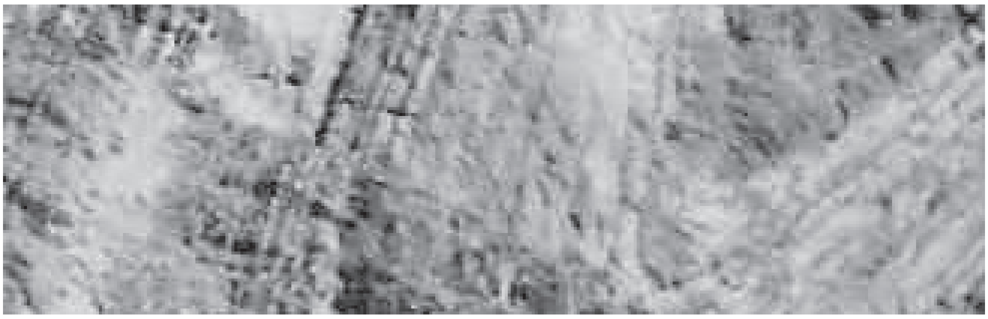
Department of Environmetal Sciences

ENVIRONMENTAL GEOLOGY

Only study guide for GEL1503



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PREFACE

A WORD OF WELCOME

We wish to welcome you in the Department of Environmental Sciences, and specifically to this introductory Geology module. In this module, we not only study various characteristics of the Earth, but we also place them in the larger context of a geosystem. Studying unifying theories such as that of plate tectonics is very exciting. Afterwards you can apply your new knowledge of the different Earth components and processes by including it in overarching theories, thus gaining an understanding of how everything comes together interactively on a global scale. Apart from the fact that this module constitutes your foundation for further studies in the Earth sciences, it also contains knowledge which you can apply in your everyday life and the Earth you inhabit. This may even induce you to come to the conclusion that the environment of the Earth is wonderful and precious enough to respect.

Your lecturer will provide you with the necessary guidance to achieve the outcomes of this module, but you in turn will have to put in the effort to master the work. You are welcome to contact your lecturer if you should experience any problems in the course of your studies for this module.

CONTACT PERSON

Please contact the relevant lecturer about academic queries – preferably by e-mail, post or telephone, during office hours.

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The Unisa Department of Environmental Sciences is based at the Florida Campus of Unisa.

RATIONALE

New technologies such as GPS use satellites to measure the changing distances between continents over time, and computers are used in the interpretation of seismological observations of earthquakes and other environmental data. From this knowledge, various theories about the interior of the Earth, volcanic eruptions and other geological events are formed. Geology not only integrates several of its own subdisciplines of knowledge into the single theory of plate tectonics, it also interacts with various other fields of study in creating a complete overview of the environment. The flow of rivers, dolomite subsidence, and mass movements are examples of geological phenomena which can be described geographically, and which have an economic impact on society. For the student of the environment, it is of the utmost importance to be able to understand, describe and apply the geology on which his/her different subject disciplines are based. This module, GEL1503, presents basic geology from an environmental perspective.

PREREQUISITES

None.

STUDY MATERIAL

Prescribed books

- This study guide for GEL1503: Environmental Geology (the abbreviation we shall be using when referring to this study guide, is **SG**).
- Grotzinger, J & Jordan, TH. 2010. *Understanding Earth.* 6th edition. Freeman: New York. 652 pp. ISBN 13-978-114292-1951-8. (We shall refer to this book as **UE-6**.)

Recommended books

- Montgomery, CW. 2003. *Environmental geology.* 6th edition. New York: McGraw-Hill. 554 pp. ISBN 0-07-366195-3.
- Skinner, BJ & Porter, SC. 2000. *The dynamic Earth: an introduction to physical geology.* New York: John Wiley. 575 pp. ISBN 0-471-16118-7.
- Bates, RL & Jackson, JA (eds). 1987. *Glossary of geology.* Alexandria: American Geological Institute. Va. 788 pp. ISBN 0-913312-89-4. (We shall refer to this book as **BJ3**.)

HOW TO USE THE STUDY GUIDE

Because the module GEL1503 deals with the theoretical aspects of Environmental Geology, no practical work has been included in the module. Practical work that has a bearing on this module will be done in module GEL1502.

The purpose of this study guide is to guide you through the learning content of GEL1503, as covered by selected sections in the prescribed textbook. The following are guidelines to help you find the relevant, prescribed sections in the textbook and to do the learning activities. The recommended books are not prescribed, but may be used as additional sources or as a similar source if the primary prescribed book is not available.

Abbreviations used in this study guide:

- **UE-6** refers to the prescribed book *Understanding Earth*, 6th edition, as mentioned above.
- **SG** refers to this study guide for GEL1503.
- Page references are indicated as follows: **p 5**, for instance, refers to page 5, and **pp 6–9** to pages 6 to 9.
- Reference to figures and tables will be made in the following form: **fig 4.4** will refer to figure 4.4, and **tab 5.5** will refer to table 5.5.

Study the **outcomes** of the various levels of the SG (module, study unit, study section) very carefully. The MODULE PLAN gives a general overview of the geology themes you will study.

The **icons** used in the SG indicate sets of consecutive study activities to be performed in conjunction with your studies of the prescribed themes in the textbook. You must have done these activities with a view to achieving the outcomes by the time you have completed your studies. We will provide you with an explanatory list of the icons.

The **layout** of the study guide is roughly as follows:

- A *selection of chapters in UE-6* that form a general theme like "surface processes" have been grouped together to form a **study unit** in the SG. A *chapter in UE-6* corresponds to a **study section** in the SG. Each study section is subdivided to correspond with a selection of subtitles in the chapter in UE-6.
- For easy navigation and a quick overview of the contents, a table of contents of the different **themes** covered in a chapter is given at the beginning of each study section, as well as a **general overview of the learning content** of the study section.
- The **objective** that appears in blue print on the first page of each chapter in UE-6 was used as the outcome of each individual study section. The outcomes will be explained in more detail in the introductory paragraphs of the various study sections.
- You must be able to reproduce the **figures (in UE-6)** prescribed in the SG neatly, in monochrome (pencil or pen). This must be done in a simple way, focusing on the point of the question. You may draw the three-dimensional (3-D) figures in UE-6 in two dimensions (2-D). It is important to know the captions/labels, as they explain the concepts shown in the diagrams, and can also serve as answers to questions or summaries.
- The **tables** show facts and descriptions in a structured way. **Figures** integrate bits of knowledge into a system, a process, or a theoretical model. Some of these are specifically prescribed in the SG, with instructions.
- **Key terms and concepts** are listed with page references at the end of each study section to help you review and test your understanding. Special attention is paid to some of them under the revision icon at the end of the study sections.

- A selection of terms is listed alphabetically in the **glossary** at the back of UE-6. Use it frequently.
- At the end of each study section in the SG there is a **summary** of the topics that were covered. These summaries provide an overview of what was discussed and, in some instances, provide feedback on questions. These summaries also act as a revision tool.
- The SG prescribes some of the **exercises** at the end of the chapters in UE-6 as learning activities. A thought question from UE-6 may appear under the application icon in a study section.
- *Earth issues* and *Earth policy* are boxed features in UE-6. The themes of environmental awareness, scientific methods and the uses of technology in the Earth sciences are dealt with so that you can relate geological phenomena to human activities.

HOW TO STUDY

Distance education is based on self-study. You are, however, encouraged to contact your lecturer if necessary.

You know your own circumstances. It is your own responsibility to arrange study time for yourself so that you will be able to master the study units. The instructions given in the study guide (under the study icon) demarcate the work to be studied and suggest how the information may be mastered. You may be instructed to **read/study** something **carefully** or **thoroughly**, or to simply scan/read quickly through the work (to **read** something **cursorily**) to gain background knowledge on something.

If you understand the concepts in a section and can apply them, you will also find them easy to remember. If you study each section purposefully and methodically, you will eventually be able to fit the consecutive sections into the larger framework of the study section, study unit and module. In each case, you will achieve outcomes that will contribute to the achievement of the overall outcomes, and finally, the module outcomes – the latter being your reason for studying this module in geology.

You have to test yourself against each learning outcome given in the study guide. This is part of the cyclical learning process used throughout the study guide. The lecturer will mark and evaluate your assignments and examination papers and give you feedback on them. The marked assignments, memorandums and your own summaries should form part of your preparation for the examination.

Tutorial Letter 101 accompanies this study guide. It contains the two sets of assignments, together with their due dates, as well as other relevant information on your studies. The purpose of Tutorial Letter 101 is to keep the study guide updated, and to help you draw up your study programme and refine your study methods. Use the tutorial letter in conjunction with the study guide.

EVALUATION

You must answer the questions that appear throughout the guide under icons like "(individual) exercise", "test your knowledge/understanding" and so forth, yourself. Do so by following the instructions and referring to the relevant sources or the tips/hints that are given to help you. This will be your way of continuously checking your own knowledge and understanding. No marks are awarded for these questions.

Assignments to be assessed for credit and examination admission will be given in Tutorial Letter 101 for this module.

You will write one examination paper of two hours in May/June for semester 1 or one examination paper of two hours in October/November for semester 2, the dates of which you will find on the timetable in the **Unisa Calendar**. The date, time and location will be confirmed in writing during April for semester 1 and in September for semester 2. A **minimum mark of 50%** is required to pass the examination.

STUDY ICONS

	Estimated study time		Important information
	Outcomes		General overview
	Introductory remarks		Study/Read the indicated material in the textbook/ article, etc
	Application		Individual exercise/Activity
	Key terms and concepts		Answers/Solutions/ Feedback
	Summary of main points/ notes		Revision

ACTION WORDS

You may have to read/study a section of work carefully/thoroughly (for examination purposes), or you will be instructed to just glance through the work/read the work cursorily (for background knowledge). Questions/instructions are phrased in a particular manner in outcomes, exercises, assignments, tests and the examination. The following verbs may be used:

Read carefully, study thoroughly	Read/study thoroughly in order to achieve the outcomes and be able to write an examination on them.
Take note, read cursorily	Read through the work for background knowledge only, and to take note of the contents only – not for examination purposes.
Describe	Write down the characteristics/properties of something in a logical, well-structured manner.
Discuss	Investigate and present the different aspects of the matter or statement in an analytical manner.
Compare	When comparing two or more issues, the similarities and differences must be pointed out. You should *not* first discuss one matter, and then the other. Comparisons are usually made in the form of a table.
Identify	Write down the essential features of an issue.
Criticise	Point out the pros and cons after considering the facts and/or viewpoints.
State	Give the information without discussion or criticism.
Evaluate	Make a value judgement based on certain points of departure/premises or criteria.
Name	Write down point by point – nothing more.
Explain	Make it clear by putting it in simple terms so that the reader will be able to understand it. Make use of descriptions, examples or illustrations.
Differentiate	Highlight the particulars that distinguish one issue from another.
Summarise (give an overview)	Write down the main points of the whole matter, retaining the essence.
Analyse	Separate the parts or elements and explain.
Substantiate (give reasons)	Give the reasons for the statements you make.
Define	Name the essential characteristics that describe/are typical of a certain term/concept.
Tabulate	Compare by using a table.

Other important instructions in the evaluation of geology are:

Make a sketch	Make a drawing that indicates the different parts of a structure. A labelled sketch is usually required.
Make a line drawing	Make a drawing that indicates only the outlines/borders of different parts/regions, without indicating the morphology of each part. A labelled line drawing is usually required.
Give a diagrammatic presentation	Compile a scheme of drawings, indicating the different stages or steps like the figures in the textbook.
Make a 2-D drawing	Make a two-dimensional drawing which depicts the main idea/ core issue (usually portrayed in a three-dimensional figure in the textbook).

MODULE PLAN

STUDY UNIT 1: THE EARTH SYSTEM	Study section 1.1	The Earth system
	Study section 1.2	Plate tectonics – the unifying theory
	Study section 1.3	Earth materials – minerals and rocks
	Study section 1.4	What are rocks?
	Study section 1.5	Earth issues relating to the Earth system
STUDY UNIT 2: INTERNAL EARTH PROCESSES	Study section 2.1	Deformation – modification of rocks by folding and fracturing
	Study section 2.2	Earthquakes
	Study section 2.3	Exploring Earth's interior
	Study section 2.4	Earth issues relating to internal Earth processes
STUDY UNIT 3: EXTERNAL EARTH PROCESSES	Study section 3.1	Weathering, erosion and mass wasting
	Study section 3.2	The hydrologic cycle and groundwater
	Study section 3.3	Streams – transport to the oceans
	Study section 3.4	Winds and deserts
	Study section 3.5	Glaciers – the work of ice
	Study section 3.6	Coastlines and ocean basins
	Study section 3.7	Landscape development
	Study section 3.8	Earth issues relating to external Earth processes

TIME SCHEDULE

You should therefore be able to master the learning contents in 120 hours.

The due dates for the submission of the two assignments are given in Tutorial Letter 101 of this module, and are usually in the months of March and April (first semester) August and September (second semester). The lecturer then marks the assignments and the marks are submitted to Unisa at the end of April (first semester) and September (second semester), at the very latest, for examination entry to be determined. The examination is usually written in May/June (first semester) and October/November (second semester)

Draw up a time schedule or study programme for yourself, taking the above dates into account. Do so in such a way that you will work on the learning activities in this study guide on a regular basis. It is essential for you to discipline yourself to keep to your study programme and to work regularly.

MODULE OUTCOMES

On completion of this module, you should be able to

- demonstrate your understanding of the Earth as a system consisting of interrelated subsystems, such as the climate and plate tectonic systems
- relate the internal processes of the Earth (such as mantle convection, the mechanism of energy transfer) to their external surface manifestations (such as the motion of tectonic plates)
- apply the plate tectonic theory (which describes the motion of plates) as a unifying theory that explains many geological phenomena and processes
- demonstrate an understanding of the surface processes that take place in and on the Earth's crust, such as mass wasting, and the transport of materials to the oceans via streams
- demonstrate a basic knowledge of research methodologies (to solve problems) and the writing of feedback reports
- react to ethical questions regarding human activities and the impact they have on the Earth as a system

STUDY UNIT 1

THE EARTH SYSTEM

The time scheduled for this study unit is 33 hours.

This study unit is based on chapters 1 to 3 of UE-6.

Learning outcomes

On completion of this study unit, you should be able to

- demonstrate an understanding of the origin and development of the Earth
- demonstrate your knowledge of the various components of the Earth system
- explain the mechanism of the movement of tectonic plates
- demonstrate your knowledge of the role of minerals in formation of the different types of rock
- explain the rock cycle in terms of the Earth system processes
- express your opinion on the scientific code of conduct
- interpret information in its context and apply it to solve problems

OVERVIEW OF THIS STUDY UNIT

Study unit 1 comprises the following study sections:

PAGE

Study section 1.1

The Earth system

The time scheduled for this study section is eight (8) hours.

Learning outcomes

On completion of this study section, you should be able to

- demonstrate an understanding of the Earth as a planet in a system of planets
- describe the formation of the Earth as an internally layered planet
- describe the main components of the Earth system and their interactions
- demonstrate your knowledge of how humankind's ethical norms are applied in the scientific method
- interpret facts and apply them in your reasoning

General overview of learning content

➯ This study section is based on chapter 1 of UE-6, pages 1–23.

- The following three **themes** referred to in the scheme (table of contents) on page 1 in UE-6 will be discussed: Earth’s shape and surface; discovery of a layered Earth and the Earth as a system of interacting components. As application, the ethical conduct of professional scientists will be discussed.
- The **outcome** of this study section is to introduce you to the scientific method as the means by which geologists study the Earth.

☞ Page through chapter 1 of UE-6 and look at some of the figures and captions to see what the themes are about. Use the outline, the introduction and the outcome on pages 1 and 2 for a good overview. The **outcome** of chapter 1 of UE-6 is printed in bold blue letters on page 1 and 2.

☞ The most important aspects of this study section are included in the summary on page 21 of UE-6. Read through it to get an overview of the most important issues in a nutshell.

Introductory remarks

The Earth may be regarded as a unique planet, the home of more than a million forms of life. No other planet with the same delicate balance of conditions crucial to life has as yet been discovered. This study section deals with the most widely accepted scientific explanation for the formation and constant changing of the Earth. A concept in geology that we, with our limited understanding, find difficult to appreciate is geological time. Geologists calculate the age of the Earth at approximately 4 530 million years. Live cells started to develop about 3 500 million years ago, yet the origin of humankind dates back but a few million years – a mere hundredth of 1 per cent of the Earth's existence.

1.1.1 Earth's shape and surface

Introduction

This section is for background knowledge only.

- The planet Earth, which we study in Geology today, came into existence in some manner together with other planets and stars and has developed into its current composition and structure. However, the limitations of science have thus far only allowed us to form hypotheses (conjectures) about the originating processes of the universe.
- After reading chapter 1 in UE-6, which is about the origin of our system of planets, you should, for instance, know what a dense point mass is, what planetesimals are, and that the Earth might be 4,5 billion years old.
- Use the above concepts to form your own opinion about the Big Bang theory and the nebular hypothesis.

1.1.2 Early Earth: formation of a layered planet

Read the text under the first three subheadings about the early formation of the Earth on pages 7–12 in UE-6 very carefully, and take note of the following:

1. Earth heats up and melts.

2. Differentiation begins. Take note of figure 1.9 in UE-6 (cross section of the Earth) and make sure that you can depict the information given in the figure in a simple diagram.

3. Earth's continents, oceans, and atmospheric form. Take note of the Earth processes that formed the Earth's atmosphere, as portrayed in figure 1.14 in UE-6.

In your own words, summarise the most important aspects of what you have read. Use the three headings given above as a structure for your summary.

Compare your summary with the example below:

1. The Earth heats up and melts.

   - Kinetic energy: planetesimals and larger bodies crash into the Earth
   - Radioactive elements disintegrate (decay) into the Earth and emit heat

2. Differentiation starts – an impact with the Earth causes exterior layer to melt, interior soft.

   - Heavy materials sink to the interior, light materials (and heat) float to the surface
   - Solidify into heavy/light zones during cooling

     » **Core** of heavy iron; molten on the outside, solid on the inside; depths
     » **Crust** of light elements (O, Si, Al, Fe, Mg, Ca, K, Na); depths
     » **Mantle** of intermediate densities (compounds of O, Mg, Fe, Si)

3. Continents, oceans and atmosphere form.

   - Repetitive melting/solidifying, erosion; comets and volcanoes produce gas and water

Exercise

Answer the following questions in writing.

1. What caused Earth to differentiate, and what was the result?

2. How does the chemical composition of Earth's crust differ from that of its deeper interior? And from that of its core?

