against the line to take a reading, e.g. N 25° E or S 65° W.

NB: The major poles NORTH and SOUTH are always written first, then the figure giving the degrees of angle between the major pole and minor pole.

TRUE DIP

It is the degree of dip of a stratum obtained by calculating the steepest slope of the stratum inclination. It is always 90° from the direction of the strike.

MINOR DIP

This stands for any dip other than true dip as it appears visually.

OUTCROPS

Strata sometimes are exposed on the surface due to erosion of top soil. This exposed portion of a stratum is referred to as an outcrop.

CONTOUR LINES

Contour lines are drawn on a map when surface areas of the same elevation above sea level are connected by a single line. These lines may be drawn at predetermined intervals, e.g. of 10 m or 50 m, etc. Therefore, at a glance on the plan view of any surface, one can determine the highest land surface, ridges and valleys (See Figure 7.2).

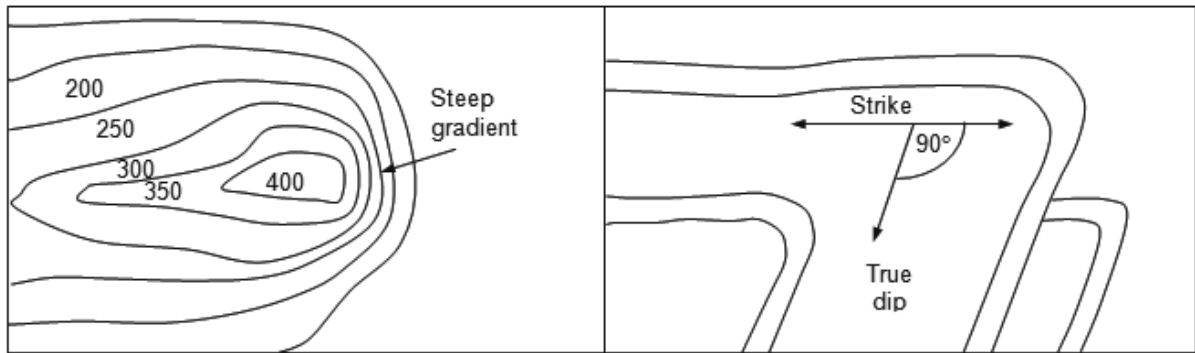


FIGURE 7.2
Contour lines; Right – Strike and dip

5. FOLD

A fold can be defined as a permanent deformation in the form of curves or bends of a sequence of originally flat sedimentary strata.

The diagram below shows the elements of a fold, which are explained further below:

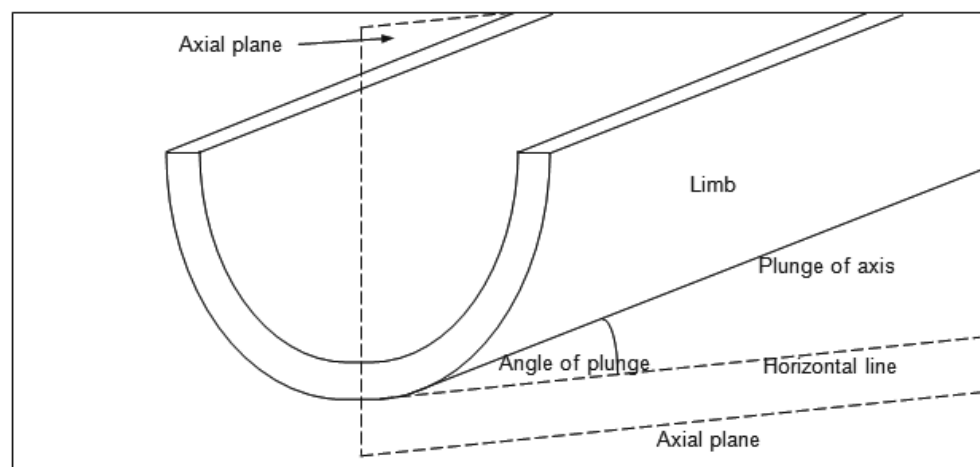


FIGURE 7.3
Elements of a fold

AXIAL PLANE – This is an imaginary plane that divides a fold symmetrically. It intersects the bedding plane of the fold along a line referred to as the axis.

AXIS – This is a line that can be drawn along the centre of a fold bisecting the fold symmetrically.

PLUNGE (or PITCH) – This occurs when the fold dips in a given direction and the axis is said to plunge or pitch at an angle between it and the horizontal.

