COURSE GUIDE

ESM 105
INTRODUCTION TO SEDIMENTARY PETROLOGY

COURSE TEAM Dr. Ede Touyu Adetutu David Uyi (Course Writer) - Mountain Top University
Dr. Agbebaku, Henry Usiobiafo &
Prof. Edafetano C. Ashano (Course Editors)-NOUN

NATIONAL OPEN UNIVERSITY OF NIGERIA

National Open University of Nigeria
Headquarters
University Village
Plot 91, Cadastral Zone
Nnamdi Azikiwe Expressway
Jabi, Abuja

Lagos Office
14/16 Ahmadu Bello Way
Victoria Island, Lagos

E-mail : centralinfo@nou.edu.ng
URL: www.nou.edu.ng

Printed 2024

ISBN: 978-978-786-262-9

Content **Page**

INTRODUCTION

ESM105: Introduction to Sedimentary Petrology is a two-credit unit course designed for undergraduate students of Environmental Science at 100 level. This course is made up of six modules with 18 units. The course will expose the student to a clear understanding of how sedimentary rocks form and evolve as they undergo burial. The knowledge gained will also assist the students and all those who may come across the material in learning more about sediment composition and how this can be used to infer source area characteristics. The course is divided into six modules. Module one deals with the major structures of the Earth and Earth discontinuities. Module two is on the theory of plate tectonics, orogeny, crust movement, mineral resources genesis, diversity and extinction of species. Module three is on the origin, growth of basins and types of basins. Module four is on types of sedimentary rocks, mechanism of sediment deposit, diagenesis, lithification of sediments, structures, textures of sediments and sedimentary rocks. Module five deals with pebble morphometry, mineral composition, and petrographic classification of sandstones and heavy minerals in sedimentary rocks. Module six is on the provenance of sediments and paleoecology.

WHAT YOU WILL LEARN IN THIS COURSE

ESM 105: Introduction to Sedimentary petrology consists of six (6) main components arranged in the form of modules and units. This course deals with the study of the internal structures of the Earth and its constituents, the theory and evidence of plate tectonics. The concepts of orogeny and orogenesis will be discussed. The key processes involved in the formation of mineral resources and their geological settings. The origin and growth of basins will be discussed to explain the complex processes tied to tectonic activity, sedimentary deposition, and erosion, among others. Basins not only shape landscapes but also host vital resources such as water, hydrocarbons, and minerals. Moreso, students will be taught petrographic attributes and origins of terrigenous and carbonate sedimentary rocks and sedimentary particles including fossils and bioclasts as well as other authigenic minerals and precipitates such as sulphates, glauconite and pyrite. It also treats the diagenesis of sediments, including cementation, recrystallisation, silicification and dolomitization. Hands-on microscopy is emphasized. This is to enhance the student's understanding of how sedimentary rocks form and evolve as they undergo burial. This starts with understanding sediment composition and how this can be used to infer source area characteristics. We will study how beginning soon after deposition, sediments become lithified. This includes both chemical and physical transformations that lead to major changes in the original petrophysical (porosity and permeability) characteristics of sediments and sedimentary rocks as lithification and diagenesis occur. Students will be shown how longstanding problems concerning the appropriate identification of detrital minerals can be solved. After a detailed analysis of most groups of heavy minerals, and rock fragments we will illustrate a wide range of examples from real case histories from different geological settings in different areas of the world. The course aims at improving student's capability to extract information from detrital sediments and to collect accurate quantitative mineralogical data. This course is designed to provide a platform for developing skills pertinent to the applied description and analysis of sedimentary rocks. Students will have access to hundreds of rock and thin-section samples. Simply put, the more time spent studying the rock materials presented in this course, the stronger the petrological skill set will become. Presently, there is a high demand for sedimentary petrologists, particularly in the energy industry. This course will provide students with the basic skills needed to work in this capacity.

COURSE OBJECTIVES

The objectives of this course are to equip students with the skill set needed for

- recognition and interpretation of sediment textures in clastic and non-clastic sediments and sedimentary rocks;
- identification and interpretation of grain compositions in siliciclastic sedimentary rocks using standard petrography;
- identification and interpretation of allochemical and orthochemical constituents of non-clastic sedimentary rocks;
- recognition of basic fossil types and their interpretation from thin-section analysis;
- understanding the basic application of XRD, SEM, and SEM-EDS techniques in sedimentary petrology.

LEARNING OUTCOMES

At the end of the course, the students should be able to:

- recognise and identify the mineral and textural characteristics of sedimentary rocks using microscopes;
- describe and classify sedimentary rocks;
- evaluate the origin of sedimentary rocks; and
- interpret the provenance of sedimentary rocks.

COURSE REQUIREMENTS

To complete this course, students are required to read each study unit of the material and other textbooks, journals or any other relevant material that may be provided by the National Open University of Nigeria. Each unit contains multiple choice questions in most cases and at certain points in the course; you would be required to submit assignments for assessment purposes. At the end of the course, there is a final examination. The course should take a total of about 17 weeks to be completed.

COURSE MATERIAL

Students will be provided with the following materials for this course:

1. Course guide: The material you are reading now is called the course guide which introduces you to the course
2. Study guide: This is the textbook prepared for this course by the National Open University of Nigeria. You will be given a copy of the book for your personal use.
3. Textbooks: At the end of each module/unit, a list of textbooks is provided for your consultation. Students are not restricted to the listed textbooks alone though most of the texts used in preparing this course materials were adapted from the referenced books.

STUDY UNITS

Several exercises are provided at the end of each unit to enable the students to brainstorm. This is to enable the students to evaluate themselves on the level of understanding of the various units discussed.

MODULE 1 EARTH STRUCTURES

Unit 1 Major Structures of the Earth
Unit2 Earth Discontinuities

MODULE 2 PLATE TECTONICS

Unit 1 Theory of plate tectonics and plate boundaries
Unit 2 Orogeny and Orogenesis
Unit 3 Crust movement
Unit 4 Mineral resources genesis.
Unit 5 Diversity and Extinction of Species

MODULES 3 BASIN EVOLUTION

Unit 1 Origin and growth of basins
Unit 2 Types of basins

MODULE 4 FORMATION OF SEDIMENTARY ROCKS

Unit 1 Types of sedimentary rocks and mechanism of Sediment deposition
Unit 2 Diagenesis and Lithification of Sediments
Unit 3 Structures and Textures of sediments and Sedimentary rocks

MODULE 5 GRAIN SIZE ANALYSIS

Unit 1 Pebble morphometry
Unit 2 mineral composition of the sedimentary rocks
Unit 3 Petrographic classification of sandstones.
Unit 4 Heavy minerals in sedimentary rocks

MODULE 6 PROVENANCE AND DEPOSITIONAL ENVIRONMENT RECONSTRUCTION

Unit 1 Provenance of sediments
Unit 2 Reconstruction of paleoenvironment, paleoclimate and paleoecology

Many exercises are provided at the end of each unit to enable the students to brainstorm. This is to enable the students to evaluate themselves on the level of understanding of the various units discussed.

TEXTBOOKS AND REFERENCES

The following textbooks will provide further useful information regarding the areas covered in the course. Students are advised to consult more recent textbooks.

Allen, P.A., & Allen, J.R. (2013). Basin Analysis: Principles and Application to Petroleum Play Assessment. Wiley-Blackwell.

Armstrong, H. A., & Brasier, M. D. (2005). *Microfossils*. Blackwell Publishing.

Aulbach, S., Massuyeau, M., and Gaillard, F. (2017), Origins of cratonic mantle discontinuities: A view from petrology, geochemistry and thermodynamic models, Lithos, 268–271, 364–382.

Barnosky, A. D., et al. (2011). *Has the Earth's Sixth Mass Extinction Already Arrived?* Nature.

Boggs, S. Jr. (2016). *Principles of Sedimentology and Stratigraphy*. Pearson.

Calò, M., Bodin, T., and Romanowicz, B. (2016), Layered structure in the upper mantle across North America from joint inversion of long and short period seismic data, Earth Planet. Sci. Lett., 449, 164–175. Chen, L. (2017), Layering of subcontinental lithospheric mantle, Sci. Bull., 62, 1030–1034.

Cardinale, B. J., et al. (2012). *Biodiversity Loss and Its Impact on Humanity*. Nature.

Ceballos, G., Ehrlich, P. R., & Dirzo, R. (2017). *Biological Annihilation Via the Ongoing Sixth Mass Extinction*. PNAS.

Chen, L., Jiang, M., Yang, J., Wei, Z., Liu, C., and Ling, Y. (2014), Presence of an integral-lithospheric discontinuity in the central and western North China Craton: Implications for the destruction of the craton, Geology, 42(3), 223–226.

Chernicoff, S. & Whitney, D. (2007) Geology: an Introduction to Physical Geology (4th edition). Pearson/Prentice Hall, New Jersey.

Craig, J., Vaughan, D. J., & Skinner, B. J. (2001). *Resources of the Earth: Origin, Use, and Environmental Impact*. Prentice Hall.

DePaolo, D. J., Cerling, T. E., Hemming, S. R., Knoll, A. H., Richter, F. M., Royden, L. R., Rudnick, R. L., Stixrude, L., Trfil, J. S., and Linn, A. M. (2008), Origin and Evolution of Earth: Research Questions for a Changing Planet, National Academies Press, Washington, DC.

Evans, A. M. (2013). *Ore Geology and Industrial Minerals: An Introduction*. Wiley-Blackwell.

Frankel, A. (2018). *Seismic Hazard and Risk Analysis*. Springer.

Grotzinger, J., Jordan, T.H., Press, F. & Siever, R. (2007) Understanding Earth (5th edition).

Freeman and Co., New York.

Guilbert, J. M., & Park, C. F. (2007). *The Geology of Ore Deposits*. Waveland Press.

Guria, Dr Narendranath. (2019). "PLATE TECTONIC THEORY". .13140/RG.2.2.21464.44803.

Kearey, P., Klepeis, K. A., & Vine, F. J. (2013). Global Tectonics (3rd ed.). Wiley-Blackwell.

Leeder, M. R. (2011). *Sedimentology and Sedimentary Basins: From Turbulence to Tectonics*. Wiley-Blackwell.

McKenzie, D. (1969). *Speculations on the Consequences and Causes of Plate Motion*.

Geological Society of America Bulletin.

Palin, R., Santosh, M., Cao, W., Li, S., Hernández-Uribe, D., Parsons, A. (2020). Secular Change and the Onset of Plate Tectonics on Earth. Earth-Science Reviews. 207.

10.1016/j.earscirev.2020.103172.

Press, F., & Siever, R. (2001). Understanding Earth (4th ed.). W.H. Freeman and Company.

Prothero, D. R., & Andrews, F. N. (2004). *Sedimentary Geology*. W.H. Freeman.

Rawat, U.S. and Agarwal, N.K. (2015). "Biodiversity: Concepts, Threats and Conservation". Environment Conservation Journal 16(3) 19-28, ISSN 0972-3099 (Print) 2278-5124 (Online).

Robb, L. J. (2005). *Introduction to Ore-Forming Processes*. Wiley-Blackwell.

Schlumberger. (2023). "Basin Types and Their Formation Mechanisms." Schlumberger Oilfield Glossary.

Stanley, S. M. (2009). Earth System History (3rd ed.). W.H. Freeman and Company.

Tarbuck, E. J., Lutgens, F. K., & Tasa, D. (2014). Earth: An Introduction to Physical Geology (11th ed.). Pearson.

Turcotte, D. L., & Schubert, G. (2014). *Geodynamics* (3rd ed.). Cambridge University Press.

Twiss, R. J., & Moores, E. M. (2007). Structural Geology (2nd ed.). W. H. Freeman.

White, C. D., & Hurst, A. (2018). *Introduction to Mineral Exploration*. Wiley-Blackwell.

Wilson, E. O. (1992). *The Diversity of Life*. Harvard University Press.

Zachos, J. C., Dickens, G. R., & Zeebe, R. E. (2008). "An Early Cenozoic Perspective on Greenhouse Warming and Carbon-Cycle Dynamics." *Nature*, 451(7176), 279-283.

MAIN COURSE

CONTENTS

MODULE 1 EARTH STRUCTURES

UNIT 1 MAJOR STRUCTURES OF THE EARTH

Unit Structure

1.1 INTRODUCTION

The Earth is a massive entity which houses all life forms on it. However, this large entity is divided into layers. These layers are called the internal structures of the Earth's interior. These internal structures are four (4); the Earth's Crust, the Mantle, Outer Core and the Inner Core. Each of them possesses their own unique physical and chemical properties which makes them distinct from the other. In this unit, we will be looking at the four (4) internal layers in detail and looking at what depth they can be found within the Earth.

1.2 OBJECTIVES

By the end of this unit, you will be able to:

- identify the different major structures of the Earth.
- discuss the respective distances between one structure of the Earth and the next one
- state the elements which make up each of the different structures of the Earth.
- discuss the physical state of the different structures.

1.3 INTERNAL STRUCTURES OF THE EARTH

1.3.1 The Structures or Layers of the Earth

1) **<u>Crust</u>:** This is the first layer or structural unit of the Earth. It is on this first layer that all living things dwell. It is on it that we have the air we breathe (**Atmosphere**), the water we drink (**Hydrosphere**) and living things (**Biosphere**). It is also referred to as **LITHOSPHERE**. However, the lithosphere can be seen as the rigid portion of the Earth which includes both the crust and the Upper mantle.

The crust is divided into two (2) parts; the **Continental Crust** and **Oceanic Crust**. The Continental Crust is the rigid and hard plates which make the various continents of the Earth. It occupies more than 70km of the Earth's interior under mountains and about 3km - 5km under the Mid-Ocean Ridge (MOR). The Continental Crust has an average thickness of 35km – 40km. Its average density is approximately $2.7g/cm^3$. It is made of mostly granitic rocks. It is composed of mostly **Silica** and **Aluminum** and is thus referred to as **SIAL**. The rocks are light coloured and in geology, we refer to those kinds of rocks as FELSIC or having FELSIC composition. The Oceanic Crust is found beneath the water bodies like Seas and Oceans. Its average thickness is between 7km – 10km. The composition of the rocks in the Oceanic Crust is **Silica** and **Magnesium** and thus are referred to as **SIMA**. The rocks are mostly dark-coloured rocks and are referred to as **MAFIC** rocks or having **MAFIC** composition. The rock types mostly seen are basalt or Gabbro. The density of this portion of the Crust is $3.0g/cm^3$. The difference in density causes the Continental Crust to "Float" on top of the Oceanic Crust.

98.5% of the entire Crust is made up of only eight (8) elements. The most abundant element on the Crust is Oxygen (O). Oxygen combines very easily and it is difficult to find it free. Thus, the silicate (SiO2-based) minerals are in abundance. On an atomic level, Oxygen occupies approximately 93% of the volume of the Crust.

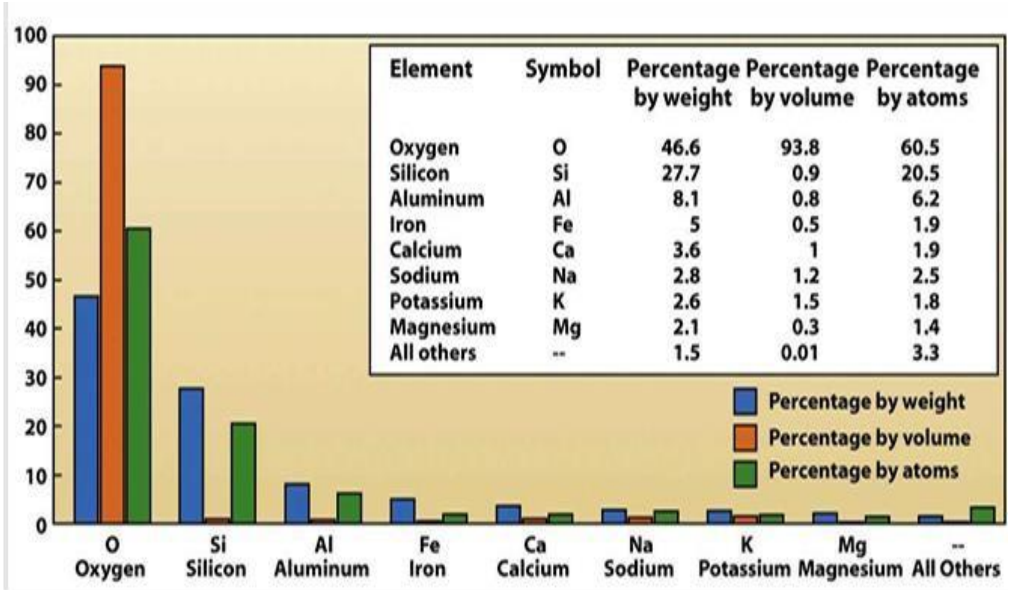

Figure 1: The Elemental Composition of the Earth's Crust Showing the Various
Percentages by Mass and Volume (Source:

2) **<u>MANTLE</u>**: This is the second major structural unit within the Earth. The Uppermost portion of this layer is solid and grouped with the Crust and referred to as **LITHOSPHERE**. Just below the solid portion of the Upper Mantle, there is a semi-solid (molten) portion whereby molten magma is moving, and on which some portion of the Earth above it, glide. This portion of the Upper Mantle is called **ASTHENOSPHERE**. The Crust and the Upper part of the Mantle has a thickness of about 200km. The entire Upper Mantle has a thickness of about 400km.
Previously, Mantle was divided into two zones:

(i) Upper Mantle from Moho's discontinuity to 1000 km depth
(ii) Lower Mantle from 1000 to 2900 km depth.

