

Geology

Senior High

Grade 11

Teacher Guide

Standards-Based



Papua New Guinea

Department of Education

**'FREE ISSUE
NOT FOR SALE'**

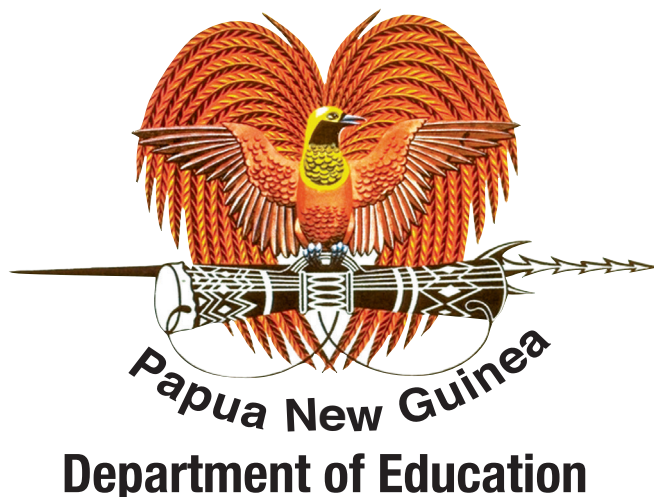
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Issued free to schools by the Department of Education

Published in 2020 by the Department of Education

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Contents

Acknowledgements.....	iv
Acronyms.....	v
Secretary’s Message	vi
Introduction	1
Structure of the Teacher Guide	2
Purpose of the Teacher Guide.....	3
How to use the Teacher Guide	5
Syllabus and Teacher Guide Alignment	10
Learning and Performance Standards	12
Core Curriculum	16
Science, Technology, Engineering, Arts, and Mathematics	18
Curriculum Intergration	28
Essential Knowledge, Skills, Values and Attitudes and Scientific Thinking Process.....	32
Teaching and Learning Strategies.....	41
Strands, Units and Topics	44
Strand 1: Science as Inquiry	50
Strand 2: Earth Science... ..	79
Standards-Based Lesson Planning.....	174
Assessment, Monitoring and Reporting.....	178
Glossary	201
References	211
Appendices.....	212

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Acronyms

AAL	Assessment As Learning
AFL	Assessment For Learning
AOL	Assessment Of Learning
BoS	Board of Studies
CDD	Curriculum Development Division
CP	Curriculum Panel
CRS	Classroom Response System
DA	Diagnostic Assessment
HOD	Head of Department
IHD	Integral Human Development
MTDG	Medium Term Development Goal
NGO	Non-Government Organisation
PBA	Performance Based Assessment
PNG	Papua New Guinea
SAC	Subject Advisory Committee
SBC	Standards Based Curriculum
SBE	Standards Based Education
SCG	Subject Curriculum Group
SRS	Student Response System
STEAM	Science, Technology, Engineering, Arts and Mathematics
STEM	Science, Technology, Engineering and Mathematics

Secretary's Message

The aims and goals of the SBC identify the important knowledge, skills, values, and attitudes that all students are expected to acquire and master in order to effectively function in society and actively contribute to its development, students' welfare and enable them to acquire and apply 21st Century knowledge, skills, values, and attitudes in their life after Grade 12.

The basic knowledge of Geology is essential to meeting the environmental challenges and natural resource limitations of the twenty-first Century. It is critical that earth-science education begin at the kindergarten level and include advanced offerings at the secondary school level, and that highly qualified earth-science teachers provide the instruction.

Geology is an integrated science, including biology, chemistry, and physics as they apply to the workings of Earth. The applied, and often visual, nature of earth science helps learners see its relevance to their lives and to their communities. Engaging students in learning about Earth supports the development of problem solving, analytical and critical thinking skills and at the same time highlights the importance of Science, Technology, Engineering, Arts and Math (STEAM) careers to society.

This is a critical time for students to understand how Earth works as a system and how humans interact with Earth. Understanding the causes and potential societal consequences of natural Earth processes and the production, availability, and potential depletion of natural resources is of particular importance.

Empowering students with scientific knowledge and skills to make informed decisions as citizens is a vital undertaking and a key responsibility for science educators, geoscientists and all citizens.

I encourage teachers to read each section of the guide carefully and become familiar with the content of the subject specified in this guide. I also encourage teachers to try out your own ideas, strategies and available resources that you believe will effectively work in your schools for your students.

I commend and approve this Grade 11 Geology Teacher Guide to be used by teachers in all Senior High Schools throughout Papua New Guinea.



.....
UKE W. KOMBRA, (PhD)
Secretary for Education

Introduction

In its broadest sense, geology is the study of Earth – its interior and its exterior surface, the rocks and other materials that are around us, the processes that have resulted in the formation of those materials, the water that flows over the surface and lies underground, the changes that have taken place over the vastness of geological time, and the changes that we can anticipate will take place in the near future.

Geology is a science, meaning that students will use deductive reasoning and scientific methods to understand geological problems. It is arguably, the most integrated of all the sciences because it involves the understanding and application of all of the other sciences: physics, chemistry, biology, mathematics, astronomy, and others. But unlike most of the other sciences, geology has an extra dimension, that of time – deep time – billions of years of it.

This Grade 11 Geology Teacher Guide was developed as a support document for the implementation of Grade 11 Geology Syllabus. It contains useful information that you should read and familiarize yourself with before you plan and teach the subject. The guidelines provided are translated from the content standards prescribed in the syllabus into teachable content. The suggested teaching and learning strategies given will assist you to plan quality and interactive science lessons based on the knowledge, skills, attitudes and values from the benchmarks.

The teacher guide also contains samples of assessment tasks and rubrics that will help you to design quality assessments to measure students' performance against the intended content standards and evidence outcomes. The learning activities prepared must engage and motivate your students to think critically and communicate ideas freely with other students in their class.

The Grade 11 Geology is timetabled for **240** minutes per week.

Structure of the Teacher Guide

There are four main components to this teacher guide. They provide essential information on what all teachers should know and do to effectively implement the Geology curriculum.

Part 1 provides generic information to help the teachers to effectively use the teacher guide and the syllabus to plan, teach and assess students' performance and proficiency on the national content standards and grade-level benchmarks. The purpose of the teacher guide, syllabus and teacher guide alignment, and the four pillars of PNG SBC, which are morals and values education, cognitive and high level thinking, and 21st Century thinking skills, STEAM, and core curriculum. There are explained to inform as well as guide the teachers so that they align SBE/SBC aims and goals, overarching and SBC principles, content standards, grade-level benchmarks, learning objectives and best practice when planning lessons, teaching, and assessing students.

Part 2 provides information on the strands, units, topics and learning objectives. How topics and learning objectives are derived is explained to the teachers to guide them to use the learning objectives provided for planning, instruction and assessment. Teachers are encouraged to develop additional topics and learning objectives to meet the learning needs of their students and communities where necessary.

Part 3 provides information on SBC planning to help guide the teachers when planning SBC lessons. Elements and standards of SBC lesson plans are described as well as how to plan for underachievers, use evidence to plan lessons, and use differentiated instruction, amongst other teaching and learning strategies.

Part 4 provides information on standards-based assessment, inclusive of performance assessment and standards, standards-based evaluation, standards-based reporting, and standards-based monitoring. This information should help the teachers to effectively assess, evaluate, report and monitor demonstration of significant aspects of a benchmark.

The above components are linked and closely aligned. They should be connected to ensure that the intended learning outcomes and the expected quality of education standards are achieved. The close alignment of planning, instruction and assessment is critical to the attainment of learning standards.

Purpose of the Teacher Guide

This teacher guide describes what all teachers should know and do to effectively plan, teach, and assess Grade 11 Geology content to enable all students to attain the required learning and proficiency standards. The overarching purpose of this teacher guide is to help teachers to effectively plan, teach, assess, evaluate, report and monitor students' learning and mastery of national and grade-level expectations. That is, the essential knowledge, skills, values and attitudes (KSVAs) described in the content standards and grade-level benchmarks, and their achievement of the national and grade-level proficiency standards.

Ample information with thorough guidelines is provided for the teacher to use to achieve the essential KSVAs embedded in the set national content standards and grade level benchmarks.

Thus, the teacher is expected to;

- understand the significance of aligning all the elements of Standards-Based Curriculum (SBC) as the basis for achieving the expected level of education quality,
- effectively align all the components of SBC when planning, teaching, and assessing students' learning and levels of proficiency,
- effectively translate and align the Geology syllabi and teacher guide to plan, teach and assess different Geology units and topics, and the KSVAs described in the grade-level benchmarks,
- understand the Geology national content standards, grade-level benchmarks, and evidence outcomes,
- effectively make sense of the content (KSVAs) described in the Geology national content standards and the essential components of the content described in the grade-level benchmarks;
- effectively guide students to progressively learn and demonstrate proficiency on a range of Geology skills, processes, concepts, ideas, principles, practices, values and attitudes,
- confidently interpret, translate and use Geology content standards and benchmarks to determine the learning objectives and performance standards, and plan appropriately to enable all students to achieve these standards,
- embed the core curriculum in their Geology lesson planning, instruction, and assessment to permit all students to learn and master the core KSVAs required of all students,

- provide opportunities for all students to understand how STEAM has and continues to shape the social, political, economic, cultural, and environment contexts and the consequences, and use STEAM principles, skills and process,
- integrate cognitive skills (critical, creative, reasoning, decision-making, and problem-solving skills), high level thinking skills (analysis, synthesis and evaluation skills), values (personal, social, work, health, peace, relationship, sustaining values), and attitudes in lesson planning, instruction and assessment;
- meaningfully connect what students learn in Geology with what is learnt in other subjects to add value and enhance students' learning so that they can integrate what they learn and develop in-depth vertical and horizontal understanding of subject content,
- formulate effective SBC lesson plans using learning objectives identified for each of the topics,
- employ SBC assessment approaches to develop performance assessments to assess students' proficiency on a content standard or a component of the content standard described in the grade-level benchmark and
- effectively score and evaluate students' performance in relation to a core set of learning standards or criteria, and make sense of the data to ascertain students' status of progress towards meeting grade-level and nationally expected proficiency standards, and use evidence from the assessment of students' performance to develop effective evidence-based intervention strategies to help students' making inadequate or slow progress towards meeting the grade-level and national expectations to improve their learning and performance.

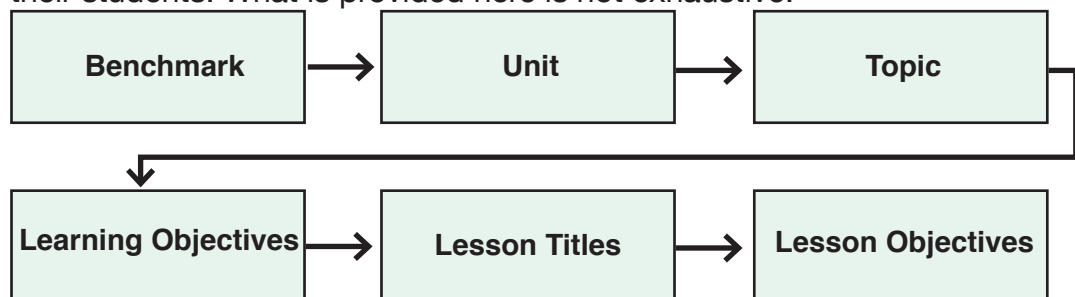
How to use the Teacher Guide

Teacher Guide provides essential information about what the teacher needs to know and do to effectively plan, teach and assess students learning and proficiency on learning and performance standards. The different components of the teacher guide are closely aligned with SBC principles and practice, and all the other components of PNG SBC. It should be read in conjunction with the syllabus in order to understand what is expected of teachers and students to achieve the envisaged quality of education outcomes.

The first thing teachers should do is to read and understand each of the sections of the teacher guide to help them understand the key SBC concepts and ideas, alignment of PNG SBC components, alignment of the syllabus and teacher guide, setting of content standards and grade-level benchmarks, core curriculum, STEAM, curriculum integration, essential knowledge, skills, values and attitudes, strands, units and topics, learning objectives, SBC lesson planning, and SBC assessment. A thorough understanding of these components will help teachers meet the teacher expectations for implementing the SBC curriculum, and therefore the effective implementation of Grades 11 and 12 Geology Curriculum. Based on this understanding, teachers should be able to effectively use the teacher guide to do the following:

Determine Lesson Objectives and Lesson Titles

Units, topics and learning objectives have been identified and described in the Teacher Guide and Syllabus. Learning objectives are derived from topics that are extracted from the grade-level benchmarks. Lesson titles are deduced from the learning objectives. Teachers should familiarise themselves with this process as it is essential for lesson planning, instruction and assessment. However, depending on the context and students' learning abilities, teachers would be required to determine additional lesson objectives and lesson titles. Teachers should use the examples provided in this teacher guide to formulate additional lesson objectives and lesson titles to meet the educational or learning needs of their students. What is provided here is not exhaustive.



Identify and Teach Grade Appropriate Content

Grade appropriate content has been identified and scoped and sequenced using appropriate content organisation principles. The content is sequenced using the spiraling sequence principles. This sequencing of content will enable students to progressively learn the essential knowledge, skills, values and attitudes as they progress further into their schooling. What students learn in previous grades is reinforced and deepens in scope with an increase in the level of complexity and difficulty in the content and learning activities.

It is important to understand how the content is organised so that grade appropriate content and learning activities can be selected, if not already embedded in the benchmarks and learning objectives, to not only help students learn and master the content, but ensure that what is taught is rigorous, challenging, and comparable.

Integrate the Core Curriculum in Lesson Planning, Instruction and Assessment

Teachers should use this teacher guide to help them integrate the core curriculum – values, cognitive and high level skills, 21st Century skills, STEAM principles and skills, and reading, writing, and communication skills in their lesson planning, instruction and assessment. All students in all subjects are required to learn and master these skills progressively through the education system.

Integrate Cognitive, High Level, and 21st Century Skills in Lesson Planning, Instruction and Assessment

Teachers should integrate the cognitive, high level and 21st Century skills in their annual teaching programs, and give prominence to these skills in their lesson preparation, teaching and learning activities, performance assessment, and performance standards for measuring students' proficiency on these skills. Science addresses the skills and processes of sensitive, moral, ethical and environmental issues in the physical world and global industries. Thus, students will be able to make informed decisions, problem – solving and management knowledge, skills, values and attitudes in Science. This enables them to function effectively in the work and higher education environments as productive and useful citizens of a culturally diverse and democratic society in an interdependent world.

In addition, it envisaged all students attaining expected proficiency levels in these skills and will be ready to pursue careers and higher education academic programs that demand these skills, and use them in their everyday life after they leave school at the end of Grade 12. Teachers should use the teacher guide to help them to effectively embed these skills, particularly in their lesson planning and in the teaching and learning activities as well as in the assessment of students' application of the skills.

Integrate Science Values and Attitudes in Lesson Planning, Instruction and Assessment

In science, students are expected to learn, promote and use work, relationship, peace, health, social, personal, family, community, national and global values in the work and study environments as well as in their conduct as community, national and global citizens. Teachers should draw from the information and suggestions provided in the syllabus and teacher guide to integrate values and attitudes in their lesson planning, instruction, and assessment. They should report on students' progression towards internalizing different values and attitudes and provide additional support to students who are yet to reach the internalization stage to make positive progress towards this level.

Integrate Science, Technology, Engineering, Arts and Mathematics (STEAM) Principles and Skills in Lesson Planning, Instruction and Assessment

Teachers should draw from both the syllabus and teacher guide in order to help them integrate STEAM principles and skills, and methodologies in their lesson planning, instruction and assessment. STEAM teaching and learning happens both inside and outside of the classroom. Effective STEAM teaching and learning requires both the teacher and the student to participate as core investigators and learners, and to work in partnership and collaboration with relevant stakeholders to achieve maximum results. Teachers should use the syllabus, teacher guides and other resources to guide them to plan and implement this and other innovative and creative approaches to STEAM teaching and learning to make STEAM principles and skills learning fun and enjoyable and, at the same time, attain the intended quality of learning outcomes.

Identify and Use Grade and Context Appropriate, Innovative, Differentiated and Creative Teaching and Learning Methodologies

SBC is an eclectic curriculum model. It is an amalgam of strengths of different curriculum types, including behavioural objectives, outcomes, and competency. Its emphasis is on students attaining clearly defined, measurable, observable and attainable learning standards, i.e., the expected level of education quality. Proficiency (competency) standards are expressed as performance standards/criteria and evidence outcomes, that is, what all students are expected to know (content) and do (application of content in real life or related situations) to indicate that they are meeting, have met or exceeded the learning standards. The selection of grade and contextually appropriate teaching and learning methodologies is critical to enabling all students to achieve the expected standard or quality of education. Teaching and learning methodologies must be aligned to the content, learning objective, and performance standard in order for the teacher to effectively teach and guide students towards meeting the performance standard for the lesson. They should be equitable and socially inclusive, differentiate, student-centred, and lifelong. They should enable STEAM principles and skills to be effectively taught and learned by students. Teachers should use the teacher guide to help them make informed decisions when selecting the types of teaching and learning methodologies to use in their teaching of the subject content, including STEAM principles and skills.

Plan Standards-Based Lessons

SBC lesson planning is quite difficult to do. However, this will be easier with more practice and experience over time. Effective SBC lesson plans must meet the required standards or criteria so that the learning objectives and performance standards are closely aligned to attain the expected learning outcomes. Teachers should use the guidelines and standards for SBC lesson planning and examples of SBC lesson plans provided in the teacher guide to plan their lessons. When planning lessons, it is important for teachers to ensure that all SBC lesson planning standards or criteria are met. If standards are not met, instruction will not lead to the attainment of intended performance and proficiency standards. Therefore, students will not attain the national content standards and grade-level benchmarks.

Use Standards-Based Assessment

Standards-Based Assessment has a number of components. These components are intertwined and serve to measure evaluate, report, and monitor students' achievement of the national and grade-level expectations, i.e., the essential knowledge, skills, values and attitudes they are expected to master and demonstrate proficiency on. Teachers should use the information and examples on standards-based assessment to plan, assess, record, evaluate, report and monitor students' performance in relation to the learning standards.

Make informed Judgments About Students' Learning and Progress Towards Meeting Learning Standards

Teachers should use the teacher guide to effectively evaluate students' performance and use the evidence to help students to continuously improve their learning as well as their classroom practice.

It is important that teachers evaluate the performance of students in relation to the performance standards and progressively the grade-level benchmarks and content standards to make informed judgments and decisions about the quality of their work and their progress towards meeting the content standards or components of the standards. Evaluation should not focus on only one aspect of students' performance. It should aim to provide a complete picture of each student's performance. The context, inputs, processes, including teaching and learning processes, and the outcomes should be evaluated to make an informed judgment about each student's performance. Teachers should identify the causal factors for poor performance, gaps in students learning, gaps in teaching, teaching and learning resource constraints, and general attitude towards learning. Evidence-based decisions can then be made regarding the interventions for closing the gaps to allow students to make the required progress towards meeting grade-level and national expectations.

Prepare Students' Performance Reports

Reporting of students' performance and progress towards the attainment of learning standards is an essential part of SBC assessment. Results of students' performance should be communicated to particularly the students and their parents to keep them informed of students' academic achievements and learning challenges as well as what needs to be done to enable the students' make positive progress towards meeting the proficiency standards and achieve the desired level of education quality. Teachers should use the information on the reporting of students' assessment results and the templates provided to report the results of students' learning.

Monitor Students' Progress Towards Meeting the National Content Standards and Grade-Level Benchmarks

Monitoring of student's progress towards the attainment of learning standards is an essential component of standards-based assessment. It is an evidence-based process that involves the use of data from students' performance assessments to make informed judgements about students' learning and proficiency on the

learning standards or their components, identify gaps in students' learning and the causal factors, set clear learning improvement targets, and develop effective evidence-based strategies (including pre-planning and re-teaching of topics), set clear time frames, and identify measures for measuring students' progress towards achieving the learning targets.

Teachers should use the teacher guide to help them use data from students' performance assessments to identify individual students' learning weaknesses and develop interventions, in collaboration with each student and his/her parents or guardians, to address the weaknesses and monitor their progress towards meeting the agreed learning goals.

Develop additional Benchmarks

Teachers can develop additional benchmarks using the examples in the teacher guide to meet the learning needs of their students and local communities. However, these benchmarks will not be nationally assessed as these are not comparable. They are not allowed to set their own content standards or manipulate the existing ones. The setting of national content standards is done at the national level to ensure that required learning standards are maintained and monitored to sustain the required level of education quality.

Avoid Standardisation

The implementation of Science curriculum must not be standardised.

SBC does not mean that the content, lesson objectives, teaching and learning strategies, and assessment are standardised. This is a misconception and any attempt to standardise the components of curriculum without due consideration of the teaching and learning contexts, student's backgrounds and experiences, and different abilities and learning styles of students will be counterproductive. It will hinder students from achieving the expected proficiency standards and hence, high academic standards and the desired level of education quality. That is, they should not be applied across all contexts and with all students, without considering the educational needs and the characteristics of each context. Teachers must use innovative, creative, culturally relevant, and differentiated teaching and learning approaches to teach the curriculum and enable their students to achieve the national content standards and grade-level benchmarks. And enable all students to experience success in learning the curriculum and achieve high academic standards.

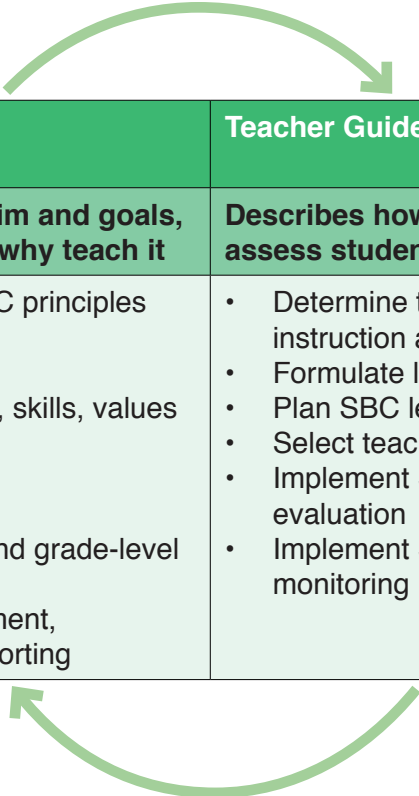
What is provided in the syllabus and teacher guide are not fixed and can be changed. Teachers should use the information and examples provided in the syllabus and the teacher guide to guide them to develop, select, and use grade, context, and learner appropriate content, learning objectives, teaching and learning strategies, and performance assessment and standards. SBC is evidence-based hence decisions about the content, learning outcomes, teaching and learning strategies, students' performance, and learning interventions should be based on evidence. Teaching and learning should be continuously improved and effectively targeted using evidence from students' assessment and other sources.

Syllabus and Teacher Guide Alignment

A teacher guide is a framework that describes how to translate the content standards and benchmarks (learning standards) outlined in the syllabus into units and topics, learning objectives, lesson plans, teaching and learning strategies, performance assessment, and measures for measuring students' performance (performance standards). It expands the content overview and describes how this content identified in the content standards and their components (essential KSVAs) can be translated into meaningful and evidence-based teaching topics and learning objectives for lesson planning, instruction and assessment. It also describes and provides examples of how to evaluate and report on students' attainment of the learning standards, and use evidence from the assessment of students' performance to develop evidence-based interventions to assist students who are making slow progress towards meeting the expected proficiency levels to improve their performance.

This subject comprises of the Syllabus and Teacher Guide. These two documents are closely aligned, complimentary and mutually beneficial.

They are the essential focal points for teaching and learning the essential Social Science knowledge, skills, values and attitudes.



Syllabus	Teacher Guide
Outlines the ultimate aim and goals, and what to teach and why teach it	Describes how to plan, teach, and assess students' performance
<ul style="list-style-type: none"> • Overarching and SBC principles • Content overview • Core curriculum • Essential knowledge, skills, values and attitudes • Strands and units • Evidence outcomes • Content standards and grade-level benchmarks • Overview of assessment, evaluation, and Reporting 	<ul style="list-style-type: none"> • Determine topics for lesson planning, instruction and assessment • Formulate learning objectives • Plan SBC lesson plans • Select teaching and learning strategies • Implement SBC assessment and evaluation • Implement SBC reporting and monitoring

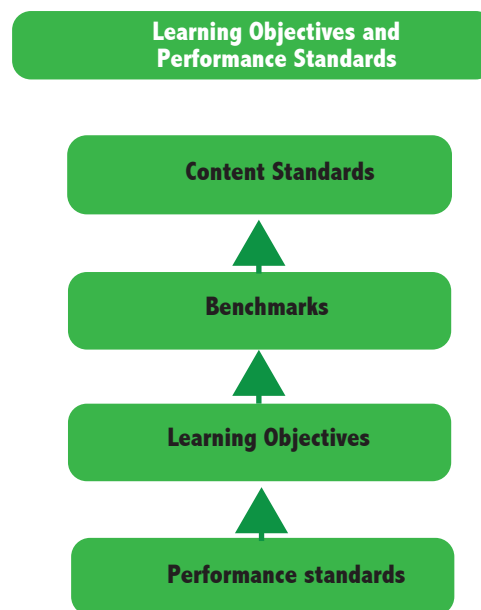
The syllabus outlines the ultimate aim and goals of SBE and SBC, what is to be taught and why it should be learned by students, the underlying principles and articulates the learning and proficiency standards that all students are expected to attain. On the other hand, the teacher guide expands on what is outlined in the syllabus by describing the approaches or the how of planning, teaching, learning, and assessing the content so that the intended learning outcomes are achieved.

This teacher guide should be used in conjunction with the syllabus. Teachers should use these documents when planning, teaching and assessing Grade 11 content.

Teachers will extract information from the syllabus (e.g., content standards and grade-level benchmarks) for lesson planning, instruction and is for measuring students' attainment a content standard as well as progress to the next grade of schooling.

Learning and Performance Standards Alignment

Content Standards, Benchmarks, Learning Objectives, and Performance Standards are very closely linked and aligned. There is a close linear relationship between these standards. Students' performance on a significant aspect of a benchmark (KSVA) is measured against a set of performance standards or criteria to determine their level of proficiency using performance assessment. Using the evidence from the performance assessment, individual student's proficiency on the aspect of the benchmark assessed and progression towards meeting the benchmark and hence the content standard are then determined.



Effective alignment of these learning standards and all the other components of PNG SBE and SBC (ultimate aim and goals, overarching, SBC and subject-based principles, core curriculum, STEAM, and cognitive, high level, and 21st Century skills) is not only critical but is also key to the achievement of high academic standards by all students and the intended level of education quality. It is essential that teachers know and can do standards alignment when planning, teaching, and assessing students' performance so that they can effectively guide their students towards meeting the grade-level benchmarks (grade expectations) and subsequently the content standards (national expectations).

Learning and Performance Standards

Standards-Based Education (SBE) and SBC are underpinned by the notion of quality. Standards define the expected level of education quality that all students should achieve at a particular point in their schooling. Students' progression and achievement of education standard(s) are measured using performance standards or criteria to determine their demonstration or performance on significant aspects of the standards and therefore their levels of proficiency or competency. When they are judged to have attained proficiency on a content standard or benchmark or components of these standards, they are then deemed to have met the standard(s) that is, achieved the intend level of education quality.

Content standards, benchmarks, and learning objectives are called learning standards while performance and proficiency standards (evidence outcomes) can be categorised as performance standards. These standards are used to measure students' performance, proficiency, progression and achievement of the desired level of education quality. Teachers are expected to understand and use these standards for lesson planning, instruction and assessment.

Content Standards

Content standards are evidence-based, rigorous and comparable regionally and globally. They have been formulated to target critical social, economic, political, cultural, environment, and employable skills gaps identified from a situational analysis. They were developed using examples and experiences from other countries and best practice, and contextualized to PNG contexts.

Content standards describe what (**content - knowledge, skills, values, and attitudes**) all students are expected to know and do (how well students must learn and apply what is set out in the content standards) at each grade-level before proceeding to the next grade. These standards are set at the national level and thus cannot be edited or changed by anyone except the National Subject-Based Standards Councils.

Content Standards;

- are evidenced-based,
- are rigorous and comparable to regional and global standards,
- are set at the national level,
- state or describe the expected levels of quality or achievement,
- are clear, measurable and attainable,
- are linked to and aligned with the ultimate aim and goals of SBE and SBC and overarching and SBC principles,
- delineate what matters, provide clear expectations of what students should progressively learn and achieve in school, and guide lesson planning, instruction, assessment,
- comprise knowledge, skills, values, and attitudes that are the basis for quality education,
- provide teachers a clear basis for planning, teaching, and assessing lessons and
- provide provinces, districts, and schools with a clear focus on how to develop and organise their instruction and assessment programs as well as the content that they will include in their curriculum.

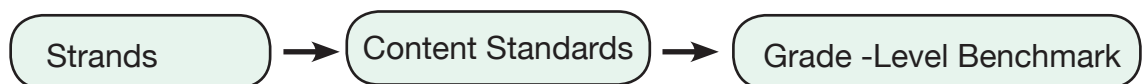
Benchmarks

Benchmarks are derived from the content standards and benchmarked at the grade-level. Benchmarks are specific statements of what students should know (i.e., essential knowledge, skills, values or attitudes) at a specific grade-level or school level. They provide the basis for measuring students' attainment of a content standard as well as progress to the next grade of schooling.

Grade-level benchmarks;

- are evidenced-based,
- are rigorous and comparable to regional and global standards,
- are set at the grade level,
- are linked to the national content standards,
- are clear, measurable, observable and attainable,
- articulate grade level expectations of what students are able to demonstrate to indicate that they are making progress towards attaining the national content standards,
- provide teachers a clear basis for planning, teaching, and assessing lessons,
- state clearly what students should do with what they have learned at the end of each school-level,
- enable students' progress towards the attainment of national content standards to be measured, and
- enable PNG students' performance to be compared with the performance of students in other countries.

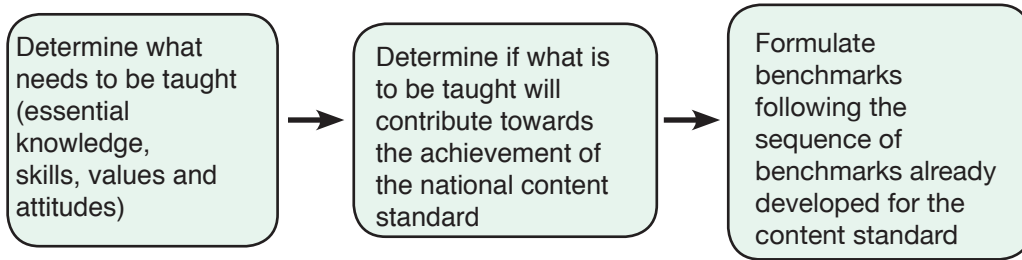
Approach for Setting National Content Standards and Grade-Level Benchmarks



Development of Additional Benchmarks

Teachers should develop additional benchmarks to meet the learning needs of their students. They should engage their students to learn about local, provincial, national and global issues that have not been catered for in the grade-level benchmarks but are important and can enhance students' understanding and application of the content. However, it is important to note that these benchmarks will not be nationally examined as they are not comparable. Only the benchmarks developed at the national level will be tested. This does not mean that teachers should not develop additional benchmarks. An innovative, reflect, creative and reflexive teacher will continuously reflect on his/her classroom practice and use evidence to provide challenging, relevant, and enjoyable learning opportunities for his/her students to build on the national expectations for students. Teachers should follow the following process when developing additional grade-level benchmarks.

Benchmark Development Process



Learning Objectives

Learning or instructional Objectives are precise statements of educational intent. They are formulated using a significant aspect or a topic derived from the benchmark, and is aligned with the educational goals, content standards, benchmarks, and performance standards. Learning objectives are stated in outcomes language that describes the products or behaviours that will be provided by students. They are stated in terms of measurable and observable student behaviour. For example, students will be able to identify all the layers of the earth.

Performance Standards

Performance Standards are concrete statements of how well students must learn what is set out in the content standards, often called the “**be able to do**” of “what students should know and be able to do.” Performance standards are the indicators of quality that specify how competent a students’ demonstration or performance must be. They are explicit definitions of what students **must do to demonstrate proficiency or competency at a specific level on the content standards**.

Performance standards;

- measure students’ performance and proficiency (using performance indicators) in the use of a specific knowledge, skill, value, or attitude in real life or related situations,
- provide the basis (performance indicators) for evaluating, reporting and monitoring students’ level of proficiency in use of a specific knowledge, skills, value, or attitude,
- are used to plan for individual instruction to help students not yet meeting expectations (desired level of mastery and proficiency) to make adequate progress towards the full attainment of benchmarks and content standards, and
- are used as the basis for measuring students’ progress towards meeting grade-level benchmarks and content standards.

Proficiency Standards

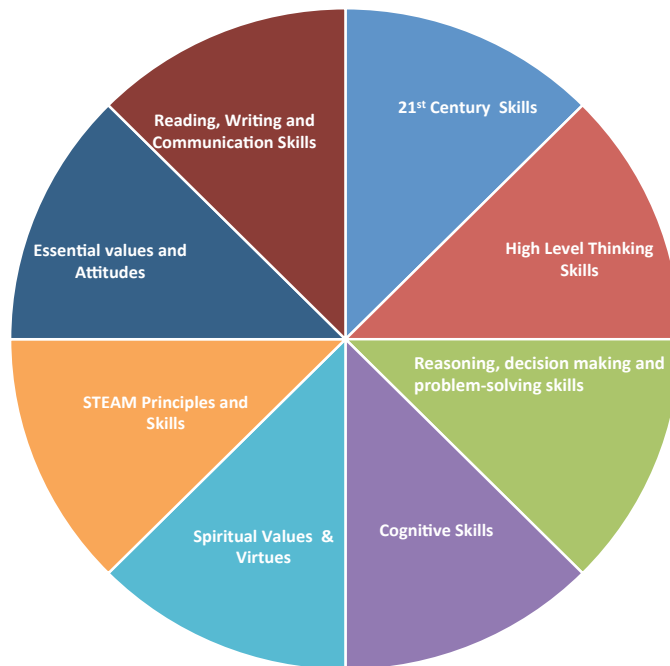
Proficiency standards describe what all students in a particular grade or school level can do at the end of a strand, or unit. These standards are sometimes called evidence outcomes because they indicate if students can actually apply or use what they have learnt in real life or similar situations. They are also categorized as benchmarks because that is what all students are expected to do before exiting a grade or are deemed ready for the next grade.

Core Curriculum

A core set of common learnings (knowledge, skills, values, and attitudes) are integrated into the content standards and grade-level benchmarks for all subjects. This is to equip all students with the most essential and in-demand knowledge, skills, and dispositions they will need to be successful in modern/postmodern work places, higher-education programs and to be productive, responsible, considerate, and harmonious citizens. Common set of learnings are spirally sequenced from Preparatory - Grade 12 to deepen the scope and increase the level of difficulty in the learning activities so that what is learned is reinforced at different grade levels.

The core curriculum includes:

- cognitive (thinking) skills (Refer to the syllabus for a list of these skills),
- reasoning, decision-making and problem-solving skills,
- high level thinking skills (analysis, synthesis and evaluation skills),
- 21st Century skills,
- reading, writing and communication skills,
- STEAM principles and skills,
- essential values and attitudes (personal and social values, and sustaining values), and
- spiritual values and virtues.



The essential knowledge, skills, values and attitudes comprising the core curriculum are interwoven and provide an essential and holistic framework for preparing all students for careers, higher education and citizenship.

All teachers are expected to include the core learnings in their lesson planning, teaching, and assessment of students in all their lessons. They are expected to foster, promote and model the essential values and attitudes as well as the spiritual values and virtues in their conduct, practice, appearance, and their

relationships and in their professional and personal lives. In addition, teachers are expected to mentor, mould and shape each student to evolve and possess the qualities envisioned by society.

Core values and attitudes must not be taught in the classroom only; they must also be demonstrated by students in real life or related situations inside and outside of the classroom, at home, and in everyday life. Likewise, they must be promoted, fostered and modelled by the school community and its stakeholders, especially parents. A holistic approach to values and attitudes in teaching, promoting and modelling is critical to students and the whole school community to internalise the core values and attitudes and making them habitual in their work and school place, and in everyday life. Be it work values, relationship values, peace values, health values, personal and social values, or religious values, teachers should give equal prominence to all common learnings in their lesson planning, teaching, assessment, and learning interventions. Common learnings must be at the heart of all teaching and extra-curricular programs and activities.

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Science, Technology, Engineering, Arts and Mathematics

STEAM education is an integrated, multidisciplinary approach to learning that uses science, technology, engineering, arts and mathematics as the basis for inquiring about how STEAM has and continues to change and impact the social, political, economic, cultural and environmental contexts and identifying and solving authentic (real life) natural and physical environment problems by integrating STEAM-based principles, cognitive, high level and 21st Century skills and processes, and values and attitudes.

Chemistry is focused on both goals of STEAM rather than just the goal of problem-solving. This is to ensure that all students are provided opportunities to learn, integrate, and demonstrate proficiency on all essential STEAM principles, processes, skills, values and attitudes to prepare them for careers, higher education and citizenship.

Objectives

Students will be able to:

- (i) Examine and use evidence to draw conclusions about how STEAM has and continues to change the social, political, economic, cultural and environmental contexts.
- (ii) Investigate and draw conclusions on the impact of STEAM solutions to problems on the social, political, economic, cultural and environmental contexts.
- (iii) Identify and solve problems using STEAM principles, skills, concepts, ideas and process.
- (iv) Identify, analyse and select the best solution to address a problem.
- (v) Build prototypes or models of solutions to problems.
- (vi) Replicate a problem solution by building models and explaining how the problem was or could be solved.
- (vii) Test and reflect on the best solution chosen to solve a problem.
- (viii) Collaborate with others on a problem and provide a report on the process of problem solving used to solve the problem.
- (ix) Use skills and processes learnt from lessons to work on and complete STEAM projects.
- (x) Demonstrate STEAM principles, skills, processes, concepts and ideas through simulation and modelling.
- (xi) Explain the significance of values and attitudes in problem-solving.

STEAM is a multidisciplinary and integrated approach to understanding how science, technology, engineering, arts and mathematics shape and are shaped by our material, intellectual, cultural, economic, social, political and environmental contexts. And for teaching students the essential in demand cognitive, high level and 21st Century skills, values and attitudes, and empower them to effectively use these skills and predispositions to identify and solve problems relating to the natural and physical environments as well as the impact of STEAM-based solutions on human existence and livelihoods, and on the social, political, economic, cultural, and environmental systems.

STEAM disciplines have and continue to shape the way we perceive knowledge and reality, think and act, our values, attitudes, and behaviours, and the way we relate to each other and the environment. Most of the things we enjoy and consume are developed using STEAM principles, skills, process, concepts and ideas. Things humans used and enjoyed in the past and at present are developed by scientists, technologists, engineers, artists and mathematicians to address particular human needs and wants. Overtime, more needs were identified and more products were developed to meet the ever changing and evolving human needs. What is produced and used is continuously reflected upon, evaluated, redesigned, and improved to make it more advanced, multipurpose, fit for purpose, and targeted towards not only improving the prevailing social, political, economic, cultural and environmental conditions but also to effectively respond to the evolving and changing dynamics of human needs and wants. And, at the same time, solutions to human problems and needs are being investigated and designed to address problems that are yet to be addressed and concurred. This is an evolving and ongoing problem-solving process that integrates cognitive, high level, and 21st Century skills, and appropriate values and attitudes.

STEAM is a significant framework and focal point for teaching and guiding students to learn, master and use a broad range of skills and processes required to meet the skills demands of PNG and the 21st Century. The skills that students will learn will reflect the demands that will be placed upon them in a complex, competitive, knowledge-based, information-age, technology-driven economy and society. These skills include cognitive (critical, synthetic, creative, reasoning, decision-making, and problem-solving) skills, high level (analysis, synthesis and evaluation) skills and 21st Century skills (see Appendix 4). Knowledge-based, information, and technology driven economies require knowledge workers not technicians. Knowledge workers are lifelong learners, are problem solvers, innovators, creators, critical and creative thinkers, reflective practitioners, researchers (knowledge producers rather than knowledge consumers), solutions seekers, outcomes oriented, evidence-based decision makers, and enablers of improved and better outcomes for all.

STEAM focuses on the skills and processes of problem solving. These skills and processes are at the heart of the STEAM movement and approach to not only problem solving and providing evidence-based solutions but also the development and use of other essential cognitive, high level and 21st century skills. These skills are intertwined and used simultaneously to gain a broader understanding of the problems to enable creative, innovative, contextually relevant, and best solutions to be developed and implemented to solve the problems and attain the desired outcomes. It is assumed that by teaching students STEAM-based problem-solving skills and providing learning opportunities inside and outside the classroom will motivate more of them to pursue careers and academic programs in STEAM related fields thus, closing the skills gaps and providing a pool of cadre of workers required by technology, engineering, science, and mathematics-oriented industries.

STEAM Problem-Solving Processes

Problem-solving involves the use of problem-solving methods and processes to identify and define a problem, gather information to understand its causes, draw conclusions, and use the evidence to design and implement solutions to address it. Even though there are many different problem-solving methods and approaches, they share some of the steps of problem-solving, such as;

- identifying the problem,
- understanding the problem by collecting data,
- analyse and interpret the data,
- draw conclusions,
- use data to consider possible solutions,
- select the best solution,
- test the effectiveness of the solution by trialling and evaluating it, and
- review and improve the solution.

STEAM problem solving processes go from simple and technical to advance and knowledge-based processes. However, regardless of the type of process used, students should be provided opportunities to learn the essential principles and processes of problem solving and, more significantly, to design and create a product that addressed a real problem and meets a human need.

The following are some of the STEAM problem solving processes.

1. Engineering and Technology Problem Solving Methods and Approaches

Engineering and technology problem-solving methods are used to identify and solve problems relating to the physical world using the design process. The following are some of the methods and approaches used to solve engineering and technology related problems.

Parts Substitution

It is the most basic of the problem-solving methods. It simply requires the parts to be substituted until the problem is solved.

Diagnostics

After identifying a problem, the technician would run tests to pinpoint the fault. The test results would be used either as a guide for further testing or for replacement of a part, which also need to be tested. This process continues until the solution is found and the device is operating properly.

Troubleshooting

Troubleshooting is a form of problem solving, often applied to repair failed products or processes.

Reverse Engineering

Reverse engineering is the process of discovering the technological principles underlying the design of a device by taking the device apart, or carefully tracing its workings or its circuitry. It is useful when students are attempting to build something for which they have no formal drawings or schematics.

Divide and Conquer

Divide and conquer is the technique of breaking down a problem into sub-problems, then breaking the sub-problems down even further until each of them is simple enough to be solved. Divide and conquer may be applied to all groups of students to tackle sub-problems of a larger problem, or when a problem is so large that its solution cannot be visualised without breaking it down into smaller components.

Extreme Cases

Considering “extreme cases” – envisioning the problem in a greatly exaggerated or greatly simplified form, or testing using extreme condition – can often help to pinpoint a problem. An example of the extreme-case method is purposely inputting an extremely high number to test a computer program.

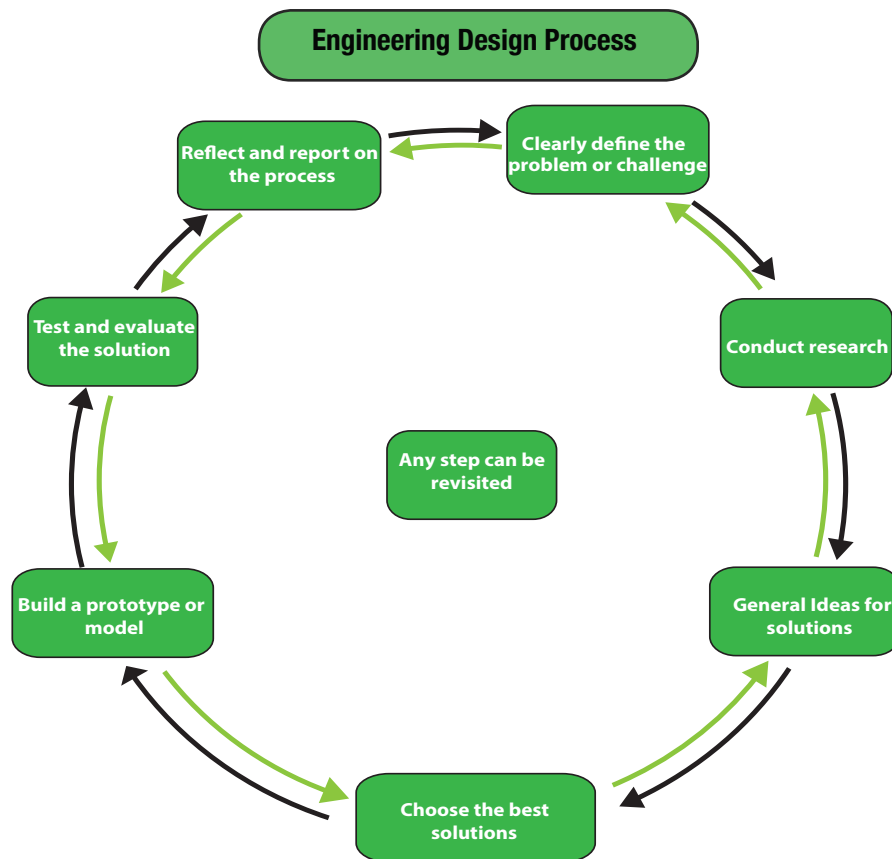
Trial and Error

The trial and error method involve trying different approaches until a solution is found. It is often used as a last resort when other methods have been exhausted.

2. Engineering Design Process

Technological fields use the engineering design process to identify and define the problem or challenge, investigate the problem, collect and analyse data, and use the data to formulate potential solutions to the problem, analyse each of the solutions in terms of its strengths and weaknesses, and choose the best solution to solve the problem. It is an open-ended problem-solving process that involves the full planning and development of products or services to meet identified needs. It involves a sequence of steps such as the following:

1. Analyse the context and background, and clearly define the problem.
2. Conduct research to determine design criteria, financial or other constraints, and availability of materials.
3. Generate ideas for potential solutions, using processes such as brainstorming and sketching.
4. Choose the best solution.
5. Build a prototype or model.
6. Test and evaluate the solution.
7. Repeat steps as necessary to modify the design or correct faults.
8. Reflect and report on the process.



STEAM-Based Lesson planning

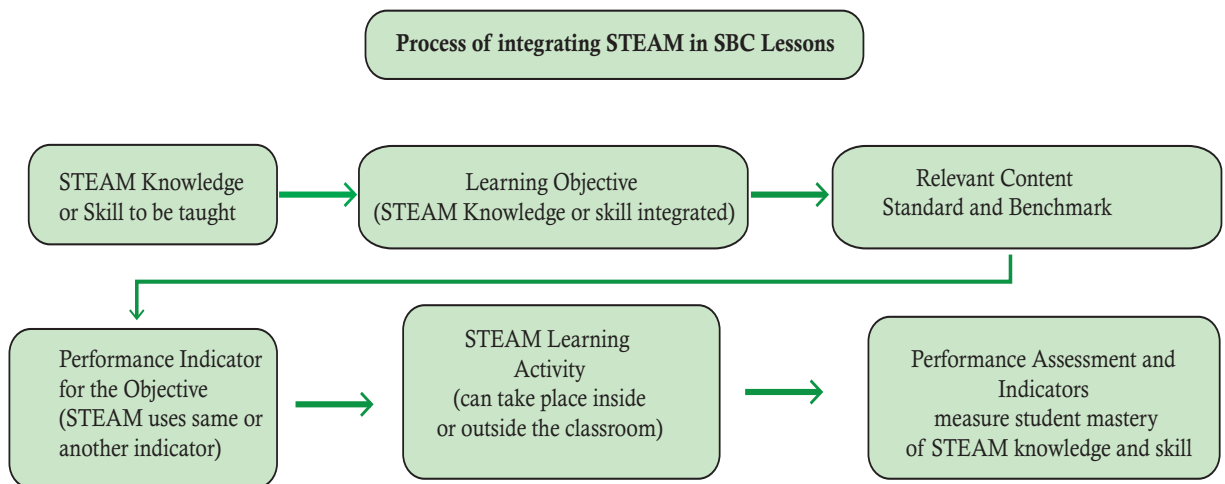
Effective STEAM lesson planning is key to the achievement of expected STEAM outcomes. STEAM skills can be planned and taught using separate STEAM-based lesson plans or integrated into the standards-based lesson plans. To effectively do this, teachers should know how to write effective standards and STEAM-based lesson plans.

An example of a STEAM-based lesson plan is provided in the Appendix. Teachers should use this to guide them to integrate STEAM content and teaching, learning and assessment strategies into their standards-based lesson plans.

Knowing how to integrate STEAM problem-solving skills, principles, values and attitudes as well as STEAM teaching, learning, and assessment strategies into standards-based lesson plans is essential for achieving the desired STEAM learning outcomes. When integrating STEAM problem-solving skills into the standards-based lesson plans, teachers should ensure that these skills are not only effectively aligned to the learning objective and performance standards, they must also be effectively taught and assessed.

Teachers are expected to integrate the essential STEAM principles, processes, skills, values and attitudes described in the grade 12 benchmarks when formulating their standards-based lesson plans. Opportunities should be provided inside and outside of the classroom for students to learn, explore, model and apply what they learn in real life or related situations. These learning experiences will enable students to develop a deeper understanding of STEAM principles, processes, skills, values and attitudes and appreciate their application in real life to solve problems.

Process for Integrating STEAM Principles and Problem-Solving Skills into Standards-Based Lessons



Teachers should follow the steps given below when integrating STEAM problem-solving principles and skills into their standards-based lesson plans.

- Step 1:** Identify the STEAM knowledge or skill to be taught (From the table of KSVAs for each content standard and benchmark). This could already be captured in the learning objective stated in the standards-based lesson plan.
- Step 2:** Develop and include a performance standard or indicator for measuring student mastery of the STEAM knowledge or skill (e.g. level of acceptable competency or proficiency) if this is different from the one already stated in the lesson plan.
- Step 3:** Develop student learning activity (An activity that will provide students the opportunity to apply the STEAM knowledge or skill specified by the learning objective and appropriate statement of the standards). Activity can take place inside or outside of the classroom, and during or after school hours.
- Step 4:** Develop and use performance descriptors (standards or indicators) to analyse students' STEAM related behaviours and products (results or outcomes), which provide evidence that the student has acquired and mastered the knowledge or skill of the learning objective specified by the indicator (s) of the standard (s).

STEAM Teaching Strategies

STEAM education takes place in both formal and informal classroom settings. It takes place during and after school hours. It is a continuous process of inquiry, data analysis, making decisions about interventions, and implementing and monitoring interventions for improvements.

There are a variety of STEAM teaching strategies. However, teaching strategies selected must enable teachers to guide students to use the engineering and artistic design processes to identify and solve natural and physical environment problems by designing prototypes and testing and refining them to effectively mitigate the problems identified. The following are some of the strategies that could be used to utilise the STEAM approach to solve problems and coming up with technological solutions.

- *Inquiry-Based Learning*
- *Problem-Based Learning*
- *Project-based learning,*
- *Collaborative Learning*

Collaborative learning involves individuals from different STEAM disciplines and expertise in a variety of STEAM problem solving approaches working together and sharing their expertise and experiences to inquire into and solve a problem.

Teachers should plan to provide students opportunities to work in collaboration and partnership with experts and practitioners engaged in STEAM related careers or disciplines to learn first-hand about how STEAM related skills, processes, concepts, and ideas are applied in real life to solve problems created by natural and physical environments. Collaborative learning experiences can be provided after school or during school holidays to enable students to work with STEAM experts and practitioners to inquiry and solve problems by developing creative, innovative and sustainable solutions. Providing real life experiences and lessons, e.g., by involving students to actually solve a scientific, technological, engineering, or mathematical, or Arts problem, would probably spark their interest in a STEAM career path. Developing STEAM partnerships with external stakeholders e.g., high education institutions, private sector, research and development institutions, and volunteer and community development organizations can enhance students' learning and application of STEAM problem solving principles and skills.

Some examples of STEAM-related partnership experiences may include:

- *Participatory Learning*
- *Group-Based Learning*
- *Task Oriented Learning*
- *Action Learning*
- *Experiential Learning*
- *Modelling*
- *Simulation*

STEAM Learning Strategies

Teachers should include in their lesson plans STEAM learning activities. These activities should be aligned to principle or a skill planned for students to learn and demonstrate proficiency at the end of the lesson to expose students to STEAM and giving them opportunities to explore STEAM-related concepts, they will develop a passion for it and, hopefully, pursue a job in a STEAM field. Providing real life experiences and lessons, e.g., by involving students to actually solve a scientific, technological, engineering, or mathematical, or arts problem, would probably spark their interest in a STEAM career path. This is the theory behind STEAM education.

STEAM-Based Assessment

STEAM-based assessment is closely linked to standards-based assessment where assessment is used to assess students' level of competency or proficiency of a specific knowledge, skill, value, or attitude taught using a set of performance standards (indicators or descriptors). The link also includes the main components such as the purpose, the assessment principles and assessment strategies and tools.

In STEAM-based assessment, assessments are designed for what students should know and be able to do. In STEAM learning, students are assessed in a variety of ways including portfolios, project/problem-based assessments, backwards design, authentic assessments, or other student-centered approaches.

When planning and designing the assessment, teachers should consider the authenticity of the assessment by designing an assessment that relates to a real world task or discipline specific attributes such as simulation, role play, placement assessment, live projects and debates. These tasks should make the activity meaningful to the student, and therefore be motivating as well as developing employability skills and discipline specific attributes.

Effective STEAM-Based Assessment Strategies

The following are the six assessment tools and strategies shown to impact teaching and learning as well as help teachers foster a 21st Century learning environment in their classrooms.

1. *Rubrics*
2. *Performance-Based Assessments (PBAs)*
3. *Portfolios*
4. *Student self-assessment*
5. *Peer-assessment*
6. *Student Response Systems(SRS).*

Although the list does not include all innovative assessment strategies, it includes what we think are the most common strategies, and ones that may be particularly relevant to the educational context of developing countries in this 21st Century. Many of the assessment strategies currently in use fit under one or more of the categories discussed. Furthermore, it is important to note that these strategies also connect in a variety of ways.

1. *Rubrics*

Rubrics are both a tool to measure students' knowledge and ability as well as an assessment strategy. A rubric allows teachers to measure certain skills and abilities not measurable by standardized testing systems that assess discrete knowledge at a fixed moment in time. Rubrics are also frequently used as part of other assessment strategies including; portfolios, performances, projects, peer-review and self-assessment which are also elaborated in this section.

2. *Performance-Based Assessments*

Performance-Based Assessments (PBA), also known as project-based or authentic assessments, are generally used as a summative evaluation strategy to capture not only what students know about a topic, but if they have the skills to apply that knowledge in a “real-world” situation. By asking them to create an end product. PBA pushes students to synthesize their knowledge and apply their skills to a potentially unfamiliar set of circumstances that is likely to occur beyond the confines of a controlled classroom setting.

The implementation of performance-based assessment strategies can also impact other instructional strategies in the classroom.

3. *Portfolio Assessment*

Portfolios are a collection of student work gathered over time that is primarily used as a summative evaluation method. The most salient characteristic of the portfolio assessment is that rather than being a snapshot of a student's knowledge at one point in time (like a single standardized test), it highlights student effort, development, and achievement over a period of time; portfolios measure a student's ability to apply knowledge rather than simply regurgitate. They are considered both student-centred and authentic assessments of learning.

4. *Self-assessment*

While the previous assessment tools and strategies listed in this report generally function as summative approaches, self-assessment is generally viewed as a formative strategy, rather than one used to determine a student's final grade. Its main purpose is for students to identify their own strengths and weakness and to work to make improvements to meet specific criteria. Self-assessment occurs when students judge their own work to improve performance as they identify discrepancies between current and desired performance". In this way, self-assessment aligns well with standards-based education because it provides clear targets and specific criteria against which students or teachers can measure learning.

Self-assessment is used to promote self-regulation, to help students reflect on their progress and to inform revisions and improvements on a project or paper. In order for self-assessment to be truly effective four conditions must be in place: the self-assessment criteria is negotiated between teachers and students, students are taught how to apply the criteria, students receive feedback on their self-assessments and teachers help students use assessment data to develop an action plan.

5. *Peer assessment*

Peer assessment, much like self-assessment, is a formative assessment strategy that gives students a key role in evaluating learning. Peer assessment approaches can vary greatly but, essentially, it is a process for learners to consider and give feedback to other learners about the quality or value of their work. Peer assessments can be used for variety of products like papers, presentations, projects, or other skilled behaviours. Peer assessment is understood as more than only a grading procedure and is also envisioned as teaching strategy since engaging in the process develops both the assessor and assessee's skills and knowledge.

Curriculum Integration

What is Curriculum Integration?

Curriculum integration is making connections in learning across the curriculum. The ultimate aim of curriculum integration is to act as a bridge to increase students' achievement and engage in relevant curriculum. (Susan M. Drake and Rebecca C. Burns)

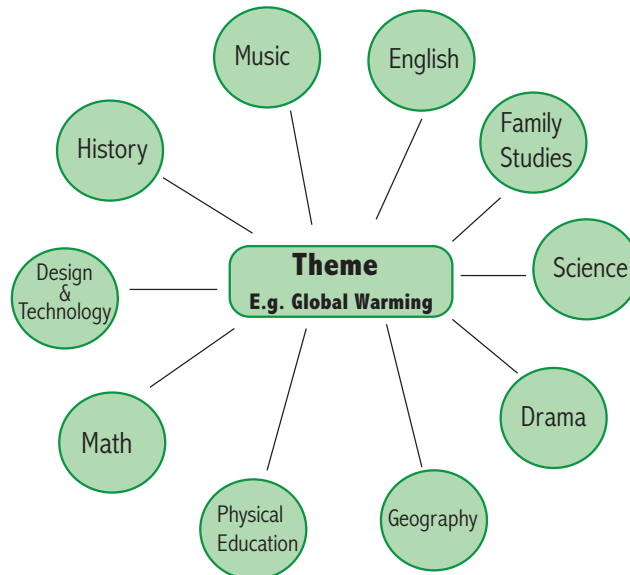
Teachers must develop intriguing curriculum by going beyond the traditional teaching of content based or fragmented teaching to one who is knowledge based and who should be perceived as a 21st Century innovative educator. Curriculum integration is a holistic approach to learning thus curriculum integration in PNG SBC will have to equip students with the essential knowledge, skills, values and attitudes that are deemed 21st Century.

There are three approaches that PNG SBC will engage to foster conducive learning for all its children whereby they all can demonstrate proficiency at any point of exit. Adapting these approaches will have an immense impact on the lives of these children thus they can be able to see themselves as catalyst of change for a competitive PNG. Not only that but they will be comparable to the world standards and as global citizens.

Engaging these three approaches in our curriculum will surely sharpen the knowledge and ability of each child who will foresee themselves as assets through their achievements thus contribute meaningfully to their country. They themselves are the agents of change. Integrated learning will bear forth a generation of knowledge based populace who can solve problems and make proper decisions based on evidence. Thus, PNG can achieve its goals like the Medium Term Development Goals (MTDG) and aims such as the Vision 2050 for a happy, healthy and wealthy society whereby, all its citizens should have access and fair distribution to income, shelter, health, education and general good and services improving the general standard of living for PNG in the long run.

1. (i) Multidisciplinary Approach

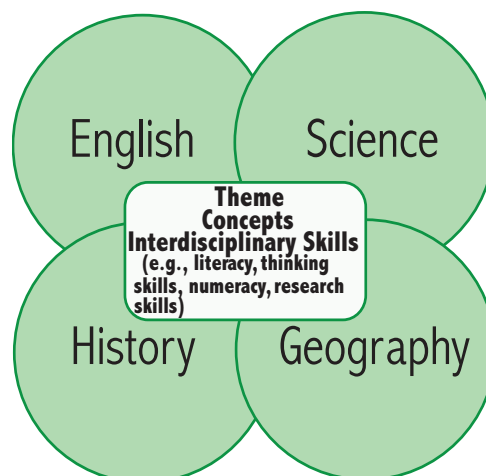
In this approach learning involves a theme or concept that will be taught right across all subject area of study by students. That is, content of a particular theme will be taught right across all subjects as shown in the diagram below. For instance, if the theme is global warming, subject areas create lessons or assessment as per their subjects around this theme. Social Science will address this issue, Science and all other subject likewise.



1. (ii) Interdisciplinary Approach

This approach addresses learning similarly to the multidisciplinary approach of integrated learning whereby learning takes place within the subject area. However, it is termed interdisciplinary in that the core curriculum of learning is interwoven into each subject under study by the students. For instance; in Social Science under the strand of geography students write essay on internal migration however, apart from addressing the issues of this topic, they are to apply the skill of writing text types in their essay such as argumentative essay, informative, explanatory, descriptive, expository and narrative essay while writing their essay. They must be able to capture the mechanics of English skills such as grammar, punctuation and so forth. Though these skills are studied under English they are considered as core skills that cut across all subjects under study. For example; if Science students were to write about human development in biology then the application of writing skills has to be captured by the students in their writing. It is not seen as an English skill but a standard essential skill all students must know and do regardless.

Therefore, essential knowledge, skills, values and attitudes comprising the core curriculum are interwoven and provide an essential and holistic framework for preparing all students for careers, higher education and citizenship in this learning.



2. Intradisciplinary approach

This approach involves teachers integrate sub disciplines within a subject area. For instance, within the subject Social Science, the strands (disciplines) of geography, environment, history, political science and environment will all be captured studying a particular content for Social Science. For example, under global warming, students will study the geographical aspects of global warming, environmental aspect of global warming and likewise for history, political science and economics. Thus, children are well aware of the issues surrounding global warming and can address it confidently at each level of learning.

3. Trans disciplinary Approach

In this approach learning goes beyond the subject area of study. Learning is organized around students' questions and concerns. That is, where there is a need for change to improve lives, students develop their own curriculum to effect these need. The trans-disciplinary approach addresses real-life situations thus giving the opportunity to students to attain real life skills. This learning approach is more to do with Project-Based Learning also referred to as problem-based learning or place-based learning.

Below are the three steps to planning project based curriculum.

1. Teachers and students select a topic of study based on student interests, curriculum standards, and local resources.
2. The teacher finds out what the students already know and helps them generate questions to explore. The teacher also provides resources for students and opportunities to work in the field
3. Students share their work with others in a culminating activity. Students display the results of their exploration and review and evaluate the project.

For instance; students may come up with slogans for school programs such as 'Our culture – clean city for a healthier PNG'. The main aim could be to curb betel nut chewing in public areas especially around bus stops and local markets. Here, students draw up their own instructions and criteria for assessment which is; they have to clean the nearest bus stop or local market once a week throughout the year. They also design and create posters to educate the general public as their program continues. They can also involve the town council and media to assist them especially to carry out awareness.

Studies have proven that Project based-programs have led to the following:

- Students go far beyond the minimum effort
- Make connections among different subject areas to answer open-ended questions
- Retain what they have learnt
- Apply learning to real-life problems
- Have fewer discipline problems
- Lower absenteeism

SUBJECT AREAS

Theme
Concepts
Life Skills

Real world Context -
(Voluntary services/Part time
job experience, exchange programs)

Students Questions

These integrated learning approaches will demand for teachers to be proactive in order to improve students learning and achievements. In order for PNG Standards-Based Curriculum to serve its purpose fully, these three approaches must be engaged for better learning for the children of Papua New Guinea now and in the future.

Essential Knowledge, Skills, Values and Attitudes and Scientific Thinking Process

Students' level of proficiency and progression towards the attainment of content standards will depend on their mastery and application of essential knowledge, skills, values, and attitudes in real life or related situations. Provided here are examples of different types of knowledge, processes, skills, values, and attitudes that all students are expected to learn and master as they progress through the grades. These are expanded and deepen in scope and the level of difficulty and complexity are increased to enable students to study in-depth the subject content as they progress from one grade to the next.

These knowledge, skills, values and attitudes have been integrated into the content standards and benchmarks. They will also be integrated into the performance standards. Teachers are expected to plan and teach essential knowledge, skills, values and attitudes in their lessons, and assess students' performance and proficiency, and progression towards the attainment of content standards.