The answers to the questions above can be found in the following references:

1. See the summary "How did Earth form and evolve over time?" on page 21 in UE-6.

2. Figure 1.12 ("The relative abundance of elements") on page 12 in UE-6 and the related paragraph give percentages of the relative abundance of elements (chemistry) in the whole Earth and the crust. You can compare differences in the quantities of the four most common elements.

1.1.3 Earth as a system of interacting components

Carefully read the section "Earth as a system of interacting components" on pages 13–17 in UE-6 and figure 1.14.

Exercise

Answer the following questions:

1. Write down the components of the climate system, the plate tectonic system and the geodynamic system. Describe each component in one sentence and state which source of energy drives each.

2. Describe/define the following terms in your own words:

   (a) Plate tectonics
   (b) Lithosphere
   (c) Asthenosphere
   (d) Convection

Compare your definitions with the definitions given where the terms are printed in bold in the text, or with those in the "Glossary" at the back of UE-6. Adjust your answers, if necessary. Also refer to the following:

1. Table 1.2, which contains the system names, and figure 1.10 on pages 12–13 in UE-6

2. (a) UE-6, page 15
   (b) UE-6, page 16
   (c) UE-6, page 14
   (d) UE-6, page 16, together with figure 1.15

1.1.4 Revision and application

Revision

1. The most important aspects of this study section are covered in the summary on page 21 in UE-6. Read it again. Make your own summary with which you are comfortable to use when revising for the examination.

2. Make sure that you can define the key terms below, and that you can use them in the context of the composition of the Earth and the theory of plate tectonics as described in chapter 1 of UE-6.

Key terms and concepts	**UE-6, page**
asthenosphere	14
climate system	15
core	12
crust	11
lithosphere	16
mantle	10
plate tectonics	15

Application

Start developing your own code of ethical scientific conduct.

☞ Read page 2 in UE-6 for background knowledge on "the scientific method" and the paradigm within which the theory of plate tectonics was developed, and give your own opinion about the credibility of the theory.

Study section 1.2

Plate tectonics – the unifying theory

The time scheduled for this study section is 10 hours.

Learning outcomes

On completion of this study section, you should be able to

- explain the theory of plate tectonics in broad terms
- describe the geological features of the different plate boundaries
- describe how the age of the seafloor is determined
- demonstrate background knowledge on the reconstruction of Pangaea
- give a broad outline of the mechanism(s) that cause(s) the formation and motion of lithosphere plates
- read up (as application of your knowledge) how modern technology such as seismic tomography can help detect and explain geological phenomena, and communicate your knowledge in the form of a report (using standard conventions and methods)

General overview of learning content

↳ This study section is based on parts of chapter 2 of UE-6, pages 25–53.

- We will cover the following **themes** referred to in the scheme on page 25: the mosaic of plates, plate motions and mantle convection. Apply your knowledge by using the scientific method you studied in study section 1.1 (formulating the problem and hypotheses, doing research by reading, and drawing a conclusion) to develop a model of mantle convection.
- The **outcome** of this study section is to study the theory of plate tectonics and to relate it to the mantle convection system (UE-6, p 25, text printed in blue).

- ☞ Page quickly through chapter 2 of UE-6, using the scheme on page 25, and look at some of the figures and their captions, in order to acquaint yourself with the themes.
- ☞ The most important issues covered in this study section have been summarised on page 52 of UE-6. Read this summary to get an overview of these issues in a nutshell.

1.2.1 The discovery of plate tectonics

Read pages 26–27 in UE-6 cursorily, from the development of the hypothesis on continental drift to the theory of plate tectonics. This will provide you with a brief overview of the development of this theory.

Overview of the theory of plate tectonics

Geologists suggest that the crust of the Earth is divided into about 12 lithosphere plates, and that these plates slide past one another, converge with one another, or diverge as they move over the interior of the Earth. New plate material is formed at diverging points and material is reabsorbed into the mantle where plates converge in a continuous process of formation and destruction. Continents embedded in the lithosphere plates drift with the moving plates. The theory of plate tectonics describes the movement of the plates and the forces between them. It also explains the distribution of large-scale geological features – mountain chains, collections of rocks, structures on the seafloor, volcanoes and earthquakes – which are the result of movement along the plate boundaries. Plate tectonics provides a conceptual framework for a large part of geology, as will be evident in the following study sections.

1.2.2 The plates and their boundaries

Carefully read the parts under the blue subheadings ("The plates and their boundaries") on pages 29–36 in UE-6, that is, the descriptions of the different plate boundaries.

Exercise

Describe the geological characteristics of the following plate boundaries:

1. divergent boundaries
2. convergent boundaries

3. transform-fault boundaries
4. combinations of plate boundaries

The following portions of text and figures describe how changes in the plate surface take place, and which geological phenomena accompany them – for instance, when two plates collide, the one rises and mountain building takes place. Short descriptions of each subdivision can be found in UE-6:

1. Divergent boundaries are divided into oceanic plate separation and continental plate separation. See figure 2.8 on page 32 in UE-6.

2. Convergent boundaries are divided into ocean-ocean convergence, ocean-continent convergence and continent-continent convergence. See figure 2.8 on page 32 in UE-6.

3. Transform-fault boundaries.

4. Combinations of plate boundaries.

After carefully studying these sections, do the following:

1. Summarise, in your own words, the way the lithosphere plates move according to the concept of plate tectonics (UE-6, p 26–27) – refer to the introductory paragraphs following the heading "The mosaic of plates".

2. Indicate the directions of movement of the lithosphere plates by making an explanatory sketch of each of the three types of plate boundary, and by citing two plate boundary names as examples in each case.

Guidelines for making a summary, and relevant figures

1. Use the points below as guidelines for your own summary. You must be able to provide the names of at least two adjoining plates for each type of plate boundary.

   - 12 large, rigid lithosphere plates each move as a unit over the Earth's surface.
   - The shapes of the plates differ from those of the continents, but both "float" around together.
   - The plates have common boundaries (UE-6, figure 2.7).

» **Divergent boundaries**, eg between the Australian and Antarctic plates
- Plates move away from each other and new lithosphere is formed
- Oceanic plate separation, eg Mid-Atlantic Ridge
- Rift – separation that forms a trough; rift valley
- Seafloor spreading takes place at the trough on the seafloor
- Ridge – ridge formed by lava that wells up and solidifies in separation
- Continental plate separation – eg Great Rift Valley of East Africa

» **Convergent boundary**, eg between the Australian and the Pacific plates
- Plates collide; one plate overrides – mountain formation; and other plate is forced down to form a subduction zone
- Nacza Plate collides with South-American Plate; Andes mountains
- Many active geological events, such as earthquakes, volcanoes

» **Transform-fault boundary**, eg between the Indian and Arabian plates
- Plates move (slide, glide) horizontally past one another
- San Andreas fault – Pacific and North American plates
- Often occurs transversely with mid-ocean ridges

2. See figure 2.7 on page 30 in UE-6 ("Earth's plates today ...")

1.2.3 Rates of plate movement

Carefully read the section on "The seafloor as a magnetic tape recorder" on pages 39–43 in UE-6.

Exercise

Answer the following questions and check your answers against the key concepts (✓).

1. What is meant by a "positive anomaly" and a "negative anomaly" when the magnetisation of rocks is measured?

   ✓ A measured magnetic field that is stronger than the local magnetic field of the Earth is a positive anomaly, while a weaker measured field is a negative anomaly.

2. How did the magnetic anomaly patterns that were discovered on the seafloor come about?

   ✓ New seafloor is created at a mid-ocean ridge and becomes magnetised, etc.

3. How do geologists go about determining the age and the spreading rate of the seafloor?

   ✓ Ages of magnetic reversals on land are compared with bands of magnetised rocks on the seafloor. The spreading rates of the various bands differ from each other, with an average rate of 50 mm/year for mid-ocean ridges.

1.2.4 The grand reconstruction of the ancient land mass of Pangaea

Introductory remarks

It is interesting to read how geologists went about reconstructing the collection of ancient continents which formed Pangaea. You can read the section on the grand reconstruction on pages 42–47 in UE-6, but read it cursorily, as it is only meant to provide you with background knowledge.

1.2.5 Mechanisms that drive plate tectonics

Carefully read the section "Mantle convection: the engine of plate tectonics" on pages 47–50 in UE-6, including figures 2.17, 2.18 and 2.19.

Exercise

Use the tips (✓) below to do the following exercises. Check your answers by once again referring to the sections indicated in the text.

1. Indicate on a sketch two of the physical forces that drive the movement of lithosphere plates. Name the cause and effect of each force.

   ✓ UE-6, page 48, figure 2.17. Pulling and pushing force.

2. Indicate by means of a sketch the main difference between the two models of mantle convection.

   ✓ UE-6, page 49, figure 2.18. Whole-mantle and stratified convection.

3. Describe briefly what a mantle plume is and where it occurs.

   ✓ UE-6, page 50, figure 2.19. Fast-rising material from the deep mantle.

1.2.6 Revision and application

Revision

1. The most important aspects of this study section are summarised on pages 52–53 in UE-6. Read this again.

2. Give a modern geographic example (plate names) of each of the types of plate boundary.

3. What is the engine that drives plate tectonics (last "Summary" item on page 53 in UE-6)?

4. Make sure that you can describe the following key terms and that you can use them in the context of the composition of the Earth and the theory of plate tectonics as discussed in chapter 2 of UE-6.

Key terms and concepts	**UE-6, page**
continental drift	26
magnetic anomaly	37
relative plate velocity	43
seafloor spreading	Glossary GL-13
subduction	35

Application

Synthesis of your current subject knowledge of plate tectonics

- Give a short description of the two competing hypotheses on mantle convection. Indicate what scientific proof would be required to make a choice between the two hypotheses. Tip: "Old subducted lithosphere is colder than the surrounding mantle ...".

- Look up the term "convection" in the index at the back of UE-6, and read the relevant source reference on seismic tomography.

- Give a short description of the geological principle on which seismic tomography is based. Tip: measurement of small differences.
- Write down whether seismic tomography can detect temperature differences between certain parts of materials in the deep mantle (yes or no). Is any physical plate tectonic process indicated by this?
- Conclude from the seismic tomography data which convection hypothesis has been proven and accepted as a theory.

Study section 1.3

Earth materials – minerals and rocks

The time scheduled for this study section is eight (8) hours.

Learning outcomes

On completion of this study section, you should be able to

- define the term "mineral" and analyse the definition
- explain how and when minerals are formed
- explain how variations in mineral composition can be explained by cation replacement
- explain how it is possible for some chemical compounds to occur in more than one crystal structure
- describe the internal structures (crystal structures) of the most common rock-forming minerals, and thus explain the physical properties of the minerals
- solve problems and communicate the solutions

General overview of learning content

↳ This study section is based on parts of chapter 3 in UE-6, pages 55–87.

- The following **themes** referred to in the scheme on page 55 will be studied: what minerals are; chemical bonds and the atomic structure of minerals; rock-forming minerals; and the physical properties of minerals. We will also pay attention to an Earth issue (practical problem), namely the health risks of the mineral asbestos. The physical properties of minerals appear in tables in appendix 4 at the back of UE-6. These properties are used in mineral identification in module GEL1502.
- The **outcome** of the chapter, which is printed in blue on page 55 in UE-6, as well as the last sentence on that page, state that minerals are the building blocks of rocks. The **focus**

of this study section is mineralogy – the branch of geology that studies the composition, structure, appearance, stability, occurrence and associations of minerals.

☞ Find the above-mentioned themes under the various subheadings throughout chapter 3. Note which figures go with each subheading.

☞ The most important aspects of this study section have been included in the summary on page 85 in UE-6. Read it to get an overview of these in a nutshell.

1.3.1 What are minerals?

Read the paragraphs under the subheading "What are minerals" on page 56 in UE-6, and study the definition of the term "mineral" carefully. Take note of the requirements that should be met by a material before it is considered to be a mineral.

Exercise

1. Write down the six prerequisites that a chemical compound must meet before it can be classified as mineral.
2. Write in your own words what each of these six requirements involves (in other words, analyse the definition).

Answers to the questions in the exercise

1. The six prerequisites are: homogeneous, naturally occurring, solid, crystalline, generally inorganic, with a specific chemical composition.
2. Each of the above-mentioned prerequisites is explained on page 56 in UE-6. For instance, "homogeneous" means that the mineral cannot be divided into smaller components by mechanical means; "crystalline" means the orderly ... complete the rest yourself.

1.3.2 The atomic structures of minerals

Carefully read the following sections in UE-6:

- Chemical bonds, on page 59
- The atomic structure of minerals, on pages 59–62

  » How do minerals form?
  » When do minerals form?

Exercise

Use the tips (✓) to do the following exercise:

1. Name the three different types of chemical bond, and state the influence of the bond strength of each on minerals.

   ✓ Covalent bonds are stronger than ionic bonds, giving rise to harder minerals.

2. Define the process of crystallisation, taking the diamond as example.

   ✓ Covalent bond. Tetrahedron.

3. Define the term "crystal".

   ✓ Ordered arrays of atoms. Crystal faces.

4. Define the term "precipitation".

   ✓ When fluids evaporate from a solution, the salt starts to drop out of solution as crystals.

5. Illustrate, with the aid of examples, what cation substitution is and what polymorphs are.

   ✓ Ions, such as those of iron and magnesium, of the same size substitute one another.

Main points to include in your summary:

- Anions occupy most of the space in crystals, with the smaller cations in between
- Cation substitution as the reason for variations in the chemical composition of some minerals
- Polymorphism as the reason for different structures for the same chemical compound

1.3.3 Rock-forming minerals

The most important mineral groups we will be investigating are silicates, carbonates, oxides, sulfides (sulphides) and sulfates (sulphates).

Study/read

- Study the chemical classification of minerals according to table 3.1 on page 63 in UE-6.
- Read about each of the mineral groups described under the heading "Rock-forming minerals" on pages 63–67 in UE-6.
- Table 3.1 on page 63 and figure 3.10 on page 62 in UE-6 are prescribed.

Exercise

Read through the list of self-assessment questions below and then answer them one by one, after systematically reading through the above-mentioned material. Examples (✓) are provided, which you may use as tips or as part of your answers.

1. What is used as the basis for the classification of minerals?
   - ✓ Anions. For example: NaCl is classified as a halide based on its chloride **anion**, Cl^-.
2. Write down the names of the five most important class eir corresponding anion groups.
   - ✓ The mineral hematite, Fe_2O_3, is an example of the class of **oxides** that contains the anion $\mathbf{O^{2-}}$. Complete the rest of your answer according to this example.
3. Make a list of the basic structures of silicates.
4. How do SiO_4^{4-} tetrahedra link together to form the plate structure of mica?
5. What bonds these basic structures in silicates?
   - ✓ Silicate bonds are formed by means of **cations**, such as K^+, which link basic structures such as mica plates with each other.
6. Make a sketch of the basic building blocks of carbonate minerals, and indicate in a diagram how the carbonate anions and calcium cations are arranged in calcite.
   - ✓ UE-6 shows the alternating layers of calcium and carbonate ions. (Please note that "ions" is the general term used for both anions and cations.)

7. Which minerals do invertebrates use for their shells?

   ✓ Calcite and aragonite.

8. To which mineral classes do the following minerals belong?

(a) dolomite	(c) olivine	(e) pyrite
(b) anhydrite	(d) copper	(f) enstatite

   ✓ Pyrite is an example of a mineral that belongs to the mineral class sulfides (sulphides). See the first three columns of appendix 4 in UE-6 where the class is indicated under the column "Structure or composition".

1.3.4 Physical properties of minerals

General overview

This section includes the following physical properties of minerals: hardness, cleavage, fracture, lustre, colour, specific gravity and density, and crystal habit. **This theory is important for the practical work of module GEL1502, which deals with mineral identification.**

While studying pages 66–72 in UE-6, make a list of the different physical properties distinguished in minerals. Table 3.2 on page 68 and table 3.4 on page 72 in UE-6 are prescribed.

Exercise

1. Briefly describe how each of the physical properties of minerals manifests itself, and give a theoretical explanation for each.

2. Write down the Mohs scale of hardness. Explain how the scale numbers can be used to distinguish between different minerals.

Answers to the questions in the exercise

1. Compare your descriptions with those in the textbook. Also make use of the glossary at the back of the textbook. After each text reference below, there is one word that

hints at the mode of occurrence (appearance of the physical property) and another that serves as a tip for the theoretical explanation.

- Hardness – scratch marks; bond strength
- Cleavage – breakage along planar surfaces; weak bonds
- Fracture – irregular breakage; bond strengths across crystal planes
- Lustre – light reflection; kind of atoms and their bonding
- Colour – imparted by light, streak; complex
- Specific gravity and density – weight; packing of atoms in crystal structure
- Crystal habit – shape of crystals; speed and direction of growth

2. Compare your answer with table 3.2 on page 68 in UE-6. Quartz, at a hardness of 7, will scratch the surface of calcite, which has a hardness of 3, thus making it possible to distinguish between the two.

1.3.5 Revision and application

Revision

1. A summary of the main points of this study section is provided on page 85 in UE-6. Read it again.

2. Write down, in a single sentence, the difference between cation substitution and polymorphs.

3. What is the difference between (a) cleavage and fracture, and (b) lustre and colour?

4. What can the colour of minerals be ascribed to?

5. Make sure that you know how the physical properties, composition and crystal structure relate to each other. Tip: Consult table 3.4 on page 72 in UE-6.

6. Make sure that you can define the following key terms and can apply them in the context of the composition of the Earth and the theory of plate tectonics as discussed in chapter 3 of UE-6.

Key terms and concepts	UE-6, page
cleavage	68
crystal	60
crystal habit	71
crystallisation	59
fracture	70
mineral	56
Mohs scale of hardness	67
polymorph	61
precipitate	61
streak	70

Application

Minerals for humankind and in Earth issues

- Explain how a field geologist would go about determining the hardness of a mineral. Tip: Measuring apparatus is not usually available in the field, yet common items like a pocket knife or copper coin should be at hand (UE-6, p 68, table 3.2).

☞ Write down which physical properties of gems, like diamonds, people find attractive. How would you, as a mineralogist, polish the hardest mineral, a diamond, until it sparkles?

Study section 1.4

What are rocks?

The time scheduled for this section is six (6) hours.

Learning outcomes

On completion of this study section, you should be able to

- distinguish between the three main groups of rocks, based on their mineralogy and texture
- demonstrate an understanding of the formation processes of each type of rock, and relate them to plate tectonics
- describe the transformation between different rock types as a rock cycle

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General overview of learning content

↳ This study section is based on the relevant sections on pages 72–85 of chapter 3 in UE-6.