But now on the basis of discovery by International Union of Geodesy and Geophysics, Mantle is divided into three zones;

Zone/Layer 1: Moho's discontinuity to 200 km depth Zone/Layer 2: 200 – 700 km depth
Zone/Layer 3: 700 – 2900 km depth

The Lower Mantle extends beyond the Asthenosphere and is in a solid state. (Note: This will be explained in Unit 2). The velocity of seismic waves relatively reduces as they move down in the Uppermost Zone of the Mantle for a depth **100km – 200km**. This reduction of velocity of seismic waves within this zone is call the **ZONE OF LOW VELOCITY**.
In summary, the mantle has a topmost part which is in **SOLID STATE**, a middle part (**ASTHENOSPHERE**) which is **Semi-Solid (Molten)**, and the Lower Mantle which is in a **SOLID STATE**.

The entire Mantle is 2,900km and is 82% of the entire earth's volume. The Mantle is composed of **ULTRAMAFIC** (very dark coloured) rock. This means that these rocks are very low in their Silica content. These ultramafic rocks are called **PERDOTITE**. Below approximately 100km **-**150km, the rock is not hot enough to flow. It leads to heat transfer through **CONVECTION**, the hot Mantle rises and the cold Mantle sinks. The density of the entire mantle is 3.3g/cm^3. The entire Mantle is also referred to the **MESOSPHERE**.

3) **<u>OUTER CORE</u>**: This is the third layer of the Earth. It is in liquid state. It is made up of **Iron (Fe)**, **Nickel (Ni)**, and **Sulphur (S).** It has a thickness of **2,255km**. It also has a density of **10g/cm^3 to 12g/cm^3**.

4) **<u>INNER CORE</u>**: this is the fourth and last layer of the Earth. It has a radius of 1,220km. It is made up of two (2) elements; **Iron (Fe)**, **Nickel (Ni)**, form an alloy. It has a **SOLID** physical state. It also has a density of 13g/cm^3.
The core collectively is responsible for Earth's magnetic field generation. It is the responsibility of the **OUTER CORE** to generates the Magnetic field. The entire Core has a radius of **3,471km**. The differing velocities of the seismic waves distinguish the core into **two (2) layers**.
They contain the records and information of the earliest history of accretion of the Earth.

Thermal and compositional features established when the c\Core was formed is largely controlled by the subsequent evolution of the Core and led to the evolution of the Mantle, Crust, and Atmosphere. The entire Core is also referred to as **BARYSPHERE.** The temperature of the Core is estimated to be about **50,000^{0}C**.

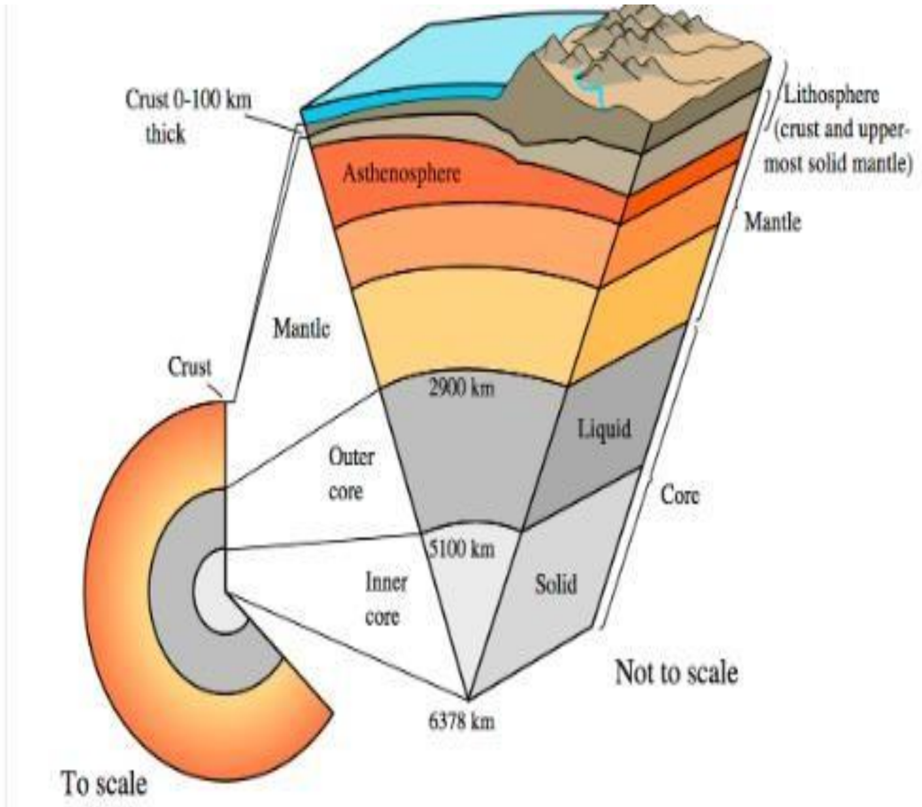

Figure 2: The Structures of the Earth (Source: https://www.iasgyan.in/blogs/discontinuities-inside-the-earth

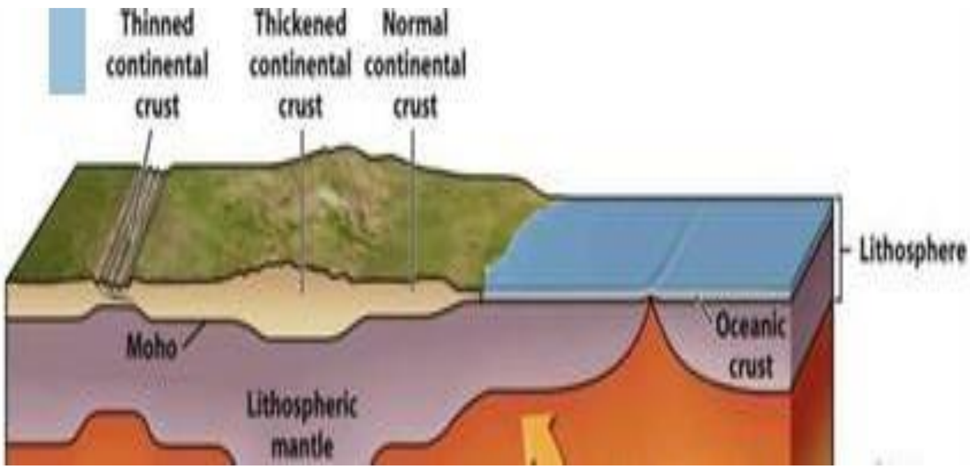

Figure 3: The Structure of the Earth Showing the Crust and the Upper Mantle (Source:)

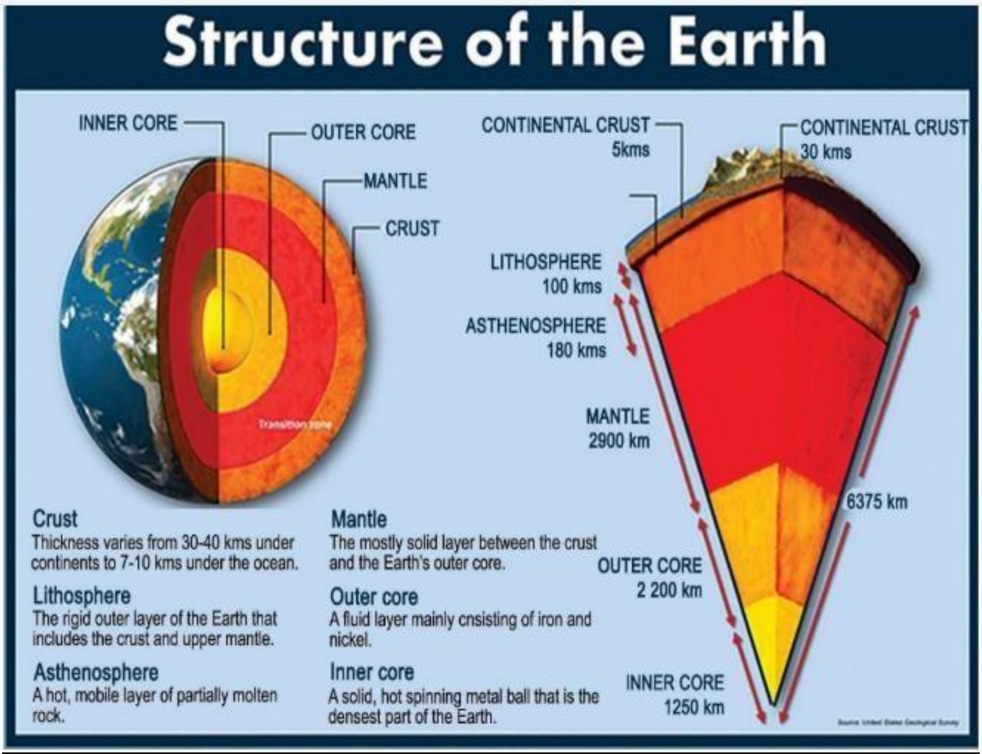

Figure 4: Layers of the Earth (Source: rauias.com/blog/internal-

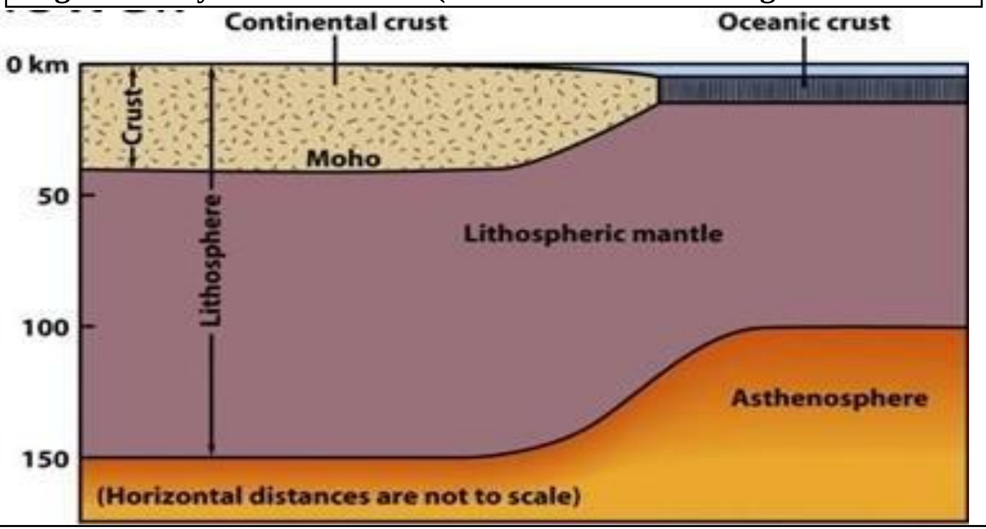

Figure 5: The Structure of the Earth showing the Crust and Mantle (Palin, *et.al.*2020)

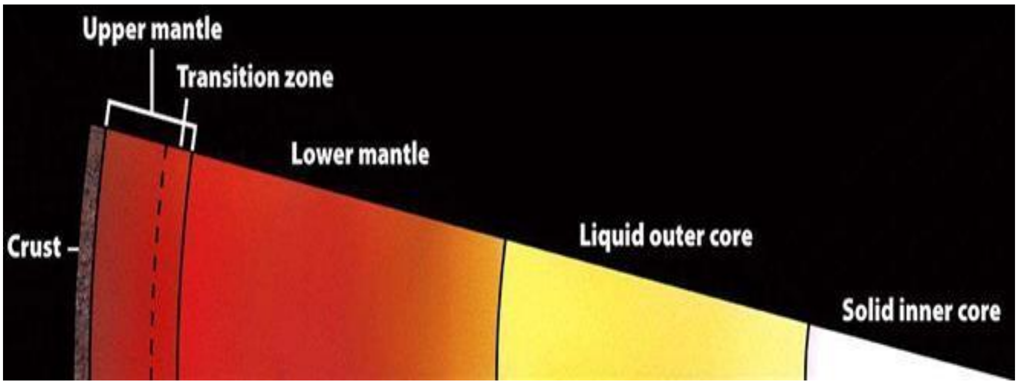

Figure 6: The Structure of the Earth Showing the different layers and the proportions to scale (Palin, *et.al.* 2020)

1.4 CONCLUSION

In this unit, the layers or structures of the Earth have been highlighted. The distances between each succeeding layer. The unit also addresses the physical characteristics and chemical elements which make up the different layers of the Earth.

1.5 SUMMARY

- The Earth is divided into four (4) distinct layers.
- The topmost layer is the Crust. The Crust is divided into two (2) distinct layers; Continental Crust and Oceanic Crust.
- The Crust and the solid Uppermost Mantle is collectively termed "**LITHOSPHERE**".
- Previously, the Mantle was divided into two layers; Upper Mantle and Lower Mantle.
- Currently, the Mantle is divided into three Upper Mantle, Transition Zone, and Lower Mantle.
- The Core is divided into two distinct layers; the Outer Core and Inner Core.
- The Outer Core is responsible for the generation of magnetic flux which makes the Earth rotate.
- The Core was the earliest portion of the Earth which evolved, and every other layer of the Earth evolved from it.
- Finally, it has the records of how the Earth evolved billions of years ago.

1.6 REFERENCES

Palin, R., Santosh, M., Cao, W., Li, S., Hernández-Uribe, D., Parsons, A. (2020). Secular Change and the Onset of Plate Tectonics on Earth. Earth-Science Reviews. 207. 10.1016/j.earscirev.2020.103172.

NCERT Notes of Geography, Structure of the Earth [Online] https://byjus.com/free- ias-prep/ncert-notes-geography-structure-of-the-earth/ (Retrieved on the 3rd September, 2024)

The Composition and Structure of Earth [Online]: https://geo.libretexts.org/Courses/Lumen_Learning/Book%3A_Physical_ Geography_(Lumen)/05%3A_Plate_Tectonics/5.03%3A_The_Compositi on_and_Structure_of_Earth (Retrieved on the 3rd September, 2024)

The Earth Structure [Online]: https://www.gsi.ie/en-ie/education/our-planet- earth/Pages/The-Earth-structure.aspx (Retrieved on the 3rd September, 2024)

1.7 MULTIPLE CHOICE QUESTIONS

1. The Continental Crust is made up of____and __

A. Silica and Iron
B. Silica and Aluminum
C. Silica and Mantle
D. Silica and Magnesium

2. What is the density of the Continental Crust and the Oceanic Crust?

A. 2.2 g/cm^3 and 4.0 g/cm^3

B. 2.9 g/cm^3 and 3.5 g/cm^3

C. 2.7 g/cm^3 and 3.0 g/cm^3

D. 3.0 g/cm^3 and 2.7 g/cm^3

3. Into how many zones is the Mantle divided?

A. none of them

B. 2

C. 4

D. 3

4. What is the density of the Outer Core and the Inner Core?

A. 2.2 g/cm^3 and 4.0 g/cm^3

B. 10-13 g/cm^3 and 12 g/cm^3

C. 2.7 - 5g/cm^3 and 3.0 g/cm^3

D. 10-12 g/cm^3 and 13 g/cm^3

5. Which layer of the Earth is responsible for generating magnetic field?

A. Upper Crust

B. Lower Mantle

C. Outer Core

D. Inner Core

6. What is the density of the entire Mantle?

A. 4.0 g/cm^3

B. 13 g/cm^3

C. 5 g/cm^3

D. 3.3 g/cm^3

7. FELSIC mean______

A. Light coloured

B. Dark Coloured

C. Very Dark Coloured

D. None of the above

8. What is the radius of the entire Core?

A. 1,909km

B. 1,859km

C. 1,959km

D. 3,471km

9. MAFIC means_____

A. Light coloured

B. Dark Coloured

C. Very Dark Coloured

D. None of the above

10. What is the radius of the Inner Core?

A. 2116km

B. 1,220km

C. 100km

D. 3,471km

ANSWER: 1B 2C 3D 4D 5C 6D 7A 8D 9B 10B

UNIT 2 EARTH DISCONTINUITIES

Unit Structure

2.1 Introduction
2.2 Objectives
2.3 Discontinuities
2.4 Conclusion
2.5 Summary
2.6 References
2.7. Multiple Choice Questions

2.1 INTRODUCTION

The structure of the Earth can be grouped into four (4) major parts/layers. These layers are the Crust, Mantle, Outer Core and Inner Core. Each layer has its own unique attributes; physically and chemically. These attributes cause these layers to impact life on Earth differently. These four (4) layers are separated from one another through a zone of transition. These zones of transitions are termed "**DISCONTINUITIES**". These "**DISCONTINUITIES**" are largely due to changes in density, as we move from the Earth's surface to its interior.