Types of Knowledge

There are different types of knowledge. These include;

- | | |
|--|--|
| <ul style="list-style-type: none"> • Public and private (privileged) knowledge • Specialised knowledge • Good and bad knowledge • Concepts, processes, ideas, skills, values, attitudes • Theory and practice • Fiction and non-fiction • Traditional, modern, and postmodern knowledge | <ul style="list-style-type: none"> • Subject and discipline-based knowledge • Lived experiences • Evidence and assumptions • Ethics and Morales • Belief systems • Facts and opinions • Wisdom • Research evidence and findings • Solutions to problems |
|--|--|

Types of Processes

There are different types of processes. These include;

- | | |
|---|---|
| <ul style="list-style-type: none"> • Problem-solving • Logical reasoning • Decision-making • Reflection | <ul style="list-style-type: none"> • Cyclic processes • Mapping (e.g. concept mapping) • Modelling • Simulating |
|---|---|

Science Inquiry processes include:

- Gathering information
- Analysing information
- Evaluating information
- Making judgements
- Taking actions

Types of Skills

There are different types of skills. These include:

1. Cognitive (Thinking) Skills

Thinking skills can be categorized into **critical thinking** and **creative thinking** skills.

i. Critical Thinking Skills

A person who thinks critically always evaluates an idea in a systematic manner before accepting or rejecting it. Critical thinking skills include;

- | | |
|---|---|
| <ul style="list-style-type: none"> • Attributing • Comparing and contrasting • Grouping and classifying • Sequencing • Prioritising • Analysing | <ul style="list-style-type: none"> • Detecting bias • Evaluating • Metacognition (Thinking about thinking) • Making informed conclusions. |
|---|---|

ii Creative Thinking Skills

A person who thinks creatively has a high level of imagination, able to generate original and innovative ideas, and able to modify ideas and products. Creative thinking skills include;

- | | |
|---|--|
| <ul style="list-style-type: none"> • Generating ideas • Deconstruction and reconstruction • Relating • Making inferences • Predicting • Making generalisations • Visualizing | <ul style="list-style-type: none"> • Synthesising • Making hypothesis • Making analogies • Invention • Transformation • Modeling • Simulating |
|---|--|

2. Reasoning Skills - Reason is a skill used in making a logical, just, and rational judgment.

3. Decision-Making Skills - Decision-making involves selection of the best solution from various alternatives based on specific criteria and evidence to achieve a specific aim.

4. Problem Solving Skills – These skills involve finding solutions to challenges or unfamiliar situations or unanticipated difficulties in a systematic manner.

5. Literacy Skills

A strong emphasis must be placed on various types of literacy, from financial to technological, from media to mathematical, from content to cultural. Literacy may be defined as the ability of an individual to use information to function in society, to achieve goals and to develop her or his knowledge and potential. Teachers emphasize certain aspects of literacy over others, depending on the nature of the content and skills they want students to learn.

The following literacy skills are intended to be exemplary rather than definitive

- | | |
|---|---|
| <ul style="list-style-type: none"> • Listens, read, write, and speak with comprehension and clarity • Define and apply discipline-based conceptual vocabulary • Describe people, places, and events, and the connections between and among them • Arrange events in chronological sequence • Differentiate fact from opinion • Determine an author's purpose • Determine and analyse similarities and differences • Analyse cause and effect relationships • Explore complex patterns, interactions and relationships • Differentiate between and among various options | <ul style="list-style-type: none"> • Listens, read, write, and speak with comprehension and clarity • Define and apply discipline-based conceptual vocabulary • Describe people, places, and events, and the connections between and among them • Arrange events in chronological sequence • Differentiate fact from opinion • Determine an author's purpose • Determine and analyse similarities and differences • Analyse cause and effect relationships • Develop an ability to use and apply abstract principals • Explore and/or observe, identify, and analyse how individuals and/or societies relate to one another |
|---|---|

6. High Level Thinking Skills - These skills include analysis, synthesis, and evaluation skills.

i Analysis Skills – Analysis skills involve examining in detail and breaking information into parts by identifying motives or causes, underlying assumptions, hidden messages; making inferences and finding evidence to support generalisations, claims, and conclusions.

Key Words				
Analyse	Differences	Find	List	Similar to
Appraise	Discover	Focus	Motivate	Simplify
Arrange	Discriminate	Function	Omit	Take part in
Assumption	Discussion	Group	Order	Test for
Breakdown	Distinction	Highlight	Organize	Theme
Categorize	Distinguish	In-depth	Point out	
Cause & effect	Dissect	Inference	Research	
Choose	Divide	Inspect	See	
Classify	Establish	Isolate	Select	
Comparing	Examine	Investigate	Separate	

Synthesis Skills – Synthesis skills involve changing or creating something new, compiling information together in a different way by combining elements in a new pattern proposing alternative solutions.

Evaluation Skills – Evaluation skills involve justifying and presenting and defending opinions by making judgments about information, validity of ideas or quality of work based on set criteria.

Types of Values

Personal engagement and civic engagement strategies help young people to acquire and apply skills and dispositions that will prepare them to become competent and responsible citizens.

1. Personal Values (importance, worth, usefulness, etc.)

Core values	Sustaining values
<ul style="list-style-type: none"> • Sanctity of life • Truth • Aesthetics • Honesty • Human • Dignity • Rationality • Creativity • Courage • Liberty • Affectivity • Individuality 	<ul style="list-style-type: none"> • Self-esteem • Self-reflection • Self-discipline • Self-cultivation • Principal morality • Self-determination • Openness • Independence • Simplicity • Integrity • Enterprise • Sensitivity • Modesty • Perseverance

2. Social Values

Core values	Sustaining values
<ul style="list-style-type: none"> • Sanctity of life • Truth • Aesthetics • Honesty • Human • Dignity • Rationality • Creativity • Courage • Liberty • Affectivity • Individuality 	<ul style="list-style-type: none"> • Self-esteem • Self-reflection • Self-discipline • Self-cultivation • Principal morality • Self-determination • Openness • Independence • Simplicity • Integrity • Enterprise • Sensitivity • Modesty • Perseverance

Types of Attitudes

Attitudes - Ways of thinking and behaving, points of view

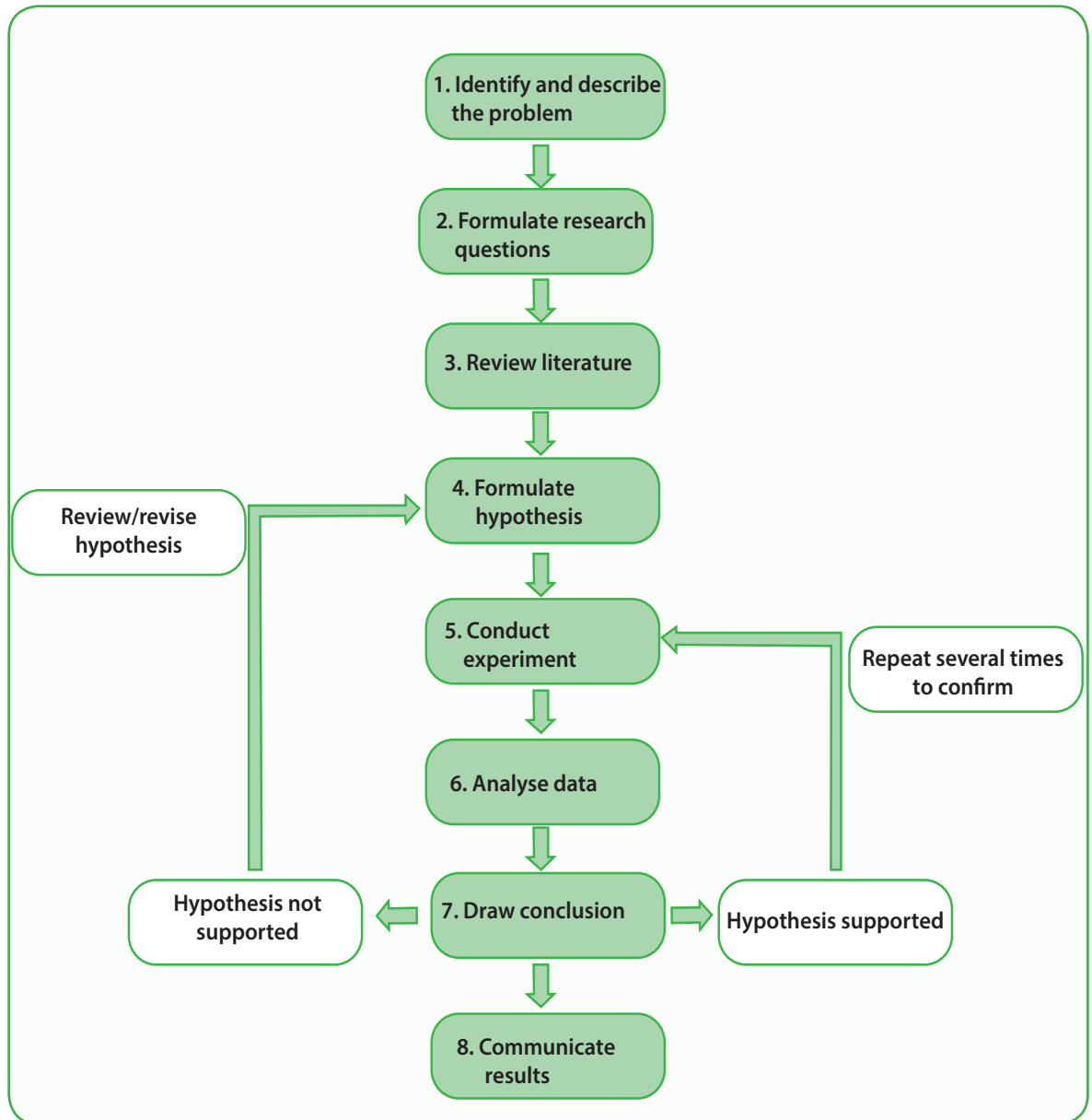
- | | |
|---|---|
| <ul style="list-style-type: none"> • Optimistic • Participatory • Critical • Creative • Appreciative • Empathetic • Caring and concern • Positive • Confident • Cooperative | <ul style="list-style-type: none"> • Responsible • Adaptable to change • Open-minded • Diligent • With a desire to learn • With respect for self, life, equality and excellence, evidence, fair play, rule of law, different ways of life, beliefs and opinions, and the environment. |
|---|---|

Scientific Thinking Process

Scientists engage in scientific inquiry by following key science practices that enable them to understand the natural and physical world and answer questions about it. Science students must become proficient at these practices to develop an understanding of how the scientific enterprise is conducted. These practices include skills from daily life and school studies that students use in a systemic way to conduct scientific inquiry. There are six (6) basic science process skills science students have to master before they apply the science inquiry problem-solving approach. The process skills that are at the heart of the scientific inquiry and problem-solving process are:

- Observation
- Communication
- Classification
- Measurement
- Inference
- Prediction

The science practices are fundamental to all science disciplines. The eight (8) steps that are fundamental to scientific inquiry are outlined below. The steps in the process vary, depending on the purpose of the inquiry and the type of questions or hypothesis created.



The steps above should be taught and demonstrated by students separately and jointly before they implement the inquiry process. Students should be guided through every step of the process so that they can explain them, their importance and use the steps and the whole process proficiently to identify, investigate and solve problems. A brief explanations and examples of each step are provided below to assist teachers plan and teach each step. Students should be provided with opportunities to practice and reflect on each step until they demonstrate the expected level of proficiency before moving on to the next step.

Step 1: Identify and describe the problem

Problems are identified mainly from observations and the use the five senses – smell, sight, sound, touch and taste. Students should be guided and provided opportunities to identify natural and physical environment problems using their five senses and describe what the problem is and its likely causes.

Example: Observation

- When I turn on a flashlight using the on/off switch, light comes out of one end.

Step 2: Formulate research question

After the problem is identified and described, the question to be answered is then formulated. This question will guide the scientist in conducting research and experiments.

Example: Question

- What makes light comes out of a flash light when I turn it on?

Step 3: Review literature

It is more likely that the research problem and question have already been investigated and reported by someone. Therefore, after asking the question, the scientist spends some time reading and reviewing papers and books on past research and discussions to learn more about the problem and the question ask to prepare her for his own research. Conducting literature review helps the scientist to better understand his/her research problem, refine the research question and decide on experiment/research approach before the experiment is conducted.

Example: Literature review

- The scientist may look in the flashlight's instruction manual for tips or conduct online search on how flashlights work using the manufacturer's or relevant websites. Scientist may even analyse information and past experiments or discoveries regarding the relationship between energy and light.

Step 4: Formulate hypothesis

With a question in mind, the researcher decides on what he/she wants to test (The question may have changed as a result of the literature review). The research will clearly state what he/she wants to find out by carrying out the experiment. He/She will make an educated guess that could answer the question or explain the problem. This statement is called a hypothesis. A hypothesis guides the experiment and must be testable.

Example: Hypothesis

- The batteries inside a flashlight give it energy to produce light when the flashlight is turned on.

Step 5: Conduct experiment

This step involves the design and conduct of experiment to test the hypothesis. Remember, a hypothesis is only an educated guess (a possible explanation), so it cannot be considered valid until an experiment verifies that it is valid.

Example: Experimental Procedure

- Remove the batteries from the flashlight, and try to turn it on using the on/off switch.
Result: The flashlight does not produce light
- Reinsert the batteries into the flashlight, and try to turn it on using the on/off switch.
Result: The flashlight does produce light.
- Write down these results

In general, it is important to design an experiment to measure only one thing at a time. This way, the researcher knows that his/her results are directly related to the one thing he/she changed. If the experiment is not designed carefully, results may be confusing and will not tell the researcher anything about his/her hypothesis.

Researchers collect data while carrying out their experiments. Data are pieces of information collected before, during, or after an experiment. To collect data, researchers read the measuring instruments carefully. Researchers record their data in notebooks, journals, or on a computer.

Step 6: Analyse data

Once the experiment is completed, the data is then analysed to determine the results. In addition, performing the experiment multiple times can be helpful in determining the credibility of the data.

Example: Analysis

- Record the results of the experiment in a table.
- Review the results that have been written down.

Step 7: Draw conclusions

If the hypothesis was testable and the experiment provided clear data, scientist can make a statement telling whether or not the hypothesis was correct. This statement is known as a conclusion. Conclusions must always be backed up by data. Therefore, scientists rely heavily on data so they can make an accurate conclusion.

If the data support the hypothesis, then the hypothesis is considered correct or valid.

If the data do not support the hypothesis, the hypothesis is considered incorrect or invalid. From here, if the hypothesis is invalid, the scientist can modify it and revert back to step 4.

Example: Valid Hypothesis

- The flashlight did not produce light without batteries. The flashlight did produce light when batteries were inserted.

Therefore, the hypothesis that batteries give the flashlight energy to produce light is valid, given that no changes are made to the flashlight during the experiment.

Example: Invalid Hypothesis

- The flashlight did NOT produce light when the batteries were inserted. Therefore, the hypothesis that batteries give the flashlight energy to produce light is invalid.

In this case, the hypothesis would have to be modified to say something like, “The batteries inside a flashlight give it energy to produce light when the batteries are in the correct order and when the flashlight is turned on.” Then, another experiment would be conducted to test the new hypothesis.

An invalid hypothesis is not a bad thing! Scientists learn something from both valid and invalid hypotheses. If a hypothesis is invalid, it must be rejected or modified. This gives scientists an opportunity to look at the initial observation in a new way. They may start over with a new hypothesis and conduct a new experiment. Doing so is simply the process of scientific inquiry and learning.

Step 8: Communicate findings

Scientists generally tell others what they have learned. Communication is a very important component of scientific progress and problem solving. It gives other people a chance to learn more and improve their own thinking and experiments. Many scientists’ greatest breakthroughs would not have been possible without published communication or results from previous experimentation.

Every experiment yields new findings and conclusions. By documenting both the successes and failures of scientific inquiry in journals, speeches, or other documents, scientists are contributing information that will serve as a basis for future research and for solving problems relating to both the natural and physical worlds. Therefore, communication of investigative findings is an important step in future scientific discovery and in solving social, political, economic, cultural, and environmental problems.

Example: Communication of findings

- Write your findings in a report or an article and share it with others, or present your findings to a group of people. Your work may guide someone else’s research on creating alternative energy sources to generate light, additional uses for battery power, etc.

Teaching and Learning Strategies

Scientific teaching emphasises and embraces the use of cognitive, reasoning, decision-making, problem solving and higher level thinking skills to teach to enhance students' understanding of inter-disciplinary concepts and issues in relation to environment, geography, history, politics and economic within PNG and globally. It aims to provide a meaningful pedagogical framework for teaching and learning essential and in demand knowledge, skills, values, and attitudes that are required for the preparation of students for careers, higher education and citizenship in the 21st Century.

Students must be prepared to gather and understand information, analyse issues critically, learn independently or collaboratively, organize and communicate information, draw and justify conclusions, create new knowledge, and act ethically.

These teaching and learning strategies will help teachers to;

- familiarize themselves with different methods of teaching in the classroom
- develop an understanding of the role of a teacher for application of various methods in the classroom

Successful teachers always keep in view that teaching must “be dynamic, challenging and in accordance with the learner’s comprehension. He/she does not depend on any single method for making his/her teaching interesting, inspirational and effective”.

A detailed table of Teaching and Learning Strategies are outlined below:

STRATEGY	TEACHER	STUDENTS
CASE STUDY Used to extend students' understanding of real life issues	Provide students with case studies related to the topic of the lesson and allow them to analyse and evaluate.	Study the case study and identify the problem addressed. They analyse the problem and suggest solutions supported by conceptual justifications and make presentations. This enriches the students' existing knowledge of the topic.
DEBATE A method used to increase students' interest, involvement and participation	Provide the topic or question of debate on current issues affecting a bigger population, clearly outlining the expectations of the debate. Explain the steps involved in debating and set a criteria/ standard to be achieved.	Conduct researches to gather supporting evidence about the selected topic and summarising the points. They are engaged in collaborative learning by delegating and sharing tasks to group members. When debating, they improve their communication skills.

<p>DISCUSSION The purpose of discussion is to educate students about the process of group thinking and collective decision.</p>	<p>The teacher opens a discussion on certain topic by asking essential questions. During the discussion, the teacher reinforces and emphasises on important points from students responses. Teacher guide the direction to motivate students to explore the topic in greater depth and the topic in more detail. Use how and why follow-up questions to guide the discussion toward the objective of helping students understand the subject and summarise main ideas.</p>	<p>Students ponder over the question and answer by providing ideas, experiences and examples. Students participate in the discussion by exchanging ideas with others.</p>
<p>GAMES AND SIMULATIONS Encourages motivation and creates a spirit of competition and challenge to enhance learning</p>	<p>Being creative and select appropriate games for the topic of the lesson. Give clear instructions and guidelines. The game selected must be fun and build a competitive spirit to score more than their peers to win small prizes.</p>	<p>Go into groups and organize. Follow the instructions and play to win</p>
<p>OBSERVATION Method used to allow students to work independently to discover why and how things happen as the way they are. It builds curiosity.</p>	<p>Give instructions and monitor every activity students do</p>	<p>Students possess instinct of curiosity and are curious to see the things for themselves and particularly those things which exist around them. A thing observed and a fact discovered by the child for himself becomes a part of mental life of the child. It is certainly more valuable to him than the same fact or facts learnt from the teacher or a book. Students Observe and ask essential questions Record Interpret</p>
<p>PEER TEACHING & LEARNING (power point presentations, pair learning) Students teach each other using different ways to learn from each other. It encourages; team work, develops confidence, feel free to ask questions, improves communication skills and most importantly develop the spirit of inquiry.</p>	<p>Distribute topics to groups to research and teach others in the classroom. Go through the basics of how to present their peer teaching.</p>	<p>Go into their established working groups. Develop a plan for the topic. Each group member is allocated a task to work on. Research and collect information about the topic allocated to the group. Outline the important points from the research and present their findings in class.</p>

<p>PERFORMANCE-RELATED TASKS (dramatization, song/ lyrics, wall magazines) Encourages creativity and take on the overarching ideas of the topic and are able to recall them at a later date</p>	<p>Students are given the opportunity to perform the using the main ideas of a topic. Provide the guidelines, expectations and the set criteria</p>	<p>Go into their established working groups. Being creative and create dramas, songs/lyrics or wall magazines in line with the topic.</p>
<p>PROJECT (individual/group) Helps students complete tasks individually or collectively</p>	<p>Teacher outline the steps and procedures of how to do and the criteria</p>	<p>Students are involved in investigations and finding solutions to problems to real life experiences. They carry out researches to analyse the causes and effects of problems to provide achievable solutions. Students carefully utilise the problem-solving approach to complete projects.</p>
<p>USE MEDIA & TECHNOLOGY to teach and generate engagement depending on the age of the students</p>	<p>Show a full movie, an animated one, a few episodes form documentaries, you tube movies and others depending on the lesson. Provide questions for students to answer before viewing</p>	<p>Viewing can provoke questions, debates, critical thinking, emotion and reaction. After viewing, students engage in critical thinking and debate</p>

Strands, Units and Topics

This section of the teacher guide contains the Geology content to be taught in grade 11. It consists of;

- a brief explanation of how the topics, learning objectives and lesson topics are derived.
- an overview of the content distributed according to the four terms in an academic year;
- the unit of work per strand

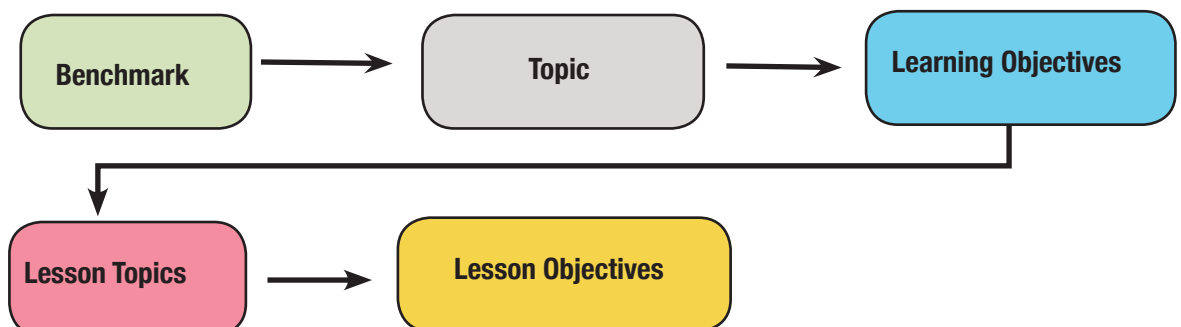
Geology is organized around two main strands – Science as Inquiry and Earth Science. These strands embed the content that students are expected to learn and master at each grade and school level. National content standards are benchmarked at each grade level, which allows for essential KSAV's to be reinforced and expanded throughout the grades. Benchmarks show grade level expectations of what students are able to do to demonstrate that they are making progress towards attaining the content standard.

These grade-level benchmarks were then unpacked to identify the topics, learning objectives and the lesson topics. Below is a description of how topics were derived from the grade-level benchmarks.

Identifying topics from benchmarks

In order to identify the topic from the benchmark, we need to unpack the benchmark. When we unpack a benchmark, we are identifying what students will know and be able to do when they have mastered the benchmark.

1. Write out the benchmark that you want to unpack.
2. Write the verbs (skills/actions) – Higher order thinking skills
3. Underline or highlight the big idea (content) in the benchmark. The big idea (content) is the topic derived from the benchmark.
4. Write essential questions that would be engaging for students
5. Develop sub-topics from the big idea (topic)
6. Write learning objectives according to the sub-topics
7. Write lesson topics from the learning objectives



Content Overview

The strand, units and topics are connected and aligned. The topics for each unit were derived from the grade level benchmarks. Unlike the units, the topics differ in grade levels. There are several topics for each unit on the content.

Strand 1: Science as Inquiry

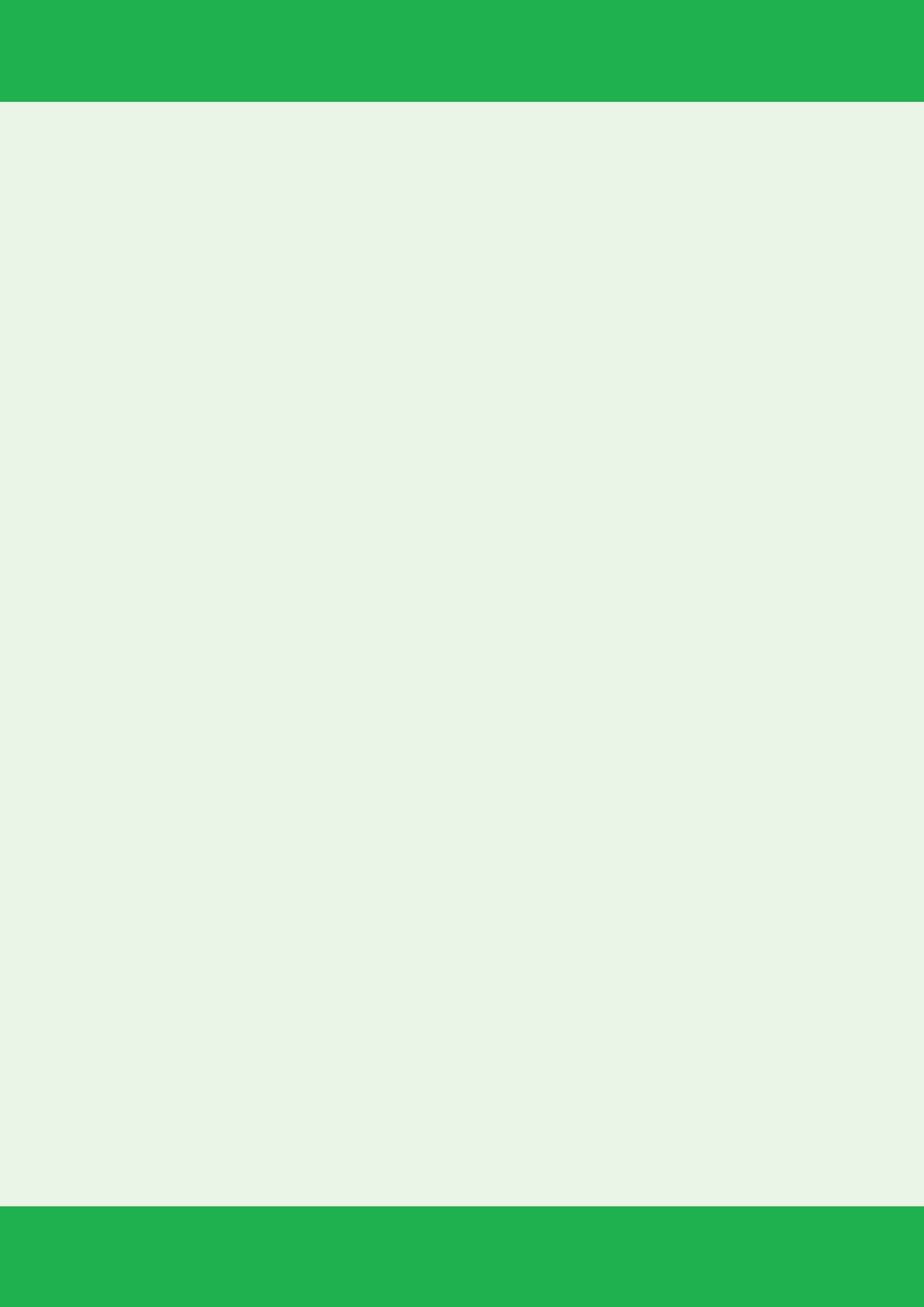
Unit	Topics
1. Thinking Scientifically 1	1. Units of Measurement 2. Geological Equipment 3. Geological Techniques and Maps

Strand 2: Earth Science

Units	Topics
1. Introduction to Geology	1. Geology as a Discipline 2. Earth
2. Earth Materials	1. Minerals 2. Rocks 3. Fossil Fuels
3. Geological Time and Fossils	1. Geological Time Scale 2. Fossils
4. Plate Tectonics	1. Plate Tectonic Theory 2. Plate Boundaries
5. Atmosphere and Hydrological Cycle	1. Atmosphere 2. Hydrological Cycle

Strand	Unit	Topic	Lesson titles	
1. Science as Inquiry	1. Thinking Scientifically 1	1. Units of measurement	1. Units of measurement	
			2. Unit conversion factors	
		2. Geological equipment	3. Geological equipment	
		3. Geological techniques and maps	4. Methods used to acquire information about the Earth	
			5. Methods used to analyse information about the Earth	
			6. Methods used to display information about the Earth	
2. Earth Science	1. Introduction to Geology	1. Geology as a discipline	7. What is Geology	
			8. What do Geologists do?	
			9. Where do geologists get their training?	
		2. Earth	10. Formation of the universe	
			11. Formation of the Earth	
			12. Development of the Earth's layers	
			13. Composition and thickness of the Earth's layers	
			14. Characteristics of various layers of the Earth	
			1. Minerals	15. Minerals
	16. The most common minerals			
	17. Physical properties of minerals			
	18. Moh's hardness scale and special properties			
	19. Classification of minerals			
	20. Formation of minerals			
	21. Uses of economic minerals			
	2. Earth Materials	2. Rocks		22. Rocks
				23. Types of igneous rocks
				24. Types of igneous textures
				25. Classification of igneous rocks using texture
				26. Classification of igneous rocks using composition
			27. Types of sediments	
			28. Types of sedimentary rocks	
			29. Classification of clastic sedimentary rocks	
			30. Classification of chemical sedimentary rocks	
			31. Classification of organic sedimentary rocks	
			32. Definitions of common terms for sediments and sedimentary rocks	
			33. Diagenesis or lithification	
			34. Textures preserved in sedimentary rocks	
			35. Chemical sedimentary rocks and their formation	
			36. Organic sedimentary rocks and their formation	
			37. Types of metamorphism	
			38. Classification of metamorphic rocks	
			39. Features of metamorphic rocks	
			40. Simple tests to identify minerals and rocks	
			41. Uses of rocks	

Strand	Unit	Topic	Lesson titles
2. Earth Science	2. Earth Materials	3. Fossil fuels	42. Fossil fuels
			43. Formation of coal
			44. Formation of crude oil and gas
			45. Formation of crude oil
			46. Characteristics of crude oil
			47. Characteristics of gas
	3. Geological Time and Fossils	1. Geological time scale	48. Importance or uses of crude oil and gas
			49. Geological time scale
			50. Evolution of different life forms
		2. Fossils	51. Major extinction events
			52. Definition and types of fossils
			53. Fossil formation processes
	4. Plate Tectonics	1. Plate tectonic theory	54. Significance of fossils
			55. Continental drift theory
			56. Past and current plate configurations
		2. Plate boundaries	57. Evidence of plate motion
			58. Major and minor lithospheric plates
			59. Distribution of earthquakes
			60. Types of plate boundaries
			61. Types of folds
			62. Types of faults
			63. Mantle convection and plate motion
			64. Subduction and its effects
			65. Magma formation processes
	5. Atmosphere and Hydrological Cycle	1. Atmosphere	66. Structure of the atmosphere
			67. Composition of the atmospheric layers
			68. Relationships amongst air particles
			69. Effects of changing the composition of the atmosphere
70. Greenhouse effect and climate change			
2. Hydrological cycle		71. Effects of sun's radiation on the atmosphere	
		72. Hydrological cycle	
		73. Humidity	
		74. Relationships between temperature, pressure and water in the atmosphere	
		75. Wind circulation patterns over the Earth	
76. Wind deflection due to Coriolis effect			
77. Characteristics of air masses			
78. Weather patterns			



Grade 11 Geology

Teaching Content

Strand 1: Science as Inquiry

Unit 1: Thinking Scientifically 1

Content Standard

11.1.1 Students will be able to understand and use the units of measurement, geological maps, common geological equipment and techniques.

Benchmark

11.1.1.1 Identify and assess the units of measurement used to quantify objects.

Topic 1 : Units of Measurement

Learning Objectives:

By the end of this topic, the students will be able to:

- Identify and assess the units of measurement used to quantify objects.
- Identify and convert one unit to another.

Essential questions

1. What are the units of measurement used in geology?
2. Why do we convert one unit to another?

Vocabulary: units of measurement, unit conversion factors,

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Units of measurement • Unit conversion factors 	<ul style="list-style-type: none"> • Converting units of measurement 	<ul style="list-style-type: none"> • Appreciate the conversion of units of measurement

Content Background

1. Measurement system and conversion factors

The units of measurement in geology is mostly in the SI system or metric system: metre-kilogram-second system. These includes measurements of length, mass, volume and area. The United States uses inches-feet-mile (for length) and barrels and gallons (for volume), which is the Imperial or English system. Where necessary, the measurements made in one system can be converted to another using standard conversion factors. These conversion factors can be found in nearly all science and mathematics text books. For example, 1 US barrel = 35 UK gallons = approx. 159 litres and 1 gallon = 4.54609 litres.

2. Units conversions in Geoscience

In the geosciences, we think about how the Earth works on a variety of scales. For example, the San Andreas Fault that runs nearly the length of US California's coastline is over 1200 km long. But we talk about movement on the fault in terms of mm per year. So, we have to be able to think about thousands of km and a few mm when talking about the same feature. In addition, a geoscientist who lives in the United States needs to be able to think in terms of English and metric units - the public thinks in terms of English units (miles, gallon, pounds, etc.) and the scientific community uses SI units (kilometres, litres, kilograms, etc.). This may seem difficult at first, but it is crucial for anyone studying geosciences to be able to move easily from one unit to another (with a little calculation). Luckily, there are some simple steps that, if followed, can help you complete unit conversions with relative ease.

How do I do a unit conversion?

You can do any unit conversion if you follow a few simple steps. Although there is no single “right” way to do unit conversions, these steps provide one way to learn to do unit conversions. Do not skip any step! Although it may seem tedious, working through unit conversions requires that each of these steps be followed so that you can be sure that you end up with what you want, especially when you are just starting out with learning to do unit conversions.

When you do any unit conversion, you should always know what units you started with and what units you want to end up with. This is key to success at unit conversions.

The Steps

The steps to successfully completing a unit conversion are outlined below. To illustrate the steps, let's use a geological example. In Southern California, slip on the San Andreas Fault is on the order of 25 km/Myr. How many cm does the San Andreas Fault move in one year?

- (a). Write (copy) out the units that you are given as a fraction. In this case, you are given km/Myr.

$$\frac{25 \text{ km}}{1 \text{ Myr}}$$

Or you could write that you have kilometres (km - a length or distance) and Myr (which is Mega years or million years - a time).

- (b). Write out the units that you want at the end of the conversion as a fraction:

In the example, you are asked to convert km/Myr to cm/year, so you want to end up with cm/year.

$$\frac{\text{cm}}{\text{yr}}$$

Or you could write that you want your units to have centimetres (cm - a length or distance) and years (yr - a time).

- (c). Determine appropriate conversion factors. Use tables in your maths or science textbook or download one from the internet (for this particular example, you probably only need to know the prefixes for metric system

For our example of movement on the San Andreas Fault, we need to convert 1 km to cm and Myr (Mega-years or Million years) to years, so with the handy guide to metric system prefixes, we need three conversion factors:

$$1 \text{ km} = 1,000 \text{ m}$$

$$1 \text{ m} = 100 \text{ cm}$$

$$1 \text{ Myr} = 1,000,000 \text{ yr}$$

- (d). Evaluate the appropriate arrangement for conversion factors. That is, copy the conversion factor(s) from step (c) into fraction form so that the units end up cancelling. Remember that when you multiply fractions (as you will in step (f) below), you can cancel units only when they appear in the numerator of one fraction and the denominator of another.

We're going to have to do several steps in this conversion and we have to start somewhere. Let's start with converting km/year to cm/year. Because km is on top, we're going to want to arrange the conversion fraction so that km is in the bottom position (denominator) like so:

$$\frac{1000 \text{ m}}{1 \text{ km}}$$

Or you could start setting up your conversion:

$$\frac{25 \text{ km}}{1 \text{ Myr}} \times \frac{1000 \text{ m}}{1 \text{ km}}$$

Now we can cancel km

$$\frac{25 \cancel{\text{ km}}}{1 \text{ Myr}} \times \frac{1000 \text{ m}}{1 \cancel{\text{ km}}}$$

But even when we cancel km, we're still left with m in the numerator so we need another conversion that has m in the denominator like this:

$$\frac{100 \text{ cm}}{1 \text{ m}}$$

We can add our next conversion factor to the string of fractions we're going to eventually multiply:

$$\frac{25 \text{ km}}{1 \text{ Myr}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{100 \text{ cm}}{1 \text{ m}}$$

And we can cancel appropriate units:

$$\frac{25 \cancel{\text{ km}}}{1 \text{ Myr}} \times \frac{1000 \cancel{\text{ m}}}{1 \cancel{\text{ km}}} \times \frac{100 \text{ cm}}{1 \cancel{\text{ m}}}$$

Now we have what we want in the numerator but we still have Myr in the denominator. So, we need a conversion factor that has Myr in the numerator:

$$\frac{1 \text{ Myr}}{1,000,000 \text{ yr}}$$

Add another fraction to the string:

$$\frac{25 \text{ km}}{1 \text{ Myr}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{100 \text{ cm}}{1 \text{ m}} \times \frac{1 \text{ Myr}}{1,000,000 \text{ yr}}$$

and then cancel units:

$$\frac{25 \cancel{\text{ km}}}{1 \cancel{\text{ Myr}}} \times \frac{1000 \cancel{\text{ m}}}{1 \cancel{\text{ km}}} \times \frac{100 \text{ cm}}{1 \cancel{\text{ m}}} \times \frac{1 \cancel{\text{ Myr}}}{1,000,000 \text{ yr}}$$

(e). Set up the conversion by writing the fractions in a row with multiplication signs in between (You may have already done this if you set the conversion up as you wrote out the conversion factors).

$$\frac{25 \text{ km}}{1 \text{ Myr}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{100 \text{ cm}}{1 \text{ m}} \times \frac{1 \text{ Myr}}{1,000,000 \text{ yr}}$$

(f). Evaluate. Do the original units cancel so that you end up with what the question is asking for? If not, repeat steps (b) and (c) until they do!

$$\frac{25 \cancel{\text{ km}}}{1 \cancel{\text{ Myr}}} \times \frac{1000 \cancel{\text{ m}}}{1 \cancel{\text{ km}}} \times \frac{100 \text{ cm}}{1 \cancel{\text{ m}}} \times \frac{1 \cancel{\text{ Myr}}}{1,000,000 \text{ yr}}$$

(Like units are cancelled with the same colour in the example above). Note that the only units that are not cancelled are cm (in the numerator) and yr (in the denominator) so the units on your answer will be cm/yr

(g). Now, let's do some arithmetic: To complete the conversion, we multiply all the numerators and then all the denominators (or multiply across the top and bottom).

$$\frac{25 \text{ km}}{1 \text{ Myr}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{100 \text{ cm}}{1 \text{ m}} \times \frac{1 \text{ Myr}}{1,000,000 \text{ yr}} = \frac{2,500,000 \text{ cm}}{1,000,000 \text{ yr}}$$

If you are unsure about how I got the numbers here, you can review what is meant by “multiply across top and bottom” below:

When fractions are multiplied, you need to keep track of numbers on the top (also called the numerator) and bottom (also called the denominator).

(i) It's easier to keep track of these numbers if you write the fractions like this: $\frac{25 \text{ km}}{1 \text{ Myr}}$. In this case, the numerator is 25 km and the denominator is 1 Myr.

(ii) To multiply fractions, treat top and bottom numbers separately (multiply top numbers and then multiply bottom numbers).

$$\frac{25 \text{ km}}{1 \text{ Myr}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{100 \text{ cm}}{1 \text{ m}} \times \frac{1 \text{ Myr}}{1,000,000 \text{ yr}} = \frac{25 \times 1000 \times 100 \text{ cm} \times 1}{1 \times 1 \times 1 \times 1,000,000 \text{ yr}}$$

(iii) Write out your new numbers as a fraction (the top product as the numerator; the bottom product as the denominator)

$$\frac{25 \text{ km}}{1 \text{ Myr}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{100 \text{ cm}}{1 \text{ m}} \times \frac{1 \text{ Myr}}{1,000,000 \text{ yr}} = \frac{25 \times 1000 \times 100 \text{ cm} \times 1}{1 \times 1 \times 1 \times 1,000,000 \text{ yr}} = \frac{2,500,000 \text{ cm}}{1,000,000 \text{ yr}}$$

(h). Reduce the fraction by dividing numerator by denominator once you have the top and bottom multiplied

$$\frac{25 \text{ km}}{1 \text{ Myr}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{100 \text{ cm}}{1 \text{ m}} \times \frac{1 \text{ Myr}}{1,000,000 \text{ yr}} = \frac{2,500,000 \text{ cm}}{1,000,000 \text{ yr}} = \frac{2.5 \text{ cm}}{\text{yr}}$$

This can also be written as 2.5 cm/yr (said “centimetres per year”).

(i). Evaluate (again). Is this a reasonable number?

Considering that plate motions are in the range of 1-10 cm/yr, 2.5 cm/yr is a reasonable answer!

Where are unit conversions used in the geosciences?

- Plate tectonics - converting rates of plate motion, etc.
- Topographic maps - converting scales
- Rivers and Streams - converting rates of flow, slope, etc.
- Groundwater - converting rates of flow
- Glaciers - converting rates of flow (or retreat), etc.
- Geologic time - converting time, rates of deposition, etc.
- And many other topics...

Unit Conversions Practice Problems

Problem 1. Speed conversion (single step problem)

Imagine that you are driving your car in Canada. As you're driving along, you notice that the speed limit signs have numbers like 120 (on the highway) and 50 (in the city). As you start to speed up, you realise that the signs are in km/hour. Unfortunately, your speedometer only reads in mi/hour. Figure out how fast you're allowed to go if the sign says: 120 km/hr

- (a). Write out the units you have (when appropriate as a fraction):

$$\frac{120 \text{ km}}{1 \text{ hr}}$$

- (b). Write out the units you want to end with

$$\frac{? \text{ mi}}{1 \text{ hr}}$$

- (c). Determine appropriate conversion factors (in some cases, there will be more than one conversion factor for each of the units you have):

Since "hours" stays the same on the bottom, you only need one conversion factor: km to mi. So, you can write $1 \text{ km} = 0.6214 \text{ mi}$

- (d). Evaluate appropriate arrangement for fractions (that is, what units belong in numerator (top) of fraction? What units need to be in denominator (bottom)? Remember, units cancel when one unit is in numerator and the other is in the denominator). Remember that when you multiply fractions (as you will in step (f) below), you can cancel units only when they appear in both the numerator and the denominator. Since km is in the numerator in the original units, km needs to be in the denominator so that we can cancel:

$$\frac{0.6214 \text{ mi}}{1 \text{ km}}$$

- (e). Set up the conversion by writing the fractions in a row with multiplication signs in between

$$\frac{120 \text{ km}}{1 \text{ hr}} \times \frac{0.6214 \text{ mi}}{1 \text{ km}}$$

- (f). Evaluate. Do the original units cancel so that you are left with only the units asked for? If not, repeat steps (c) and (d) until you are left with appropriate units. We cancel km and end with mi/hr (which is what we want).

$$\frac{120 \cancel{\text{ km}}}{1 \text{ hr}} \times \frac{0.6214 \text{ mi}}{1 \cancel{\text{ km}}}$$

- (g). Multiply across top and bottom

$$\frac{120 \cancel{\text{ km}}}{1 \text{ hr}} \times \frac{0.6214 \text{ mi}}{1 \cancel{\text{ km}}} = \frac{74.6 \text{ mi}}{1 \text{ hr}}$$

- (h). If necessary, reduce the fraction

$$\frac{120 \cancel{\text{ km}}}{1 \text{ hr}} \times \frac{0.6214 \text{ mi}}{1 \cancel{\text{ km}}} = 74.6 \frac{\text{mi}}{\text{hr}}$$

- (i). Evaluate your answer

Is a speed limit of about 75 mph (mi/hr) a reasonable speed limit? If you got 0.75 or 750, would you recognise that it is not reasonable?

Problem 2. Density Conversions (multiple step problem)

Geologists' observations suggest that the two most common rocks exposed at the surface of the Earth are granite (continental crust) and basalt (oceanic crust). From travel times of earthquake waves, we also know that the average density of the Earth is about 5.5 g/cm³. See if you can do some unit conversions using information given in the questions below to determine whether the whole Earth could be made of these two rock types only.

(i) As an intelligent observer walking around on continental crust (granite), you might decide to test the hypothesis that the Earth is made entirely of granite. You weigh a 1.00 cubic ft piece of granite on your home scale and find that it weighs 171 lbs. Thus you determine that the granite has a density of 171 lb/ft³. Convert your granite's density to g/cm³. Given the information above, could the Earth be made completely of granite?

(a) Copy the number and units as a fraction

$$\frac{171 \text{ lb}}{1 \text{ ft}^3}$$

(b) Write out the units you want to end with

$$\frac{\text{g}}{\text{cm}^3}$$

(c) Look up the conversion factors for what you have (pounds and feet or cubic feet) to what you want (grams and cm or cubic cm).

pounds to grams: 1 lb = 453.3924 g

feet to cm: 1 foot = 30.48 cm

feet to cubic feet: 1 ft * 1 ft * 1 ft = 1 ft³

cubic feet to cubic centimetres: 1 ft³ = 30.48 cm * 30.48 cm * 30.48 cm = 28,316 cm³

(d) Take note of what you have and what you want to end up with. Then, write out conversion factors from step (b) as fractions so that units cancel.

You want to be able to cancel lb (so that unit has to be on the bottom of the converting fraction) and ft³ (so that unit has to be on the top of the converting fraction):

$$\frac{171 \text{ lb}}{1 \text{ ft}^3} * \frac{453.5924 \text{ g}}{1 \text{ lb}} * \frac{1 \text{ ft}^3}{28316 \text{ cm}^3}$$

(e) Once you have written all the conversion fractions so that the original value is being multiplied by them (see last step), evaluate. Do the original units cancel so that you end up with what the question is asking for?

$$\frac{171 \text{ lb}}{1 \text{ ft}^3} * \frac{453.5924 \text{ g}}{1 \text{ lb}} * \frac{1 \text{ ft}^3}{28316 \text{ cm}^3}$$

(f) Multiply the fractions (across the top and bottom)

$$\frac{171 \text{ lb}}{1 \text{ ft}^3} * \frac{453.5924 \text{ g}}{1 \text{ lb}} * \frac{1 \text{ ft}^3}{28316 \text{ cm}^3} = \frac{77564 \text{ g}}{28316 \text{ cm}^3}$$

(g) Divide the resulting number to get an answer

$$\frac{171 \cancel{\text{lb}} * 453.5924\text{g}}{1 \cancel{\text{ft}}^3} * \frac{\cancel{\text{lb}}}{28316\text{cm}^3} = \frac{77564\text{g}}{28316\text{cm}^3} = 2.74 \frac{\text{g}}{\text{cm}^3}$$

(h) Is this a reasonable answer?

This isn't the answer we were looking for - 5.5 g/cm³. But it is within an order of magnitude. It is also a number that is greater than the density of water (which is 1 g/cm³) and we know that granite is denser than water. So it's a reasonable number. However, it shows that the Earth cannot be made completely of granite.

(i) Given that basalt seems to well up when ocean crust pulls apart at mid-ocean ridges, you might decide that maybe the entire Earth is made of basalt. On your home scale, a 64 in³ (4in x 4in x 4in) block of basalt weighs 116 ounces. Use this information to calculate whether the average density of the Earth (5.5 g/cm³) can be explained by an Earth made completely of basalt.

Let's go through this using the steps from the Unit Conversions Page. This can be found in the link (<https://serc.carleton.edu/mathyouneed/units/index.html>)

(a) Copy the number and units as a fraction

$$\frac{116 \text{ oz}}{64 \text{ in}^3}$$

(b) Write out the units you want to end with

$$\frac{\text{g}}{\text{cm}^3}$$

(c) Look up the conversion factors for what you have (pounds and feet or cubic feet) to what you want (grams and cm or cubic cm).

oz to grams: 1 oz = 28.349523 g

in to cm: 1 inch = 2.54 cm

inches to cubic inches: 1 in * 1 in * 1 in = 1 in³

cubic in to cubic centimetres: 1 in³ = 2.54 cm * 2.54 cm * 2.54 cm = 16.4 cm³

(d) Take note of what you have and what you want to end up with. Then, write out conversion factors from step (b) as fractions so that units cancel. You want to be able to cancel oz (so that unit has to be on the bottom of the converting fraction) and in³ (so that unit has to be on the top of the converting fraction):

$$\frac{116 \text{ oz}}{64 \text{ in}^3} * \frac{28.349523\text{g}}{1\text{oz}} * \frac{1\text{in}^3}{16.4\text{cm}^3}$$

(e) Once you have written all the conversion fractions so that the original value is being multiplied by them (see last step), evaluate. Do the original units cancel so that you end up with what the question is asking for?

$$\frac{116 \cancel{\text{oz}}}{64 \text{ in}^3} * \frac{28.349523\text{g}}{1\cancel{\text{oz}}} * \frac{1\cancel{\text{in}}^3}{16.4\text{cm}^3}$$

(f) Multiply the fractions (across the top and bottom)

$$\frac{116 \text{ oz}}{64 \text{ in}^3} * \frac{28.349523 \text{ g}}{1 \text{ oz}} * \frac{1 \text{ in}^3}{16.4 \text{ cm}^3} = \frac{3288.5 \text{ g}}{1049.6 \text{ cm}^3}$$

(g) Divide the resulting number to get an answer

$$\frac{116 \text{ oz}}{64 \text{ in}^3} * \frac{28.349523 \text{ g}}{1 \text{ oz}} * \frac{1 \text{ in}^3}{16.4 \text{ cm}^3} = \frac{3288.5 \text{ g}}{1049.6 \text{ cm}^3} = 3.13 \frac{\text{g}}{\text{cm}^3}$$

(h) Is this a reasonable answer

This isn't the answer we were looking for - 5.5 g/cm³. But it is within an order of magnitude. It is also a number that is greater than the density of water (which is 1 g/cm³) and we know that basalt is denser than water (it sinks). So it's a reasonable number. However, it shows that the Earth cannot be made completely of basalt either! So, there must be something denser down there - like the iron/nickel core.

Problem 3. Scaling problems

You are working with a map that has a fractional scale of 1:24,000 (meaning that 1 unit on the map is equal to 24,000 units on the ground – 1 mm = 24,000 mm or 1 in = 24,000 in). See if you can determine solutions to the following problems that geologists face when working with maps.

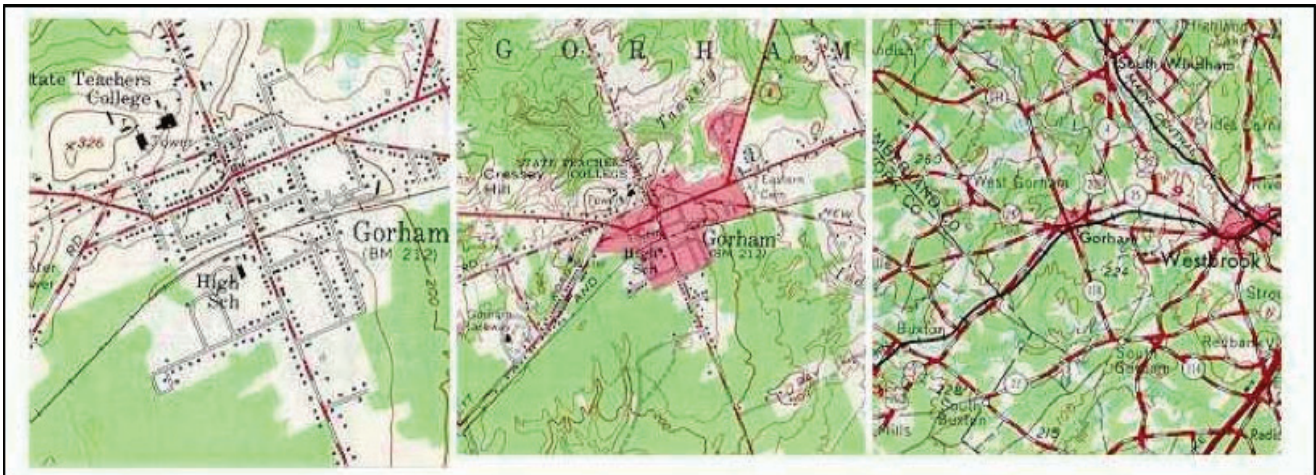


Figure 1. Different map scales. Left (1:24,000), centre (1:62,500), right (1:250,000)

(i) You are hiking to a field area and measure the length of the trail as 18.5 inches. Calculate how many miles you have to hike to get to the interesting rocks/geology?

This is actually a two-step conversion problem. First you have to convert your map measurements to measurements on the ground. Then you can convert to units that you understand.

First, think about what you have (18.5 in on the map and a scale) and what you want to know (how many miles 18.5 inches represents on the ground). It may help to think about inches on the map and inches on the ground as different units.

To begin, write the fractional scale as a fraction (with the distance on the ground on top - since that is what we want to ultimately end up with).

$$18.5 \text{ in on the map} \times \frac{24,000 \text{ in on the ground}}{1 \text{ in on the map}} = 444,000 \text{ in on the ground}$$

You have just calculated how many inches you have to cover on the trail. But, that's just seems like a lot, so let's convert those inches to miles!

First, let's write out the appropriate conversion factors:

1 foot = 12 inches and

1 mile = 5280 feet.

Next, we have to write these conversion factors as fractions. Remember to arrange them so that units you do not want cancel and you end up with units that you do want!

$$444,000 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} \times \frac{1 \text{ mi}}{5280 \text{ ft}}$$

Then we can cancel units. Do we end up with miles?

$$444,000 \text{ in} \times \frac{1 \cancel{\text{ft}}}{12 \cancel{\text{in}}} \times \frac{1 \text{ mi}}{5280 \cancel{\text{ft}}}$$

Yes! Now we multiply across the top and bottom (note that the bottom number does not have any units because both are cancelled by others):

$$444,000 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} \times \frac{1 \text{ mi}}{5280 \text{ ft}} = \frac{444,000 \text{ mi}}{63,360}$$

And when we clear fractions:

$$444,000 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} \times \frac{1 \text{ mi}}{5280 \text{ ft}} = 7.0 \text{ mi}$$

We find that our hike will be 7 miles.

(ii) Once you get to your field area, you are going to create a geologic map of that area. You have a mechanical pencil that has a lead that is 0.3 mm thick. The smallest feature you can map will be something that is 0.3 mm wide on the map. How wide (in metres) can that feature be?

This, like 3.1 is actually a two-step conversion problem. First you have to convert your map measurements to measurements on the ground. Then you can convert to units that you understand.

First, think about what you know (0.3 mm on the map and a scale) and what you want to know (how many metres 0.3 mm represents on the ground). It may help to think about mm on the map and mm on the ground as different units.

To begin, write the fractional scale as a fraction (with the distance on the ground on top - since that is what we want to ultimately end up with).

$$0.3 \text{ mm on the map} \times \frac{24,000 \text{ mm on the ground}}{1 \text{ mm on the map}} = 7,200 \text{ mm on the ground}$$

You have just calculated how many millimetres thick a feature can be. But, because this is the metric system, we can modify that so that you do not have to keep a lot of zeros in your head.

First, let's write out the appropriate conversion factors:

$$1 \text{ m} = 1000 \text{ mm}$$

Next, we have to write these conversion factors as fractions. Remember to arrange them so that units you do not want cancel and you end up with units that you do want.

$$7200 \text{ mm} \times \frac{1 \text{ m}}{1000 \text{ mm}}$$

Finally, cancel the appropriate units (mm in this case) and multiply across the top and bottom.

$$7200 \text{ ~~mm~~} \times \frac{1 \text{ m}}{1000 \text{ ~~mm~~}} = \frac{7200 \text{ m}}{1000} = 7.2 \text{ m}$$

You can map any feature wider than 7.2 m.

The cool thing about the metric system is that it is based in the number 10. This means that conversions within the metric system involve moving zeros around. It also means that when doing calculations, many times you can cancel out zeros.

How does this work? Zeros can only be cancelled if they occur on the top and bottom of a fraction. In the problem above, you can cancel two zeros on either side of the fraction:

$$7200 \text{ ~~mm~~} \times \frac{1 \text{ m}}{1000 \text{ ~~mm~~}} = \frac{7200 \text{ m}}{1000} = \frac{72 \text{ m}}{10} = 7.2 \text{ m}$$

Note that the calculation then becomes 72 divided by 10. Most of us can easily divide by 10, making this calculation much easier. In fact, when you get to that point, you may not even need a calculator. Keep this in mind as you do calculations!

(iii) Now you have an idea of the size of features that can be drawn on your map. Convert your answer in problem (ii) to feet

This is a simple conversion with only one step.

The conversion factor listed in the table (see link above) is 1 m = 3.281 feet.

First let's set up our equation with fractions:

$$7.2 \text{ m} \times \frac{3.281 \text{ ft}}{1 \text{ m}}$$

Then cancel units and multiply top and bottom

$$7.2 \text{ ~~m~~} \times \frac{3.281 \text{ ft}}{1 \text{ ~~m~~}} = \frac{23.6 \text{ ft}}{1} = 23.6 \text{ ft}$$

You can map a feature that is about 24 feet wide.

Teaching and Learning Strategies

Teaching Strategies:	Learning Strategies
<p>Teachers prepare information, display and ask questions on units of measurement. Teachers can take students to outdoor to make measurements in one unit and convert to another.</p>	<p>Students will use the information provided to answer questions on units of measurement.</p>
<p>STEAM Approach Learning Objective: By the end of the topic, students will be able to;</p> <ul style="list-style-type: none"> • Visualise, convert units of measurement - STEAM 	
<p>Teaching Strategies Teachers will provide the criteria and the materials to make measurements in one form and convert to another within a given period</p>	<p>Learning Strategies In groups, students read the criteria and follow the steps and use the materials available to convert units of measurement from one form to another</p>
<p>Recommended Resources:</p> <ul style="list-style-type: none"> • https://serc.carleton.edu/mathyouneed/units/index.html • Internet 	

Unit 1: Thinking Scientifically 1

Content Standard

11.1.1 Students will be able to understand and use the units of measurement, geological maps, common geological equipment and techniques.

Benchmark

11.1.1.2 Analyse the use of common geological equipment used by geologist.

Topic 2: Geological Equipment

Learning Objectives:

By the end of this topic, the students will be able to:

- Identify the use of common geological equipment such as geological hammers, hand lenses, compasses, clinometers, petrographic microscopes and global positioning systems.
- Explain the difference between an ordinary microscope and a petrographic microscope.

Essential questions

1. What are the purpose and uses of common geological equipment?
2. What is the main difference between an ordinary microscope and petrographic microscope?

Vocabulary: geological hammer, hand lenses, compass, clinometer, petrographic microscope, global positioning system

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Common geological equipment • Purpose and uses of geological equipment 	<ul style="list-style-type: none"> • Common geological equipment • Purpose and uses of geological equipment 	<ul style="list-style-type: none"> • Appreciate the common geological equipment • Show desire to learn and understand the purpose and uses of geological equipment

Content Background

Geological Equipment

There is various equipment used by geologists. The most common ones are briefly discussed below and include geological hammers, hand lenses, compasses and clinometers, field books, petrographic microscopes and global positioning system.

1. Geological hammer



Figure 1. A geologist's hammer used to break up rocks, as well as scale in the photograph.

A geologist hammer, rock hammer, rock pick, or geological pick is a hammer used for splitting and breaking rocks. In field geology, they are used to obtain a fresh surface of a rock to determine the composition, nature, mineralogy, history, and field estimate of rock strength. In fossil and mineral collection, they are employed to break up the rock.

Shape

Geologist's hammers, as with most hammers, have two heads, one on either side. Most commonly, the tool consists of a flat head on one end, with either a chisel or a pick head on the other end.

- A chisel head (Figs. 1 & 2), which is shaped like a chisel, is useful for clearing vegetation cover from exposures and is sometimes used to pry open fissures. Some rocks can be easily split, like slate or shale, to reveal any fossils. Others are hard such as limestone and granite.
- A pick head, which terminates in a sharp point to deliver maximum pressure, is often preferred for harder rocks. A geologist's hammer bearing a pick end is often referred to as a rock pick instead of a geologist's hammer.
- A flat head is used to deliver a blow to a rock with the intention of splitting it. Specimens or samples can be trimmed to remove sharp corners or reduce them in size.

Construction



Figure 2. A geologist's hammer with tabular shaft and chisel head

The effective power of a geologist's hammer is mainly considered to reflect its head weight and handle length. Head weight may range from 225g to 680g and greater. A hammer of 450g is often quoted as sufficient for all rock types, although metamorphic or igneous rocks often require heavier hammers for a more powerful blow.

The best geologist's hammers are forged from one piece of hardened steel, which renders them sturdy and long-lasting. Alternatives such as tubular-and-wooden-shafted hammers are more commonly used, in part due to their lower cost. Such alternative handles sacrifice strength and make the hammer unsuitable for high-strain activities such as prying.

The form and weighting of the shaft defines the balance, which itself defines ease, efficiency, and comfort of use of the geologist's hammer.

2. Hand lenses



Figure 3. Loupe (hand lens) used by geologist

The hand lens is a vital geological field tool used to identify small mineral crystals and structures in rocks. It is a simple, small magnification device used to see small details more closely. Unlike a magnifying glass, a loupe does not have an attached handle, and its focusing lens(es) are contained in an opaque cylinder or cone or fold into an enclosing housing that protects the lenses when not in use.

Three basic types of hand lenses exist.

- Simple lenses, which result in the highest degree of optical aberration and are generally lower magnification.
- Multiple lenses, generally higher magnification because of the reduced optical aberration.
- Prismatic, multiple lenses with prisms used to change the perspective.

Jewellers typically use a monocular, hand-held loupe in order to magnify gemstones and other jewellery that they wish to inspect. A 10x magnification is good to use for inspecting jewellery and hallmarks, and is the Gemological Institute of America's standard for grading diamond clarity. Stones will sometimes be inspected at higher magnifications than 10x, although the depth of field, which is the area in focus, becomes too small to be instructive. The accepted standard for grading diamonds is therefore that inclusions and blemishes visible at 10x impact the clarity grade.

3. Compasses and clinometers

There are several (specialised) magnetic compasses used by geologists to measure orientation of geological structures, as they map in the field, to analyse (and document) the geometry of bedding planes, joints, and/or metamorphic foliation and lineation. In this aspect the most common device used to date is the analogue compass. In addition, there are several clinometers or dipmeters used to measure the dip of the bedding plane or plunge of a fold.

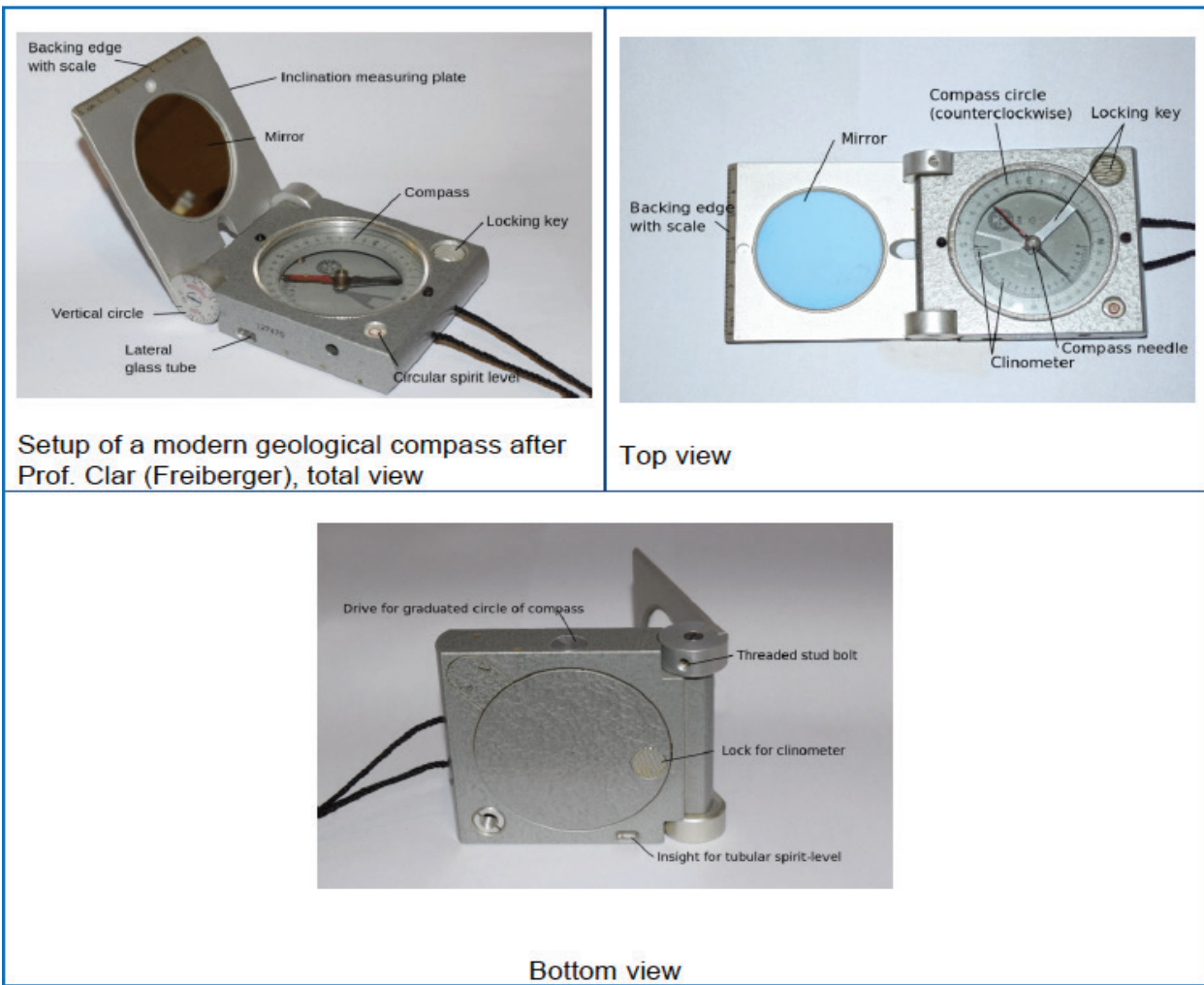
Classic geological compasses

Classic geological compasses that are of practical use combine two functions, direction finding and navigation (especially in remote areas), and the ability to measure strike and dip of bedding surfaces and/or metamorphic foliation planes. Structural geologists (i.e. those concerned with geometry and the pattern of relative movement) also have a need to measure the plunge and plunge direction of lineations.