- You will study the following **themes** referred to in the scheme on page 55: the appearance and properties of igneous, sedimentary and metamorphic rocks, as well as the role of the rock cycle in the Earth's unique systems. An Earth issue (practical problem) about the uniqueness of the Earth's rock cycle in the universe will be pointed out.
- The **outcome** of the chapter, printed in blue, and the last two sentences of the introduction confirm the concept that minerals are the building blocks of rocks. The **focus** of this study section is the mineralogy and texture of rocks, and how the interactive processes of the plate tectonic system and the climate system give rise to the rock cycle.

1.4.1 Igneous rocks, sedimentary rocks and metamorphic rocks

Introductory remarks

The minerals and textures of the three main rock groups are formed in different places in and on the Earth by different geological processes.

☞ Take note of the tectonic occurrence of the source materials, the different rock-forming processes involved and an example of each group, as portrayed in figure 3.24 on page 74 in UE-6.

Read

Read the sections on the rock groups on pages 72–85 in UE-6, and make summarising notes of the processes, textures and mineralogy as you read. You must be able to make simple 2-D drawings of the figures mentioned below to illustrate your main points. Then check your notes and add to them by comparing them with the labels of the following figures:

- igneous rocks, figure 3.25
- sedimentary rocks, figure 3.26
- metamorphic rocks, figure 3.27

Exercise

Answer the following questions in neat, legible writing. Each may serve as an example of part of an exam question.

1. What is the difference between extrusive and intrusive igneous rocks?
2. What is the difference between regional and contact metamorphism?
3. What is the difference between clastic, and chemical and biochemical, sedimentary rocks?
4. Name three common silicate minerals that can be found in each rock group. Tip: Consult table 3.5 on page 75 in UE-6.
5. Which of the rock types of the three main groups are formed on the surface of the Earth and which are formed inside the Earth?

Short answers to the questions above

1. - **Extrusive rocks:** This is warm lava which erupts at the surface of the Earth, cools rapidly and solidifies. The texture is glassy to finely grained. Basalt is an example.
   - **Intrusive rocks:** This is warm magma which forces its way under the surface into the crust, where it cools slowly and crystallises. The texture is coarsely grained. Granite is an example.

2. - **Regional metamorphism:** This occurs over a large area where high directed pressure and temperatures occur, such as subduction zones and mountain-building areas. The texture is foliated. Schist and gneiss are examples.
   - **Contact metamorphism:** This occurs in the direct, close vicinity of warm magma intrusions, under high pressure and temperatures. The texture is grained. Hornfels is an example.

3. - **Clastic rocks:** These are sedimentary particles formed by processes of weathering or erosion, which are physically deposited somewhere and lithified there. They are laid down in layers consisting of sand, silt and gravel and contain the minerals quartz and feldspar and clay minerals. Sandstone is an example.
   - **Chemical and biochemical sedimentary rocks:** These consist of materials that have been dissolved chemically during the weathering processes of rocks and precipitated elsewhere to form new minerals. They contain various new minerals, such as calcite. Limestone is an example.

4. - **Igneous rocks:** quartz, feldspar, mica, pyroxene, amphibole, olivine
   - **Sedimentary rocks:** quartz, feldspar, clay minerals
   - **Metamorphic rocks:** quartz, feldspar, mica, garnet, pyroxene, staurolite

5. - **Surface of the Earth:** extrusive igneous rocks, clastic sedimentary rocks
   - **Interior of the Earth:** intrusive igneous rocks, chemical sedimentary rocks and metamorphic rocks

1.4.2 The rock cycle: interactions between the plate tectonic and climatic systems

Carefully work through steps 1–6 of figure 3.28 on page 78 in UE-6. The mutual transformation of the three types of rock is described here. Read one numbered statement at a time, following the line to the relevant sketch to see the application. Spend several minutes visualising and understanding the tectonic dynamics portrayed in the sketch. Each time refer to the small subfigure of the Earth system to determine which subsystem (atmosphere, hydrosphere, lithosphere or asthenosphere) is driving the process that is being described.

Summary: plate tectonic processes transform rock types

The rock cycle relates geological processes to the formation of the three types of rocks from one another. We can view the processes by starting at any point in the cycle. We began with the formation of igneous rocks by crystallization of a magma in the interior of the Earth. Igneous rocks then are uplifted to the surface in the mountain-building process. There, they are exposed to weathering and erosion, which produce sediment. The sediment is cycled back to the interior by burial and lithification into sedimentary rock. Deep burial leads to metamorphism or melting, at which point the cycle begins again. Plate tectonics is the mechanism by which the cycle operates.

1.4.3 Revision and application

Revision

1. Once again read the summary of this study section on page 85 in UE-6.

2. What determines the appearance of rocks – that is, what they look like? Read the answer (✓) below.

   ✓ Rocks differ in colour, the size of the grains of minerals, and the type of minerals that constitute them. The appearance of the rocks is determined partly by their mineralogy (ie the different minerals they are made up of) and partly by their texture. The texture of a rock is determined by the size, shape and arrangement of the minerals that constitute it. In turn, the mineralogy and texture of a rock is determined by the geological source of the rock – that is, where and how the rock was formed.

3. Make sure that you can define the key terms below and that you can apply them in relation to the three main groups of rocks described in chapter 3 in UE-6.

Key terms and concepts	UE-6, page
bedding	75
chemical and biochemical sediments	78
siliciclastic sediments	75
contact metamorphism	76
erosion	74
extrusive igneous rocks	74
foliation	76
intrusive igneous rocks	74
lithification	75
regional metamorphism	76
sediments	74
weathering	74

Application

Rocks for humankind and in Earth issues

- **Earth issue:** The uniqueness of the Earth's rock cycle in the universe.

  Read the paragraph on pages 79–85 in UE-6, which describes the uniqueness of the EARTH's rock cycle, cursorily. This precious uniqueness should serve as an incentive for us to develop a sense of responsibility towards our unique environment and all the systems of the Earth.

- **Develop your geological perceptiveness in the field**

  Our understanding of how rocks were formed may help us to solve environmental problems. The following method may help you to be more perceptive when you are in the field:

  » **Examples of possible field questions**

  Is this rock going to cause a landslide in the event of Earth tremors? Will this rock let polluted water through and how? Chemical analyses are essential when a suitable underground storage facility for radioactive waste is being considered.

When we observe rocks in their original situations, we can better interpret the local geology, as well as the greater Earth system framework, which in turn might lead to solutions to humankind's environmental problems.

» **Observation methods**

Look at the rocks in the field in the following manner:

First distinguish between the different rock types. Then deduce from their properties what surface and subsurface conditions were prevalent when they were formed. The appearance, texture, mineralogy and chemical composition of rocks tell us how and where they were formed.

This is an extremely extensive field of study and you should concentrate on the following: (a) the origin, constituent minerals and textures of the three main rock groups, namely igneous rocks, sedimentary rocks and metamorphic rocks; and (b) the occurrence of the different rock groups in terms of plate tectonic settings.

» **Conclusions**

The conclusions should be fairly simple, such as having gained a better understanding of the rock cycle and having had the opportunity to apply your knowledge in nature. You will be taught to describe and classify rocks in the practical module, GEL1502.

Study section 1.5

Earth issues relating to the Earth system

The time scheduled for this section is one (1) hour.

Learning outcomes

On completion of this study section, you should be able to

- develop your own (elementary) scientific code of conduct
- form and write down your own synthesis of your current subject knowledge of plate tectonics
- argue about the applications of minerals and the dangers they pose to humankind
- display a sense of responsibility towards our unique rock cycle in its earthly environment

General overview of learning content

↳ This study section is based on chapters 1 to 3 of UE-6, pages 1–87.

- The following **themes** have already been studied as Earth issues in study sections 1.1 to 1.4: the scientific method, a hypothesis of mantle convection proven by seismic tomography, the hardness of minerals, the dangers of asbestos, and humankind's realisation of the uniqueness of the Earth and ability to make field observations.
- The **outcome** of this study section is to let you participate in discussions on Earth issues following from some of the subject themes covered in study unit 1. The Earth issues **focus** on how the scientific method and technology are applied in practice in respect of the plate tectonic theory, minerals and rocks as records of geological processes.

☞ These themes can be found in study sections 1.1 to 1.4 of the study guide (SG) in the "Revision and application" sections, as well as in chapters 1 to 3 in UE-6 in the boxed articles with the subtitles "Earth issues" and "Earth policy".

Revising the following Earth issues relating to the outcomes you have already reached in this study unit will help you to answer a possible examination question on it.

1.5.1 Earth issues: the scientific method and technology

Revision

Once again read through your notes on all the Earth issues you have already covered in the "application" sections referred to below. Make use of the tips (✓) given to you.

1. In section 1.1.4 – **Start developing your own code of ethical scientific conduct**
   - ✓ Opinion of the authors of UE-6, given on page 2: "honesty, generosity, a respect for evidence, openness to all ideas and opinions."
2. In section 1.2.6 – **Synthesis of your current subject knowledge of plate tectonics**
   - ✓ Choice between the two competing hypotheses on mantle convection (see new information obtained through seismic tomographic technology) – you make the decision in your conclusion (synthesis). Check your work method by rereading "The scientific method" on page 2 in UE-6.
3. In section 1.3.5 – **Minerals for humankind and in Earth issues**
   - ✓ Using common items such as a pocket knife or a copper coin to determine the hardness of a mineral
   - ✓ Using a second diamond to polish a diamond until it sparkles
   - ✓ Former asbestos mine workers in South Africa have been compensated after winning law suits. Form your own opinion on the mining and use of a dangerous mineral such as asbestos in the community
4. In section 1.4.3 – **Rocks for humankind and in Earth issues**
   - ✓ Develop a sense of responsibility towards our unique Earth environment
   - ✓ The identification of types of rock in the field helps you to understand environmental problems in terms of the rock cycle

Summary of study unit 1 – The Earth system

In study unit 1 you were introduced to the Earth system and saw how its components interact through various geological processes. You learnt how the explanations for the cause and effect of the different processes are formulated into hypotheses to be proven and established as theory later on. The theory of plate tectonics explains various geologic phenomena in one, unifying theory. This theory includes the rock cycle, which taught you about minerals, the building blocks of the three main types of rock. On the historical side, you learnt how geological scientific research methods led to the theory of plate tectonics. You also learnt to apply your knowledge of geology to tackle problems in your own Earth environment.

STUDY UNIT 2

INTERNAL EARTH PROCESSES

The time scheduled for this study unit is 30 hours.

This study unit is based on chapters 7, 13 and 14 in UE-6.

Learning outcomes

On completion of this study unit, you should be able to

- describe and typify the modes of deformation, fracture and folding of rocks under the influence of tectonic forces
- describe the method by which the geological history of a geographical area is reconstructed
- describe the technology and methodology used by seismologists to localise, measure and attempt to forecast earthquakes in terms of the Earth system
- discuss the plate tectonic system and the role it plays in earthquakes
- demonstrate your knowledge of the different techniques of Earth observation, such as seismic, gravitational, magnetic and temperature measurements
- describe how these observations help to create models of the interior of the Earth
- discuss various Earth issues, such as a tsunami (seismic sea wave)

OVERVIEW OF THIS STUDY UNIT

Study unit 2 comprises the following study sections:

PAGE

Study section 2.1

Deformation – Modification of rocks by folding and fracturing

The time scheduled for this study section is 12 hours.

Learning outcomes

On completion of this study section, you should be able to

- relate tectonic forces to the deformation of rocks
- relate tectonic forces to the formation of joints and faults when rocks fracture
- typify and describe the folding of rocks and portray it in figures
- unravel the geological history of an area

General overview of learning content

This study section is based on parts of chapter 7, on pages 167–187 in UE-6.

- The following **themes** referred to in the scheme on page 167 will be discussed: the reasons why and the manner in which rocks become deformed; how rocks fracture to create joints and faults; how rocks fold; and the unraveling of geological history.
- The **outcome** of this chapter is to study the manner in which geologists collect and interpret field observations to reconstruct the geological history of a region. This study section **focuses** on describing and typifying the modes of deformation, fracture and folding of rocks under the influence of tectonic forces.

☞ The above-mentioned themes can be found under the different subheadings throughout chapter 7. Note which figures belong to each subheading. Also read the summary on pages 187–188 in UE-6 cursorily, the first time round.

Introductory remarks

For background knowledge read the introductory paragraphs of chapter 7 cursorily. Take note of the vertical cross section in figure 7.4 and how different rock layers that lie on each other do not always appear horizontal. Some layers are curved and others protrude above the surface as outcrops. The direction (strike) and angle (dip) of outcrops can be measured and depicted on a geological map.

Geologists have, over the years, asked how it is possible for rocks, which are solid and hard, to be tilted, bent and fractured. What forces cause the deformation of hard rocks? Can the history of rocks be inferred from the patterns of deformation? How does this deformation relate to plate tectonics?

In chapter 7 of UE-6, field observations are followed up with laboratory experiments to determine, for instance, the influence of pressure and temperature on the deformation of marble. Such results have also been incorporated in the unifying theory of plate tectonics to create a framework (paradigm) within which many geological processes and theories can be explained.

2.1.1 How rocks become deformed

Study the following sections in the textbook:

1. Study pages 173–181 in UE-6, with regard to the three types of tectonic force, ductile materials and brittle materials. You should be able to draw the line diagrams neatly, at least in two dimensions (2-D) – but not the photos.

2. Study the section "What determines whether a rock bends or breaks?" on page 172 in UE-6.

3. Study "Brittleness and ductility under natural conditions" on page 172.

Exercise

Do the following exercises, referring to the tips (✓) provided.

1. Make a diagram of the three tectonic forces, namely compressive forces, tensional forces and shearing forces, which can be exerted on a plate of rocks. What type of deformation do these forces cause in ductile and brittle materials?

   ✓ Use arrows (→) in your diagram to indicate the directions of the forces as they are indicated in figure 7.8 on page 174 in UE-6 and show the deformed rocks.
   ✓ The deformations in ductile materials are plastic, resulting in folding, stretching and shearing.
   ✓ The deformations in brittle materials are fractures and the rocks fault as follows in relation to the fracture: reverse faulting, normal faulting and strike-slip faulting.

2. Which type of plate boundary is associated with each of these forces?

   ✓ Convergent, divergent and transform-fault boundaries (UE-6, p 182).

3. Under what conditions will rocks tend to break and when will they undergo folding? Use marble and mylonite as examples.

   ✓ Marble is ductile (pliable/plastic) deep in the crust, but brittle near the surface.
   ✓ Mylonite is a metamorphic rock which is formed deep in the crust where the pressure is high (ductile deformation).

2.1.2 How rocks fracture: joints and faults

Study the following sections and figures in the textbook:

- Carefully read the section "Basic Deformation Structures" on pages 173–181 in UE-6.
- Sketches (not photos) you should know in UE-6: figure 7.8 on page 174 (types of faults), figure 7.21 on page 183 (thrust fault), and figure 7.19 on page 182 (rift valley).

Exercise

Use the following questions and tips (✓) as guidelines for summarising the work. Your summary should be of such a nature that you will be able to provide comprehensive answers (as in the textbook) during assessment.

1. Name the two types of rock fracture that can be distinguished. Define/explain each term in your own words.

   ✓ Joints and faults with/without movement relative to the fracture

2. Explain why joints form in rocks.
   - ✓ There are three possible causes.
3. Name the forces that may cause faults.
   - ✓ Tensional forces, compressive forces and shearing forces.
4. Define the following terms that are used to describe a fault: (a) offset, (b) slip, and (c) fault plane.
   - ✓ Distinguish between the relative movements when defining these terms.
5. Make sketches to illustrate the following types of faults. Indicate with arrows (→) the relative movements of the fault blocks in relation to each other.

   (a) dip-slip fault
   (b) strike-slip fault
   (c) oblique-slip fault
   (d) normal fault
   (e) reverse fault
   (f) right-lateral fault
   (g) left-lateral fault
   (h) transform fault

   - ✓ Combine the existing sketches in figure 7.8 with the description in the text on pages 173–177 in UE-6, in order to draw all the types of fault.
6. Use a sketch to briefly describe a thrust fault.
   - ✓ One block of rock moves over the next block, as depicted in figure 7.21 on page 183 in UE-6.
7. How are rift valleys formed?
   - ✓ There is a relative downward shift of a number of adjacent blocks of rocks, as depicted in figure 7.20 on page 183 in UE-6.

2.1.3 How rocks fold

Study the following sections in UE-6:

- Study the introductory paragraphs of "Folds" on pages 175–177.
- Study figures 7.12, 7.13 and 7.14, where it is explained that "Rock folding is influenced by the type of rock and the compressive forces" carefully.
- You must be able to draw and describe a plunging anticline/syncline (fig 7.13, p 177), as well as a dome (fig 7.16, p 180) and a basin (fig 7.15, p 179).

Exercise

Answer the following questions with the aid of the tips or source references (✓). Practise drawing the folds mentioned below so that you can draw any that might be asked in the examination quickly and easily. Always add labels to your sketches to indicate what they depict. In most cases you can simplify the three-dimensional (3-D) sketches in UE-6 to two-dimensional (2-D) ones.

1. What does the term "fold" mean?

   ✓ It is an originally planar structure, like layers of sediment, which has been bent (UE-6, p 175).

2. Indicate the different parts of a fold in a sketch adding clear labels.

   ✓ Limb, axial plane, fold axis (UE-6, p 175, fig 7.12).

3. Make simple 2-D sketches to illustrate the following types of fold:

   (a) anticline
   (b) syncline
   (c) horizontal fold
   (d) plunging fold
   (e) symmetrical fold
   (f) asymmetrical fold
   (g) overturned fold

   ✓ Consult fig 7.12 and the related text on pages 175–177 in UE-6. For each sketch describe the particular fold in one or two sentences.

4. What are (a) a dome, and (b) a basin?

   ✓ Complete the sentences:

   - A dome is an anticline structure ...
   - A basin is a syncline structure ... (UE-6, p 179)

2.1.4 Unravelling geological history

Introductory remarks

The geological history of a region usually involves a succession of episodes of sedimentation, deformation and faulting, erosion and other geological processes in the rock cycle. Geologists see only the rock on the surface which is the result of the latest geological process. They then have to reconstruct the previous processes from the older structures beneath the surface.

When determining the geological history of a region, field observations are first noted on a map of the region, and then a cross section is drawn to portray the surface map in depth. Look at fig 7.23 on page 185.

According to the principle of superposition, older geological layers are shown under the newer, top layers in a cross section. Thus the geological history of a region can be seen on a cross section drawn with the oldest (first) rock layer at the bottom. If deformation has taken place, the cross section will show the deformed layers, such as an anticline, just as it will show every other geological event in the region.

Understanding the different kinds of faults and folds and determining the geological history of a region are important, because they have an economic and environmental impact.