2.2 OBJECTIVES

By the end of this unit, you will be able to:

- identify the different discontinuities within the Earth
- explain the respective distances between one discontinuity within the Earth and the next one
- state the different layers/structures of the Earth between each of the discontinuities within the Earth
- mention how each of the discontinuities within the Earth was discovered by whom

2.3 DISCONTINUITIES

2.3.1 Types of Discontinuities

There are five (5) DISCONTINUITIES within the Earth's interior. They are as follows:

- **CONRAD DISCONTINUITY**: Transition zone between **UPPER CRUST (*CONTINENTAL CRUST/LITHOSPHERE*)** and **LOWER CRUST** (***OCEANIC CRUST/LITHOSPHERE***).
- **MOHOROVICIC DISCONTINUITY**: Transition zone between the **CRUST** (***LITHOSPHERE***) and **MANTLE**.
- **REPITI / REPETTI DISCONTINUITY**: Transition zone between **OUTER MANTLE (*ASTHENOSPHERE*)** and **INNER MANTLE.**
- **GUTENBERG DISCONTINUITY**: Transition zone between **MANTLE** (***MESOSPHERE***) and **CORE**.
- **LEHMAN DISCONTINUITY**: Transition zone between **OUTER CORE** and **INNER CORE.**

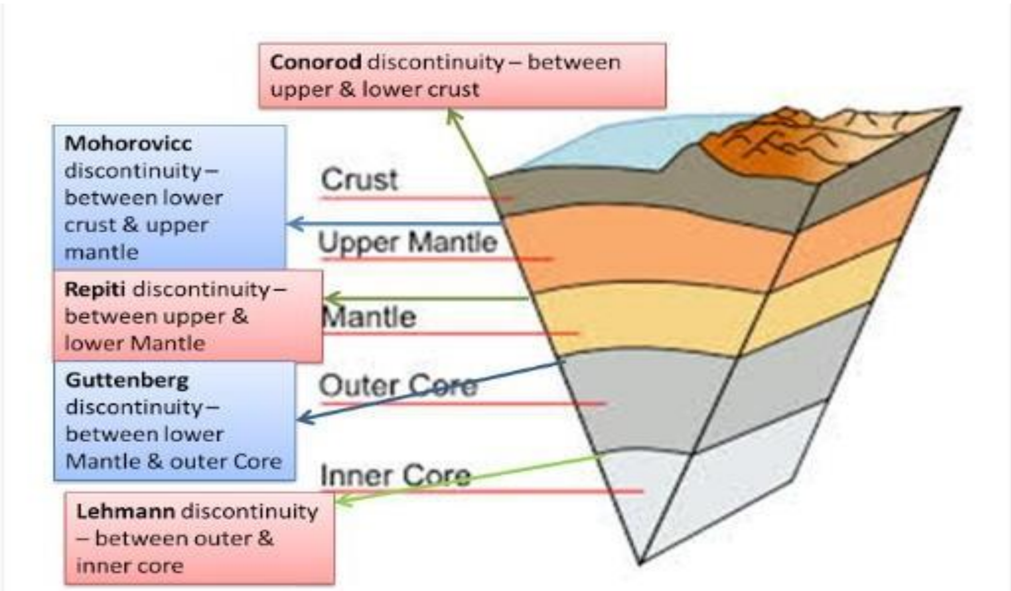

Figure 1: The Layers of the Earth and the Discontinuities between the Respective Layers. (Source: rauias.com/blog/internal-structure-of-earth)

The Conrad Discontinuity: The first zone of transition was named after the seismologist who discovered it in 1923. His name is **Victor Conrad. He was an Austrian Geophysicist.** It is the boundary between the Upper Continental Crust and the Lower Oceanic Crust. It is the sub-horizontal boundary in continental crust at which the seismic wave velocity increases in a discontinuous manner.

This boundary is seen in several continental regions at a depth range of **15km to 20km.** However, this boundary cannot be found in oceanic regions. There are two (2) types of main seismic waves in physics; Longitudinal (Primary or P) and Transverse (Secondary or S) Seismic waves. Both seismic waves are used to distinguish zones of transitions within the interior of the Earth. In passing through the Conrad discontinuity the velocity of longitudinal seismic waves increases abruptly from approximately 6 to 6.5km/sec.

Mohorovicic Discontinuity: This second zone of transition within the Earth was named after its founder; **Croatian Seismologist Andrjia Mohorovicic** in **1909**. It is the seismic boundary between the entire Lithosphere/Crust and the Mantle/Mesosphere. It is referred to "MOHO" for short. It is found at a depth of 35km beneath the Continental Crust and 8km beneath the Oceanic Crust. It separates that mantle beneath from the Crust above it. The "MOHO" lies almost entirely within the lithosphere. It is only beneath the Mid-Oceanic Ridge (MOR), is this discontinuity refers to as the Lithosphere – Asthenosphere (Upper Mantle) boundary. Above the MOHO velocity, the longitudinal seismic waves is 6km/sec, and immediately below it, MOHO velocity is 8km/sec. The thickness of the zone of MOHO is 500km.

Gutenberg Discontinuity: The third zone of transition is named after the German Seismologist **Weichert Gutenberg** in 1912. The depth beneath the Earth's surface where this seismic discontinuity can be observed is 2,900km. At this depth, seismic wave velocity suddenly alters. The Longitudinal (Primary or P) seismic wave velocity decreases while that of the Transverse (Secondary or S) seismic waves entirely disappear at 2,900km.

It is a narrow and varying zone of 5km to 8km wide in places. This variation in its width is because of heat driven convection motion within the mantle lying above it. Thus, the Mantle – Core boundary is not constant, as the heat of the Earth's interior slowly and steadily goes down, the Core which is molten (semi-solid like Custard) becomes solid and reduces in size. Hence, the Mantle- Core boundary will slowly steadily deeper within the Earth's interior.

Repiti / Repetti Discontinuity: This fourth zone of transition within the Earth's interior was discovered by **American Seismologist William. Charles Repetti** in **1909**. It is the boundary between the Upper Mantle (Asthenosphere) and the Lower Mantle. It is also referred to as the" Zone of Low Velocity". This zone of transition occurs between 100km to 200km of the Upper Mantle. At this depth with the Upper Mantle, the velocity of the seismic waves suddenly reduces to 7.8km/sec. This discontinuity, just like others, is largely due to density variation and chemical interface between the Upper and Lower Mantle, and as we move from the surface of the Earth to its interior.

Lehmann Discontinuity: It is the last zone of transition with the Earth's interior. It separates the Outer Core from the Inner Core. The seismic boundary was discovered by a **female Danish Seismologist Inge Lehmann**. It occurs at a depth of 220km within the Core, due to differences in physical (temperature, density etc.), chemical characters of the layers of the Core. She discovered the discontinuity in 1959.

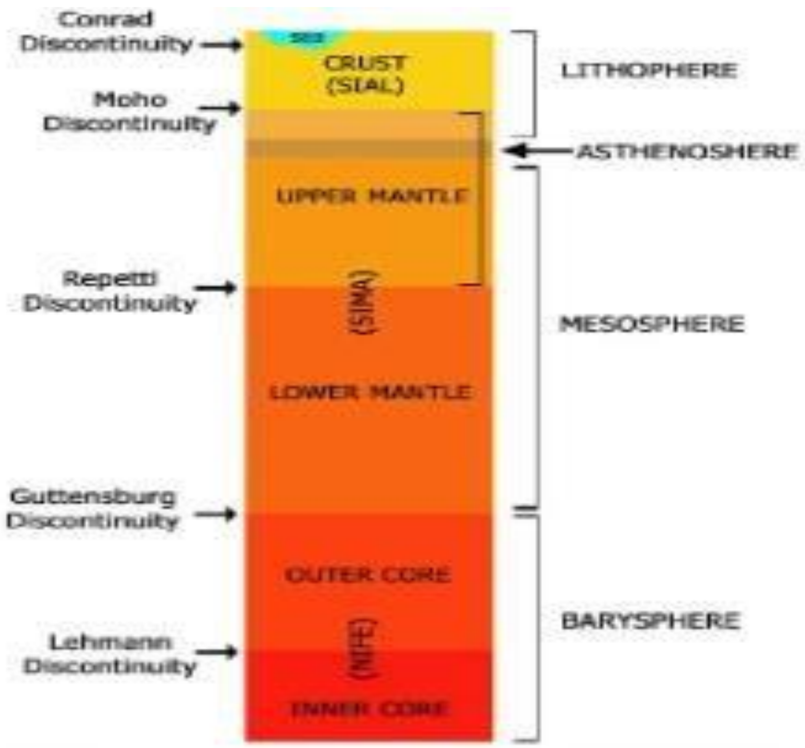

Figure 2: The Structures of the Earth and the Respective Discontinuities (Source: https://www.iasgyan.in/blogs/discontinuities-inside-the-earth

2.4 CONCLUSION

In this study, the interior of the Earth was examined with respect to the separating boundaries between its different layers. It was made clear that there are five (5) distinct zones of discontinuities within the earth's interior. These boundaries are made known by differences in density as one moves from the Earth's surface to its interior.

2.5 SUMMARY

1. There are four (4) distinct layers within the Earth; Lithosphere, Mantle, Outer Core and Inner Core.
2. Seismologists used differences in the movement of P and S – waves to distinguish between different layers of the Earth. They used seismic waves to explain the Earth more clearly.
3. From 1909 to 1959, five (5) Seismologists discovered five (5) discontinuities (Zones of Transitions) between different layers of the Earth's interior.

4. The zones of transitions are based on difference in physical (temperature, density etc.) and chemical characteristics of the different layers of the Earth.
5. Finally, the zones of transitions are Conrad, Mohorovicic, Repetti, Gutenberg, and Lehmann Discontinuities.

2.6 REFERENCES

Aulbach, S., Massuyeau, M., and Gaillard, F. (2017), Origins of cratonic mantle discontinuities: A view from petrology, geochemistry and thermodynamic models, Lithos, 268–271, 364– 382.

Bostock, M. G. (1997), Anisotropic upper-mantle stratigraphy and architecture of the Slave craton, Nature, 390, 392–395.

Calò, M., Bodin, T., and Romanowicz, B. (2016), Layered struc ture in the upper mantle across North America from joint inversion of long and short period seismic data, Earth Planet. Sci. Lett., 449, 164–175. Chen, L. (2017), Layering of subcontinental lithospheric mantle, Sci. Bull., 62, 1030–1034.

Chen, L., Jiang, M., Yang, J., Wei, Z., Liu, C., and Ling, Y. (2014), Presence of an intralithospheric discontinuity in the central and western North China Craton: Implications for destruction of the craton, Geology, 42(3), 223–226.

Cooper, C. M. and Miller, M. S. (2014), Craton formation: Internal structure inherited from closing of the early oceans, Lithosphere, 6, 35–42.

Cooper, C. M., Miller, M. S., and Moresi, L. (2017), The struc tural evolution of the deep continental lithosphere, Tectonophysics, 695, 100–121.

DePaolo, D. J., Cerling, T. E., Hemming, S. R., Knoll, A. H., Richter, F. M., Royden, L. R., Rudnick, R. L., Stixrude, L., Trfil, J. S., and Linn, A. M. (2008), Origin and Evolution of Earth: Research Questions for a Changing Planet, National Academies Press, Washington, DC.

Discontinuities Inside the Earth [Online] https://www.iasgyan.in/blogs/discontinuities-inside-the- earth , Posted on 28th May, 2021, Retrieved on 7th September, 2024.

Eaton, D. W., Darbyshire, F., Evans, R. L., Grütter, H., Jones, A. G., and Yuan, X. (2009), The elusive lithosphere–asthenosphere boundary (LAB) beneath cratons, Lithos, 109, 1–22.

Fischer, K. M. (2015), Crust and lithospheric structure— seismological constraints on the lithosphere–asthenosphere boundary, in G. Schubert (ed.), Treatise on Geophysics, 2nd edn, pp. 587–612, Elsevier, Oxford.

Internal Structures of Earth [Online] http://www.**rauias.com/blog/internal-structure-of-earth,** **Retrieved on the 3rd September, 2024**

Yuan, H. and Romanowicz, B. (2019). "Introduction - Lithospheric Discontinuities". Pp 1 – 3. In: Geophysical Monograph 239, First Edition. Yuan, H. and Romanowicz, B. (Eds.). © 2019 American Geophysical Union. Published 2019 by John Wiley & Sons, Inc. DOI:10.1002/9781119249740.ch0

2.7 MULTIPLE CHOICE QUESTIONS

ATTEMPT ALL QUESTIONS

1. The Mohorovicic Discontinuity separates ______

(a. Upper and Lower Crust b. Outer and Inner Core c. Crust and Mantle d. Crust and Core)

2. When was Repiti Discontinuity discovered? (a. 2022 b. 2009 c. 1909 d. 1923)

3. How many discontinuities are there within the Earth? (a. none of them b. 5 c. 9 d. 3)

4. The Conrad Discontinuity separates _____

(a. Upper and Lower Crust b. Outer and Inner Core c. Crust and Mantle d. Crust and Core)

5. The Repetti Discontinuity separates _____

(a. Upper and Lower Crust b. Upper and Lower Mantle c. Crust and Mantle d. Crust and Core)

6. The Gutenberg Discontinuity separates __

(a. Upper and Lower Crust b. Mantle and Core c. Crust and Mantle d. Crust and Core)

7. The Lehmann Discontinuity separates ___

(a. Upper and Lower Crust b. Upper and Lower Mantle c. Outer and Inner Core d. Crust and Core)

8. When was Lehmann Discontinuity discovered? (a. 1909 b. 1859 c. 1959 d. 1923)

9. The Gutenberg Discontinuity was discovered by the Seismologist ______(a. Dr. Inge Repetti b. Inge Gutenberg c. Inge Lehmann d. Victor Conrad)

10. How wide is the zone of transition called Gutenberg Discontinuity? (a. 2 km – 6km b. 6km - 10km c. 5km - 8km d. 3km - 7km)

ANSWER: 1C 2C 3B 4A 5B 6B 7C 8C 9B 10C

MODULE 2 PLATE TECTONICS

UNIT 1 THEORY OF PLATE TECTONICS AND PLATE BOUNDARIES

Unit Structure

1.1 INTRODUCTION

The Theory of Plate Tectonics is the combination of two (2) proven hypothesis; Theory of Continental Drifting and Theory of Sea-floor Spreading. The father of Plate Tectonics is believed to be the **German Alfred Lothar Wegener (1880 - 1930)**. He wanted to have a unifying theory to explain why certain structures on Earth are as we see them now. Thus, he set upon writing a series of papers from **1910 to 1928.** A summary of his theory was that the whole Earth was one giant solid structure; a super continent called **Pangaea** which was surrounded by a global sea or ocean called **Panthalassa** and had an **Eastern Embayment** called the **Paleo – Tethys Sea**. This super continent was broken up to two (2) smaller super continents; **Gondwana Land** (on the South) and **Laurasia** (on the North)**. Gondwana Land** broke up to form smaller continents like **Antarctica**, **Australia**, **South America**, **Africa** and **Laurasia** broke up to form smaller continents like **North America**, **Asia**, and **Europe**. **Panthalassa** also broke to form other smaller Seas, Oceans and other smaller water bodies.