Compasses in common use include the Brunton and the Silva.

Modern geological compasses

The concept of modern geological compass was developed by Eberhard Clar of the University of Vienna during his career as a structural geologist. He published his work in 1954. An advantage of his concept is that strike, and dip is measured in one step, using the vertical circle for dip angle and the compass for the strike direction. The first implementation was done by the VEB Freiburger Präzisionsmechanik in Freiberg, Germany. The details of the design were made in close cooperation with the Freiberg University of Mining and Technology.



Setup of a modern geological compass after Prof. Clar (Freiberger), total view

Top view

Bottom view

Figure 4. Modern geological compass (with in-built clinometer)

Usage

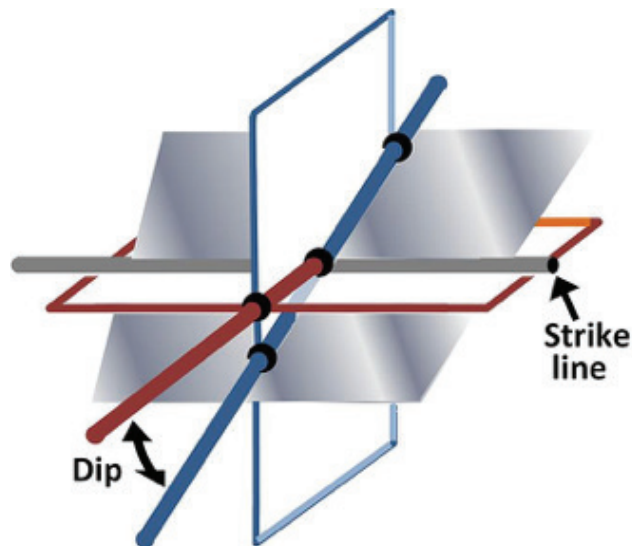


Figure 5. Strike line and dip of a plane describing attitude relative to a horizontal plane and a vertical plane perpendicular to the strike line.

From the start, the compass-clinometer equipment can be confusing. Because the numbers on the compass dial ascend in an anticlockwise direction. This is because the equipment is used to determine dip and dip-direction of surfaces (foliations), and plunge and plunge-direction of lines (lineations).

Digital compasses

With the advent of smartphone, geological compass based on the 3-axis teslameter and the 3-axis accelerometer has also begun to appear. These compass programs use vector algebra to compute plane and lineation orientations from the accelerometer and magnetometer data and permit rapid collection of many measurements. However, some problems are potentially present. Smartphones produce a strong magnetic field of their own which must be compensated by software; as well, because the Earth's magnetic field fluctuates rapidly, measurement made by smartphone geological compasses can potentially be susceptible to considerable noise. Users of a smartphone compass should carefully calibrate their devices and run several tests against traditional magnetic compasses in order to understand the limitations of their chosen program.

4. Field books

Field books are used to take field notes; they can be anything from a composition type notebook to a spiral, but most use an actual "field book" like those available for purchase in stationery shops. Field notes refer to qualitative notes recorded by scientists during or after their observation of a specific phenomenon they are studying. They are intended to be read as evidence that gives meaning and aids in the understanding of the phenomenon. Field notes allow the researcher to access the subject and record what they observe in an unobtrusive manner.

One major disadvantage of taking field notes is that they are recorded by an observer and are thus subject to (a) memory and (b) possibly, the conscious or unconscious bias of the observer. It is best to record field notes immediately after leaving the site to avoid forgetting important details.

Field notes are particularly value in geology and other descriptive sciences such as ethnography, biology, and archaeology.

Structure

There are two components of field notes: descriptive information and reflective information.

- Descriptive information is factual data that being recorded. Factual data includes time and date, the state of the physical setting, social environment, descriptions of the subjects being studied and their roles in the setting, and the impact that the observer may have had on the environment.
- Reflective information is the observer's reflections about the observation being conducted. These reflections are ideas, questions, concerns, and other related thoughts.

5. Petrographic microscope

A petrographic microscope is used to observe a series of characteristics in a thin section (thinly sliced rock) or mineral which reflect its properties and allow the observer us to identify it.

The petrographic microscope is a compound microscope which can work with plane polarised light, meaning that it has some peculiarities.

This is always done with transmitted plane polarised light, meaning that the polariser must be inserted. The type of illumination varies according to the feature to be studied, and may be orthoscopic (parallel, without the condenser) or conosopic (convergent, with the condenser incorporated).

The size of minerals that allows for optical identification is not smaller than 0.010 mm. Identification of cryptocrystalline and amorphous materials can be achieved using sub-microscopic techniques such as a scanning electron microscope.

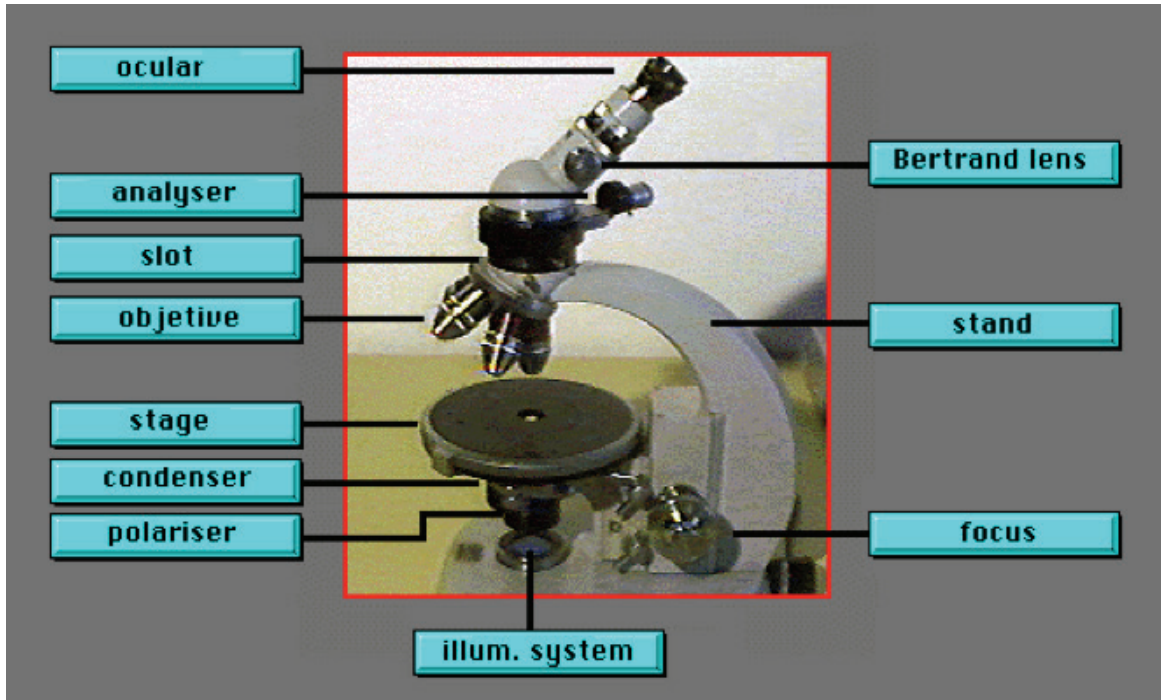
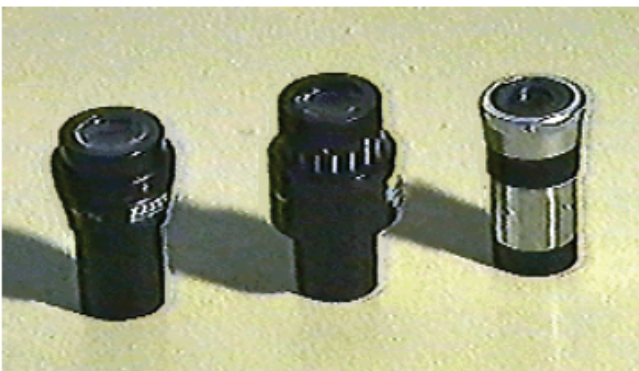
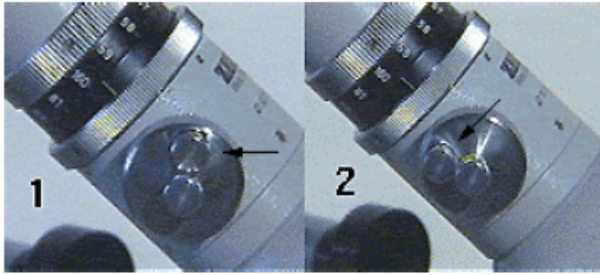


Figure 6. Petrographic microscope. (Source: <http://www.edafologia.net/optmine/intro/microscw.htm>)

The petrographic microscope differs from an ordinary microscope in two ways: it uses polarised light and the stage rotates.

There are two sheets of polaroid: the one below the stage of the microscope is the polariser, the other, above the stage is the analyser. The analyser can be moved in and out. Most rocks cut and ground to a thickness of 0.03mm become transparent.

Parts of a petrographic microscope	Functions of the parts
<p>Ocular</p> 	<p>This is a system of lenses fitted to the top of the microscope and whose function is to form a virtual and amplified image from the real image created by the objective.</p> <p>The eyepiece assembly contains two cross-hairs and is slotted into the microscope tube so that the cross-hairs are orientated E-W and N-S, i.e. parallel to the vibration directions of the polariser and analyser.</p> <p>Most eyepieces have a magnification of x8 or x10.</p> <p>The focal plane of the new image is about 25cm from the upper lens, the normal distance of vision of the human eye.</p>
<p>Bertrand lens</p>	<p>This is found immediately below the ocular. It may be incorporated (1) or removed (2) at will. It can only be used</p>



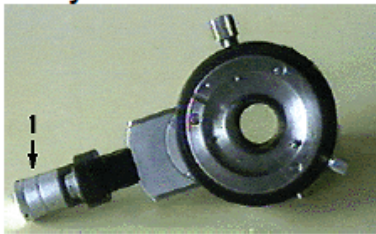
3

when convergent light is used to observe the property called the Interference figure (3).

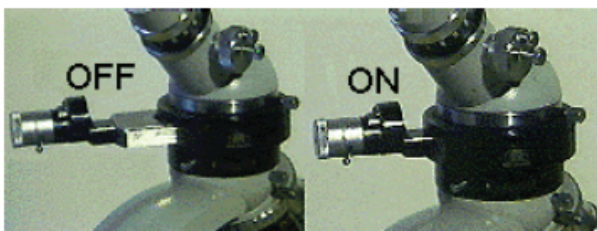
The Bertrand lens magnifies and focuses interference figures, but the Bertrand lens does not produce the interference figure but modifies the focal plane of the image formed by the objective to allow it to be focussed and amplified by the ocular.

An alternative means of viewing interference figures is to remove the eyepiece and look down the microscope tube at the high-power objective lens, preferably with the aid of a pin-hole stop inserted at the top of the tube.

Analyser



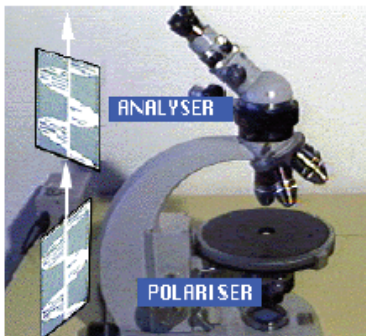
This is above the objective, and is made up of a polarising plate, whose height may be adjusted at will, using a graduated dial (1).



Unlike the polariser, the analyser does not always have a part to play in the passage of the light rays and can be installed or removed at will. It is used to study certain properties but is not necessary for others.

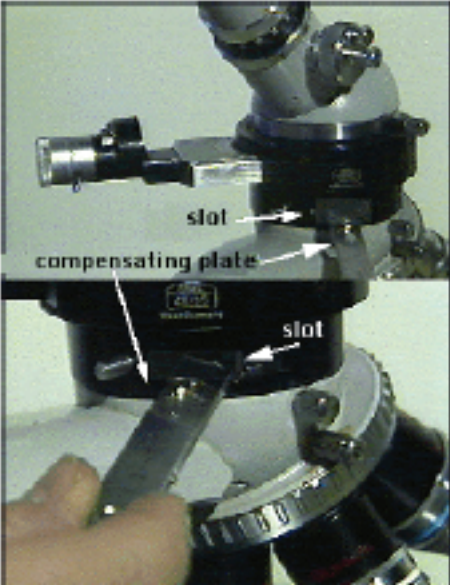
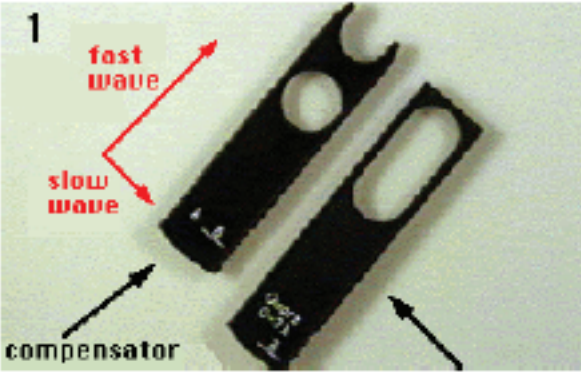
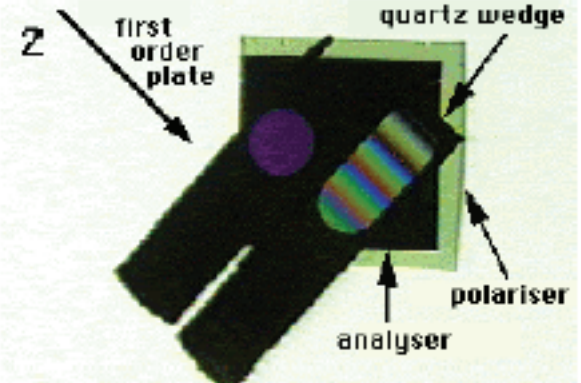
The polarising plane is generally N-S, and it is always perpendicular to the polariser, such that if there is no object in the way, no light passes, and extinction occurs.

Below it is a slot where compensating plates can be inserted.

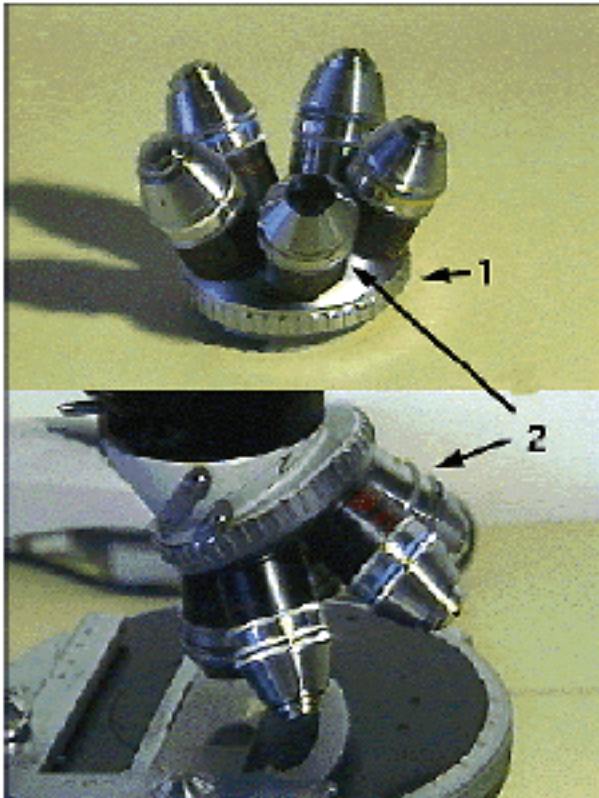


When only the polariser (1) is being used, a normal image is observed, but when the analyser is in place (2), an extinction of light occurs.

If an anisotropic substance is in the light's path, the light splits into two rays which vibrate perpendicularly and do not necessarily coincide with the directions of the polariser or analyser. When these rays reach the analyser, two components come into being which vibrate, one on the plane of the analyser and the other on a

	<p>perpendicular one. The former is responsible for the grain being seen, whilst the latter is annulled. A false colour appears, known as an interference colour (3).</p>
<p>Slot</p>  <p>1</p>  <p>2</p> 	<p>This is immediately below the analyser and its greatest dimension forms an angle of 45° with the direction of vibration of the Nicols (polariser and analyser).</p> <p>The main directions of vibration of the compensating plate and those of the polariser and analyser are situated at 45°.</p> <p>Compensators</p> <p>These are plates of anisotropic substances, whose planes of vibration coincide with their two dimensions, length and width.</p> <p>Accessory plates consist of mineral sections of a thickness such that they produce a known amount of retardation.</p> <p>They may be wedge-shaped so that retardation (and thus colour) will depend on the thickness acting at any moment in time.</p> <p>The effects that these compensators introduce are superimposed on the effects that the minerals on the microscope stage introduce.</p> <p>They are used for studying interference figures and the retardation produced by mineral specimens.</p> <p>When required, they are inserted into the microscope tube in a slot between the objectives and the analyser.</p>

Objective



These are the **lenses** used for magnifying the specimen on the stage. Four or five are normally supplied (x4, x10, x25, x50).

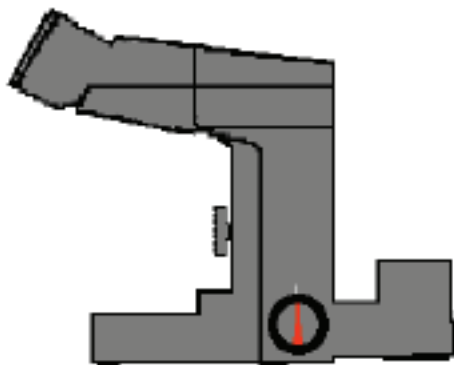
This allows a real and inverted image to be obtained of the object under examination.

It lets the polarised light pass through without affecting the polarisation plane. Objectives are often mounted on a revolving objective holder (1), which allows quick and easy change of magnification.

When the stage is rotated, the axis of rotation should coincide with the centre of the field of view (the axis of the microscope). This is achieved on some microscopes by adjusting a collar on the barrel of each objective (2)

To centre a microscope, the point about which an object is seen to rotate when the stage is rotated must be brought to the centre of the cross-hairs by adjusting the centering screws.

Stand

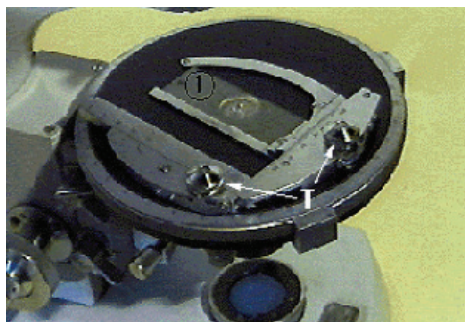


This is the physical support to the other elements of the microscope.

Attached to it are the mechanisms which move the stage and focus the sample.

Other accessories are also joined to it by the same bracket as the stage, such as the condenser and the polariser.

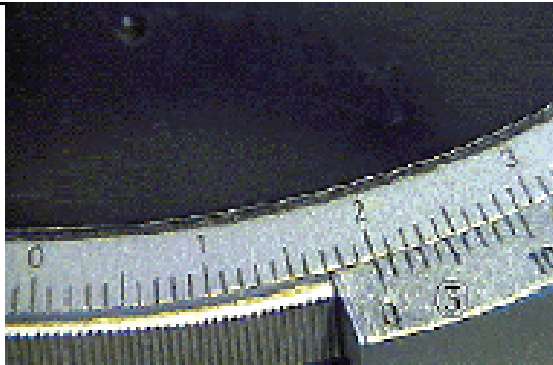
Stage



This serves as a support to the thin section (1) which is to be studied. It may be heightened or lowered (2) to allow the object to be focussed.

It is round and can be rotated on a vertical axis which passes through its centre.

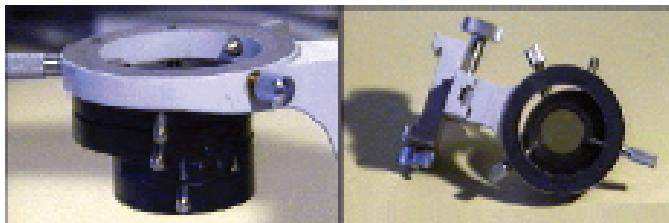
It is graduated, and on the outside, it has

**Condenser**

Situated between the polariser and the object, it has a removable lens (1) in such a way that when it is fitted in the "ON" position it makes the light rays converge onto the thin section placed on the stage of the microscope. In this situation one speaks of convergent light or, more normally, conoscopic illumination.

By contrast, when the convergent light lens is in the "OFF" position, the light rays no longer inside convergent but rather follow an approximately parallel path and all of them inside perpendicularly on the slide. In this situation one speaks of parallel light or, to be more correct, orthoscopic illumination.


An iris diaphragm allows the illuminated area to be varied (known as the aperture diaphragm). For observing relief and Becker line it is usually necessary to partially close this diaphragm.

Polariser

This is situated immediately above the illumination system and below the condenser, although it is connected to the stage and the condenser by the same upright bracket.

Its function is to convert the natural light from the illumination system into plane polarised light.

The plane of vibration of the light in the polariser can be turned in some kinds of microscopes but in normal working conditions it is always fixed at 0°, often coinciding with what could be called the "East-West" direction.

	<p>The polariser is always positioned in the pathways of the light rays for the study of any optical property.</p> <p>Polarised light is produced by the polariser and analyser, both of which in modern microscopes consist of a sheet of plastic (polaroid) which absorbs all light except that vibrating in one direction. Older microscopes employed an ingenious combination of calcite prism to produce polarised light (described first by W. Nicol and known as Nicol prisms).</p>
<p>Focus</p> 	<p>The focus of the image in the microscope is done by separating the object to be studied from the objectives. By means of rings (1 and 2) the stage can be raised and lowered to find the focus (in the old microscopes the stage remains fixed, the targets being the ones that move). In this microscope there is a "macro" amilla of abrupt displacement (1), to approximate the focus, and one, called "micro" (2), to adjust it.</p> <p>The focus operation requires following certain steps to perform it safely. The correct procedure is as follows. Looking out of the microscope, the lens is taken next to the preparation and then looking through the eyepiece slowly separates until the image is obtained. If the approach is approached by bringing the objective closer to the preparation, it runs the risk of producing fractures (in the preparation or, in what is much worse, in the front lens of the lens) if we go beyond the focus plane.</p>
<p>illumination system</p>	<p>This is in the base of the stand at the foot of the microscope. In research microscopes, it is made up of a Light source (1), a set of Lenses (2) which allow a parallel beam of light to be obtained to avoid the loss of intensity by dispersion, an anti-thermic filter (3) which prevents the other elements from overheating, a set of chromatic filters (4) which allow the chromatic characteristics</p>

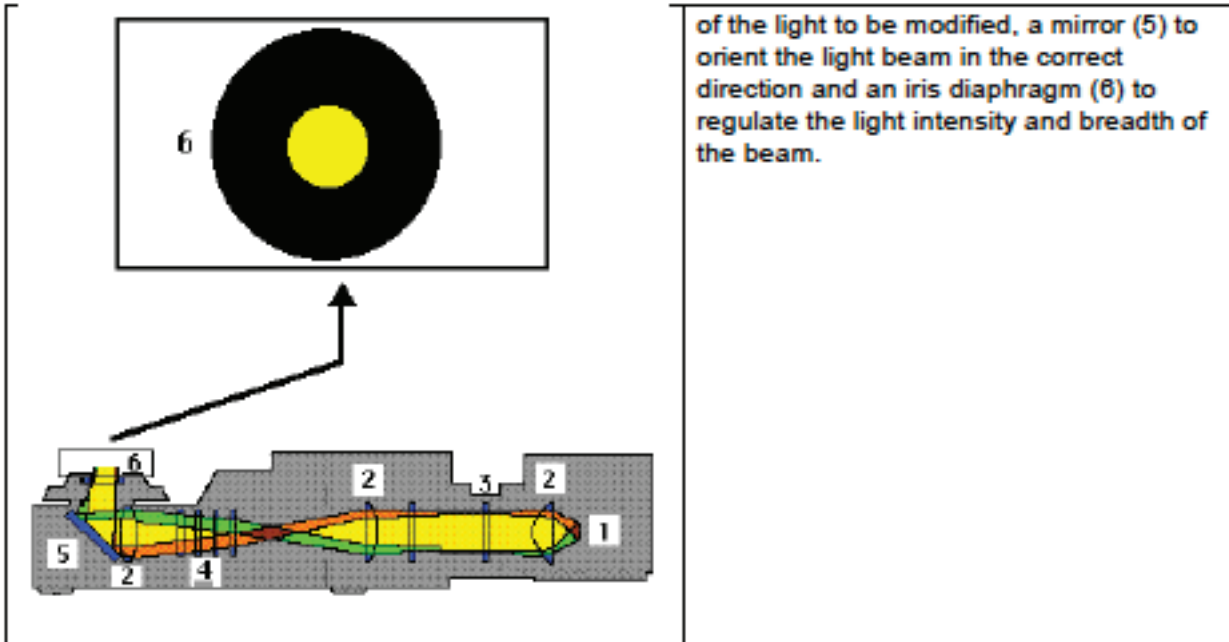


Figure 7. Parts of the petrographic microscope (Source: <http://www.edafologia.net/optmine/intro/microscw.htm>)

6. Global positioning systems (GPS) application in Geoscience

GPS technology has matured into a resource that goes far beyond its original design goals. These days scientists, sportsmen, farmers, soldiers, pilots, surveyors, hikers, delivery drivers, sailors, dispatchers, lumberjacks, fire-fighters, and people from many other walks of life are using GPS in ways that make their work more productive, safer, and sometimes even easier.

Understanding some of the things a GPS receiver can do will help you understand what all it can be used for. Some of the geological uses are described below, but first, just think of the GPS as a calculator - it calculates distances and directions from your current location. A GPS unit can record in memory, its current location (and 499 other locations) in latitude and longitude, or in map grid format.

Each location can be given a name or number, and time and date (automatically if you wish).

It can then calculate distance and bearing between any of those logged locations (called waypoints).

It can guide you from and to any location, with a graphic highway symbol, and tells you if you veer off path.

It can automatically log your geological traverse, and then guide you back over the same trail.

It can be used as a hand-held, in a boat, or can be mounted under the windscreen of a car, or within the panel of a boat control station for practical route guidance. It can be hooked up to a 12-volt supply.

It can store locations in routes, and the whole route can be retained and recalled.

You can download all this information to a computer, and backload it to any other GPS at any time.

In use, the GPS will act as a compass, indicating your heading and bearing (true north or magnetic), and will display your speed very accurately.

Many GPS units also show sunrise and sunset, battery strength, satellite positions and signal strengths, DOP (DOP is dilution of precision, read more about GPS to understand what this is), graphic displays and feature mapping of waterways, roads, rivers and railways.

The most stringent of GPS applications in geosciences is surveying and mapping. Using GPS saves time and money. GPS makes it possible for a single surveyor to accomplish in a day what used to take weeks with an entire team. And they can do their work with a higher level of accuracy than ever before.

Today, mapping is the art and science of using GPS to locate items, and then create maps and models of everything in the world.

Geological mapping is the first step in geological investigations. The concept of mapping has all together changed with the arrival of the modern techniques of investigations like GPS, Geographic information system and Remote sensing technique. GPS is the only system today to show one's exact position on the Earth anytime, in terms of longitudes and latitudes, giving accuracy up to 1mm to 1cm.

- Mountains, rivers, forests and other landforms.
- Roads, routes, and city streets.
- Endangered animals, minerals and other resources.
- Damage and disasters, trash and archaeological treasures.

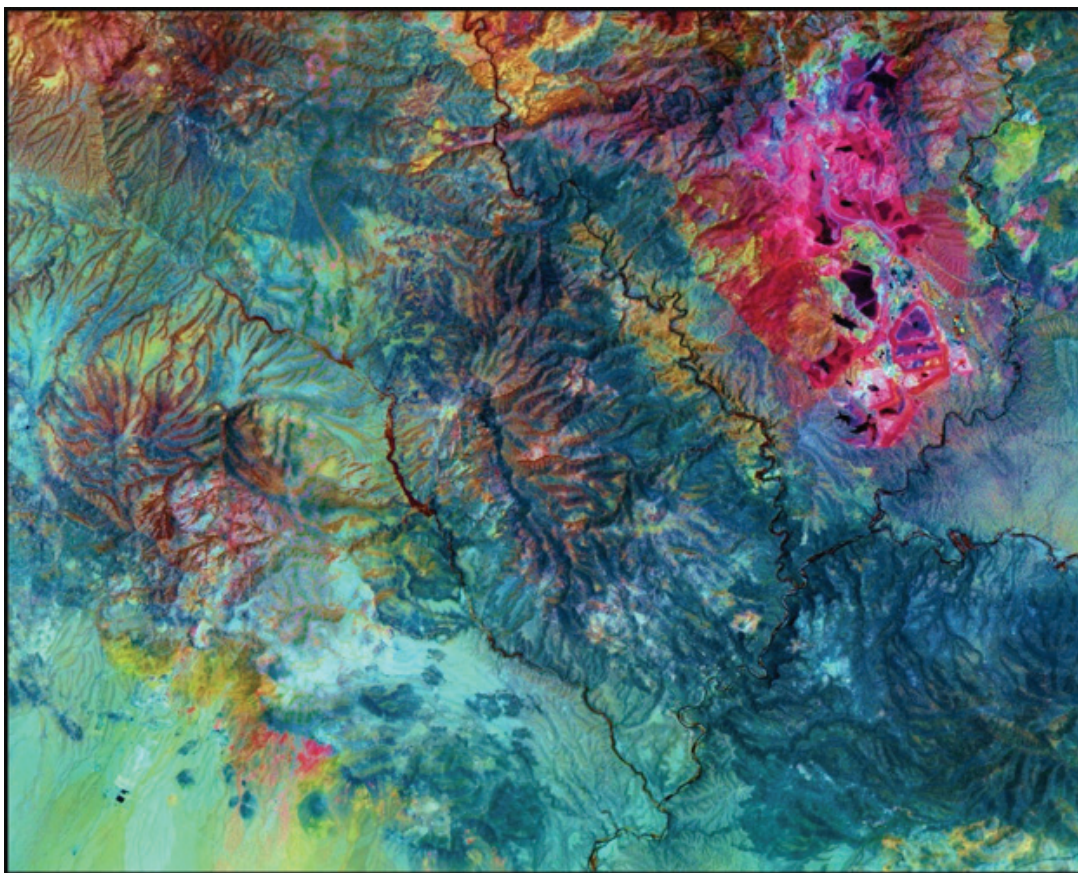


Figure 8. Satellite image of mineralised areas (<https://content.satimagingcorp.com/static/galleryimages/aster-arizona-morenci-mine.jpg>)

GPS technology is, nowadays, being used as a tool in many applications at the implementation stage even in engineering works, as has been observed in the construction of the tunnel under the English Channel. During its construction British and French crew started digging from the opposite ends. They relied on GPS receivers outside the tunnel to check their positions along the way to make sure they met exactly in the middle. The accuracy and correction factors of GPS technique, in the same way can be applied to give authenticity to geological mapping.

In the case of geological mapping with GPS there is no need of the measurement of horizontal distance as well as the measurement of horizontal direction as we get the location of the observation point directly in terms of longitude and latitude. More over the altitude of the observation point can be noted down directly from the GPS reading.

Since Global positioning system is most accurate of all the known methods to determine location, it is highly useful for mapping-based operations such as mineral prospecting and exploration, engineering geology application such as construction of tunnel and dam and mapping of ocean floor. GPS is already being used for tracking the movement of lithospheric plates, crustal deformation and the geomorphological change with the help of remote sensing satellites.

Watershed management projects are being carried out across different areas by using the technique of GPS, being supplemented with GIS and remote sensing technique. Land use pattern of any area can be prepared with high accuracy if GPS is used along with satellite imagery. GPS can be used in any vehicle such as car or any public transport system. It is also being used in aircraft in aerial surveys or on-board ships during marine surveys, or for positioning jack-up and off-shore rigs.

In view of all these observations it can be termed as history's most exciting and revolutionary development which has the capacity to establish a new concept in the different area of academic interest, industry or day to day life.

Teaching and learning strategies

Teaching Strategies:	Learning Strategies
Teachers prepare information (including pictures) and display actual geological equipment and ask questions on geological equipment.	Students will use the information provided to answer questions on geological equipment.
STEAM Approach Learning Objective: By the end of the topic, students will be able to; <ul style="list-style-type: none"> • Visualise, construct models of geological equipment - STEAM 	
Teaching Strategies Teachers will provide the criteria and the materials to construct models of geological equipment within a given period.	Learning Strategies In groups, students read the criteria and follow the steps and use the materials available to create models (prototype) of geological equipment within the given period.
Recommended Resources: <ul style="list-style-type: none"> • http://www.edafologia.net/optmine/intro/microscw.htm • https://content.satimagingcorp.com/static/galleryimages/aster-arizona-morenci-mine.jpg • Internet 	

Unit 1: Thinking Scientifically 1

Content Standard 11.1.1 Students will be able to understand and use the units of measurement, geological maps, common geological equipment and techniques.

Benchmark 11.1.1.3 Analyse the techniques used to acquire, analyse and display information about the Earth.

Topic 3: Geological Techniques and Maps

Learning Objectives:

By the end of this topic, the students will be able to:

- Identify different methods used to acquire information about the Earth
- Identify different methods used to analyse and display information about the Earth
- Identify the information presented on a geological map

Essential questions

1. What are the different methods used to acquire information about the Earth?
2. What are the different methods used to analyse information about the Earth?
3. What information is presented on a geological map?

Vocabulary: geological techniques, geological maps

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Methods and tools used to obtain, analyse and display information about the Earth 	<ul style="list-style-type: none"> • Acquiring information about the Earth • Analysing information about the Earth • Displaying information about the Earth (map) 	<ul style="list-style-type: none"> • Appreciate the geological techniques • Show desire to learn and understand the different geological techniques • Appreciate the geological map

Content Background

1. Methods used to acquire information about the Earth

There are various techniques used to acquire data to understand Earth – its composition, structure, surface and subsurface processes. Some involve direct observation and measurement, others indirect. After the data has been acquired, it must be processed in different ways to a format easy to interpret, then displayed in different formats (graphs, tables, maps, cross-sections, etc). These two last methods are discussed in the next section.

2. Methods used to analyse and display information about the Earth

When geological data is acquired and filtered, the next step is to analyse and then displayed – makes it easy to interpret. Filtering is one of the ways to remove bad data or noise which results from non-geological phenomena. Below briefly discusses the general Earth Science data analysis.

Data analytics activities fall within the scope and expertise of the data scientist. Data scientists study and develop methods for analysing, storing, and presenting data. When they practice their skills on specific problems, they are performing data analytics, applying tools and techniques to co-analyse heterogeneous data. Data scientists, as researchers, developers, or data analytics practitioners, require similar skill sets.

Several steps involved are:

- Data preparation – Preparing heterogeneous data so that they can be jointly analyzed.
- Data reduction – Correcting, ordering, and simplifying data in support of analytic objectives.
- Data analysis – Applying techniques/methods to derive results.

Data preparation includes the methods and techniques that uncover, discover, and extract data of greatest interest. This can involve filtering, mining, format conversion, smoothing, visualization, etc. Data reduction addresses very large amounts of heterogeneous data that face Earth science research. Several methods for the purpose of data reduction can be applied, with the goal of making data transfer, computation, and analysis easier and/or more focused. Analytics to perform data analysis is not as clear cut. Science, by its nature, often utilises technologies that are not decided upon until data/information is initially looked at and better understood. It is then that researchers experiment with existing and/or novel analytics techniques.

Earth science data analytics techniques are considered to be computational methods. Repeatedly, individuals seeking to perform Earth science express their need to utilise mathematics, numerical modelling, statistics, software engineering and the ability to integrate data from across multiple disciplines. Also, there is a need for expertise in techniques, such as: classification, cluster analysis, data fusion, anomaly detection, modelling, time series analysis, visualization, amongst others. In addition, many other computational methods have been identified as potential techniques to be used in performing Earth science data analysis.

When data analysis is completed, the result/information has to be presented in formats that can be better understood and perhaps interpreted. In geology, the geological map is one such presentation and is the record of surface or subsurface geological information.

3. Geological maps

A geological map (Fig. 1) is a pictorial record of surface or underground geological data. Geological mapping is the most essential and first role undertaken by the exploration geologist. Study of known mineral deposits has shown that certain types of ore minerals are only associated with certain types of rock. It is therefore important to know at the beginning of an exploration programme the types of rocks which are present in the area.

For example, if a company is searching for diamonds, the first part of the exploration programme is to search for kimberlites which are known to be the host rock for diamonds. Similarly nickel ore minerals are usually associated with basic (mafic) or ultrabasic (mafic) igneous rocks; gold, copper and silver are associated with intrusive igneous rocks; and nickel and cobalt are associated with altered ultramafic rocks.

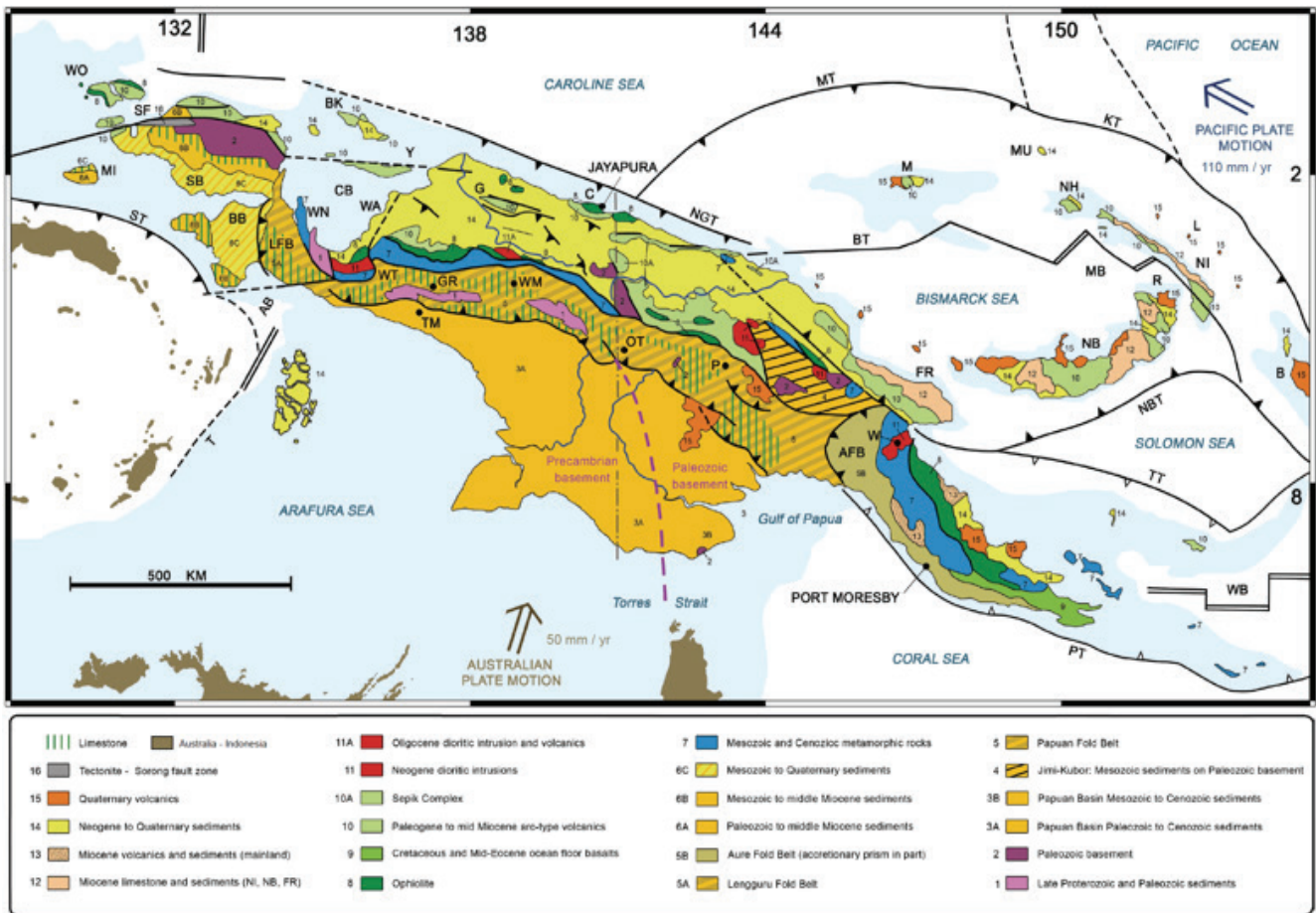


Figure 1. An example of a geological map (after Davies, 2013) (<https://i0.wp.com/exploringtheearth.com/wp-content/uploads/2018/04/PNG-geology.png>)

In mineral exploration a geological map brings together and presents the mineralogical, stratigraphic, structural and time relations of the rocks in the area and helps the geologist to understand how the rocks were formed and whether there is potential for mineral resources. The data collected by the exploration geologist are used to build a four-dimensional picture which makes it possible to interpret the geological evolution of the area through time. In addition, the geological map provides a basis for applying other exploration techniques such as geochemistry and geophysics and for relating the results of such work to geology.

When preparing a geological map, it is necessary to observe and record the features of the rocks which crop out as well as to deduce what lies beneath soil cover or is otherwise hidden. The scale or detail of the mapping is determined by the purpose for which the map is to be used. Geological mapping progresses from broad-scale reconnaissance mapping to detailed mapping, and as exploration becomes more detailed and more expensive, drilling may be used to obtain samples where there are no outcrops. The ultimate purpose of the mapping is to allow the selection of the most likely areas for mineralisation and thus to locate the sites for drilling and other testing.

Geologic maps are uniquely suited to solving problems involving Earth resources, hazards, and environments. Geologic maps represent the distribution of different types of rock and surficial deposits, as well as locations of geologic structures such as faults and folds. Geologic maps are the primary source of information for various aspects of land-use planning, including the siting of buildings and transportation systems. Such maps also help identify ground-water aquifers, aid in locating water-supply wells, and assist in locating potential polluting operations, such as landfills, safely away from the aquifers.

Geologic maps are four-dimensional data systems, and it is the fourth dimension of time that is crucial to assessing natural hazards and environmental or socio-economic risk. To read a geologic map is to understand not only where materials and structures are located, but also how and when these features formed.

Digital geologic maps are interactive electronic documents that put Earth science issues into geospatial frameworks. They capture the size, the shape, the depth, and the physical and chemical contexts of Earth materials, and they blend data display with the results of interpretive research. The combination of geological maps and Geographical Information System databases help us address a great variety of complex geologic and hydrologic issues, such as: how does subsurface distribution of porous and impermeable rock affect the flow of water, the potential for contamination, and the volume available for use?

Teaching and learning strategies

Teaching Strategies:

Teachers prepare information (including pictures) and ask questions on methods used to acquire, analyse and display information about the Earth. Teachers can take students out for an excursion to the nearest Geological Survey office.

Learning Strategies

Students will use the information provided to answer questions on methods used to acquire, analyse and display information about the Earth.

STEAM Approach

Learning Objective: By the end of the topic, students will be able to;

- Visualise, compare methods used to display information about the Earth - STEAM

Teaching Strategies

Teachers will provide the criteria and the materials to construct models of the Earth and a sample geological map.

Learning Strategies

In groups, students read the criteria and follow the steps and use the materials available to create models (prototype) of the Earth within the given period.

Recommended Resources:

- Clark, I.F. and Cook, B.J., 1992. Perspectives of the Earth. Australian Academy of Science, Canberra, ACT, 561p.
- Coe, A. (ed), Geological field techniques. The Open University, UK.
- Davies, H.L., 2013. Earth Tok, Third Edition. Alan Caudel and Associates, 231p.
- <https://datascience.codata.org/articles/10.5334/dsj-2017-006/>
- <https://geoinfo.nmt.edu/publications/maps/geologic/whatis.html>
- <https://i0.wp.com/exploringtheearth.com/wp-content/uploads/2018/04/PNG-geology.png>
- Internet

Strand 2: Earth Science

Unit 1: Introduction to Geology

Content Standard **11.2.1** Students will be able to understand the significance of geology as a discipline and the formation of the Earth.

Benchmark **11.2.1.1** Recognise geology as a discipline.

Topic 1: Geological Techniques and Maps

Learning Objectives:

By the end of this topic, the students will be able to:

- Recognise geology as a science discipline
- Discover what geologists do and where they get their training

Essential questions

1. What is Geology?
2. Who are geologists?
3. What do geologists do?

Vocabulary: geology, geologist

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Differences between geology and other sciences • Training to become a geologist • Career as a geologist 	<ul style="list-style-type: none"> • Distinguish the geology profession • Recognise the work of a geologist • Discover where geologists work 	<ul style="list-style-type: none"> • Appreciate the geology discipline • Show desire to learn and understand the different careers in geology

Content Background

1. Geology as a discipline

Geology is the science which is devoted to the study of the Earth. It deals with the Earth's surface and subsurface, and its origin, composition, structure and inhabitants. There are different branches of geology. A few examples are: Structural geology - it includes the study of the structure of the rocks of the Earth's crust; Stratigraphy - studying of rock layers (strata) and layering (stratification); Palaeontology - it deals with the study of fossils and ancient life forms; Economic geology - it deals with the study of minerals of economic importance; Mining and engineering geology - it is concerned with the study of application of geology to mining and civil engineering.

2. Geologists

Geologists are scientists trained up to the University level. The University of Papua New Guinea (UPNG) has a Geology Department that trains and produces an average of 20 geologists per year. Most of the PNG geologists got their training at UPNG.

Geologists are scientists trained up to the University level. The University of Papua New Guinea (UPNG) has a Geology Department that trains and produces an average of 20 geologists per year. Most of the PNG geologists got their training at UPNG.

Geologists are normally happy and humble people. Happy because wherever they go they see new features of the Earth that they can puzzle and ponder. Humble because no matter how clever they are they rarely can be sure of their conclusions. They will say to you “on the one hand it could be this, and on the other hand it could be that”. This is because the answers for most geological puzzles are concealed deep in the Earth. The geologist learns to live with uncertainty. More than most scientists he or she must juggle multiple hypotheses.

Geologists today, or most of them, are very concerned people because they fear for the future of our planet. They see in the geological literature all the evidence that our planet is approaching a tipping point where global warming cannot be constrained, where climate change and rise of sea level can lead to the loss of crops and to the flooding of much of what is now habitable land, and where the oceans are acidified to the extent that coral will not grow. They fear for the future of our communities and indeed of our society. They look hopefully for global action to reduce greenhouse gas emission and to find a way to reduce the greenhouse gas content of Earth’s atmosphere.

So, one thinks geology is about rocks, and indeed it is. But it longer has such a narrow focus. It is about our planet: from core to crust and from crust to biosphere and beyond to the Solar System and the Universe. It is about understanding how life has developed, about the great extinction events, about past changes of climate, and past impact events. It is also about understanding the behaviour of the Earth at times of earthquake and volcanic eruption, and guiding those who must manage disasters, about seeking and finding resources in the ground that can bring wealth to even the poorest nation, and about limiting the damage that may be done when resources are extracted.

Geologists are employed in a diverse range of jobs. Some work in the field, some in offices and others have a mixture of both. Generally, geologists work to better understand the Earth, but what do they do?

3. Work geologist do

Below are some examples of the tasks geologists can undertake.

Mapping and fieldwork

This a field-based task many geologists undertake.

- Field mapping looks at rock types and geological structures of an area and how they all relate to one another – the primary aim is to produce a ‘geological map’. It is usually undertaken by geologists from universities, Government Geological Surveys, mining and companies.
- Sampling trips are common for researchers and mining and petroleum companies.
- Geotechnical mapping assesses the engineering properties of a rock formation and its stability prior to undertaking any sort of construction or modification of the rock formations (such as building a tunnel).



Figure 1. Equipment and map (some tools) used by geologists.

Logging

This is often a field-based activity undertaken with mineral, petroleum or geotechnical drilling. Geologists describe rock chips extracted by the drilling to understand the geology below the surface. Logging sedimentary or volcanic rocks above ground is also used to study past environments. Some examples of logging include:

- Core logging for mining and exploration companies
- Mud and wireline logging are undertaken for oil and gas exploration
- Geotechnical logging assesses how strong or weak rocks are below the ground.

Laboratory work

Some geologists work in laboratories. Most of what we know about global and planetary geology result from laboratory studies. Researchers and those who work for some mining and petroleum companies work in laboratories. Laboratory work can include:

- Microscope work - looking at very fine details of rocks and fossils
- Geochemical analyses – using chemical methods to reveal details about samples (such as the metal content or the quality of oil)
- Geomechanical tests – testing the strength of rocks.

Computer-based work

Geologists nowadays do a lot of their work on computers mostly in offices – analysing and reducing field data, modelling, interpreting and writing reports, often using specialist software, but field-based computer work is becoming more common. Computer work include:

- Geographical Information System (GIS) – essentially, this is field mapping on computers – producing a digital database of the field data acquired by geologists.

- Database management – Geologists spend a lot of time ensuring databases are up to date. This can be vital for the modelling.
- Modelling programs – this has become increasingly important for geologists, both those who do research and in commercial companies. This means many geologists are trained in specialist software or programming. Geologists produce and maintain these for a range of purposes:
 - Modelling geological processes (often for research purposes)
 - Producing a 3-D model of a mineral deposit, oil field or aquifer.
 - Modelling the subsurface geology that an engineering project will require.

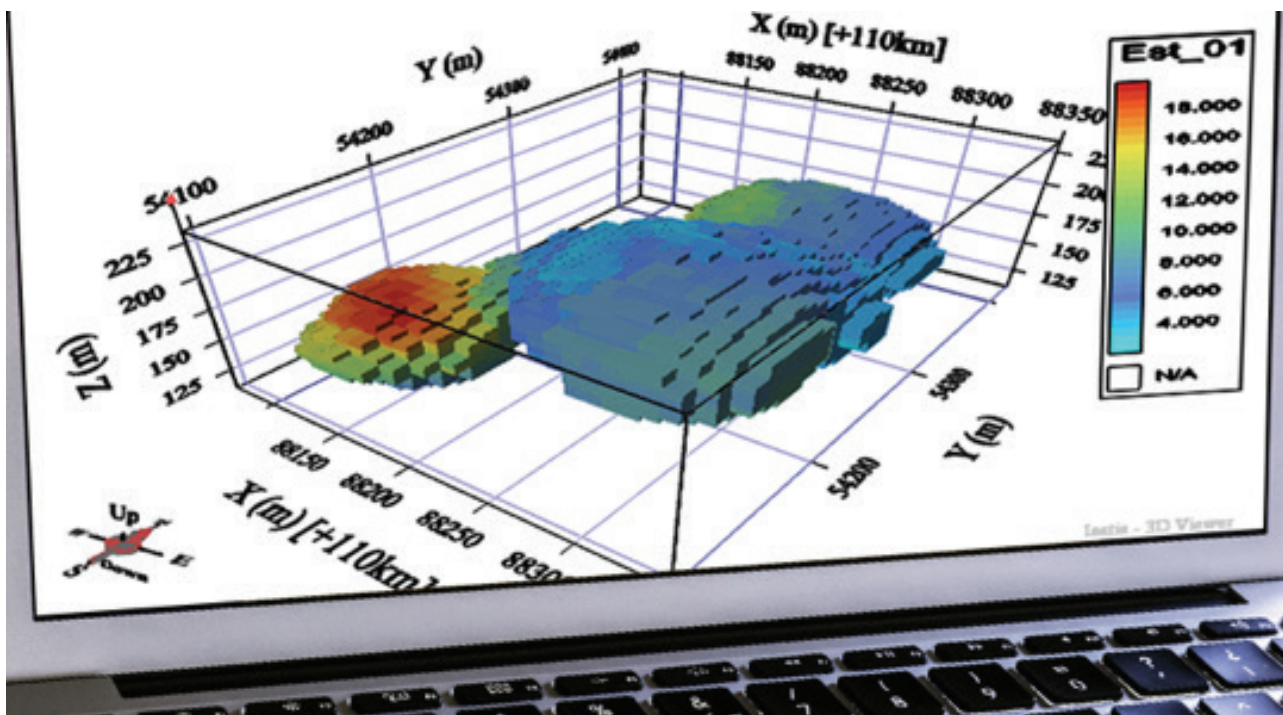


Figure 2. Producing a 3-D model of a mineral deposit, oil field and aquifer
 (<https://www.geolsoc.org.uk/Geology-Career-Pathways/What-is-Geology/What-do-Geologists-do>)

Report writing

Summarising the findings from all the tasks mentioned above in a concise yet comprehensive manner is crucial for all scientists, and geologists are no different. Reports can range from short daily updates to supervisors or colleagues (such as drilling progress reports) all the way to some very hefty documents of several hundred pages (such as doctoral dissertations or economic assessments for turning exploration targets into active oil fields or mines).

Teaching and Learning Strategies

Teaching Strategies:

Teachers prepare information (including pictures) and display and ask questions on geology discipline and geologists. Teachers can take students out for an excursion to the nearest institution that trains geologists

Learning Strategies

Students will use the information provided to answer questions on geology discipline and geologists.

STEAM Approach

Learning Objective: By the end of the topic, students will be able to;

- Construct models or structure of the geology discipline - STEAM

Teaching Strategies

Teachers will provide the criteria and the materials to construct structure of geology discipline within a given period.

Learning Strategies

In groups, students read the criteria and follow the steps and use the materials available to create structure (prototype) of geology discipline within the given period.

Recommended Resources:

- Clark, I.F. and Cook, B.J., 1992. Perspectives of the Earth. Australian Academy of Science, Canberra, ACT, 561p.
- Davies, H.L., 2013. Earth Tok, Third Edition. Alan Caudel and Associates, 231p.
- <https://www.geolsoc.org.uk/Geology-Career-Pathways/What-is-Geology/What-do-Geologists-do>
- Internet

Unit 1: Introduction to Geology

Content Standard

11.2.1 Students will be able to understand the significance of geology as a discipline and the formation of the Earth.

Benchmark

11.2.1.2 Investigate and analyse the formation of the Earth.

Topic 2: Earth

Learning Objectives:

By the end of this topic, the students will be able to:

- Investigate the formation of the universe and the Earth
- Describe the internal structure and composition of the Earth
- Diagram or model the interior of the Earth, labelling all principal parts and showing the approximate thickness of each layer
- Describe the characteristics of the various layers of the Earth

Essential questions

1. How was the universe formed?
2. How was the Earth formed?
3. What are the composition and characteristics of the Earth's layers?

Vocabulary: Earth's layers, composition, characteristics

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Formation of the universe • Formation of the Earth • Development of the Earth's layers • Composition and thickness of the Earth's layers 	<ul style="list-style-type: none"> • Analyse the formation of the universe • Analyse the development of the Earth's layers • Recognise the composition and thickness of the Earth's layers 	<ul style="list-style-type: none"> • Appreciate the formation of the universe • Show desire to learn and understand the development of the Earth's layers • Appreciate the composition and thickness of the Earth's layers

Content Background

1. Formation of the Universe

The Big Bang Theory is the most widely accepted cosmological explanation of how the universe formed. If we start at the present and go back in the past, the universe is contracting, getting smaller and smaller. What is the result of a contracting universe? According to the Big Bang Theory, the universe began about 13.7 billion years ago. Everything that is now in the universe was squeezed into a very small volume. Imagine all the known universe in a single, hot, chaotic mass. An enormous explosion – a big bang – caused the universe to start expanding rapidly. All the matter and energy in the universe, and even space itself, came out of this explosion. What came before the Big Bang? There is no way for scientists to know since there is no remaining evidence.

2. Formation of the Earth

Formation of the Earth occurred about 4.6 billion years ago. The dense cloud (nebula), compressed due to gravity, grew immensely hot and heavy in the centre. This became the Sun. The matter on the outskirts of this nebula was pushed outward into space due to the force of solar winds. This matter aggregated through gravity and coalesced into what are called proto-planets and the potential moons. This is how Earth was formed because the third proto-planet from the Sun was Earth.

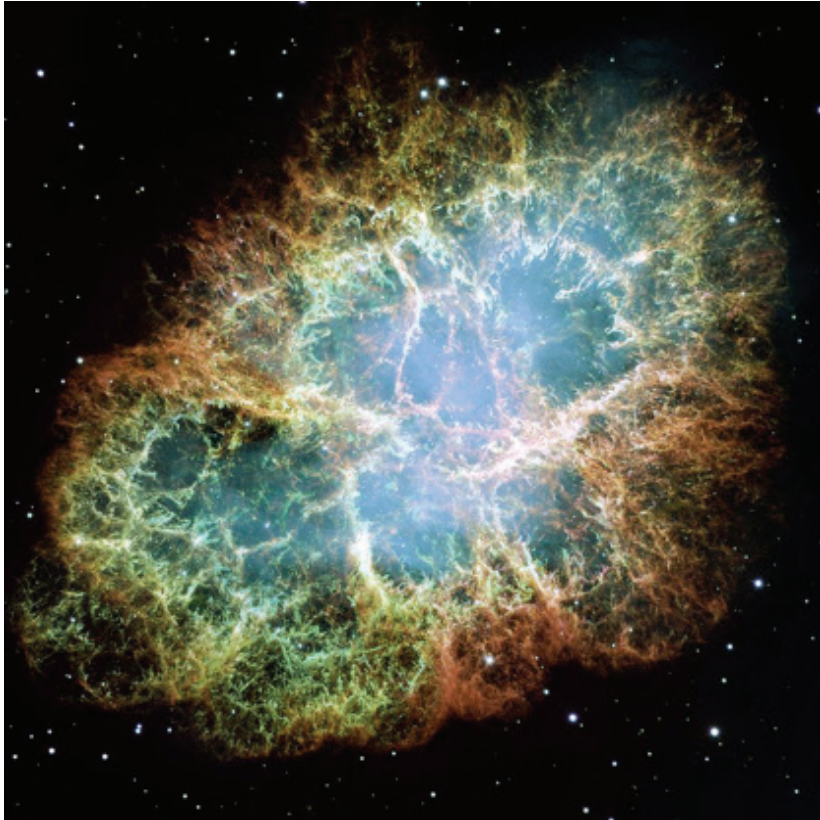


Figure 1. An example of RT instability in the Crab Nebula, a supernova remnant and pulsar wind nebula in the constellation of Taurus (Image Source: Wikimedia Commons)

Earth started out as a hot, lifeless, sturdy rock, constantly buffeted by comets and meteorites for half a billion years. With volcanoes occasionally vomiting molten lava and beings, if any, perishing under the sun's scorching rays. Rewinding even further, it seems that the planet emanated from sputtered particles and gas that came together under the inescapable lure of gravity.

3. Development of Earth's layers

The Earth formed about 4.6 billion years ago during the birth of our solar system. This date comes from meteorites and moon rocks. For several hundred million years after the formation of the solar system the planets were continuously bombarded by meteoric debris thus the surface of the Earth probably remelted repeatedly by the impacts of large asteroids. This early bombardment continued until about 3.8 billion years ago.

During the next major phase of Earth's formation, cooling and differentiation of the Earth's layers occurred. Dense materials sank to the centre, forming an iron-nickel rich core. Lighter buoyant silicate-rich magma rose to the surface. The remaining material between the core and the magma formed Earth's thickest layer, the mantle, which is composed mainly of iron, magnesium, calcium-rich silicate minerals.

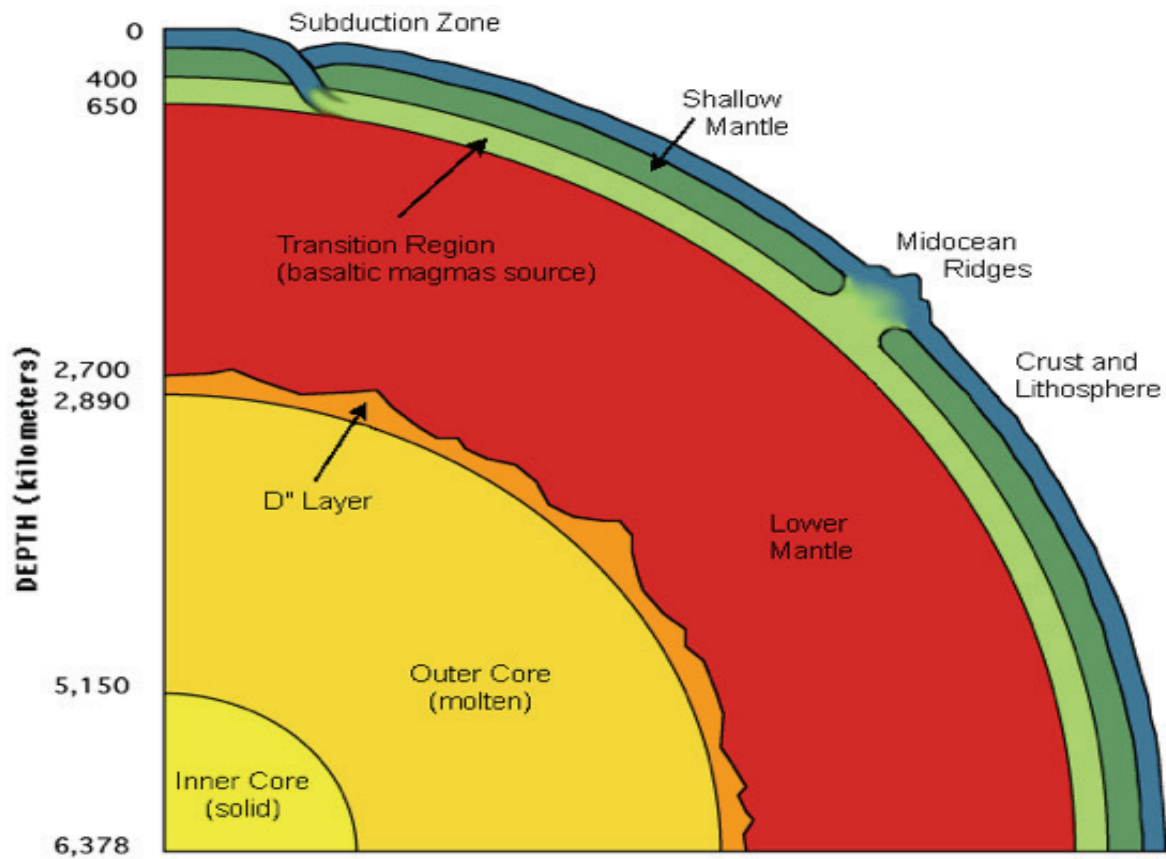


Figure 2. Cross sectional view of Earth illustrating its heterogeneous layers (after Beatty et al., 1990).

Eventually, the magma cooled to form a thin layer of silica/aluminium-rich crust. Oceanic crust is composed of dense basalt and gabbro. Continental crust is less dense and has a granitic composition overall.

The division of the Earth's interior into 3 distinct layers called the core, mantle, and crust is based on chemical composition. Earth's interior is commonly further differentiated into 5 layers based on physical properties (Fig. 2). Starting from the Earth's surface, the interior is divided into the lithosphere, asthenosphere, mesosphere, outer core, and inner core.