LIMBS – The strata of a fold from the axis upwards are referred to as limbs. An inclined stratum is invariably a limb of a fold whose axis is somewhere below.

The figures below show different types of folds which are explained in more detail further below.

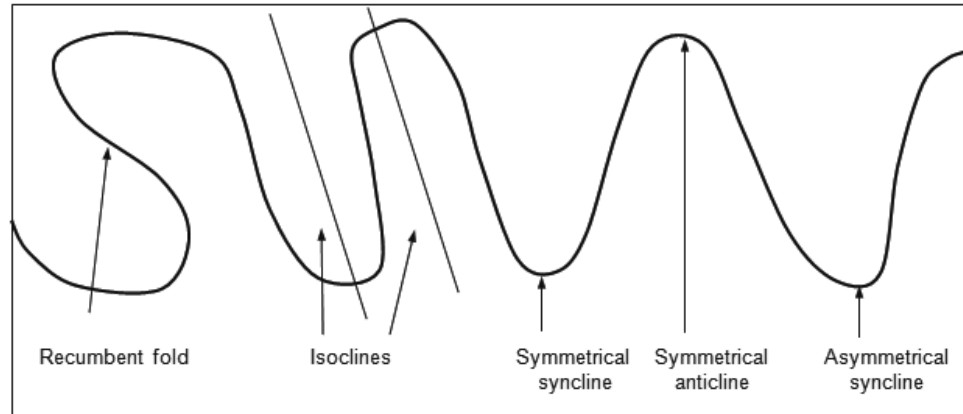


FIGURE 7.4
Types of folds

ANTICLINE – A fold whose limbs drop away from the axis in an “upside-down” form is called an anticline (see “symmetrical anticline” in Figure 7.4 which shows the basic shape of an anticline).

SYNCLINE – A fold whose limbs rise up from the axis in the shape of a canoe is referred to as a syncline (see “symmetrical anticline” in Figure 7.4 which shows the basic shape of a syncline).

SYMMETRICAL FOLD – Where the two limbs of either a syncline or anticline have the same degree of dip, the fold is said to be symmetrical.

ASYMMETRICAL FOLD – Where the two limbs of a fold (syncline or anticline) dip at different angles, the fold is said to be asymmetrical.

ISOCLINE – Where two limbs of a syncline or anticline are dipping in the same direction and at the same degree of dip, the fold is referred to as an isocline.

OVERFOLD – As the word states, it is the fold where the limbs fold over beyond the vertical.

RECUMBENT FOLD – An excessively folded over anticline whose limbs are near-horizontal is regarded as a recumbent fold. As in an overfold and in some isoclinal folds, the order of the beds is reversed, i.e. the footwall becomes the hangingwall and vice versa. See the photograph of a recumbent fold in Figure 7.5 below.



FIGURE 7.5
Recumbent fold

(Source: http://commons.wikimedia.org/wiki/File:Recumbent_Fold_at_Godrevy_in_Cornwall.jpg)

DOMES – The circular shape of an upside-down basin in which the strata dip away in all directions from a central point is known as a dome.

BASINS – The circular shape formed by a syncline whose “limb” rises in all directions from a central point is known as a basin. It is the right side up from a dome.

Activity 7.1

Draw your own diagrams to illustrate the various types of folds and fold features described above, and then briefly explain each type in your own words.

6. FAULT

A fault is a crack across rock formation where the relative rock features are displaced along the crack. There is relative movement of rock across the fracture plane. If there is no relative movement, the feature is simply a fissure or a joint.

Figure 7.6 below illustrates this. The upthrow and downthrow areas were originally part of the same rock formation. A fissure developed between them, and eventually the downthrow area slipped downwards while the upthrow area moved upwards. The two areas were thus displaced, and the crack between them is now called a fault.

Figure 7.7 also shows the elements of a fault. The different types of fault structures that can be found are shown in the table below.