Study the following in UE-6:

- Study the section on the unravelling of geological history on pages 185–186.
- Study fig 7.23 on page 185, where the stages in the development of a geologic province are depicted.

Exercise

Do the following exercises and check your answers against the feedback below (✓) and against the information given on pages 187–188 in UE-6.

- Draw a 2-D version of the geologic cross section portrayed in fig 7.23 showing vertically, from top to bottom, the succession of (1) sedimentation, deformation, uplift; (2) erosion, lava flow; and then (3) normal faulting.
- Interpret and describe in words, from the oldest to the latest, the succession of geological processes that you have drawn above.

Feedback

(1), (2) and (3) below agree with (1), (2) and (3) in the exercise.

(1) A series of marine sediments were laid down horizontally, whereupon they were deformed by compressive forces to create folds and faults.

(2) The exposed surface eroded and was then covered by lava flow.

(3) Then tectonic tensional forces in the crust caused various faults, creating downfaulted blocks.

2.1.5 Revision and application

Revision

1. Read the summary of this study section on pages 187–188 in UE-6.

2. Explain why some rocks fold, while others fracture along faults when subjected to forces in the crust.

3. Name the types of deformation that can be expected at each of the three types of plate boundary.

4. If you were to find tilted layers in the field, how would you know whether they are anticlines or synclines? Illustrate your answer by means of a sketch.

5. Draw a cross section of a rift valley and indicate with arrows in which directions the forces that formed it were exerted. Do the same for a thrust fault.

6. Make sure that you can define and use the following key terms relating to rock deformation, as described in chapter 7 in UE-6:

Key terms and concepts	**UE-6, page**
anticline	176
axial plane	176
brittle material	172
compressive force	168
ductile material	172

/continued ...

fault	173
fold	175
joint	180
shearing force	168
syncline	176
tensional force	168

Application

In order to get an idea of the scale of geological processes, read the following quotations and relevant sections of the text in UE-6:

- "Present-day surface relief – such as we find in the Alps, the Rocky Mountains, the Pacific Coast ranges, and the Himalaya – can be traced in large part to deformation that occurred over the past **tens of millions of years**" (UE-6, p 185).
- "On a much smaller scale, very thin beds can be crumpled into folds a **few centimetres** long" (UE-6, p 176).
- "The bending can be **gentle**, **or severe**, depending on the magnitude of applied forces, the length of time that they were applied, and the ability of the beds to resist deformation" (UE-6, p 176).

Summary

Realise, with awe and respect, the vast dimensions, time-scale and power of the forces of nature that drive geological processes.

Study section 2.2

Earthquakes

The time scheduled for this study section is 10 hours.

Learning outcomes

On completion of this study section, you should be able to

- explain how and why earthquakes take place
- explain the relationship between seismic waves and the scales measuring earthquakes
- indicate, in respect of earthquake mechanisms, the relationship between earthquakes and plate tectonics
- discuss the destructiveness of earthquakes and tsunamis as Earth issues
- explain practical examples scientifically

General overview of learning content

↳ This study section is based on parts of chapter 13 in UE-6, pages 337–367.

- We will study the following **themes** referred to in the scheme on page 337: what an earthquake is and how earthquakes are studied; earthquakes and patterns of faulting; and the destructiveness and predictability of earthquakes. The Earth issue themes investigate the physical consequences of earthquakes, such as tsunamis, in the human environment.
- In this study section you should **focus** on (a) why earthquakes take place, (b) where they occur, (c) how they are measured, (d) the prediction of earthquakes, and (e) the consequences of earthquakes for humankind.
- You will find out about the technology and methodology used by seismologists to locate, measure and try to predict earthquakes in terms of the Earth system (**outcome** printed in blue on page 337 in UE-6).

☞ Find the above-mentioned themes under the relevant subheadings throughout chapter 13 in UE-6. Note which figures belong to each subheading. Also read the summary on pages 366–367 in UE-6 cursorily the first time round.

☞ Read the introductory paragraphs of chapter 13 on pages 337–340 in UE-6, where the authors give an idea of the absolute, destructive violence of big earthquakes.

2.2.1 What is an earthquake?

Study the section "What is an earthquake" on pages 338–340 in UE-6 as follows:

- Read the introductory paragraph on page 338 in UE-6, which explains stress and strain in rocks during the earthquake cycle. Study the steps in fig 13.3 on page 339 in UE-6, and the explanations "time A, B, C and D", so that you will be able to understand the stress/time graph of a locked fault and draw it yourself. You do not have to be able to draw the other sketches in fig 13.3.
- Summarise the section "Elastic rebound theory explains why earthquakes occur" on page 338 in UE-6 in such a manner that it constitutes a short description of the elastic rebound theory.
  - ✓ Use the words in fig 13.3 on page 339 as part of your summary of the elastic rebound theory.
- Read the section on fault rupture ("Fault rupture during earthquakes") on page 346 in UE-6 carefully. Practise drawing the sketches of the development of a fault rupture in 3-D (UE-6, p 341, fig 13.5) and describing it according to the labels of the figure.

Exercise

Do the following exercises with the aid of the references/tips (✓):

☞ The following are examples of short questions that may be combined to form longer examination questions.

1. What is an earthquake? Translate the quotation (✓) into the language of your choice.
   - ✓ "An earthquake is a shaking of the ground caused by seismic waves that emanate from a fault that breaks suddenly. When the fault breaks, the strain built up over years of slow deformation by tectonic forces is released in a few minutes as seismic waves".

2. Explain how brittle rock will act under strain due to tectonic stress.
   - ✓ Use the words "break suddenly" in the context of the description quoted in question 1 above.

3. Draw a stress/time graph, with a brief explanation of how the stress in rocks that gives rise to earthquakes builds up cyclically to breaking point.
   - ✓ "Stress builds until it exceeds strength".

4. Briefly describe how rocks that have been deformed elastically go into a fault rupture and rebound after slip has taken place.
   - ✓ Use the terms "epicentre" and "focus" as in "time B–D" in fig 13.3 on page 339 in UE-6.

5. Explain, with the aid of a single sketch, where a fault rupture occurs, where seismic waves originate, and how elastically deformed rocks rebound.
   - ✓ Make a sketch of the 5 seconds or 10 seconds figure in fig 13.5 on page 341 in UE-6, and summarise the labels and description of the figure to form the rest of your answer.

2.2.2 Studying earthquakes

Study the section "How do we study earthquakes" on pages 343–352 in UE-6 as follows:

Use the indicated answers (✓) to answer the numbered practical questions on each prescribed section (☞).

☞ **Seismographs.** Read the text and fig 13.7 on page 343 in UE-6 cursorily for background knowledge.

1. Question: What does a seismograph measure?
   - ✓ Answer: A seismograph records the movement of the Earth's surface (the extent to which the surface moves) during earthquakes, in other words, seismic waves.

☞ **Seismic waves.** Carefully study the text and fig 13.8 on pages 344–345 in UE-6.

1. Summarise the text on the three types of seismic wave.
   - ✓ Tip: The three types of seismic wave are P waves, S waves and surface waves.

2. Indicate on a sketch how the three types of seismic wave move through the Earth and, on another sketch, how the time differences in these waves are reflected on the graph of a seismograph.

   ✓ The answers can be found in fig 13.8 on page 344 in UE-6.

3. Make a sketch of the primary, secondary and surface waves and briefly describe the type of movement each causes in the Earth's material.

   ✓ P waves causes compressive (compressional) movement, S waves shear movement, and surface waves perform elliptical movements. Each movement is explained with the aid of sketches in fig 13.8 on page 344 in UE-6. Choose one sketch of each type of wave, together with a short description.

☞ **Determining the epicentre.** Carefully study the text and fig 13.9 on pages 345–346 in UE-6.

1. Make a 3-D sketch indicating the focus, the epicentre and concentric spreading of seismic waves.

   ✓ The first diagram of fig 13.9 on p 346 in UE-6 shows the epicentre on the surface of the Earth, directly above the focus of the earthquake.

2. Draw the seismic travel-time curve of an imaginary earthquake which has been observed by three seismic stations. For each station's observation, indicate the difference in the travel time between the P wave and the S wave on their seismogram. Explain how you would calculate the position of the epicentre of the earthquake.

   ✓ The travel time/distance graph is depicted in the second diagram of fig 13.9 (UE-6, p 346). The distance between the station and the epicentre can in each case be calculated from the graph. The intersection of three distance circles on a map will locate the epicentre of the earthquake precisely.

☞ **Measuring the size of an earthquake.** Carefully read the discussions on Richter magnitude and moment magnitude on pages 346–347. Read the rest of the text cursorily for background knowledge.

1. With the aid of numbers, give an example of the logarithmic nature of the Richter scale, which is used to measure the magnitude of earthquakes.

   ✓ "Richter took the logarithm of the largest ground motion registered by a seismograph as his measure of earthquake size ... . In Richter's scale, two earthquakes at the same distance from a seismograph that differ in size of ground motion by a factor of 10 differ in magnitude by 1 Richter unit" (UE-6, p 346). The largest earthquake is assigned a 10 on the Richter scale.

2. On which physical properties of an earthquake is the moment magnitude scale based?

   ✓ The quantity of seismic energy generated through the surface of the fault.

☞ **Determining fault mechanisms from earthquake data.** Read the text on pages 351–352 in UE-6 cursorily to take note of the method according to which fault mechanisms are determined. Make sure that you can make a 2-D drawing of fig 13.13 (UE-6, p 351), which indicates the tectonic forces involved in normal, thrust and strike-slip faults.

1. Translate the following definition of a fault mechanism into the language of your choice:

   ✓ "The type of fault rupture (normal, thrust, or strike-slip) that produced an earthquake; it is determined by the orientation of the fault rupture and the direction of slip".

2. What is the relationship between an earthquake and a fault?

   ✓ See the Glossary description of an earthquake, which indicates that the fault exists before breaking occurs.

☞ **GPS measurements and "silent" earthquakes.** Read the text on page 352 in UE-6 for background knowledge.

✓ This is when tectonic plates creep past each other without causing seismic waves.

2.2.3 Earthquakes and patterns of faulting

Study the section "Earthquakes and patterns of faulting" on pages 352–355 in UE-6 as follows:

- Just take note of the distribution of deep and shallow-focus earthquakes on the world map of seismicity (UE-6, p 353, fig 13.15a).
- Summarise the text on page 352 in UE-6 with the aid of fig 13.15b on page 353. Also make a simple 2-D drawing of each case (there is no sketch of intraplate earthquakes) to explain earthquakes at divergent, transform fault and convergent boundaries.

Exercise

Do the following, with the aid of the source references (✓).

1. Indicate, on simple sketches, where deep and shallow-focus earthquakes occur at the three types of plate boundary. Then decide which faulting mechanism and tectonic forces come into play in each instance.

   ✓ The types of fault movement, such as normal faulting due to tensile stress at a mid-ocean ridge, are indicated in both figures 13.13 and 13.15 on pages 351 and 353 in UE-6. Make your own synthesis (work out your own combination) of which type of earthquake occurs with which type of fault at which type of tectonic plate boundary, based on the above-mentioned figures.

2.2.4 Earthquake hazards and risks

Introductory remarks

In South Africa we are on a very old part of the lithosphere plate, far from plate boundaries – and earthquakes are relatively uncommon. Earth shocks associated with mining activities are, however, fairly common and these do not pose much danger to human beings on the surface. The danger is when rocks burst underground. The rocks give way because of an intense build-up of tension in the remaining rocks following the removal of tons of gold ore. The mass and pressure of the very large volumes of overlying rocks exceed the strength of the remaining rocks, and they give way.

Read the whole of the section "Earthquake: hazards and risks" on pages 355–365 in UE-6 cursorily, and take note of how earthquakes can cause destruction in the human environment. Then study the following sections thoroughly, so that you can apply your knowledge in an assignment on earthquakes.

- Study fig 13.20, "A tsunami is a sea wave generated by earthquakes on the seafloor", on page 357 in UE-6 thoroughly, together with its labels (1–3) and the related text.
- Carefully read the section tsunamis on pages 357–358 in UE-6.

2.2.5 Can earthquakes be predicted?

General overview

The prediction of earthquakes has many advantages for humankind, like making it possible to evacuate a potential disaster area in time. By combining our knowledge of plate tectonics with detailed geological maps and information, this technology can be further improved.

- You can read the sections on long-term, short-term and intermediate-term predictions on pages 365–366 in UE-6 cursorily, just to take note of them. The limitations that make accurate and reliable predictions difficult will be clear from the passage.

2.2.6 Revision and application

Revision

1. Once again read through the summary of this study section on pages 366–367 in UE-6.
2. What is the relationship between seismic waves and an earthquake? (See UE-6, p 366, "Summary: what is an earthquake?".)
3. What is a seismograph used for? Briefly describe how a seismograph works.
4. How does the ductility of crust material influence the depth at which earthquakes occur?
5. Name three properties of each of the three types of seismic wave.
6. Describe the technique that is used to determine the position of the epicentre of an earthquake.
7. Name the two types of scale that are used to measure earthquakes. Which one is preferred? Substantiate your answer (UE-6, p 366, "Summary: what is earthquake magnitude and how is it measured?").
8. Explain briefly why destructive earthquakes seldom occur within tectonic plates.
9. Make sure that you can define and use the following key terms relating to earthquakes as described in chapter 13 in UE-6:

Key terms and concepts	UE-6, page
earthquake	338
elastic rebound theory	338
epicentre	340
/continued ...	

fault mechanism	351
foci	340
P wave	345
S wave	345
seismic wave	338
seismicity map	353
seismograph	343
slip	173
surface wave	345
tsunami	356

Application

Earth issues

1. Tsunamis

- Carefully study fig 13.20 on page 357 in UE-6. It explains how a tsunami develops during an earthquake.
- Carefully read the theme "Tsunamis" on page 356 in UE-6, especially with regard to their prevalence and the damage they have previously caused.
- Try to find an article in the popular or scientific press on the tsunami that followed the Japanese earthquake of April 2011.

☞ Write an essay of approximately two to three (2–3) pages in which you explain how a tsunami develops and the dire consequences it may have for humans.

2. Protection during an earthquake

- Read the Earth issue theme "Seven steps to earthquake safety" on page 362 cursorily for your own background.

☞ Make notes for yourself on the measures you can take when visiting areas where earthquakes occur.

Study section 2.3

Exploring Earth's interior

The time scheduled for this study section is six (6) hours.

Learning objectives

On completion of this study section, you should be able to explain

- how seismic waves are used to do research on the interior of the Earth
- how the internal heat of the layers of the Earth varies with depth
- how seismic tomography and variations in the gravity field of the Earth support the convection model of the mantle
- how magnetic processes occur within the geodynamic system of the Earth
- how the pressure a glacier exerts on the crust of the Earth is lifted as it melts causing the crust to rebound, thus demonstrating an application of the principle of isostasy

General overview of learning content

↳ This study section is based on parts of chapter 14, on pages 369–391 in UE-6.

- The following **themes** referred to in the scheme on page 369 will be discussed: how seismic observations give us indications of the layering, composition and temperatures of the interior of the Earth; and how gravitational and magnetic measurements help us to create 3-D models of the structure of the mantle. The Earth issue we investigate is how isostasy makes continental drift possible.
- The **focus** of this study section is to demonstrate how the different techniques of seismic, gravitational, magnetic and temperature measurements also yield models of the interior of the Earth, thus contributing to the unifying theory of plate tectonics (see the text printed in blue on page 369 in UE-6).

☞ The above-mentioned themes can be found under the different subheadings throughout chapter 14. Take note of the figures that belong to each subheading. Also read the summary on pages 390–391 cursorily, the first time round.

Introductory remarks

Volcanoes and deformation bring rocks from depths of 50 to 100 km to the surface of the Earth. By studying these rocks, we can make deductions about the properties of the Earth at those depths. However, geologists who wish to investigate the Earth to its maximum depth of 6 400 km do not have such tangible materials to work with. They observe processes and phenomena on the surface of the Earth to give them an indication of the properties and behaviour of material deep in the Earth.

One of the ways in which to investigate the interior of the Earth is to measure the speed of seismic waves, which varies according to the type of material through which the waves travel. Geologists can also infer facts about the interior of the Earth by measuring the heat of materials that flow from the depths of the Earth to its surface, and by measuring the properties of the Earth's magnetic and gravity fields.

2.3.1 Exploring the interior with seismic waves

Study the following sections under the heading "Exploring the interior with seismic waves" on pages 370–374 in UE-6:

- Read the section "Basic types of waves" carefully, together with fig 14.1, which demonstrates the refraction and reflection of waves.
- Study the text under "Paths of seismic waves in the Earth" thoroughly and summarise it under the following headings:

  (a) How seismic waves move through the Earth – together with fig 14.2 on page 371 in UE-6, which shows the bent paths (refraction) and shadow zones of the P and S waves
  (b) How seismic waves are reflected in the Earth – together with fig 14.3 on page 372 in UE-6, which shows the reflection of P and S waves at the different layers of the Earth

Exercise

Answer the following questions. The answers are given further down.

1. Are seismic waves propagated at a constant speed through all types of rock? Substantiate your answer.

2. What will happen to seismic waves if they travel from one medium to another? Tip: Use the experiment with the laser beam in fig 14.1 on page 370 in UE-6 as an analogy (example).

3. How can you explain the observation of two P waves (one faster than the other) during earthquakes and explosions?

4. Which properties of seismic waves do seismologists study and why?

5. How do the seismic waves reappear deeper in the Earth in the following case? "After the P and S waves had travelled beyond about 11 600 km from the earthquake focus, they suddenly disappeared!" Use this finding to come to a conclusion about the core of the Earth.

Feedback

☞ The answers to the questions above are based on the text on pages 370–373 in UE-6.

1. No, the speeds of P and S waves differ in mediums of different density, such as granite and basalt.

2. They will be partly reflected and partly refracted/bent along the interface between the two mediums.

3. The P waves are propagated faster through a rock type like basalt than through, say, granite. P waves which pass through basalt will be observed first at a seismic station.

4. The refraction and reflection of seismic waves reveal certain characteristics of the interior of the Earth.

5. The behaviour of seismic waves deeper in the Earth is as follows: "Then, beyond about 15 800 km from the focus ..., the P waves suddenly reappeared as big arrivals, but they were much delayed compared to their expected travel times. The S waves never reappeared". Because P waves travel more slowly through liquid and S waves are totally absorbed by liquid (causing a shadow zone), one can deduce that the outside core of the Earth is liquid.

2.3.2 Layering and composition of the interior

Read, on pages 374–377 in UE-6, the indicated sections (☞) on the layering of the interior of the Earth, and let yourself be guided by the tips (✓), because it is not necessary to know all the particulars in detail.