4. Composition and thickness of the Earth's layers

Earth is unique among the known planets: it has an abundance of water. Other worlds – including a few moons – have atmospheres, ice, and even oceans, but only Earth has the right combination to sustain life.

Earth's oceans cover about 70 percent of the planet's surface with an average depth of 4 kilometres. Fresh water exists in liquid form in lakes and rivers and as water vapour in the atmosphere, which causes much of Earth's weather.

Earth has multiple layers. The ocean basins and the continents compose the crust, the outermost layer. Earth's crust is between five and 75 km deep. The thickest parts are under the continents and the thinnest parts are under the oceans.

Crust

Earth's crust is made up of several elements: oxygen, 46.6 percent by weight; silicon, 27.7 percent; aluminium, 8.1 percent; iron, 5 percent; calcium, 3.6 percent; sodium, 2.8 percent, potassium, 2.6 percent, and magnesium, 2.1 percent.

The crust is divided into huge plates that float on the mantle, the next layer. The plates are constantly in motion; they move at about the same rate as fingernails grow. Earthquakes occur when these plates grind against each other. Mountains form when the plates collide and deep trenches form when one plate slides under another plate. Plate tectonics is the theory explaining the motion of these plates.

Mantle

The mantle under the crust is about 2,890 km. It is composed mostly of silicate rocks rich in magnesium and iron. Intense heat causes the rocks to rise. They then cool and sink back down to the core. This convection is thought to cause the tectonic plates to move. When the mantle pushes through the crust, volcanoes erupt.

Core

At the centre of the Earth is the core, which has two parts. The solid, inner core of iron has a radius of about 1,220 km. It is surrounded by a liquid, outer core composed of a nickel-iron alloy. The outer core is about 2,180 km thick. The inner core spins at a different speed than the rest of the planet. This is thought to cause Earth's magnetic field. When charge particles from the solar wind collide with air molecules above Earth's magnetic poles, it causes the air molecules to glow, causing the auroras – the northern and southern lights.

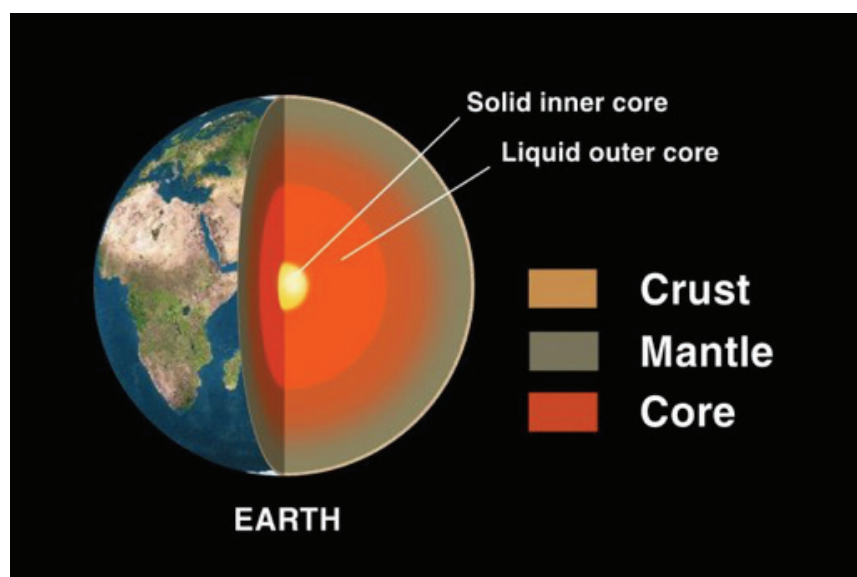


Figure 3. Earth has multiple layers: the crust, mantle and core (Image: © NASA)

The crust

The crust is a relatively thin layer of rock. In some places it is above the sea and forms the continents and islands. The crust is thickest under the continents. It may reach a thickness of more than 100 kilometres. The crust is the thinnest under the ocean where it may be less than 10 kilometres thick.

Tests on the ages of the rocks in the crust have shown that the rocks of the continents are much older than the rocks under the oceans. Further tests have shown that rocks which make up the continents are different from the ocean rocks.

Oceanic rocks are darker in colour and heavier in weight. Continental rocks are lighter in colour and lighter in weight. Beneath the crust is a very thick layer, the mantle. Because the rocks of the crust are lighter than the mantle rocks, the crustal rocks 'float' on the mantle. Like other floating objects, they can move, but the movement is very slow.

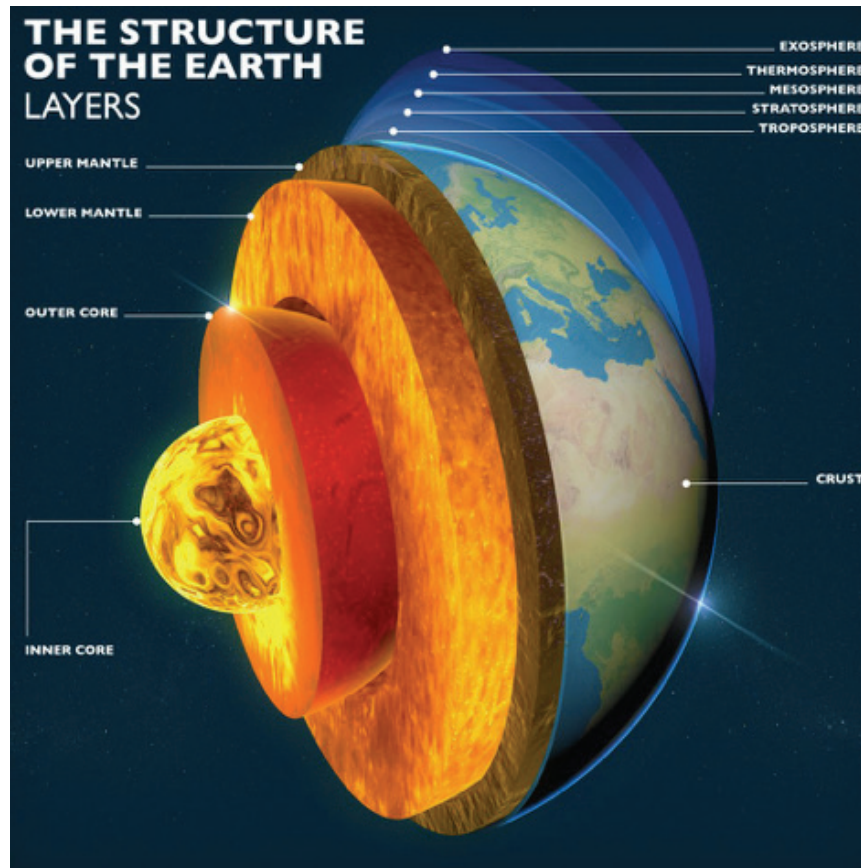


Figure 4. Structure of the Earth (Photo Credit: Naeblys / Shutterstock)

The mantle

The mantle is a very thick layer of the Earth. It makes up about 80 percent of the Earth's volume and is approximately 2800 kilometres thick. It consists of heavy rocks which are thought to be very hot and in a semi-molten state. These rocks are like plasticine, tar or stirred sago, and come to the surface when volcanoes erupt. When they come to the surface they are called lava.

The core

The core forms about 15 percent of the Earth's volume and consists of a large ball-like shape in the middle of the Earth. It has a diameter of approximately 7000 kilometres. The core consists of two parts: the inner core, which scientists think is solid; and the outer core, which they think is a thick liquid.

Geologists use the occurrence of earthquakes to find out about the interior of the Earth. When an earthquake occurs, shock waves travel around and through the Earth. Recording stations pick up the shock waves and a 'picture' of the structure of the Earth can be developed.

Teaching and Learning Strategies

Teaching Strategies:

Teachers prepare information (including pictures) and display and ask questions on Earth. Teachers can take students out for an excursion to the nearest Earth Observatory if the school is located closer to an observatory.

Learning Strategies

Students will use the information provided to answer questions on Earth.

STEAM Approach

Learning Objective: By the end of the topic, students will be able to;

- Construct models of the Earth layers - STEAM

Teaching Strategies

Teachers will provide the criteria and the materials to construct models of Earth within a given period.

Learning Strategies

In groups, students read the criteria and follow the steps and use the materials available to create models (prototype) of the Earth within the given period.

Recommended Resources:

- Beatty, J.K. and Chaikin, A., 1990, (eds). The New Solar System, Sky Publishing, 3rd Edition, Massachusetts.
- Clark, I.F. and Cook, B.J., 1992. Perspectives of the Earth. Australian Academy of Science, Canberra, ACT, 561p.
- Davies, H.L., 2013. Earth Tok, 3rd Edition. Alan Caudel and Associates, 231p.
- Lutgens, K. Frederick and Tarbuck, J. Edward, 2000. Essentials of Geology, 7th Edition, Prentice Hall.
- Internet

Unit 2: Earth Materials

Content Standard **11.2.2** Students will be able to compare and contrast between minerals, minerals and rocks, rocks, and understand the formation of rocks, minerals and fossil fuels, and their uses.

Benchmark **11.2.2.1** Analyse and compare minerals according to their properties, formation and uses.

Topic 1: Minerals

Learning Objectives:

By the end of this topic, the students will be able to:

- Describe mineral lattices and explain how they influence mineral properties.
- Categorise minerals into groups based on their compositions.

Essential questions

1. What is Moh's hardness scale?
2. What are some special properties of minerals?
3. How are minerals classified?

Vocabulary: Minerals, mineralogist, Mohs hardness scale, cleavage, luster, streak

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Properties of minerals • Moh's hardness scale • Classification of minerals 	<ul style="list-style-type: none"> • Understanding, reasoning, comparing and contrasting 	<ul style="list-style-type: none"> • Open-minded, with a desire to learn

Content Background

1. Minerals

The solid Earth is composed of rocks which are made up of minerals and/or mineral groups. Elements essential to life, metals of industry, materials for building, are all obtained from, or made up of, minerals. The calcium and phosphorous in bones and the iron in blood are made available to the body through plants which extracted these elements from minerals.

A mineral is a naturally-occurring inorganic solid having a regular atomic arrangement and a chemical composition that is either fixed, for example, quartz (SiO_2) or varies between fixed limits, for example, olivine (Mg_2SiO_4 to Fe_2SiO_4).

2. Formation of minerals

A mineral forms when elements combine to form a solid because of some change in the physical conditions. In a liquid, atoms and groups of atoms are in constant motion. Atoms may bond briefly but collision with other atoms breaks these arrangements. However, for example, when basaltic lava cools, atoms of magnesium (Mg), iron (Fe), silicon (Si) and oxygen (O) gradually lose heat energy, and their movement slows down enough to form permanent bonds. They may combine to form the mineral olivine. At the same time atoms of calcium (Ca), sodium (Na), aluminium (Al), Si and O can combine to form the mineral plagioclase feldspar. In turn these minerals may change into new minerals if the physical conditions are changed greatly.

When seawater evaporates, the sodium and chlorine atoms in solution slowly move close together as the number of water molecules surrounding them decreases. Eventually the atoms are close enough so that more are meeting and bonding than are being separated by the water molecules, and solid or crystalline sodium chloride (NaCl) starts to form as cubes or crystals of the mineral halite.

The processes of mineral formation

Minerals form in and on Earth by a variety of processes. A mineral will only form when the chemical composition of the system and physical conditions, such as temperature and pressure, are appropriate to that mineral. The processes of mineral formation may be classified in the following ways:

Igneous. Crystallised from magma (molten rock) at temperatures generally between 600°C and 1200°C, and from the surface to depths of 30 km or more.

Weathering. Crystallised under surface conditions following chemical reaction between pre-existing minerals and the atmosphere or surface solutions.

Sedimentary. Crystallised from solution by the evaporation of water, forming the evaporative minerals such as halite and gypsum, or precipitated from water due to changes in chemical conditions. Examples are chert (silica) and iron oxides and carbonates, or deposited by organisms as shells or bones, for example aragonite (CaCO₃).

Metamorphic. Recrystallisation and reaction with pre-existing rocks produce new minerals in response to variations in temperature and pressure.

3. Physical properties of minerals

Minerals can be identified by their physical characteristics. The physical properties of minerals are related to their chemical composition and bonding. Some characteristics, such as a mineral's hardness, are more useful for mineral identification. Colour is readily observable and certainly obvious, but it is usually less reliable than other physical properties.

There are approximately 4000 different minerals, and each of those minerals has a unique set of physical properties. These include: colour, lustre, streak, hardness, diaphaneity, specific gravity, cleavage, fracture, magnetism, solubility, and many more.

Mineralogists are scientists who study minerals. One of the things mineralogists must do is identify and categorize minerals. While a mineralogist might use a high-powered microscope to identify some minerals, most are recognizable using physical properties.

Colour

Colour is often useful but should not be relied upon. Different minerals may be the same colour. Real gold, as seen in Fig. 1, is very similar in colour to pyrite in Fig. 2.



Figure 1. Gold

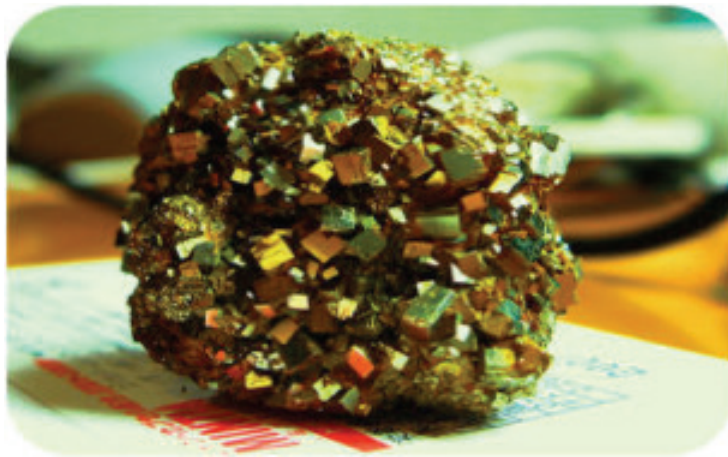


Figure 2. This mineral has shiny, gold, cubic crystals with striations, so it is pyrite.

Additionally, some minerals come in many different colours. Quartz, for example, may be clear, white, grey, brown, yellow, pink, red, or orange. So, colour can help, but do not rely on colour as the determining property. Figure 3, shows one sample of quartz that is colourless and another quartz that is purple. A tiny amount of iron makes the quartz purple. Many minerals are coloured by chemical impurities.



Figure 3. Purple quartz, known as amethyst, and clear quartz are the same mineral despite the different colours.

Lustre

Lustre describes the reflection of light off a mineral's surface. Mineralogists have special terms to describe lustre. One simple way to classify lustre is based on whether the mineral is metallic or non-metallic. Minerals that are opaque and shiny, such as pyrite, have a metallic lustre. Minerals such as quartz have a non-metallic lustre.

Lustre is how the surface of a mineral reflects light. It is not the same thing as colour, so it is crucial to distinguish lustre from colour. For example, a mineral described as "shiny yellow" is being described in terms of lustre ("shiny") and colour ("yellow"), which are two different physical properties. Standard names for lustre include metallic, glassy, pearly, silky, greasy, and dull. It is often useful to first determine if a mineral has a metallic lustre. A metallic lustre means shiny like polished metal. For example, cleaned polished pieces of chrome, steel, titanium, copper, and brass all exhibit metallic lustre as do many other minerals. Of the non-metallic lustres, glassy is the most common and means the surface of the mineral reflects light like glass. Pearly lustre is important in identifying the feldspars, which are the most common type of mineral. Pearly lustre refers to a subtle iridescence or colour play in the reflected light; same way pearls reflect light. Silky means reflecting light with a silk-like sheen. Greasy lustre looks like the lustre of solidified bacon grease. Minerals with dull lustre reflect very little light. Identifying lustre takes a little practice. Remember to distinguish lustre from colour.

Different types of non-metallic lustre are described in table below.

Six types of non-metallic lustre.	
Lustre	Appearance
Adamantine	Sparkly
Earthy	Dull, clay-like
Pearly	Pearl-like
Resinous	Like resins, such as tree sap
Silky	Soft-looking with long fibres
Vitreous	Glassy

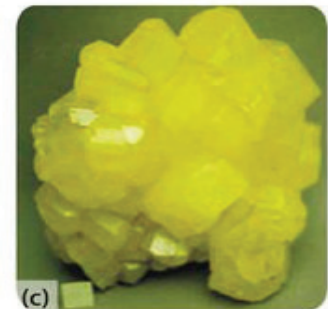
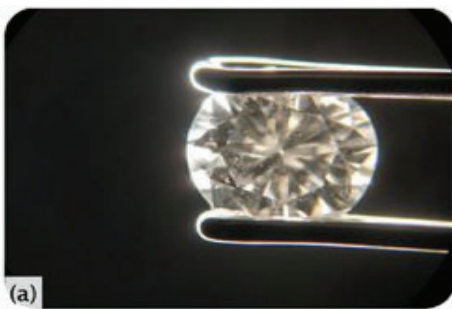


Figure 4. (a) Diamond has an adamantine lustre. (b) Quartz is not sparkly and has a vitreous, or glassy, lustre. (c) Sulphur reflects less light than quartz, so it has a resinous lustre.

Streak

Streak is the colour of a mineral's powder. Streak is a more reliable property than colour because streak does not vary. Minerals that are the same colour may have a different coloured streak. Many minerals, such as the quartz in the Fig. 3, do not have streak.

To check streak, scrape the mineral across an unglazed porcelain plate (Fig. 5). Yellow-gold pyrite has a blackish streak, another indicator that pyrite is not gold, which has a golden yellow streak.



Figure 5. The streak of hematite across an unglazed porcelain plate is red-brown.

Specific gravity

Density describes how much matter is in a certain amount of space: $\text{density} = \text{mass}/\text{volume}$.

Mass is a measure of the amount of matter in an object. The amount of space an object takes up is described by its volume. The density of an object depends on its mass and its volume. For example, the water in a drinking glass has the same density as the water in the same volume of a swimming pool.

The specific gravity of a substance compares its density to that of water. Substances that are denser have higher specific gravity.

Hardness

Hardness is the strength with which a mineral resists its surface being scraped or punctured. In working with hand samples without specialised tools, mineral hardness is specified by the Mohs hardness scale.

The Mohs hardness scale is based on 10 reference minerals, from talc the softest (Mohs hardness of 1), to diamond the hardest (Mohs hardness of 10). It is a relative, or nonlinear, scale. A hardness of 2.5 simply means that the mineral is harder than gypsum (Mohs hardness of 2) and softer than calcite (Mohs hardness of 3). To compare the hardness of two minerals, see which mineral scratches the surface of the other.

With a Mohs scale, anyone can test an unknown mineral for its hardness. Imagine you have an unknown mineral. You find that it can scratch fluorite or even feldspar, but apatite scratches it. You know then that the mineral's hardness is between 5 and 6. Note that no other mineral can scratch diamond.

Cleavage

Breaking a mineral breaks its chemical bonds. Since some bonds are weaker than others, each type of mineral is likely to break where the bonds between the atoms are weaker. For that reason, minerals break apart in characteristic ways.

Cleavage is the tendency of a mineral to break along certain planes to make smooth surfaces. Halite breaks between layers of sodium and chlorine to form cubes with smooth surfaces (Fig.6).

A mineral that naturally breaks into perfectly flat surfaces is exhibiting cleavage. Not all minerals have cleavage. A cleavage represents a direction of weakness in the crystal lattice. Cleavage surfaces can be distinguished by how they consistently reflect light, as if polished, smooth, and even. The cleavage properties of a mineral are described in terms of the number of cleavages and, if more than one cleavage, the angles between the cleavages. The number of cleavages is the number or directions in which the mineral cleaves. A mineral may exhibit 100 cleavage surfaces parallel to each other. Those represent a single cleavage because the surfaces are all oriented in the same direction. The possible number of cleavages a mineral may have are 1,2,3,4, or 6. If more than 1 cleavage is present, and a device for measuring angles is not available, simply state whether the cleavages intersect at 90° or not 90° .

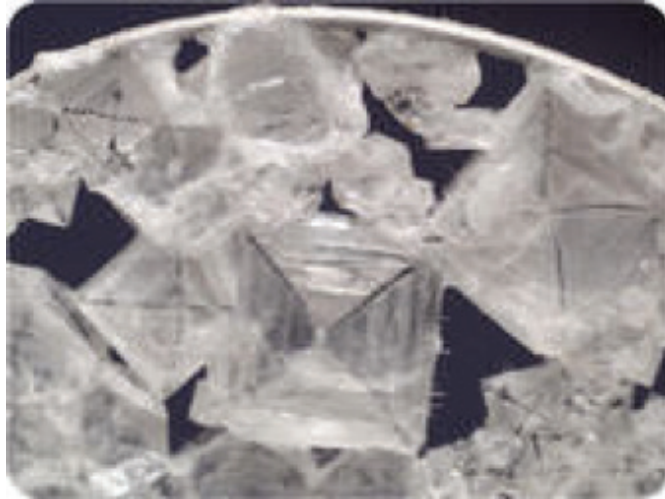


Figure 6. A close-up view of sodium chloride in a water bubble aboard the International Space Station.

To see mineral cleavage, hold the mineral up beneath a strong light and move it around to see how the different sides reflect light. A cleavage direction will show up as a smooth, shiny, evenly bright sheen of light reflected by one set of parallel surfaces on the mineral.

Mica has cleavage in one direction and forms sheets (Fig. 7).



Figure 7. Sheets of mica.

Minerals can cleave into polygons. Fluorite and diamond forms octahedrons (Fig. 8).

One reason gemstones are beautiful is that the cleavage planes make an attractive crystal shape with smooth faces.



Figure 8. This rough diamond shows its octahedral cleavage.

Fracture

Fracture is a break in a mineral that is not along a cleavage plane. Fracture is not always the same in the same mineral because fracture is not determined by the structure of the mineral.

Minerals may have characteristic fractures (Fig. 9). Metals usually fracture into jagged edges. If a mineral splinters like wood, it may be fibrous. Some minerals, such as quartz, form smooth curved surfaces when they fracture.



Figure 9. Chrysotile has splintery fracture.

All minerals have fracture. Fracture is breakage, which occurs in directions that are not cleavage directions. Some minerals, such as quartz, have no cleavage whatsoever. When a mineral with no cleavage is broken apart by a hammer, it fractures in all directions. Quartz is said to exhibit conchoidal fracture. Conchoidal fracture is the way a thick piece of glass breaks with concentric, curving ridges on the broken surfaces. However, some quartz crystals have so many flaws that instead of exhibiting conchoidal fracture they simply exhibit irregular fracture. Irregular fracture is a standard term for fractures that do not exhibit any of the qualities of the other fracture types. In introductory geology, the key fracture types to remember are irregular, which most minerals exhibit, and conchoidal, seen in quartz.

Crystal shape

All minerals are crystalline, but only some can exhibit the shapes of their crystals, their crystal forms. Many minerals in an introductory geology lab do not exhibit their crystal form. If a mineral has space while it grows, it may form natural crystals, with a crystal shape reflecting the geometry of the mineral's internal crystal lattice. The shape of a crystal follows the symmetry of its crystal lattice. Quartz, for instance, forms six-sided crystals, showing the hexagonal symmetry of its crystal lattice. There are two complicating factors to remember here: (a) minerals do not always form nice crystals when they grow, and (b) a crystal face is different from a cleavage surface. A crystal face forms during the growth of the mineral. A cleavage surface is formed when the mineral is broken.

4. Moh's hardness scale and special properties

The Mohs' hardness scale (Fig. 10) was developed in 1822 by Frederick Mohs. This scale is a chart of relative hardness of the various minerals (1 - softest to 10 - hardest). Since hardness depends upon the crystallographic direction (ultimately on the strength of the bonds between atoms in a crystal), there can be variations in hardness depending upon the direction in which one measures this property. One of the most striking examples of this is kyanite, which has a hardness of 5.5 parallel to the 1 direction (c-axis), while it has a hardness of 7.0 parallel to the a-axis. Talc (1), the softest mineral on the Mohs scale has a hardness greater than gypsum (2) in the direction that is perpendicular to the cleavage. Diamonds (10) also show a variation in hardness (the octahedral faces are harder than the cube faces). For further information see articles from the American Mineralogist on micro-hardness, the Knoop tester, and diamonds.

Mohs' hardness is a measure of the relative hardness and resistance to scratching between minerals. Other hardness scales rely on the ability to create an indentation into the tested mineral (such as the Rockwell, Vickers, and Brinell hardness - these are used mainly to determine hardness in metals and metal alloys). The scratch hardness is related to the breaking of the chemical bonds in the material, creation of micro fractures on the surface, or displacing atoms (in metals) of the mineral. Generally, minerals with covalent bonds are the hardest while minerals with ionic, metallic, or van der Waals bonding are much softer.

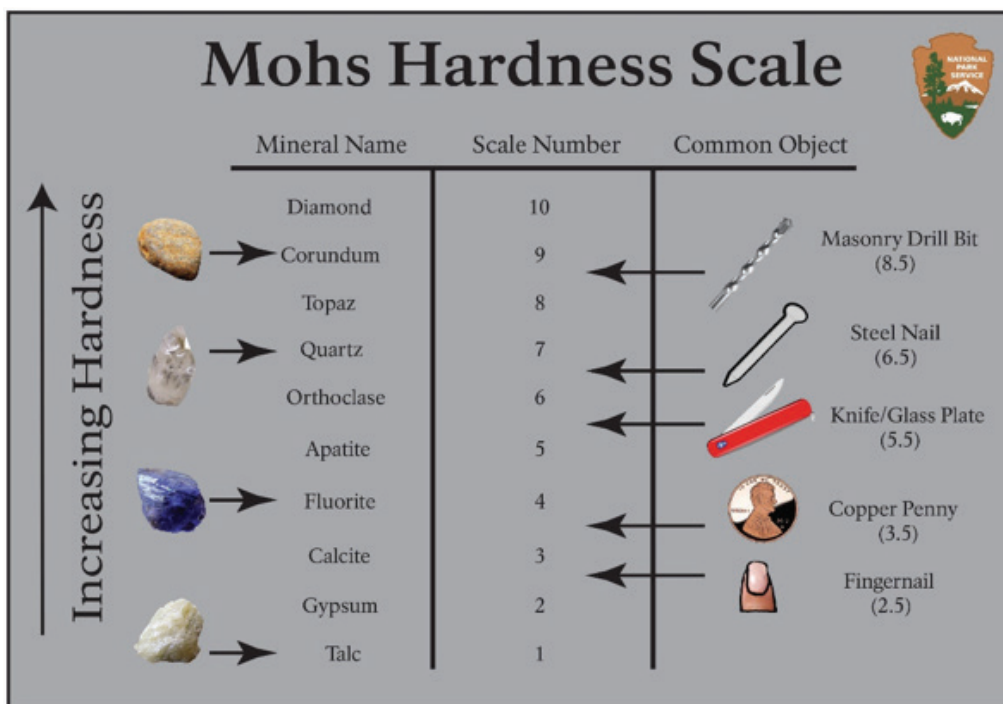


Figure 10. Mohs hardness scale (Source: <https://et.wikipedia.org/wiki/Fail:Mohs.jpg>)

When doing tests on the minerals it is necessary to determine which mineral was scratched. The powder can be rubbed or blown off and surface scratches can usually be felt by running the fingernail over the surface. One can also get a relative feel for the hardness difference between two minerals. For instance, quartz will be able to scratch calcite with much greater ease than you can scratch calcite with fluorite. One must also use enough force to create the scratch (if you don't use enough force even diamond will not be able to scratch quartz - this is an area where practice is important). You also must be careful to test the material that you think you are testing and not some small inclusion in the sample. This is where using a small hand lens can be very useful to determine if the test area is homogenous.

Special Properties of Minerals

Several minerals react when placed within a magnetic field. Some minerals are strongly attracted to the magnet, others are weakly attracted, and one mineral is repelled. There are also several minerals that are attracted to magnetic fields only when heated.

Magnetic field is an area encompassing a magnet or electrical current that can attract or repel certain objects placed in the field. The closer the object is to the magnet or electrical current, the more powerful the magnetic effect. In virtually all cases, the presence of the element iron as a component of the mineral's chemical structure is responsible for its magnetic properties. Magnetic properties of minerals are defined as follows:

Ferromagnetism describes strong attraction to magnetic fields. This property is exhibited in a few minerals, notably magnetite and pyrrhotite.

Paramagnetism is weak attraction to magnetic fields. The attraction is usually discernible, but it may be so weak that it is undetectable. Most paramagnetic minerals become strongly magnetic when heated. A small number of paramagnetic minerals, such as platinum, are not essentially paramagnetic, but contain iron impurities which are responsible for the paramagnetism. However, some specimens lacking iron also exist, and these are not paramagnetic. Some examples of paramagnetic minerals are hematite and franklinite.

Diamagnetism. Only one mineral, bismuth, is diamagnetic, meaning it is repelled from magnetic fields.

Another property, which is unnamed, is attraction to magnetic fields when heated. Some iron sulfides and oxides become ferromagnetic after heating, because of combined sulfur or oxygen ions freeing themselves from the iron. Some minerals may even act as magnets when heated.

Magnetism. Only a variety of one mineral acts as a magnet, generating magnetic fields on its own. This mineral is lodestone, the magnetic variety of magnetite, which is found in only a few deposits throughout the world. Although it is only weakly magnetic, its magnetism is discernible.



Figure 11. Lodestone. The magnetism of this magnetic variety of magnetite is clearly visible.

Magnetic properties are useful for identifying a mineral, for if observed it can pinpoint a mineral. The most effective testing results are obtained with the use of a powerful magnet. The only minerals that possibly respond to magnets without heating are opaque, metallic-looking minerals.


Other Identifying Characteristics

There are some properties that only help to distinguish a small number of minerals, or even just a single mineral. An example of such a special property is the effervescent reaction of calcite to a weak solution of hydrochloric acid (5% HCl). Calcite fizzes or effervesces as the HCl solution dissolves it and creates CO² gas. Calcite is easy to identify even without testing the reaction to HCl, by its hardness, luster and cleavage.

Other special properties may be encountered on a mineral to mineral basis.

Some minerals have unusual properties that can be used for identification		
Property	Description	Example of Mineral
Fluorescence	Minerals glow under ultraviolet light	Fluorite
Magnetism	Mineral is attracted to a magnet	Magnetite
Radioactivity	Mineral gives off radiation that can be measured with Geiger counter	Uraninite
Reactivity	Bubbles form when mineral is expose to a weak acid	Calcite
Smell	Some minerals have distinctive smell	Sulphur (smells like rotten eggs)
Taste	Some minerals taste salty	Halite


Special Properties of Some Minerals



Fluorescence
Calcite and fluorite glow under ultraviolet light. The same fluorite sample is shown in ultraviolet light (top) and in white light (bottom).



Chemical Reaction
Calcite will become bubbly, or "fizz," when a drop of weak acid is placed on it.



Optical Properties
A thin, clear piece of calcite placed over an image will cause a double image.



Magnetism
Both magnetite and pyrrhotite are natural magnets that attract iron.



Taste
Halite has a salty taste.



Radioactivity
Minerals that contain radium or uranium can be detected by a Geiger counter.

5. Classifying minerals using tests and references

Minerals are classified according to their chemical properties. Except for the native element class, the chemical basis for classifying minerals is the anion, the negatively charged ion that usually shows up at the end of the chemical formula of the mineral. For example, the sulphides are based on the sulphur ion, S^{2-} . Pyrite, for example, FeS_2 , is a sulphide mineral. In some cases, the anion is of a mineral class is polyatomic, such as $(CO_3)^{2-}$, the carbonate ion. The major classes of minerals are: silicates, sulphides, carbonates, oxides, halides, sulfates, phosphates, and native elements.

Silicates

Based on the polyatomic anion, $(SiO_4)^{-4}$, which has a tetrahedral shape. Most minerals in the Earth's crust and mantle are silicate minerals. All silicate minerals are built of silicon-oxygen tetrahedra $(SiO_4)^{-4}$ in different bonding arrangements which create different crystal lattices. You can understand the properties of a silicate mineral such as crystal shape and cleavage by knowing which type of crystal lattice it has.

- In nesosilicates, also called island silicates, the silicate tetrahedra are separate from each other and bonded completely to non-silicate atoms. Olivine is an island silicate.
- In sorosilicates or paired silicates, such as epidote, the silicate tetrahedra are bonded in pairs.
- In cyclosilicates, also called ring silicates, the silicate tetrahedra are joined in rings. Beryl or emerald is a ring silicate.
- In phyllosilicates or sheet silicates, the tetrahedra are bonded at three corners to form flat sheets. Biotite is a sheet silicate.
- In single-chain inosilicates the silicate tetrahedra are bonded in single chains. Pyroxenes are single-chain inosilicates.
- In double-chain inosilicates the silicate tetrahedra are bonded in double chains. Amphiboles are double-chain inosilicates.
- In tectosilicates, also known as framework silicates, all corners of the silicate tetrahedra are bonded to corners of other silicate tetrahedra, forming a complete framework of silicate tetrahedra in all directions. Feldspar, the most common mineral in Earth's crust, and quartz are both framework silicates

Sulphides

These are based on the sulphide ion (S^{2-}). Examples include pyrite (FeS_2), galena (PbS), and sphalerite (ZnS) in its pure zinc form. Some sulphides are mined as sources of such metals as zinc, lead, copper, and tin.

Carbonates

These are based on the carbonate ion $(CO_3)^{2-}$, calcite ($CaCO_3$), and dolomite ($CaMg(CO_3)_2$), are carbonate minerals. Carbonate minerals tend to dissolve relatively easily in water, especially acid water, and natural rain water is slightly acid.

Oxides

These are based on the oxygen anion (O_2^-). Examples include iron oxides such as hematite (Fe_2O_3) and magnetite (Fe_3O_4), and pyrolusite (MnO).

Halides

These have a halogen element as the anion, whether it be fluoride, F^- , chloride, Cl^- , bromide, Br^- , iodide, I^- , or astatide, At^- . Halite, $NaCl$, is a halide mineral.

Sulfates

These have the polyatomic sulfate ion, $(\text{SO}_4)^{2-}$, as the anion. Anhydrite, CaSO_4 , is a sulfate.

Phosphates

These have the polyatomic phosphate ion, $(\text{PO}_4)^{3-}$, as the anion. Fluorapatite, $\text{Ca}_5(\text{PO}_4)_3\text{F}$, which makes your teeth hard, is a phosphate mineral.

Native Elements

These are made of nothing but a single element. Gold (Au), native copper (Cu), and diamond and graphite, which are made of carbon, are all native element minerals. Recall that a mineral is defined as naturally occurring. Therefore, elements purified and crystallized in a laboratory do not qualify as minerals, unless they have also been found in nature.

6. How to identify minerals

First, you need good light and a hand lens or magnifying glass. A hand lens is a small, double-lens magnifying glass that has a magnification power of at least 8× and can be purchased at some bookstores and nature stores.

Minerals are identified based on their physical properties, which have been described in the previous section. To identify a mineral, you look at it closely. At a glance, calcite and quartz look similar. Both are usually colourless, with a glassy luster. However, their other properties they are completely different. Quartz is much harder, hard enough to scratch glass. Calcite is soft and will not scratch glass. Quartz has no mineral cleavage and fractures the same irregular way glass breaks. Calcite has three cleavage directions which meet at angles other than 90°, so it breaks into solid pieces with perfectly flat, smooth, shiny sides.

When identifying a mineral, you must:

- Look at it closely on all visible sides to see how it reflects light
- Test its hardness
- Identify its cleavage or fracture
- Name its luster
- Evaluate any other physical properties necessary to determine the mineral's identity

In the minerals tables that accompanies this section, the minerals are grouped according to their luster and colour. They are also classified based on their hardness and their cleavage or fracture. If you can identify several of these physical properties, you can identify the mineral.

7. Uses of economic minerals

Minerals themselves are useful as:

- (a) A resource for the extraction of metals and other chemical substances – a result of their *chemical nature*; for example, copper (Cu) from chalcopyrite (CuFeS₂).
- (b) A source of materials to use untreated – a result of their *physical properties*; for example, gemstones and the use of garnet as an abrasive on ‘garnet paper’.
- (c) A source of chemical components essential to living organisms (nutrients) – a result of their chemical properties, particularly of the way they react with water and organic acids.

Minerals are also fundamental to the study of geology because they are:

- (a) Essential components of rocks, and thus indicate the chemical constitution of rocks.
- (b) Indicators of the physical conditions of formation of rocks.
- (c) Indicators of the processes and history of formation of rocks.

Teaching and Learning Strategies

Teaching Strategies:	Learning Strategies
Teachers prepare information (notes, mineral samples, and pictures) and ask questions on minerals. Teachers can take students out for an excursion to the nearest metal refinery to observe how minerals are refined and/or processed after extraction.	Students will use the information provided to answer questions on minerals.
STEAM Approach Learning Objective: By the end of the topic, students will be able to; <ul style="list-style-type: none"> • Visualise, compare between minerals - STEAM 	
Teaching Strategies Teachers will provide the information for students to read, observe and answer questions within a given period.	Learning Strategies Students read the notes and use the materials available to understand the difference between different minerals.
Recommended Resources: <ul style="list-style-type: none"> • Clark, I.F. and Cook, B.J., 1992. Perspectives of the Earth. Australian Academy of Science, Canberra, ACT, 561p. • Davidson, J.P., Reed, W.E., and Davis, P.M., 1997. Exploring Earth. An Introduction to Physical Geology, Prentice-Hall Inc., 264p. • Davies, H.L., 2013. Earth Tok, Third Edition. Alan Caudel and Associates, 231p. • https://courses.lumenlearning.com/wmopen-geology/chapter/outcome-identifying-minerals/ • https://www.amazon.com/Mohs-Hardness-Scale-Collection-Specimens/dp/B00K24O1G8 • https://www.minerals.net/resource/property/magnetic.aspx • https://www.slideshare.net/cfoltz/earth-science-chapter-12 • http://volcano.oregonstate.edu/book/export/html/196 • Internet 	

Unit 2: Earth Materials

Content Standard **11.2.2** Students will be able to compare and contrast between minerals, minerals and rocks, rocks, and understand the formation of rocks, minerals and fossil fuels, and their uses.

Benchmark **11.2.2.2** Recognise and analyse the types of rocks based on their properties, compositions and uses.

Topic 2: Rocks

Learning Objectives:

By the end of this topic, the students will be able to:

- Understand the composition of rocks
- Compare extrusive and intrusive igneous rocks
- Know the processes of sedimentation, lithification, diagenesis and metamorphism
- Know the features of igneous, sedimentary and metamorphic rocks

Essential questions

1. What are the composition of rocks?
2. How are igneous rocks classified?
3. What are the features of sedimentary rocks?
4. What are the features of metamorphism?

Vocabulary: Rocks, sedimentation, lithification, diagenesis, metamorphism

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Composition of rocks • Sedimentation and lithification • Extrusive and intrusive igneous rocks and their composition • Classifying of sedimentary rocks • Features of metamorphic rocks 	<ul style="list-style-type: none"> • Understanding, reasoning, comparing and contrasting 	<ul style="list-style-type: none"> • Open-minded, with a desire to learn

Content Background

1. Rocks

Rocks can form in a variety of ways. Igneous rocks form from magma (molten rock) that has either cooled slowly underground (e.g., to produce granite) or cooled quickly at the surface after a volcanic eruption (e.g., andesite and basalt).

Sedimentary rocks, such as sandstone, form when the weathered products of other rocks accumulate at the surface and are then buried by other sediments. Metamorphic rocks form when either igneous or sedimentary rocks are heated and squeezed to the point where some of their minerals are unstable and new minerals form to create a different type of rock. An example is schist.

The rock components of the crust are slowly but constantly being changed from one form to another and the processes involved are summarised in the rock cycle (Fig. 1). The rock cycle is driven by two forces: (a) Earth's internal heat engine, which moves material around in the core and the mantle and leads to slow but significant changes within the crust, and (b) the hydrological cycle, which is the movement of water, ice, and air at the surface, and is powered by the sun.

The rock cycle is still active on Earth because our core is hot enough to keep the mantle moving, our atmosphere is relatively thick, and we have liquid water. On some other planets or their satellites, such as the Moon, the rock cycle is virtually dead because the core is no longer hot enough to drive mantle convection and there is no atmosphere or liquid water.

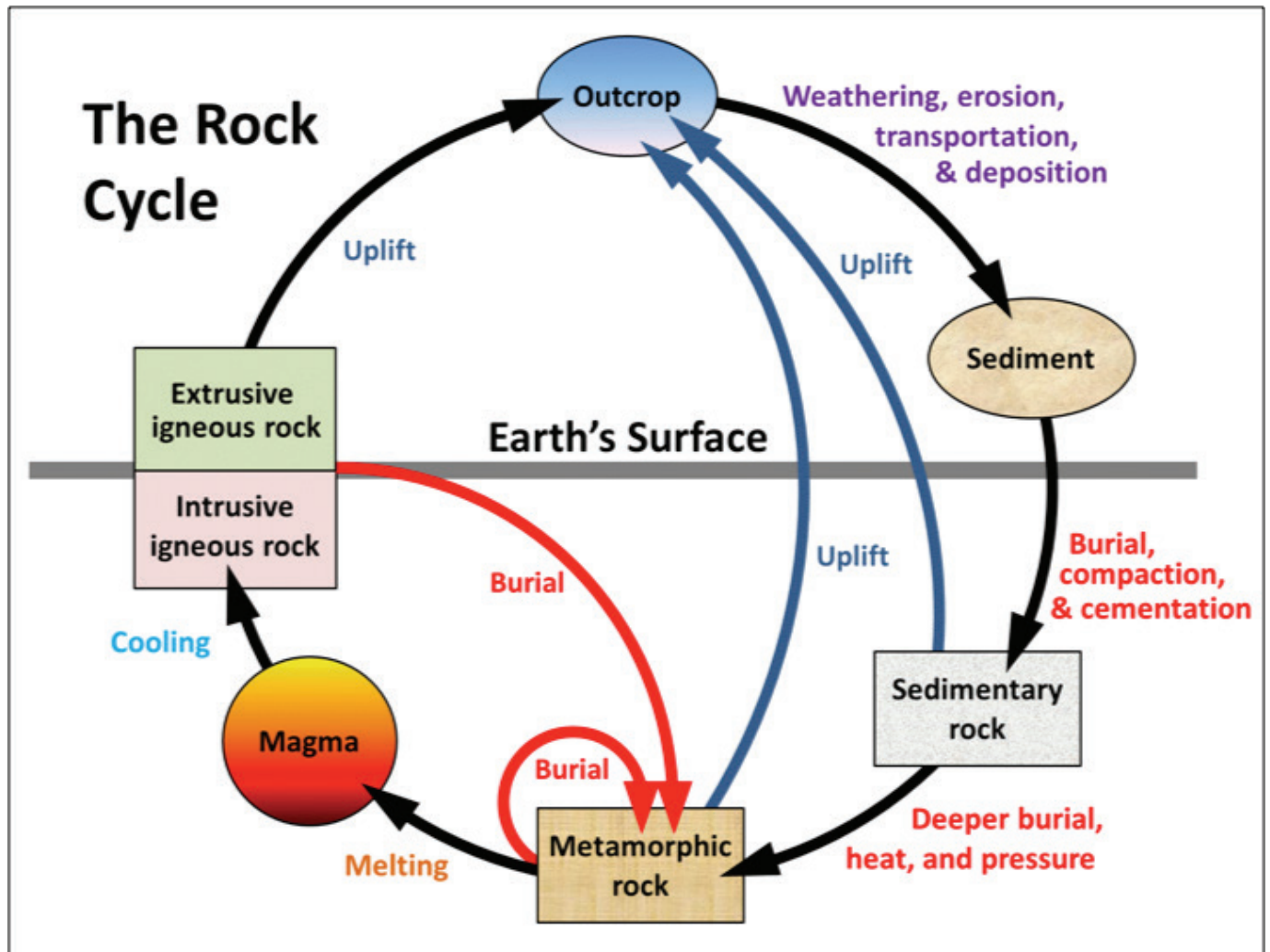


Figure 1. A schematic view of the rock cycle (Source: <https://opentextbc.ca/physicalgeology2ed/chapter/3-1-the-rock-cycle/>)

In describing the rock cycle, we can start anywhere we like, although it's convenient to start with magma. As we'll see in more detail below, magma is rock that is hot to the point of being entirely molten. This happens at between about 800° and 1300°C, depending on the composition and the pressure, onto the surface and cool quickly (within seconds to years) - forming extrusive igneous rock.

Magma can either cool slowly within the crust (over centuries to millions of years) - forming intrusive igneous rock or erupt onto the surface and cool quickly (within seconds to years) - forming extrusive igneous rock. Intrusive igneous rock typically crystallises at depths of hundreds of metres to tens of kilometres below the surface. To change its position in the rock cycle, intrusive igneous rock must be uplifted and exposed by the erosion of the overlying rocks.

Through the various plate-tectonics-related processes of mountain building, all types of rocks are uplifted and exposed at the surface. Once exposed, they are weathered, both physically (by mechanical breaking of the rock) and chemically (by weathering of the minerals), and the weathering products - mostly small rock and mineral fragments.



Figure 2. Magma forming pahoehoe basalt at Kilauea Volcano, Hawaii

Rocks are eroded, transported, and then deposited as sediments. Transportation and deposition occur through the action of glaciers, streams, waves, wind, and other agents, and sediments are deposited in rivers, lakes, deserts, and the ocean.

2. Classifying rocks

In nature, there are different types of rocks available, i.e., rocks are classified into three categories, geologically, chemically, and structurally. The classification is based on the mode or process of formation of a rock. Thus, some rocks may be formed from natural hot molten materials. Others may be formed at ordinary temperatures from compaction of particles or sediments.



Figure 3. Different types of rocks (Source: <https://www.polytechnichub.com/types-of-rocks/>)

(a) Geological classification

Based upon how they are formed and the geological process involved in it, rocks are classified into following three types:

Igneous rocks

These are formed by cooling the molten lava on or inside the Earth's surface during volcanic eruption. They do not contain any fossils or shells. The rocks may be acidic or alkaline depending upon silica content.

- When magma is forced up as volcanic eruptions and spreads over the surface of Earth where it solidifies, it forms basalt and is known as effusive rock.
- If the magma solidifies below the Earth's surface itself, the solid crystalline rock is termed as deep-seated plutonic rock. The examples are granite, syenite, diorite and gabbro.
- If the magma solidifies at a relatively shallow depth, the resultant rock possesses a finely grained crystalline structure - and is termed as hypabyssal rock. Dolerite is such a rock.
- The principal constituents of magma are quartz, mica and felspar.

Type	% of Silica	Example
Acid rocks	70-80	granite, rhyolite
Intermediate rocks	60-70	syenite, andesite
Basic rocks	45-60	gabbro, dolerite
Ultra-basic rocks	30-45	peridotite, basalt

Sedimentary rocks

These are formed by gradual deposition of disintegrated rocks at the bottom of rivers, lakes or sea.

- Sedimentary rocks resulting from the precipitation of salts in drying water basin (chemical deposits) are gypsum, anhydrite, magnesite and dolomite.
- Sedimentary rocks resulting from the accumulation of plant or animal remains (organogenous rocks) are limestone, shale, chalk and diatomite.
- The examples of rocks resulting from the deterioration of massive magmatic or sedimentary rocks (fragmental rocks) are sandstone, laterite, sand, gravel, carbonate conglomerate and breccia.

Metamorphic rocks

These are formed when sedimentary or igneous rocks are subjected to great heat and pressure inside the Earth. The metamorphic process causes a complete recrystallisation of the original rock into an interlocking mosaic of calcite, aragonite or dolomite crystals.

Original rock	Metamorphic rock	Original rock	Metamorphic rock
Granite	Gneiss	Shale	Slate, schist, phyllite
Syenite	Gneiss	Laterite and granite	Schist
Sandstone	Quartzite	Dolomite	Marble
Limestone and Marl	Marble, schist	Dolerite, basalt	Schist
Mudstone	Slate	Felsite, tuff	Schist, slate
Conglomerate	Gneiss, schist	Claystone	Hornblende

(b) Physical and petrological classification of rocks

Based upon the physical properties and alignment, rocks may be classified into following types:

- (i) Stratified rocks are those which exhibit distinct layers that can be separated. The plane along which the separation of the layers can be carried out is called as the cleavage plane. Examples: limestone, slate, sandstone, etc.
- (ii) Unstratified rocks do not show any sign of strata and cannot be easily split into the slabs. Examples: granite, gabbro, etc.
- (iii) Foliated or fragmented rocks tend to split up only in a definite direction. Most of the metamorphic rocks have a foliated structure, except for quartzite and marble which have granulose structure.

(c) Chemical classification of rocks

Based upon the chemical composition, rocks may be classified into the following types:

- (i) Siliceous rocks are those which have silica as the main constituent. The silica in the free form is called *sand* and in combined state is *silicate*. Examples: granite, quartzite, sandstone.
- (ii) Argillaceous rocks are those which have clay or alumina as the main constituent. Examples: kaolin, laterite, slate.
- (iii) Calcareous rocks have calcium carbonate or lime as their leading constituent. These rocks are readily acted upon by even dilute HCl. Examples: limestone, marble.


3. Classifying igneous rocks using texture and composition

Igneous rocks may be simply classified according to their chemical/mineral composition as felsic, intermediate, mafic, and ultramafic, and by texture or grain size: intrusive rocks are coarse grained (all crystals are visible to the naked eye) while extrusive rocks may be fine-grained (microscopic crystals) or glass (no crystalline structure). Volcanic rocks, especially felsic and intermediate, often have a porphyritic texture characterized by visible crystals floating in a fine-grained groundmass.

Shown below is a simple classification scheme. Alternative, complex classification schemes take into account finer gradations in composition and especially the varying amounts of the elements potassium, aluminum, sodium, and calcium.

Note that felsic rocks are light in colour; intermediate rocks range through greys, and mafic rocks are black in colour. Ultramafic rocks (peridotite) may range black to olive green (dunite) from the mineral olivine.

			Composition			
			felsic	intermediate	mafic	ultramafic
Texture	extrusive (volcanic)	glass	Obsidian			
		Fine-grained	rhyolite	andesite	basalt	
	Intrusive (plutonic)	Coarse-grained	granite	diorite	gabbro	peridotite

<p>Lower temperature crystallization</p> <p>Low in metal cations</p> <p>High silica</p> <p>More covalent</p> <p>High weathering stability</p>		<p>High temperature crystallization</p> <p>High metal cations</p> <p>Low silica</p> <p>More ionic</p> <p>Low weathering stability</p>
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4. Igneous rock textures

If magma remains within the Earth's crust it will cool slowly, over thousands to millions of years, and crystals will have time to grow to several millimetres or more. The result is that most intrusive igneous rocks are medium to coarse-grained, or *phaneritic*. If magma reaches the Earth's surface it will cool quickly, over seconds to months, and so will be fine-grained (*aphanitic*) or glassy.

An intrusive igneous rock that is extremely coarse grained is said to be *pegmatitic*; some pegmatites have crystals up to 10 cm or more. These rocks have cooled slowly, and crystal growth has been assisted by the presence of a high proportion of gases or volatiles dissolved in the melt.

If the magma starts to crystallise while in the crust but then is rapidly cooled it may develop a *porphyritic* texture of larger crystals within a fine-grained matrix.

When magma is emplaced in the crust the outer margin of the magma body will cool more rapidly because it is in contact with cooler country rock, and the centre more slowly. As a result, the outer margin is fine-grained and the inner part coarse-grained. The body is said to have a *chilled margin*. Early formed crystals may be aligned parallel to the flow direction, so we may see a *flow texture*.

5. Classification of extrusive igneous rocks (volcanic rocks)

Extrusive igneous rocks (volcanic rocks) are of two types: (a) lavas and (b) fragmental or pyroclastic rocks. Lava is magma that has flowed peacefully as a liquid in a coherent tongue or sheet on to the Earth's surface. Pyroclastic volcanic deposits form when magma erupts explosively, violently throwing fragments of magma and country rock into the air. When the fragments settle they form a pyroclastic deposit or tephra deposit.

Pyroclastic or tephra deposits are classified by grain size and the presence or absence of bombs. The coarsest tephra is called breccia, or agglomerate if bombs are present; the medium and finer grained tephra are *lapilli tuff* and *tuff*. Ash comprises unconsolidated fine rock and mineral fragments. Consolidated ash is *tuff*.

	Pyroclastic deposits	
Grain size	Unconsolidated Tephra	Consolidated Pyroclastic Rock
>64 mm	Bomb tephra, Block tephra	Pyroclastic breccia, Agglomerate if bombs present
2-64 mm	Lapilli tephra	Lapilli tuff or lapillistone
1/16 -2 mm	Coarse ash	Coarse tuff
<1/16 mm	Fine ash	Fine tuff

Bomb is the term for an erupted block that is still fluid at the time of eruption and so can take on an aerodynamic shape. *Block* is the term for an erupted block of material that was solid at the time of eruption and so will tend to be angular.

When the magma erupts passively under the sea it may form a simple lava flow or, more commonly, the magma separates into spherules, each with a chilled outer margin. These come to rest as *pillow lavas*.

Volcanic rocks commonly contain small cavities where gases have separated from the melt; these are known as gas bubbles or vesicles. Some cavities may be filled with low temperature alteration minerals. *Pumice* is lava so saturated with gas cavities that it is buoyant enough to float on water.

When magma is cooled extremely quickly there is no time for crystals to grow and the result is glass. The obsidian (black glass) of Manus, Witu Island, Talasea, and the D'Entrecasteaux Islands formed in this way.

6. Sediments and sedimentary rocks

When rocks are exposed at the Earth's surface they are attacked by weathering and erosion. This produces three kinds of material:

- Fragments or detritus broken from rocks by erosion;
- New minerals such as clays formed by weathering of the exposed rocks; and
- Material in solution.

These products are removed and re-deposited as sediments by landslides and streams. When the sediments are buried and lithified (compacted and water squeezed out) they become sedimentary rock.

Sedimentary rocks are of three types:

- Clastic** rocks (conglomerate, sandstone, siltstone, shale) – made up of fragments (clasts) of older rocks and of clay derived from the weathering of older rocks;
- Chemical** rocks (some limestone, rock salt, gypsum) – formed by chemical processes; and
- Organic** rocks (coral and some limestone) – rocks formed by biological processes.

Most sedimentary rocks are mixtures of two or even all three of these categories. For example, a calcareous siltstone may be a clastic rock with a chemically-precipitated carbonate cement. A coarse fragmental limestone may be a mixture of organically-derived coral and shelly material cemented by a chemically precipitated carbonate cement; and an impure coal may be mainly organic (vegetable) matter but with minor fine detritus (silt) of clastic origin.

Sediments and sedimentary rocks can be classified as follows:

Clast size	Sediment name	Rock name		Calcareous equivalent
> 2 mm	Gravel	Conglomerate if clasts are rounded, Breccia if clasts are angular		Calcirudite or limestone conglomerate
0.625 – 2 mm	Sand	Sandstone		Calcareenite or calcareous sandstone
0.004 – 0.625 mm	Silt	Siltstone	Mudstone	Marl or calcareous mudstone
< 0.004 mm	Clay	Claystone		

The coarse-grained clastic sediments may be further classified according to clast size as follows:

- Granule** conglomerate or breccia if the clasts are 2–4 mm;
- Pebble** conglomerate or breccia if the clasts are 4–64 mm;
- Cobble** conglomerate or breccia if the clasts are 64–254 mm;
- Boulder** conglomerate or breccia if the clasts are > 254 mm.

To distinguish siltstone from claystone or shale rub your finger across a freshly broken surface of the rock. If you feel the grains it is siltstone and if you cannot it is claystone or shale. If in doubt call it by the more general name *mudstone*.

Further classification of the coarse sediments depends on the composition of the clasts. For example, a sandstone may be a quartz sandstone if the grains are quartz, an arkose if the grains are quartz and feldspar, or lithic sandstone if the grains are rock fragments. A conglomerate may be volcanolithic if the clasts are all of volcanic rock, or polymict if the clasts are of a variety of rock types.

Here are some descriptive terms for sedimentary rocks:

- Terrigenous** clastic sediment derived from land (terra);
- Bioclastic** sediment made up of shelly material, fragments of corals, bryozoan and algae (i.e., made up of clasts of biological origin); and
- Volcaniclastic** or **volcanogenic** clastic sediment made up of clasts of volcanic origin.

Diagenesis

Unconsolidated sediment becomes sedimentary rock by the process of compaction, squeezing out of intergranular water, and cementation. The process is called diagenesis or lithification.

When sediment is first deposited the grains are loosely packed and pore spaces are filled with water. If the loosely packed sediment is then buried, the sediment is compacted, grains fit together more tightly, and water is squeezed out. Upon further burial the grains are squeezed more tightly together and may start to dissolve and join with each other. Cementing material such as calcite may precipitate from the intergranular fluids.

Grain shapes and sorting

Grain size, grain shapes, and sorting of grains within a sediment give information about the history of the grains and the environment in which the sediments were deposited.

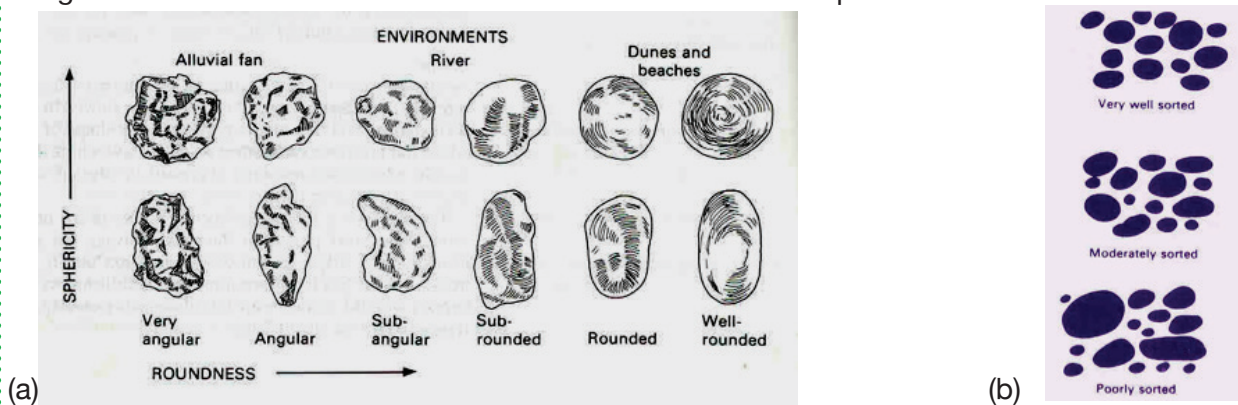


Figure 4. (a) Shapes of grains in sedimentary rocks provide clues to the environment of deposition of rocks (Source: Australian Academy of Science).
 (b) Sorting or lack of sorting of grains in a sedimentary rock is another indication of the environment of deposition (after Davies, 2013).

Coarse sediments are deposited in high-energy environments, such as fast-flowing rivers in steep terrain, or at the base of a cliff. Fine sediments are deposited in low-energy environments, such as muddy, slow-flowing river or swamp.

If the grains in a clastic sediment are **poorly sorted** this tells us that the grains were rapidly deposited. They may have been dumped from a river in flood for instance, or from a melting glacier. If the grains are **well sorted** we know the grains have been reworked by river, surf or wind, the finer material winnowed out and the coarser material deposited elsewhere.

Poorly sorted muddy sandstone, in which the sand grains are mostly rock fragments (lithic fragments), are characteristic of environments where erosion and sedimentation are rapid, such as in mountainous regions in the wet tropics. This rock type is given the name **greywacke**.

If the grains are **well rounded**, we know they have a history of transport by wind or water and abrasion that has rubbed off any angular corners. If the grains are **angular** this tells us they have not been transported far. For example, boulders in a landslide deposit are angular. Boulders on a surf beach are well rounded. The grains in desert sand, which have been worked and re-worked by the wind, are almost perfectly rounded.

Sphericity is how closely the shape of the clast approaches a sphere, Sphericity depends mainly on the nature of the material making up the grain. For example, clasts of material that has a strong foliation or layering, such as mica schist, will tend to be flat and thin and so to have low sphericity.

Two other important qualities of clastic sediment, especially for the petroleum man or the driller of water wells, are porosity and permeability. **Porosity** is the proportion of pore spaces in the rock, and **permeability** is the ease with which fluid can flow through the rock. Permeability depends on whether the pore spaces are connected.

Textures in sediments

Textures that may be preserved in clastic sediments include current bedding (also known as cross bedding), graded bedding, ripple marks, and flute casts. A graded bedding has fine sediment at top grading to coarser sediment at base. Graded beds will form in any place where sediment settles out from a slurry. For example, graded beds will form from sediment transported in turbid density flows to the continental slope or abyssal plain.

Clastic sediments common show **bioturbation** – the effect of burrowing by sea floor creatures.

If wet fine-grained sediments are rapidly buried, they may flow upwards through the overlying sediment to produce flame texture.

All these textures tell something about the environment of deposition. When the geologist is mapping beds that have been steeply folded these features help to reveal the facing of the beds, that is, they indicate which was top and which the bottom of the bed.

7. Chemical sedimentary rocks

Chemical sediments may form by precipitation from seawater (e.g. limestone) or from evaporative brines (e.g., dolomite or salt beds), or may form by replacement of earlier-formed sediments. Most of the chert around Port Moresby originated when silica replaced fine calcareous sediment. Probably the silica was always present, dispersed through the sediment, and has migrated in solution during lithification to be re-deposited in local concentrations. In the same way, concretions of siderite can develop when iron-rich carbonate solutions migrate through wet sediment.

Phosphate is chemically deposited in relatively shallow sea water (a few hundred metres below surface) and commonly replaces earlier-formed carbonate. Phosphatic sediments are known in the Gulf and Milne Bay provinces.

The great iron formations of Australia and North and South America were deposited chemically early in the history of the Earth when the atmosphere and oceans contained less oxygen than now. Because there was less oxygen the iron could remain in solution in the ferrous state.

8. Organic sedimentary rocks

Many marine creatures extract Ca^{2+} and CO_3^{2-} ions from sea water and use these to construct their shells. When the organisms die their shells accumulate on the sea floor as calcareous ooze or sediment and will in time become limestone. Chalk is a limestone made up of the remains of microscopically small marine creatures. If the organisms are organised into colonies, such as coral and calcareous algae, they will construct a reef. Raised reefs, or reefs that have been lifted from beneath the sea by vertical land movements, are common around the shores of PNG.

If plant remains accumulate in a swamp and are then buried by muddy sediment so that they are protected from oxidation, the vegetable matter will, over time, be transformed into coal. Oil, too, is formed by the slow transformation of buried organic matter in an environment where there is no oxygen. Oil and coal will form only if the organic sediment is sequestered beneath an impermeable cover, so that the organic matter cannot be oxidised.

9. Types of metamorphism

The most common type of metamorphism is **regional metamorphism**. This happens when a body of rock from the Earth's surface is carried down into the Earth's crust and mantle where pressures and temperatures are higher.

Surface rocks may be carried down into the Earth's crust and mantle when parts of the Earth's crust move towards each other, collide and buckle and bend; that is, Earth's surface is shortened.

The metamorphic rocks of the Owen Stanley Range are an example. This is an enormous body of metamorphic rock, 70 km across and 350 km long, that extends from near Lae to 100 km east of Port Moresby. The metamorphic rocks began their existence as sediment on a continental margin but were carried down into the Earth and metamorphosed (changed) when the continent collided with a volcanic island arc. They emerged to the Earth's surface subsequently due to their own buoyancy, being less dense than the rocks of the mantle.

There are three other types of metamorphism: thermal, dynamic, and metasomatic.

Thermal or contact metamorphism

Thermal metamorphism is the baking effect when magma intrudes into cold rocks or sediments. Sedimentary rocks inland from Port Moresby have been intruded by gabbro and show some thermal or contact metamorphic effects. The rock that results from thermal metamorphism is usually hardened and is given the name hornfels. Burning your finger on a hot stove is thermal metamorphism.

Dynamic or shearing metamorphism

Dynamic metamorphism is the effect when two parts of the Earth's crust slide past each other. Where the two parts are in contact a fracture or fault develops, and the rocks become broken and sheared. If this happens at a relatively shallow depth the rocks will simply be broken into angular fragments (breccia) set in a fine matrix of powdered rock or clay (fault gouge). If shearing happens at greater depth, where pressure and temperature are greater, the finely broken fragments may recrystallise to form new minerals. If a sheared rock has partly or completely recrystallised it is called **mylonite**. In some cases, the heating and shearing at depth can cause the crushed rock to melt to form a glass (tachylite).