In trying to explain the **Theory of Continental Drifting**, **Arthur Holmes** proposed in the **1930s** the **Convectional Current Theory**. It states that conventional currents from the mantle is the driving force which moves the Continents from one another.

In the 1960's, years after his death, that a supporting theory called the **Theory** of **Sea-floor Spreading** emerged. This theory was proposed by an Oceanographer Harry Hess in the early 1960s. In summary, it is a geologic theory that implies that there is creation of younger ocean floors at the middle of each Ocean, leading to the oceanic plates shifting or moving apart (diverging). Both theories were combined to form the Theory of Plate Tectonics.

1.2 OBJECTIVES

By the end of this unit, you will be able to:

- describe the Theory of Continental Drifting.
- discuss the evidences that support the Theory of Continental Drifting.
- describe the Theory of Sea-floor Spreading.
- discuss the evidences of the Theory of Sea-floor Spreading.
- describe the Theory of Plate Tectonics.
- state the evidence of the Theory of Plate Tectonics.
- describe the different Plate Boundaries and interactions.

1.3 THEORY OF PLATE TECTONICS

1.3.1 Continental Drifting and Its Evidence

In the introduction, the **Theory of Continental Drifting** has been briefly explained. It explains why the Earth's surface is the way it is. It gives reasons why the Continentals are where they are today and prosing where they will be in the future. It proposed that the Continents were moving to and fro by different forces. The forces of movement of the Continents which were proposed:

- **Buoyancy (Floating)**
- **Gravity (Force pulling things to the center of the Earth)**
- **Tidal Currents**
- **Tides**
- **Pole Fleeing Force**

The evidence to prove this theory:

- **Fossils Similarities:** Diverse fossils from different Continents which are several million kilometres apart are very similar. It means that these landmasses were once together before.

- **Continental Fit:** When the outlines of the different Continents are placed together, they fit together like a jig-saw puzzle.
- **Botanical Similarities:** Diverse plants from different Continents which are several million kilometers apart have been found to be very similar. It means that these landmasses were once together before.
- **Distribution of Glacial Features:** The different glacial features reveal that the different Continents were once connected.
- **Similarity of the Rock Sequences and Mountains:** Geoscientists have been researching the rock strata and the geographic features of adjacent Continents. They have found out that there are similarities and continuity of these structures across these adjacent Continents.

- This theory was insufficient to answer all of the questions about how the Continents drifted away from one another. Also, the Theory of Continental Drifting only handles the movement of Continental plates.

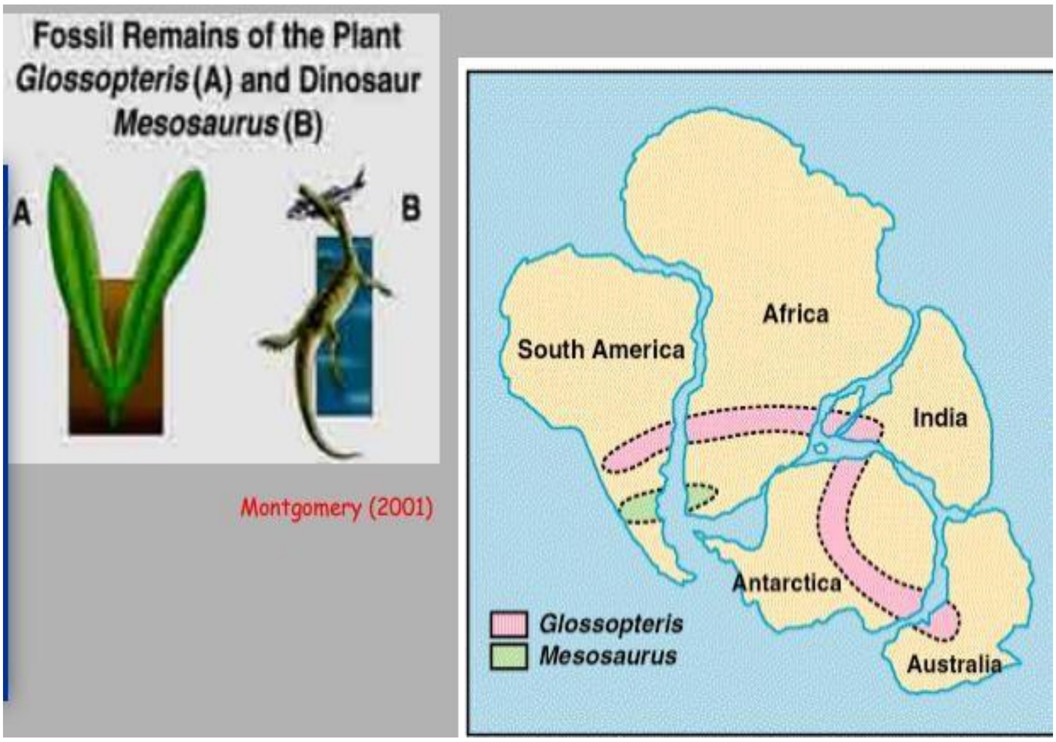

Figure 1: Some Evidences to Prove the Theory of Continental Drifting showing Continental Fit and Similarities in Fossils across Continents (Source: Tarbuck,

1.3.2 Sea-floor Spreading and Its Evidence

The introduction also summarizes the Theory of Sea-floor Spreading. This theory helped to give more understanding about the movement of the lithosphere. It proposes that middle of every Sea and Ocean is also getting younger because of the creation of new crust. The creation of new plates in the Oceans means that the older ones are moving away from the middle of the water body or water bodies (Mid-Oceanic Ridges).

Though, partly correct, it only explains how the oceanic plates (lower part of the lithosphere) move. It does not give all the answers why Continental and Oceanic plates move.

It proposes that the Oceanic plates were moving from one another by different forces. The force of movement of the Oceanic plates which was proposed:

- **Convection Currents in the Mantle dragging crustal plates.**

The evidences to prove this theory:

- **Ocean Bottom Relief:** Relief means the ups and downs of a terrain**.** It is also called its **Topography.** Each Ocean has at its middle newly formed rocks. As someone moves away from the middle, the rocks would show lowland and highlands in the Ocean. There are regions underneath the Oceans which also show crushing of older rocks.
- **Paleomagnetic Rocks:** The Earth has a magnetic field. The magnetic field of the Earth is stored in the rocks with magnetic properties such as **Magnetite**. It also shows the direction of the **Magnetic North** of the area when those rocks were formed. **Paleomagnetic Rocks** mean past magnetism. It keeps record of the past magnetism of rocks formed. These past magnetic records show that the magnetic north changes per time and is not constant. This evidence show that all the stripe of Oceans rocks is not made of the same material and the same time.
- **Distribution of Earthquakes and Volcanoes:** Geoscientists have found out that the places where earthquakes and volcanoes occur, are places which are called **SUBDUCTION** zones. Subduction zones where Oceanic plates slide underneath overlying Continental plates.
- **Symmetry of Oceanic Stripes:** Every Ocean show similarity in the symmetry (identical geometry) of the stripes of the Oceanic rock beneath the water body.
- **Radiometric Dating:** Geoscientists have used radiometric dating, which is the use of isotopes of radioactive elements to determine the age of things, to date the adjacent stripes of Oceanic plates. It showed that the age of the stripes of Oceanic

rocks are getting older as a person moves from the middle of the Ocean and Sea.

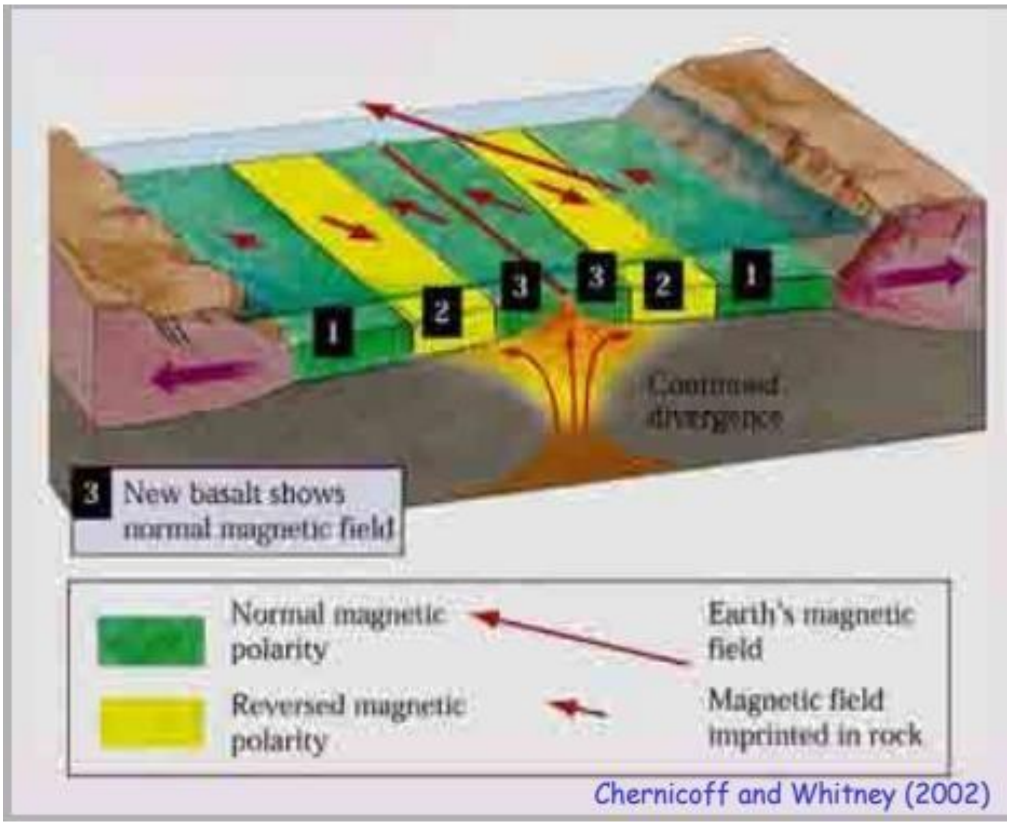

Figure 2: Some of the evidences to prove the Theory of Sea-floor Spreading. It shows the Symmetry of stripes of Oceanic rocks, Paleomagnetism (Source: Stanley, 2009)

1.3.3 Plate Tectonics and Its Evidences

In **1967**, geoscientists **Mckenzie** and **Parker** suggested this theory in the resolution of the evolving pattens of the structures on the Earth's surface. It was **W. Jason Morgan** of Princeton University in **1968** that proposed the Theory of Plate Tectonics in details. It is the combination of both theories discussed above.

The word "**Tectonics**" means "**Movements**". The theory implies that the Earth's surface has been broken up by internal forces. It was broken into rigid surfaces called Continental plates. These Continental plates are the Continental Plates, Oceanic Plates, and the Uppermost Part of the Mantle. Collectively, they are referred to as the **Lithosphere.** The Oceanic plates increase in age and thickness with distance away from the crest of the middle of the Ocean ridge. It explains how the Lithosphere moves from the different **Mid-Ocean Ridges (MORs)** which bring the Continental Plates or Oceanic Plates together or away from one another. The break-up and the movement of the lithospheric plates have led to the formation of inland water bodies and the end of ancient Seas and Oceans.

Young Oceanic lithosphere close to the ridge crest may be approximately 10km thick whereas the old Oceanic lithosphere may be as high as 100km thick. Continental lithosphere is generally thicker and can be as high as 250km.

The plates are rigid slabs of rocks that move as a single unit. As such, the inner part of the plates is relative inactive in terms of movement (tectonics). The interior of these plates lacks any evidence of geologic activity. It is believed that the lithospheric plates are "floating" on partially molten part of the Mantle called the "**Asthenosphere**". This theory explains the movement of all the lithospheric plates.
The forces of movement of the lithospheric plates which were proposed:

- **Convection Currents in the Mantle dragging crustal plates.**
- **Hot Spots (Thermal Plumes)**

The evidences to prove this theory:

- **Ocean Bottom Relief:** Relief means the ups and downs of a terrain**.** It is also called its
Topography. Each Ocean has at its middle newly formed rocks. As someone moves away
from the middle, the rocks would show lowland and highlands in the Ocean. There are regions underneath the Oceans which also show crushing of older rocks.
- **Paleomagnetic Rocks:** The Earth has a magnetic field. The magnetic field of the Earth is stored in the rocks with magnetic properties such as **Magnetite**. It also shows the direction of the **Magnetic North** of the area when those rocks were formed. **Paleomagnetic Rocks** mean past magnetism. It keeps record of the past magnetism of rocks formed. These past magnetic records show that the magnetic north changes per time and is not constant. This evidence show that all the stripe of Oceans rocks is not made of the same material and the same time.
- **Distribution of Earthquakes and Volcanoes:** Geoscientists have found out that the places where earthquakes and volcanoes occur, are places which are called **SUBDUCTION** zones. Subduction zones where Oceanic plates slide underneath overlying Continental plates.
- **Symmetry of Oceanic Stripes:** Every Ocean show similarity in the symmetry (identical geometry) of the stripes of the Oceanic rock beneath the water body.

- **Radiometric Dating:** Geoscientists have used radiometric dating, which is the use of isotopes of radioactive elements to determine the age of things, to date the adjacent stripes of Oceanic plates. It showed that the age of the stripes of Oceanic rocks are getting older away from the Mid-Oceanic Ridge (**MOR**).
- **Gravity and Magnetic Anomalies at Trenches:** The word "**Anomalies**" means "**Difference/Abnormal**". Trenches simply mean a long steep-sided depression in the Oceans. When gravity and magnetic instruments were used to measure the trenches, the readings show the abnormal readings different from the surrounding terrain. Also, the alternation of positive and negative magnetic reading forms a strip-like anomalous pattern parallel to the Mid-Oceanic Ridge (MOR). Fred Vine and Drummond Matthews, two (2) British geoscientists made several critical findings. These anomalies imply that there are tectonic activity occurring at these trenches.

Finally, the average rate of plate movement can be known by dividing the age of a magnetic anomaly in oceanic crust by the distance between the particular anomaly and the present Mid- Oceanic Ridge (MOR). The motion (forward or backward) of one Continent with another

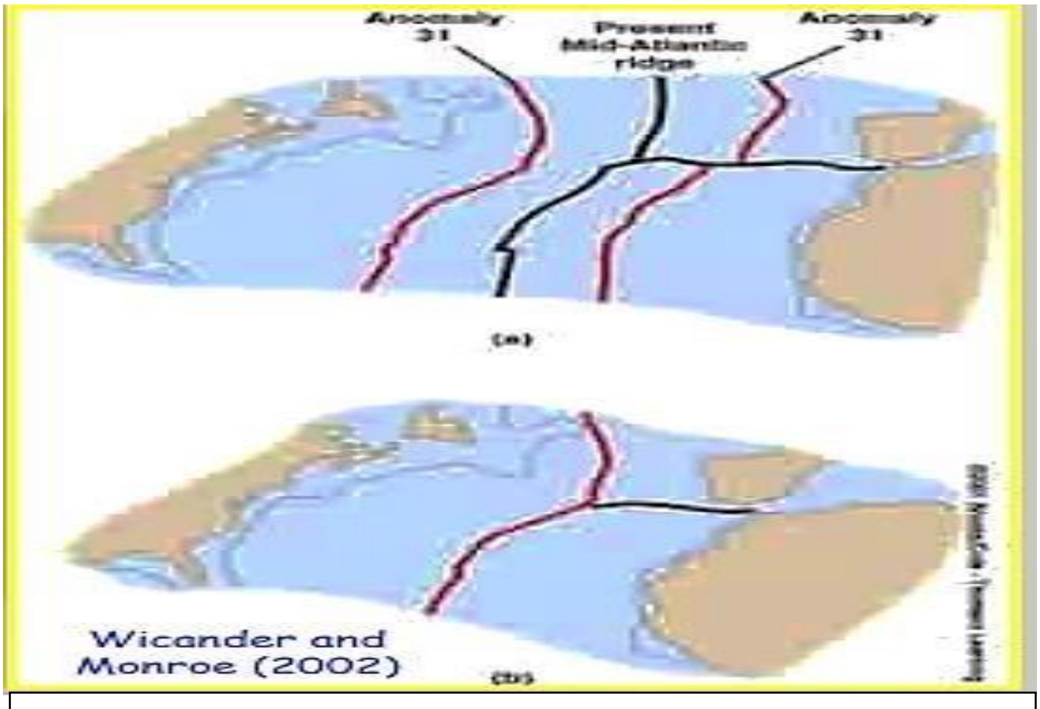

Figure 3: One of the pieces of evidence to prove the Theory of Plate Tectonics. It shows the Similar Magnetic and Gravity Anomalies and their distance away from the Mid-Oceanic Ridge.(Source: Kaerey, *et.al.*, 2013)

Continent can be known by moving matching anomalies on either side of Ocean's ridge back together along the Ocean's ridge.