☞ **The crust** (UE-6, p 374)

1. According to seismograms, which types of rock occur in the crust?
   - ✓ Felsic rocks such as granite occur in the upper continental crust, and mafic rocks such as gabbro occur in the oceanic crust or the lower continental crust.
2. Define Moho discontinuity.
   - ✓ See the glossary in UE-6.
3. Explain briefly, with the aid of a diagram, how the principle of isostasy makes it possible for continents to float or move on solid rocks.
   - ✓ Use the following concept in your answer: "The additional weight of the high mountains is supported by the buoyancy from a deeper root of low-density crustal rocks". The mountain and its root are portrayed in the figure on p 375 in UE-6.

☞ **The mantle** (UE-6, p 376)

1. According to seismograms, what kinds of rocks occur in the mantle?
   - ✓ The ultramafic rock peridotite is the primary rock of the upper mantle. Deeper in the mantle the atoms of the peridotite crystals are packed more closely together because of the higher pressure.
2. Draw a graph and explain briefly how the speed of S waves varies with depth, and correlate this with the physical zoning of lithosphere and asthenosphere.
   - ✓ Fig 14.8 on page 376 in UE-6 and its labels explain the variation in speed that is due to the denser peridotite crystals.

☞ **The core-mantle boundary** (UE-6, p 377)

1. How can seismologists be sure that the boundary between the mantle and the core is a very sharp interface?
   - ✓ The speed of the S waves suddenly drops to zero.

2. Where do mantle plumes originate?

   ✓ Possibly in a thin layer right above the core-mantle boundary, where the mantle is partly molten in places. There is a steep reduction in wave speeds in this area.

☞ **The core** (UE-6, p 377)

1. Briefly state what the physical state (phase) of the core is and which materials constitute it.

   ✓ The core material is a nickel-iron composition, which is layered to form a fluid outer core and solid inner core.

2.3.3 Earth's internal temperature

Study the section "Earth's internal heat and temperature" on pages 378–381 in UE-6.

Exercise

Do the following exercises with the aid of the indicated tips (✓).

1. What is the geothermal gradient of the continental crust?

   ✓ The temperature of the continental crust changes with depth by approximately 20–30° C per kilometre.

2. Draw a graph of the Earth's geotherm. Briefly discuss the sections of the geotherm curve with different gradients, and how these indicate the processes of heat conduction and convection in the Earth.

   ✓ The steep geothermal gradient near the surface of the Earth indicates outward cooling through conduction ... .Now continue your discussion of the geotherm with regard to the lithosphere, the mantle, and the outer and the inner core, as depicted in fig 14.10 and as discussed in the text on page 379 in UE-6.

2.3.4 The three-dimensional structure of the Earth

Study the section "The three-dimensional structure of the Earth" on pages 381–383 in UE-6 as follows:

- Read the introductory paragraph cursorily, taking note of what a mantle plume is.
- You have already read the section on seismic tomography as part of the application of a previous study section. Read it again, cursorily, and follow fig 14.11 on page 382 in UE-6 for background knowledge. Take special note of step 2 of the figure and the related text which mentions the mantle plume directly under South Africa.
- Read the section on the Earth's gravity field cursorily, for your own background knowledge.

Exercise

Answer the following questions:

1. What is a mantle plume?
2. How is seismic tomography applied to observe rising mantle plumes?
3. Write down the hypothesis on how a mantle plume might be the cause of the high plateaus in South Africa.

Feedback

1. The definition of a mantle plume can be found on page GL-09 of the glossary in UE-6.
2. Tip: rising, less dense material, such as mantle plumes, slow seismic waves down.
3. The driving force which hot, rising material exerts on the overlying cold mass of crust material is relevant.

2.3.5 Earth's magnetic field and the geodynamo

Revision

Once again study fig 1.14 on page 14 in UE-6 to see the global structure and interaction of the main components of the Earth system. Take particular note of how the geodynamic system, which probably causes the magnetic field of the Earth, comes into play.

Exercise

Summarise the following sections for thorough studying. Subdivide the summary as indicated under "feedback" below.

- Carefully read the section on the Earth's magnetic field on pages 383–390 in UE-6.
- Glance at figures 14.13 and 14.14 and their labels on pages 386–387, which describe the simple dipole and the complexities at the core-mantle boundary.
- Study fig 14.16 on page 389 in UE-6, on the magnetisation of sedimentary deposits.

Feedback

Use the following scheme as a guideline for your summary, and let the key words (in brackets) help you when revising your summary.

✓ The geodynamo system (dipole field).
✓ Behaviour of the magnetic field (nondipole field, secular field, magnetic reversals).
✓ Paleomagnetism (thermoremanent magnetisation; depositional remanent magnetisation).

2.3.6 Revision and application

Revision

1. Once again read the summary of this study section on pages 390–391 in UE-6.

2. How does the speed of P waves differ in granite, gabbro and peridotite?

3. Which findings indicate that the asthenosphere is possibly partly molten? (Slower S waves.)

4. Which findings indicate that the Earth's outer core is molten and consists largely of iron?

5. What is the depth of the core and how do we know that? (P waves suddenly accelerate at a depth of 5 150 km.)

6. What is the difference between heat conduction and convection?

7. How can a mountain float on the mantle if both consist of rocks? (Principle of isostasy.)

8. How do the rocks become magnetised during their formation? (Thermoremanent and depositional remanent magnetisation.)

9. Make sure that you can define and use the following key terms relating to the Earth's interior as described in chapter 14 in UE-6:

Key terms and concepts	**UE-6, page**
compressional wave	370
conduction	378
convection	379
core-mantle boundary	377
depositional remanent magnetisation	389
dipole	383
geotherm	379
geodynamo	383
low-velocity zone	376
magnetic stratigraphy	210
paleomagnetism	388
seismic tomography	381
shadow zone	371
shear wave	370
thermoremanent magnetisation	388

Application

Earth issue – Applying the principle of isostasy as an Earth issue theme

- Look at the graph of seismic wave speed/depth (UE-6, p 374, fig 14.7) and note the sudden increase of 8 km/s which indicates the boundary between the crust and the mantle.
- Look at fig 14.8 (UE-6, p 375), where the continental crust takes the form of a mountain with its root below. Changes in seismic wave speed indicate the boundary between the crust and the mantle under mountains.

☞ Relate the weight of a mountain which is sinking into the mantle (as indicated with seismology) to the weight of a glacier which is melting and becoming smaller. Write an essay of one to two (1–2) pages, with an appropriate figure, applying the principle of isostasy in both instances.

Study section 2.4

Earth issues relating to internal Earth processes

The time scheduled for this section is two (2) hours.

Learning outcomes

On completion of this study section, you should be able to

- demonstrate the understanding, respect and awe you have developed (during your exposure to the scientific method and knowledge) for the vastness of geological time and processes and the forces of nature – and you should be able to convey this in all forms of communication
- display a certain attitude with regard to human emergency situations resulting from the mechanisms of geological processes
- communicate on the topic of Earth issues, such as the dangers earthquakes and tsunamis pose to human existence
- link large-scale geological processes in the unifying theoretical framework of plate tectonics (such as earthquakes, tsunamis and the melting of glaciers), to real-life examples, such as the 2011 tsunami in Japan.

General overview of learning content

↳ This study section is based on chapters 7, 13 and 14 in UE-6.

- The following **themes** have already been studied as Earth issues in study sections 2.1 to 2.3: the scales of time, the magnitude and intensity of geological processes, the mechanism of tsunamis and the resultant damage, protection during earthquakes, and the principle of isostasy as applied to glaciers and mountains.
- The **outcome** and **objective** of this study section is to give you the opportunity to take part in discussions on Earth issues arising from some of the subject themes in study unit 2. The purpose of these Earth issues is to instil in you a human value in terms of which you can understand and respect the greatness of nature and its

forces – Earth forces which can build up over a long period of time to be triggered all of a sudden causing an earthquake or a tsunami.

☞ The above-mentioned themes can be found in the "revision and application" sections of study sections 2.1 to 2.3 in the SG.

Revising the following Earth issue themes already covered in this study unit will help you answer a possible examination question set on them.

2.4.1 Earth issues: perspective and the laws of nature in geological processes

Revision

Once again read your notes on all the Earth issues referred to in the "applications" sections of the following study material which you have already covered. Also make use of the tips (✓) below.

☞ **Perspective creates respect for the greatness of nature (**in section 2.1.5)

1. The scales on which not only individual geological processes, but also the causes and effects of numerous of the Earth's processes take place, are extremely varied. Measured by the human lifespan and conception of time and space, this is something about nature to consider and respect.

   ✓ For instance, it takes 150 years to accumulate sufficient deformation energy in two moving blocks of rock on a fault, to cause a destructive earthquake lasting about 20 seconds.

☞ **Earthquakes instil respect for the forces of nature** (in section 2.2.6)

1. Compare the number of human deaths caused by the giant tsunami following the Sumatra earthquake on 26 December 2004 with the number of deaths caused by previous tsunamis.

2. The deformation forces involved in plate tectonic motions which cause earthquakes are enormous.

   ✓ Earthquakes have caused more than 10 000 deaths annually during the previous century. Simultaneously, immeasurable damage was done to the structures erected by humankind.

3. **Application:** The respect for, and understanding of the destructive forces of earthquakes and tsunamis that you must by now have developed, would have created a preparedness in you that will influence how you would act in such circumstances.

☞ **Principles like that of isostasy describe theories according to scientific laws** (in section 2.3.6)

1. Various scientific observations such as the rebound of bent layers of crust when a glacier melts, and the investigation of the interior of the Earth with seismic waves, contribute to the formulation of natural laws and principles like isostasy. The laws of nature are applied in theories. For instance, continental drift, a process in the theory of plate tectonics, is based on the principle of isostasy.

Summary of study unit 2 – Internal Earth processes

Within the framework of plate tectonics, you have learnt how the internal heat engine of the Earth causes external effects in processes such as mantle convection and continental drift. The properties of Earth materials, such as being ductile or brittle, play a role in processes like deformation. The deformation of rocks into folds, fractures and faults can in turn cause earthquakes and tsunamis. The effects of these destructive geological phenomena on humans were investigated as Earth issues, making it possible for you to form your own opinion.

STUDY UNIT 3

EXTERNAL EARTH PROCESSES

The time scheduled for this study unit is 57 hours.

This study unit is based on chapters 16–22 in UE-6.

Learning outcomes

On completion of this study unit, you should be able to

- demonstrate your understanding of the causes and effects of mass movements such as landslides
- demonstrate your understanding of the prevalence and processes of groundwater in terms of the hydrologic cycle
- explain how water streams cause erosion and sedimentation during the formation of drainage networks and landscapes such as valleys and flood plains
- explain how wind is an agent of eolian erosion, the formation and movement of sand dunes, and the formation of desert landscapes
- explain how ice as a rock forms glaciers which move forward by means of plastic flow or basal slip, and how glaciers form landscapes and deposit glacier debris
- describe submarine geological structures such as rift valleys, as well as processes such as the origin of turbidity currents
- demonstrate your understanding of landscapes and the formative geological processes of erosion and sedimentation, and describe the interrelationship between landscapes and these geological processes
- give your own input on Earth issues such as the use of limited water resources, and Earth policies such as the responsible use of beaches

OVERVIEW OF THIS STUDY UNIT

Study unit 3 comprises the following study sections:

Study section 3.1

Weathering, erosion and mass wasting

The time scheduled for this study section is three (3) hours.

Learning outcomes

On completion of this study section, you should be able to

- distinguish between mass wasting and mass movements
- demonstrate an understanding of the mechanism of mass movements and the factors controlling it
- display your background knowledge of the classification and origins of mass movements
- name the plate tectonic environments of mass wasting
- suggest, as an application, an Earth policy that will prevent landslides

General overview of learning content

↳ This study section is based on parts of chapter 16 in UE-6, pages 421–453.

- The following **themes** referred to in the scheme on page 421 will be discussed: what makes masses move; the classification of mass movements; and understanding the origins of mass movements.
- The **objective** and **outcomes** are to understand why the different types of mass of soil materials move, and which factors, such as the weather, plate tectonic environment and human activities, contribute towards mass movements. This study section **focuses** particularly on understanding the mechanism and characteristics of mass movements, as well as the factors in nature and humankind that interact to contribute to such mass movements.

☞ The above-mentioned themes can be found under the various subheadings throughout chapter 16. Note which figures and tables go with each subheading. Also read the summary on page 453 in UE-6 cursorily, the first time round.

Introductory remarks

Read the introductory paragraphs of chapter 16, on pages 422–452 in UE-6 ("Mass wasting") cursorily, and then use the glossary to distinguish between the following four geological terms:

- **Weathering**
- **Erosion**
- **Mass wasting:** This is a general term which includes all **processes** by which masses of rock and soil move downhill under the influence of gravity. "Mass wasting includes slow displacements, such as creep and solifluction, and rapid movements such as rockfalls, rockslides, and debris flows" (BJ3 [Bates & Jackson, one of your recommended books – see at the beginning of the SG], p 405).
- **Mass movement:** This is the downhill movement of masses of soil or rock under the force of gravity. It is a "unit movement of a portion of the land surface" (BJ3, p 405).

✓ The **difference** is this: Mass wasting is a manner in which a mass moves, for example *sliding*. This manner of movement of a mass is described further and more specifically in a classification by specifying the velocity at which it moves, the nature of the material involved, and movement as a unit. Such an accurate description of a specific case is called a mass movement, for instance a *rock slide*. The general term "mass wasting" still applies to this example, because the sliding process takes place under the influence of gravitation.

3.1.1 What makes masses move?

Study the following sections in the textbook:

1. Carefully read the short descriptions of the three factors that influence mass movements, namely the nature of the slope material, the steepness and stability of slopes, and water content – and correlate this with table 16.4 on page 436 in UE-6.

2. Carefully read steps 1–9 of fig 16.13 on page 437 in UE-6, while studying the relevant diagrams, so that you can visualise the mechanism of the three factors mentioned above. Practise making 2-D sketches of some of the figures you deem important.

3. Carefully read the entire discussion under the heading "Slope materials", on page 436 in UE-6.

4. Carefully read the entire discussion under the heading "Water content", on page 438 in UE-6.

5. Carefully read the entire discussion under the heading "Slope steepness", on page 439 in UE-6.

6. Carefully read the text under the heading "Triggers of mass movements", on page 440 in UE-6.

Exercise

Do the following exercises with the aid of the key concepts (✓) and the references to UE-6.

1. Define the angle of repose of a sand pile. Discuss briefly why the sand pile remains stable and motionless with slope angles smaller than, or equal to, the angle of repose. What happens if the angle of repose becomes too steep, and why?

   Key concept: Maximum slope angle without collapsing; friction between sand grains.

2. Make a drawing of a pile of each of the following unconsolidated materials, showing how the angle of repose changes with grain size and angularity: fine sand, coarse sand, and angular pebbles.

   Key concept: Angle of repose increases with grain size and angularity.

3. Briefly discuss cohesion, friction and lubrication between grains, and the resultant ability of damp, dry and water-saturated sand piles to move.

   Key concept: The angle of repose of damp sand is larger than that of dry sand.

4. Describe briefly how the weathering and fragmentation of different rocks such as shale and granite influence the steepness and stability of a slope and cause mass waste.

   Key concept: Fragments accumulate on slope until angle of repose is exceeded.

5. What role do earthquakes play in the occurrence of landslides?

   Key concept: The shaking ground serves as a trigger.

3.1.2 Classification of mass movements

General overview (for background knowledge)

- Page quickly through the section on the classification of mass movements and the accompanying figures (UE-6, pp 441–448).

- You should merely take note of this section in order to know where to find the relevant information if you should need it. You will not be examined on it.
- Look at the 3-D diagrams of the different kinds of mass movements in the classification table (UE-6, p 442, fig 16.17) so that you will be able to recognise these in nature and find them in the textbook.
- The classification of mass movements is done according to three already known factors, namely the nature of the material (consolidated or not), and the velocity and the nature of the motion.

3.1.3 Understanding the origins of mass movements

Study the relevant sections in UE-6 as follows:

- Carefully read the introductory paragraph to this section on page 449 in UE-6.
- Read the section "Natural causes of landslides" on page 449 cursorily, together with the photographs and figures, in order to take note of the examples given.
- Read the section "Human activities that promote or trigger slides" on page 450 in UE-6 cursorily, as part of the Earth policy theme.

Summary

Make a short summary of the ways in which mass waste may occur at the three types of tectonic plate boundaries.

Key concept: Steep mountain slopes at convergent zones, volcanoes that spew ash, steep slopes in rift valleys, and so forth.

3.1.4 Revision and application

Revision

1. Once again read the summary of this study section on page 452 in UE-6.

2. Distinguish between the terms "mass waste" and "mass movement" (SG, study section 3.1).

3. How does the absorption of water weaken unconsolidated material?

4. What is the difference between a slide and a flow?

5. What is the angle of repose and how does it vary with water content?

6. How does the steepness of a slope affect mass waste?

7. Make sure that you can define the following key terms as discussed in chapter 16 of UE-6:

Key terms and concepts	UE-6, page
angle of repose	436
consolidated materials	436
creep	444
debris flow	420
liquefaction	439
mass movement	435
mass wasting	422
unconsolidated materials	436

Application

Earth policy to prevent landslides

Read the following texts and relevant sections in UE-6:

- "Human activities that promote or trigger slides" on page 450 in UE-6.
- If you have recently read an article in the popular press on one of the mass movements depicted in the classification in fig 16.17 on page 442 in UE-6, read it again and check its accuracy (whether the facts given are geologically correct).

Use the reading matter above to write a short essay focusing on the stabilising and drainage of building sites against slopes.

Study section 3.2

The hydrologic cycle and groundwater

The time scheduled for this study section is 11 hours.

Learning outcomes

On completion of this study section, you should be able to

- demonstrate an understanding of the hydrologic cycle as a component of the Earth system
- demonstrate an understanding of the geology of groundwater with regard to porosity, permeability and aquifers
- demonstrate an understanding of the water table and dynamics of groundwater as far as boreholes (wells) are concerned
- describe the subsurface erosion caused by the movement of groundwater
- demonstrate an understanding of the presence of water deep in the crust and near hot magma
- arrive at a synthesis on the responsible use of water in South Africa, because of your knowledge of different relevant Earth issue themes

General overview of learning content

➯ This study section is based on parts of chapter 17 in UE-6, pages 455–481.

- You will study the following **themes** referred to in the scheme on page 455: the hydrologic cycle, which incorporates flows and reservoirs; hydrology and climate; the hydrology of runoff; groundwater; erosion by groundwater; water quality; and water deep in the crust. These themes **focus** in particular on the hydrologic cycle as part of the Earth system, climate and drought, the geology of groundwater, water quality and water deep in the crust.