Metasomatism and skarns

Metasomatism, the fourth type of metamorphism, is the result of fluids (soma) moving through the rock and reacting with the rock. Metasomatism happens on a grand scale in the basalts that are erupted on to the ocean floor. Sea water circulates through the basalts, following fine cracks and fissures, with the result that hydrous minerals form and some elements, such as calcium, are selectively removed. Almost all ocean floor basalts are affected by hydrous metasomatic alteration.

Metasomatism commonly accompanies thermal or contact metamorphism. Hydrous fluids from the intruding magma travel across the contact into the cold country rock, and hydrous fluids from the country rock travel in the reverse direction. The fluids react with the host rock to form skarn – exoskarn if the skarn is in the country rock and endoskarn if it is within the igneous rock. Common skarn minerals are magnetite, garnet, Ca-pyroxene and epidote. Skarns at the contact between granitic rocks and limestone at Ok Tedi are iron-rich with much magnetite, pyrite, copper sulphides and gold.

10. How are metamorphic rocks classified?

Unfortunately, no widely accepted system of classifying and naming metamorphic rocks is in use. Several systems are used, depending on the information available and the purpose for which a certain system is required. The different types of information which might be available to classify, and name metamorphic rock include the overall texture and grain size, the mineralogical composition, the bulk chemical composition, the type of metamorphism, and the nature of the pre-metamorphic rock.

Firstly, there are the general rock names based on the overall textural features. These are as follows:

Foliated	
slate	Very fine-grained, strong slaty cleavage
phyllite	Fine-grained, grain size intermediate between slate and schist
schist	Medium-grained, with strong schistosity due to visible mica flakes
gneiss	Medium to coarse-grained, more granular than a schist, often with aligned dark minerals concentrated in layers or streaky patches
Non-foliated	
hornfels	Granular rock lacking mineral alignment (contact metamorphic)
granulite	Medium to coarse-grained like gneiss, lacking obvious mineral alignment but usually with some compositional banding (regional metamorphic)

These general rock names can be supplemented by adding the names of one or two prominent constituent minerals. Some examples are kyanite schist, garnet gneiss, and andalusite hornfels. These terms do not mean there is only one mineral present. The term garnet gneiss, for instance, implies that there will be additional major minerals present such as quartz, feldspar, and biotite.

Another approach uses the name for the general rock type from the list above prefixed by a general term which indicates the overall bulk chemical composition of the rock. There are several terms which describe the bulk composition of metamorphic rocks. These are as follows:

- Pelitic – aluminium-rich or clay-rich (e.g., originally a shale)
- Basic – basic igneous rock (e.g., originally a basalt)
- Quartzo-feldspathic – acid igneous rock or quartz-feldspathic sediment (e.g., originally a granite or arkose)
- Calcareous – a rock rich in calcium carbonate (e.g., originally a limestone)

Thus, terms like pelitic schist or basic granulite are produced by combining the terms from the two lists.

In addition to these general terms, there are a few terms which have specific meanings for composition and texture.

- Quartzite – a granular, almost pure quartz rock
- Marble – a granular, almost pure carbonate rock, generally composed of calcite
- Greenschist – a foliated low-grade, regionally metamorphosed basic igneous rock with green minerals like chlorite, actinolite and epidote
- Amphibole – a medium grade regional metamorphic basic igneous rock composed mainly of hornblende and plagioclase.

11. Recognising metamorphic rocks

How can an unknown rock be recognised as having been produced by metamorphic processes rather than by igneous or sedimentary processes? The main clues are listed below:

- (a) The presence of characteristic metamorphic minerals like garnet and kyanite or abundant micas.
- (b) The presence of strong mineral alignment (foliation/lineation)
- (c) Field occurrence (e.g., contact metamorphic rocks near igneous intrusions). Some high grade metamorphic rocks (granulites) can resemble intrusive igneous rocks.

However, careful observation shows the respective grain shapes are different. For example, plagioclase often has a granular equi-dimensional texture in metamorphic rocks rather than the elongate, lath-shaped interlocking grains in most igneous rocks.

12. Uses of rocks

Construction materials

Previously, we looked at minerals and rocks which are extracted from the crust of the Earth because they contain concentrations of metals. Here we will look at the uses and formation of materials which are called non-metallic resources. These materials are mined for a wide range of uses, including construction materials, fertilizers and chemicals.

To maintain the ways of life in modern cities, people consume construction materials at an approximate rate of several tonnes per head of population annually. These materials have been formed by geological processes and events in the past and therefore are non-renewable. Until recently they were mined as close as possible to their place of use and so cost little to produce. Today, however, because of environmental constraints and the use of land for other purposes, this is not always possible.

Another of our vital non-renewable resource needs is raw material for the manufacture of fertilisers. To meet the demands of an expanding world population, increased food production is essential. Chemical elements such as nitrogen, phosphorus, potassium, calcium and sulphur are essential for plant growth and must be replenished in the soil in the form of fertilizers. The raw materials for the manufacture of fertilisers are mainly substances mined from the Earth's crust.

As well as fertilisers, non-metallic materials are also used for raw materials in the chemical industry. The manufacture of soap, detergents, dyes, lubricants, paper, antiseptics, toothpaste and many other commonly-used materials depends on raw materials derived from the mining of rocks and minerals. In this section, we are going to look at construction materials.

What sorts of materials are used for construction? Construction materials derived from the Earth's crust are, after fossil fuels, the next most valuable commodity used by people. Because almost every common rock type and common mineral is used in some way for building, there is no simple geological classification. In this section we will divide these materials into two groups: those which are used as they come from the ground without any treatment except physical shaping such as cutting or crushing; and those which must be treated chemically or otherwise altered before they are used. The first group includes building stones, sand, gravel and crushed stone; the second includes raw materials for cement, clay for bricks, and plaster and asbestos.

Building stones

In areas where suitable construction timber was not available such as South Australia, early settlers used mineral substances for building purposes, particularly natural stone which was either rough or sawn.

Later, stone was used in major city buildings, but its use has changed over the past fifty or so years.

In older city buildings, the masonry walls were thick and built of stone strong enough to support the upper floors. Composite walls with dressed stone in front and with brick or stone rubble backing were common. Present-day multi-storey buildings have a steel or concrete skeleton supporting walls of thin cladding which is either polished slabs of natural stone or concrete products, such as exposed aggregate panels.

Rocks suitable for building stone vary widely in physical and chemical properties. Although there are differences between the properties of igneous, sedimentary and metamorphic rocks, all may be used as construction materials. Different rocks are used for different purposes and some of the following factors are considered in the selection of stone: (a) physical appearance, colour, texture and grain size; (b) strength, durability and resistance to damp; (c) ease of working, cost of preparing, polishing and fixing in place; and (d) accessibility of deposit, and cost of quarrying the transport.

A major factor in the use of otherwise suitable stone is its general acceptance by architects, designers and the public. Imported marble and granite have been used for facing stone in recent years in cases where local stone would have served equally well.

Igneous rocks were originally used as large rough sawn blocks for the bottom rows in buildings, but now they are mainly used as polished panels. When these blocks are quarried there is little waste because the rock is either sawn or drilled. All types of sedimentary rock are used including fine-grained shale, siltstone, coarse-grained sandstone, limestone and calcrete. Marble is the most widely metamorphic rock used as building material. It is used as polished panels, and as crushed aggregate and chips in terrazzo. In the construction industry, the term marble covers all carbonate rocks capable of taking a good polish and includes fine-grained dense limestone and dolomite as well as true marble. Slate is another metamorphic rock which has been used for roofing and paving.

Coarse aggregate

Coarse aggregate used for concrete aggregate, road construction, railway construction (ballast) and fill is obtained from natural gravel or crushed rock. In concrete, aggregate provides the bulk of the material. The spaces between the aggregate particles are filled with sand, and the sand and aggregate are bound together by cement. Concrete is therefore like a natural conglomerate. Coarse aggregate is used to provide the foundation layers in road and highway construction and is used as a stable base on which railways are laid. It is therefore important that it is strong and does not contain fractures or impurities which would lead to compaction or settling after construction.

Sand

Sand is general term which refers to the particle size range between 0.06 millimetres and 2.0 millimetres. Although different substances are contained in this group, the sand which we commonly use consists mainly of quartz grains. Sand is used for construction purposes in concrete, mortar and plaster as well as in the making of roads. It is also used extensively for other industrial purposes such as glass-making, ceramics, paint and as an abrasive.

Construction sand is obtained either from natural sand in present-day streams or older deposits, or from the fine material which remains after crushing of rock or gravel to produce coarse aggregate. Most sand requires washing to reduce clay content.

Another major use for quartz sand is the manufacture of glass. Glass is made by melting the raw materials and then cooling (quenching) the liquid so fast that crystals do not have time to form. The melting point of quartz is very high (1713°C), and to reduce this to a more easily attainable temperature, fluxes such as lime (CaO) from limestone, soda (Na₂O) from sodium carbonate and borax (Na₂B₄O₇·10H₂O) from evaporite deposits are added.

Sands used to make glass must meet very stringent specifications otherwise the products do not have the clarity, colour or other physical characteristics required. Because of this, all-natural quartz sand requires washing, screening and separation. Some sands also require attrition, flotation and treatment with acid and alkali. Depending on the kind of glass being made, the sand must also not contain too much iron oxide or chromium oxide because these impurities colour the product.

Similar fine grained high silica sand, free of organic material and low in clay and other impurities, is required by the foundry industry, where it is used to make moulds for molten metal casting.

Limestone

Like quartz, limestone is another Earth material which is used extensively in the construction and manufacturing industries. It is quarried mostly for: (a) the manufacture of Portland cement; (b) construction material; (c) the production of quick lime and slaked lime; (d) metallurgical flux in the smelting of iron and non-ferrous metals; (e) addition to soil to neutralise soil acids and supply essential plant nutrients calcium and magnesium; (f) the manufacture of chemicals such as soda ash and caustic soda; (g) building and monumental stone; (h) whiting-filler in paint, carpet, paper, rubber and as soft abrasive in toothpaste; (i) the manufacture of paper and newsprint; and (j) the manufacture of glass and calcium carbide.

Limestone of all types and geological ages is used. Limestone for chemical and lime processing and for metal smelting must be relatively pure.

Cement

Cement is used to bind particles together. Many sedimentary rocks contain natural cement such as silica or calcium carbonate. Commercially manufactured cement is added to sand, gravel, crushed rock or other aggregate to make *concrete*, which is a sort of instant rock.

Cement was first used by the ancient Romans. They found that adding water to a mixture of lime and volcanic ash caused the mixture to recrystallise and harden. Today another type of cement called *Portland cement* is used. It was first made by an Englishman, Joseph Aspidin, in 1824, and since that time has become the most common construction material in the world.

The chemical components to make the varieties of Portland cement, namely calcium, silicon, aluminium and iron, may occur in whole or part in an impure limestone or in the associated rocks. Otherwise the limestone must be blended with sand, shale, clay or iron bearing materials obtained elsewhere.

These components are ground to the same particle size, then heated to a temperature of about 1500°C. This expels the carbon dioxide and water, reacts the calcium oxide with alumina and silica, and causes part of the material to melt to a glass. The resulting material is called *clinker*. The clinker is then ground, and gypsum is added. When water is added during concrete-making, the cement forms crystals which bind the sand and aggregate together and the gypsum controls the setting time.

Clays

Today people are extracting and processing clay into products for home, industry and civil engineering projects. Many are coming to know the properties and problems of handling clay through pottery crafts, and nearly everyone handles clay minerals during agriculture or gardening. Although a lot of practical knowledge for using clays has been built up over the past several thousand years, it is only in the last fifty years that modern instrumentation and techniques such as X-ray crystallography, electron microscopy, rapid chemical analysis and physical testing have given us fundamental explanations about the nature of clays and their properties. This new approach has also shed much light on the role of clay minerals in soils and agriculture.

There are two broad categories of use for clay minerals. In the first, the whole natural mixture of clay minerals plus non-clay minerals is used in applications such as heavy clay industries (manufacture of bricks, sewer pipes, roof tiles and light weight aggregate for construction), agriculture, civil engineering projects and cement production. In the second category, individual clay minerals are mined or beneficiated from clay deposits for use in making such things as: electrical insulators, tiles, sanitary ware, chemical ware, spark plugs and dentures; in drilling muds (bentonites); bonding clays in foundry moulding sands and pelletising processes (e.g. iron ores); fillers in paper, rubber, plastics and fabrics; coating for glossy papers; filter acids and absorbents in clarification of water supplies, wines, beer, cider and cooking oils; catalysts in oil refining; components in paints, inks, lead pencils, greases and lubricants, medicines, cosmetics, pesticides, soaps and polishing compounds.

In agriculture the amount and type of clay mineral determines the water holding capacity of soils and their tilth (the physical condition of soil). Clays also control the bonding of humic compounds and fertiliser nutrients in the soil. Civil engineering projects (dams, road construction, building foundations) require assessment of the ability of clay materials to compact, swell, slip, or seal against water leakage.

Teaching and Learning Strategies

Teaching Strategies:

Teachers prepare information (notes, rock samples, and pictures) and ask questions on rock types. Teachers can take students out for an excursion to the nearest road to observe a road-cut geologic section.

Learning Strategies

Students will use the information provided to answer questions on different types of rocks.

STEAM Approach

Learning Objective: By the end of the topic, students will be able to;

- Visualise, compare the rock types - STEAM

Teaching Strategies

Teachers will provide the information for students to read, observe and answer questions within a given period of time.

Learning Strategies

Students read the notes and use the materials available to understand the difference between rocks types.

Recommended Resources:

- Clark, I.F. and Cook, B.J., 1992. Perspectives of the Earth. Australian Academy of Science, Canberra, ACT, 561p.
- Davidson, J.P., Reed, W.E., and Davis, P.M., 1997. Exploring Earth. An Introduction to Physical Geology, Prentice-Hall Inc., 264p.
- Davies, H.L., 2013. Earth Tok, Third Edition. Alan Caudel and Associates, 231p.
- <http://volcano.oregonstate.edu/book/export/html/196>
- Internet

Unit 2: Earth Materials

Content Standard

11.2.2 Students will be able to compare and contrast between minerals, minerals and rocks, rocks, and understand the formation of rocks, minerals and fossil fuels, and their uses.

Benchmark

11.2.2.3 Investigate and assess the formation of fossil fuels such as coal, crude oil and the importance of crude oil and gas.

Topic 3: Fossil Fuels

Learning Objectives:

By the end of this topic, the students will be able to:

- Describe how fossil fuels are formed and their uses.
- Describe the characteristics of crude oil and gas.

Essential questions

1. How are fossil fuels classified?
2. How are coal, crude oil and gas formed?
3. What are some importance and uses of fossil fuels?

Vocabulary: fossil fuels, coal, crude oil, gas

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Fossil fuels – definition and classification • Formation of coal, crude oil and gas • Characteristics of crude oil and gas • Importance and uses of crude oil and gas 	<ul style="list-style-type: none"> • Understanding, reasoning, comparing and contrasting 	<ul style="list-style-type: none"> • Open-minded, with a desire to learn

Content Background

1. Fossil fuels

A fossil fuel is a fuel formed by natural processes, such as anaerobic decomposition of buried dead organisms, containing energy originating in ancient photosynthesis. Such organisms and their resulting fossil fuels typically have an age of millions of years, and sometimes more than 650 million years. Fossil fuels contain high percentages of carbon and include petroleum, coal, and natural gas. Commonly used derivatives of fossil fuels include kerosene and propane. Fossil fuels range from volatile materials with low carbon-to-hydrogen ratios (like methane), to liquids (like petroleum), to non-volatile materials composed of almost pure carbon, like anthracite coal. Methane can be found in hydrocarbon fields either alone, associated with oil, or in the form of methane clathrates.

Examples of fossil fuels

- Coal: It is the primary fuel to produce electricity and is responsible for about 40% of the electric power supply in some countries.
- Oil: Oil is the primary source for the world's transportation
- Natural Gas: Up to about 25% of some countries energy is fueled by natural gas.

2. Formation of coal

Coal is a combustible black or brownish-black sedimentary rock, formed as rock strata called coal seams. Coal is mostly carbon with variable amounts of other elements; chiefly hydrogen, sulphur, oxygen, and nitrogen. Coal is formed if dead plant matter decays into peat and over millions of years the heat and pressure of deep burial converts the peat into coal. Vast deposits of coal originate in former wetlands called coal forests that covered much of the Earth's tropical land areas during the late Carboniferous (Pennsylvanian) and Permian times.

As a fossil fuel burned for heat, coal supplies about a quarter of the world's primary energy and two-fifths of its electricity. Some iron and steel making, and other industrial processes burn coal.

The extraction and use of coal causes many premature deaths and much illness. Coal industry damages the environment, including climate change as it is the largest anthropogenic source of carbon dioxide. As part of the worldwide energy transition many countries have stopped using coal or use less coal.

Coal formation process

At various times in the geologic past, the Earth had dense forests in low-lying wetland areas. Due to natural processes such as flooding, these forests were buried underneath the soil. As more and more soil was deposited over them, they were compressed. The temperature also rose as they sank deeper and deeper. As the process continued the plant matter was protected from biodegradation and oxidation, usually by mud or acidic water. This trapped the carbon in immense peat bogs that were eventually covered and deeply buried by sediments. Under high pressure and high temperature, the dead vegetation was slowly converted to coal. The conversion of dead vegetation into coal is called *coalification*. Coalification starts with dead plant matter decaying into peat. Then over millions of years the heat and pressure of deep burial causes the loss of water, methane and carbon dioxide and an increase in the proportion of carbon. Thus, first lignite (also called brown coal), then sub-bituminous coal, bituminous coal, and lastly anthracite (also called hard coal or black coal) may be formed.

The wide, shallow seas of the Carboniferous Period provided ideal conditions for coal formation, although coal is known from most geological periods. The exception is the coal gap in the Permian-Triassic extinction event, where coal is rare.

Coal is known from Precambrian strata, which predate land plants - this coal is presumed to have originated from residues of algae. Sometimes coal seams (also known as coal beds) are interbedded with other sediments in a cyclothem.

Types

As geological processes apply pressure to dead biotic material over time, under suitable conditions, its metamorphic grade or rank increases successively into:

- Peat, a precursor of coal
- Lignite, or brown coal, the lowest rank of coal, most harmful to health, used almost exclusively as fuel for electric power generation. Jet, a compact form of lignite, sometimes polished was used as an ornamental stone since the Upper Palaeolithic.
- Sub-bituminous coal, whose properties range between those of lignite and those of bituminous coal, is used primarily as fuel for steam-electric power generation.
- Bituminous coal, a dense sedimentary rock, usually black, but sometimes dark brown, often with well-defined bands of bright and dull material. It is used primarily as fuel in steam-electric power generation and to make coke.
- Anthracite, the highest rank of coal is a harder, glossy black coal used primarily for residential and commercial space heating.
- Graphite is difficult to ignite and not commonly used as fuel; it is most used in pencils or powdered for lubrication.



Figure 1. Lignite or brown coal (the lowest rank of coal)



Figure 2. Coal – bituminous



Figure 3. Anthracite (the highest rank of coal)

Cannel coal (sometimes called *candle coal*) is a variety of fine-grained, high-rank coal with significant hydrogen content, which consists primarily of liptinite.

There are several international standards for coal. The classification of coal is generally based on the content of volatiles. However, the most important distinction is between thermal coal (also known as *steam coal*), which is burnt to generate electricity via steam; and metallurgical coal (also known as *coking coal*), which is burnt at high temperature to make steel.

3. Formation of crude oil and gas

Oil and natural gas are naturally occurring chemicals that are made up of just two elements -- carbon and hydrogen. The class of chemicals based on carbon and hydrogen are called *hydrocarbons*.

The simplest hydrocarbon, methane, is made up of one carbon atom and four hydrogen atoms. Other hydrocarbons like octane and octadecane have more complicated structures. Plastics are made of molecules called *polymers* that are very long chains of hydrocarbons.

Most people know natural gas and oil are fossil fuels used as energy sources but may not know exactly what these substances are made of. Understanding exactly what oil and gas are composed of is crucial to understanding their origins, uses and importance.

Liquid crude oil and natural gas occur together in nature, and so are collectively called *petroleum*. The word derives from the Greek words *petra* and *oleum*, meaning rock and oil, respectively. Another term for petroleum is hydrocarbons - it is called this because petroleum primarily consists of hydrocarbon molecules, and these molecules are the reason for petroleum's value as a source of fuel.

Petroleum in both gas and oil forms atomically consists of around 95 percent hydrogen and carbon molecules. The approximate percentages of each atom is: 83-8 percent carbon, 10-14 percent hydrogen, less than 6 percent sulphur, less than 2 percent nitrogen, less than 1.5 percent oxygen, and less than 0.1 percent metals and salts.

Under high temperatures and pressures, these atoms bind and combine to form the hydrocarbon molecules. Within crude oil, the hydrocarbons formed typically include the following:

- Paraffins (15-60 percent), which include methane, ethane, propane, butane, isobutane, pentane and hexane
- Naphthenes or cycloalkanes (30-60 percent), which include cyclohexane and methyl cyclopentane.
- Aromatics (3-30 percent), which include benzene and naphthalene
- Alkenes, dienes and alkynes make up the remainder of the oil, and typically include ethylene, butene, isobutene, acetylene and butadienes.

Natural gas, on the other hand, is almost entirely methane, with this molecule making up over 98 percent of the natural gas found in deposits. Rarer, more valuable molecules within natural gas include ethane, propane and butane, but these are often only found in trace quantities.

These hydrocarbons are the reason petroleum is such a wanted substance. Hydrocarbons contain huge amounts of chemical energy in their chemical bonds. Additionally, they can be used to make a huge variety of products, including anything from gas to plastic and paraffin wax.

All these molecules appear in different proportions in each petroleum deposit, primarily because each deposit forms in a different way, with different portions of each atom. This can be explained by the unique way in which gas and oil naturally form.

Oil and natural gas are organic fossil fuels, formed from the remains of plants and animals trapped in and between layers of fine-grained sediment from ancient oceans and lakes. While many people talk about fossil fuels being the converted remains of dead dinosaurs, the fossil fuels we use today were formed much earlier in the Earth's history than the age of reptiles.

Most of the fossil fuels we use today were formed from ancient plants and animals that died millions of years ago, living long before the first dinosaurs ever stepped foot on the planet. Over the years, these organisms would die and decompose into organic materials, which would eventually wash away into lakes and oceans. This is where the fossil fuel formation process

Crude oil and gas formation process

- (a) The material settles: Organic material from prehistoric plants and animals, washed from the land by rain, settling into still water portions of seas and inland lakes. They settle at the bottom of these water sources, slowly being covered by sand, silt and clay in increasing layers. These layers of sand and silt would trap the organic material before it had a chance to completely decompose, creating organic-rich mud.
- (b) The material hardens: Before the organic matter is destroyed by decomposition, it combines with more sediment and forms sedimentary rock known as organic shale.
- (c) The shale is buried: As time goes on, increasing layers of silt and organic matter cover this shale, causing it to sink further and further into the Earth. If the shale reaches a depth of two to four kilometres, the pressure of all the material on top of it, along with the temperature rising because of being closer to the Earth's interior, will cause the shale to transform into kerogen, a precursor to oil which appears as a waxy substance.
- (d) The kerogen cooks: At temperatures greater than 70°C but lower than 150°C, kerogen effectively cooks, transforming over the years into oil and natural gas. If the temperature exceeds 150°C during this time, kerogen will instead produce graphite and natural gas.

(e) The gas and oil rise: Both oil and natural gas are lighter than water, so if they escape from the source oil shale, they will rise through pores in the Earth, displacing water. For the oil and gas to remain trapped in the reservoir (a porous and permeable layer of rock like sandstone), there must be a thick, impermeable layer of rock (such as shale or evaporate) to seal it. If this reservoir exists, it can be drilled into to obtain oil and natural gas. Over time, these deposits naturally rise to the surface, making them easier to access.

Natural gas does occur outside of these conditions, most notably in cases like swamps, where organic material is trapped under mud and forms gas. This is called biogenic gas, as it forms from biodegradation. This same gas can also be produced with manure and controlled decomposition.

4. Characteristics of crude oil

Crude oil is categorised according to its density, the presence of impurities and its location. The density of crude oil is traditionally measured using the API (American Petroleum Institute) gravity, the lower the API gravity, the heavier the crude oil. A medium crude oil has a gravity of 20° to 30°. Density is indicative of the composition of the crude oil and the ease with which it can be processed. Lighter crudes are normally more valuable than heavier crudes as a greater volume of more useful lighter components can be produced with less processing cost.

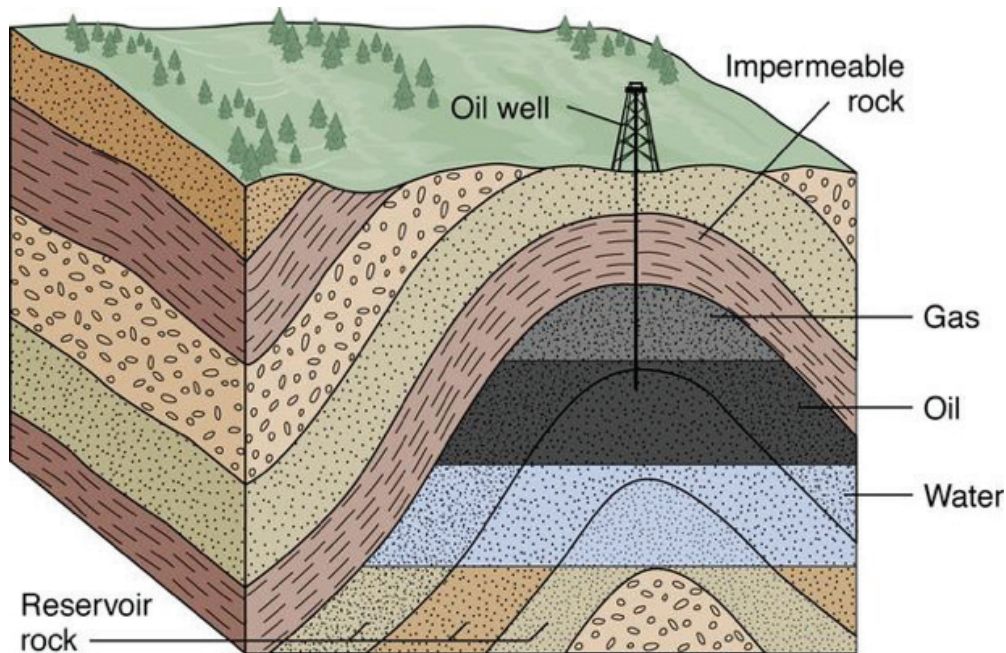


Figure 4. Structural trap showing the relationship of gas, oil and water
(Source: https://energyeducation.ca/encyclopedia/Source_rock)

Crude oils contain many different types of impurities including toxic, corrosive and reactive substances that can be costly to deal with. One of the most important impurities is sulphur and crude oils are generally classified according to sulphur content as sweet or sour, sweet crudes typically containing less than 0.5 percent sulphur and sour crudes more than 2 percent sulphur. Higher sulphur crude oil requires costly treatment and hence sour crude oils are generally sold at a significant discount as compared to sweet crude oils.

In addition to API gravity and sulphur content, petroleum refining and processing requires many more physical and chemical properties and characteristics of crude oils. This information is typically supplied in the form of an assay. An assay is the product of extensive laboratory testing and provides a detailed physical and chemical analysis of a crude oil. This information is used to determine the suitability of crude oils for a refinery configuration and is important in determining the potential value of the crude oil.

5. Characteristics of gas

Natural gas is a fuel gas which is used in steel plants as an auxiliary fuel for injection in blast furnace, to produce gas-based direct reduced iron, and for heating in various furnaces subject to local availability and the cost. It is an environmentally friendly non-renewable fossil fuel which is found in underground deposits in its gas phase. Natural gas exists as a gas under atmospheric conditions. It is principally a hydrocarbon gas mixture consisting primarily of methane and a clean fuel with a high efficiency.

Natural gas is normally supplied as (i) piped natural gas (PNG), (ii) compressed natural gas (CNG), and (iii) liquefied natural gas (LNG).

PNG is transported normally to long distances (up to 5000 km) through a pipeline network. The pressure of natural gas in the pipeline depends on several factors which include (i) quantity of gas to be transported, (ii) diameter of the pipeline, (iii) the distances involved, and (iv) the safety of the gas pipeline and environment. However, at the consumer end the pipeline pressure is generally less than 16 atmospheres.

CNG is a form of natural gas which undergoes compression (200 to 250 kg/cm²) into containers where it is relayed to consumers who, due to geographic and other reasons are incapable of connecting into the natural gas pipeline. CNG is storable. Unlike natural gas conveyed via pipelines and immediately consumed (similarly to electricity), CNG can be used for storage and for discontinuous utilization. Natural gas compression into containers raises risk levels.

LNG is made by cooling natural gas to a temperature of -162°C. At this temperature, natural gas becomes a liquid and its volume is reduced by 600 times. LNG gas is easier to store than the gaseous form since it takes up much less space. LNG is stored at atmospheric pressure in designed vessels and is easier to transport to the users. Natural gas is normally transported in LNG form where the distances of the destination is usually above 5000 km.



Figure 5. An LNG tanker loading at the PNG LNG terminal 20 km northwest of Port Moresby.

Natural gas is a fuel found in deposits in its gas phase. It is colourless and odourless, non-toxic, lighter than air and it does not contain olefins (hydrocarbons produced during the process of destructive distillation or reforming). It is a highly flammable and combustible gas. It burns with a pale luminous flame.

If the natural gas contains enough carbon dioxide to cause its calorific value to fall below the specified values then it is usually subjected to a process to extract this element, in addition to hydrogen sulphide or other sulphur compounds causing it to be highly corrosive and inadmissible for certain industrial applications.

Once extracted, the gas is treated for removing undesirable components such as water vapour, carbon dioxide, sulphur compounds, condensable hydrocarbons and solid and liquid particles. This process is known as *gas drying*. Dry gas is gas which has been dehydrated and subjected to a process in which condensable hydrocarbons such as propane, butane, pentane and higher hydrocarbons have been extracted. The amounts which may be recovered from the above-mentioned components depend on the original composition of the natural gas and the process used to dry it. Dry gases are also known as *lean gases*, and wet gases are also known as *rich gases*.

6. Importance and/or uses of crude oil and gas

When crude oil is refined and separated, most easily by distillation, into many consumer products, from gasoline (petrol) and kerosene to asphalt and chemical reagents used to make plastics, pesticides and pharmaceuticals. Petroleum is used in manufacturing a wide variety of materials, and it is estimated that the world consumes about 95 million barrels each day.

The use of petroleum as fuel is controversial due to its impact on global warming and ocean acidification. Fossil fuel phase-out, including petroleum, need to be completed by the end of 21st Century to avoid “severe, pervasive, and irreversible impacts for people and ecosystems”, according to the United Nations’ Intergovernmental Panel on Climate Change.

Natural gas is a non-renewable hydrocarbon used as a source of energy for heating, cooking, and electricity generation. It is also used as a fuel for vehicles and as a chemical feedstock in the manufacture of plastics and other commercially important organic chemicals.

Natural gas is a major cause of global warming, both when leaked and due to the carbon dioxide, it produces when burnt.

Nevertheless, crude oil and gas are very important to a developing economy like Papua New Guinea. The sale of these commodities brings in income, thereby increasing domestic wealth, helping to develop a nation, and increasing gross domestic product (GDP). This also applies to countries who produce and export oil and gas, because the petroleum industry drives their economy in a vast number of ways as seen in Papua New Guinea - employment for citizens, training, investment, etc.

Teaching and Learning Strategies

Teaching Strategies:	Learning Strategies
Teachers prepare information (notes, coal, oil and gas samples, and pictures) and ask questions on these fossil fuels. Teachers can take students out for an excursion to the nearest oil well or mine site (if possible).	Students will use the information provided to answer questions on fossil fuels.
STEAM Approach Learning Objective: By the end of the topic, students will be able to; <ul style="list-style-type: none"> • visualise, compare fossil fuels - STEAM 	
Teaching Strategies Teachers will provide the information for students to read, observe and answer questions within a given period.	Learning Strategies Students read the notes and use the materials available to understand the difference between fossil fuels.
Recommended Resources: <ul style="list-style-type: none"> • https://topdifferences.com/difference-between-renewable-resources-and-non-renewable-resources/ • https://en.wikipedia.org/wiki/Industrial_mineral • Internet • www.png.OreSomeResources.com 	

Unit 3: Geological Time and Fossils

Content Standard

11.2.3 Students will be able to assess the significance of the geological time scale and fossils.

Benchmark

11.2.3.1 Examine the geological time scale in terms of Eon, Era, Period and Epoch.

Topic 1: Geological Time Scale

Learning Objectives:

By the end of this topic, the students will be able to:

- Understand the geological time scale
- Understand past life forms
- Understand past mass extinctions

Essential questions

1. What do we understand about geological history?
2. When did the Earth form in relation to geological time?
3. What are some major events in geological time?

Vocabulary: Geological time scale, eon, era, period, epoch, extinction

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Geological time • Life forms • Extinctions of life forms 	<ul style="list-style-type: none"> • Understanding, reasoning 	<ul style="list-style-type: none"> • Open-minded, with a desire to learn

Content Background

1. Geological time scale

The geologic time scale is like a calendar extending from Earth's formation to the present. The scale is divided into eons, eras, periods and epochs.

- Eon: The largest group – billions of years long
- Era: Mass extinctions mark the boundaries between the eras – hundreds of millions of years long
- Period: tens of millions of years long
- Epoch: divisions of the most recent periods – several million years long

The geological time is divided into two main intervals: Precambrian and Phanerozoic (Fig. 1). The Precambrian is the time of poor fossil record and the Phanerozoic the time of rich fossil record. The Precambrian occupies by far the larger part of Earth's history, 4.6 to 0.542 billion years (4.6 – 0.542 Ga). The Phanerozoic occupies only the last 542 million years (the last 542 Ma).

The Precambrian, in turn, is divided in two: the Archaean from 4.6 to 2.5 Ga and the Proterozoic from 2.5 to 0.542 Ga. The name Proterozoic means the time of early life. It is now known that there was life before the Proterozoic, in fact as old as 3.8 Ga. However, the subdivision into Archaean and Proterozoic remains.

The geological time scale grew from the work of early geologists in various parts of Europe and North America. Most of the time units are renamed for the regions where rocks of that age were first recognized. For example, rocks of Cambrian, Ordovician and Silurian age were first recognized in Wales and are named for Wales (Cambria) and two of the Welsh tribes; rocks of Devonian age were recognized in Devon, England; of Permian age in Perm, Russia; and Jurassic age in the Jura Mountains, France. Some names were descriptive. For example, Carboniferous is the name given to the sequence of rocks that contain coal in Europe, and Cretaceous to the sequence that contain chalk (creta) in Europe.

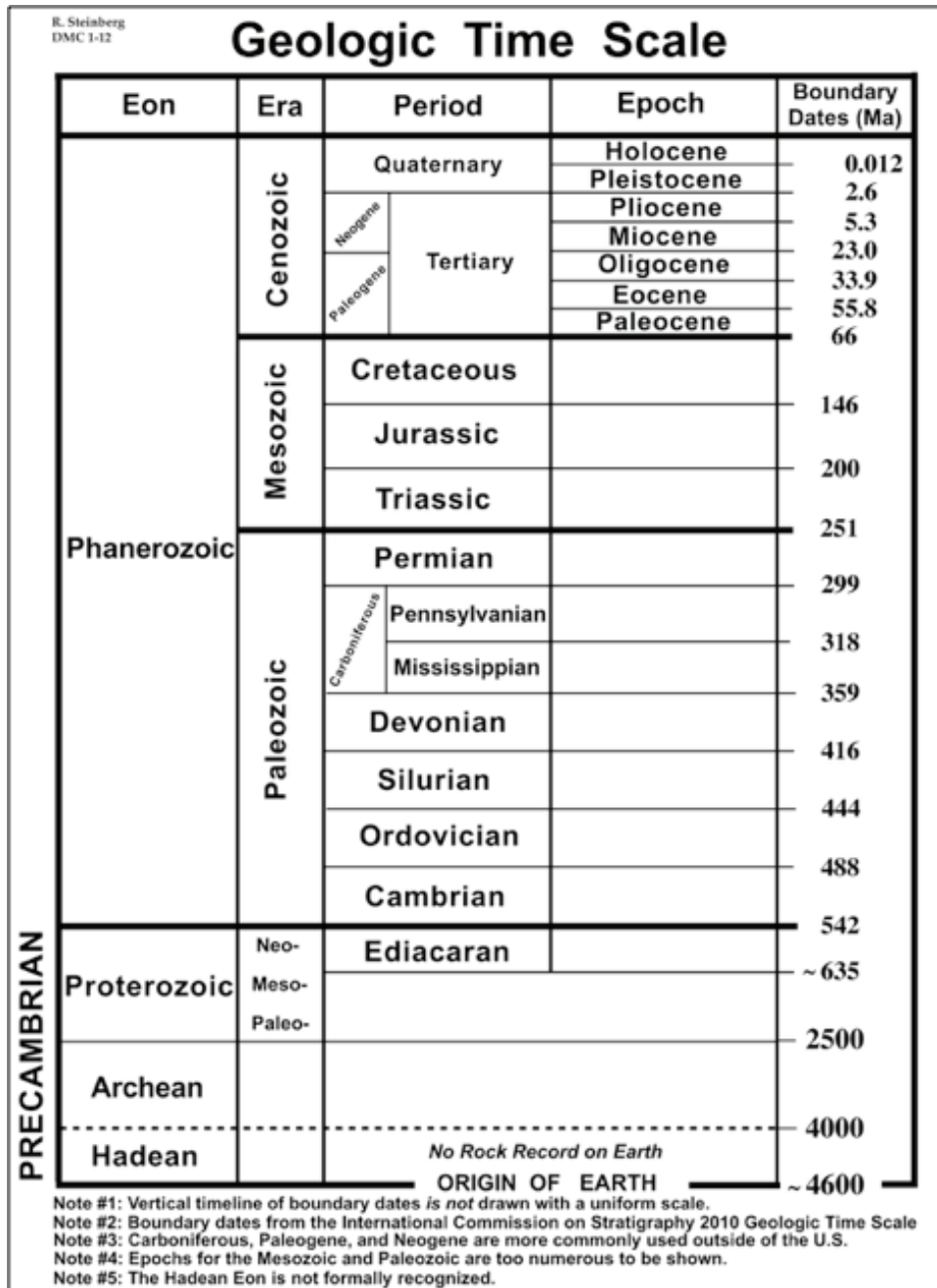


Figure 1. The geological time scale (Source: www.serc.carleton.edu). Ma = millions of years.

The subdivisions of the Cainozoic (Paleocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene) to the proportion of modern life forms that are found as fossils in each sequence – the least proportion is in the Paleocene and Eocene, and the largest proportion is in the Pleistocene and Holocene.

Correlation of rock sequences between one region and another was made possible by recognizing the same sequences of fossils.

A timeline can provide additional information about life's history not visible on an evolutionary tree. These include major geologic events, climate changes, radiation of organisms into new habitats, changes in ecosystems, changes in continental positions, and major extinctions. Explore the timeline below to view some of the major events in life's history.

Years ago	Event
130,000	Anatomically modern humans evolve. Seventy thousand years later, their descendants create cave paintings - early expressions of consciousness.
4 million	In Africa, an early hominid, affectionately named "Lucy" by scientists, lives. The ice ages begin, and many large mammals go extinct.
65 million	A massive asteroid hits the Yucatan Peninsula (Gulf of Mexico), and ammonites and non-avian dinosaurs go extinct. Birds and mammals are among the survivors.
130 million	As the continents drift toward their present positions, the earliest flowers evolve, and dinosaurs dominate the landscape. In the sea, bony fish diversify.
225 million	Dinosaurs and mammals evolve. Pangea has begun to break apart.
248 million	Over 90% of marine life and 70% of terrestrial life go extinct during the Earth's largest mass extinction. Ammonites are among the survivors.
250 million	The supercontinent called Pangea forms. Conifer-like forests, reptiles, and synapsids (the ancestors of mammals) are common.
360 million	Four-limbed vertebrates move onto the land as seed plants and large forests appear. The Earth's oceans support vast reef systems.
420 million	Land plants evolve, drastically changing Earth's landscape and creating new habitats.
450 million	Arthropods move onto the land. Their descendants evolve into scorpions, spiders, mites, and millipedes.
500 million	Fish-like vertebrates evolve. Invertebrates, such as trilobites, crinoids, brachiopods, and cephalopods, are common in the oceans.
555 million	Multi-cellular marine organisms are common. The diverse assortment of life includes bizarre-looking animals like <i>Wiwaxia</i> .
3.5 billion	Unicellular life evolves. Photosynthetic bacteria begin to release oxygen into the atmosphere.
3.8 billion	Replicating molecules (the precursors of DNA) form.
4.6 billion	The Earth forms and is bombarded by meteorites and comets.

2. Evolution of different life forms

The oldest record of life on our planet has been found in rocks dated at 3.8 billion years (3.8 Ga). The fossils are prokaryotes which are very simple life forms. At this time the Earth's atmosphere probably was oxygen-poor, with the result that iron and uranium could be carried in solution in their reduced state and re-deposited to form the great iron and uranium deposits that are mined today. Because of photosynthesis by cyano-bacteria, the atmosphere gradually became richer in oxygen, and may have reached the present level of oxygen content at about 1.8 Ga. By this time ozone that developed with the oxygen-rich atmosphere provided a protective shield against the sun's ultraviolet radiation. This was essential for the further evolution of life on Earth.

The oldest record of eukaryotes, which are more complex life forms, is in rocks dated at 2.6 Ga. The oldest record of more diverse life forms is in rocks of Vendian age, at about 570 Ma, about 20 million years before the start of the Cambrian and Phanerozoic. All of the Vendian life forms died out and were replaced by completely different life forms at the start of the Cambrian (542 Ma).

All early life was in the oceans. It was only in the Devonian that animals and plants moved to land.

3. Major extinction events

The Phanerozoic is divided into three major divisions based on changes in the assemblage of fossils in each. The Palaeozoic means time of ancient life, the Mesozoic the time of middle life, and the Cainozoic the time of recent life.

At the end of the Palaeozoic, at 251 Ma, there was an extreme extinction event that terminated most of the life forms that had developed through Palaeozoic time. There is much debate about the cause of this extinction event. At the end of the Mesozoic, at 65.5 Ma, there was another extinction event but on a somewhat smaller scale (Fig. 2). This was the event that saw an end to the dinosaurs (Fig. 3). It was caused by a meteorite crashing into our planet. An impact crater of the right age and size has been discovered and mapped off the Yucatan Peninsula in the Gulf of Mexico.

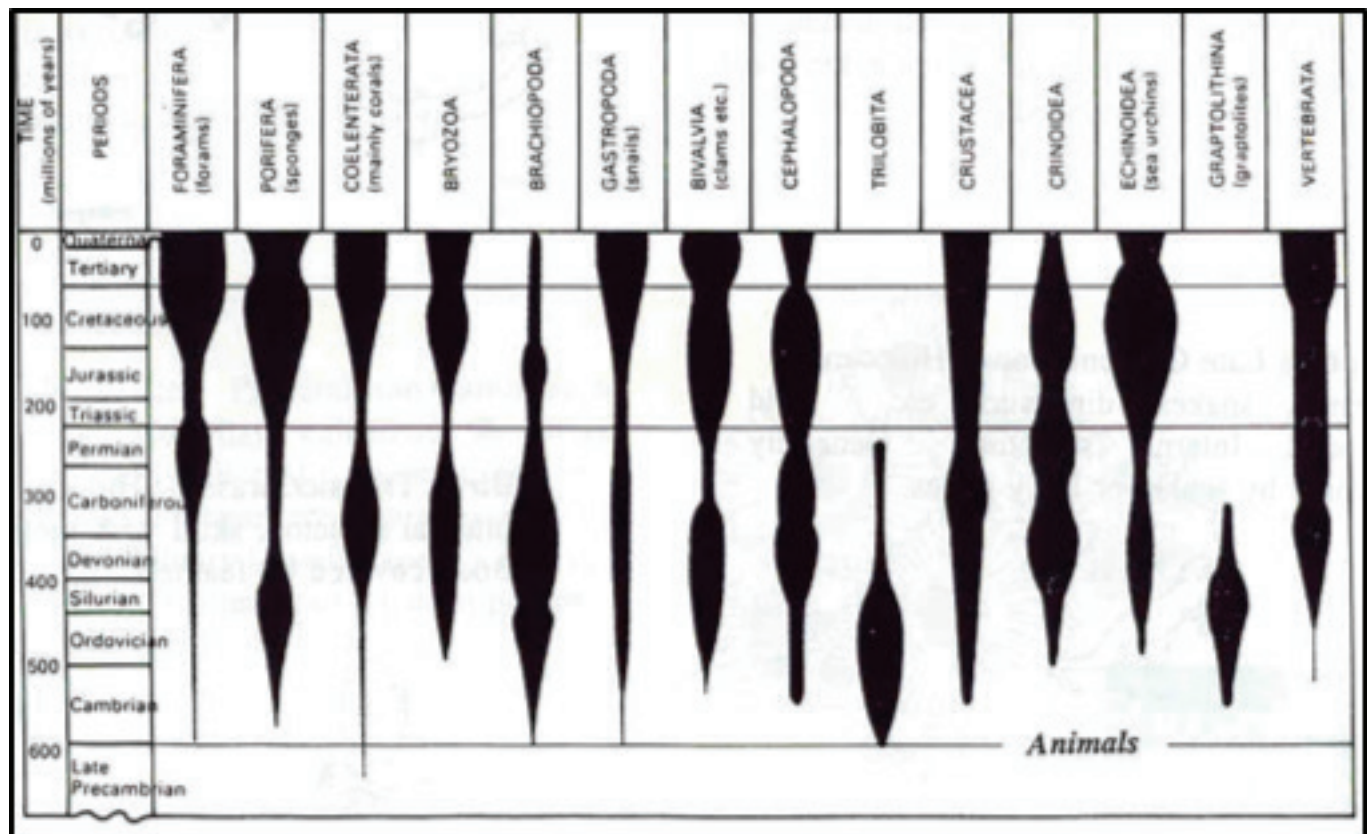


Figure 2. Boundaries between Palaeozoic, Mesozoic and Cainozoic are times when old forms died out and new forms appeared (after Davies, 2013).

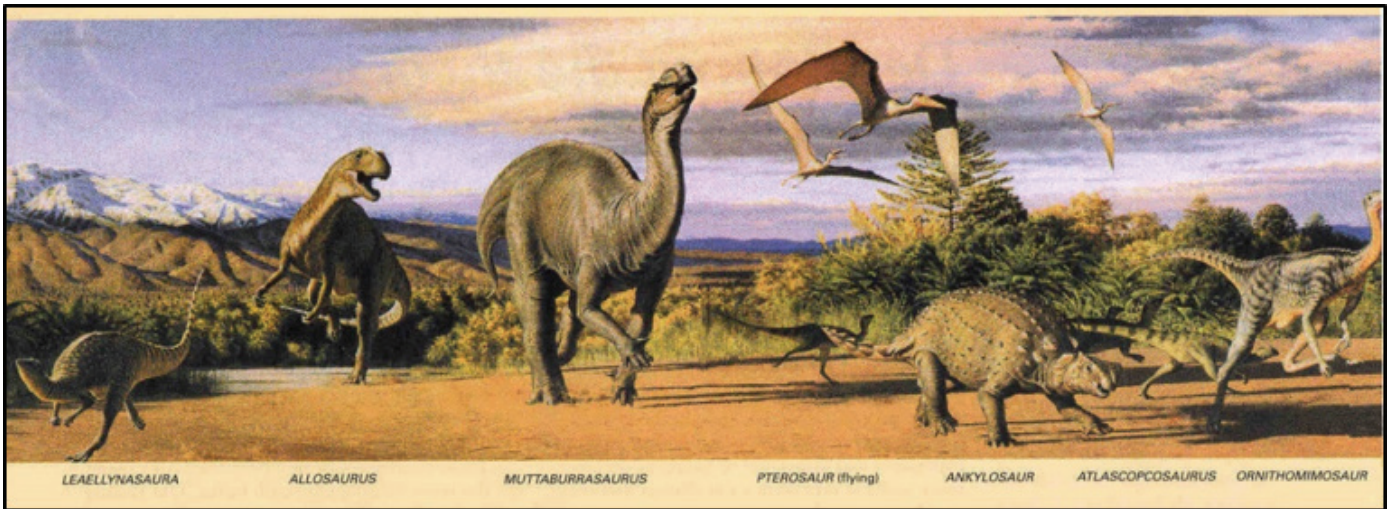


Figure 3. Images of dinosaurs that roamed the Australia-New Guinea continent in the Mesozoic. We know them from their fossil record (after Davies, 2013).

Other extinction events on a scale similar to the 65.5 Ma event occurred at the end of the Ordovician, in the Late Devonian, and at the end of the Triassic. After each extinction event there was an opportunity for new life forms to develop to occupy the ecological environments that had become vacant. For example, the extinction of the dinosaurs made it possible for the mammals to become the dominant animals.

Revisiting the geological time scale

Can the geological time scale be revisited? The geological time scale grew as the science of geology grew, in the 19th Century. Now that we have the advantage of “absolute date” determination using rates of decay of unstable isotopes, one could argue that it might make more sense to drop the old divisions and simply refer to geological time by numbers of millions of years.

There are three reasons this has not happened. First, the names and their usage are deeply ingrained in the literature and in the way of thinking of geologists. Secondly, the boundaries between major divisions mark times when there were major changes in the evolution of life on Earth. Third, the absolute age time scale is revised from time to time as dating methods become more accurate.

The time system that is based on rock sequences and their contained fossils also is revised from time to time, as further study refines boundaries.

Teaching and Learning Strategies

Teaching Strategies:	Learning Strategies
Teachers prepare information (notes, charts, and pictures) and ask questions on geological time scale.	Students will use the information provided to answer questions on geological time scale.
STEAM Approach Learning Objective: By the end of the topic, students will be able to; <ul style="list-style-type: none"> • Visualise and understand past life, geological time scale - STEAM 	
Teaching Strategies Teachers will provide the information for students to read, observe and answer questions within a given period of time.	Learning Strategies Students read the notes and use the materials available to understand the geological time scale.
Recommended Resources: <ul style="list-style-type: none"> • Clark, I.F. and Cook, B.J., 1992. Perspectives of the Earth. Australian Academy of Science, Canberra, ACT, 561p. • Davidson, J.P., Reed, W.E. and Davis, P.M., 1997. Exploring Earth. An Introduction to Physical Geology, Prentice-Hall Inc., 264p. • Davies, H.L., 2013. Earth Tok, 3rd Edition, Alan Caudell & Associates, 231p. • https://en.wikipedia.org/wiki/Geological_history_of_Earth • https://evolution.berkeley.edu/evolibrary/article/0_0_0/evotext_13 • Internet 	

Unit 3: Geological Time and Fossils

Content Standard

11.2.3 Students will be able to assess the significance of the geological time scale and fossils.

Benchmark

11.2.3.1 Examine the geological time scale in terms of Eon, Era, Period and Epoch.

Topic 2: Fossils

Learning Objectives:

By the end of this topic, the students will be able to:

- Understand what fossils are
- Understand the processes involved in the formation of fossils
- Appreciate the usefulness of fossils

Essential questions

1. What is a fossil?
2. How are fossils formed?
3. Why are fossils useful?

Vocabulary: Fossils, fossilisation

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Fossils • Fossil formation processes • Significance of fossils 	Understanding, reasoning	Open-minded, with a desire to learn

Content Background

1. Definition and types of fossils

Fossils offer a record of the past, specifically a record of the life that lived on Earth a long, long time ago. Although they are often wrongly conceived of as nothing more than very old bones, fossils are far more than that. The broadest definition of a fossil is that it is the remains of ancient organisms or even evidence of the activity of such organisms. There are thus plant fossils, animal fossils and other types.

Body fossils are actual remains that have been preserved by physical processes such as drying, freezing, mineralization and petrification. Trace fossils are footprints, trails and other changes to the environment that only living things cause. As of 2018, fossils up to about 600 million years old have been unearthed.

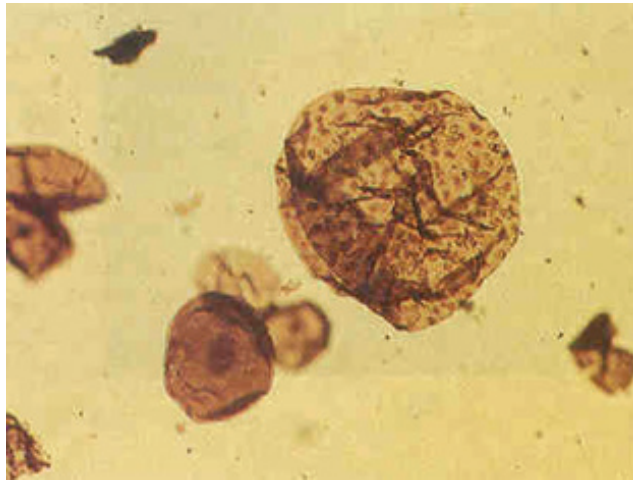


Figure 1. Late Precambrian (850 Ma) eukaryotic bacterium, much more complex than the prokaryotes. First eukaryotes appeared at 2.6 Ga (after Davies, 2013).

2. Fossil formation processes

The stages of fossil formation are the same regardless of the organism being fossilized, the circumstances under which its life ended and the environment in which the preservation of its legacy unfolds.

- (a) First, any soft tissue that was present in life decays, leaving behind the hard parts: bones, teeth, shells. This usually happens very quickly because of bacterial action.
- (b) Next, these hard parts may be moved, such as by rivers, and broken. It is very rare for an entire fossilized skeleton, especially one from a large animal, to be found. Even when an animal dies and is initially preserved in its entirety, gradual or sudden shifts in the Earth's crust can be sufficient to separate the parts by considerable distances.
- (c) In the last and most important step in the process, the hard tissue, having been buried, becomes physically altered. Usually this means that the original material is replaced by similar material. For example, as hard as bones are, the minerals they contain gradually decay. But in the case of fossils, these are replaced by minerals that assume the same size and shape thanks to the limitations of whatever material (e.g., sediment) has encased the fossil. This leaves behind a cast of the original that for all intents and purposes is an ideal representation of that original.

Palaeontology is the study of prehistoric life, primarily conducted through the analysis of fossils. By studying the preserved remains of creatures and plants that lived millions of years ago, scientists can glean valuable information about the origin and evolution of life on this planet.

The most basic information a fossil can provide is about what animals and plants looked like. While a complete fossil is best for understanding body structure, even a partial fossil can provide valuable information. The condition of a fossil can indicate what type of environment existed at the time. Well-preserved and complete fossils might indicate a bog, whose soft organic matter helped prevent the fossil from deteriorating.

The relative depth of fossils can give clues as to when the organisms lived, as the deeper they are buried, the older the fossil. This information can be verified by carbon dating, which can pinpoint a fossil's age. Finding similar fossils in different areas can indicate patterns in the movement of the Earth's crust, scattering the remains of creatures that once lived in a single place. Finding similar fossils from different ages can help scientists understand how organisms evolved and changed over millions of years of development.

3. Significance of fossils

Fossils are useful because principally they help scientists interpret geological time. By carefully sampling sequences of bedded sediments a chronology has been established based on the appearance and disappearance (extinction) of different life forms. By reference to this data base, which is now quite enormous, we can determine the age of a rock. For example, different types of trilobite characterized different intervals of the Palaeozoic (Fig. 2). Fossils can be used to correlate (match up) rock units that are some distance apart (Fig. 3).

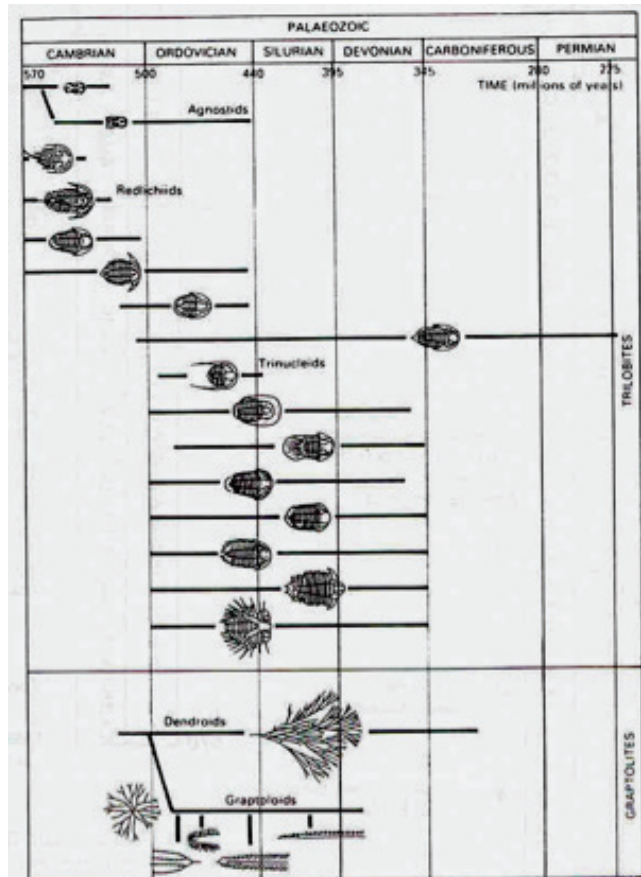


Figure 2. Using fossils (trilobites) to determine the age of a rock (Palaeozoic) (after Davies, 2013).

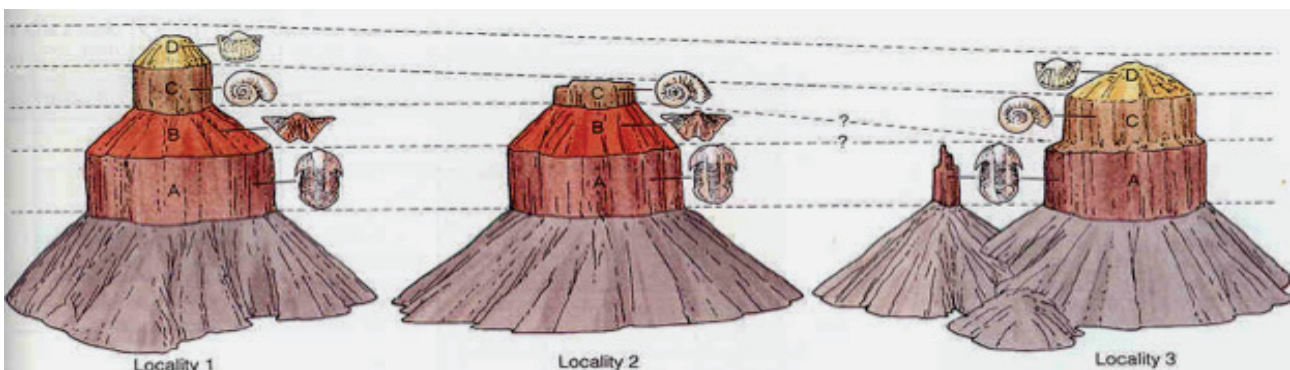


Figure 3. Using fossils to correlate (match up) rock units that are some distance apart (after Davies, 2013).

For geological mapping and oil exploration the most useful fossils are the microfossils including foraminifera (Fig. 4), plant spores and pollen.

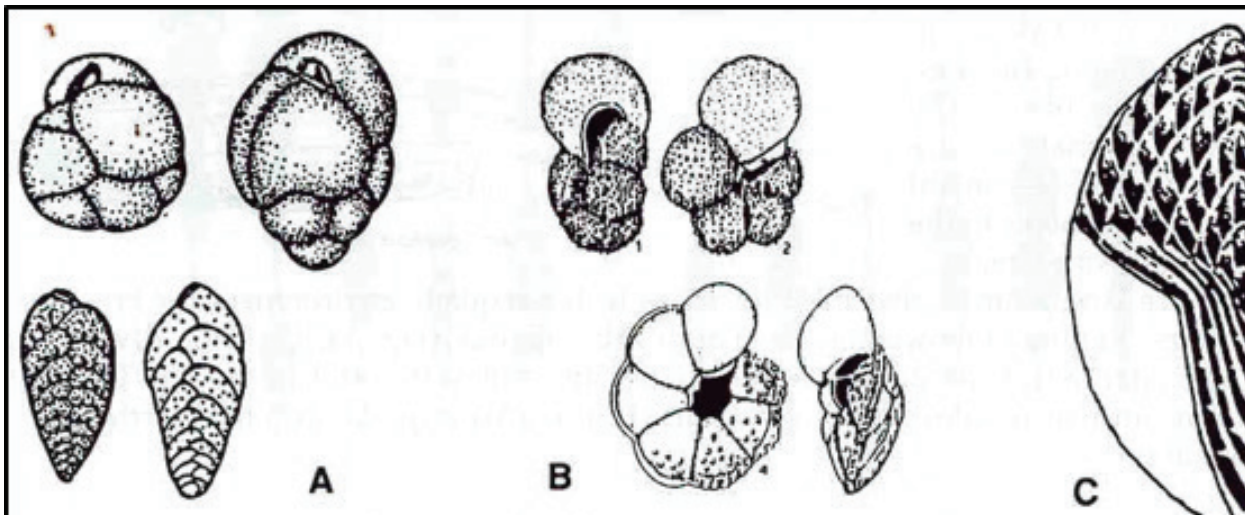


Figure 4. Foraminifera (microscopic marine life) are the fossils most commonly used for dating rocks in Papua New Guinea (after Davies, 2013).

Disadvantages of dating using fossils to interpret geological time

Fossils tell us the relative age of the rock. Thus rocks with Cambrian fossils are older than rocks with Ordovician fossils. There were two disadvantages in this system of dating. First, there was no means of dating rocks that are unfossiliferous, such as most of the Precambrian rocks. Second, we had no idea how long ago each rock series was deposited.

Teaching and Learning Strategies

Teaching Strategies:

Teachers prepare information (notes, fossil samples, and pictures) and ask questions on fossils and their uses. Teachers can take students out for an excursion to the nearest geological museum (if possible).

Learning Strategies

Students will use the information provided to answer questions on fossils and their uses.

STEAM Approach

Learning Objective: By the end of the topic, students will be able to;

- Visualise, understand and appreciate fossils and their use in interpreting past life - STEAM

Teaching Strategies

Teachers will provide the information for students to read, observe and answer questions within a given period of time.

Learning Strategies

Students read the notes and use the materials available to understand and appreciate fossils and their usage in interpreting past life

Recommended Resources:

- Clark, I.F. and Cook, B.J., 1992. Perspectives of the Earth. Australian Academy of Science, Canberra, ACT, 561p.
- Davidson, J.P., Reed, W.E., and Davis, P.M., 1997. Exploring Earth. An Introduction to Physical Geology, Prentice-Hall Inc., 264p.
- Davies, H.L., 2013. Earth Tok, 3rd Edition, Alan Caudell & Associates, 231p
- <https://sciencing.com/information-can-scientists-fossils-6184047.html>
- Internet

Unit 4: Plate Tectonics

Content Standard 11.2.4 Students will be able to understand and explain the plate tectonics with supporting evidence.

Benchmark 11.2.4.1 Analyse and explain the plate tectonic process and the supporting evidence for the drifting of continents.

Topic 1: Plate Tectonic Theory

Learning Objectives:

By the end of this topic, the students will be able to:

- Explain theories related to plate tectonics.
- Explain the evidences of plate movement.

Essential questions

1. What is plate tectonics?
2. Are the continents the same as plates?
3. What causes plates to move?

Vocabulary: plate tectonics, plate motion

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Plate tectonics • Moving plates • Evidence of plate motion 	<ul style="list-style-type: none"> • Reasoning 	<ul style="list-style-type: none"> • Understanding, and appreciate that the plates are in constant motion.

Content Background

1. Plate tectonics

Three hundred years ago when the early navigators produced the first maps of the Atlantic it became clear that the coastlines of South America and Africa were remarkably well matched. It looked as though the two had once been joined together and had since broken and drifted apart. The idea gathered favour in the 20th Century when geologists found matching rocks and structures on the two coasts, and evidence from fossil plant and animal life that the two continents were once joined. In fact, evidence from fossils showed that all of the southern continents were once joined. In 1915, a German meteorologist, Alfred Wegener, brought the evidence together in a book that argued convincingly for continental drift.