1.3.4 Plate Boundaries and their Interactions

Plate boundaries are the edges where two tectonic plates meet. The Earth's lithosphere (the outermost layer) is divided into these large, rigid plates that move slowly over the asthenosphere (a softer, partially molten layer below the lithosphere). The interactions between plates at their boundaries cause many geological features and phenomena such as earthquakes, volcanoes, and mountain formation. There are three main types of plate boundaries:

1. **Divergent Boundaries (Constructive Boundaries)**

Description: At divergent boundaries, tectonic plates move away from each other.

Processes:

- As the plates separate, magma from the mantle rises to fill the gap.
- The magma cools and solidifies, forming new crust.

Geological Features:

- Mid-ocean ridges (e.g., Mid-Atlantic Ridge).
- Rift valleys on continents (e.g., East African Rift).
- Volcanic activity and shallow earthquakes.

Examples: Mid-Atlantic Ridge, East African Rift.

2. **Convergent Boundaries (Destructive Boundaries)**

Description: At convergent boundaries, plates move toward each other, and one plate is usually forced beneath the other in a process called subduction.

Types of Convergent Boundaries:

Oceanic-Continental Convergence:

- The denser oceanic plate is subducted beneath the lighter continental plate.
- Causes deep ocean trenches, volcanic mountain ranges, and powerful earthquakes.
- **Example**: Andes Mountains.

Oceanic-Oceanic Convergence:

- One oceanic plate is subducted under another, forming volcanic island arcs and ocean trenches.
- **Example**: Mariana Trench, Japan.

Continental-Continental Convergence:

- Neither plate is subducted because both are buoyant. Instead, the crust crumples and thickens, forming large mountain ranges.
- **Example**: Himalayas (Indian Plate colliding with the Eurasian Plate).

Geological Features:

- Mountain ranges, deep ocean trenches, volcanic arcs, large earthquakes.

3. Transform Boundaries (Conservative Boundaries)

Description: At transform boundaries, plates slide past each other horizontally.
Processes: As plates move laterally, they can become stuck due to friction. When the stress is released, it causes earthquakes.
Geological Features: No new crust is formed or destroyed. These boundaries often feature faults and seismic activity.
Examples: San Andreas Fault (California), North Anatolian Fault (Turkey). **Earthquakes**: Transform boundaries are often associated with shallow and strong earthquakes due to the release of built-up tension.

Plate Boundary Interactions

- **Earthquakes**: Most earthquakes occur at or near plate boundaries due to the movement of plates. The strongest quakes are usually at convergent and transform boundaries.
- **Volcanoes**: Convergent boundaries with subduction zones are often associated with volcanic arcs, while divergent boundaries can produce volcanic activity along mid-ocean ridges.
- **Mountain Formation**: Continental collisions at convergent boundaries create massive mountain ranges like the Himalayas or the Alps.

1.4. CONCLUSION

The theory of plate tectonics is a powerful framework that explains Earth's geological processes. It integrates various concepts like continental drift and seafloor spreading, and through the study of plate boundaries, we can understand the causes behind earthquakes, volcanic eruptions, and the formation of mountain ranges. This theory not only explains the past and present configuration of Earth's continents and oceans but also allows scientists to predict future geological events and their impact on human life.

1.5. SUMMARY

- The theory of plate tectonics explains the movement of Earth's lithospheric plates and their interactions.
- Divergent boundaries result in the formation of new crust, while convergent boundaries involve the destruction or crumpling of plates, and transform boundaries involve lateral movement.
- Earthquakes, volcanoes, and mountain ranges are closely related to the movements at these plate boundaries.
- Evidence supporting plate tectonics includes the fit of the continents, fossil distribution, paleomagnetism, and the global pattern of seismic and volcanic activity.

1.6 REFERENCES

Guria, Dr Narendranath. (2019). “PLATE TECTONIC THEORY”. .13140/RG.2.2.21464.44803.

Kearey, P., Klepeis, K. A., & Vine, F. J. (2013). Global Tectonics (3rd ed.). Wiley-Blackwell. Stanley, S. M. (2009). Earth System History (3rd ed.). W.H. Freeman and Company.

Tarbuck, E. J., Lutgens, F. K., & Tasa, D. (2014). Earth: An Introduction to Physical Geology (11th ed.). Pearson.

Le Pichon, X. (1968). Sea-floor spreading and continental drift. Journal of Geophysical Research, 73(12), 3661-3697.

1.7 MULTIPLE CHOICE QUESTIONS

1. What is the primary driver of tectonic plate movement?

A) Solar energy
B) Gravitational pull of the Moon
C) Mantle convection currents
D) Wind currents

2. Which type of plate boundary is associated with the formation of the Himalayas?

A) Divergent boundary
B) Oceanic-oceanic convergent boundary
C) Continental-continental convergent boundary
D) Transform boundary

3. What feature is commonly found at divergent boundaries?

A) Deep ocean trenches
B) Volcanic island arcs
C) Mid-ocean ridges
D) Mountain ranges

4. Which plate boundary is responsible for the San Andreas Fault?

A) Divergent boundary
B) Transform boundary
C) Oceanic-continental convergent boundary
D) Continental-continental convergent boundary

5. Which of the following is an example of oceanic-continental convergence?

A) Mariana Trench
B) East African Rift
C) Andes Mountains
D) Mid-Atlantic Ridge

6. What is the lithosphere composed of?

A) Earth's inner core and mantle
B) The rigid outer layer, including the crust and upper mantle

C) The Earth's core
D) The soft, partially molten layer beneath the crust

7. What evidence supports the theory of seafloor spreading?

A) Presence of ocean trenches
B) The fit of continents across the Atlantic Ocean
C) Fossil records of dinosaurs
D) Symmetrical patterns of magnetic stripes on the ocean floor

8. Which of the following is a consequence of transform plate boundaries?

A) Formation of new oceanic crust
B) Creation of deep ocean trenches
C) Frequent earthquakes
D) Mountain formation

9. What is one major result of a continental-continental convergent boundary?

A) Deep-sea trenches
B) Mountain ranges
C) Volcanoes
D) Rift valleys

10. Which of the following best describes a divergent boundary?

A) Two plates collide and create mountains
B) Two plates move away from each other
C) Two plates slide horizontally past each other
D) One plate is subducted beneath another

ANSWER: 1C 2C 3C 4B 5C 6B 7D 8C 9B 10B

UNIT 2 OROGENY AND OROGENESIS

Unit Structure

2.1 INTRODUCTION

DiPietro (2018) stated that the word "**OROGENY**" was derived from two (2) Greek words "***Oros***" meaning **MOUNTAINS** and "**Genesis**" meaning the **ORIGIN** or **MODE OF FOMATION**. Thus, Orogeny can be defined as **Mountain Building Events and Processes**. The term "**Mountain Building**" implies that the rate of surface uplift is greater than the rate of erosion such that, over time, a lowland area evolves into a mountain system. **Orogeny** refers to the process of mountain building through the deformation of Earth's crust, typically occurring at convergent plate boundaries. It results from complex interactions between tectonic plates, such as collisions or subduction. **Orogenesis** is the broader term for the processes involved in creating orogens (mountain ranges). This includes not only the tectonic forces that build mountains but also erosion, sedimentation, and volcanic activity. These processes shape much of Earth's surface and are key to understanding the formation of landforms over geological time.

2.2 OBJECTIVES

By the end of this unit, you will be able to:

- define orogeny and orogenesis.
- describe the different types of orogenic processes and how they contribute to mountain formation.

- explain the relationship between plate tectonics and orogeny.
- identify the stages involved in the orogenetic process.
- recognize major mountain ranges and the orogenies responsible for their formation.

2.3 CONCEPT OF OROGENY AND OROGENESIS

2.3.1 Definition of Orogeny and Orogenesis

- **Orogeny**: The process of mountain formation caused by the structural deformation of Earth's crust, typically resulting from tectonic forces at convergent boundaries.
- **Orogenesis:** The collective processes, including tectonic, sedimentary, and metamorphic actions, that contribute to the formation of orogenic belts (mountain chains).

2.3.2 Plate Tectonics and Orogeny

- **Convergent Plate Boundaries:** Orogeny primarily occurs at convergent boundaries where tectonic plates collide, leading to compression, folding, faulting, and thickening of the crust.
    - Continental-Continental Convergence: The collision of two continental plates leads to the crumpling and thickening of the crust, forming large mountain ranges like the Himalayas.
    - Oceanic-Continental Convergence: Subduction of an oceanic plate beneath a continental plate result in volcanic mountain chains, such as the Andes.
    - Oceanic-Oceanic Convergence: Leads to the formation of volcanic island arcs, as seen in the Mariana Islands.

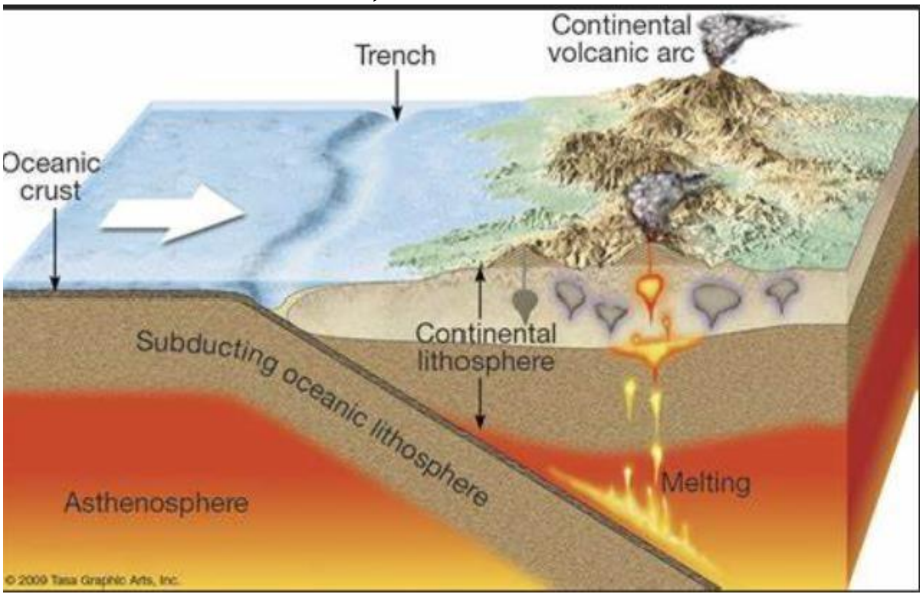

Figure 1. Orogenic processes (Twiss and Moores, 2007)

2.3.3 Stages of Orogenesis

- Subduction: When an oceanic plate sinks beneath another plate, sediments and parts of the oceanic crust are scraped off and accreted to the overriding plate, forming an accretionary wedge.
- Collision: When two continental plates collide, the crust is compressed and thickened, causing extensive folding, faulting, and uplift.
- Uplift and Erosion: Once mountains are formed, they are subjected to erosion. Over millions of years, the erosional forces wear down the mountains, redistributing sediment to nearby basins.
- Metamorphism: The heat and pressure associated with orogeny cause rocks to metamorphose, changing their mineral structure.

2.3.4 Types of Orogeny

1. Cordilleran Orogeny: Involves the subduction of an oceanic plate beneath a continental plate, resulting in volcanic activity and mountain chains.
2. Alpine-Type Orogeny: Results from the collision of two continental plates, forming massive, non-volcanic mountain ranges.
3. Andean Orogeny: A type of orogeny along the edge of a continental plate where oceanic crust is subducted, resulting in volcanic mountain ranges like the Andes.

2.3.5 Examples of Major Orogenic Belts

a. Himalayan Orogeny: Formed by the collision of the Indian Plate and Eurasian Plate, resulting in the uplift of the Himalayas.
b. Alps Orogeny: Formed by the collision of the African and Eurasian plates.
c. Appalachian Orogeny: Resulted from multiple orogenic events, including the collision of North America and Africa during the formation of Pangaea.
d. Andean Orogeny: Formed by the subduction of the Nazca Plate beneath the South American Plate, creating the Andes Mountains.

2.3.6 Effects of Orogenesis

- Crustal Thickening: Leads to uplift and the formation of mountain ranges.
- Metamorphism: The intense pressure and heat during orogeny lead to the metamorphosis of rocks.
- Erosion and Sedimentation: Over time, orogens are eroded, and

the resulting sediments are deposited in surrounding basins.

2.4. CONCLUSION

Orogeny and orogenesis are vital processes in shaping Earth's surface. Through the movement of tectonic plates, forces of compression and uplift create towering mountain ranges. Orogenesis is a continuous process that involves multiple geological activities like subduction, collision, metamorphism, and erosion. The study of orogeny is essential for understanding the formation of
various landforms and their evolution over time, as well as the broader tectonic activities that govern the Earth's structure.

2.5 SUMMARY

- Orogeny refers to the mountain-building process, typically occurring at convergent plate boundaries.
- Orogenesis includes all geological processes involved in the formation of mountains, from tectonic movement to erosion and sedimentation.
- The Himalayas, Andes, Alps, and Appalachians are major mountain ranges formed through various orogenic processes.
- Orogenic processes include subduction, collision, uplift, and metamorphism.

- Plate tectonics is the driving force behind orogenic activity, with convergent boundaries playing a key role.

2.6. REFERENCES

Press, F., & Siever, R. (2001). Understanding Earth (4th ed.). W.H. Freeman and Company. Kearey, P., Klepeis, K. A., & Vine, F. J. (2013). Global Tectonics (3rd ed.). Wiley-Blackwell. Twiss, R. J., & Moores, E. M. (2007). Structural Geology (2nd ed.). W. H. Freeman.

Dewey, J. F. (1969). Continental margins: a model for conversion of passive into active margins.

Earth and Planetary Science Letters, 6(2), 71-78.

Ramsay, J. G., & Huber, M. I. (1987). The Techniques of Modern

Structural Geology. Academic Press.

2.7 MULTIPLE CHOICE QUESTIONS

1. What is orogeny?
A) A process of volcanic activity
B) The mountain-building process
C) The process of ocean formation
D) A type of earthquake

2. Which of the following plate boundaries is most associated with orogeny?
A) Divergent boundary
B) Transform boundary
C) Convergent boundary
D) Rift boundary

3. The Himalayan mountains are primarily formed due to which type of orogeny?
A) Andean-type orogeny
B) Alpine-type orogeny
C) Cordilleran-type orogeny
D) Oceanic-continental orogeny

4. What is a key process in the early stage of orogenesis at oceanic-continental boundaries?
A) Subduction
B) Erosion
C) Rift formation
D) Sedimentation

5. Which orogeny resulted in the formation of the Andes Mountains?
A) Alpine Orogeny
B) Cordilleran Orogeny
C) Andean Orogeny
D) Appalachian Orogeny

6. What happens to rocks during orogeny due to pressure and heat?
A) They erode
B) They undergo metamorphism
C) They become sedimentary rocks
D) They melt completely

7. Which of the following is not an example of a mountain range

formed by orogeny?

A) Himalayas

B) Andes

C) Mariana Trench

D) Alps

8. The term "orogenesis" refers to what process?

A) Volcano formation

B) Earthquake formation

C) Mountain-building processes

D) Ocean basin formation

9. Which geological feature is a direct result of continental-continental collision?

A) Oceanic trench

B) Volcanic island arcs

C) Rift valleys

D) Large mountain ranges

10. The Appalachian Mountains were formed as a result of which event?

A) Continental drift

B) Collision of North America and Africa during the formation of Pangaea

C) Subduction of the Pacific Plate

D) Divergence of tectonic plates

ANSWER: 1B 2C 3B 4A 5C 6B 7C 8C 9D 10B

UNIT 3 CRUST MOVEMENT

Unit Structure

3.1 INTRODUCTION

The Earth’s crust, the outermost layer of our planet, is not static but is in a state of constant motion. This movement, although slow, is responsible for shaping the Earth’s landscape, causing phenomena such as earthquakes, volcanic activity, and the formation of mountains and oceanic trenches. Understanding crust movement is essential to comprehending Earth's geologic processes. The movement is driven by forces originating from the Earth’s interior and manifests through mechanisms like plate tectonics and mantle convection. This unit explores the dynamics of crust movement, its causes, effects, and significance in geology.