- The **objective** of this chapter in UE-6 is to conduct "a survey of water in and on the Earth". The outcome of this study section is to achieve an understanding of the geology of water in and on the Earth.

☞ The above-mentioned themes can be found under the different subheadings throughout chapter 17. Note which figures belong to each subheading. Also read the summary on page 480 in UE-6 cursorily the first time round.

☞ Read the introductory paragraphs of chapter 17 on pages 455–458 in UE-6, where the authors give an overview of the presence of water in and on the Earth.

3.2.1 The geologic cycling of water

Study the section "The geologic cycling of water" on pages 456–458 in UE-6 as follows:

- Read the introductory paragraphs and subsequent section on page 456 in UE-6 cursorily. The definitions of "groundwater" and "reservoir" are given, as well as an explanation of how much water there is.
- Carefully read the section "The hydrologic cycle" on page 457 in UE-6. Simplify fig 17.2 (UE-6, p 457) on the hydrologic cycle for yourself by drawing it in two dimensions (2-D). Indicate what the main components of interaction between the different Earth systems, such as infiltration, evaporation, etc entail.

Exercise

Do the following exercises with the aid of the references (✓):

☞ Revise the main components and subsystems of the Earth system, for instance the climate system, which has the atmosphere and hydrosphere as subsystems.

1. Indicate, in a simple figure, the possible ways the climate system and the plate tectonic system can interact as a result of the flow of water.

   ✓ See fig 17.2 on page 457 in UE-6, which indicates the hydrological processes of evaporation, precipitation, runoff and infiltration, and refers to the groundwater table.

2. Summarise briefly, in words, how water in and on the Earth moves between reservoirs in the hydrologic cycle.

   ✓ Tip: Water can move in all three of its phases (gas, liquid, solid).

3.2.2 Hydrology and climate

Read the following sections in UE-6 cursorily for background knowledge, paying special attention to the issue of droughts.

- "Hydrology and climate", where humidity, rainfall, landscape and droughts are discussed.
- "The hydrology of runoff", that is the runoff between reservoirs during wet and dry periods.

3.2.3 Hydrology of groundwater

Study the section "Hydrology of groundwater" on pages 463–470 in UE-6 as follows:

☞ Take note of the definition of an aquifer in the introductory paragraph on page 466 in UE-6.

- Carefully read the section "Porosity and permeability", including fig 17.9 ("Pores in rocks ...") and table 17.2 ("Porosity and permeability of aquifer rock types") on pages 464–465 in UE-6.
- Carefully read the section "The groundwater table", together with fig 17.10 ("The groundwater table is the boundary ...") and fig 17.11 ("Dynamics of the groundwater table ...") on pages 466–467.
- Carefully read the section "Aquifers", together with fig 17.12 ("A confined aquifer ...") and fig 17.14 ("A perched water table ...") on pages 467–468 in UE-6.
- Carefully read the section "Balancing recharge and discharge", together with fig 17.15 ("Excessive pumping ... water table into cone-shaped depression") on pages 468–469.
- Merely take note of the section "The speed of groundwater flows" on page 470 in UE-6. You will not be examined on it.

Exercise

Do the following exercises while referring to the key concepts and references (✓) provided.

1. Explain how the porosity of rocks relates to their permeability.

   ✓ See UE-6 on how much water a rock can hold and how fast it can travel through a rock.

2. Indicate on different sketches how cementing, roundness (shape) and the sorting of grains can change the porosity of sandstone.
   - ✓ See fig 17.9 on page 464 in UE-6 – pores in rocks are usually fully or partially filled with water.

3. Draw a simple 2-D profile of the relative positions of the surface of the Earth, the unsaturated (vadose) zone, the water table, and the saturated (phreatic) zone.
   - ✓ Distinguish between the saturated and unsaturated zone (UE-6, p 465, fig 17.10).

4. Follow steps 1–10 in fig 17.11 (UE-6, p 466), which explains how the water table rises and drops in wet and dry periods.
   - ✓ During wet periods the water table is high, etc.

5. Sketch a 2-D profile to demonstrate the following situation: an aquifer situated between two aquicludes, and an artesian well that yields water.
   - ✓ See fig 17.12 on page 467 in UE-6. A two-dimensional sketch is sufficient.

6. Discuss briefly, with the aid of a diagram, the condition of the water table in an aquifer if the water is pumped out faster from a well than it can be replenished.
   - ✓ A cone-shaped depression is formed.

3.2.4 Erosion by groundwater

Study the section "Erosion by groundwater" on pages 472–475 in UE-6 thoroughly.

Exercise

Answer the following questions:

1. Briefly explain the process by which groundwater dissolves limestone.

2. Relate the dissolution of limestone to karst topography.

Feedback (tips for answering the questions above)

1. Start with "Carbon dioxide-rich water infiltrates the soluble rocks from the surface ..." and explain further.

2. Karst topography comes about through the formation of sinkholes and caves and lacks surface streams. Explain further.

3.2.5 Water quality

Read the following sections on water quality on pages 475–478 in UE-6 cursorily for background knowledge:

- "Contamination of the water supply"
- "Is the water drinkable?"
- Use the above-mentioned sections as sources for doing the Earth issue exercises in this study section, especially in respect of the question whether the contamination of water can be reversed to the extent that it becomes drinkable again.
  - ✓ Water contamination is reversible (under certain conditions) and standards have been set for drinkable water.

3.2.6 Water deep in the crust

Study the following sections and figures in UE-6 thoroughly:

- The section "Water deep in the crust" on pages 478–480 in UE-6
- Fig 17.25 ("The distribution of water in a typical section of continental crust") on page 478 in UE-6
- Fig 17.27 ("Circulation of water over a magma body produces geysers or hot springs") on page 480 in UE-6

Exercise

Answer the following questions with the aid of the tips and references (✓).

1. Illustrate the following statement with one or two sketches: "Porosity and water content generally decrease with increasing depth and greater structural deformation."
   - ✓ See the micro-scale depiction of particles in fig 17.25 on page 478 in UE-6.
2. Make a 2-D sketch with labels to show how the water content of the crust changes over a depth of 10 km. Also indicate the deformation of sedimentary rocks.
   - ✓ The macro-scale section (profile) in fig 17.25 on page 478 in UE-6 illustrates the statement above. A two-dimensional sketch is sufficient.

3. Discuss briefly the origin of the water that is heated by magma and appears as hydrothermal water in the form of geysers and hot springs.
   - ✓ Meteoric water and water from the magma itself constitute hydrothermal water. Expand on this, referring to pages 478–479 in UE-6.

3.2.7 Revision and application

Revision

1. Once again read the summary of this study section on page 480 in UE-6.
2. Name the active processes of the hydrologic cycle, such as infiltration.
3. What are an aquifer and an aquiclude?
4. What is the difference between saturated and unsaturated zones of groundwater?
5. Which aspects of the recharge and discharge of groundwater contribute to instability in the water table?
6. Briefly describe a theory which explains the intermittent nature of geyser eruptions.
7. Make sure that you can define and use the following key terms used in chapter 17 in UE-6:

Key terms and concepts	UE-6, page
aquiclude	466
aquifer	466
artesian flow	467
un/confined aquifer	467
discharge	466
effluent stream	466
groundwater	456
groundwater table	465

/continued ...

hydrologic cycle	457
hydrothermal water	478
influent stream	466
karst topography	474
meteoric water	463
perched water table	467
permeability	465
recharge	466
un/saturated zone	465

Application

Earth issues

1. Earth issue – Limited water in South Africa

- Use the texts on hydrology and climate mentioned in section 3.2.2 as a source for this theme.
- Read the Earth Policy "Water is a precious resource: who should get it?" on page 460 in UE-6 cursorily, concentrating on the factors mentioned below.
- Briefly discuss the influence of the following factors on water consumption in South Africa: individual needs; industrial and agricultural consumption; the cost of water; traditional use of water; limited water supplies; and the hydrologic cycle, which includes borehole water (wells).
  - ✓ From your discussion, draw a conclusion on whether or not South Africa has a limited water supply.

2. Earth issue – The responsible use of water in South Africa

- Read the section on the Earth Policy on page 473 in UE-6 cursorily, concentrating on the factors mentioned below.
  - ✓ Is it your hypothesis (suspicion/feeling) that there is enough water in South Africa's soil to meet its needs with boreholes (wells)? Substantiate your hypothesis in a few sentences.

- Use the text on water quality mentioned in section 3.2.5 as a source for this theme.
  - ✓ Is it your hypothesis (suspicion/feeling) that the groundwater in South Africa is being polluted? Give a number of ways in which you suspect pollution might be taking place.
  - ✓ Integrate the three short thematic answers you have given above (✓) into one synthesis (composition) on the limited availability of water, on borehole (well) water, and on water pollution in South Africa. Then use this synthesis to make some recommendations for the way in which, in your view, water consumption could be handled in a responsible manner in South Africa.

Study section 3.3

Streams – transport to the oceans

The time scheduled for this study section is 11 hours.

Learning outcomes

On completion of this study section, you should be able to

- explain how streams of water flow and transport earth materials
- explain how erosion and sedimentation processes take place
- explain how stream valleys, channels and floodplains come into being
- describe typical drainage patterns
- describe how rivers get to flow into the ocean in a delta shape
- reason about the Earth issue of human habitation on floodplains

General overview of learning content

➪ This study section is based on parts of chapter 18 of UE-6, pages 483–511.

- You will study the following **themes** referred to in the scheme on page 483: the form of streams; stream loads and sediment movement; how running water erodes solid rock; stream valleys, channels, and floodplains; drainage networks; and deltas, the mouths of rivers. This study section **focuses** particularly on how stream waters flow and transport sediment, how rocks erode, and how streams form drainage patterns in which they flow to the ocean.
- The **overall objective** of this chapter in UE-6 is to explain the processes whereby streams of water interact with the different parts of the Earth system. For instance, the water in a steam is derived from the atmosphere, and eroded materials (lithosphere) are transported to the sea in rivers. The **outcome** of this study section is to create an understanding of how the hydrologic cycle, through stream flow, interacts with the tectonic, climate and biological spheres (UE-6, p 484).

☞ The themes mentioned above can be found under the different subheadings throughout chapter 18 in UE-6. Note which figures go with each subheading. Also read the summary on page 510 in UE-6 cursorily the first time round.

☞ Read the introductory paragraphs of chapter 18 on pages 483–484, where the authors give an overview of the geological processes that take place in flowing streams.

3.3.1 The form of streams

Study the following sections in UE-6 thoroughly:

☞ Take special note of the following sentence on page 484 in UE-6: "We reserve the word **stream** for any flowing body of water, large or small, and **river** for the major branches of a large stream system."

☞ Study the section "The form of streams" thoroughly, together with fig 18.1 on page 485 in UE-6.

Exercise

Make sure that you can answer the following questions and expand on the short answers (✓) by referring to the indicated passages in UE-6.

1. Define a stream line.
   - ✓ Stream lines are the lines of movement of a particle in a flow (UE-6, p 494).
2. Briefly describe laminar flow in a fluid/flow.
   - ✓ In laminar flow, the movement is along straight or gently curved lines (UE-6, p 494).
3. Briefly describe turbulent flow in a liquid/flow.
   - ✓ "Turbulent flow has a more complex pattern of movement, in which streamlines mix, cross, and form swirls and eddies" (UE-6, p 494).
4. Which three factors determine whether flow will be laminar or turbulent?
   - ✓ The velocity, geometry and viscosity of the fluid/stream (UE-6, p 494).

3.3.2 Stream loads and sediment movement

Study the section "Stream loads and sediment movement" on pages 494–496 in UE-6 thoroughly, as follows:

- Carefully read the section "Erosion and transport" on page 495 in UE-6, together with fig 18.15 with its labels (steps 1–7), where the ways (such as saltation) in which particles move in streams are described.
- Read the section "Settling from suspension" cursorily for background knowledge.
- Carefully read the section "Bed forms: dunes and ripples" on pages 496–497 in UE-6, together with fig 18.17 ("The change in the form of a sand bed with increasing flow velocity").
- Make sure that you know the meaning of the term "ripple" (UE-6, Glossary, p GL-12). The term "ripple" refers to a sedimentary structure, the upper side (of a bed) of which is not flat, but corrugated. It is formed in a stream by, amongst other things, the process of saltation. "Ripples are very small dunes – with heights ranging from less than a centimeter to several centimeters – whose long dimension is formed at right angles to the current".

Exercise

Make sure that you can answer the following questions and expand on the short answers and tips (✓) by referring to the indicated passages in UE-6.

1. Which two Earth system components interact to transport sediments in streams?

   ✓ The hydrosphere and lithosphere.

2. How would stream velocity influence the transport of different particle sizes of the various sediments if the bed of a river were to consist of sand, silt and clay?

   ✓ Particles are transported in suspension in a water stream, or through sliding and rolling movements, or by saltation (jumping movements).

3. Define the ability of a stream to transport load.

   ✓ It is a flow's ability to carry material of a given size. A greater stream velocity ... (complete the statement).

4. Name one property that distinguishes dunes and ripples in large rivers.

   ✓ There is a difference in height. Dunes may be metres high in rivers, whereas ripples are only centimetres high.

5. With the aid of a sketch, describe briefly how the shape of a sand layer on the bed of a river changes as the flow moves it downstream. Also indicate a cross-bedded structure on your sketch.
   - ✓ See fig 18.17 on page 497 in UE-6. Tips: Different stream velocities have different effects; cross-layers are not deposited horizontally.

3.3.3 How running water erodes solid rock

Summarise the following sections of "How water erodes solid rock" on pages 492–493 in UE-6:

- The introductory paragraph and "Abrasion" on page 492 in UE-6.
- "Chemical and physical weathering" on page 492.
- "The undercutting action of currents" on page 492.

✓ See the summary on page 510 in UE-6: "Running water erodes solid rock by abrasion; by chemical weathering that enlarges and opens cracks; by physical weathering as sand, pebbles, and boulders crash against rock; and by the plucking and undercutting actions of currents."

3.3.4 Stream valleys, channels, and floodplains

Study the section "Stream valleys, channels, and floodplains" on pages 484–488 in UE-6 thoroughly, as follows:

- The introductory paragraph, "Stream valleys" and fig 18.1 with its labels on page 485 in UE-6.
- "Channel patterns" on pages 485–486, including figure 18.3, which explains that channel patterns depend on flow velocity and sediment load.
- "The stream flood plain" and fig 18.5, on page 487.

Exercise

Answer the following questions and check the answers (✓) against the text references.

1. Draw a sketch showing a river flowing into a channel, another (river) moving over a floodplain, and another situated in a valley.
   - ✓ See fig 18.1 on page 485, the lower, enlarged sketch.

2. Say, in one or two sentences, what a "point bar" is, and how it develops.
   - ✓ Key words: erosion, outside bank, curved sandbar, inside bank, slower current

3. Describe, using sketches, how a low-velocity river with a small sediment load meanders and ultimately forms an oxbow lake.
   - ✓ See steps 1–7 of fig 18.3 on page 486 in UE-6. Tip: point bars are formed as a river meanders.

4. Under what circumstances do braided streams develop?
   - ✓ See page 486 in UE-6. Key concepts: great variation in flow volume; large sediment load.

5. How is a natural levée formed at the edge of a river's channel?
   - ✓ See page 487–488 in UE-6. Tips: coarse sediment; successive floods.

3.3.5 Drainage networks

Study the section "Drainage networks" on pages 490–491 in UE-6 thoroughly, as follows:

- Pages 490–491 in UE-6: the introductory paragraph and the section "Drainage patterns", including fig 18.6 ("Stream valleys and drainage basins ...") and fig 18.8 ("Typical drainage networks").
- Pages 490–491 in UE-6: the section "Drainage patterns and geologic history", together with fig 18.9 (a) ("An antecedent stream") and fig 18.10 ("The development of a superposed stream ...").

Exercise

Answer the following questions and check the answers with the aid of the key concepts (✓) and the references to your textbook:

1. Describe briefly, by means of a sketch, what a drainage basin is.
   - ✓ A basin collects water in streams. See fig 18.6 on page 488 in UE-6.

2. For each of the following drainage patterns, draw a 2–D plan illustrating the direction of flow by means of arrows: a trunk stream with a tributary which displays dendritic drainage; which displays rectangular drainage; which displays trellis drainage; and which displays radial drainage.

- ✓ Most rivers follow the same kind of irregular branching pattern. See fig 18.8 on page 490 in UE-6.

3. With the aid of sketches, describe the development of a superposed stream.

   - ✓ The resistance of bed layers against erosion may vary. See fig 18.9 on page 491 in UE-6.

3.3.6 Deltas: the mouths of rivers

Study the section "Deltas: the mouths of rivers" on pages 497–499 in UE-6, as follows:

- Study the introductory paragraph and the section "Delta sedimentation", together with fig 18.18 ("A typical large marine delta ...") on pages 497–499 in UE-6 thoroughly.
- Read "The growth of deltas" on page 498 cursorily. Take note how LANDSAT can photograph delta sedimentation by means of infrared.
- Read "The effects of waves, tides and tectonics" on page 499 cursorily in order to gain an understanding of delta formation within the framework of plate tectonics.

Exercise

Do the following exercise and check your answer against the key concepts (✓) and the textbook reference:

1. Use a sketch to describe briefly how a river that flows into the ocean forms a delta at its mouth.

   - ✓ See fig 18.16 on page 496 in UE-6, where topset beds, foreset beds and bottomset beds are illustrated.

3.3.7 Revision and application

Revision

1. Once again read the summary of this study section on page 510 in UE-6.
2. How does velocity determine whether a given flow will be laminar or turbulent?
3. What are dunes and ripples?

4. How do braided streams and meanders differ from each other?

5. What is a delta distributary?

6. Make sure that you can define and use the following key terms in respect of water streams that carry earth loads to the oceans (UE-6, chapter 18):

Key terms and concepts	**UE-6, page**
antecedent stream	490
bed load	495
bottomset bed	497
braided stream	486
capacity	495
channel	495
competence	495
delta	497
dendritic drainage	490
discharge	466
distributary	497
drainage basin	489
drainage network	490
floodplain	484
foreset bed	497
laminar flow	494
natural levée	487
oxbow lake	486
point bar	485
ripple	496
saltation	495
stream	484
superposed stream	490

/continued ...

suspended load	495
topset bed	497
tributary	490
turbulent flow	494
valley	484
viscosity	95

Application

Earth issue – Human habitation of a floodplain

- Read the section "Earth issues – the development of cities on floodplains" on page 488 in UE-6.
- Find an article to read in the popular press on one of the areas in Southern Africa which is flooded regularly, such as KwaZulu-Natal, the Western Cape or Mozambique. Decide whether the flood in question happened on a floodplain.