Since Wegener's time, people were still arguing about whether the continents might have moved. For those people who worked in the interior of continents, which are stable part of the Earth's crust, such as Western Australia, drift seemed highly unlikely and hardly talked about it, but for others, especially those who work in places like PNG, drift was an attractive idea because it would explain much of the deformation of the Earth's surface that they could see. However, no one could adequately explain how the continents could move. What strange mechanism could do this?

The idea came to life again after the Second World War when improved mapping of the floor of the world's oceans established that in each ocean there is a ridge, that the ridge from one ocean joins to the ridge in the next, and that the ridge in some cases had a central rift valley, or graben, indicating extension. In some but not all oceans the ridge is centrally located, equidistant from the nearest landmasses – hence the name mid-ocean ridge.

Additionally, seafloor mapping showed that the ocean floor near the mid-ocean ridge is bare rock with no cover of sediment, while further from the ridge there is a cover of sediment. This suggested that the seafloor near the ridge is very young and seafloor far from the ridge is older.

In 1961 American geologists Hess and Dietz, working independently, put together a scheme that would link the mid-ocean ridges to continental drift. They proposed that the two parts of the ocean floor on either side of the mid-ocean ridge are moving apart, and that new ocean crust is being generated by eruption of lava at the ridge crest. In essence, the lava fills the void that would otherwise be created as the two sides moved apart. At last a mechanism for continental drift had been found. Scottish geologist Arthur Holmes had proposed a similar scheme in the 1920s but without the supporting evidence that had become available by the 1960s.

The difference between the new concept and what Wegener had proposed was that, where Wegener had thought of the continents as moving independently across the ocean floor, like great ships, the new model required that the continents and the adjacent ocean floor moved together, in one piece.

The concept of plate tectonics was born.

The essence of plate tectonics is that the lithosphere comprises a number of plates, each constantly in motion. Any one plate may include areas of continental crust and of oceanic crust, plus the uppermost part of the mantle. Rates of motion may be as much as 15 cm per year. The interactions between the plates is discussed next under plate boundaries.

The evidence for continental drift includes:

- Jigsaw fit between South American and African continents
- Same fossils of plants and animals found on both sides of the Atlantic Ocean
- Similar Mountain ranges in the two continents
- Ice sheets found in places that have hot temperatures
- Magnetic reversal data and seafloor spreading

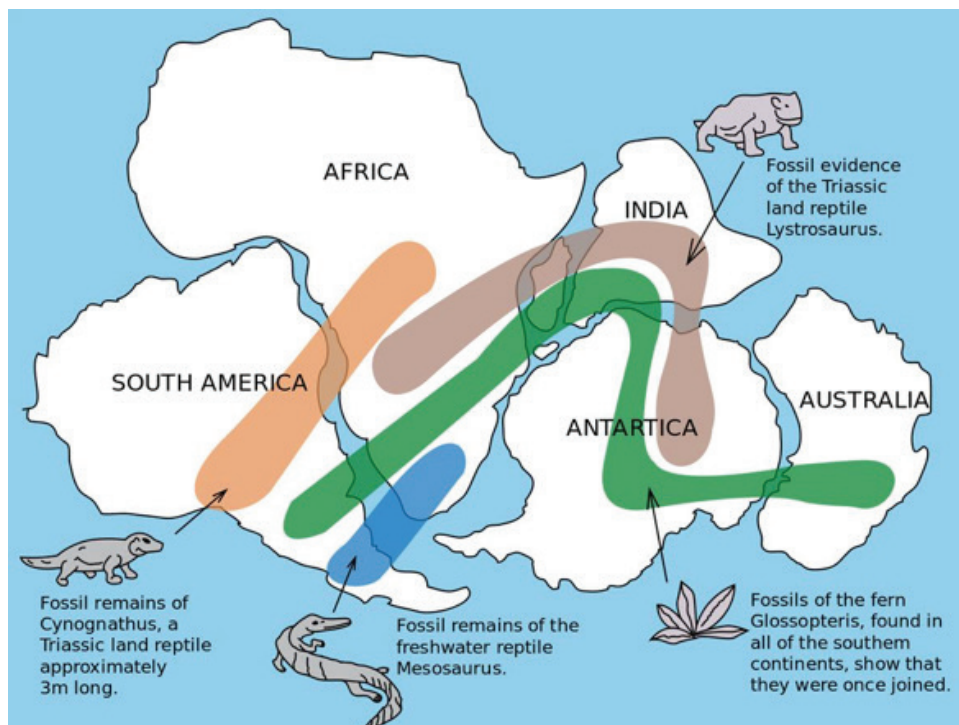


Figure 1. The Southern continents once were joined and for this reason have rocks of the same age on matching parts of each coastline and share a common fossil flora and fauna (after Davies, 2013).

2. Major and minor lithospheric plates

Figure 2 shows the global tectonic plates. There are seven major plates (over 40 million km² in area) and eight or so minor ones (less than 20 million km² in area). The major plates include the African, Antarctic, Eurasian, North American, South American, India-Australian, and the Pacific.



Figure 2. Global tectonic plates (source: WorldAtlas.com)

Rank	Tectonic Plate	Type	Size (km ²)	Rank	Tectonic Plate	Type	Size (km ²)
1	Pacific plate	Major	103 300 000	10	Philippine plate	Minor	5 500 000
2	North American plate	Major	75 900 000	11	Arabian plate	Minor	5 000 000
3	Eurasian plate	Major	67 800 000	12	Caribbean plate	Minor	3 300 000
4	African plate	Major	61 300 000	13	Cocos plate	Minor	2 900 000
5	Antarctic plate	Major	60 900 000	14	Caroline plate	Minor	1 700 000
6	Indo-Australian plate	Major	58 900 000	15	Scotia plate	Minor	1 600 000
7	South American plate	Major	43 600 000	16	Burma plate	Minor	1 100 000
8	Somali plate	Minor	16 700 000	17	New Hebrides plate	Minor	1 100 000
9	Nazca plate	Minor	15 600 000				

3. Mantle convection theory and plate movement

The mechanisms for plate motions are still not clearly understood and it is likely that more than one force is operating. The movement of the continents and ocean floor may in general terms be seen as a result of thermal convection in the mantle below the lithosphere. However, models commonly invoke convection of the upper mantle and transition zone. It is possible that two processes may be involved.

- (a) Low density mantle material underlies the mid-ocean ridges so that they are relatively elevated. Gravitational sliding of the newly created lithosphere down the slopes of the ridges probably exerts a force on the oceanic part of the plate.
- (b) The down-going lithosphere is colder than the underlying asthenosphere so it has greater density. The lithosphere tends to sink and exert a pull on the horizontal part of the plate.

The lithospheric plates are continuously being created on one side and consumed at their opposite plate boundaries. Accretion occurs as mantle is added to the growing edges of a plate, associated with seafloor spreading. This hot added material cools by conduction and convection of heat. At the consumption edges of the plate, the material has thermally contracted to become dense, and it sinks under its own weight in the process of subduction usually at an ocean trench.

This subduction material sinks through the Earth's interior. Some subducted materials appear to reach the lower mantle, while in other regions, this material is impeded from sinking further, possibly due to a phase transition from spinel to silicate perovskite and magnesiowustite, an endothermic reaction.

The subducted oceanic crust triggers volcanism, although the basic mechanisms are varied. Volcanism may occur due to processes that add buoyancy to partially melted mantle, which would cause upward flow of the partial melt due to decrease in its density. Secondary convection may cause surface volcanism because of intraplate extension and mantle plumes.

Mantle convection causes tectonic plates to move around the Earth's surface. It seems to have been much more active during the Hadean period, resulting in gravitational sorting of heavier molten iron, nickel, and sulphides to the core and lighter silicate minerals to the mantle.

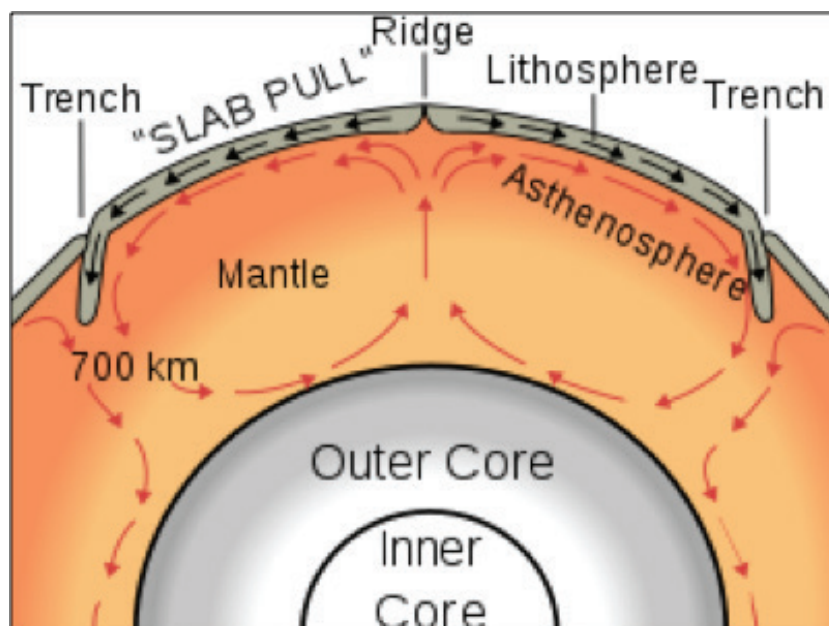


Figure 3. Mantle convection causes the lithospheric plates to move (Source: https://en.wikipedia.org/wiki/Mantle_convection).

4. Paleomagnetism

Two key elements of the proof of continental drift came from paleomagnetic research. When a rock is formed, whether it is a sediment laid down on the sea floor, or a lava erupted from a volcano, or a granite that cools and solidifies within the crust, it is imprinted with the magnetic field that applies in that part of the Earth. The magnetic particles (or magnetic domains) in the rock (mainly magnetite) align themselves parallel to the Earth's magnetic field. The rock carries that imprint, like a passport, for the rest of its existence.

The orientation of the Earth's magnetic field varies with latitude. Near the poles the field dips very steeply. Near the equator the field is near-horizontal. At all locations the field points towards the North magnetic pole or, at times of polarity reversal, to the South magnetic pole.

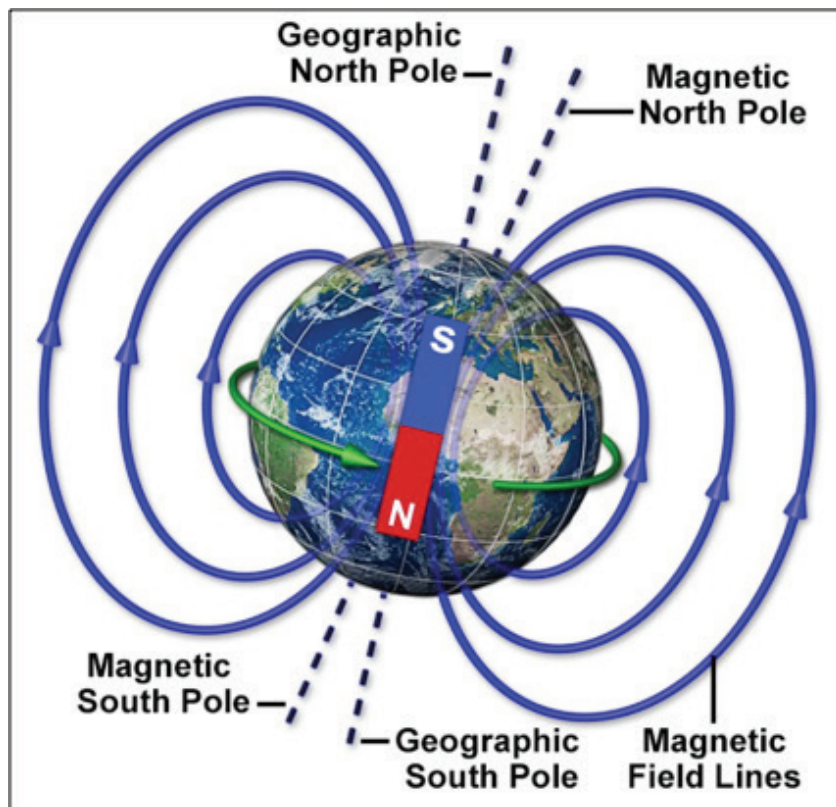


Figure 4. The Earth's magnetic field

The Earth's magnetic field dips steeply at the poles and is near horizontal at the equator. When a rock is formed at a point in the Earth's crust it is imprinted with the magnetic field that applies at the point. By measuring the orientation of the magnetic field in a rock we can determine whether the rock has moved north or south from its original location, and whether it has rotated.

For a rock formed at high altitude (near the poles) the magnetism recorded in the rock will dip steeply. Conversely, if the rock formed at low latitudes (near the equator) the magnetism recorded in the rock will be near-horizontal. If we collect a rock sample from near the equator and find that it is imprinted with a steeply-dipping magnetic field, we know it has moved from near one of the poles to its present position. Similarly, if we collect a rock from a location near the poles and find the magnetism recorded in the rock is near horizontal (i.e., near parallel to bedding), then we know the rock has moved from a position near the equator to its present position.

Thus, from the dip of the magnetic field recorded in the rock we can determine the approximate latitude at which the rock was formed. The preserved magnetic imprint is called the remanent magnetic field.

If a rock has been rotated, clockwise or anticlockwise, the remanent magnetic field in the rock will no longer point towards one of the magnetic poles. Thus, from the direction of the recorded magnetic field we can determine whether it formed at a time of normal polarity, or at a time of reversed polarity.

5. Reversals of the Magnetic field and the development of the Paleomagnetic time scale

As paleomagnetic research progressed it became clear that rocks of certain ages recorded a magnetic field that is the reverse of today's magnetic field. This led to the conclusion that at intervals of time in the past the north magnetic pole has switched with the south magnetic pole. The magnetic field had reversed. As more data were gathered it became possible to construct a time scale comprising intervals of reversed and normal polarity.

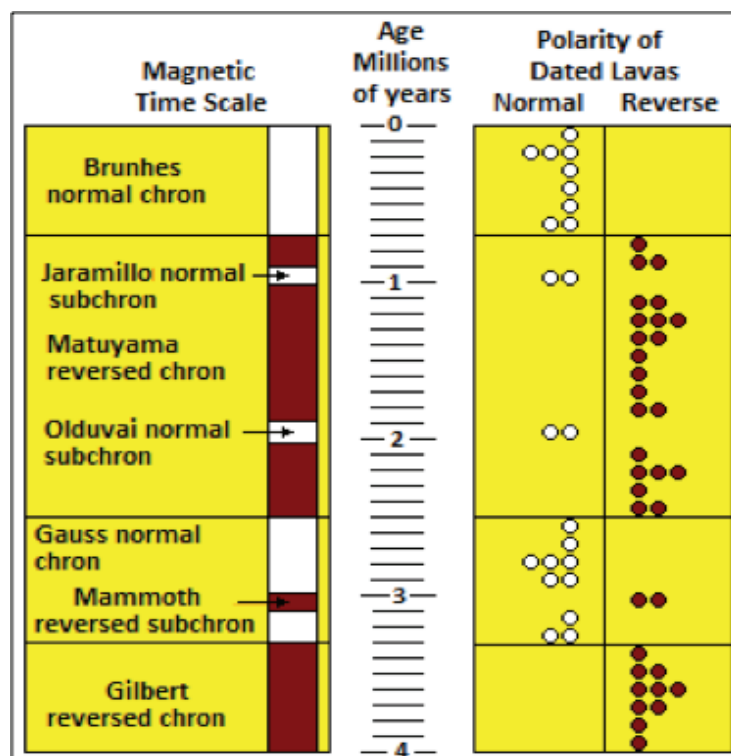


Figure 5. The magnetic reversal time scale for the last 4 million years comprises four chrons and several sub-chrons (after Davies, 2013). The scale was developed by determining the magnetic polarity, whether reversed or normal, in carefully-dated lava flows. The sampling interval is shown in the right column.

Marine magnetometers were developed as a tool for searching for enemy submarines during the Second World War. After the war geophysicist Maurice Ewing insisted that all U.S. research ships should continue to tow a magnetometer wherever they went and whatever they were doing – whether on survey or simply moving from one survey location to another. As a result, an enormous volume of magnetic data was collected.

When these data were plotted to form maps of the magnetic field of the ocean floor there was a surprising outcome. The maps show linear anomalies or stripes of positive and negative values. The stripe was oriented parallel to the mid-ocean ridges, and the pattern of stripes on one side of any ridge was the mirror image of the stripes on the other side. How could this pattern have developed?

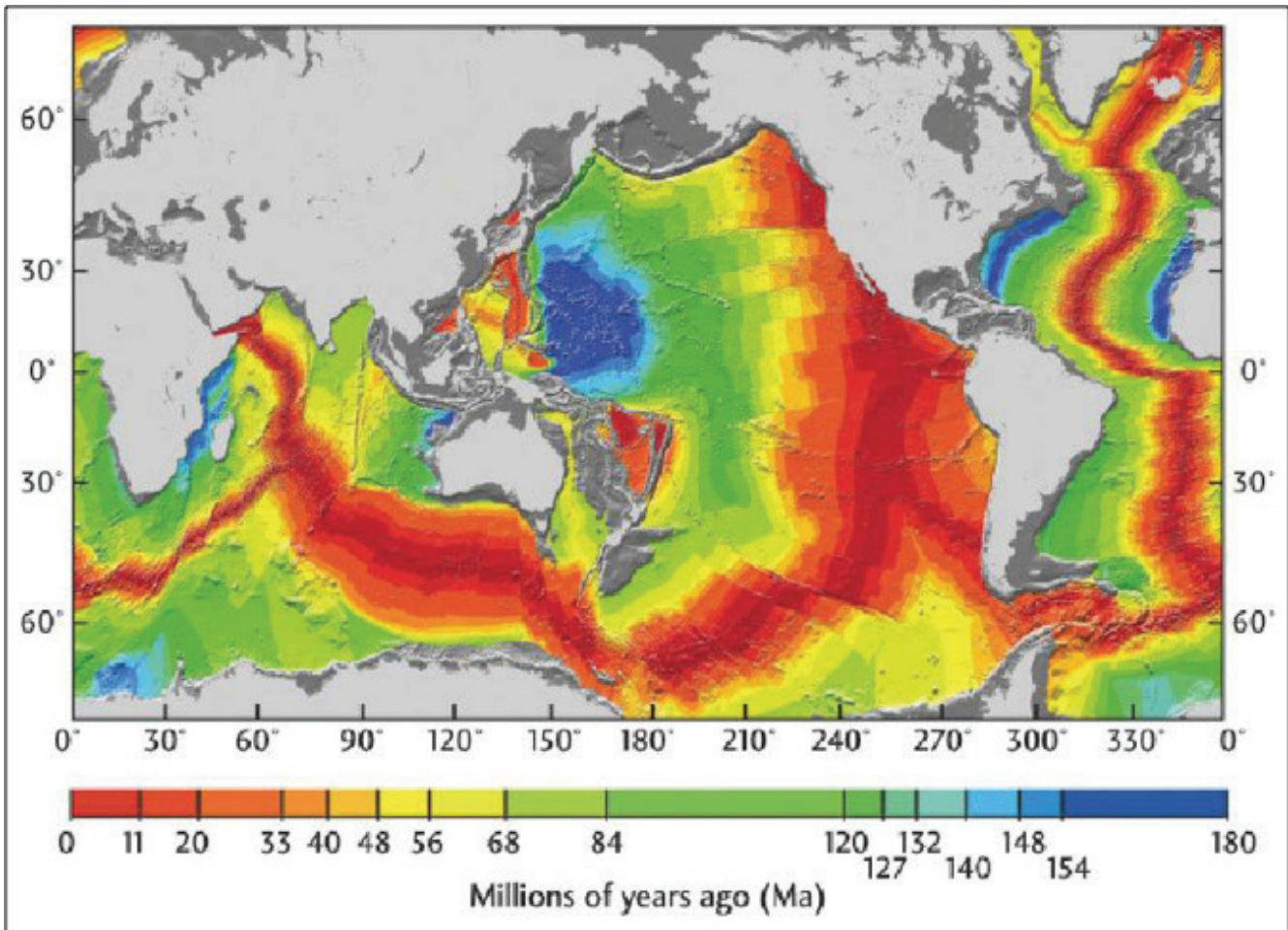


Figure 6. Map of the ocean floor. The red-brown colours are the younger crust, the green is Cretaceous and the blue is Jurassic. The oldest crust is in the western Pacific (after Davies, 2013).

The puzzle was solved by Canadian L.C. Morley and, independently, by Englishmen Vine and Mathews. They were aware that the Earth's magnetic field had reversed from time to time, and aware of the current idea that new ocean crust is being formed at the mid-ocean ridges. They concluded that the stripes of positive magnetic anomaly coincide with lava that was erupted at the mid-ocean ridge during an interval of normal polarity, and the stripes of negative magnetic anomaly coincide with lavas erupted at the ridge during an interval of reversed polarity. The symmetry of the stripes proved that after each sequence of lavas was erupted at the mid-ocean ridge it was rifted and the two halves moved apart, one on each side of the ridge.

Using the maps of the magnetic field and the newly-defined paleomagnetic time scale, it became possible to determine the age of any part of the ocean floor by matching its magnetic pattern to the appropriate segment of the paleomagnetic time scale.

6. Past configurations of the continents

The map of the age of the ocean basins is constructed from magnetic field data of the type shown in Figure 6. From the map we can reconstruct the positions of the continents at various times in the past (Fig. 7).

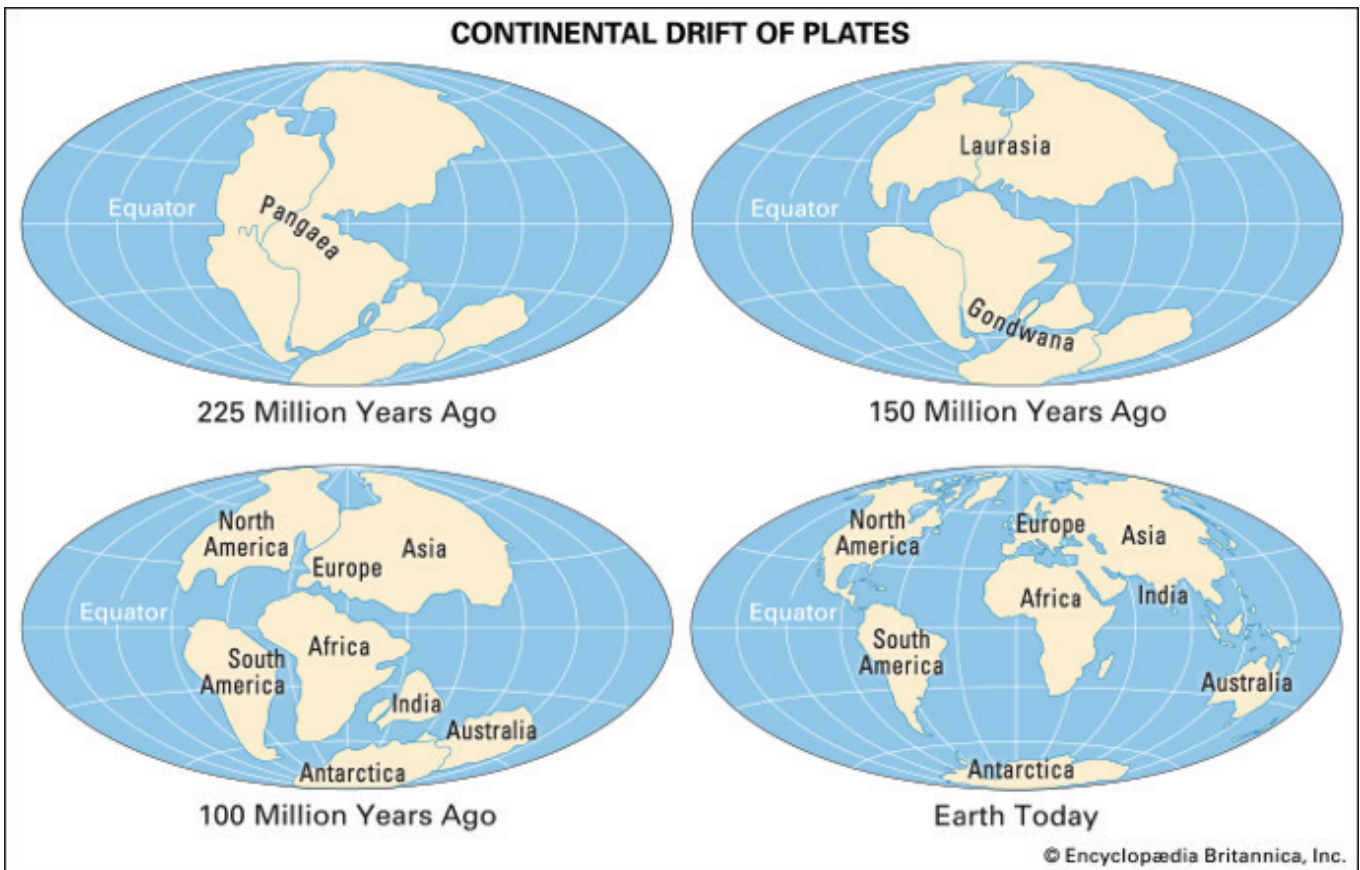


Figure 7. Reconstructing the positions of the continents at various times in the past
(Source: Encyclopædia Britannica)

Age of small ocean basins using magnetic anomalies

The small ocean basins at the eastern end of PNG were formed by sea-floor spreading. The age of each basin can be determined from the magnetic anomalies (stripes). The Woodlark Basin is an example. The opening of the Woodlark Basin started in the east and has caused extension and rifting of the southeastern PNG mainland.

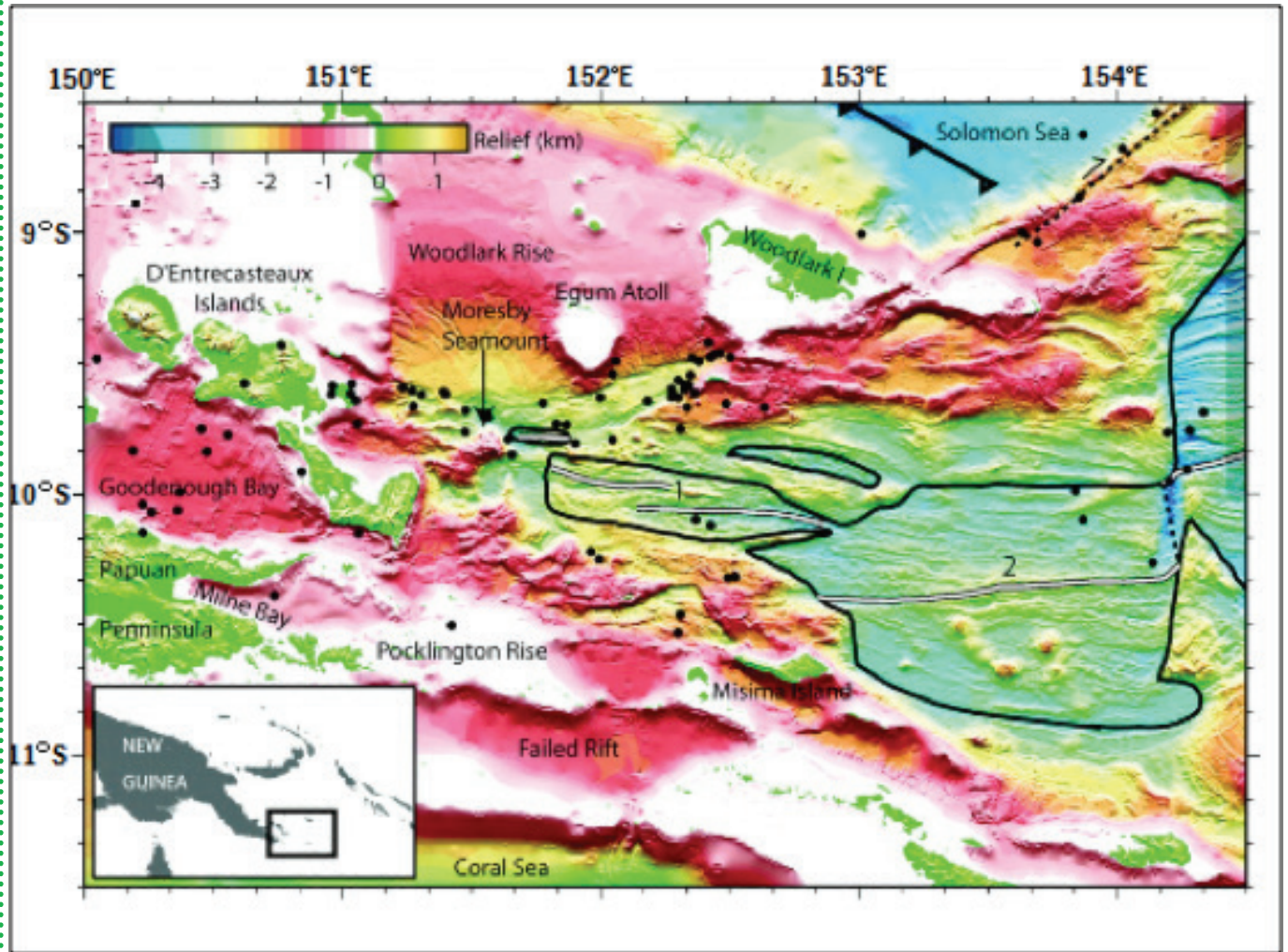


Figure 8. Rifting of the Woodlark basin from paleomagnetic data (after Davies, 2013).

Teaching and Learning Strategies

Teaching Strategies:	Learning Strategies
Teachers prepare information (including pictures) and ask questions on plate tectonics.	Students will use the information provided to answer questions on plate tectonics.
<p>STEAM Approach</p> <p>Learning Objective: By the end of the topic, students will be able to;</p> <ul style="list-style-type: none"> • Construct models of showing plate tectonics - STEAM 	
<p>Teaching Strategies</p> <p>Teachers will provide the criteria and the materials to construct models showing plate tectonics.</p>	<p>Learning Strategies</p> <p>In groups, students read the criteria and follow the steps and use the materials available to create models (prototype) showing plate tectonics.</p>
<p>Recommended Resources:</p> <ul style="list-style-type: none"> • Clark, I.F. and Cook, B.J., 1992. Perspectives of the Earth. Australian Academy of Science, Canberra, ACT, 561p. • Davidson, J.P., Reed, W.E., and Davis, P.M., 1997. Exploring Earth. An Introduction to Physical Geology, Prentice-Hall Inc., 264p. • Davies, H.L., 2013. Earth Tok, 3rd Edition, Alan Caudell & Associates, 231p. • GCSE Physics • Internet 	

Unit 4: Plate Tectonics

Content Standard

11.2.4 Students will be able to understand and explain the plate tectonics with supporting evidence.

Benchmark

11.2.4.2 Apply the understanding of divergent, transform, and convergent plate boundaries to provide evidence supporting plate movement.

Topic 2: Plate Boundries

Learning Objectives:

By the end of this topic, the students will be able to:

- Explain the activities that occur at diverging plate margins.
- Explain the activities that occur at converging plate margins.
- Explain the activities that occur at transform plate margins.

Essential questions

1. What geological activities are found at a plate boundary?
2. What kind of plate boundary creates volcanoes?
3. What kind of plate boundary give rise to mountain building?

Vocabulary: plate boundaries, convergent, divergent, transform, folds, faults

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Plate boundaries • Plate interactions • Folds and faults 	<ul style="list-style-type: none"> • Reasoning 	<ul style="list-style-type: none"> • Understanding, and appreciate that the plates are in constant motion.

Content Background

1. Plate boundaries

The principle of plate tectonics as seen in the previous topic is that the lithosphere (the outermost 70-150 km of the Earth) comprises several plates, each constantly in motion. Any one plate may include areas of continental crust (average thickness 35 km) and of oceanic crust (average thickness 10 km), plus the uppermost part of the mantle or mantle-lid (Fig. 1). Rates of motion may be as much as 15 cm per year. The four possible types of interactions between the plates are:

- (a) Where plates are moving apart (diverging), new oceanic lithosphere will form at a mid-ocean spreading ridge (Fig. 2a);
- (b) Where plates are moving towards each other (converging), if at least one of the plates is of oceanic lithosphere, one plate will slide beneath the other (Fig. 2b). We say that the plate is subducted into the mantle. In this case a trench and volcanic arc will develop;
- (c) Where the plates past each other there is a transform boundary (Fig. 2c), a unique kind of strike-slip fault that connects two plate boundaries;
- (d) Where plates are converging, and neither is oceanic lithosphere there is a collision and a mountain range will form.

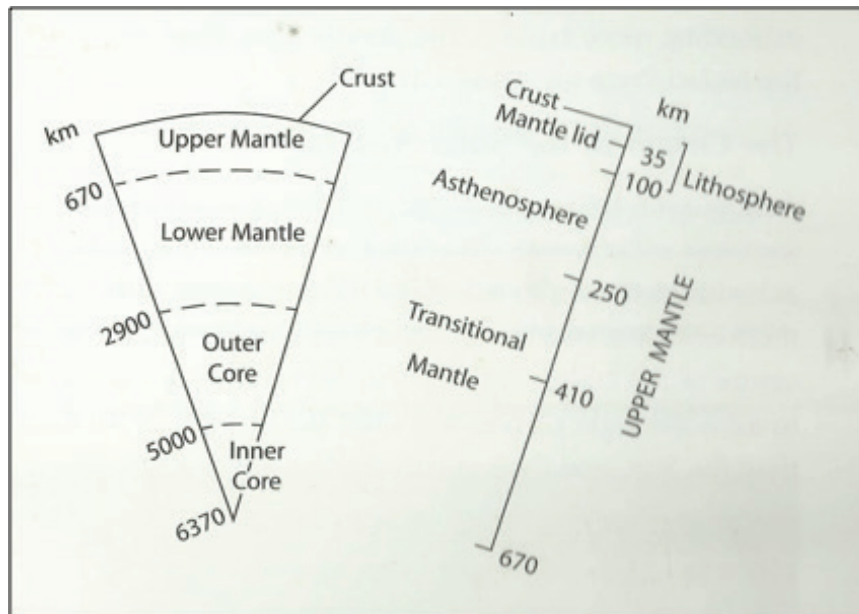


Figure 1. The structure of the Earth showing the lithosphere (crust + uppermost part of mantle) (after Davies, 2013).

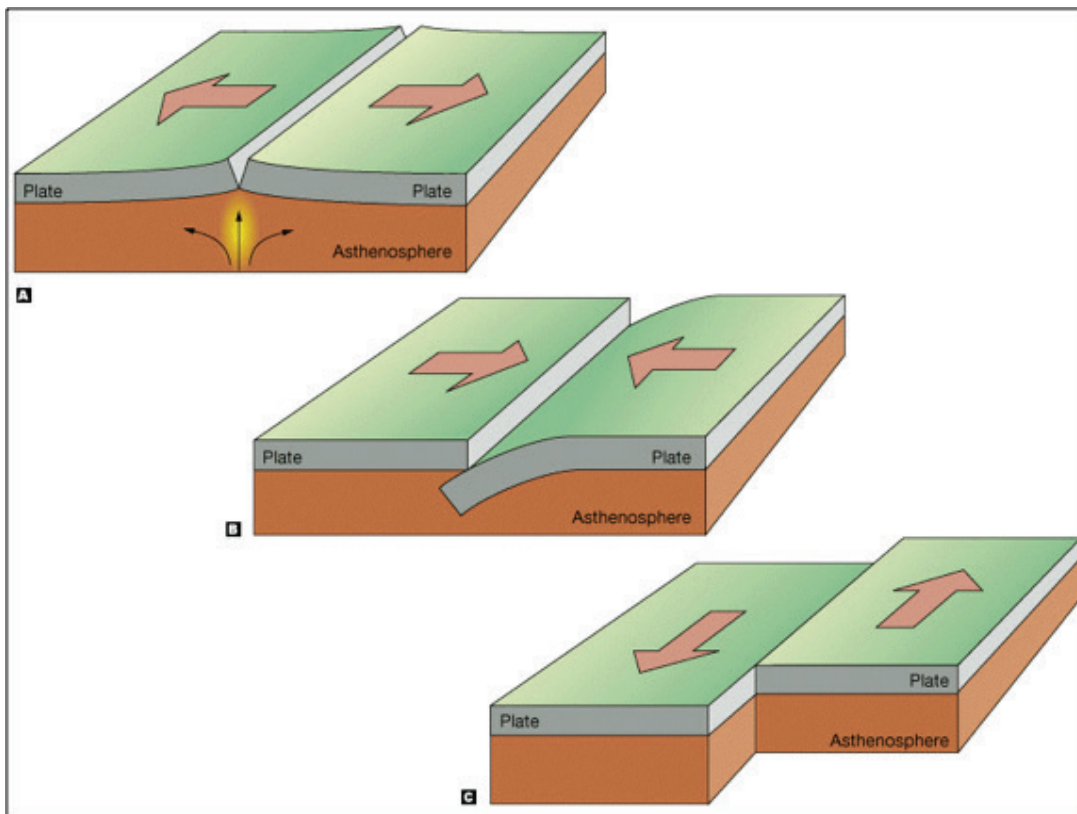


Figure 2. The different types of plate boundaries (after Davies, 2013). A – divergent, B – convergent, C – transform (strike-slip).

If subduction moves too slowly to take up all the crustal shortening, then both a trench and a collisional mountain range may form; this is the case in the South American Andes and across the central part of the island of New Guinea.

Oceanic lithosphere can be subducted because oceanic crust is relatively thin and dense and becomes much denser as it sinks into the mantle, because basalt and gabbro metamorphose to eclogite. Continental lithosphere is difficult to subduct because continental crust is thick, has low density, and cannot change to dense eclogite when pressure and temperature are increased. This is because it has the wrong chemistry – too much silicon, aluminium, sodium and potassium. Lithosphere that includes volcanic islands or volcanic island arcs also has thick low-density crust and is difficult to subduct.

2. Plate boundaries on a global scale

Shallow earthquakes occur at all plate boundaries. Thus, a map of shallow earthquake epicentres (Fig. 3) is also a map of plate boundaries (Fig. 4). In Figure 4 the arrows show the direction each plate is moving. Notice that all the plate boundaries are connected. Segments of mid-ocean ridges are connected to each other by transform faults, and the ridges and transforms are in turn connected to the trenches. Around the northern margin of the Pacific a series of trenches are connected to each other.

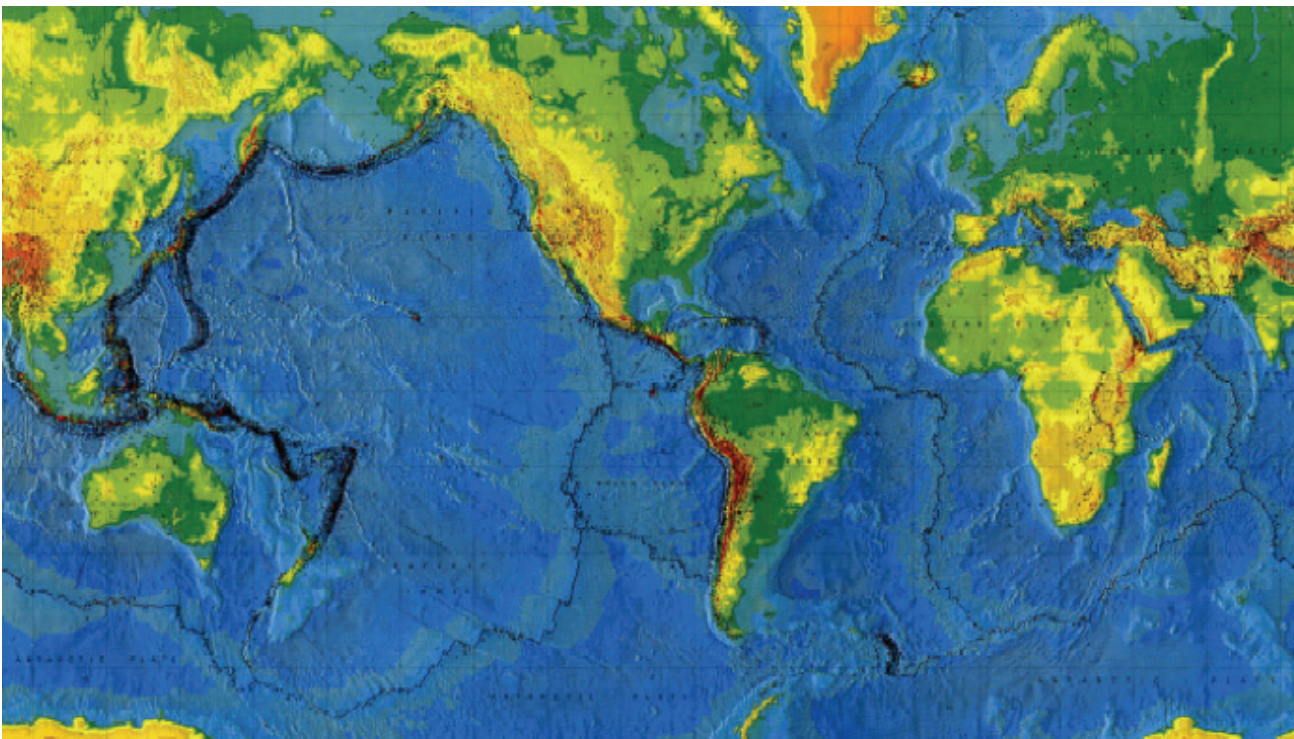


Figure 3. Location of shallow earthquake epicentres (Source: <http://geology.usgs.gov>)

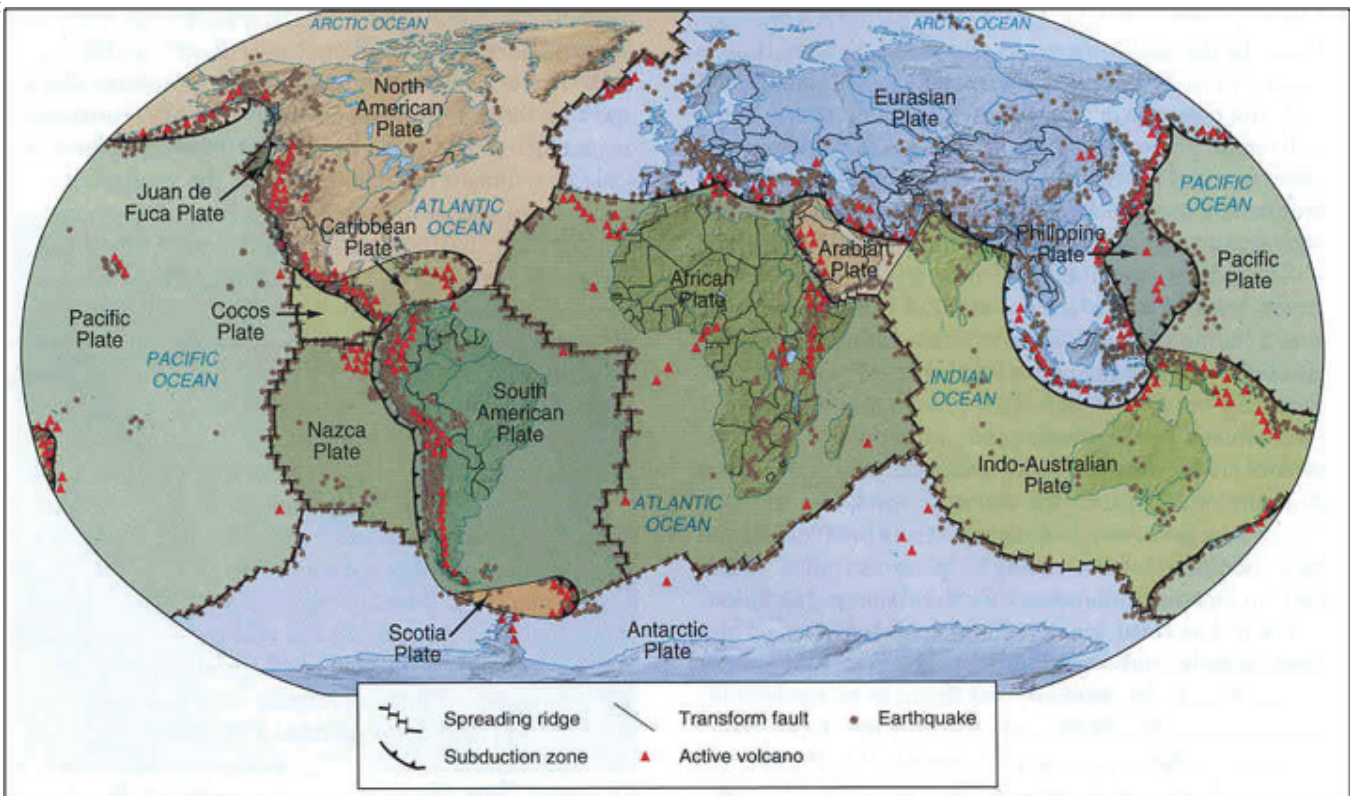


Figure 4. Map showing the connection of plate boundaries (after Davies, 2013).

Each type of plate boundary has its own expression in the Earth's surface. The extensional boundaries are marked by mid-ocean ridges, the subduction zones by deep sea trenches, the transform faults by linear valleys, and the collisional boundaries by great mountain ranges. For example, the Himalaya mountains were formed by the collision of India with Eurasia, and the Alps and the mountain ranges of the Middle East were formed by the collision of Africa with Eurasia. Similarly, westward movement of the Americas and collision with smaller landmasses has generated the great mountain ranges on the west side of North and South America.

Transform faults are expressed at the Earth's surface by fracture zones on the sea floor, and by long linear valleys where they cut the land surface. The San Andreas Fault in the western United States is one example and the Alpine Fault in New Zealand is another. A transform fault north of the Red Sea defines a valley that contains the Jordan River, the Dead Sea, and the Sea of Galilee (Fig. 5).



Figure 5. Photograph from the space shuttle shows the Red Sea spreading ridge and the transform that runs through the Gulf of Aqaba and the Dead Sea (after Davies, 2013).

Within PNG, the Weitin Fault, which defines the valleys of the Weitin and Kamdaru Rivers in southern New Ireland (Fig. 6), is an active transform fault. Another transform fault extends east-west across the western Bismarck Sea.



Figure 6. The Weitin Fault in southern New Ireland (after Davies, 2013).

3. Earthquakes and subduction

Friction between the subducted slab and the overlying mantle generates earthquakes. The result is a dipping seismic zone, with earthquake foci becoming progressively deeper further from the trench. The dipping seismic zone is called the Wadati-Benioff zone after the Japanese and American geophysicists who first drew attention to it.

4. Volcanoes and subduction

Volcanic activity is associated with most trenches. The volcanic centres are usually 100-150 km away from the trench and lie at roughly 80 km spacings along an arc-like line parallel to the trench. The volcanic products typically are basalt and andesite. Andesite is more prevalent where the volcanic arc rests on thick crust, as in South America, for example. In fact, the name andesite is taken from the Andes Mountains. In PNG, the volcanoes of the Bismarck volcanic arc are associated with subduction at the New Britain Trench. These volcanoes produce basalt and basaltic andesite.

The volcanic activity is triggered by the release of volatiles from the subducted slab as it sinks through depths of 100-150 km in the mantle. The volatiles lower the melting point of the overlying mantle rocks sufficiently for them to become partially molten. The melts rise to the crust and the Earth's surface.

5. Volcanic activity at spreading ridges

At any spreading ridge two lithospheric plates are moving apart. This causes a reduction of pressure in the mantle below the spreading ridge and triggers melting of the mantle at relatively shallow depth. The resulting melt is a distinctive low-K basalt: mid-ocean ridge basalt or MORB.

6. Metamorphism and subduction

Most regional metamorphic rocks develop because of crustal shortening, such as happens in zones of collision and subduction, when surface rocks are pushed down into the lower crust or upper mantle. In a subduction system the rocks of the down-going slab can be subjected to conditions of high pressure and relatively low temperature. This is because the down-going slab is cold relative to the surrounding mantle and does not warm immediately. Unusual minerals such as lawsonite and blue sodic amphibolite will form under these conditions. The rocks have a blue tinge and are given the name blueschist.

7. Accretionary prism

When oceanic lithosphere is subducted, the sediments that are sitting on the sea floor may be scraped off and stacked up as thrust slices on the inner wall of the trench. This is wedge-shaped in cross-sectional view and is referred to as an accretionary prism or accretionary wedge. The faulted blocks of sedimentary rocks that are exposed in the Poreporena Highway road cut in Port Moresby are thought to have formed as an accretionary prism.

8. Intraplate volcanic activity

Most volcanic activity develops at plate boundaries, either at a spreading ridge or in an arc-trench environment. However, there is also some major volcanic activity that is not at a plate boundary. The intraplate volcanic activity occurs in two settings: (i) associated with mantle plums or hot spots, and (ii) associated with continental rifting. Volcanic rocks in continental rifts are basalts with rhyolites. They can be unusually enriched in sodium and potassium and can be associated with carbonatite, some unusual igneous rocks rich in calcium carbonate.

9. Hot spot volcanic activity

Long linear chains of volcanic islands in the Pacific and Atlantic oceans are thought to have formed as the result of a stationary mantle plume or hot spot burning through the moving lithosphere. The Samoan and Hawaiian island chains are good examples. In the case of the Hawaiian Islands, the big island of Hawaii is currently above the hot spot. The island of Oahu was above the hot spot 3 million years ago as is indicated by the age of the volcanic rocks on Oahu. The lavas of hot spot volcanoes typically are basaltic, but the basalt differs from mid-ocean ridge basalts in having higher potassium.

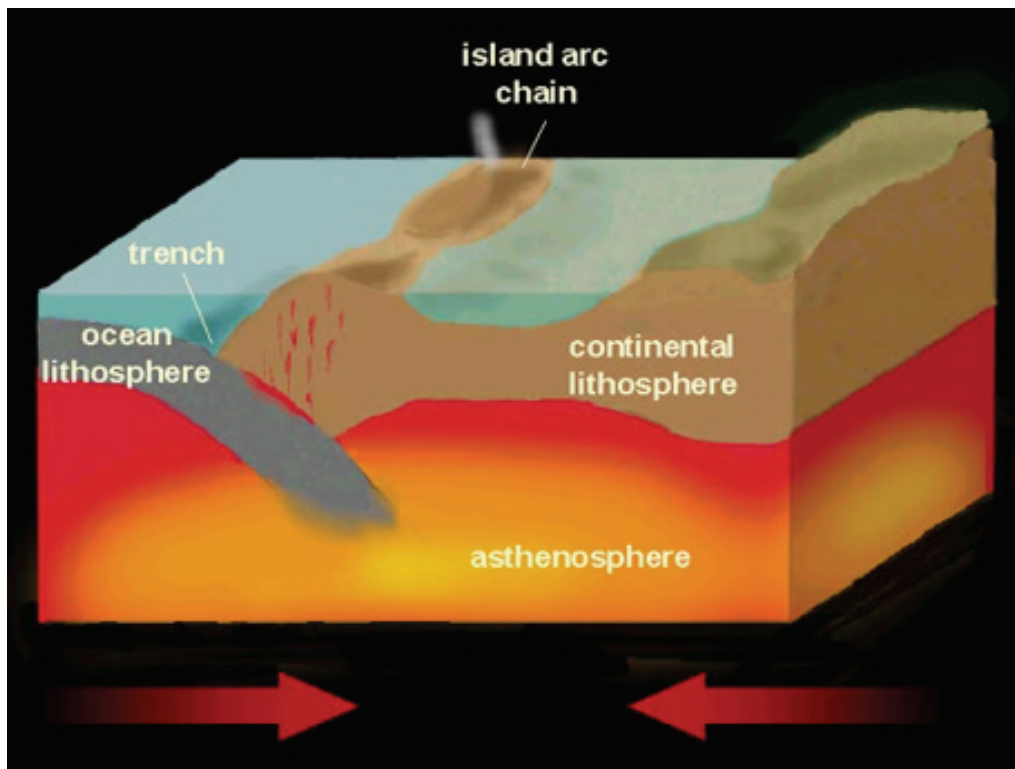


Figure 7. The diagram shows how a chain of volcanic islands can develop as a plate moves over a hot spot (after Davies, 2013)

10. Folds, faults and unconformities

When the great plates that form the Earth's surface move towards or away from each other the rocks that are caught in the movement may be shortened or stretched and may respond to bending (folding) or breaking (faulting). Folding is ductile behaviour and faulting is brittle behaviour.

Rocks subjected to stress will show deformation or strain. Whether rocks respond to stress in a ductile or brittle fashion depends on several factors such as the magnitude of the stress, the confining pressure, the temperature, the nature of the rock, and the strain rate.

Effect of confining pressure and elevated temperature

If a stress is applied to rocks that are deep in the Earth's crust, where temperature (T) and confining pressure (P) are high, the rock will tend to respond by ductile failure; it will fold and, in the extreme case, may flow plastically. Examples are the great nappes or thrust sheets which formed deep in the crust but have been uplifted and are now exposed in rock faces in the European Alps.

If the same stress is applied to the same rocks when they are near the Earth's surface, where T and P are lower, the rocks are likely to respond by brittle failure (faulting).

Effect of strain rate

If the stress is applied over a short period of time the rock will tend to brittle failure. A simple example would be hitting a slab of concrete with a sledge hammer. That is a high strain rate.

If the stress is applied over a long period of time, then the strain rate is low, and the rock will tend to ductile failure. As an example, imagine a slab of concrete that is supported at both ends but has no support in the middle. Over a period, the centre part of the slab will bend downwards.

Effect of rock strength

If the rock is strong, such as a body of granite, it will tend to brittle failure, but if the rock is weak, such as a bed of mudstone, or of salt, it will tend to ductile behaviour. If weak and strong rock types occur together, such as sandstone beds (strong) with interbeds of mudstone (weak), then the stronger beds may respond to stress with folding and faulting, and the weaker beds by plastic flow, moving from the limb of the fold to the nose of the fold.

Folds

An anticline (anti = against) is a fold where the strata are folded upwards (Fig. 8). A syncline (syn = together) is a fold in which the strata are folded downwards (Fig. 8). To remember the terms, think A for anticline and for the shape of a letter A, and S for syncline and for a smile.

A fold has limbs and an axial plane – the axial plane is the plane that bisects the angle between the two limbs, or that is equidistant between the two limbs. The angle between the two limbs is the interlimb angle. This may be a large angle if the fold is broad or open, or a small angle if the fold is tight or closed. If the two limbs are parallel, then the fold is said to be isoclinal.

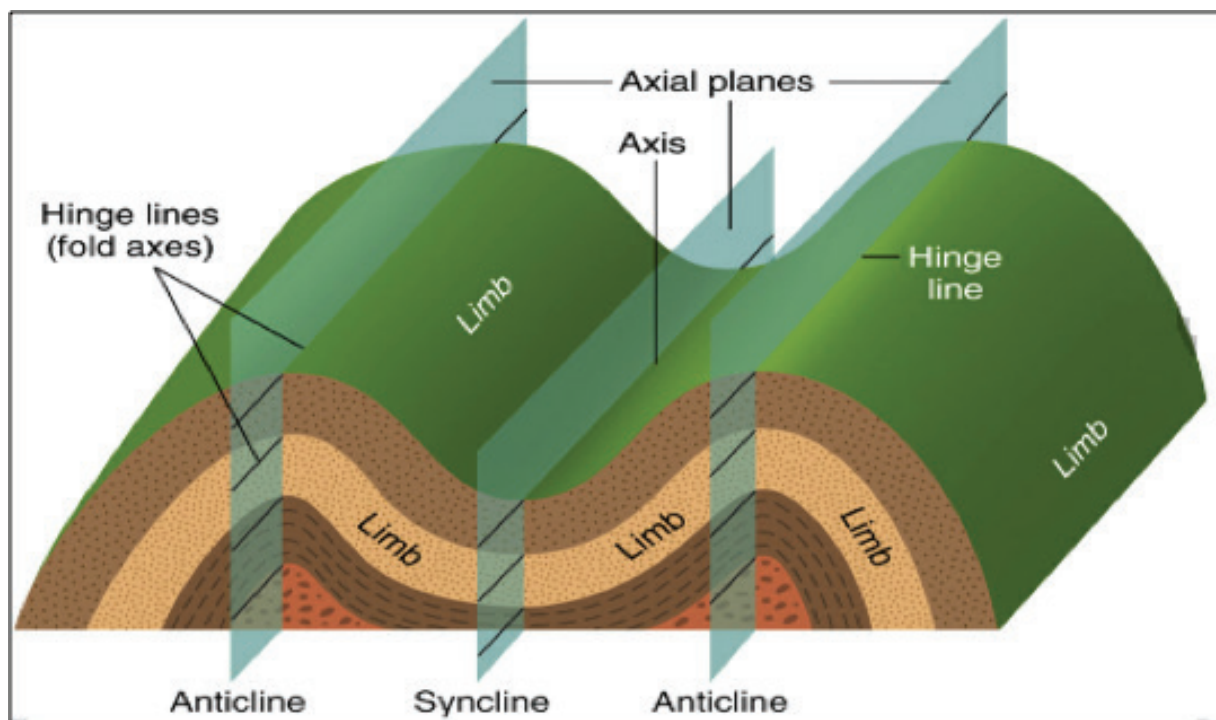


Figure 8. The parts of a fold (Source: www3.nd.edu)

If the axial plane is inclined, we say the fold is asymmetric; if the angle of inclination of the axial plane is more extreme then the fold may be overturned or even recumbent.

Faults

A normal fault (Fig. 9b) displaces one block downward and away from the other. The net result is extension or lengthening of the Earth's crust. A reverse fault (Fig. 9c) displaces one block upward and over the other (or downward and under the other); the net result is a shortening of the crust. A reverse fault that dips at a shallow angle ($< 45^\circ$) is a thrust fault (Fig. 9d).

A fault that slides one block past another (Fig. 9e), with no relative vertical movement, is a strike-slip or transcurrent fault. A fault that mixes strike-slip and vertical movement is an oblique-slip fault.

Strike-slip faults are either right-lateral or left-lateral. If you stand on one side of the fault and determine that the other side has moved to the right, then we say that the fault is right-lateral. If you determine that the rocks on the other side of the fault have moved to your left, then the fault movement was left-lateral. Some geologists prefer the term dextral for right-lateral and sinistral for left-lateral.

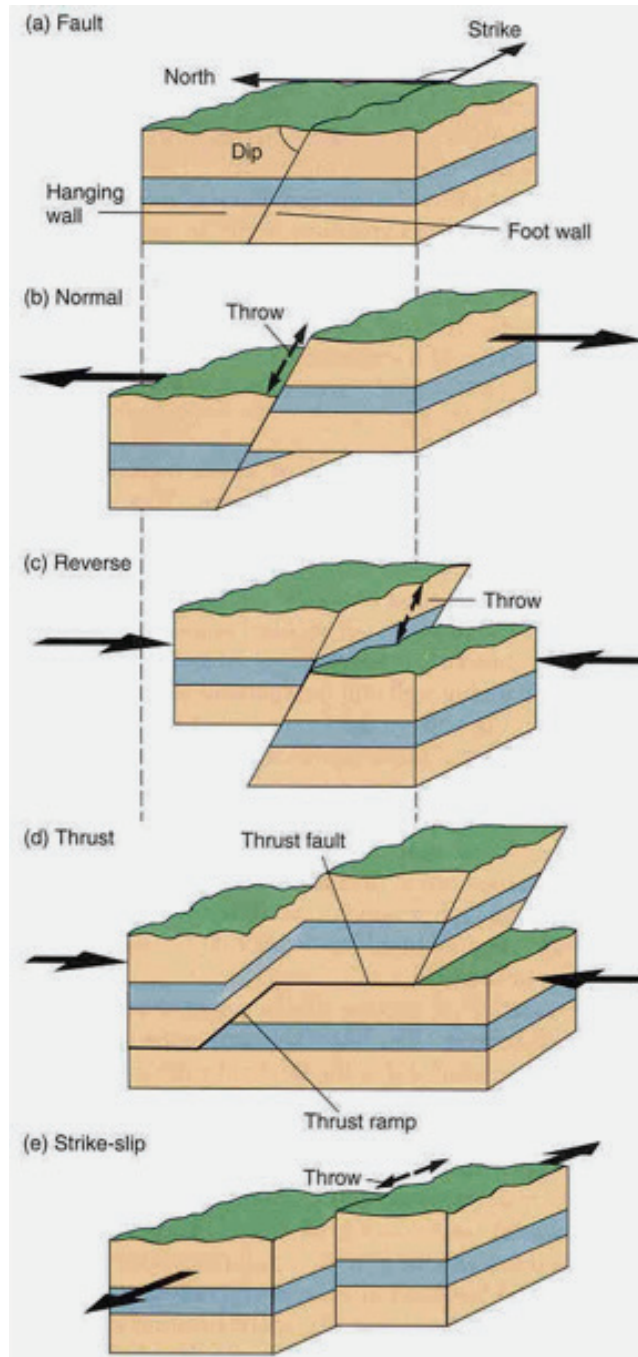


Figure 9. The different kinds of faults (after Davidson et al., 1997). a – fault, b – normal fault (extends crust), c – reverse fault (shortens crust), d – thrust fault (shortens crust), e – strike-slip fault.

Extensional fault systems. When the crust is extended or stretched, a series of normal faults may develop and may give rise to a set of horsts (high blocks, from the German word for a high nest such as an eagle's nest) and grabens (depressed blocks, from the German word for ditch). Alternatively, a series of half-grabens may develop

Contractional fault systems. Shortening of the crust may result in the development of several near-parallel reverse faults, with the shortening shared among them. The thrust faults may be connected to each other by transfer faults. Similarly, the extension of the crust that causes normal faulting may result in the development of several near-parallel normal faults and transfer faults that connect the normal faults.

Thrust-bounded anticline. These are common in the Papuan fold belt of the Papuan Basin. The structures are essentially a simple anticlinal fold that has ridden forward on an underlying thrust fault. In detail the structure is more complex, with the development of splays from the main thrust fault and of back-thrusts (thrust faults that dip in the opposite direction of the main thrust)

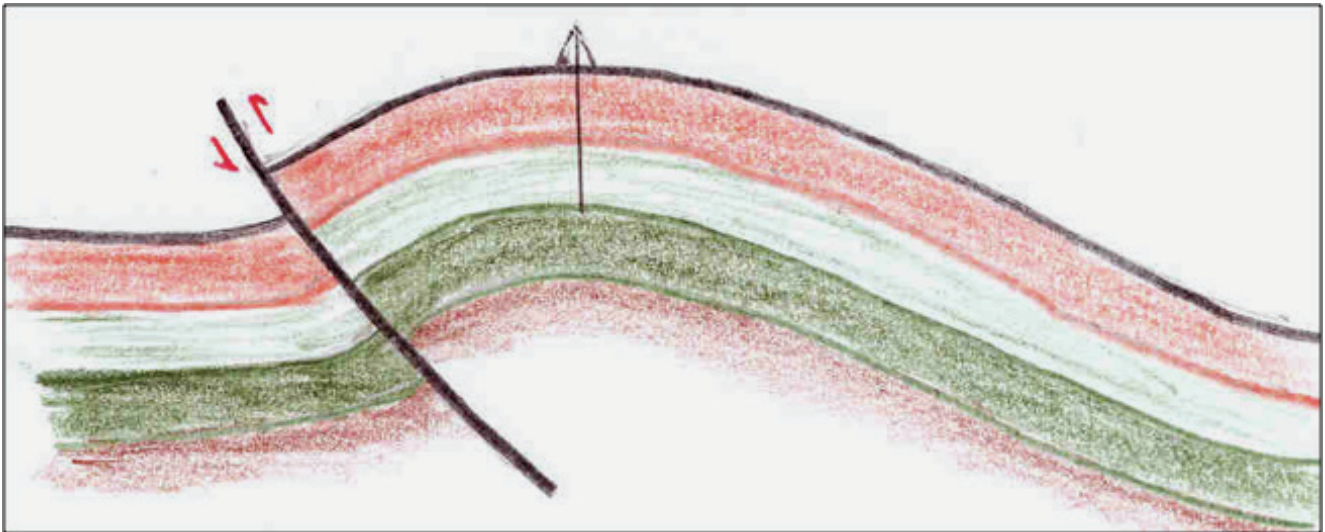


Figure 10. *Thrust-bounded anticline (after Davies, 2006). This is a common structure in the Papuan fold belt - very popular with oil geologists.*

Unconformities

When sediments are laid down on the sea floor the bedding is horizontal (Fig. 11). The horizontal sediments will likely be modified to form sedimentary rocks. They may then be disturbed and tilted by folding or faulting and elevated to form mountains. If the tilted rocks are then partly eroded, and once again subside beneath the sea, a new series of sediments may be deposited on the former erosional surface. The angle of dip of the older beds will differ from the angle of dip of the younger beds. We say the contact is unconformable.