3.2 OBJECTIVES

By the end of this unit, you will be able to:

- explain the fundamental processes driving crust movement
- explore different types of plate boundaries and their associated phenomena
- discuss the effects of crustal movement on Earth’s surface
- highlight the relevance of studying crust movement in understanding natural disasters like earthquakes and volcanic eruptions.

3.3 CONCEPT OF CRUST MOVEMENT

3.3.1 Mechanisms Of Crust Movement

The Earth's lithosphere, which includes the crust and the uppermost part of the mantle, is broken into tectonic plates. These plates are rigid and are constantly moving over the more ductile asthenosphere below. The movement of these plates can be described through the theory of plate tectonics, which provides an explanation for many of Earth’s surface processes.

Plate Tectonics

Tectonic plates move because of several interrelated processes. At the core of these movements is mantle convection, a process driven by the heat emanating from the Earth's core. This heat causes the mantle to behave like a viscous fluid, moving in a slow but continuous convection current. Hot material rises from deep within the mantle, reaches the cooler lithosphere, and then spreads outwards, pushing the plates apart. At the same time, cooler, denser parts of the lithosphere sink back into the mantle at subduction zones, driving the plates to move.

Types Of Plate Boundaries

There are three main types of plate boundaries, each associated with different kinds of movement and geological features:

- Divergent Boundaries: At these boundaries, plates move away from each other. This process, known as seafloor spreading, occurs mainly at mid-ocean ridges. Magma rises from the mantle to fill the gap, creating new oceanic crust. As a result, oceans slowly widen over time, and geologic activity, such as volcanic eruptions and shallow earthquakes, often occurs along these ridges.
- Convergent Boundaries: At convergent boundaries, plates move towards each other. Depending on the type of plates involved, this can result in different geologic phenomena:
    - Oceanic-continental convergence leads to the subduction of the denser oceanic plate beneath the continental plate, forming deep ocean trenches and volcanic arcs along the continent’s edge (e.g., the Andes Mountains).
    - Oceanic-oceanic convergence also leads to subduction, creating island arcs and oceanic trenches (e.g., the Marianas Trench).
    - Continental-continental convergence results in the collision of two landmasses, leading to the uplift of massive mountain ranges, such as the Himalayas, as neither plate subducts easily.

- Transform Boundaries: Plates slide past each other horizontally at transform boundaries. This movement causes friction and stress to build up along the fault lines. When this stress is released, earthquakes occur. A well-known example of a transform fault is the San Andreas Fault in California.

Forces Driving Crust Movement

Several forces drive the movement of tectonic plates:

- Mantle Convection: The heat from the Earth's core creates convection currents in the mantle, which are the primary drivers of crustal movement. As hot material rises, it spreads out beneath the lithosphere, moving the plates along.
- Slab Pull and Ridge Push: Slab pull occurs in subduction zones where a cold, dense oceanic plate sinks into the mantle. This pulling force helps drive the plate's movement. Ridge push occurs at divergent boundaries, where newly formed lithosphere at mid-ocean ridges pushes older, denser lithosphere away from the ridge.
- Gravitational Forces: The weight of elevated ocean ridges creates gravitational forces that cause the lithosphere to slide down and away from the ridge axis, further aiding the plate's movement.

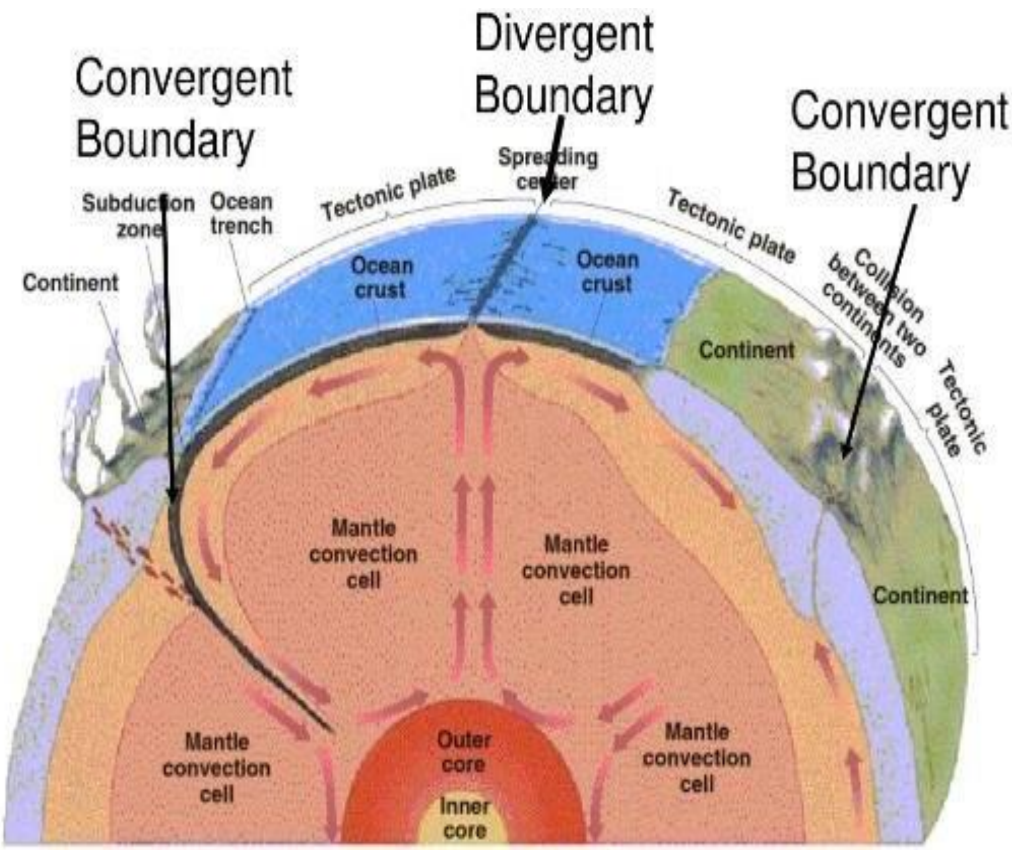

Figure 1: Crust movement showing plate movement (McKenzie, 1969).

3.3.2 Consequences Of Crust Movement

Crustal movement is responsible for many of Earth's dynamic geological features. Its effects can be both gradual and catastrophic.

Earthquakes

Most earthquakes are the result of crustal movements along fault lines. As tectonic plates grind against each other, they accumulate strain energy. When the energy is released, it causes the ground to shake, leading to an earthquake. The severity of an earthquake depends on the amount of strain released, and they are most common at convergent and transform boundaries.

Volcanic Activity
Volcanic eruptions are another direct consequence of crust movement, particularly at divergent and convergent plate boundaries. At divergent boundaries, magma from the mantle rises to fill the gaps created by spreading plates, leading to volcanic activity. At convergent boundaries, subducting oceanic plates melt as they descend into the mantle, and the resulting magma rises to the surface, creating volcanoes.

Mountain Building
Over millions of years, crustal movements at convergent boundaries can lead to the uplift of massive mountain ranges. The Himalayas, for instance, are still growing as the Indian plate continues to push against the Eurasian plate. This process, called orogeny, can take millions of years but results in the creation of some of the Earth's most prominent features.

Oceanic Trench Formation
Oceanic trenches, the deepest parts of the ocean floor, form at subduction zones where one plate is forced beneath another. These trenches are sites of significant geological activity, including earthquakes and volcanism. The Mariana Trench, the deepest point in the Earth's oceans, is a result of such crustal movement.

Continental Drift
Crustal movement is also responsible for the slow drifting of continents over geological time. The theory of continental drift, proposed by Alfred Wegener in 1912, was the precursor to modern plate tectonics. The theory explained how continents that were once part of a supercontinent (Pangaea) drifted to their current positions. This process is ongoing, with continents continuing to shift at a prolonged rate of a few

centimeters per year.

3.3.3 Implications Of Crust Movement

Crust movement has significant implications for both the Earth's physical landscape and human populations.

Natural Disasters

Understanding crustal movement is critical for assessing the risk of natural disasters like earthquakes and volcanic eruptions. Seismic studies and plate movement monitoring help scientists predict the likelihood of such events. In earthquake-prone regions like Japan and California, early warning systems and building codes are designed to minimize the impact of seismic activity.

Climate Change

Crustal movement also affects global climate over geological timescales. The shifting of continents can alter ocean currents, which, in turn, impact global climate patterns. For example, the movement of tectonic plates that resulted in the formation of the Isthmus of Panama changed ocean circulation, contributing to the Ice Age.

Resource Distribution

The movement of tectonic plates also influences the distribution of natural resources. The formation of mountain ranges, for example, can lead to the concentration of minerals, while volcanic activity can create rich soils that are highly fertile for agriculture.

3.4 CONCLUSION

The movement of the Earth’s crust is a fundamental process that drives the planet's geology. From the slow drift of continents to the sudden and violent release of energy in earthquakes, crustal movement shapes the Earth in profound ways. The theory of plate tectonics provides a framework for understanding these processes and the forces behind them, helping to explain the formation of mountains, oceanic trenches, earthquakes, and volcanoes. Continued study of crustal movement is essential for predicting natural disasters and understanding the long-term evolution of the Earth's surface.

3.5 SUMMARY

Crust movement is a dynamic process driven by plate tectonics, mantle convection, and other forces. It is responsible for earthquakes, volcanic activity, mountain building, and oceanic trench formation. Understanding crustal movement is vital for predicting natural disasters and for studying Earth's long-term geological evolution.

3.8 REFERENCES

Kearey, P., Klepeis, K. A., & Vine, F. J. (2009). *Global Tectonics* (3rd ed.). Wiley-Blackwell.

Turcotte, D. L., & Schubert, G. (2014). *Geodynamics* (3rd ed.). Cambridge University Press. McKenzie, D. (1969). *Speculations on the Consequences and Causes of Plate Motion*.

Geological Society of America Bulletin.

Frankel, A. (2018). *Seismic Hazard and Risk Analysis*. Springer.

3.9 MULTIPLE CHOICE QUESTIONS

1. Which of the following processes primarily drives the movement of tectonic plates?
a) Ocean currents
b) Mantle convection
c) Solar radiation
d) Atmospheric pressure

2. At which type of plate boundary do plates move apart from each other?
a) Convergent
b) Divergent
c) Transform
d) Subduction

3. The San Andreas Fault in California is an example of which type of boundary?
a) Convergent
b) Divergent
c) Transform
d) Rift

4. What is the name of the process where one tectonic plate is forced beneath another?

a) Spreading
b) Folding
c) Subduction
d) Fracturing

5. Which of the following geological features forms at a divergent boundary in the ocean?
a) Mid-ocean ridge
b) Island arc
c) Ocean trench
d) Volcano

6. Which force helps to pull a tectonic plate downward into the mantle at a subduction zone?
a) Ridge push
b) Slab pull

c) Mantle upwelling
d) Gravity sliding

7. Mountain ranges such as the Himalayas are formed as a result of:
a) Oceanic-continental convergence
b) Oceanic-oceanic convergence
c) Continental-continental convergence
d) Continental-oceanic divergence

8. Which of the following is *not* typically caused by crustal movements?
a) Earthquakes
b) Volcanic eruptions
c) Tsunamis
d) Tornadoes

9. Ocean trenches are commonly found at which type of plate boundary?
a) Divergent boundary
b) Transform boundary
c) Convergent boundary
d) Hotspot

10. Which of the following is the primary cause of earthquakes?
a) Sudden movements along fault lines due to tectonic plate motion
b) Erosion of Earth's surface
c) Changes in atmospheric pressure
d) Oceanic currents

ANSWER: 1B 2B 3C 4C 5A 6B 7C 8D 9C 10A

UNIT 4 MINERAL RESOURCES GENESIS.

Unit Structure

4.1 INTRODUCTION

Mineral resources are naturally occurring substances that are extracted and used by humans for various purposes, ranging from building materials to electronics and energy production. The genesis, or formation, of mineral resources is a complex process driven by geological, chemical, and biological factors. These processes can take place over millions of years, involving the accumulation and concentration of minerals in the Earth's crust. Understanding the genesis of mineral resources is essential for effective exploration, extraction, and management of these finite materials. This unit provides insights into the various processes that lead to the formation of different types of mineral deposits.

4.2. OBJECTIVES

By the end of this unit, you will be able to:

- define mineral resources
- explain the key processes involved in the formation of mineral resources
- describe the different types of mineral deposits and their geological settings
- explore the significance of mineral resources in modern society.
- state how mineral resource genesis informs exploration and extraction techniques.

4.3 INTRODUCTION TO MINERAL RESOURCES

4.3.1 Definition Of Mineral Resources

Mineral resources are naturally occurring, inorganic substances found in the Earth's crust that can be extracted and utilized for various purposes. These resources encompass a wide range of materials, including metals (such as gold, silver, copper, and aluminum), non-metals (such as gypsum, salt, and graphite), and industrial minerals (such as limestone and clay). Mineral resources are essential for numerous industries, including construction, manufacturing, energy production, and technology. They are classified into two main categories: reserves, which are known deposits that can be economically extracted, and resources, which include both known and estimated deposits that may be economically viable in the future.

4.3.2 Classification of Mineral Resources

Mineral resources can be classified based on several criteria:

- **Metallic Minerals**: These minerals contain metals that can be extracted and are typically shiny, good conductors of heat and electricity, and malleable. Examples include:
  - **Ferrous Minerals**: Contain iron (e.g., hematite, magnetite).
  - **Non-Ferrous Minerals**: Do not contain iron (e.g., copper, gold, aluminum).
- **Non-Metallic Minerals**: These do not contain metals and are typically used in their natural state. Examples include:
  - **Industrial Minerals**: Such as limestone, clay, and gypsum, used in construction and manufacturing.
  - **Energy Minerals**: Such as coal, oil, and natural gas, used for energy production.

4.3.3 Geological Processes Leading to Mineral Formation

The origin of mineral resources is primarily rooted in geological processes. These processes can be categorised into several key mechanisms: **magmatic**, **hydrothermal**, **sedimentary**, and **metamorphic**.

- **Magmatic Processes**

Magmatic processes involve the crystallization of minerals from molten rock (magma) as it cools and solidifies. The origin of mineral deposits through magmatic processes can be further detailed as follows:

- **Layered Intrusions**: In some cases, the crystallization occurs in layers within the magma chamber, leading to the formation of layered mafic intrusions that can concentrate valuable metals such as chromium, nickel, and platinum.
- **Crystallization**: As magma rises to the Earth's crust, it cools, allowing minerals to crystallize. Different minerals crystallize at different temperatures, leading to a diverse range of mineral compositions within igneous rocks.
- **Pegmatites**: These are coarse-grained igneous rocks that form from the slow cooling of magma. They are often enriched in rare minerals like lithium, tantalum, and beryllium due to the concentration of incompatible elements that do not easily fit into the crystal structure of common minerals.

- **Hydrothermal Processes**

Hydrothermal processes involve the circulation of hot, mineral-rich fluids through fractures and pores in the Earth's crust. These processes lead to the origin of various mineral deposits:

- **Vein Deposits**: Hydrothermal fluids can precipitate minerals as they cool or react with surrounding rock. This process can create vein deposits rich in metals such as gold, silver, and lead. These deposits are often found in regions of tectonic activity, such as subduction zones.
- **Porphyry Deposits**: These large, disseminated deposits of copper and gold form in volcanic regions due to hydrothermal activity associated with magma intrusions. The fluids bring metal ions into the surrounding rock, leading to widespread mineralization.
- **Geothermal Systems**: Hydrothermal activity is also associated with geothermal energy systems, where heated water rises to the surface, leading to the deposition of minerals such as silica and sulfides.