☞ Weigh up some of the advantages, like fertile soil on a floodplain, against the dangers of people inhabiting such an area. Can floodplains be protected from floods?

Study section 3.4

Winds and deserts

The time scheduled for this study section is 11 hours.

Learning outcomes

On completion of this study section, you should be able to

- explain that wind is the flow of air in a current
- explain how wind acts as agent for transport, erosion and the deposition of earth materials during the process of eolian erosion
- explain how sand dunes are formed, how they move and what types of dune there are
- explain how desert landscapes are formed
- explain why desertification is an Earth issue in Southern Africa

General overview of learning content

↳ This study section is based on parts of chapter 19 of UE-6, pages 513–533.

- You will study the following **themes** referred to in the scheme on page 513: wind as a flow of air, as a transport agent, as an agent of erosion, as a depositional agent, and wind in the desert environment. This study section **focuses** on how wind acts as an agent of erosion during the transport and deposition of loose grains of earth material, especially in the desert environment.
- The **objective** and **outcome** of this chapter in UE-6 (as stated in blue on page 514 in UE-6) is to gain an understanding of the influence of wind and the power with which it shapes the surface of the Earth, especially in deserts.

☞ The above-mentioned themes can be found under the different subheadings throughout chapter 19. Note which figures belong to which subheading. Also read the summary on pages 532–533 in UE-6 cursorily, the first time round.

3.4.1 Global wind patterns

Read the following section cursorily for background knowledge:

- Read the section "Global wind patterns" on pages 514–515 in UE-6 cursorily to take note of the flow properties of air.
  - ✓ Wind, as a flow, acts according to the same laws of nature as a flow of water except that it is not confined to channels, but flows in all directions.

3.4.2 Wind as a transport agent

Study the relevant sections in UE-6, as follows:

- Carefully read the introductory paragraph to this section on page 515.
- Carefully read the section "Wind strength" on page 515, taking note of fig 19.2.
- Carefully read the section "Particle size" on page 515.
- Carefully read the section "Surface material" on page 516.
- Read the section "Materials carried by wind" on page 516 cursorily, taking note of windblown dust, windblown sand and frosted and rounded grains.

Summary

- Make a short summary of the factors that influence the transport of earth material grains by wind.
  - ✓ Relevant factors are mentioned on page 515 in UE-6: "The amount of material the wind can carry depends on the strength of the wind, the sizes of the particles, and the surface materials of the area over which the wind blows".

3.4.3 Wind as an agent of erosion

Study the relevant sections in UE-6, as follows:

- Study the introductory paragraph and the section "Sandblasting" on page 518, together with fig 19.5 ("A ventifact"), thoroughly.

- Study the section "Deflation" and steps 1–5 of fig 19.7 ("Desert pavement ...") thoroughly. Look at the photos in fig 19.6 ("A shallow deflation hollow ...") and fig 19.7 to get a better idea of these concepts.

Exercise

1. Briefly explain the process whereby a pebble gets its flat surfaces (which meet at sharp ridges) through sandblasting.
   - ✓ High-speed sand particles in the wind collide incessantly with the windward side of a pebble and polishes it until it is smooth. When a strong wind rolls the pebble over, another side is sandblasted.
2. Briefly describe the two theories on how a desert pavement is formed, and give your own opinion on which of the two is more likely to be true.
   - ✓ The two theories are: (i) the process of deflation results in a desert pavement, and (ii) pebbles are driven to the surface during soil-formation processes (UE-6, pp 518–519, including fig 19.7). Briefly describe each.

3.4.4 Wind as a depositional agent

Work through the following sections in UE-6, as indicated:

- Read the introductory paragraph and the section "Where sand dunes form" cursorily for background knowledge.
- Study the section "How sand dunes form and move" thoroughly, together with the sketches of fig 19.10 ("Sand dunes may form in the lee of a rock ...") and steps 1–5 of fig 19.11 ("Sand dune formation ...").

Exercise

Answer the following questions on the formation and movement of sand dunes with aid of the tips (✓) provided.

1. Describe how the particles in a sand bed are driven downwind to form ripples.
   - ✓ Grains saltate in the wind. Ripples are transverse, that is, at right angles to the rent.

2. Describe briefly, with the aid of sketches, how sand grains blown in the wind form a dune on the lee side of an obstacle.

   ✓ The velocity, and therefore the carrying capacity of wind, is lowest on the lee side of the object on the ground. See the text and fig 19.10 on page 521 in UE-6.

3. Explain, with the aid of sketches, how a sand dune is eroded on the windward side, grows to a limited height on the lee side, and is thus displaced downwind if wind keeps exerting its forces on it in the long run.

   ✓ The processes of saltation, deposition and slip are relevant (UE-6, p 522, fig 19.11).

Study the various types of dune, as discussed on page 523 in UE-6, as follows:

- Practise drawing and giving a brief description of each of the four types of dune mentioned below (✓).

  ✓ Barchans – crescent-shaped dunes, concave downwind
  ✓ Transverse dunes – long ridges at right angles to the wind direction
  ✓ Blowout dunes – crescent-shaped dunes, convex downwind
  ✓ Linear or longitudinal dunes – long ridges parallel to the wind direction

Study the formation of loess thoroughly, and read the rest of the section "Dust fall and loess" on pages 523–524 in UE-6 cursorily.

- Write down what loess is and how it forms.

  ✓ "As the velocity of dust-laden wind decreases, the dust settles to form loess, a blanket of sediment composed of fine-grained particles" (UE-6, p 523). Make two brief comments on the stratification and fertility of loess.

3.4.5 The desert environment

Study the relevant sections in UE-6, as follows:

- UE-6, pages 524–530. Read the section "Where deserts are found" cursorily and take note of where the Kalahari, Namib and Sahara deserts are situated in Africa.
- UE-6, pages 527–528. Read the section "Desert weathering" cursorily.
- UE-6, pages 529–531. Summarise the text under the heading "Desert sediment and sedimentation".

- ✓ Make brief notes on each of the three types of sediment, that is alluvial, eolian and evaporite sediment.

- UE-6, pages 529–531. Carefully read the section "Desert landscape", including fig 19.21 on the evolution of pediment.

Exercise

Answer the following questions with the aid of the tips (✓) provided.

1. Define the term "pediment", which is the description of a typical desert land form.
   - ✓ A pediment consists of eroded bedrock surface and a mountain front which retreats to form a broad, gently sloping platform.
2. Draw and describe the four developmental stages of a typical pediment.
   - ✓ UE-6, pages 529–530, fig 19.21: "... a pediment is formed by running water that both cuts the erosional platform above and deposits an alluvial fan apron below".

3.4.6 Revision and application

Revision

1. Once again read the summary of this study section on pages 532–533 in UE-6.
2. What kinds of materials and grain sizes can wind transport ("particle size")?
3. How does vegetation slow down the deflation process?
4. Where are sand dunes formed?
5. Name three types of sand dune and the position of each in relation to the wind direction.
6. Which typical desert landform consists of sediment?
7. How is loess formed?
8. Make sure that you can define and apply the following key terms in respect of winds and deserts, as discussed in chapter 19 in UE-6:

Key terms and concepts	UE-6, page
barchan	522
blowout dune	522
deflation	519
desertification	525
desert pavement	519
linear (longitudinal) dune	522
loess	523
pediment	530
playa	529
sandblasting	518
slip face	522
transverse dune	522
ventifact	518

Application

Earth issue – Desertification in Southern Africa

- Use the map of the desert areas of the world (UE-6, p 525, fig 19.15) to decide whether the landscape of Southern Africa is arid or semiarid.
- Discuss briefly the influence that plate tectonics, climate change, and human inhabitants have on the process of desertification in Southern Africa. Use the section on pages 524–525 in UE-6 as a basis and apply it to Southern Africa.

☞ From the above, conclude briefly, in writing, what the main causes of desertification in Southern Africa are, and make suggestions on how the inhabitants (humankind and animals) can limit their contribution to desertification.

Study section 3.5

Glaciers – the work of ice

The time scheduled for this study section is six (6) hours.

Learning outcomes

On completion of this study section, you should be able to explain

- that ice crystals constitute a mineral which compacts to form like a rock ice
- that glacier balance involves the simultaneous accumulation and ablation of ice
- that glaciers move by means of plastic flow or basal slip
- how glacier landscapes such as a hanging valley and an esker are formed
- how a controversy in the Snowball Earth hypothesis can be applied as a research method in geological science

General overview of learning content

↳ This study section is based on part of chapter 21 of UE-6, pages 569–596.

- You will study the following **themes** referred to in the scheme on page 596: ice as a rock; how glaciers move; glacial landscapes; and the Pleistocene ice age. This study section **focuses** on the effects of the forward movement and retreat of glaciers, during which time they carry loads and deposit them as sediments, and contribute to the marks and shapes of the surface of the Earth.
- The **objective** and **outcome** of this chapter in UE-6 (UE-6, p 570, the text in blue) are, briefly, to investigate the ways in which the glaciers of the Earth change, and to gain an understanding of how these changes are influenced or caused by the Earth system and human activities.

✓ The above-mentioned themes can be found under the different subheadings throughout chapter 21. Note which figures and tables belong to each subheading. Also read the summary on page 596 in UE-6 cursorily the first time round.

3.5.1 Ice as a rock

Study the section "Ice as a rock" on pages 570–571 in UE-6 as follows:

- Briefly summarise the introductory paragraph, as well as the section "What is a glacier".
  - ✓ Ice is a mineral. The concepts "valley glacier" and "continental glacier" are relevant.
- Read the section "How glaciers form" on pages 573–575 in UE-6 cursorily for background information.
- Carefully read the section "Glacial growth: accumulation", together with fig 21.7, on pages 574–575.
- Carefully read "Glacial shrinkage: ablation" on page 574.
- Carefully read "Glacial budgets: accumulation minus ablation" together with fig 21.8 on pages 574–575.

Exercise

Answer the following questions with the aid of the tips (✓).

1. What is a glacier?

   ✓ "Glaciers are large masses of ice on land that show evidence of being in motion or of once having moved".

2. Describe the different stages in the transformation of snow crystals into glacial ice.

   ✓ "Burial and aging produce solid glacial ice as the smallest grains recrystallize, cementing all the grains together." The stages are snow, granular ice, firn and glacial ice.

3. Name and briefly describe the four mechanisms whereby a glacier can lose some of its ice (ablation).

   ✓ Melting, calving, sublimation and wind erosion. Explain each in a single sentence.

4. Portray the forward motion and retreat (accumulation and ablation) of ice in a labelled sketch of the glacial budget.

   ✓ See fig 21.8 on page 575 in UE-6. The glacial budget is the difference between accumulation and ablation.

3.5.2 How glaciers move

Study the various sections of "How glaciers move" (UE-6, pp 576–580) as follows:

- Carefully read the introductory paragraph and the section "Mechanisms of glacial flow", as well as steps 1–8 of fig 21.10 ("Glaciers flow by plastic flow and basal slip") on pages 576–579 in UE-6.
- Briefly summarise the section "Flow patterns and speeds" on pages 578–579, to indicate the difference between valley and continental glaciers.

  ✓ Valley glaciers flow partly by basal slip and partly by plastic flow, whereas continental glaciers flow mostly by basal slip.

Exercise

Answer the following questions with the aid of the tips (✓).

1. Briefly describe how plastic flow of the ice crystals in a glacier takes place.

   ✓ Under high pressure "ice crystals may stretch and rotate, or grow and recrystallize, and in some cases slide past each other" (text and fig 21.10 on page 577 in UE-6).

2. Compare the different mechanisms of motion and the direction of flow of the ice mass of valley glaciers and continental glaciers.

   ✓ Valley glacier: the fastest movement of ice occurs in the centre and at top of the glacier, mostly by means of plastic flow. Continental glacier: the ice moves down and out from the thickest section, mostly by means of basal slip.

3. Where and why does a crevasse occur on the surface of a moving glacier?

   ✓ The ice mass is deformed most where it rubs against valley walls or on the bedrock. Ice is a brittle material under low pressure, which has a breaking point when deformed. Integrate these two concepts.

3.5.3 Glacial landscapes

Study the various sections under "Glacial landscapes" (UE-6, pp 580–588) as follows:

- Carefully read the introductory paragraph and the section "Glacial erosion and erosional landforms" on pages 580–584 in UE-6. Make simplified 2-D sketches for yourself so that you will be able to describe the glacial action that formed a roche moutonée (UE-6, p 582, fig 21.15), a U-shaped valley and a hanging valley (UE-6, p 583, fig 21.16).
- Carefully read, on pages 584–588 in UE-6, the introductory paragraph and the rest of the section "Glacial sedimentation and sedimentary landforms", together with table 21.1 ("Glacial morains"), fig 21.17 ("Glacial drift is deposited ...") and fig 21.18 ("Glacial deposits. As a glacier retreats ...").

Exercise

Answer the following questions with the aid of the tips given to you (✓).

1. Distinguish between glacial debris, rock flour and striations with regard to their origins.

   ✓ The fragments of rock which are broken from the walls and taken along as a glacier flow are caught up in the middle of the ice and deposited unchanged as glacial debris elsewhere. If, however, the fragments of rock are dragged along the base of the ice, the rocks scratch or groove the glacial pavement (striations), while the rock itself is crushed finer and pulverised (rock flour).

2. Indicate on simple sketches the origins and shapes of a V-shaped valley, a U-shaped valley and a hanging valley.

   ✓ These valleys are caused respectively by a river, a glacier and a tributary glacier that flows into a main valley glacier.

3. Indicate on a simple sketch the different positions where a glacier deposited transported rock material as a ground moraine, an end moraine, drift and outwash.

   ✓ The above-mentioned deposits were listed as they occur in the direction of flow.

4. Name the depositing mechanisms for a moraine and an esker.

   ✓ A moraine is an ice deposit, whereas an esker is deposited by the flowing meltwater of a glacier.

3.5.4 Glacial cycles

Study the various sections of "Ice ages: the Pleistocene glaciation" (UE-6, page 592) as follows:

- Read the section "The record of ancient glaciation" (UE-6, pp 592–593) cursorily, together with fig 21.25, with a view to a discussion on the Snowball Earth hypothesis and its place in geological science, in the application of section 3.5.5 on scientific method.
  - ✓ South Africa was part of the ancient land Pangaea which experienced a glaciation and thereafter drifted to its current position, according to the theory of plate tectonics (fig 21.25).
  - ✓ The oldest Precambrian glaciation occurred about 3 billion years ago, the deposits of which occur as tillites, that is lithified till, in South Africa as well.

3.5.5 Revision and application

Revision

1. Once again read the summary of this study section on page 596 in UE-6.
2. How are valley glaciers distinguished from continental glaciers?
3. How is snow turned into glacial ice?
4. What is the mechanism of glacial flow?
5. How do glaciers erode bedrock?
6. Why are striations proof of previous ice ages?
7. Name three kinds of glacial sediment.
8. Name three landforms that have been created by glaciers.
9. Make sure that you can define and apply the following key terms with regard to glaciers, as described in chapter 21 of UE-6.

Key terms and concepts	UE-6, page
ablation	574
basal slip	576
continental glacier	572
crevasse	576
drift	585
drumlin	585
esker	586
glacier	570
ice stream	578
kame	585
kettle	586
moraine	585
outwash	585
permafrost	588
plastic flow	576
rock flour	580
surge	576
till	585
tillite	592
valley glacier	570

Application

Controversy in the scientific method

Once again look at section 3.5.4 and read the section "The record of ancient glaciation" again, taking special note of the following statements:

- Hypothesis: On the Snowball Earth, there was ice everywhere – even the oceans were frozen.
- Paleomagnetic data indicate that the Precambrian ice might have extended throughout, from the Pangaea (near today's Antarctica) to the equator.
- The authors of UE-6 say "the Snowball Earth hypothesis is controversial" because some geologists have challenged the idea that the oceans may have frozen.

☞ Form your own opinion on the Snowball Earth hypothesis, and decide whether you would be prepared to accept it as a theory.

  ✓ A hypothesis becomes a theory when it has been proven sufficiently to be accepted by a broad scientific community, that is, when controversies have been set aside by scientific research (UE-6, page 2).

Study section 3.6

Coastlines and ocean basins

The time scheduled for this study section is six (6) hours.

Learning outcomes

On completion of this study section, you should be able to

- name the basic differences between the geology of oceans and continents
- describe the geological structures of a topographic profile of the Atlantic Ocean
- draw a profile of a rift valley in a mid-ocean ridge
- demonstrate your understanding of why a turbidity current is triggered by an earthquake
- develop a draft Earth policy on the responsible use of beaches

General overview of learning content

↳ This study section is based on parts of chapter 20 in UE-6, pages 535–567.

- You will study the following **themes** referred to in the scheme on page 535: basic differences in the geology of oceans and continents; the geology of the deep oceans; continental margins; physical and chemical sedimentation in the ocean; and shorelines. The **focus** of this study section is on descriptions of the submarine geologic structures of the Atlantic Ocean floor and on the continental margins.
- The **objectives** and **outcomes** of this chapter in UE-6 (see the text printed in blue on page 536) are, in brief, to discover the geology of the Earth's ocean basins, and to gain an understanding of the underwater Earth processes of volcanism, erosion, sedimentation and the subduction of tectonic plates in terms of the interaction between the lithosphere and hydrosphere.

✓ The above-mentioned themes can be found under the various subheadings throughout chapter 20. Note which figures belong to each subheading. Also read the summary on pages 566–567 of UE-6 cursorily the first time round.

The word **ocean** is used for the five major oceans, namely the Atlantic, Pacific, Indian, Arctic and Antarctic oceans, which are connected to each other to form the world ocean. The term sea is used more generally for the major oceans and all the smaller bodies of water which are connected to the world ocean.

3.6.1 Basic differences in the geology of oceans and continents

Study the following, with the aid of the tips/textbook reference (✓):

Summarise the section "Basic differences in the geology of oceans and continents" on page 536 in UE-6, after carefully studying its contents.

✓ "The geology of the continents is complex, and only a portion of their history is preserved in the rock record. Ocean basins are simple in comparison. They are created at mid-ocean ridges where plates separate and are destroyed by subduction ... Deep-sea sediments provide an almost complete record of the relatively brief geologic history of ocean basins". Expand somewhat on this short summary.

3.6.2 Topology of the deep seafloor

Study the various sections of "Topology of the deep seafloor" on pages 557–564 in UE-6 as follows:

- Read the introductory paragraphs and the sections "Probing the seafloor from surface ships" and "Charting the seafloor by satellite" cursorily for background knowledge.
- Carefully read the section on "An Atlantic profile" under the heading "Profiles across two oceans" together with the profile sketch in fig 20.23 and the profile of a rift valley in fig 20.24.
- Carefully read the section "Main features of the deep ocean floor" on pages 562–563 in UE-6.