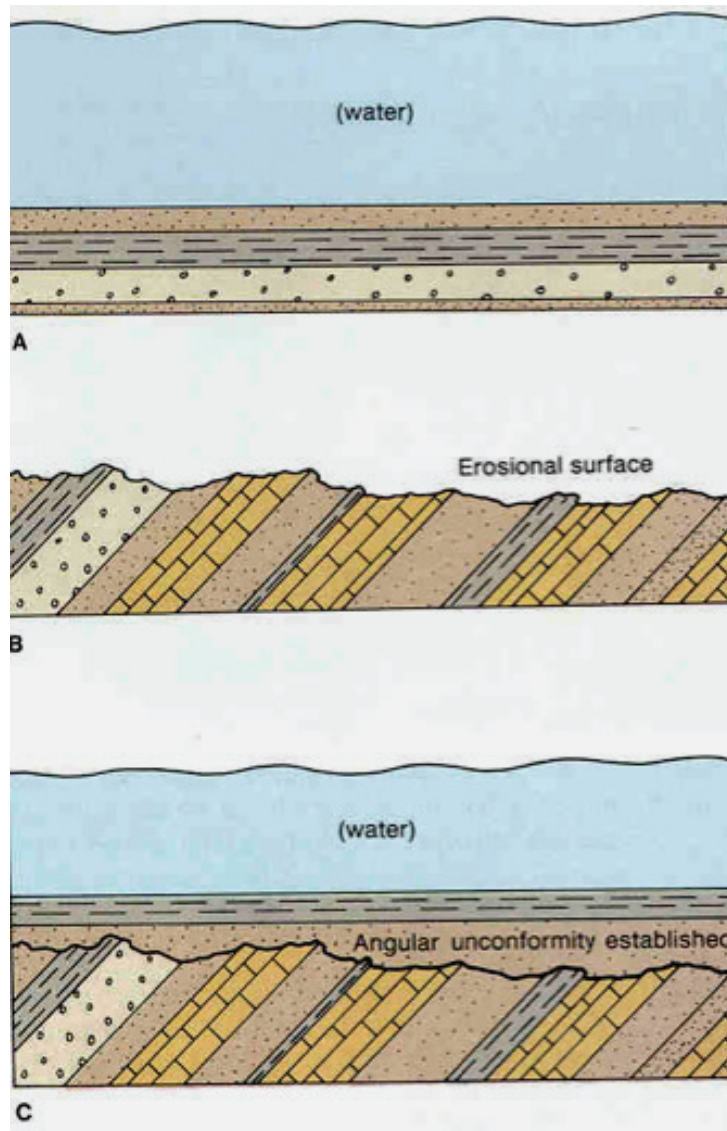


Figure 11. The formation of an unconformity (after Davidson et al., 1997). (A) Sediments are laid down on the sea floor. (B) The sediments are folded and uplifted to form a mountain range, and then eroded. (C) The eroded land surface submerges again, and more sediments are laid down on it.

The former erosional surface that now marks the boundary between the two series of sediments is an unconformity. We say the younger sediments unconformably overlie the older, or that the older unconformably underlie the younger. An unconformity is a break in the rock record. The geologist, who works like a detective trying to reconstruct past events, values the unconformity as a source of information about the timing and nature of past tectonic events.

Geological history

Unconformities provide information about the geological history of an area. The geologist works like a detective trying to solve a crime. He draws together all the information and deduces a history of events. The events may be, for example, sedimentation, folding, faulting, igneous intrusion, erosion, in any sequence, and with or without repetitions.

Here is a geological puzzle!

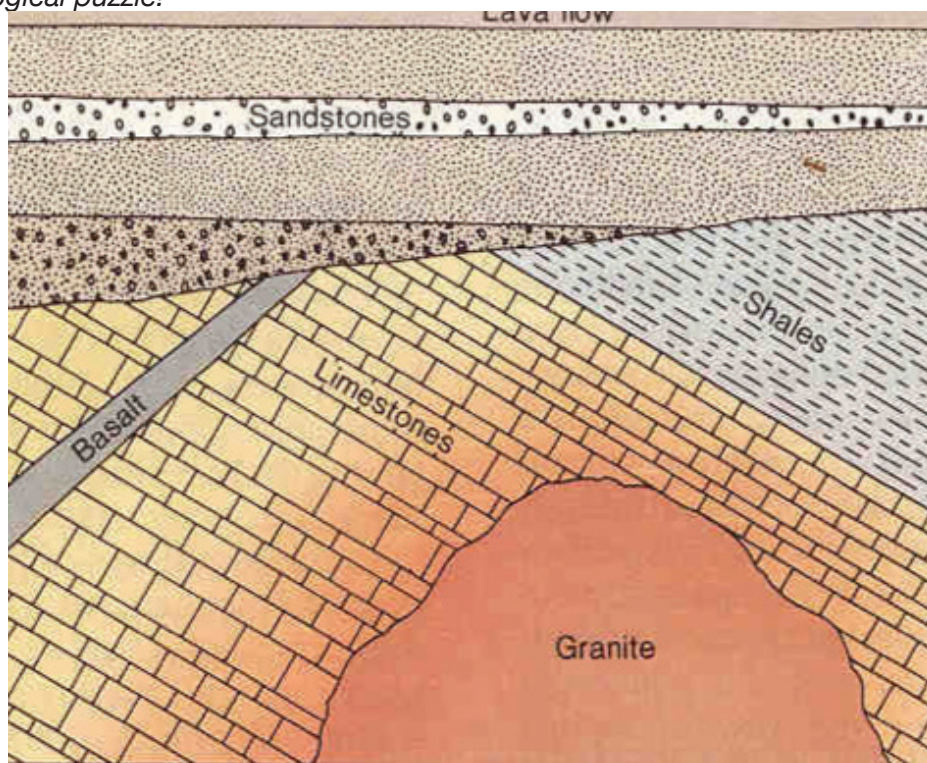


Figure 12. A geological puzzle (after Davidson et al., 1997). What was the sequence of events? Do you see an unconformity?

Teaching and Learning Strategies

Teaching Strategies:	Learning Strategies
Teachers prepare information (including pictures) and ask questions on plate boundaries. Teachers can show videos or documentaries to students in relation to interactions at plate boundaries.	Students will use the information provided to answer questions on plate boundaries.

STEAM Approach
 Learning Objective: By the end of the topic, students will be able to;
 • Construct models of plate boundaries - STEAM

Teaching Strategies	Learning Strategies
Teachers will provide the criteria and the materials to construct models of plate boundaries.	In groups, students read the criteria and follow the steps and use the materials available to create models (prototype) of the different types of plate boundaries.

- Recommended Resources:**
- Clark, I.F. and Cook, B.J., 1992. Perspectives of the Earth. Australian Academy of Science, Canberra, ACT, 561p.
 - Davidson, J.P., Reed, W.E., and Davis, P.M., 1997. Exploring Earth. An Introduction to Physical Geology, Prentice-Hall Inc., 264p.
 - Davies, H.L., 2013. Earth Tok, 3rd Edition, Alan Caudell & Associates, 231p
 - Internet

Unit 5: Atmosphere and the Hydrological Cycle

Content Standard 11.2.5 Students will be able to explain the characteristics and movement of water among the mantle, oceans, land and atmosphere of the Earth.

Benchmark 11.2.5.1 Examine the structure and composition of the atmosphere.

Topic 1: Atmosphere

Learning Objectives:

By the end of this topic, the students will be able to:

- Explain the layering of the atmosphere.
- Understand the effects of increased emission of greenhouse gases.

Essential questions

1. Is the atmosphere layered?
2. What happens to the density, temperature and pressure of air as the height increases?
3. What happens when water evaporates?
4. What is greenhouse effect?

Vocabulary: atmosphere, density, temperature, pressure

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Atmosphere • Density • Temperature • Pressure 	<ul style="list-style-type: none"> • Critical thinking • Communication • Creativity • Problem solving • Responsibility • Organizational • Collaboration 	<ul style="list-style-type: none"> • Be strategic in preventing or minimizing effects of weathering and erosion. • Be responsible in cutting on air polluting activities.

Content Background

1. Structure of the atmosphere

The structure of the atmosphere dictates the way the atmosphere behaves and controls how weather develops near the surface of the Earth. The atmosphere is density stratified, with the denser layers near the Earth's surface. The atmosphere consists of four layers: the troposphere, stratosphere, mesosphere, and thermosphere.

Figures 1 and 2 show the placement of the different layers of the atmosphere and how the temperature changes with height as you go from the ground up to space. The troposphere is the lowest layer of the atmosphere. This is the layer where weather happens. Temperature in this layer generally decreases with height. The boundary between the stratosphere and the troposphere is the tropopause. The jet stream sits at this level and it marks the highest point that weather can occur. The height of the troposphere varies with location, being higher over warmer areas and lower over colder areas.

Above the tropopause lies the stratosphere. In this layer the temperature increases with height. This is because the stratosphere houses the ozone layer. The ozone layer is warmer because it absorbs ultraviolet (UV) rays coming from the sun. The mesosphere is the layer above the stratosphere. The temperature decreases with height here just like it does in the troposphere. This layer also contains ratios of nitrogen and oxygen like the troposphere, except the concentrations are 1000 times less and there is little water vapour there, so the air is too thin for the weather to occur.

The thermosphere is the uppermost layer of the atmosphere. In this layer the temperature increases with height because it is being directly heated by the sun.

Why do temperature and pressure decrease with height?

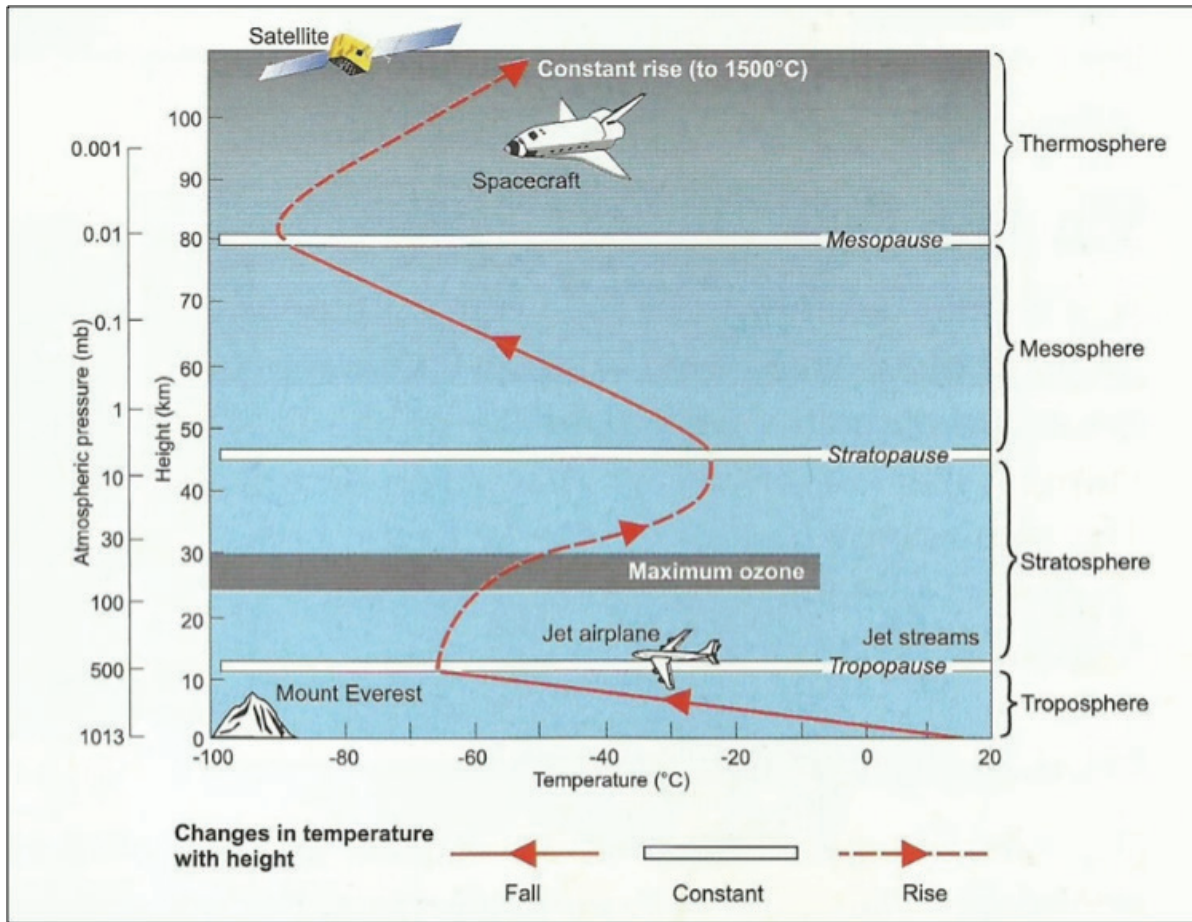


Figure 1. The layers of the Earth’s atmosphere, including the ozone layer (after Davies, 2013).

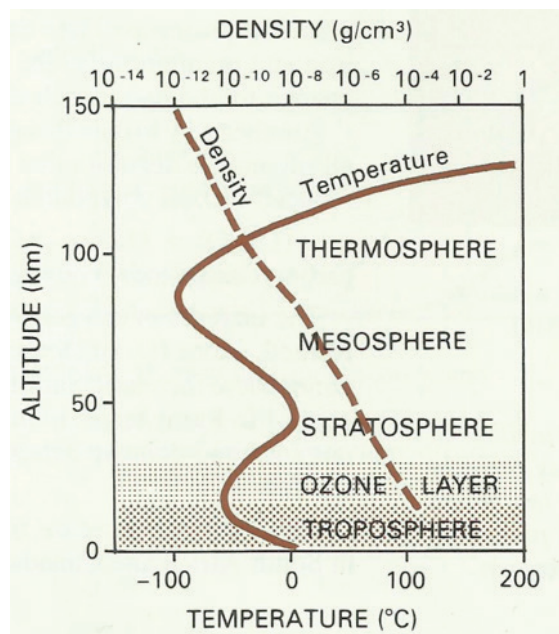


Figure 2. Pressure decreases with height rapidly above the surface (after Davies, 2013).

The molecules that make up the atmosphere are pulled close to the Earth's surface by gravity. This causes the atmosphere to be concentrated at the Earth's surface and thin rapidly with height. Air pressure is a measure of the weight of the molecules above you. As you move up in the atmosphere there are fewer molecules above you. So, the air pressure is lower. Figure 2 shows how pressure decreases with height. The black dotted lines show how much of the atmosphere is below you at a certain level. For example, at 10 km up, 90% of the atmosphere is below you. At the peak of Mount Everest, as shown in Fig. 1, the air pressure is 70% lower than it is at sea level. This means when mountain climbers breathe air on top of the mountain, they are only inhaling 30% of the oxygen they would get at sea level. It is no surprise that most climbers use oxygen tanks when they climb Mt. Everest.

Temperature decreases with height in the troposphere. This is true for a couple of reasons. First, even though the sun's energy comes down from the sky, it is mostly absorbed by the ground. The ground is constantly releasing this energy, as heat in infrared light, so the troposphere is heated from the ground up, causing it to be warmer near the surface and cooler higher up. Another reason is the decreasing air pressure with height. If the warm air at the surface gets blown upward into the cooler air above it, the surface air will continue to rise. As air rises into areas of lower pressure it expands because there are less molecules around it to compress it. The molecules in the air use some of their energy to move apart from each other, causing the air temperature to decrease. The constantly decreasing air pressure in conjunction with the ground-up heating keeps the temperature in the troposphere decreasing with height.

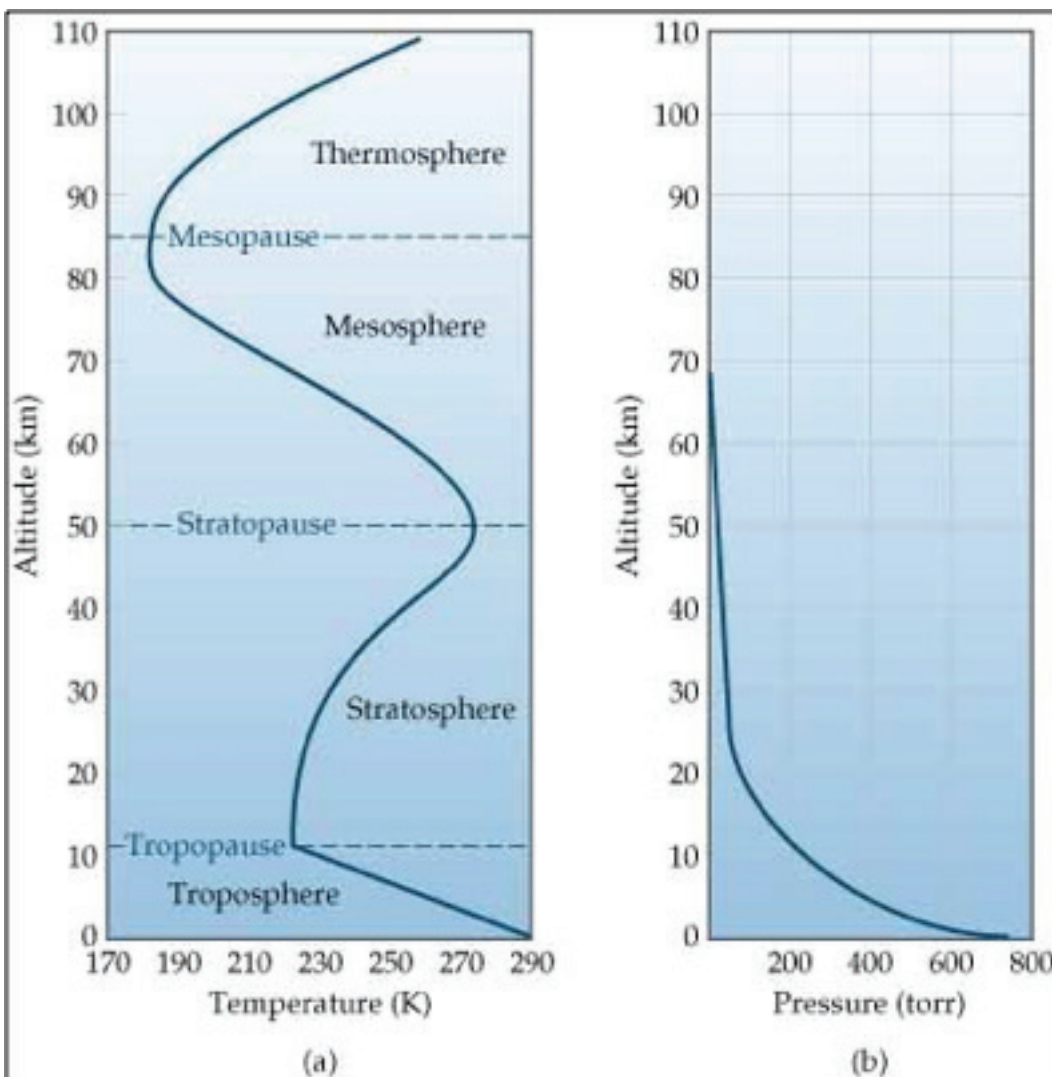


Figure 3. Temperature versus height and pressure of the troposphere (after Davies, 2013)

In the real atmosphere, the actual vertical temperature structure depends on air masses with specific properties of temperature and humidity being blown into the area as well as effects of daytime heating. If you have a layer of air with warm temperatures above the surface, we call that an inversion. That layer can act as a cap which prevents clouds and sometimes severe weather can develop.

2. Effects of changing the composition of the atmosphere

Composition of the atmosphere

The atmosphere is the great volume of gas that is held immediately above the Earth's surface by the Earth's gravitational attraction. It consists mostly of 2 elements: nitrogen (77%) and oxygen (21%). Water vapour (1%), argon (0.93%) and carbon dioxide (0.03%) make up the remainder. Within the lowermost 110 km of the atmosphere the gases are well mixed, and these proportions hold. Above 110 km the atmosphere is ionized and charged ions and free electrons are sufficiently abundant to reflect radio waves.

The atmosphere filters the sun's radiation, letting through light and infrared waves, and filtering out harmful ultraviolet radiation. The Earth's surface would be 35°C cooler than at present if the atmosphere were transparent to solar radiation.

Pollutants

The common atmospheric pollutants are:

- Particulate matter
- Ozone (O₃)
- Nitrogen dioxide (NO₂)
- Carbon monoxide (CO)
- Sulphur dioxide (SO₂)

3. Greenhouse gases and Greenhouse effect

During much of Earth's history, the geological carbon cycle has been balanced, with carbon being released by volcanism at approximately the same rate that it is stored by the other processes. Under these conditions, the climate remains relatively stable.

During some periods of Earth's history, that balance has been upset. This can happen during prolonged periods of greater than average volcanism. One example is the eruption of the Siberian Traps at around 250 Ma, which appears to have led to strong climate warming over a few million years. A carbon imbalance is also associated with significant mountain-building events. For example, the Himalayan Range was formed between about 40 and 10 Ma and over that time and still today the rate of weathering on Earth has been enhanced because those mountains are so high, and the range is so extensive. The weathering of these rocks most importantly the hydrolysis of feldspar - has resulted in consumption of atmospheric carbon dioxide and transfer of the carbon to the oceans and to ocean-floor carbonate minerals.

The steady drop in carbon dioxide levels over the past 40 million years, which led to the Pleistocene glaciations, is partly attributable to the formation of the Himalayan Range. Another, non-geological form of carbon-cycle imbalance is happening today on a very rapid time scale. We are in the process of extracting vast volumes of fossil fuels (coal, oil, and gas) that was stored in rocks over the past several hundred million years and converting these fuels to energy and carbon dioxide. By doing so, we are changing the climate faster than has ever happened in the past.

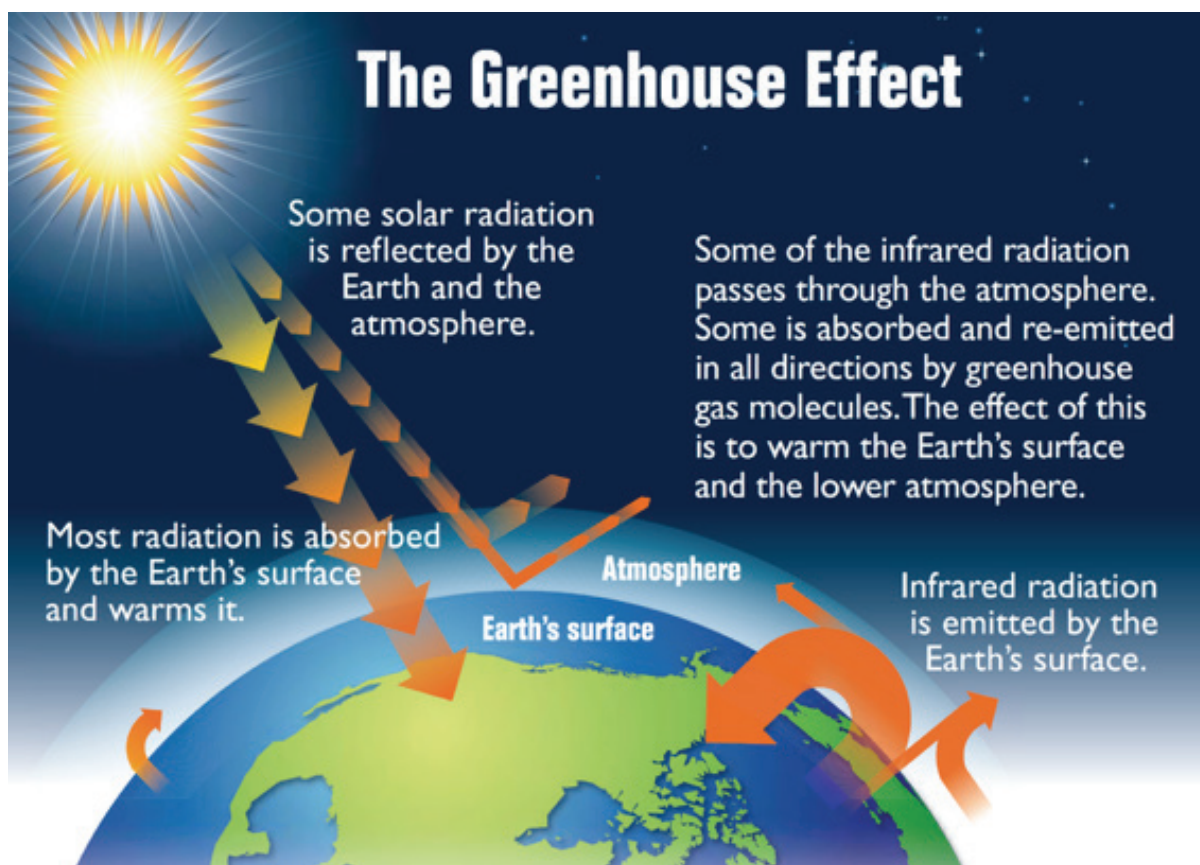


Figure 4. A diagram showing how the greenhouse effect works on Earth (Source: [https://commons.wikimedia.org/wiki/File:Earth%27s_greenhouse_effect_\(US_EPA,_2012\).png](https://commons.wikimedia.org/wiki/File:Earth%27s_greenhouse_effect_(US_EPA,_2012).png))

Since the industrial revolution in Western society in the early 19th Century, man has generated increasing volumes of atmospheric waste, most notably carbon dioxide (CO_2) from the burning of fossil fuels. CO_2 and methane (CH_4) are known as greenhouse gases (GHGs) because they increase the capacity of the troposphere to absorb (and re-radiate) heat that might otherwise escape from the Earth.

As we know, the dominant gases of the atmosphere are nitrogen (as N_2) and oxygen (as O_2). These gas molecules have only two atoms each and are not GHGs. Some of the other important gases of the atmosphere are water vapour (H_2O), carbon dioxide (CO_2), and methane (CH_4). All of these have more than two atoms, and they are GHGs.

It is important to understand what greenhouse gases are and how they work.

All molecules vibrate at various frequencies and in various ways, and some of those vibrations take place at frequencies within the range of the infrared (IR) radiation that is emitted by Earth's surface. Gases with two atoms, such as O_2 , can only vibrate by stretching (back and forth), and those vibrations are much faster than the IR radiation. Gases with three or more atoms (such as CO_2) vibrate by stretching as well, but they can also vibrate in other ways, such as by bending. Those vibrations are slower and match IR. When IR radiation interacts with CO_2 or with one of the other GHGs, the molecular vibrations are enhanced because there is a match between the wavelength of the light and the vibrational frequency of the molecule. This makes the molecule vibrate more vigorously, heating the surrounding air in the process. These molecules also emit IR radiation in all directions, some of which reaches Earth's surface and causes the greenhouse effect. The trapping of heat by the greenhouse gases leads to other greenhouse effects such as Global Warming and Climate Change.

4. Effects of Sun's radiation on the atmosphere

The Earth receives radiation from the sun at a rate of about 0.5 calories per square cm per minute. Radiation is more intense near the equator than near the poles. One might expect the influx of solar radiation to lead to a gradual warming of the Earth's atmosphere. However, evidence from ice cores shows that the temperature at the surface of the Earth has remained relatively constant for at least the last 850,000 years. This indicates that the Earth radiates back to space as much energy as it receives from the sun.

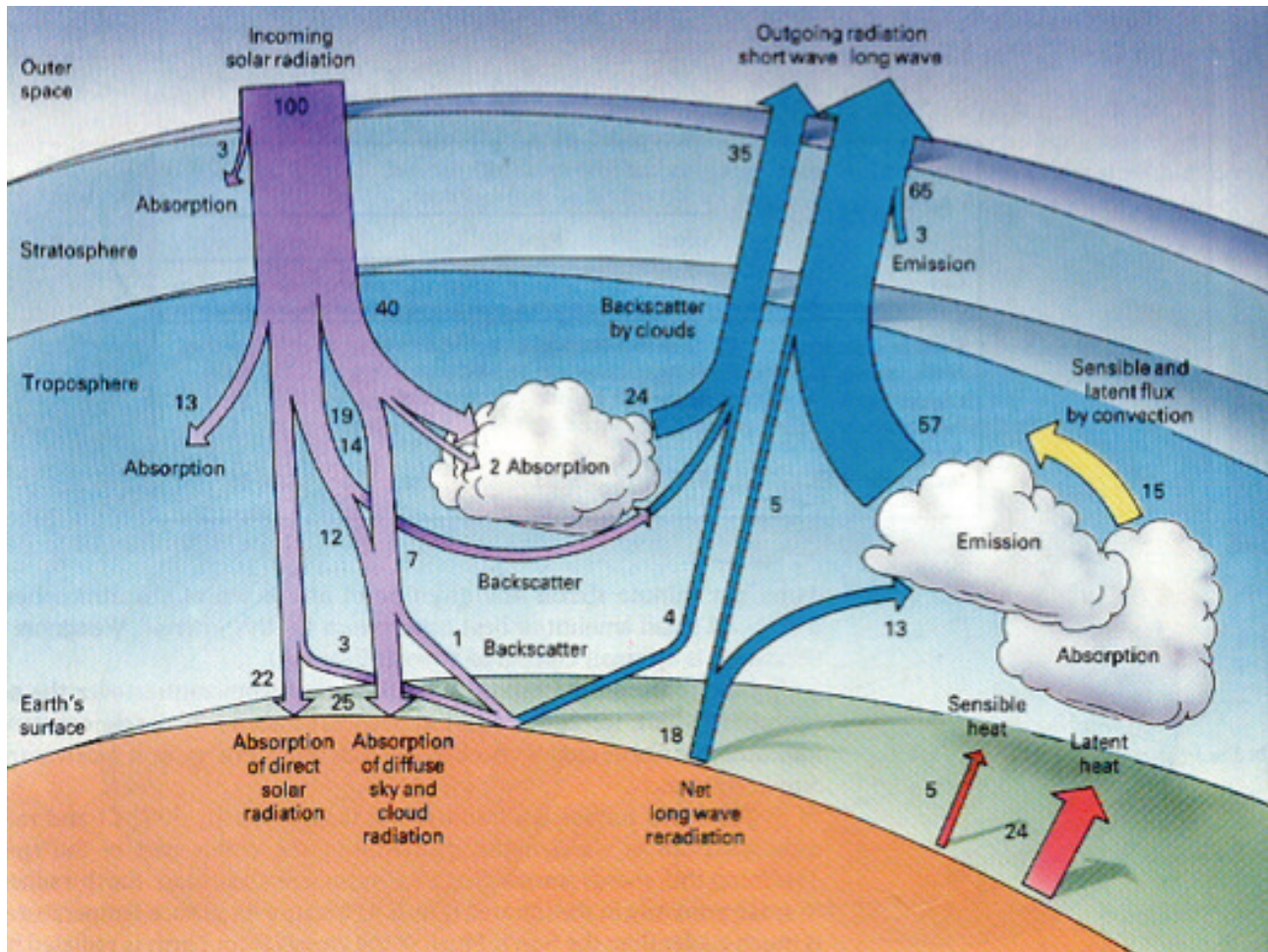


Figure 5. The global annual mean Earth's energy budget for the period March 2000 to May 2004 (after Davies, 2013).

Clouds reflect about one fourth of the incoming solar radiation back into space (Fig. 5). The ratio of energy reflected to total incoming energy is called the albedo. One fourth of the remaining solar radiation is absorbed in the atmosphere and may be radiated from the atmosphere into space.

The remaining half of the solar radiation makes it through to the Earth's surface. Here some is reflected but most is absorbed into the oceans and land areas. Radiation is absorbed into the top several metres of the oceans but penetrates only centimetres into the land surface.

Heat absorbed by the land surface and oceans is radiated back into the atmosphere as long-wave (infra-red) radiation. Heat absorbed into the oceans also is lost by evaporation of surface water. Part of the radiated heat is absorbed in the troposphere by clouds and carbon dioxide gas, with the result that the troposphere is warmed. The troposphere also is warmed by latent heat from condensation of water vapour – the heat that went into evaporating water at the sea surface is released when water vapour condenses as clouds in the troposphere. The warm troposphere radiates heat out into space and back towards the Earth.

The entrapment of heat in the troposphere and radiation back to Earth is the greenhouse effect. Like the glass greenhouse that gardeners use in cold climates, the troposphere lets solar radiation through to warm the Earth, then retards loss of heat from the Earth. If absorption of heat in the troposphere should become more efficient, for example, by increase of CO₂ and other greenhouse gases in the troposphere, less heat will escape and surface temperatures on the Earth will rise. This is the reason for the increase in average temperatures at the Earth's surface in recent decades.

Teaching and Learning Strategies

Teaching Strategies:	Learning Strategies
Teachers prepare information (including pictures) and ask questions on the structure and composition of the atmosphere. Teachers can take students out for an excursion to a nearby weather station or show videos related to atmosphere.	Students will use the information provided to answer questions on the structure and composition of the atmosphere.
<p>STEAM Approach</p> <p>Learning Objective: By the end of the topic, students will be able to;</p> <ul style="list-style-type: none"> • Construct models of showing the structure of the atmosphere - STEAM 	
<p>Teaching Strategies</p> <p>Teachers will provide the criteria and the materials to construct models showing the structure of the atmosphere.</p>	<p>Learning Strategies</p> <p>In groups, students read the criteria and follow the steps and use the materials available to create models (prototype) showing the structure of the atmosphere.</p>
<p>Recommended Resources:</p> <ul style="list-style-type: none"> • Clark, I.F. and Cook, B.J., 1992. Perspectives of the Earth. Australian Academy of Science, Canberra, ACT, 561p. • Davidson, J.P., Reed, W.E., and Davis, P.M., 1997. Exploring Earth. An Introduction to Physical Geology, Prentice-Hall Inc., 264p. • Davies, H.L., 2913. Earth Tok, 3rd Edition. Alan Caudell & Associates, 351p. • Internet 	

Unit 5: Atmosphere and the Hydrological Cycle

Content Standard

11.2.5 Students will be able to explain the characteristics and movement of water among the mantle, oceans, land and atmosphere of the Earth.

Benchmark

11.2.5.2 Examine and explain the hydrological cycle including how temperature and pressure are related to the phase changes of water in the atmosphere.

Topic 2: Hydrological Cycle

Learning Objectives:

By the end of this topic, the students will be able to:

- Explain the hydrological cycle and its relevance to life on Earth
- Explain the wind circulation patterns over the Earth
- Elaborate the characteristics of air masses

Essential questions

1. How can we explain the hydrological cycle?
2. What is humidity?
3. How do we describe the wind circulation patterns over the Earth?

Vocabulary: hydrological cycle, humidity, weather

Concepts	Essential Skills	Essential Values and Attitudes
<ul style="list-style-type: none"> • Hydrological cycle • Humidity • Wind circulation patterns • Air masses • Weather pattern 	<ul style="list-style-type: none"> • Critical thinking • Communication • Creativity • Problem solving • Responsibility 	<ul style="list-style-type: none"> • Be strategic in preventing or minimizing effects of weathering and erosion. • Be responsible in cutting on air polluting activities.

Content Background

1. The hydrological cycle

Relationship between temperature and pressure to water in the atmosphere

As temperature increases, the air particles tend to move further apart leading to less pressure amongst each other. Now that the warm air becomes less dense, it rises and paves way for the colder, denser and high-pressured air particles to fall in to take its place. Thus, the convection cycle continues.

On the other hand, if the warm air contains more water vapour (i.e., high humidity), it has the potential to carry moisture upwards. The temperature of air decreases as the altitude increases so if moist air moves further upwards, the water molecules get closer and closer together to condense and eventually form tiny water droplets. If the temperature is low enough the then clouds are formed.

Clouds are a collection of water in small droplet form, or small particles of ice sufficiently numerous to be seen. Clouds can almost completely absorb both incoming and outgoing radiations.

2. Humidity

Warm air has more space in between the air particles. This space can be filled with evaporating water molecules (or water vapour). The amount of water vapour in air at any one time is known as *humidity*. If no wind is blowing and the humidity is high, that means much of the space in between warm, expand air is filled with water vapour and there's not enough space for any more water vapour particles to be added. This causes the rate of evaporation to be very slow and leads to situations such as wet clothes not drying quickly and sweat running on the skin and not evaporating off quickly.

Relative humidity is the ratio of the amount of moisture in the air to the total moisture that can be absorbed by air at that temperature. Air with high moisture content will intercept and re-radiate downward more heat than air with little moisture. Warm air holds more moisture than cold, and air under high pressure can hold more moisture than air under low pressure. Moist air is less dense than dry air. Most of our lowlands of New Guinea have high humidity due to their proximity to the equator and the ocean.

3. Wind circulation pattern over the Earth

More solar radiation is received at the equator than at the poles. As a result, there is net heat gain near the equator than at the poles.

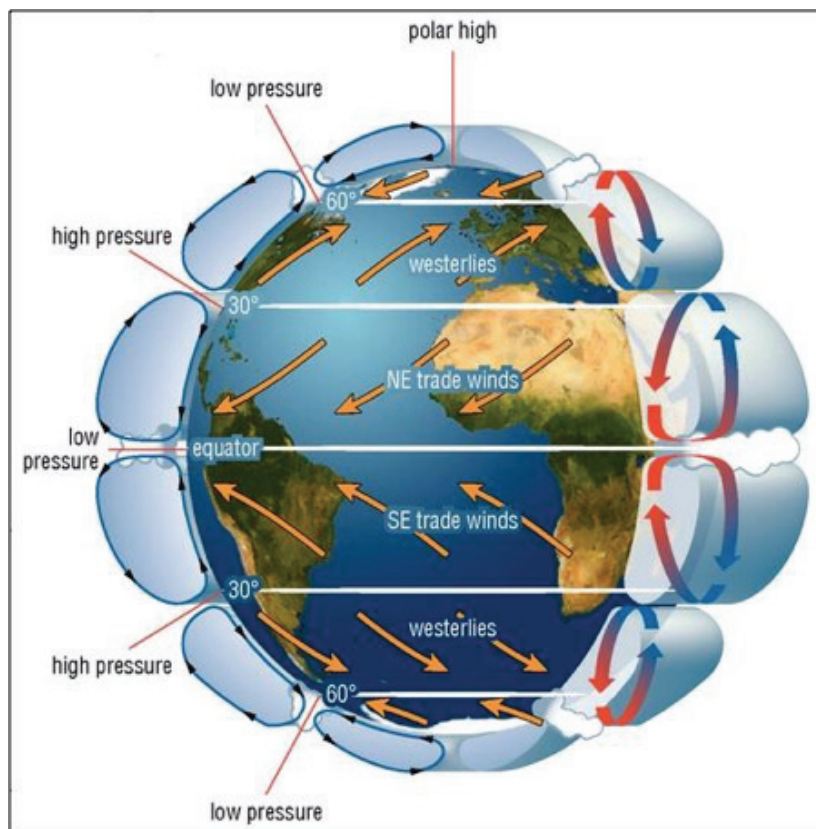


Figure 1. Wind circulation patterns over the Earth (after Davies, 2013).

Three cells of air circulation on either side of the equator serve to transfer heat from the equator to the poles. The system is driven by the more intense solar radiation (and resulting net heat gain) at the equator and the less intense radiation (and resulting net heat loss) at high altitudes.

Air near the equator is heated, becomes less dense, and rises, to be replaced by air from both sides of the equator. The result is to set up cells of air circulation on either side of the equator. The best developed cell is that nearest the equator, the Hadley cell (0° to 30° latitude; Fig. 1). The Ferrel cell is from 30° to 60° latitude, and the Polar cell from 60° to near 90° latitude. The Walker cell is an east-west cell aligned along the equator that takes warm moist rising air from the western Pacific back to the eastern Pacific where it cools and descends.

Because of the Earth's rotation and the resulting Coriolis effect (Fig. 2) the surface winds of the Hadley cell do not flow directly to the equator but are deflected to the west to form the southeast trade winds of the southern hemisphere and the northeast trade winds of the northern hemisphere.

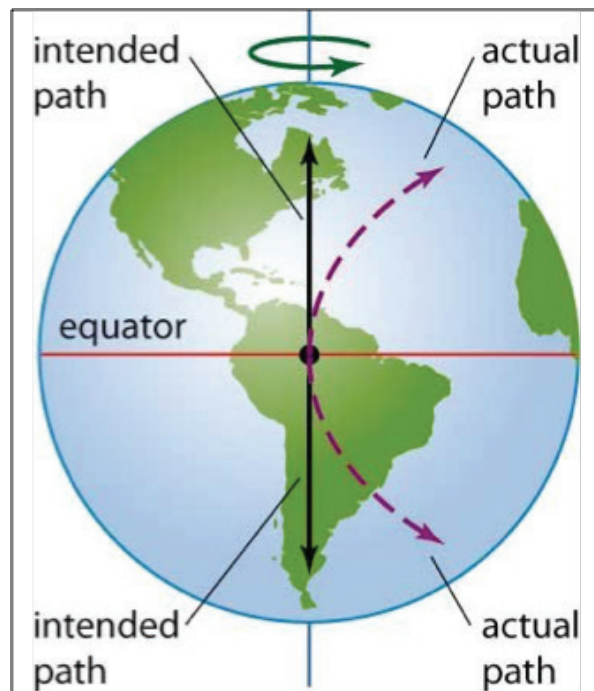


Figure 2. The Coriolis effect is caused by the Earth's rotation (after Davies, 2013).

In the illustration (Fig. 2) the Earth is viewed from above the North Pole. Because of the rotation of the Earth to the left, air moving from the pole towards the equator in a straight line crosses the Earth's surface with a path that is deflected to the right. Air moving from the South Pole towards the Equator has a path relative to the Earth's surface that is deflected to the left.

In the southern hemisphere there is a zone of high atmospheric pressure south of the Hadley cell, at about 30°S , and beyond this zone of westerly winds, the "roaring forties". From Figure 1, we can see the reason for high air pressure to develop between the two cells.

4. Characteristics of air masses – continental polar

The components of the weather are temperature, precipitation and wind. Weather varies day by day. Climate is weather averaged over a considerable period, say 30 years. As someone has said, climate is what you expect, weather is what you get.

Temperature varies with distance from the equator and, for land areas, with distance from the oceans and elevation above sea level. The oceans have a moderating effect with the result that temperatures are less extreme on the coast (maritime climate) and more extreme inland (continental climate).

When moist air rises, the contained water vapour is condensed and may fall as rain or snow. The rain belts of the Earth are in those regions where ascent of air is most frequent and pronounced. Regions of little or no precipitation are found where descending motion of air predominates or where the atmosphere is cold and thus can retain little water.

The principle zones of precipitation are (a) near the equator where the northeast and southeast trade winds converge, and (b) the regions pole ward of the subtropical high pressure belt, i.e., latitudes greater than 30° or 40° S and N (Fig. 1) the subtropical high pressure belts are generally dry and coincide with the great deserts: Sahara and Arabian Peninsula deserts in the northern hemisphere and the Australian and southwest African deserts in the southern hemisphere. Other desert areas are caused by the rain shadow effects of adjacent mountain belts; for example, the desert areas of Western North America, Southern South America, and central Asia.

5. Land and sea winds

The global wind patterns are geostrophic, being driven by global-scale atmospheric pressure system and the Coriolis Effect. The land and sea breezes are derived from the unequal heating properties of land and sea, as follows.

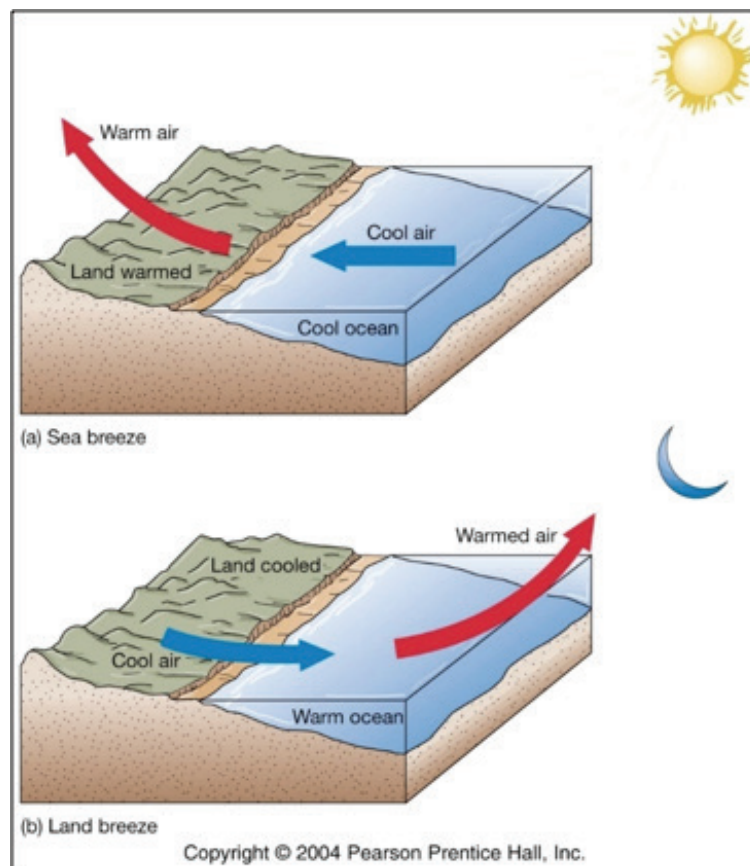


Figure 3. Land and sea winds. a – Sea breeze, b – Land breeze (From Pearson Prentice Hall, 2004).

Land areas respond more rapidly and more markedly to variations in solar radiations than do sea areas. The warming of a land mass during the day, relative to the adjoining ocean, will cause development of a sea breeze: cool dense air from above the ocean moves landward to replace the rising hot air (Fig. 3).

The reverse applies at night, when the land mass will cool more rapidly than the ocean, and cool dense air will flow from the land to replace warmer less dense air over the ocean. We get a similar effect at night in mountainous parts of PNG, when cool dense air flows off the mountains into the valleys.

6. Monsoon winds

The monsoons are driven by the same factors: the differential heating of the land and sea, though on a much larger scale. In the northern summer the heating of air over the continent of Asia causes air to rise. It is replaced by air that moves from Indian Ocean towards India. This is the moisture-bearing southwest monsoon that brings rain to India. In the northern winter, cold air from Asia flows to the Indian Ocean and brings cool dry winds to India. Further east the air flow from Asia is drawn towards northern Australia by the summer heating of Australian continent and brings monsoonal rains to PNG and northern Australia (Fig. 4).



Figure 4. The southwest and northeast monsoons are driven by the heating and cooling of Asia relative to the adjacent oceans. In the New Guinea region, the northerly monsoon blows from northwest rather than northeast (Source: <https://www.latestgkgs.com/monsoon-3909-a>)

New Guinea climate

The climate of New Guinea and the highlands is dominated by the northward and southward movement of Intertropical Convergence Zone moving in response to the changing sun angle. From December to March climate is dominated by northwest monsoon, which is moisture laden, and from May to October by the southeast trade winds, which are cooler and drier.

7. El Nino – Southern Oscillation

The El Nino – Southern Oscillation (ENSO) phenomenon develops regularly every 3-5 years (rarely 7 years) and lasts for 1-2 years. It causes reduced rainfall or drought in northern Australia and PNG and increased rainfall in the mid Pacific and the west coast of South America.

In normal years the trade winds cause warm ocean waters to pile up in the western Pacific (Fig. 5). As a result, the sea level is higher in the western Pacific and the water temperature warmer. We say the Pacific Warm Pool is in the west Pacific. Surface currents are intense and are directed westward. Rainfall is heavy in the western Pacific because of the warm ocean water. At the same time cold water is exposed to the surface in the east because of upwelling.

When the trade winds relax, as happens during El Nino, the warm waters surge to the east, the westward currents at the equator weaken and may reverse.

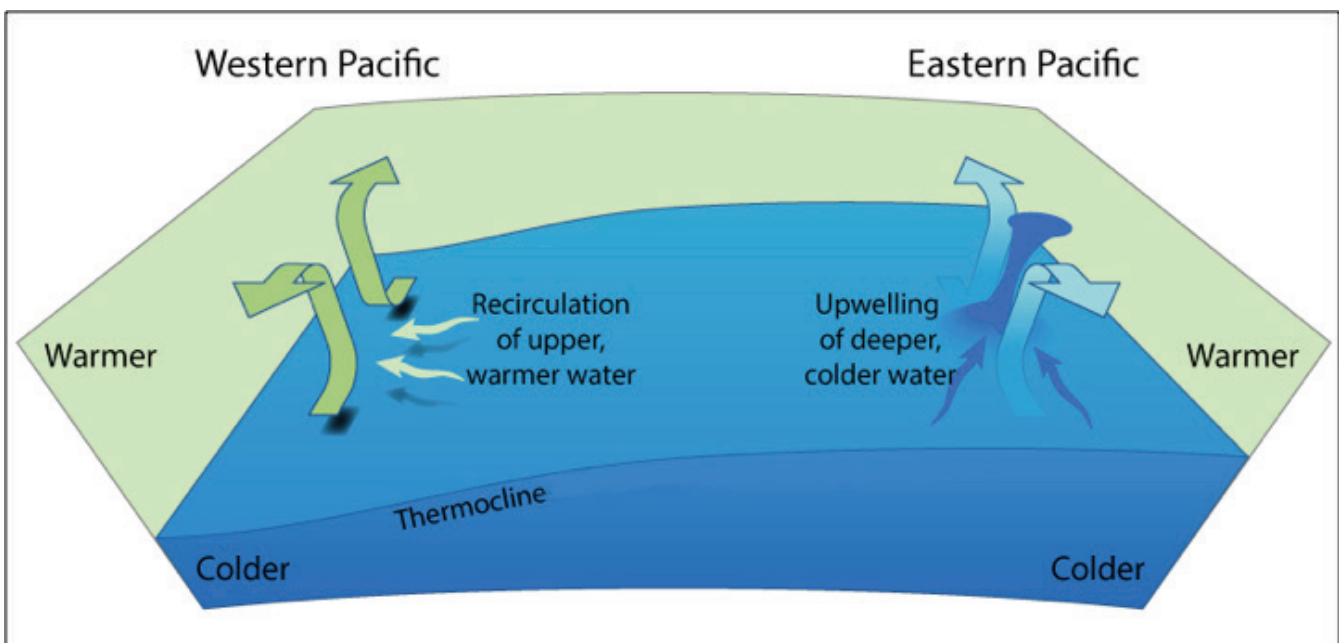


Figure 5. Upwelling at the equator

The trade winds result in a net flow of water away from the equator due to the Coriolis Force. At the equator subsurface water is drawn up to the surface to replace it. The shallow thermocline (a result of water displacement to the west in the thin equatorial strip where the Coriolis Force drops to zero) in the east enables nutrient rich cold water from the deep to be drawn up to the surface, whereas in the west the deep thermocline results in recirculation within the layer above the thermocline. The result is warm ocean water (and hence more rain) in the central and eastern Pacific, and cooler ocean water (and hence lower than usual rainfall) in the western Pacific.

El Nino conditions also affect the northern Pacific by deflecting the jet stream southwards. This in turn results in severe storms in North America, causing erosion on the west coast and flooding further east (Fig. 6).

The term **Southern Oscillation** refers to the relative difference in air pressure as measured in Darwin and Tahiti. When the southern oscillation index is negative it is likely that an El Nino will develop. South American fishermen gave this phenomenon the name El Nino or “the small boy” or “the Christ child” because it arrives on the South American coast at around Christmas time. More recently the name El Nina, or the “small girl”, has been adopted to describe the conditions that are the opposite of El Nino, when the waters around PNG are warm and rainfall increases.

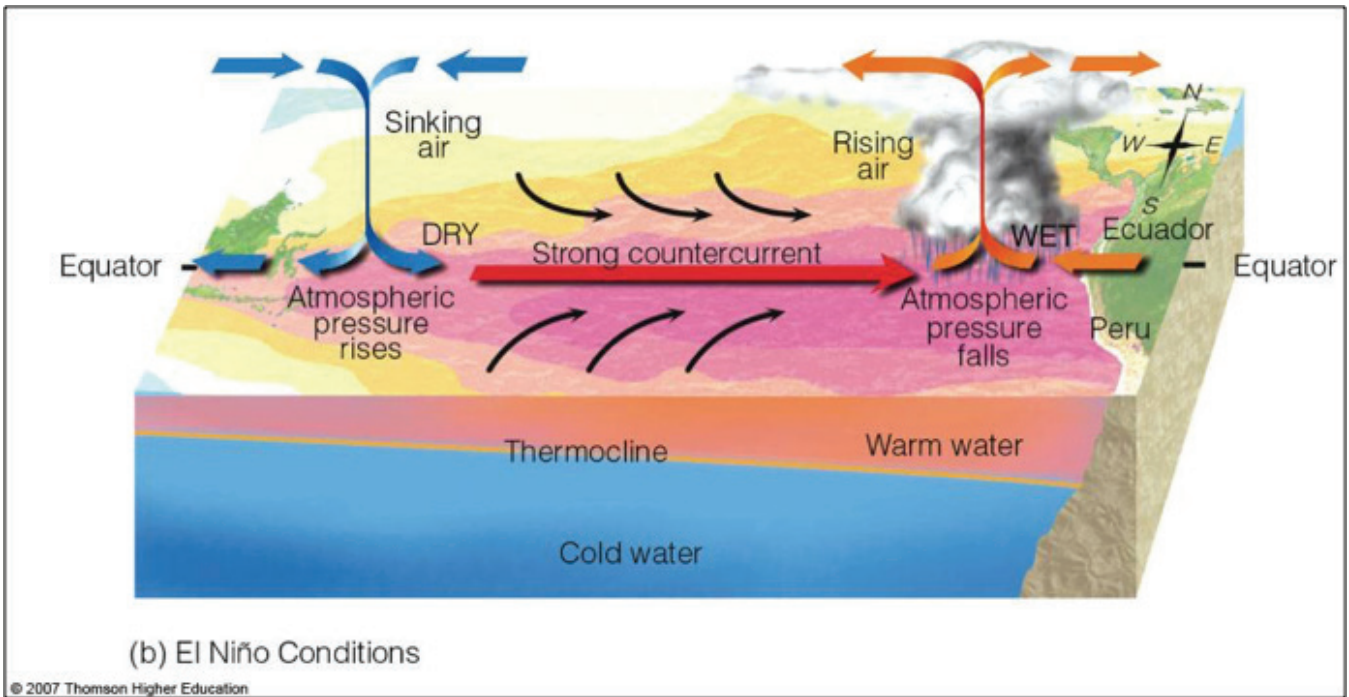


Figure 6. In an El Niño year the trade wind relaxes allowing a surge of warm water eastward across the Pacific (Source: Thomas Higher Education, 2007). Rain falls in the central Pacific and rainfall is reduced in the Western Pacific).

Teaching and Learning Strategies

Teaching Strategies:	Learning Strategies
Teachers prepare information (including pictures) and ask questions on the hydrological cycle. Teachers can take students out for an excursion to a nearby weather station or show videos related to the hydrological cycle.	Students will use the information provided to answer questions the hydrological cycle.
<p>STEAM Approach</p> <p>Learning Objective: By the end of the topic, students will be able to;</p> <ul style="list-style-type: none"> • Construct models of showing the hydrological cycle - STEAM 	
<p>Teaching Strategies</p> <p>Teachers will provide the criteria and the materials to construct models showing layers of the hydrological cycle.</p>	<p>Learning Strategies</p> <p>In groups, students read the criteria and follow the steps and use the materials available to create models (prototype) showing the hydrological cycle</p>
<p>Recommended Resources:</p> <ul style="list-style-type: none"> • Clark, I.F. and Cook, B.J., 1992. Perspectives of the Earth. Australian Academy of Science, Canberra, ACT, 561p. • Davidson, J.P., Reed, W.E. and Davis, P.M., 1997. Exploring Earth. An Introduction to Physical Geology, Prentice-Hall Inc., 264p. • Davies, H.L., 2013. Earth Tok, 3rd Edition, Alan Caudell & Associates, 351p • Internet 	

Standards-Based Lesson Planning

What are Standards-Based Lessons?

In a Standards-Based Lesson, the most important or key distinction is that, a student is expected to meet a defined standard for proficiency. When planning a lesson, the teacher ensures that the content and the methods of teaching the content enable students to learn both the skills and the concepts defined in the standard for that grade level and to demonstrate evidence of their learning.

Planning lessons that are built on standards and creating aligned assessments that measure student progress towards standards is the first step teacher must take to help their students reach success. A lesson plan is a step-by-step guide that provides a structure for an essential learning.

When planning a standards-based lesson, teacher instructions are very crucial for your lessons. How teachers instruct the students is what really points out an innovative teacher to an ordinary teacher. Teacher must engage and prepare motivating instructional activities that will provide the students with opportunities to demonstrate the benchmarks. For instance, teacher should at least identify 3-5 teaching strategies in a lesson; teacher lectures, ask questions, put students into groups for discussion and role play what was discussed.

Why is Standards-Based Lesson Planning Important?

There are many important benefits of having a clear and organized set of lesson plans. Good planning allows for more effective teaching and learning. The lesson plan is a guide and map for organizing the materials and the teacher for the purpose of helping the students achieve the standards. Lesson plans also provide a record that allows good, reflective teachers to go back, analyze their own teaching (what went well, what didn't), and then improve on it in the future. Standards-based lesson planning is vital because the content standards and benchmarks must be comparable, rigorous, measurable and of course evidence based and be applicable in real life that we expect students to achieve. Therefore, teachers must plan effective lessons to teach students to meet these standards. As schools implement new standards, there will be much more evidence that teachers will use to support student learning to help them reach the highest levels of cognitive complexity. That is, students will be developing high-level cognitive skills.

Components of a Standards-Based Lesson Plan

An effective lesson plan has three basic components;

- aims and objectives of the course;
- teaching and learning activities;
- assessments to check student understanding of the topic.

Effective teaching demonstrates deep subject knowledge, including key concepts, current and relevant research, methodologies, tools and techniques, and meaningful applications.

Planning for under-achievers NORMA

Who are underachieving students?

Under achievers are students who fail or do not perform as expected.

Underachievement may be caused by emotions (low self-esteem) and the environment (cultural influences, unsupportive family)

How can we help underachievement?

Underachievement varies between students. Not all students are in the same category of underachievement.

Given below a suggested strategies teachers may adopt to assist underachievers in the classroom.

- Examine the Problem Individually
It is important that underachieving students are addressed individually by focusing on the student's strengths.
- Create a Teacher-Parent Collaboration
Teachers and parents need to work together and pool their information and experience regarding the child. Teachers and parents begin by asking questions such as;
 - In what areas has the child shown exceptional ability?
 - What are the child's preferred learning styles?
 - What insights do parents and teachers have about the child's strengths and problem areas?
- Help student to plan every activity in the classroom
- Help students set realistic expectations
- Encourage and promote the student's interests and passions.
- Help children set short and long-term academic goals
- Talk with them about possible goals.
- Ensure that all students are challenged (but not frustrated) by classroom activities
- Always reinforce students

Standards-Based Lesson Planning

Sample Standards-Based Lesson Plan (Integrating STEAM)

TOPIC: Mining and the environment

Lesson Topic: Mine Closure Plan

Grade: 12

Length of Lesson: 40 minutes

National Content Standard 12.1.1: Students will be able to trace the origins of Earth resources including the deposition of minerals, coal, petroleum, and natural gas, and their economic development and the regulations relating to the environment in which they are operating in.

Grade Level Benchmark 12.2.1.5 Explore and analyse the environmental regulations of mining activities set by the government.

Essential Knowledge, Skills, Values, and Attitudes

Knowledge: Mine closure planning

Skills: Evaluating - Reasoning

Values: Common good, sustainability, and interdependence

Attitudes: Caring, responsible, and respect

STEAM Knowledge and Skill

Knowledge: Environmental rehabilitation after mine closure

Skill: Evaluating - reasoning

Performance Indicator: Identify environmental rehabilitation after mine closure

STEAM Performance Indicator: As above

Materials: Copies of mine closure plan

- **Lesson Objective:** Students will be able to differentiate between Standard units and Derived Units

Essential Questions:

What are standard and derived SI units?

What STEAM principles and practices can be used to enhance the ability to make conversions and derivations between units?

Lesson Procedure

Teacher Activities	Student Activities
Introduction	
<ul style="list-style-type: none"> Explain what students will learn and how it will be useful. Connect what they will learn to prior learning or experience. 	<ul style="list-style-type: none"> Listen to the teacher.
Body	
Modelling	
<ul style="list-style-type: none"> Identify and discuss a Standard and Derived units. 	<ul style="list-style-type: none"> Listen and respond when prompted by the teacher.
Guided Practice	
<ul style="list-style-type: none"> Give students a copy of the conversion scale. Ask students to read the conversion scale and identify one process involved in deriving units from standard units. Ask students to stop and give a process for deriving units. Ascertain if students understand what they are supposed to do. 	<ul style="list-style-type: none"> Read the conversion scale and identify one process involved in deriving units from standard units. Give one process given in the conversion scale in deriving units from standard units. Let teacher know if they understand what to do.
Independent Practice	
<ul style="list-style-type: none"> Ask students to read the conversion scale and identify one process involved in deriving units from standard units. Ask students to suggest and defend one process to derive units from standard units. 	<ul style="list-style-type: none"> Read the conversion scale and identify one process involved in deriving units from standard units. Suggest and defend one other conversion process to derive units from standard units.
Conclusion	
<ul style="list-style-type: none"> Emphasise the reasons given in the conversion scale to derive units from standard units. Ask students to provide a process given in the process for deriving units. 	<ul style="list-style-type: none"> Listen to the teacher. Give reasons to make conversions and their importance, orally

Performance Assessment and Standards

National Content Standard : Students will be able to trace the origins of Earth resources including mineral deposits, coal, petroleum, and natural gas and their economic development

Lesson Topic	Topic	Benchmark	Performance Assessment	
Mine Closure Plan	Mining and the environment	12.2.1.5. Explore and analyse the environmental regulations of mining activities set by the government.	Student reads one mine closure plan and identify its reasons for rehabilitating the natural environment	
		PROFICIENCY RUBRIC		
		Advanced	Proficient	Partially Proficient
	Identify all the reasons given in the mine closure plan for rehabilitating the environment, and justified at least one reason	Identify all the reasons given in the mine closure plan for rehabilitating the environment	Identify more than 50% of the reasons given in the mine closure plan for rehabilitating the environment	Identify less than 50% of the reasons given in the mine closure plan for rehabilitating the environment

STEAM Activity

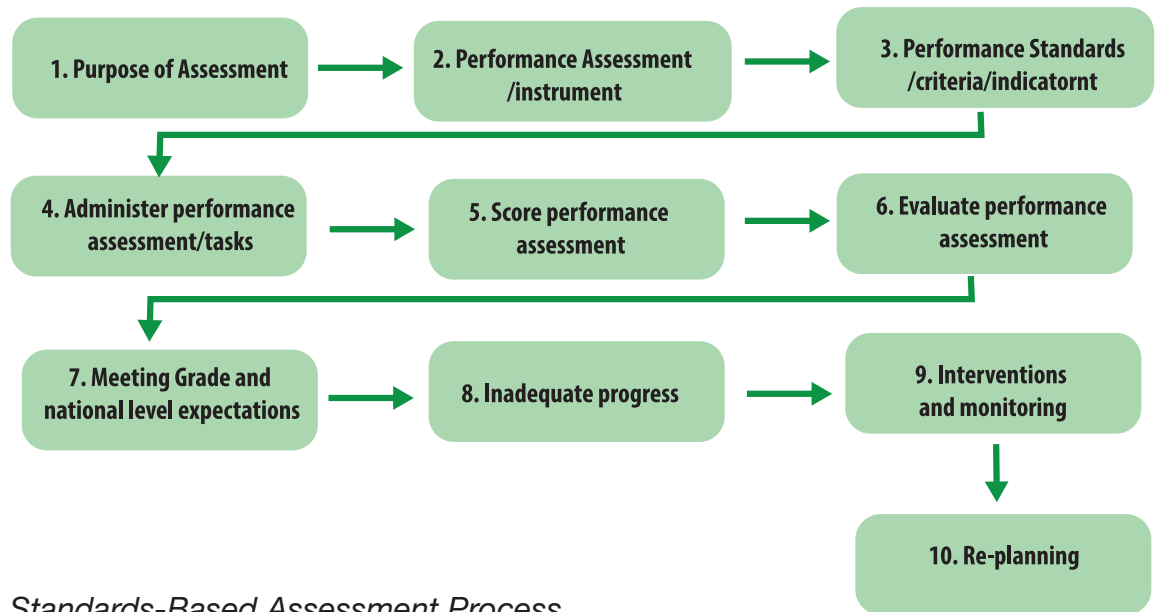
Students create a model of a mine that is going to be closed soon shown in the plan and the natural environment that is worth rehabilitating using the values of common good, sustainability, and interdependence; and the attitudes of caring, responsible, and respect.