- **Sedimentary Processes**

Sedimentary processes involve the weathering, erosion, transport, and deposition of minerals and sediments. The origin of mineral resources through sedimentary processes includes:

- **Placer Deposits**: These deposits form through the mechanical concentration of heavy minerals, such as gold, tin, and diamonds, in riverbeds or beach sands. The movement of water separates heavier minerals from lighter sediments, leading to concentrated deposits.
- **Evaporites**: When saline water evaporates in enclosed basins, minerals like halite (rock salt) and gypsum crystallize out of solution. These evaporite deposits are significant sources of salt

and other industrial minerals.

- **Chemical precipitates:** Minerals are dissolved from and redeposited, or precipitated, as the water evaporates. Example of chemical precipitate is Banded Iron Formations (BIFs), it consists of alternating layers of iron-rich minerals and silica. BIFs are believed to have formed in ancient oceans through biochemical processes, where dissolved iron precipitated due to changes in oxygen levels. Other examples are

- **Metamorphic Processes**

Metamorphic processes involve the alteration of existing rocks under high pressure and temperature, leading to the formation of new minerals. This can lead to the origin of specific mineral resources:

Metamorphosed Minerals: The transformation of rocks during metamorphism can produce economically important minerals such as graphite (from carbon-rich rocks), talc (from ultramafic rocks), and marble (from limestone). These processes is the solid state recrystallization. Some ore deposits are formed through metamorphic processes where original sedimentary or igneous rocks are altered to concentrate metals, such as in the case of some lead and zinc deposits.

4.3.4 Types Of Mineral Deposits and Their Characteristics

Understanding the origin of mineral resources also involves categorizing the types of deposits formed through these processes:

1. Igneous Deposits

- Formed from the cooling of magma.
- Examples include layered intrusions (chromite) and pegmatites (lithium).

2. Hydrothermal Deposits

- Formed from mineral-rich fluids.
- Examples include vein deposits (gold and silver) and porphyry deposits (copper and molybdenum).

3. Sedimentary Deposits

- Formed through the accumulation of sediments.
- Precipitation of elements from fluids to form concentration.
- Examples include placer deposits (gold and diamonds) and evaporites (salt and gypsum).

4. Metamorphic Deposits

- Formed through the alteration of existing rocks.
- Formed through solid state recrystallization
- Examples include graphite, marble and talc.

4.3.5 The Role of Plate Tectonics In Mineral Resource Formation

The movement of tectonic plates plays a crucial role in the origin of mineral resources. Plate tectonics influences the distribution and types of geological processes that lead to mineral formation. Key aspects include:

- **Subduction Zones**: Areas where one tectonic plate is forced beneath another are often sites of significant hydrothermal activity, leading to the formation of valuable mineral deposits. Porphyry Cu zones.
- **Mid-Ocean Ridges**: Divergent boundaries create new oceanic crust and can lead to the formation of massive sulfide deposits due to hydrothermal vent systems / manganese nodules.
- **Continental Collision Zones**: These regions are characterized by intense metamorphism and can concentrate minerals through processes like folding and faulting. BIF; Au in Schist belts, hot saline metamorphic metal bearing fluids interacting with cooler meteoric fluids – precipitate as vein deposits in fractures and faults.

4.3.6 Economic Importance of Mineral Resources

Mineral resources are essential to the global economy, contributing to various sectors, including:

- **Construction**: Aggregates, cement, and limestone are critical for infrastructure development.
- **Technology**: Rare earth elements, copper, and lithium are vital for electronics, batteries, and renewable energy technologies.
- **Energy**: Coal, uranium, and natural gas are important for energy production.

Understanding the origin of mineral resources enables better exploration and sustainable management practices, ensuring that these finite resources are used efficiently and responsibly.

4.4. CONCLUSION

The origin of mineral resources is a multifaceted process shaped by geological mechanisms that occur over extensive timescales. From magmatic crystallization to hydrothermal fluid circulation, sedimentary accumulation, and metamorphic transformation, these processes contribute to the formation of diverse mineral deposits essential to modern society. Recognizing the complex interactions that lead to the genesis of mineral resources is crucial for effective exploration, sustainable extraction, and responsible resource management.

4.5 SUMMARY

Mineral resources originate from various geological processes, including magmatic, hydrothermal, sedimentary, and metamorphic processes. Each of these processes contributes to the formation of specific types of mineral deposits, such as igneous, hydrothermal, sedimentary, and metamorphic deposits. The role of plate tectonics is significant in shaping the geological settings where these resources form. Understanding the origin of mineral resources is vital for sustainable exploration and responsible management of these essential materials.

4.6 REFERENCES

Evans, A. M. (2013). *Ore Geology and Industrial Minerals: An Introduction*. Wiley-Blackwell. Guilbert, J. M., & Park, C. F. (2007). *The Geology of Ore Deposits*. Waveland Press.

Robb, L. J. (2005). *Introduction to Ore-Forming Processes*. Wiley-Blackwell.

Craig, J., Vaughan, D. J., & Skinner, B. J. (2001). *Resources of the Earth: Origin, Use, and Environmental Impact*. Prentice Hall.

White, C. D., & Hurst, A. (2018). *Introduction to Mineral Exploration*. Wiley-Blackwell.

4.7 MULTIPLE CHOICE QUESTIONS

1. What is the primary driver of mineral resource genesis?

a) Wind erosion
b) Geological processes
c) Biological activity
d) Atmospheric conditions

2. Which type of mineral deposit is formed by the cooling and solidification of magma?

a) Sedimentary deposit
b) Hydrothermal deposit
c) Igneous deposit
d) Metamorphic deposit

3. What type of mineral resource forms through the evaporation of saline water?

a) Hydrothermal deposit
b) Placer deposit
c) Evaporite deposit
d) Banded iron formation

4. Which geological process is associated with the concentration of minerals through the movement of mineral-rich fluids?

a) Erosion
b) Sedimentation
c) Hydrothermal processes
d) Metamorphism

5. Banded iron formations (BIFs) are primarily composed of which mineral?

a) Gold
b) Graphite
c) Iron ore
d) Copper

6. Placer deposits are most commonly associated with:

a) Mountain building

b) Erosion and transportation by water
c) Volcanic activity
d) Deep-sea sedimentation

7. Which of the following metals is typically found in porphyry deposits?

a) Silver
b) Lead
c) Copper
d) Zinc

8. What type of deposit is formed by high pressure and temperature altering existing rocks?

a) Igneous deposit
b) Hydrothermal deposit
c) Metamorphic deposit
d) Sedimentary deposit

9. Which of the following is an example of a sedimentary mineral deposit?

a) Diamond
b) Gypsum
c) Nickel
d) Chromite

10. The genesis of mineral resources plays a crucial role in which aspect of modern society?

a) Agriculture
b) Renewable energy
c) Transportation
d) All of the above

ANSWER: 1B 2C 3C 4C 5C 6B 7C 8C 9B 10D

UNIT 5 DIVERSITY AND EXTINCTION OF SPECIES

Unit Structure

5.1 INTRODUCTION

Biodiversity, or biological diversity, refers to the variety of life on Earth, from genes to species to ecosystems. It plays a vital role in maintaining ecosystem services, which in turn support life, including human civilization. However, species extinction, the permanent loss of species, threatens biodiversity. Throughout Earth's history, extinction has occurred due to natural causes, but in recent centuries, human activities have significantly accelerated the rate of extinction. Understanding both biodiversity and extinction helps us assess the health of ecosystems and guides efforts to conserve species and maintain ecological balance.

5.2 OBJECTIVES

By the end of this unit, you will be able to:

- explain the concept of biodiversity and its levels
- explore the role of biodiversity in ecosystems and human well-being
- examine the causes and consequences of species extinction.
- investigate past and present extinction events
- identify conservation efforts aimed at protecting species and biodiversity.

5.4 BIODIVERSITY

5.4.1 Definition Of Biodiversity

Biodiversity encompasses the variety of all life forms on Earth, measured at three levels:

- Genetic Diversity: The variation of genes within species, allowing populations to adapt to environmental changes.
- Species Diversity: The variety of species within a habitat or region.
- Ecosystem Diversity: The range of different ecosystems, such as forests, grasslands, and oceans.

5.3.2 Importance of Biodiversity

Biodiversity is essential for:

- Ecosystem Functioning: Diverse species contribute to processes such as pollination, nutrient cycling, and decomposition.
- Human Survival: Biodiversity provides resources like food, medicine, and raw materials.
- Ecosystem Resilience: Biodiverse ecosystems are more resilient to disturbances such as climate change, disease, and habitat destruction.

5.3.3 Causes Of Species Extinction

Species extinction has both natural and human-induced causes:

Natural Causes of Extinction

- Catastrophic Events: Natural disasters like volcanic eruptions, asteroid impacts, and massive climate shifts have caused past extinctions, such as the one that wiped out the dinosaurs 66 million years ago.
- Environmental Changes: Gradual shifts in climate and habitat, along with evolutionary pressures, can drive species to extinction.

Anthropogenic (Human-Induced) Causes of Extinction

- Habitat Destruction: Deforestation, urbanization, and agricultural expansion reduce the habitats available for species.
- Climate Change: Human activities such as fossil fuel burning contribute to global warming, which alters habitats, making them unsuitable for some species.
- Pollution: Contaminants like plastic, heavy metals, and chemicals

degrade ecosystems and harm species.

- Overexploitation: Overhunting, overfishing, and unsustainable harvesting of resources lead to population decline.
- Invasive Species: Non-native species introduced by humans can outcompete, prey on, or introduce diseases to native species, driving them to extinction.

Major Extinction Events

Historical Mass Extinctions

Earth has experienced five major mass extinctions in the past:

- Ordovician-Silurian Extinction (440 million years ago): Triggered by climate changes, wiping out 85% of species.
- Permian-Triassic Extinction (252 million years ago): Known as "The Great Dying," this event killed 96% of marine species and 70% of land species.
- Cretaceous-Paleogene Extinction (66 million years ago): An asteroid impact led to the extinction of the dinosaurs.

Current Extinction Event: The Sixth Mass Extinction

Many scientists believe we are currently experiencing a sixth mass extinction, driven largely by human activity. Species are going extinct at rates 100 to 1,000 times faster than the natural background rate. Factors include habitat destruction, climate change, pollution, and overexploitation. This modern extinction event has severe consequences for ecosystems, economies, and human well-being.

5.3.7 Consequences Of Species Extinction

Ecosystem Imbalance

Species extinctions lead to imbalances in ecosystems:

- The loss of keystone species, such as predators or pollinators, can disrupt entire ecosystems, affecting other species and ecosystem functions.
- Trophic Cascades: Extinctions can cause cascading effects up and down the food chain. For example, the extinction of a predator may lead to the overpopulation of herbivores, which can deplete vegetation and destabilize the ecosystem.

Loss of Ecosystem Services

Biodiversity loss reduces ecosystems' ability to provide essential services, including:

- Pollination: The decline in pollinators like bees threatens food production.
- Water Purification and Soil Fertility: The degradation of

ecosystems compromises these natural processes.

Economic and Social Impact

Human communities, particularly those in developing countries, depend on biodiversity for food, medicine, and livelihoods. The loss of species and ecosystem services can lead to food insecurity, health crises, and economic instability.

5.3.8 Conservation Strategies

Protected Areas and Wildlife Reserves

Establishing protected areas such as national parks and marine reserves helps safeguard critical habitats and species. Notable examples include the Amazon Rainforest, Galápagos Islands, and Great Barrier Reef.

Legal Frameworks

International agreements like the Convention on Biological Diversity (CBD) and Convention on International Trade in Endangered Species (CITES) aim to protect species from overexploitation and ensure sustainable use of natural resources.

Habitat Restoration and Reintroduction Programs

Restoration projects, such as reforestation and wetland rehabilitation, help restore ecosystems and bring back endangered species. Reintroduction programs, like the return of wolves to Yellowstone National Park, have helped restore ecological balance.

Sustainable Resource Management

Practices such as sustainable agriculture, fisheries, and forestry reduce habitat destruction and overexploitation while ensuring the responsible use of biodiversity.

Addressing Climate Change

Mitigating climate change by reducing greenhouse gas emissions is essential for protecting habitats and species from further decline. This includes efforts like transitioning to renewable energy and promoting energy efficiency.

5.4. CONCLUSION

The diversity of species on Earth is essential for maintaining ecosystem health and human well- being. However, human activities have accelerated the rate of extinction, threatening ecosystems and biodiversity. The consequences of species extinction are severe, leading to ecosystem imbalance, loss of ecosystem services, and economic and social impacts. Addressing this crisis requires urgent action, including the creation of protected areas, habitat restoration, and policies aimed at sustainable resource use and climate change mitigation. A collective global effort is needed to preserve the planet's biodiversity and prevent further species extinction.

5.5 SUMMARY

- Biodiversity includes genetic, species, and ecosystem diversity and is essential for the resilience and functioning of ecosystems.
- Human activities such as habitat destruction, climate change, pollution, and overexploitation have significantly accelerated species extinction.
- Past mass extinctions were caused by natural events, but the current sixth mass extinction is primarily due to human activities.
- Extinctions have cascading effects, leading to ecosystem imbalance and the loss of ecosystem services.
- Conservation efforts, including protected areas, sustainable practices, and international agreements, are crucial to halting biodiversity loss and preventing further extinctions.

5.6 REFERENCES

Rawat, U.S. and Agarwal, N.K. (2015). "Biodiversity: Concepts, Threats and Conservation". Environment Conservation Journal 16(3) 19-28, ISSN 0972-3099 (Print) 2278-5124 (Online).

Wilson, E. O. (1992). *The Diversity of Life*. Harvard University Press.

Ceballos, G., Ehrlich, P. R., & Dirzo, R. (2017). *Biological Annihilation Via the Ongoing Sixth Mass Extinction*. PNAS.

Barnosky, A. D., et al. (2011). *Has the Earth's Sixth Mass Extinction Already Arrived?* Nature.

Secretariat of the Convention on Biological Diversity (2020). *Global Biodiversity Outlook 5*.

United Nations Environment Programme.

Cardinale, B. J., et al. (2012). *Biodiversity Loss and Its Impact on Humanity*. Nature.

5.7 MULTIPLE CHOICE QUESTIONS

1. What is biodiversity?

a) The number of living organisms on Earth
b) The variety of life, including species, genes, and ecosystems
c) The rate of species extinction
d) A measure of how ecosystems function

2. Which of the following is an example of species diversity?

a) Different climates in an ecosystem
b) Variety of habitats in a forest
c) A range of species in a coral reef
d) Genetic variation within a plant species

3. Which of the following is NOT a cause of extinction?

a) Habitat destruction
b) Genetic diversity
c) Climate change
d) Overexploitation

4. The Cretaceous-Paleogene extinction event is known for:

a) The extinction of large mammals
b) The extinction of the dinosaurs
c) The extinction of marine species
d) The extinction of early humans

5. Which term refers to the introduction of non-native species that disrupt ecosystems?

a) Habitat loss
b) Invasive species
c) Genetic diversity
d) Climate change

6. The loss of which of the following is an example of ecosystem imbalance?
a) Soil nutrients
b) Keystone species
c) Pollutants

d) Primary producers

7. What is the main cause of the current (sixth) mass extinction?

a) Volcanic eruptions
b) Human activities
c) Natural selection
d) Asteroid impact

8. Which of the following is a strategy for preventing extinction?

a) Overhunting
b) Establishing protected areas
c) Increasing pollution
d) Removing natural habitats

9. The Convention on Biological Diversity (CBD) is primarily concerned with:

a) Promoting deforestation
b) Mitigating climate change
c) Protecting species from extinction
d) Advancing genetic engineering

10. The extinction of pollinator species would most likely impact:

a) Agricultural production
b) Ocean acidification
c) The spread of invasive species
d) Earthquake activity

ANSWER: 1B 2C 3B 4B 5B 6B 7B 8B 9C 10A

MODULE 3 BASIN EVOLUTION

UNIT 1 ORIGIN AND GROWTH OF BASINS

Unit Structure

1.1 INTRODUCTION

Basins are depressions on the Earth's surface where sediments accumulate, typically over millions of years. They vary greatly in size, shape, and origin, playing critical roles in natural systems like water bodies, ecosystems, and sedimentary processes. Understanding the formation and evolution of basins is crucial for fields such as geology, hydrology, and environmental science. The origin and growth of basins involve complex processes tied to tectonic activity, sedimentary deposition, and erosion, among others. Basins not only shape landscapes but also host vital resources such as water, hydrocarbons, and minerals.