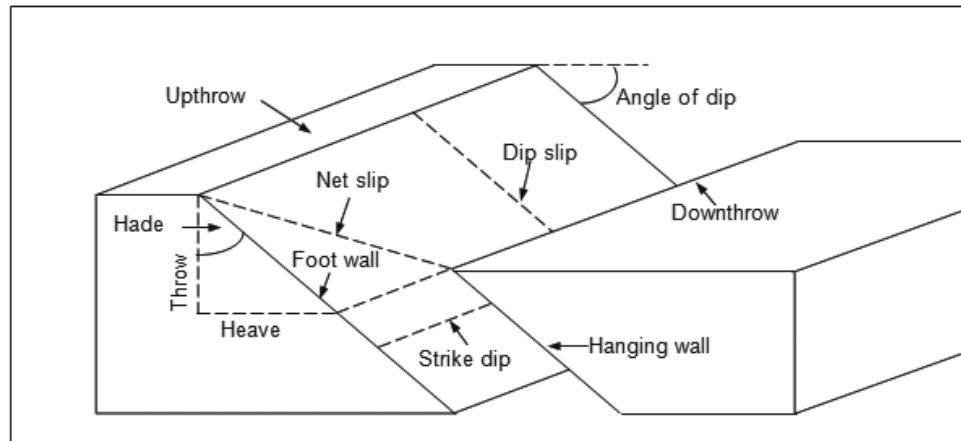
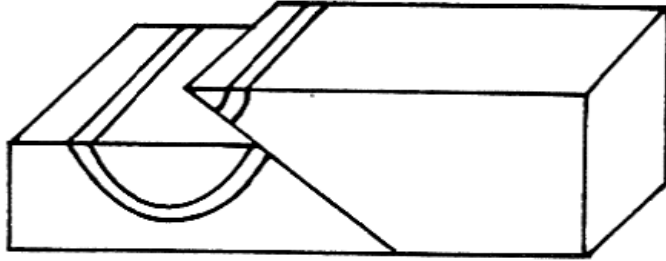


FIGURE 7.6
Elements of a fault

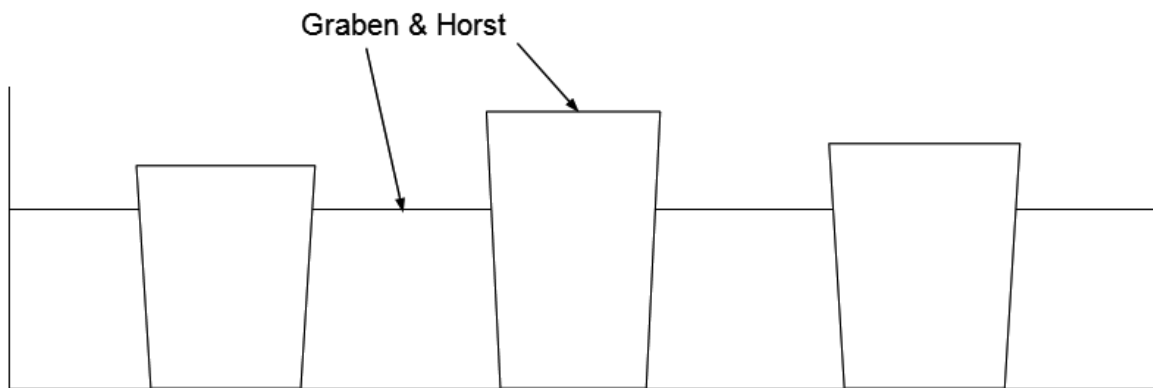
normal dip fault	Cue: on the face of the fault one is able to see the dip of the limbs
normal strike fault	Cue: on the face of the fault one is able to see the strike of the limb
oblique fault	Cue: on the face of the fault one is able to see the oblique strike of the limb

Reverse fault



Cue: a reverse fault is the opposite to a normal fault.

GRABEN & horst



The two features that are commonly encountered where faults occur are grabens and horsts. A **graben** is a section of the earth's crust lying between two faults that has been displaced downwards relative to the blocks on either side. A **horst** is the raised block.

Activity 7.2

If you have access to the internet, do your own search to find illustrations or photographs of the various types of folds and faults described above.

7. CONCLUSION

This study unit concludes the GEOLOGY section of the module.

We have seen the natural forces reshape the surface of the earth. We have studied the properties and characteristics that differentiate minerals from each other. We have also defined and classified minerals while keeping in mind their importance in the mining industry.

We have then reviewed the most important minerals found in South Africa that form the basis of its mining activities and support its economy. We also covered the different types of rocks (igneous, sedimentary, and metamorphic) and travelled around the rock cycle. We have highlighted the importance of

these rocks in mining engineering. We then studied the different shapes under which these rocks can be found in the earth.

In the next section of the module, i.e. MINING, we will see how minerals of economic value can be discovered and how their associated ore bodies can be excavated from the earth safely and efficiently.