Assessment, Monitoring and Reporting

What is Standards-Based Assessment (SBA)?

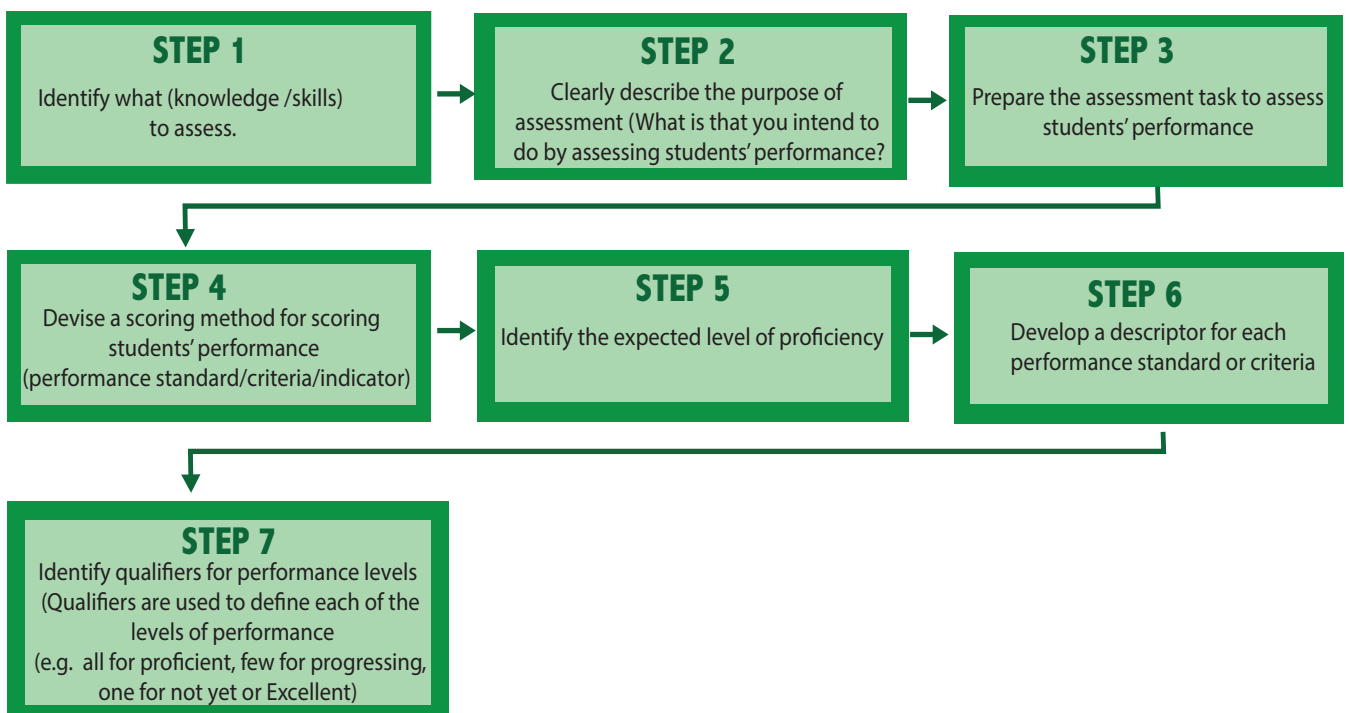
Assessment and reporting is an integral part of the delivery of any curriculum used in the schools. In Standard Based Curriculum (SBC) assessment encourages the use of benchmarks and commended types of assessment that promote standards for a range of purposes.

Standards-Based Assessment Cycle



Standards-Based Assessment Process

Teachers are required to use the steps outlined below when planning assessment. These steps will guide you to develop effective assessments to improve student's learning as well as evaluating their progress towards meeting national and grade –level expectations.



Purpose of Standards-Based Assessment

Standards-Based Assessment (SBA) serves different purposes. These include instruction and learning purposes. The primary purpose of SBA is to improve student learning so that all students can attain the expected level of proficiency or quality of learning.

Enabling purposes of SBA is to:

- Measure students' proficiency on well-defined content standards, benchmarks and learning objectives
- Ascertain students' attainment or progress towards the attainment of specific component of a content standard
- Ascertain what each student knows and can do and what each student needs to learn to reach the expected level of proficiency
- Enable teachers to make informed decisions and plans about how and what they would do to assist weak students to make adequate progress towards meeting the expected level of proficiency
- Enable students to know what they can do and help them to develop and implement strategies to improve their learning and proficiency level
- Communicate to parents, guardians, and relevant stakeholders the performance and progress towards the attainment of content standards or its components
- Compare students' performances and the performances of other students

Principles of Standards-Based Assessment

The principle of SBA is for assessment to be;

- emphasise on tasks that should encourage deeper learning,
- be an integral component of a course, unit or topic and not something to add on afterward,
- a good assessment requires clarity of purpose, goals, standards and criteria of practices that should use a range of measures allowing students to demonstrate what they know and can do,
- based on an understanding of how students learn of practices that promote deeper understanding of learning processes by developing their capacity for self-assessment,
- for improving performance that involves feedback and reflection,
- on-going rather than episodic,
- given the required attention to outcomes and processes, and be closely aligned and linked to learning objectives, benchmarks and content standards

Standards-Based Assessment Types

In standards-Based Assessment, there are three broad assessments types.

1. Formative Assessment

Formative assessment includes ‘assessment *for* and *as Learning*’ and is conducted during the teaching and learning of activities of a topic.

Purposes of assessment for Learning

- On-going assessment that allows teachers to monitor students on a day-to-day basis.
- Provide continuous feedback and evidence to the teachers that should enable them to identify gaps and issues with their teaching, and improve their classroom teaching practice.
- Helps students to continuously evaluate, reflect on, and improve their learning.

Purposes of assessment as Learning

- Occurs when students reflect on and monitor their progress to inform their future learning goals.
- Helps students to continuously evaluate, reflect, and improve their own learning.
- Helps students to understand the purpose of their learning and clarify learning goals.

2. Summative Assessment

Summative assessment focuses on ‘assessment *of learning*’ and is conducted after or at the conclusion of teaching and learning of activities or a topic.

Purposes of assessment of Learning

- Help teachers to determine what each student has achieved and how much progress he/she has made towards meeting national and grade-level expectations.
- Help teachers to determine what each student has achieved at the end of a learning sequence or a unit.
- Enable teachers to ascertain each student’s development against the unit or topic objectives and to set future directions for learning.
- Help students to evaluate, reflect on, and prepare for next stage of learning.

3. Authentic Assessment

- Is performed in a real life context that approximates as much as possible, the use of a skill or concept in the real world.
- Is based on the development of a meaningful product, performance or process
- Students develop and demonstrate the application of their knowledge, skills, values and attitudes in real life situations which promote and support the development of deeper levels of understanding.
- Uses either summative or formative assessment methods in real life context.

Authentic assessment refers to assessment that:

- Looks at students actively engaged in completing a task that represents the achievement of a learning objective or standard.
- Takes place in real life situations.
- Asks students to apply their knowledge, skills, values and attitudes in real life situations.
- Students are given the criteria against which they are being assessed.

Performance Assessment

Performance assessment is a form of testing that requires students to perform a task rather than select an answer from a ready-made list. For example, a student may be asked to explain historical events, generate scientific hypotheses, solve math problems, converse in a foreign language, or conduct research on an assigned topic. Teachers, then judge the quality of the student's work based on an agreed-upon set of criteria. It is an assessment which requires students to demonstrate that they have mastered specific skills and competencies by performing or producing something.

Types of performance assessment

i. Products

This refers to concrete tangible items that students create through either the visual, written or auditory media such as:

- Creating a health/physical activity poster.
- Video a class game or performance and write a broadcast commentary.
- Write a speech to be given at a school council meeting advocating for increased time for health and physical education in the curriculum.
- Write the skill cues for a series of skill photo's.
- Create a brochure to be handed out to parents during education week.
- Develop an interview for a favourite sportsperson.
- Write a review of a dance performance.
- Essays.
- Projects.

ii. Process Focused Tasks

It shows the thinking processes and learning strategies students use as they work such as:

- Survival scenarios.
- Problem solving initiative/adventure/ activities.
- Decision making such as scenario's related to health issues.
- Event tasks such as creating a game, choreographing a dance/gymnastics routine, creating an obstacle course.
- Game play analysis.
- Peer assessment of skills or performances.
- Self-assessment activities.
- Goal setting, deciding a strategy and monitoring progress towards achievement.

iii. Portfolio

This refers to a collection of student work and additional information gathered over a period of time that demonstrates learning progress.

iv. Performances

It deals with observable affective or psycho-motor behaviours put into action such as:

- Skills check during game play.
- Role plays.
- Officiating a game.
- Debates.
- Performing dance/gymnastics routines.
- Teaching a skill/game/dance to peers.

Assessment Strategies

It is important for teachers to know that, assessment is administered in different ways. Assessment does not mean a test only. There are many different ways to find out about student's strengths and weaknesses. Relying on only one method of assessing will not reflect student's achievement.

Provided in the table below is a list of suggested strategies you can use to assess student's performances. These strategies are applicable in all the standards-based assessment types.

Assessment Strategies

STRATEGY	DESCRIPTION
ANALOGIES	Students create an analogy between something they are familiar with and the new information they have learned. When asking students to explain the analogy, it will show the depth of their understanding of a topic.
CLASSROOM PRESENTATIONS	A classroom presentation is an assessment strategy that requires students to verbalize their knowledge, select and present samples of finished work, and organize their thoughts about a topic in order to present a summary of their learning. It may provide the basis for assessment upon completion of a student's project or essay.
CONFERENCES	A conference is a formal or informal meeting between the teacher and a student for the purpose of exchanging information or sharing ideas. A conference might be held to explore the student's thinking and suggest next steps; assess the student's level of understanding of a particular concept or procedure; and review, clarify, and extend what the student has already completed
DISCUSSIONS	Having a class discussion on a unit of study provides teachers with valuable information about what the students know about the subject. Focus the discussions on higher level thinking skills and allow students to reflect their learning before the discussion commences.
ESSAYS	An essay is a writing sample in which a student constructs a response to a question, topic, or brief statement, and supplies supporting details or arguments. The essay allows the teacher to assess the student's understanding and/or ability to analyse and synthesize information.
EXHIBITIONS/ DEMONSTRATIONS	An exhibition/demonstration is a performance in a public setting, during which a student explains and applies a process, procedure, etc., in concrete ways to show individual achievement of specific skills and knowledge.
INTERVIEWS	An interview is a face-to-face conversation in which teacher and student use inquiry to share their knowledge and understanding of a topic or problem, and can be used by the teacher to explore the student's thinking; assess the student's level of understanding of a concept or procedure and gather information, obtain clarification, determine positions, and probe for motivations.
LEARNING LOGS	A learning log is an ongoing, visible record kept by a student and recording what he or she is doing or thinking while working on a particular task or assignment. It can be used to assess student progress and growth over time.
OBSERVATION	Observation is a process of systematically viewing and recording students while they work, for the purpose of making programming and instruction decisions. Observation can take place at any time and in any setting. It provides information on students' strengths and weaknesses, learning styles, interests, and attitudes.
PEER ASSESSMENT	Assessment by peers is a powerful way to gather information about students and their understanding. Students can use set criteria to assess the work of their classmates.
PERFORMANCE TASKS	During a performance task, students create, produce, perform, or present works on "real world" issues. The performance task may be used to assess a skill or proficiency, and provides useful information on the process as well as the product.

PORTFOLIOS	A portfolio is a collection of samples of a student's work, and is focused, selective, reflective, and collaborative. It offers a visual demonstration of a student's achievement, capabilities, strengths, weaknesses, knowledge, and specific skills, over time and in a variety of contexts.
QUESTIONS AND ANSWERS (ORAL)	In the question–and-answer strategy, the teacher poses a question and the student answers verbally, rather than in writing. This strategy helps the teacher to determine whether students understand what is being, or has been, presented, and helps students to extend their thinking, generate ideas, or solve problems.
QUIZZES, TESTS, EXAMINATIONS	A quiz, test, or examination requires students to respond to prompts in order to demonstrate their knowledge (orally or in writing) or their skills (e.g., through performance). Quizzes are usually short; examinations are usually longer. Quizzes, tests, or examinations can be adapted for exceptional students and for re-teaching and retesting.
QUESTIONNAIRES	Questionnaires can be used for a variety of purposes. When used as a formative assessment strategy, they provide teachers with information on student learning that they can use to plan further instruction.
RESPONSE JOURNALS	A response journal is a student's personal record containing written, reflective responses to material he or she is reading, viewing, listening to, or discussing. The response journal can be used as an assessment tool in all subject areas.
SELECTED RESPONSES	Strictly speaking a part of quizzes, tests, and examinations, selected responses require students to identify the one correct answer. The strategy can take the form of multiple-choice or true/false formats. Selected response is a commonly used formal procedure for gathering objective evidence about student learning, specifically in memory, recall, and comprehension.
STUDENT SELF-ASSESSMENTS	Self-assessment is a process by which the student gathers information about, and reflects on, his or her own learning. It is the student's own assessment of personal progress in terms of knowledge, skills, processes, or attitudes. Self-assessment leads students to a greater awareness and understanding of themselves as learners.

Samples of Assessment Types

Sample 1: Formative Assessment

Strand 2: Earth Science

Unit 2: Earth Materials

Content Standard: 11.2.2 Students will be able to compare and contrast between minerals, minerals and rocks, rocks, and understand the formation of rocks, minerals and fossil fuels, and their uses.

Benchmark: 11.2.2.1 Analyse and compare minerals according to their properties, formation and uses.

Topic 1: Minerals

Lesson Title: Classification of minerals

Lesson Objective: By the end of the lesson, students should be able to:

- Categorise minerals into groups based on their compositions.

Knowledge	Skills	Values and Attitudes
<ul style="list-style-type: none"> • Minerals • Composition of minerals 	<ul style="list-style-type: none"> • Classify the minerals into groups according to their compositions 	<ul style="list-style-type: none"> • Display desire to learn about the composition of minerals • Appreciate the compositions of minerals

What to be assessed?

Classify the minerals into groups according to their compositions.

Purpose of the assessment

To measure the students' proficiency on the achievement of the benchmark and learning objectives

Expected level of proficiency

Identify and classify the minerals into groups according to their compositions.

Performance Task

Identify and classify the minerals into groups according to their compositions.

Assessment Strategy

This assessment can be conducted in one lesson as an assessed lesson exercise

Assessment Tool

An exercise will be used to measure their level of proficiency

Assessment Scoring

Rubrics must be developed to articulate the real proficiency of the child. This is an analytical rubrics used to assess the child's learning through the assessment tool a lesson exercise.

Performance standards/ Criteria	A	B	C	D	Score
	Advance 10	Proficient 9 - 5	Progressing 3 - 4	Not Yet 2	___/10 Marks
Identify and classify the minerals according to their compositions (10 marks)	Precise and correct classification of minerals according to their compositions	Correct classification of minerals according to their compositions	Satisfactory classification of minerals according to their compositions	Poor classification of minerals according to their compositions	

Recommended Resources:

- <https://courses.lumenlearning.com/wmopen-geology/chapter/outcome-identifying-minerals/>
- <https://www.amazon.com/Mohs-Hardness-Scale-Collection-Specimens/dp/B00K24O1G8>
- <https://www.minerals.net/resource/property/magnetic.aspx>

Sample 2 : Summative Assessment**Strand 2: Earth Science****Unit 2: Earth Materials**

Content Standard: 11.2.2 Students will be able to compare and contrast between minerals, minerals and rocks, rocks, and understand the formation of rocks, minerals and fossil fuels, and their uses.

Benchmark: 11.2.1.1 – 11.2.1.3 (refer to the benchmarks unit 2 of strand 2)

Topic 1: Minerals**Topic 2: Rocks****Topic 3: Fossil Fuels**

Lesson Topic: (Refer to the lesson topics in Unit 2 of Strand 2)

Skill(s): Understanding (identify, interpret), remembering (define), analyzing (investigate, compare, use, examine, analysis)

Instructional Objective(s): (Refer to Topics in Unit 2 of Strand 2)

Knowledge	Skills	Values and Attitudes
<ul style="list-style-type: none"> • Properties of minerals • Moh's hardness scale • Classification of minerals • Composition of rocks • Extrusive and intrusive igneous rocks and their composition • Classifying of sedimentary rocks • Features of metamorphic rocks • Classification of fossil fuels • Characteristics of crude oil and gas and their uses 	<ul style="list-style-type: none"> • Understanding (identify, interpret) • remembering (define) • analyzing (investigate, compare, use, examine, analysis) 	<ul style="list-style-type: none"> • Appreciate the properties and composition of minerals, rocks and fossil fuels and their uses.

What to be assessed?

The Unit, Unit 2: 'Earth Materials'.

Purpose of the assessment

To measure students' proficiency on the achievement of the benchmarks and learning objectives in this unit. (This assessment is to be conducted after teaching the unit)

Expected level of proficiency

All students are expected to;

- Categorise minerals into groups based on their compositions.
- Explain the processes of sedimentation, lithification, diagenesis and metamorphism.
- Describe the features of igneous, sedimentary and metamorphic rocks
- Describe the formation of coal, crude oil and gas.
- Explain the importance and uses fossil fuels.

Performance Task

Students will do an assignment out of 50marks. You can use other assessment tools (assignment, projects, etc.) assess student's proficiency on these benchmarks.

Assessment Strategy

Assignment will be used to measure student's proficiency.

Assessment Scoring

Rubrics must be developed to articulate the real proficiency of the child. This is an analytical rubrics used to assess the child's learning through the assessment tool an assignment.

Performance standards/ Criteria	A	B	C	D	Score
	Advance 50	Proficient 49 - 30	Progressing 29-10	Not Yet 9-0	___/50 Marks
Classify the minerals into groups according to their compositions. (5 marks)	Exceptional detailed, clear classification of minerals according to their composition	Good clear classification of minerals according to their composition	Fair and satisfactory classification of minerals according to their composition	Classification of minerals according to their composition is poor and vague.	

<p>Use a schematic view of the rock cycle process chart to explain the processes involved in rocks formation.</p> <p>(15 marks)</p>	<p>Detailed schematic view of the rock cycle process chart showing all the process in the different rocks formation with clear, detailed explanation</p>	<p>Good schematic view of the rock cycle process chart showing some of the process in the different rock formation with clear explanation</p>	<p>Satisfactory schematic view of the rock cycle process chart showing few of the process in the different rocks formation with vague, explanation</p>	<p>Poor schematic view of the rock cycle process chart showing few of the process in the different rock formation with no explanation at all</p>	
<p>Use pictorial chart to show the processes involved in the formation of crude oil and gas.</p> <p>(15 marks)</p>	<p>Detailed, clear, step by step pictorial chart showing the processes involved in the formation of the crude oil and gas with correct heading</p>	<p>Clear, step by step pictorial chart showing the processes involved in the formation of the crude oil and gas with some correct headings.</p>	<p>Inconsistencies in the steps of pictorial chart showing the processes involved in the formation of the crude oil and gas with few correct heading Inconsistencies in the steps of pictorial chart showing the processes involved in the formation of the crude oil and gas with few correct heading</p>	<p>Vague in the steps of pictorial chart showing the processes involved in the formation of the crude oil and gas with no correct heading</p>	
<p>Explain the three (3) methods of how the natural gas is supplied.</p> <p>(10 marks)</p>	<p>Exceptional detailed, clear and succinct explanation of how natural gas is supplied as; i. Piped Natural Gas (PNG) ii. Compressed Natural Gas (CNG) iii. Liquefied Natural Gas (LNG)</p>	<p>Good clear explanation of explanation of how natural gas is supplied as; i. Piped Natural Gas (PNG) ii. Compressed Natural Gas (CNG) iii. Liquefied Natural Gas (LNG)</p>	<p>Fair and satisfactory explanation of explanation of how natural gas is supplied as; i. Piped Natural Gas (PNG) ii. Compressed Natural Gas (CNG) iii. Liquefied Natural Gas (LNG)</p>	<p>Explanation of explanation of how oil and gas licenses are issued explanation of how natural gas is supplied as; i. Piped Natural Gas (PNG) ii. Compressed Natural Gas (CNG) iii. Liquefied Natural Gas (LNG) is poor and vague.</p>	

Explain the importance and uses of crude oil and gas. (5 marks)	Detailed, clear explanation of the importance and uses of crude oil and gas	Good clear explanation of explanation of the importance and uses of crude oil and gas	Fair the importance and uses of crude oil and gas	Unsatisfactory the importance and uses of crude oil and gas	
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Recommended Resources:

- Davies, H.L., 2013. Earth Tok, 3rd Edition, Alan Caudel & Associates, 351p
- <http://www.ispatguru.com/natural-gas-its-characteristics-and-safetyrequirements/>
- <http://www.OilScams.org>
- Internet
- PNG OresomeResources.com – Minerals and Energy Education

Sample 3 : Authentic Assessment

Strand 2: Earth Science

Unit 2: Earth Materials

Content Standard: 11.2.2 Students will be able to compare and contrast between minerals, minerals and rocks, rocks, and understand the formation of rocks, minerals and fossil fuels, and their uses.

Benchmark: 11.2.2.1 – 11.2.2.3 (refer to the benchmarks in unit 2 of Strand 2)

Topic 1: (refer to the topics in Unit 2 of this Strand)

Lesson Topics: (Refer to the topics in the Unit: Earth Materials, Strand 2)

Instructional Objective(s): (Refer to Topics in Unit: Earth Materials)

What to be assessed?

The essential knowledge, skills, attitudes and values in the unit: 'Earth Materials'

Purpose of the assessment

To measure students proficiency on the achievement of the benchmarks and learning objectives in this unit. This assessment is to be conducted after teaching this unit.

Expected level of proficiency

All students are expected to;

- Describe the formation of coal, crude oil and natural gas.
- Describe the importance and uses of fossil fuels.

Performance Task

Students will do a project out of 30 marks. You can use other assessment tools (assignment, simulation, interview etc) assess students proficiency on these benchmarks.

Task: Students will be given two weeks to complete this project then carry out awareness.

1. Research information on;
 - formation of coal, crude oil and natural gas.
 - importance and uses of fossil fuels.
2. They will make presentation on these rights during assembly, recess and lunch time. (Students will be grouped into 5-6 students per group)
3. The best presentation will be given a chance to make presentation in public in their local community.

The aim of this project is to develop students to do research and analyse the information and present to the class. The students will do oral presentation based on this project assignment.

Assessment Strategy

A project will be used to measure student's proficiency.

Assessment Scoring

Rubrics will be developed to find out the real proficiency of the child. This is an analytical rubrics used to assess the child's learning through the assessment tool a project.

Performance standards/ Criteria	A	B	C	D	Score
	Advance 30-25	Proficient 24- 20	Progressing 19-10	Not Yet 9-2	___/30 Marks
<i>Explain the formation of coal, crude oil and natural gas. (10marks)</i>	Very clear, logical explanations on formation of coal, crude oil and natural gas.	Very good explanations on formation of coal, crude oil and natural gas.	Satisfactory explanation of the key words and fair explanations covering formation of coal, crude oil and natural gas.	Poor explanations on formation of coal, crude oil and natural gas.	
<i>Explain the importance and uses of fossil fuels. (10 marks)</i>	Very clear, logical explanations on the importance and uses of fossil fuels.	Very good explanations on the importance and uses of fossil fuels.	Satisfactory explanation of the key words and fair explanations covering the importance and uses of fossil fuels.	Poor explanations on the importance and uses of fossil fuels.	
<i>Presentation of finding as an awareness in the school (10 marks)</i>	Work presented is clear on the chart, oral presentation is loud and clear and confidence is clearly portrayed	Good presentation of the awareness, that is poster was logic but oral presentation and confidence were moderate	Fair presentation of the awareness, that is poster had few inconsistency on the findings and oral presentation and confidence was fair	Poor presentation of the awareness, poster work was oral presentation was inaudible and general lack in confidence during presentation	

Recommended Resources:

- <https://topdifferences.com/difference-between-renewable-resources-and-non-renewable-resources/>
- www.png.OreSomeResources.com

Sample 4 : STEAM Assessment

(Integrated Strands in relation to the project from integrated subjects)

Unit: (Integrated Units from all Subjects in this project)

Content Standard: (Integrated Content Standard from all Subjects in project)

Benchmark: (Integrated Benchmarks from all Subjects in this project)

Topic: (Integrated Topics from all Subjects in this project)

Lesson topic: (Integrated Topics from all Subjects in concern)

Instructional Objective (s): Students will be able to;

- Create a STEAM project “building a prototype model of a catapult launching system” to enhance their understand of this concept

VASK-MT	
Values/Attitudes	Appreciate the beauty of the application of mathematics during the designing process of the project.
Skills	Calculating size and space Time management and efficiency, Linear measurement and scaling techniques, Calculating mechanical advantage
Knowledge	Size and space Time management and efficiency, Linear measurement and scaling techniques
Mathematical Thinking	Think about how to integrate and apply the mathematical knowledge in the project

What is to be assessed? - (KSAVs)

Integrated subjects concepts used designing the projects.

Purpose of the assessment

To measure students proficiency on the achievement of the benchmarks and learning objectives for integrated subjects in the project. (STEAM Project)

Expected level of proficiency

All students are expected to:

- Build a prototype model of a catapult launching system through integrating concepts learned in other subjects.

Performance Task

Student will carry out a project worth 30 marks that should contribute to the School Learning Improvement Program (SLIP). This project will assess students proficiency on the mentioned benchmarks. In order for this assessment type to attain its intended purpose the following must be done carefully;

Task: Students will be given a month to complete this project.

1. All grade 12 Science teachers discuss the STEAM project with their HOD
2. The Science HOD brings this project to the attention of the Head Teacher hence it will involve the learning of all grade 12 classes in the school.
3. Once approved by the Head Teacher, the Science HOD now convenes a meeting with all other subject HOD to integrate this project into their learning. HOD for Science will have developed criteria already and will discuss around that.
4. The HOD for other subjects meet with their respective subject teachers to gauge their views and write up criteria's with reference to the theme of the project, "STEM Design and Engineering Challenge" bringing out the essence of their subjects in this project.
5. The Head Teacher then convenes a meeting with all teachers as they are now aware of the project. HOD for respective subjects give feedback from their meetings. Issues concerning this project must be ironed out and all subjects now carry out this assessment, starting with Science.

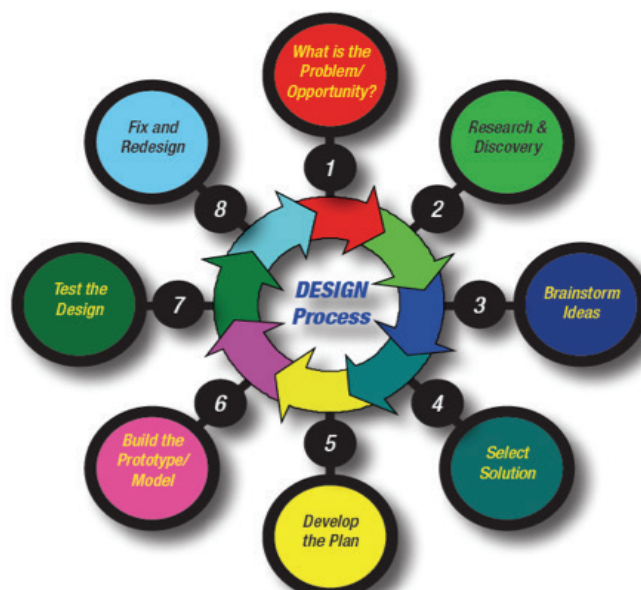
The grade 12 Science teachers will now do the following;

- (i) Group the students into groups of 6 to design (drawing and manual) a tangible technology that will enhance the notion of "building a prototype model of a catapult launching system"
- (ii) The teacher then assesses their designs and the best designs now compete with the other best designs from other grade 12 classes.
- (iii) All the best designers now create models of their designs with assistance from their class members. At this stage the other subjects now carry forward this assessed projects theme, 'building a prototype model of a catapult launching system" however in the context of their subjects. STEAM is an integrated approach of teaching. All subjects must

incorporate the theme put forward by Science. They develop criteria that should address this theme. For instance; Technology and Industrial Arts (TIA) will develop criteria that will engage the students to construct the models. Mathematics teachers will develop criteria to test students' knowledge of the Mathematical thinking process of Engineering Design thinking when they create the models around the theme of "prototype model of a catapult launching system". The English subject teachers will set criteria and guidelines for students on how to write reports so they write to tell others what they have learned and experienced. They must also be given guidelines to writing report. Students get to write report of how they designed this technology. The Science teacher will provide criteria for the students in terms of the physical, chemical, biological and geological properties of the materials used to work out the size and shape of the technology.

Task: Students will be given 6 weeks to complete this project. They are to;

- Design and build a prototype model of a catapult launching system that is easy to use and easy to transport.
- Follow the Design Process to prepare their prototype model in time.
- Write and prepare a short presentation to explain the catapult that was built and the process of building it.



Design Specification:

The catapult should be designed to launch a golf ball at least fifteen feet, to a 18cm x 18cm target.

- The catapult should include a system for determining range, reliability, and accuracy.
- The catapult should be mobile, yet stable. Outriggers or other support systems need to be included to maintain stability when the launcher is used.
- The catapult should be no larger than 30cm long x 30 cm deep x 90cm tall.
- The catapult should feature a locking pin or trigger that activates the catapult to launch.
- Your team should prepare to deliver a presentation about the merits of your catapult model and design.

Assessment Strategy

Design Project will be used to measure student's proficiency.

The students will be reinforced in the following STEAM concepts.

Science

- Applications of simple machines, including wheels and axles, levers, and pulleys
- Balance and equilibrium
- Energy transformations, such as rotary motion to linear motion
- Mechanical advantage

Technology and Engineering

- Prototyping and modelling
- Invention and innovation
- Structural integrity/strength
- Brainstorming and problem solving
- Trial and error engineering concepts

Arts

- Sketching and painting

Mathematics

- Calculating size and space
- Time management and efficiency
- Linear measurement and scaling techniques
- Calculating mechanical advantage

Project Rubric

Category	Advanced	Satisfactory	Partial Credit	Unacceptable
	9 -10 points	7- 8 points	1 - 6 points	0 points
Quality/ Workmanship	Maximum effort was put forth to complete the project in a professional manner. Project demonstrates a high degree of quality and attention to detail. Workmanship is excellent.	Some effort was made to complete the project to a level that was sufficient for grading, but does not meet a professional level of quality or appearance. Workmanship is of acceptable quality.	Minimal effort was made to complete the project and the quality and workmanship is sub-par, but still meets the minimal standard.	Little or no effort was made to produce a quality project. Project obviously does not meet minimal standards.
Creativity/ Design	Project reflects many fundamental elements of design and creativity. Project demonstrates an advanced understanding of creative thinking and attention to aesthetics and presentation.	Project reflects some of the elements of design and creativity, but lacks attention to aesthetics and presentation.	Project was completed, but does not reflect the acceptable levels of design and creativity. Effort was minimal and project is mediocre at best.	Project was not completed on time or reflects little or no effort to complete assignment at an acceptable level.
Functionality	Project meets or exceeds the design requirements of purpose and functionality. All elements of the design have been met and the project does what it was designed to do.	Project meets some of the design requirements of purpose and functionality. Not all elements of the design have been met, but the project does what it was designed to do.	Project is somewhat functional, but reflects minimal effort. It is intermittent and doesn't always do what it was designed to do.	Project does not work and demonstrates a lack of effort or understanding of the basic elements of functionality and purpose.
Design Process	Project reflects a clear understanding and application of design process including evidence of research, brainstorming, design and problem solving, prototyping and testing.	Project reflects some understanding and application of accepted design loop principles and sequence including evidence of research, brainstorming, design and problem solving, prototyping and testing.	Project reflects minimal understanding and application of design process.	Project does not show evidence that design process was used. Project does not meet accepted levels of design criteria.
Criteria/ Constraints	Project was completed with all constraints and criteria met or exceeded. Reflects attention to detail and quality.	Project was completed with some of the constraints and criteria met. Reflects some attention to detail, but quality is minimal.	Project was completed with a few of the constraints and criteria met. Reflects minimal effort and lacks detail or quality.	Project was not completed and does not reflect the adherence to the constraints or criteria.

Time Management	Project completed and turned in on time. Student worked diligently when project time was available. Student was on task most of the time.	Project was completed, but had notable errors. Student utilized project time somewhat efficiently, but spent time socializing. Student was on task 70% - 80% of the time.	Project was not turned in on time and/or complete. The student was on task less than 60% of the time.	Project was not turned in on time and was not completed. Student wasted project time and at times was disruptive to others.
Resource Management	Always takes responsibility for use and care of all building components and resources. Always returns building components and materials to proper storage compartments.	Consistently takes responsibility for use and care of building components and resources. Somewhat consistent in returning building components to proper storage compartments.	Sometimes takes responsibility for use and care of building components and resources. Inconsistent in returning building components to proper storage compartments.	Does not take responsibility for the proper use and care of building components and resources. Is careless and does not practice proper storage and safety practices.
Teamwork	Notable teamwork shown with a determination to participate/contribute to team success. Completed required individual tasks that contributed to the success of the team.	Teamwork was noted, but was sometimes off task or working on non-related tasks. Contributed to the success of the team, but could have been more engaged to complete tasks sooner.	Notable time off-task with minimal effort given for team success, or did the project alone without relying on others to do their share of the project.	Was not a team player. Either took over project completely, or did not engage in team direction or plans.
Writing/ Reflection	Writing/reflection is very well organized and explained. Student includes all details in design process. Document has almost no grammatical errors.	Writing/reflection is somewhat organized and explained. Student includes most details in design process. Document has very few grammatical errors.	Writing/reflection is not organized and explained. Student includes only a few details in design process. Document has many grammatical errors.	Writing/reflection is incomplete or not turned in. Student includes no details in design process. Document has many grammatical errors.
Presentation	Presentation was well organized and presented in a logical sequence. Presentation reflects a full knowledge of the topic with clear answers and explanations to questions asked.	Presentation was fairly organized and most information presented in a logical sequence. Answers to questions were vague or lacked clarity or accuracy.	Presentation was unorganized and lacked a logical sequence. Presentation reflected little attention to detail. Answers to questions were inaccurate and confusing.	Presentation was not acceptable and reflects a lack of organization or knowledge of the topic. Presentation shows little effort to meet expectations.

Checklist

Checklists contain lists of behaviours, traits or characteristic that can be scored on a yes/no, present/absent or 0/1 basis. Checklist is similar to rating scales however the basic difference between them is the judgement needed.

- checklist = yes/no
- rating scale = one has to indicate the degree to which a character is present or the frequency with which a behaviour occurs.

To obtain the most information possible observers need to develop a checking system which is organised, easy to use and time efficient.

Sample Checklist

Topic: Geological Equipment

Hand Lens – Task:

1. Identifying the parts of a petrographic microscope.
2. Describing the function of each parts of a petrographic microscope.

Checklist: Place a tick in the following boxes.

Identifying and describing parts and functions of petrographic microscope	Yes	No
Correctly, identifying and describing the Ocular and its function.		
Correctly, identifying and describing the Bertrand lens and its function.		
Correctly, identifying and describing the analyser and its function.		
Correctly, identifying and describing the slot and its function.		
Correctly, identifying and describing the objective and its function.		
Correctly, identifying and describing the stand and its function.		
Correctly, identifying and describing the stage and its function.		
Correctly, identifying and describing the condenser and its function.		
Correctly, identifying and describing the polariser and its function.		
Correctly, identifying and describing the focus and its function.		
Correctly, identifying and describing the condenser and its function.		
Correctly, identifying and describing the illumination system and its function.		

Rating Scale

Rating Scales are a type of checklist that judge the degree to which a criteria is met. So they often use a rating scale. They generally have a scale of between 1-6 options.

Types of Rating Scales

1. Frequency Rating Scale (Consistency) e.g. Always, Sometimes, Rarely, Never
2. Grade Rating Scale. i.e. A, B, C, D
3. Number scales, e.g. Not all true

Very true

2 2 3 4 5

Like checklists they are easy to administer, develop and understand although they are more subjective. They are very effective for peer assessment activities which measures one criteria or performance standard at a time.

Glossary

This section presents important and new terminologies used in the Teacher Guide. Geology terms and definitions used in programming, teaching, learning and assessment.

Word	Definition
Accretionary wedge	A mass of sediment that is transferred from a subducting plate to the less dense overriding plate with which it converges.
Andesite	The dark, aphanitic, extrusive rock that has a silica content of about 60% and is the second most abundant volcanic rock.
Anticline	A convex fold in rock, the central part of which contains the oldest section of rock. See also syncline.
Asthenosphere	A layer of soft but solid, mobile rock comprising the lower part of the upper mantle from about 100 to 250 km beneath the Earth's surface. See also lithosphere.
Atmosphere	The great volume of gas that is held immediately above the Earth's surface by the Earth's gravitational attraction. It consists mostly of two elements – nitrogen (77%) and hydrogen (21%).
Atmospheric layers	The layering of atmosphere – troposphere, stratosphere, mesosphere and thermosphere.
Banded iron formation	A rock that is made up of alternating light silica-rich layers and dark-coloured layers of iron-rich minerals deposited more than 2.5 billion years ago.
Basalt	The dark, dense, aphanitic, extrusive rock that has a silica content of 40-50% and makes up most of the ocean floor. Basalt is the most abundant volcanic rock in the Earth's crust.
Basin	A round or oval depression in the Earth's surface, containing the youngest section of rock in its lowest, central part.
Batholith	A massive discordant pluton with a surface area greater than 100 km ² , typically having a depth of about 30 km. Batholiths are generally found in elongated mountain ranges after the country rock above them has eroded.
Bedding	The division of sediment or sedimentary rock into parallel layers (beds) that can be distinguished from each other by such features as chemical composition and grain size.
Big Bang theory	Postulates that a primeval fireball, from which the Universe is thought to have evolved, contained all the matter and energy of the Universe. This matter is now distributed throughout the Universe as galaxies, stars, gas and dust.
Bioclastic sediment	Sediment made up of shelly material, fragments of coral, bryozoan and algae.
Bitumen	Any of a group of solid and semi-solid hydrocarbons that can be converted into liquid form by heating. Bitumen can be refined to produce such commercial products as gasoline, fuel oil, and asphalt.

Bituminous coal	A shiny black coal that develops from deeply buried lignite through heat and pressure. It has a carbon content of 80% to 93%, which makes it a more efficient heating fuel than lignite.
Breccia	A clastic rock composed of particles more than 2 mm in diameter and marked by the angularity of its component grains and rock fragments.
Cainozoic era	The latest era of the Phanerozoic Eon, following the Mesozoic era and continuing to the present time, and marked by the presence of a wide variety of mammals, including the first hominids.
Calcite	CaCO_3 ; the dominant mineral in limestone and marble and the most common carbonate.
Caprock	Comparatively impervious stratum overlying an oil- or gas-bearing rock. See also seal.
Cementation	The diagenetic process by which sediment grains are bound together by precipitated minerals originally dissolved during the chemical weathering of pre-existing rocks.
Chemical sediment	Sediment that is composed of previously dissolved minerals that have either precipitated from evaporated water or been extracted from water by living organisms and deposited when the organisms died or discarded their shells.
Chemical sedimentary rock	Sedimentary rocks derived from living organisms. Common examples of this include fossiliferous limestones and coal.
Chalk	Limestone in which the fragments are skeletal remains of microscopic plants and animals.
Chert	A member of a group of sedimentary rocks that consist primarily of microscopic silica crystals. Chert may be either organic or inorganic, but the most common forms are inorganic.
Chilled margin	The border of an igneous intrusion; of relatively finer grain size than the interior of the rock mass due to more rapid cooling.
Clastic	Being or pertaining to a sedimentary rock composed primarily from fragments of pre-existing rocks or fossils.
Cleavage	The tendency of certain minerals to break along distinct planes in their crystal structures where the bonds are weakest.
Clastic sedimentary rock	Sedimentary rock predominantly consists of grains.
Clinometer	A geological equipment for measuring the dip of a bedding plane with respect to the horizontal.
Coal	A member of a group of easily combustible, organic sedimentary rocks composed mostly of plant remains and containing a high proportion of carbon.
Coalification	The process of coal formation
Compaction	The diagenetic process by which the volume or thickness of sediment is reduced due to pressure from overlying layers of sediment.
Compass	A tool used by geologist for finding his direction and working his way around in the field.
Compression	Stress that reduces the volume or length of a rock, as that produced by the convergence of plate margins.

Conglomerate	A clastic rock composed of particles more than 2 mm in diameter and marked by the roundness of its component grains and rock fragments.
Constructive margin	Mid-ocean ridge plate boundary where new lithosphere is created along the spreading axis of the ridge.
Contact metamorphism	Metamorphism that is caused by heat from a magmatic intrusion. Also called thermal metamorphism.
Continental collision	The convergence of two plates that includes continents, resulting in the formation of mountain ranges.
Continental drift	The hypothesis, proposed by Alfred Wegener, that today's continents broke off from a single supercontinent and then flowed through the ocean floors into their present positions. This explanation of the shapes and locations of the Earth's current continents evolved into the theory of plate tectonics.
Convection cell	The cycle of movement in the asthenosphere that causes the plates of the lithosphere to move. Heated material in the asthenosphere becomes less dense and rises toward the solid lithosphere, through which it cannot rise further. It therefore begins to move horizontally, dragging the lithosphere along with it and pushing forward the cooler, denser material in its path. The cooler material eventually sinks down lower into the mantle, becoming heated there and rising again, continuing the cycle. See also plate tectonics.
Convergence	The coming together of two lithospheric plates. Convergence causes subduction when one or both plates is oceanic, and mountain formation when both plates include continental lithosphere. See also divergence.
Core	The innermost layer of the Earth, consisting primarily of pure metals such as iron and nickel. The core is the densest layer of the Earth, and is divided into the outer core, which is molten, and the inner core, which is solid. See also crust and mantle.
Coriolis effect	The deflection of wind flowing to the equator to the right (north) or left (south) due to the Earth's rotation.
Country rock	The rock intruded by and surrounding an igneous intrusion.
Cross-bedding	Bedding made of particles dropped from a moving current, as of wind or water, and marked by a downward slope that indicates the direction of the current.
Crossed polars	In a polarising microscope, two polarised plates that are oriented so that the transmission planes of polarised light are at right angles.
Crust	The outermost layer of the Earth, consisting of relatively low-density rocks. See also core and mantle.
Crude oil	Refers to oil produced from wells and has not been refined.
Detritus	Material which is not easily dissolved by surface water or groundwater surviving from the original source rock.
Diagenesis	The set of processes that cause physical and chemical changes in sediment after it has been deposited and buried under another layer of sediment. Diagenesis may culminate in lithification.
Deformation	General term for the process of folding, faulting, shearing compression or extension of rocks because of various Earth forces.

Dike	A tabular body of intrusive rock, commonly steeply inclined or near-vertical cuts across bedding. See also sill.
Diorite	Intrusive phaneritic rock of intermediate composition, plutonic equivalent of andesite.
Dip	The angle between the horizontal and a line in the plane of the bed; measured perpendicular to strike to get the true dip.
Divergence	The process by which two lithospheric plates separated by rifting move further apart, with soft mantle rock rising between them and forming new oceanic lithosphere. See also convergence.
Dolomite	Similar properties to calcite but usually must be scratched before the powder will react with acid.
Earth	The third planet in the Solar System and the planet we live on.
Earthquake	A movement within the Earth's crust of mantle, caused by the sudden rupture or repositioning of underground rocks as they release stress.
Evaporation	The change from liquid to gas.
Evaporite	An inorganic chemical sediment that precipitates when the salty water in which it had dissolved evaporates
Evolution	Theory that life on Earth has developed gradually, generally from simple to complex, by change and branching of species.
Extinction	Time at which species ceases to exist.
Extrusive rock	An igneous rock that has reached the Earth's surface, characterised by rapid solidification and grains that are so small as to be barely visible to the naked eye.
Fault	A fracture dividing the rock into two sections that have visibly moved relative to each other
Felsic	Light coloured igneous rocks
Fold	A bend that develops in an initially horizontal layer of rock, usually caused by plastic deformation
Foliation	Planar structure resulting from the near-parallel alignment of flaky or tabular minerals (e.g., micas).
Fossil	The remains of ancient organisms, or other evidence of their existence, that has been preserved in geological material.
Fossil fuel	A non-renewable energy resource, such as oil, gas or coal, that derives from the organic remains of past life. Fossil fuels primarily consists of hydrocarbons.
Gabbro	Dark, dense, phaneritic, intrusive rock; the plutonic equivalent of basalt.
Galaxy	Large system of stars, nebulae, star clusters, globular clusters, and interstellar matter.
Geological hammer	A tool use by geologists to break up rock samples and check their mineral contents and other information.
Geological map	A pictorial record of surface or underground geological data, geological mapping is the most essential and first role undertaken by the geologist.
Geological techniques	Techniques used by geologist to study the Earth, mostly include acquiring and interpreting surface and subsurface geological data.

Geological time scale	The division of all of Earth history into blocks of time distinguished by geologic and evolutionary events, ordered sequentially and arranged into eons made up of eras, which are in turn made up of periods, which are in turn made up of epochs.
Geologist	A person who studies the Earth, its origins and evolution, the materials it is made up of, and the processes that act on it.
Geology	The scientific study of the Earth, its origins and evolution, the materials it is made up of, and the processes that act on it.
Global positioning system	A modern tool used in geological mapping. This modern technology is not only used by geologist but nearly everyone.
Gneiss	A coarse-grained, foliated metamorphic rock marked by bands of light coloured minerals such as quartz and feldspar that alternate with bands of dark-coloured minerals. The alternation develops through metamorphic differentiation.
Graben	A block of rock that lies between two faults and has moved downward to form a depression between the two adjacent fault blocks. See also horst.
Graded bedding	Bedding formed by the deposition of sediment in relatively still water, marked by the presence of particles that vary in size, density, and shape, with the coarsest particles at the bottom and the finest at the top.
Granite	A felsic, plutonic rock that contains potassium and sodium feldspars, micas and possibly amphibole, and has a quartz content of about 10%. Granite is commonly found on continents but is virtually absent from the ocean basins.
Greenhouse effect	Short wavelength visible light waves from the Sun penetrates the atmosphere (or the glass) and are absorbed. The surface heats up and re-radiates long wavelength infra-red waves which are trapped by the atmosphere and cloud (or the glass).
Greenhouse gases	These gases are carbon dioxide, water vapour, methane, chlorofluorocarbons, nitrous oxide and ozone. CO ₂ and N ₂ O have an atmospheric residence time of 1,000 to 10,000 years.
Hand lens	A form of magnifying glass use by geologists to observe the grain and mineral content in a sample of rock.
Hardness	The degree of resistance of a given mineral to scratching, indicating the strength of the bonds that hold the mineral's atoms together. The hardness of a mineral is measured by rubbing it with substances of known hardness.
Hornfels	A hard, dark-coloured, dense metamorphic rock that forms from the intrusion of magma into shale or basalt.
Horst	A block of rock that lies between two faults and has moved upward between the two adjacent fault blocks. See also graben.
Hot spot	An area in the upper mantle, ranging from 100 to 200 km in width, from which magma rises in a plume to form volcanoes. A hot spot may endure for 10 million years or more.
Relative humidity	The ratio of the amount of moisture in the air to the total moisture that can be absorbed by air at that temperature.
Hydrocarbon	A molecule that is entirely made up of hydrogen and carbon.

Hydrological cycle	The perpetual movement of water among the mantle, oceans, land, and atmosphere of the Earth.
Igneous rock	A rock made from molten (melted) or partially molten material that has cooled and solidified.
Index fossil	The fossil of an organism known to have existed for a relatively short period of time. Index fossils are used to date the rocks in which they are found.
Inner core	The central part of the Earth's core, extending from a depth of about 5100 km to the centre.
Intertropical convergence zone	Equator ward movement of air in both hemispheres which converges.
Intrusive rock	An igneous rock that has entered a host rock.
Island arc	Composite volcanoes and calderas found on the continental side of deep ocean trenches marking zone of subduction.
Lava	Molten silicate magma reaching the surface and being extruded by a volcano or volcanic fissure.
Limestone	A sedimentary rock composed primarily of calcium carbonate. Some 10 to 15% of all sedimentary rocks are limestones. Limestone is usually organic, but it may also be inorganic.
Lithification	The conversion of loose sediment into solid sedimentary rock.
Lithosphere	A layer of solid, brittle rock making up the outer 100 km of the Earth, encompassing both the crust and the outermost part of the mantle. See also asthenosphere.
Mafic	Dark coloured igneous rock
Magma	Molten (melted) rock that forms naturally within the Earth. Magma may be either liquid or a solid mixture of liquid, crystals, and dissolved gases.
Magnetic reversal	The process by which the Earth's magnetic north pole and its magnetic south pole reverse their positions over time.
Mantle	The middle layer of the Earth, lying just below the crust and consisting of relatively dense rocks. The mantle is divided into two sections: the upper mantle and the lower mantle. The lower mantle has greater density than the upper mantle. See also core and crust.
Marble	A coarse-grained, non-foliated metamorphic rock derived from limestone and dolostone.
Marine magnetic anomaly	An irregularity in magnetic strength along the ocean floor that reflects sea floor spreading during periods of magnetic reversal.
Mesozoic era	The intermediate era of the Phanerozoic Eon, following the Palaeozoic Era and preceding the Cainozoic Era, and marked by the dominance of marine and terrestrial reptiles, as well as the appearance of birds, mammals, and flowering plants.
Maturation	The extent to which the organic matter, which will later form oil and gas, is 'cooked' in the source rock.
Metamorphic rock	A rock that has been changed by heat, pressure or chemical reaction.

Metamorphism	The process by which conditions within the Earth, below the zone of diagenesis, alter the mineral content, chemical composition, and structure of solid rock without melting it. Igneous, sedimentary, and metamorphic rocks may all undergo metamorphism.
Metasomatism	The replacement of one mineral or mineral assemblage by others of different chemical composition without the development of a melt-phase.
Mid-ocean ridge	Site of volcanism and shallow earthquake activity at a plate boundary.
Migration	The movement of hydrocarbons from source to the reservoir or between reservoirs.
Migmatite	A high-grade metamorphic rocks parts of which have been mobilised as melt.
Mineral	A naturally occurring, usually inorganic, solid consisting of either a single element or a compound and having definite chemical composition and a systematic internal arrangement of atoms.
Moh's hardness scale	Ten minerals numbered on the basis that a mineral higher in the scale scratches one lower in the scale.
Mould	A hollow form or matrix for giving a particular shape to something in a molten or plastic state
Mudstone	A detrital sedimentary rock composed of fine-grained particles.
Nebula hypothesis	Kant and Laplace suggested that the Sun and the planets condensed from a rotating disc of gases and dust, called the solar nebula.
Normal fault	A dip-slip fault along which the hanging wall has moved downward relative to the footwall.
Ocean trench	A deep, linear, relatively narrow depression in the sea floor, formed by the subduction of oceanic plates.
Palaeozoic era	The earliest era of the Phanerozoic Eon, marked by the presence of marine invertebrates, fish, amphibians, insects, and land plants.
Pangaea	Means 'all the continents', supercontinent which broke up by continental drift in the Mesozoic and Cainozoic.
Permeability	The capability of a given substance to allow the passage of a fluid. Permeability depends on the size and degree of the connections between pore spaces.
Petrographic microscope	Microscope used for studying thin sections in polarised light.
Petroleum	Any of a group of naturally occurring substances made up of hydrocarbons. These substances may be gaseous, liquid, or semi-solid.
Phyllite	A foliated metamorphic rock that develops from slate and is marked by silky sheen.
Plate tectonics	The theory that the Earth's lithosphere consists of large, rigid plates that move horizontally in response to the flow of asthenosphere beneath them, and that interactions among the plates at their borders cause most major geologic activity, including the creation of oceans, continents, mountains, volcanoes and earthquakes.
Pluton	A large body of igneous rock that was emplaced at some depth in the Earth's crust.
Plutonic rock	An intrusive rock formed inside the Earth.

Polarised light	Consists of light rays vibrating in only one plane (unpolarised light consists of light rays vibrating in all planes through 360°).
Porosity	The percentage of a soil, rock, or sediment's volume that is made up of pores.
Principle of cross-cutting relationships	The scientific law stating that a pluton is always younger than the rock that surround it.
Principle of faunal succession	The scientific law stating that specific groups of animals have followed, or succeeded, one another in a definite sequence through Earth's history.
Principle of original horizontality	The scientific law stating that sediments settling out from bodies of water are deposited horizontally or nearly horizontally in layers that lie parallel or nearly parallel to the Earth's surface.
Principle of superposition	The scientific law stating that, in any unaltered sequence of rock strata, each stratum is younger than the one beneath it and older than the one above it, so that the youngest stratum will be at the top of the sequence and the oldest at the bottom.
Principle of uniformitarianism	The scientific law stating that the geological processes taking place in the present operated similarly in the past and can therefore be used to explain past geological events.
Pyroclastics	(used in the plural) Particles and chunks of igneous rock ejected from a volcanic vent during an eruption.
Quartzite	An extremely durable, non-foliated metamorphic rock derived from pure quartz sandstone.
Recrystallisation	The diagenetic process by which unstable minerals in buried sediment are transformed into stable ones.
Regional metamorphism	Metamorphism that affects rocks over vast geographic areas stretching for thousands of square kilometres.
Replacement	Process of practically simultaneous solution and deposition by which a new mineral of differing chemical composition may grow in the body of an old mineral.
Reservoir rock	A permeable rock containing oil and gas.
Reverse fault	A dip-slip fault marked by a hanging wall that has moved upward relative to the footwall. Reverse faults are often caused by the convergence of lithospheric plates.
Rhyolite	A felsic igneous rock that is the extrusive equivalents of granite.
Rifting	The tearing apart of a plate to form a depression in the Earth's crust; may eventually separate the plate into two or more smaller plates.
Ripple marks	A pattern of wavy lines formed along the top of a bed by wind, water currents, or waves.
Rock	A naturally formed aggregate of usually inorganic materials from within the Earth.
Rock cycle	A series of events through which a rock changes, over time, between igneous, sedimentary, and metamorphic forms.
Roundness	Refers to the shape of the corners of a grain viewed in two dimensions.
Sandstone	A clastic rock composed of particles that range in diameter from 1/16 – 2 mm. Sandstones make up about 25% of all sedimentary rocks.

Schist	A coarse-grained, strongly foliated metamorphic rock that develops from phyllite and splits easily into flat, parallel slabs.
Sea-floor spreading	The formation and growth of ocean basins that occurs following rifting and is characterised by eruptions along mid-ocean ridges, forming new oceanic lithosphere, and expanding oceans. See also divergence.
Seal	Comparatively impervious stratum overlying an oil- or gas-bearing rock. See also caprock
Sediment	A collection of transported fragments or precipitated materials that accumulate, typically in loose layers, as of sand or mud.
Sedimentary environment	The continental, oceanic, or coastal surroundings in which sediment accumulates.
Sedimentary rock	A rock made from the consolidation of solid fragments, as of other rocks or organic remains, or by precipitation of minerals from solution.
Shale	A sedimentary rock composed of very fine detrital sediment.
Silicate	One of the several rock-forming minerals that contain silicon, oxygen, and usually one or more other common elements.
Sill	A tabular body of intrusive rock that may be sub-horizontal or shallow-dipping and may be conformable with bedding in the host rock.
Skarn	Iron-enriched rock containing abundant garnet and pyroxene produced by contact metamorphism in a limestone.
Slab pull	A subducted slab of oceanic lithosphere is denser than the adjacent upper mantle rocks and so will sink through the upper mantle. Slab pull may be a driving force of plate motion.
Slate	A fine-grained, foliated metamorphic rock that develops from shale and tends to break into thin, flat sheets.
Solar nebula	Rotating disc of gas and dust from which the Sun and planets condensed.
Sorting	The process by which a given transport medium separates out certain particles, as on the basis of size, shape, or density.
Source rock	A rock from which oil and gas originate.
Sphericity	The extent to which a grain approaches the shape of a sphere or cube.
Streak	The colour of a mineral in its powdered form. This colour is usually determined by rubbing the mineral against an unglazed porcelain slab and observing the mark made by it on the slab.
Strike	1. The horizontal line marking the intersection between the inclined plane of a solid geological structure and the Earth's surface. 2. The compass direction of this line, measured in degrees from true north.
Strike-slip fault	A fault in which two sections of rock have moved horizontally in opposite directions, parallel to the line of the fracture that divided them.
Subduction	The sinking of a slab of oceanic lithosphere as a result of convergence with a plate of lesser density. Subduction causes earthquakes and may trigger volcanic activity.
Syncline	A concave fold, the central part of which contains the youngest section of rock. See also anticline.

Tephra	(plural noun) Pyroclastic materials that fly from an erupting volcano through the air before cooling, and range in size from fine dust to massive blocks.
Terrane	Fault-bounded blocks of rock that formed elsewhere but have been subsequently added to a continent as a result of plate convergence.
Terrigenous	Clastic rocks consisting of material eroded from the land surface.
Texture	Aspects of the particles in a rock, including size, shape and arrangement.
Thermal plume	A vertical column of upwelling mantle material, 100 to 250 km in diameter that rises from beneath a continent or ocean and can be perceived at the Earth's surface as a hot spot. Thermal plumes carry enough energy to move a plate, and they may be found both at plate boundaries and plate interiors.
Thrust fault	A reverse fault marked by a dip of 45° or less.
Trace fossil	Disruption of sediment by the normal activity of animals; tracks, trails or animal burrows.
Transform fault	A strike-slip fault that connects two other plate boundaries.
Trap	A geometrical arrangement of geological strata to contain the migrating oil and gas; can be structural, stratigraphic or a combination of these.
Ultramafic	Rocks that are extremely mafic, having very high iron and magnesium.
Unconformity	A boundary separating two or more rocks of markedly different ages, marking a gap in the geologic (rock) record.
Volcanic arc	A chain of volcanoes, commonly arc-shaped on plan view, fed by magma that rises from the mantle above a subducted slab.
Volcaniclastic	Clastic sediment made up of clasts of volcanic origin. Also referred to as volcanogenic.
Volcano	Magma (molten rock) that reaches the Earth's surface in the form of pyroclastics (explosive) or lava flow (non-explosive).
Wadati-Benioff zone	A dipping planar zone where the subduction of oceanic plates causes earthquakes.

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Appendices

Appendix 1: Bloom's Taxonomy

LEVEL OF UNDERSTANDING	KEY VERBS
CREATING Can the student create a new product or point of view?	Construct, design, and develop, generate, hypothesize, invent, plan, produce, compose, create, make, perform, plan, produce, assemble, formulate,
EVALUATING Can the student justify a stand or decision?	Appraise, argue, assess, choose, conclude, critique, decide, defend, evaluate, judge, justify, predict, prioritize, provoke, rank, rate, select, support, monitor,
ANALYSING Can the student distinguish between the different parts?	Analysing, characterize, classify, compare, contrast, debate, criticise, deconstruct, deduce, differentiate, discriminate, distinguish, examine, organize, outline, relate, research, separate, experiment, question, test,
APPLYING Can the student use the information in a new way	Apply, change, choose, compute, dramatize, implement, interview, prepare, produce, role play, select, show, transfer, use, demonstrate, illustrate, interpret, operate, sketch, solve, write,
UNDERSTANDING Can the student comprehend ideas or concepts?	Classify, compare, exemplify, conclude, demonstrate, discuss, explain, identify, illustrate, interpret, paraphrase, predict, report, translate, describe, classify,
REMEMBERING Can the student recall or remember the information?	Define, describe, draw, find, identify, label, list, match, name, quote, recall, recite, tell, write, duplicate, memorise, recall, repeat, reproduce, state,

Appendix 2: 21st Century Skills

WAYS OF THINKING	<ul style="list-style-type: none"> Creativity and innovation Think creatively Work creatively with others Implement innovations Critical thinking, problem solving and decision making Reason effectively and evaluate evidence Solve problems Articulate findings Learning to learn and meta-cognition Self-motivation Positive appreciation of learning Adaptability and flexibility
WAYS OF WORKING	<ul style="list-style-type: none"> Communication Competency in written and oral language Open minded and preparedness to listen Sensitivity to cultural differences Collaboration and teamwork Interact effectively with others Work effectively in diverse teams Prioritise, plan and manage projects
TOOLS FOR WORKING	<ul style="list-style-type: none"> Information literacy Access and evaluate information Use and manage information Apply technology effectively ICT literacy Open to new ideas, information, tools and ways of thinking Use ICT accurately, creatively, ethically and legally Be aware of cultural and social differences Apply technology appropriately and effectively
LIVING IN THE WORLD	<ul style="list-style-type: none"> Citizenship – global and local Awareness and understanding of rights and responsibilities as a global citizen Preparedness to participate in community activities Respect the values and privacy of others Personal and social responsibility Communicate constructively in different social situations Understand different viewpoints and perspectives Life and career Adapt to change Manage goals and time Be a self-directed learner Interact effectively with others

Appendix 3: Standards-Based Lesson Plan Template

Standards-Based Lesson Plan (Integrating STEAM)

Topic:

Lesson Topic:

Grade:

Length of Lesson:

National Content Standard

Grade Level Benchmark

Essential Knowledge, Skills, Values, and Attitudes

Knowledge:

Skills:

Values:

Attitudes:

Materials:

- **Lesson Objective:**

Essential Questions:

Lesson Procedure

Teacher Activities	Student Activities
Introduction	
Body	
Guided Practice	
Independent Practice	
Conclusion	

Performance Assessment and Standards

National Content Standard :			
Lesson Topic	Topic	Benchmark	Performance Assessment
	PROFICIENCY RUBRIC		
	Advanced	Proficient	Partially Proficient
			Novice

Appendix 4: Standards-Based Lesson Plan Template-Integrating STEAM

Standards-Based Lesson Plan (Integrating STEAM)

Topic:
Lesson Topic:
Grade:
Length of Lesson:

National Content Standard

Grade Level Benchmark

Essential Knowledge, Skills, Values, and Attitudes

Knowledge:

Skills:

Values:

Attitudes:

STEAM Knowledge and Skill

Knowledge:

Skill:

Performance Indicator:

STEAM Performance Indicator:

Materials:

• **Lesson Objective:**

Essential Questions:

Lesson Procedure

Teacher Activities	Student Activities
Introduction	
Body	
Modelling	
Guided Practice	
Independent Practice	
Conclusion	

Performance Assessment and Standards

National Content Standard :				
Lesson Topic	Topic	Benchmark	Performance Assessment	
	PROFICIENCY RUBRIC			
	Advanced	Proficient	Partially Proficient	Novice

STEAM Activity

Students create a model of a mine that is going to be closed soon shown in the plan and the natural environment that is worth rehabilitating using the values of common good, sustainability, and interdependence; and the attitudes of caring, responsible, and respect.

Appendix 5: Time Allocation

Grade 9 and 10	No. Ln/wk	Min/week	Gr 11 and 12	No. Ln/wk	Min/week
English	6	6 x 40=240	Applied English	6	6 x 40 = 240
Mathematics	5	8 x 40 = 320	L &L	6	6 x 40 = 240
Science	5	5 x 40 =200	Advance Math	8	8 x 40 = 320
Social Science	5	5 x 40 =200	Gen Math	6	6 x 40 = 240
Personal Development	5	5 x 40 =200	Physics	6	6 x 40 = 240
Business Studies	5	5 x 40 =200	Biology	6	6 x 40 = 240
Design & Technology	5	5 x 40 =200	Chemistry	6	6 x 40 = 240
Arts	5	5 x 40 =200	Applied Science	6	6 x 40 = 240
CCVE	3	3 x 40=120	Geology	6	6 x 40 = 240
RI	1	1 x 60 = 60	Geography	6	6 x 40 = 240
Agriculture	5	5 x 40 = 200	History	6	6 x 40 = 240
			Legal Studies	6	6 x 40 = 240
			Health Phy. Educ.	6	6 x 40 = 240
			Physical Educ.	6	6 x 40 = 240
			RE	1	1 x 60 = 60
			Business Studies	6	6 x 40 = 240
			Accounting	6	6 x 40 = 240
			Economics	6	6 x 40 = 240
			Design & Tech	6	6 x 40 = 240
			Computer Studies	6	6 x 40 = 240
			ICT	6	6 x 40 = 240
			CCVE	2	3 x 40 =120
			ANRM	6	6 x 40 = 240

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