Exercise

Do the following exercise with the aid of the tips (✓) given.

1. You will not be asked to draw the profile of the Atlantic Ocean floor (UE-6, p 562, fig 20.23) in an examination. Do, however, study the profile carefully, so that you can keep on referring back to it in order to understand the whole of the parts you will be studying further on. Make sure that you can describe, in words, every deep-sea feature on the profile, for example the abyssal plain, submarine canyons, seamounts and guyots, as these appear in the text on pages 562 and 563 in UE-6.

2. Draw a profile of a rift valley in a mid-ocean ridge.
   - ✓ The valley walls form part of the ridge (UE-6, p 561, fig 20.24).

3. Summarise the section "Main features of the deep ocean floor".
   - ✓ Arrange your summary according to the geological processes involved – the tectonic and volcanic activities around a mid-ocean ridge, seafloor spreading and sedimentation on the abyssal hills and plains, volcanism and erosion as far as seamounts are concerned, hotspot islands and plateaus.

4. What kind of rocks does a rift valley in an ocean ridge contain?
   - ✓ The valley walls are faulted and intruded by basaltic magma in the form of sills and dykes (plates and channels), while the valley floor is covered with flows of basalt and talus blocks from the valley walls (chunks or rock that have broken off the walls) mixed with a little sediment.

5. Which kinds of minerals are formed near a hydrothermal spring on the seafloor?
   - ✓ Mounds consisting of iron-rich clay minerals ... and what else?

6. What kind of earth material do abyssal hills and the seafloor consist of?
   - ✓ Older basaltic rocks form new seafloor which drifts away from the ocean ridge ... and what else?

7. How did the flat tops of guyots come about?
   - ✓ Write down how the tops of the seamounts were eroded.

3.6.3 Continental margins

Study the sections under "Continental margins" on pages 555–557 in UE-6 as follows:

☞ Take note of the definition of "continental margins": "The shorelines, shelves, and slopes of the continents are together called continental margins" (UE-6, p 555).

- Carefully read the introductory paragraphs on active and passive margins, together with fig 20.18, on page 555 in UE-6.
- Read the section "Continental shelf" on page 556 cursorily.
- Carefully read the section "Continental slope and rise: turbidity currents", together with fig 20.19, on page 556.
- Read the section "Submarine canyons" on page 556 cursorily.

Exercise

Do the following exercises with the aid of the tips (✓).

1. Indicate the different parts of a passive continental margin on a simple sketch – from the coastal plain to the abyssal plain.

   ✓ See fig 20.18(a) on page 555 in UE-6. Also indicate the continental shelf, the continental slope, and the continental rise.

2. With the aid of a sketch, describe briefly how a turbidity current develops in the ocean, and flows further to form a submarine fan and comes to rest in layers of sand, silt and mud.

   ✓ See fig 20.19(a) and the text on pages 556 and 557 in UE-6. A mass of sediment which is draped over the edge of the continental shelf is disturbed by an earthquake, slumps onto the continental slope and rapidly moves further down it. Expand on this.

3.6.4 Ocean sedimentation

Read the sections under "Ocean sedimentation" on pages 563–564 in UE-6 cursorily.

- Note that different sedimentation processes are involved in each of the continental margin and deep-sea environments.

- ✓ There are two main types of sedimentation processes in the sea, namely terrigenous sedimentation – mud and sand which have been eroded from the continents; and biochemical sedimentation – precipitates from the shells of sea organisms.

3.6.5 Shorelines

Read the text under the heading "Shorelines" on pages 548–555 cursorily.

- Use the information to help you form your own opinion on the Earth issue of the preservation of beaches.
  - ✓ Take note of the sand budget, which is the balance of natural erosion and sedimentation processes on a beach.

3.6.6 Revision and application

Revision

1. Once again read the summary of this study section on pages 566–567 in UE-6.
2. Which kinds of sediments occur on the continental shelf and continental rise?
3. Name the irregular features of the continental slope.
4. Where do abyssal hills occur?
5. Where do turbidity currents develop?
6. Why is there so little sediment on the rift valley floor of the mid-Atlantic ridge?
7. How did human interference affect some beaches?
8. Make sure that you can define and apply the following key terms in respect of the Earth beneath the ocean, as described in chapter 20 of UE-6:

Key terms and concepts	UE-6, page
abyssal hill	561
abyssal plain	555
active margin	556
continental margin	556
continental rise	555
continental shelf	557
continental slope	555
guyot	563
passive margin	556
pelagic sediment	563
sand budget	550
submarine canyon	556
turbidite	556
turbidity current	556

Application

Earth issue – The preservation of our beaches

- Read the following cursorily for ideas to use in a draft policy.
- Find an article in the popular press about a recent beach issue. Typical issues that are reported on are buildings and structures on beaches, mining activities to extract heavy metals from the sand on beaches, and four-wheel-drive vehicles on beaches.

☞ Use the above reading to draw up a draft policy for the responsible use of beaches which, in your opinion, will strike a balance between conservation and sensible human use.

✓ Apply, in particular, the concept of sand budget as described under "The structure of beaches" on page 549 in UE-6. Humans may, for instance, influence the rate of erosion and deposition of sand, which in turn may disturb the vegetation on sand dunes.

Study section 3.7

Landscape development

The time scheduled for this study section is seven (7) hours.

Learning outcomes

On completion of the study section, you should be able to

- describe the geomorphology of a landscape in terms of the concepts of topography, elevation and relief
- describe the interaction between landscapes and the formative geological processes of erosion and sedimentation in a manner that is indicative of your understanding of this interaction
- explain how various processes in interactive geosystems reach a balance through feedback mechanisms

General overview of learning content

↳ This study section is based on parts of chapter 22 in UE-6, pages 599–621.

- You will study the following **themes** referred to in the scheme on page 599 in UE-6: how the terms topography, elevation and relief are applied; how the features of landforms have been sculpted by erosion and sedimentation; and how interacting geosystems control landscape. This study section **focuses** on the balance between the processes of erosion and sedimentation in the formation of landscapes, as well as on the balance in the interactions between different geosystems.
- The **objective** and **outcome** of this chapter, in brief (see the text printed in blue on page 600 in UE-6), is to gain an understanding of how the tectonic processes of uplift, and the climate-driven processes of weathering, erosion and sedimentation interact dynamically to shape landscapes.

✓ The themes mentioned above can be found under the different subheadings throughout chapter 22. Note which figures belong to which subheading. Also read the summary on page 620 in UE-6 cursorily, the first time round.

☞ The modern study of geomorphology not only describes the relief of the crust of the Earth, but also explains, by means of scientific methods, how these landforms have been shaped by geological processes.

3.7.1 Topography, elevation, and relief

Study the section "Topography, elevation and relief" on pages 600–603 in UE-6 selectively, as follows:

- You must understand the definitions of topography (UE-6, p 600, fig 22.1), elevation and relief (UE-6, p 602, fig 22.3) and be able to put them in words. Write them down now.

  ✓ The **topography** of a terrain is the "general configuration of varying heights that give shape to Earth's surface" (UE-6, Glossary, p GL-15).
  ✓ **Elevation** is "the altitude, or vertical distance, above or below sea level" (UE-6, Glossary, p GL-5).
  ✓ **Relief** is "the difference between the highest and lowest elevations in a particular area" (UE-6, Glossary, p GL-12).

3.7.2 Landforms: features sculpted by erosion and sedimentation

Study the section "Landforms: features sculpted by erosion and sedimentation" on pages 603–611 in UE-6 as follows:

- With the aid of the tips (✓) given to you, summarise this section with regard to the physical descriptions of the various landforms and the geological processes giving rise to them. Do so as follows:

  ✓ The introductory paragraph on page 603. Examples of landforms are mountains, valleys, floodplains and dunes. Erosion, for one, is a process which has contributed to the formation of landforms.
  ✓ "Mountains and hills" on page 604. The steepness of the slopes of mountains and hills generally correlates with elevation and relief. Plate tectonic processes such as uplift and folding shape mountains.
  ✓ "Plateaus" on page 605. A plateau is a high, broad, flat area which has been lifted regionally by tectonic forces. A mesa is a kind of plateau.

- ✓ "Structurally controlled ridges and valleys", together with fig 22.12, on page 610 in UE-6. The erosional process of a hill is determined by the resistance the layers in an anticline poses to erosion. Thus a valley can be formed on top of an anticline ridge, through the erosion caused by a river.
- ✓ Regions with varying topography and types of bedrock have river valleys of varying shapes and widths. Narrow and wide V- and U-shapes are created through different erosion processes.
- ✓ "Balance between stream power and resistance to erosion" (UE-6, figure 22.9, p 606). Erosion is determined by the balance between the stream power and the bedrock's ability to resist erosion.
- ✓ "Structurally controlled cliffs", UE-6, page 611. A cuesta is an asymmetrical ridge, formed by differential erosion. A hogback is a small, symmetrical ridge of resistant strata which has been tilted nearly vertically by tectonic forces.

Exercise

Do the following exercises, with the aid of the tips (✓) given to you.

1. Discuss briefly, with the aid of sketches, how a river valley develops on the ridge of an anticline.
   - ✓ The erosion-resistant layer on top of the anticline prevents the walls of the valley from eroding away, while the stream cuts faster through the softer layers.

2. Draw sketches to depict the following types of valley, and describe in words the balance between resistance and stream power which determines the shape of the valley in each case:
   - The steep, V-shaped walls of a canyon eroded by a river in a mountainous area
     - ✓ In steep, wet terrain stream power exceeds resistance to erosion.
   - A wide, open valley in an area with low mountains
     - ✓ Where slopes are gentler, and the flow of the river is slower, stream power and resistance are in balance.
   - A river flowing through a broad, flat lowland valley
     - ✓ The slopes of the valley walls are even flatter, and the stream power is so low that little erosion takes place and the sediment load is deposited on the valley floor.

3.7.3 Interacting geosystems control landscape

Study the sections under the heading "Interacting geosystems control landscape" on pages 611–615 as follows:

- Carefully read the introductory paragraphs and fig 22.16 on pages 611–612 where the interaction between the plate tectonic and climate geosystems is explained.
- Carefully read the section "Feedback between uplift and erosion" on pages 613–614 together with fig 22.18(a) (Uplift – "A negative feedback loop ...") and fig 22.18(b) (Isostasy – "A positive feedback response ...").
- Carefully read the section "Models of landscape development" on pages 615–616.

Exercise

Do the following exercises with the aid of the tips (✓):

1. Identify in fig 22.16 the following components of the geosystem that participate in mutual interactions and determine the shapes of landscapes:

    - the rock cycle of the plate tectonic system, which functions in the lithosphere and asthenosphere and is driven by the internal heat of the Earth
    - the weather/climate and the ocean circulation in the climate system, which is driven by the sun as external source of heat and which functions in the atmosphere and hydrosphere

2. Explain briefly how uplift stimulates erosion because of negative feedback.

    ✓ The uplifting of the mountains causes increased rainfall and erosion, which then cancel out (wear away) the uplift.

3. Explain briefly how isostatic mantle rebound raises mountain elevation as a result of positive feedback.

    ✓ According to the principle of isostasy, mountains float on the plastic asthenosphere. Weathering of the tops of the mountains reduces the mass and the mountains rise/rebound isostatically accelerating the weathering action.

4. Briefly describe the feedback between the climate and topography of a landscape.

    ✓ The agents of erosion (eg glaciers, rivers and landslides) determine the topography of an area. These agents work at different rates at different altitudes, depending on the climate.

3.7.4 Revision and application

Revision

1. Once again read the summary of this study section on page 620 in UE-6.
2. Name three examples of landforms.
3. What is topographic relief, and how does it relate to altitude?
4. Compare the different processes of erosion in topographically high and low areas.
5. How do river slope and discharge influence the stream power of a river?
6. How does climate influence the topography of a region and the topography of a region influence climate?
7. Make sure that you can define and apply the following key terms relating to landscapes formed by tectonic and climate interaction, as described in chapter 22 in UE-6:

Key terms and concepts	UE-6, page
abrasion	492
contour	601
badland	607
cuesta	611
elevation	601
geomorphology	600
hogback	611
landform	603
mesa	605
negative feedback	615
plateau	605
relief	601
stream power	605
topography	600

Application

Feedback mechanisms between geosystems

1. Briefly describe the hypothesis that mountain building (tectonic uplift) in the Northern Hemisphere influences climate. This is an example of positive feedback between the plate tectonic system and the climate system.

2. Briefly describe the hypothesis that climate change in Tibet may lead to the isostatic uplift of high mountains. This is an example of negative feedback between the plate tectonic system and the climate system.

Study section 3.8

Earth issues relating to external Earth processes

The time scheduled for this study section is two (2) hours.

Learning outcomes

On completion of this study section, you should be able to add your input on

- the prevention of landslides and the flooding of floodplains
- the limited water resources of Southern Africa as they relate to its desertification
- a policy on the preservation of beaches
- the hydrological processes involved in the ice ages and the formation of landscapes on the Earth

General overview of learning content

↳ This study section is based on chapters 16–22 in UE-6.

- The following **themes** have already been studied as Earth issues in study sections 3.1 to 3.7: the prevention of landslides; the flooding of floodplains; the prevalence of water and deserts in Southern Africa; the preservation of beaches; a hypothesis on ice ages; and feedback mechanisms in the geosystem.
- The **objective** and **outcome** of this study section is to allow you to take part in discussions on the Earth issues following from the subject themes covered in study unit 3. The **focus** of this section on Earth issues is to gain an understanding of the interactions between humankind and the geosystem, and to encourage a sense of responsibility for humankind's share in and usage of that system.

✓ The above-mentioned themes can be found in the "Revision and application" sections of study sections 3.1 to 3.7 in the SG, as well as in the boxed articles titled "Earth issues" or "Earth policy" in chapters 16 to 22 in UE-6.

Revising the following Earth issues will help you answer a possible examination question.

3.8.1 Earth issues: perspectives on humankind and the surface of the Earth

Revision

Once again read your notes on all the Earth issue themes covered under "Applications" in the previous study sections. Also use the tips (✓) below.

1. In study section 3.1.4: **Earth policy to prevent landslides**

   - The environmental scientist must be able to apply his/her knowledge of geology and the earth/soils to check and evaluate the facts of an impact study and other terrain data before human activities take place in a particular environment. In this manner landslides caused by human activities can be prevented.
     - ✓ Read in UE-6 how engineers underestimated three early warning signs of a landslide, which ultimately resulted in a flooding disaster.

2. In study section 3.2.7: **Water in South Africa**

   - Water is limited in South Africa.
     - ✓ The investigation you have done in study section 3.2.7 has probably convinced you that water supplies in South Africa, which consist of groundwater, the water in rivers and reservoir dams, and rainfall, are limited.
   - How can water in South Africa be used responsibly?
     - ✓ You have investigated a hypothesis that borehole water (groundwater) in South Africa is being polluted. What was your conclusion?
     - ✓ You have made a synthesis of three conclusions on the availability, borehole origin and pollution of water in relation to the demand for water in South Africa.
     - ✓ Based on your synthesis, make a recommendation on how South Africa's population can use water responsibly.

3. In study section 3.3.7: **Streams on floodplains**

- The issue of human habitation on a floodplain was discussed.
  - ✓ Do you think that people would go and live on a floodplain even if they were informed about previous floods? What can be done in advance to limit human losses?

4. In study section 3.4.6: **Desertification in Southern Africa**

- Integrate your conclusions on the reasons for desertification in Southern Africa with the hypothesis in study section 3.2.7 that the water supplies of the region are limited. Is there a relationship?
  - ✓ The Southern African landscape is arid or semiarid (UE-6, p 525, fig 19.15, "Major desert areas of the world").

5. In study section 3.5.4: **Glacial cycles**

- Hypothesis: On the Snowball Earth there was ice all over, even the oceans were frozen.
- What are ice ages and what causes them?
  - ✓ An ice age occurs when continental glaciers expand far beyond the polar regions. Although continental drift is cited as a possible cause, this is still uncertain.

6. In study section 3.6.6: **The dynamics of beaches**

- An Earth policy for the preservation of our beaches was discussed.
  - ✓ What do you think of the statement of the authors: "Sooner or later, we must learn to let the beaches remain in their natural state"?

7. In study section 3.7.4: **Feedback mechanisms between geosystems**

- The rock cycle is the interaction between the plate tectonic and climate systems (UE-6, p 77).
- The hydrologic cycle occurs between the subsystems of the geosystem – the atmosphere, the hydrosphere and the lithosphere.
- "The hydrologic cycle is a component of the Earth system and thus interacts with the atmospheric, ocean, and landscape components" (UE-6, p 457).
  - ✓ Landscapes are formed by geosystem processes and in turn influence the formative processes through negative and positive feedback.
  - ✓ The finding of this interaction is a very good example of the results of modern research methods. Models of natural phenomena are shaped into unifying theories, such as that of plate tectonics. The processes that form landscapes interact with the different geosystems, which are driven by internal and external sources of heat.

Summary of study unit 3 – External Earth processes

The external processes of the Earth system, as driven by the internal heat energy of the Earth and the Sun as external source of energy, determine the different geological expressions found on the surface of the Earth. They are processes near the surface of the Earth which cause the movement of glaciers, soil, water and sand dunes, thus forming the local and global landscapes. The interaction between the climate system and the plate tectonic system not only determines the processes of the hydrologic system, but also the processes which create landscapes under the oceans. Because water on the surface of the Earth is also a crucial commodity for humans and animals alike, the prevalence, pollution and control of water and its accompanying processes were discussed as Earth issues.

Summary of module GEL1503 – Environmental geology

The **outcome** you should have attained with this course is an understanding of the following – in the words of the authors: "We present geology as a unified, process-based science with the power to convey global meaning to geologic features wherever they are found".

In this module on the subject of geology, we have used a model that portrays the Earth as a system consisting of subsystems like the climate and plate tectonic systems. In this model, the internal processes of the Earth, such as mantle convection (which is a method of transferring energy), are related to corresponding surface phenomena, like the movement of tectonic plates. The theory of plate tectonics integrates the explanations for a number of geological phenomena into one global theory which takes all internal and external Earth processes into account.

External geological processes, such as mass wasting and streams that convey weathered rock material to the sea through the process of erosion, were also discussed as interactive subsystems. By viewing these interactive systems as a balance of formative processes, we can identify and describe landforms.

The place of standard scientific research methodologies in the discipline of geology was also explained. During the course of your studies, you were given the opportunity to practise putting your knowledge into words by giving short answers, writing reports and doing assignments. In the process you have developed the skills to provide your own input on ethical issues in the field of geology and your environment.

May each student who completes this course apply his/her skills in a useful, responsible way.

This study guide was written and compiled by Mr L Smuts.