1.2 OBJECTIVES

By the end of this unit, you will be able to:

- explain the different types of basins and their formation mechanisms.
- analyse the geological and tectonic processes that contribute to the origin and growth of basins.
- explore the role of basins in the deposition of sediments and the

formation of natural resources.
- examine case studies of major basins worldwide and their economic significance**.**

1.4 BASIN EVOLUTION

1.4.1 **Origin of Basins**

Basin formation is typically driven by tectonic activities that affect the Earth's lithosphere. The Earth's outer shell, or lithosphere, is divided into tectonic plates that move over the more fluid asthenosphere. These movements create different types of basins through mechanisms such as crustal extension, compression, and lateral displacement. The various types of basins are associated with specific tectonic environments.

1.3.9. **Tectonic Mechanisms**

- Extensional Tectonics (Rift Basins): Rift basins form when tectonic forces pull the crust apart, leading to the development of a depression. This type of basin is associated with divergent plate boundaries, where a new oceanic crust is being created. The East African Rift is a classic example of a rift basin, where the African continent is slowly being pulled apart.
- Compressional Tectonics (Foreland Basins): Foreland basins form as a result of compressional forces where tectonic plates collide, pushing up mountain ranges. These basins develop adjacent to the mountains and are formed by the flexure of the lithosphere under the weight of the rising mountain belt. The basins associated with the Himalayas and the Alps are classic examples of foreland basins.
- Strike-slip tectonics (Strike-Slip Basins): These basins form due to lateral (horizontal) movement along strike-slip faults. As the fault slips, a depression can form along the fault zone. An example is the Los Angeles Basin, which is associated with the San Andreas Fault system.
- Subduction-Related Tectonics (Back-Arc Basins): Back-arc basins form in regions where one tectonic plate is being subducted under another. The overriding plate experiences extension, leading to the formation of a basin behind the volcanic arc. The Sea of Japan is a well-known example of a back-arc basin.

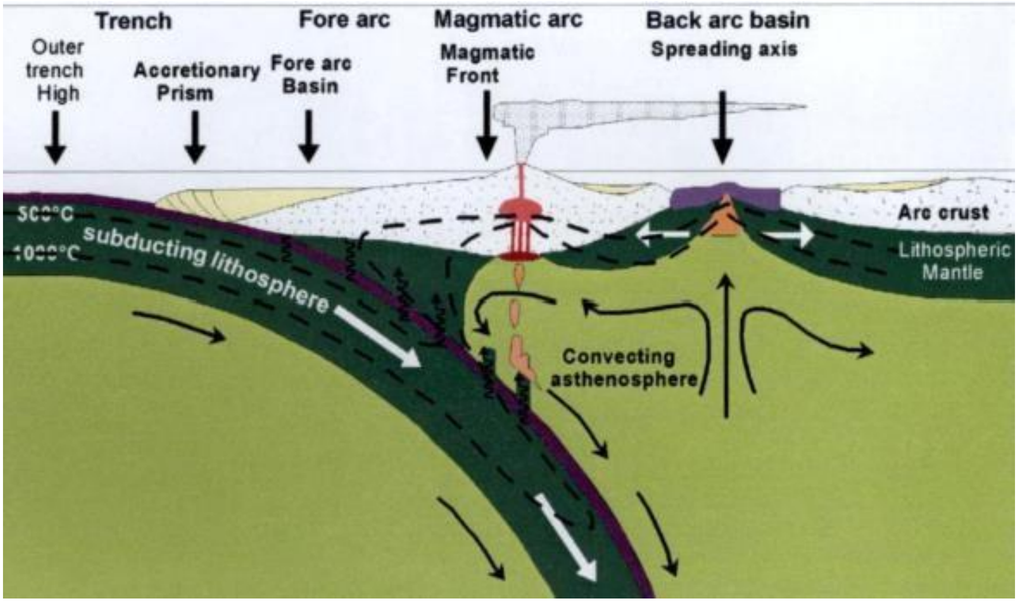

Figure 1: Tectonism mechanism for basin formation (Allen and Allen, 2013)

1.3.10. **Subsidence And Erosional Processes**

- Thermal Subsidence Basins: These basins form when the lithosphere cools and contracts after tectonic rifting. The cooling leads to subsidence, which can create a large basin that continues to accumulate sediments over millions of years. The North Sea Basin is an example of a thermal subsidence basin, where hydrocarbon-rich sediments have been deposited over time.
- Erosional Basins: In some cases, basins are formed not through tectonic forces but through erosion. These basins form as surrounding landmasses are eroded away by wind, water, or ice, leaving a depression that fills with sediments. The Michigan Basin in the U.S. is an example of a basin formed by erosion and long-term subsidence.

1.3.11. **Growth Of Basins**

Once a basin forms, its growth is primarily driven by the processes of sedimentation and tectonic subsidence. Sedimentation occurs when material such as rock fragments, organic matter, and minerals is transported by rivers, glaciers, or wind into the basin. Over time, these sediments accumulate and compact, eventually forming sedimentary rock layers. Basin growth involves the gradual deepening and filling of the depression through these processes.

1.3.12. **Sediment Deposition**

The rate at which sediment accumulates in a basin is determined by factors such as the local climate, topography, and the availability of sediment. Large river systems, such as the Nile or the Mississippi, deliver massive amounts of sediment to their respective basins, leading to the gradual filling and growth of these basins. The following factors play critical roles in sediment deposition:

- Source of Sediments: Rivers, glaciers, and wind transport sediments into basins. The size, type, and rate of sediment input vary based on the basin's location, nearby geology, and climate conditions.
- Basin Morphology and Accommodation Space: The shape and size of the basin determine how much sediment can be deposited. As basins subsides due to tectonic processes or natural compaction, more space becomes available for sediment accumulation.
- Sea-Level Changes: Sea-level fluctuations, often driven by climatic changes such as glacial and interglacial periods, affect the amount of sediment deposited in coastal and shallow marine basins. During periods of sea-level rise, basins can receive more sediments, while during sea-level falls, coastal basins may be exposed to erosion and limited sediment input.

1.3.13. **Tectonic Subsidence**

Subsidence is a key factor in the growth of basins. As tectonic forces cause a basin to sink, accommodation space for sediments increases. Subsidence rates can vary depending on tectonic activity and the weight of the accumulating sediments. In regions with high rates of subsidence, such as the Mississippi Delta, basins can grow rapidly as sediments fill the depression created by the sinking crust.

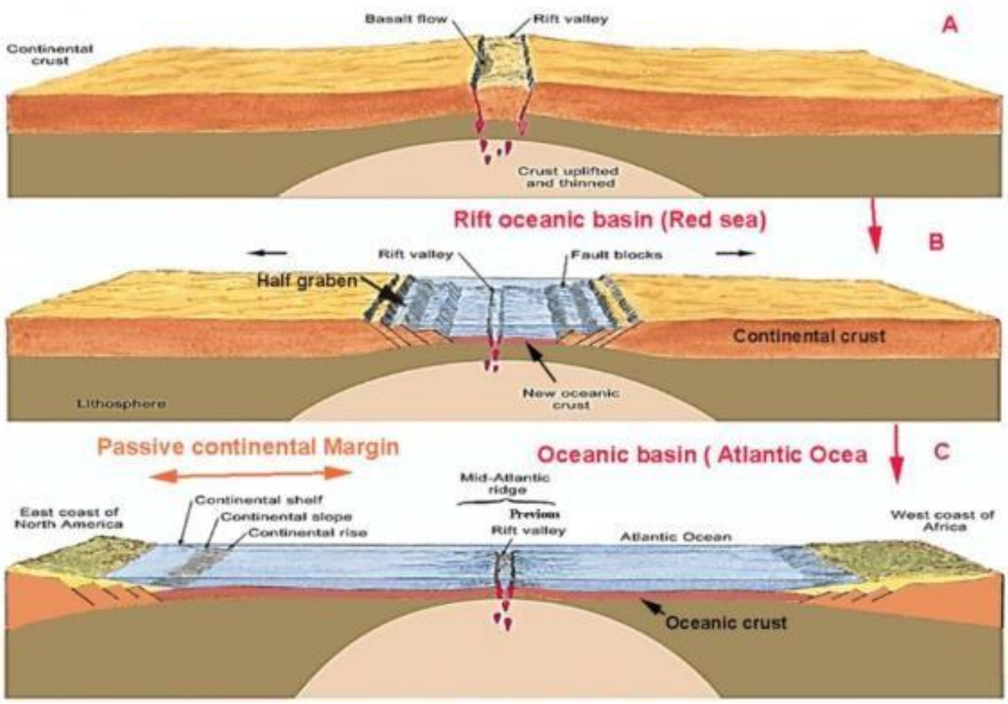

Figure 2: Tectonic subsidence for basin formation (Miall, 2016).

1.3.14. **Compaction And Diagenesis**

As sediments accumulate, the weight of the overlying material compresses the lower layers, driving water out of the pores and causing the sediments to compact. Over time, these compacted sediments undergo diagenesis, a process where they are transformed into solid rock. This process continues the growth and evolution of the basin by creating layers of sedimentary rock that preserve records of the Earth’s history.

1.3.15. **Economic And Environmental Importance of Basins**

Basins are not only important geological structures but also have significant economic and environmental value:

- Hydrocarbon Reservoirs: Many basins contain rich deposits of oil and natural gas. These hydrocarbons form from organic material trapped in sedimentary layers that, over millions of years, were subjected to heat and pressure, transforming them into fossil fuels. The North Sea Basin, the Persian Gulf, and the Permian Basin are major oil and gas-producing regions.
- Water Resources: Basins often host large water bodies such as lakes, rivers, and aquifers, which are essential for human consumption, agriculture, and industry. The Amazon Basin, for example, is the world’s largest drainage basin, crucial for global water cycles and biodiversity.

- Mineral Resources: Sedimentary basins can also contain valuable mineral deposits, such as coal, evaporites (salt, gypsum), and phosphates. Some basins also host metallic minerals that formed in specific sedimentary environments.
- Biodiversity and Ecosystems: Basins, especially those associated with large river systems, are critical for maintaining biodiversity. Wetlands, floodplains, and deltas are among the most productive ecosystems on the planet, supporting a wide range of species.

1.4. CONCLUSION

The origin and growth of basins are driven by a complex interplay of tectonic, sedimentary, and erosional processes. Basins form in response to tectonic forces, such as extension, compression, and lateral movement, and they grow through the accumulation of sediments and continued subsidence. Understanding these processes is essential for interpreting the Earth's geological history and for managing natural resources like water, oil, and minerals. As basins continue to evolve, they provide invaluable insights into the dynamics of Earth's surface and subsurface processes, as well as offering substantial economic benefits.

1.5. SUMMARY

- Basins are depressions on the Earth's surface formed by tectonic forces such as extension, compression, and lateral movement.
- Rift basins form due to crustal extension, foreland basins form due to compression, and strike-slip basins form due to lateral displacement.
- Sedimentation and tectonic subsidence are key processes in the growth of basins, with sediments accumulating in the basin over time.
- Basins have significant economic importance due to their role as reservoirs for water, oil, gas, and minerals.
- Examples of major basins include the Amazon Basin, North Sea Basin, and Michigan Basin.

1.6 REFERENCES

Allen, P.A., & Allen, J.R. (2013). Basin Analysis: Principles and Application to Petroleum Play Assessment. Wiley-Blackwell.

Miall, A.D. (2016). The Geology of Sedimentary Basins. Springer.

Schlumberger. (2023). "Basin Types and Their Formation Mechanisms." Schlumberger Oilfield Glossary.

North, F.K. (2012). Petroleum Geology. Allen & Unwin.

1.7 MULTIPLE CHOICE QUESTIONS

1. Which of the following basins forms as a result of tectonic extension?

a) Foreland Basin
b) Rift Basin
c) Back-arc Basin
d) Strike-slip Basin

2. What geological process primarily leads to the formation of foreland basins?

a) Lateral movement of tectonic plates
b) Crustal extension
c) Compressional forces
d) Volcanic activity

3. Which type of basin is formed due to horizontal displacement along faults?

a) Rift Basin
b) Foreland Basin
c) Strike-slip Basin
d) Thermal Subsidence Basin

4. What factor is crucial for the growth of a sedimentary basin?

a) Erosion rates
b) Tectonic uplift
c) Sedimentation rates
d) Volcanic eruptions

5. What is the main source of sediment in most basins?

a) Glaciers
b) Wind
c) Rivers

d) Volcanic ash

6. Which of the following basins is an example of a thermal subsidence basin?

a) East African Rift
b) Gulf of Mexico
c) Himalayan Foreland
d) Los Angeles Basin

7. What role do basins play in the accumulation of hydrocarbons?

a) They prevent sedimentation.
b) They serve as sites for organic material burial and transformation.
c) They are areas of active volcanic activity.
d) They are only formed by erosion.

8. Which process leads to the compaction and transformation of sediments into sedimentary rock?

a) Erosion
b) Diagenesis
c) Weathering
d) Subduction

9. The Amazon Basin is primarily known for its significance in which of the following?

a) Oil and gas reserves
b) Biodiversity and water resources
c) Mineral deposits
d) Coal production

10. What can trigger significant changes in sedimentation patterns within a basin?

a) Changes in tectonic activity
b) Seasonal weather variations
c) Changes in sea level
d) All of the above

ANSWER: 1B 2C 3C 4C 5C 6B 7B 8B 9B 10D

UNIT 2 TYPES OF BASINS

Unit Structure

2.1. INTRODUCTION

Basins are depressions in the Earth's surface that can be structural, erosional, or depositional. They are crucial features in the study of geology because they host significant amounts of sedimentary material and often provide a record of the Earth's history, including tectonic activity, climatic changes, and the evolution of life. Basins are also important because they contain valuable natural resources, such as oil, gas, coal, and minerals, making them prime targets for exploration. There are many different types of basins, each formed through specific geological processes. These processes can include tectonic plate movements, erosion, sediment deposition, and volcanic activity. This extensive discussion will explore the various types of basins, their formation mechanisms, characteristics, and their economic significance.

2.2 OBJECTIVES

By the end of this unit, you will be able to:

- discuss the various types of basins and their formation processes.
- examine the tectonic, sedimentary, and erosional processes that lead to basin formation.
- explore the significance of different basins in terms of natural resources and geological history.

2.3. TYPES OF BASINS

Basin classification is typically based on their formation process, location within the Earth's crust, and tectonic setting. Broadly, basins can be divided into tectonic basins, sedimentary basins, volcanic basins, and impact basins.

2.3.6. Tectonic Basins

Tectonic basins are formed due to the movements of the Earth's tectonic plates. These movements can involve crustal extension, compression, or lateral displacement.

a) Rift Basins

- Formation Mechanism: Rift basins form due to extensional tectonics, where the Earth's crust is pulled apart. This process creates a down-dropped block or depression known as a graben, bordered by normal faults.
- Example: The East African Rift Basin is a notable example where the African Plate is splitting into the Somali Plate and Nubian Plate. Benue Trough Basin in Nigeria
- Significance: Rift basins are important for understanding continental breakup, and they often accumulate thick sequences of sediments, making them potential hydrocarbon reservoirs.

b) Foreland Basins

- Formation Mechanism: Foreland basins are created due to compressional tectonics at convergent plate boundaries. The weight of an overriding mountain belt causes the lithosphere to flex downward, creating a basin.
- Example: The Ganges Basin in India, located adjacent to the Himalayas, is a classic foreland basin formed by the collision between the Indian and Eurasian plates.
- Significance: Foreland basins accumulate large amounts of sediments eroded from adjacent mountains and are significant for oil and gas exploration.

c) Strike-Slip Basins

- Formation Mechanism: These basins form along strike-slip faults where lateral (horizontal) movements create localized areas of extension, leading to basin formation.
- Example: The Los Angeles Basin, located near the San Andreas

Fault, is a well-known strike-slip basin.

- Significance: Strike-slip basins are relatively small but can be rich in hydrocarbons, as seen in the oil-rich Los Angeles Basin.

d) Back-Arc Basins

- Formation Mechanism: Back-arc basins form behind volcanic arcs in subduction zones. As one tectonic plate is forced beneath another, extensional forces in the overriding plate create a basin behind the volcanic arc.
- Example: The Sea of Japan is a back-arc basin formed due to the subduction of the Pacific Plate beneath the Eurasian Plate.
- Significance: Back-arc basins can accumulate significant volcanic and sedimentary deposits and are often rich in mineral resources.

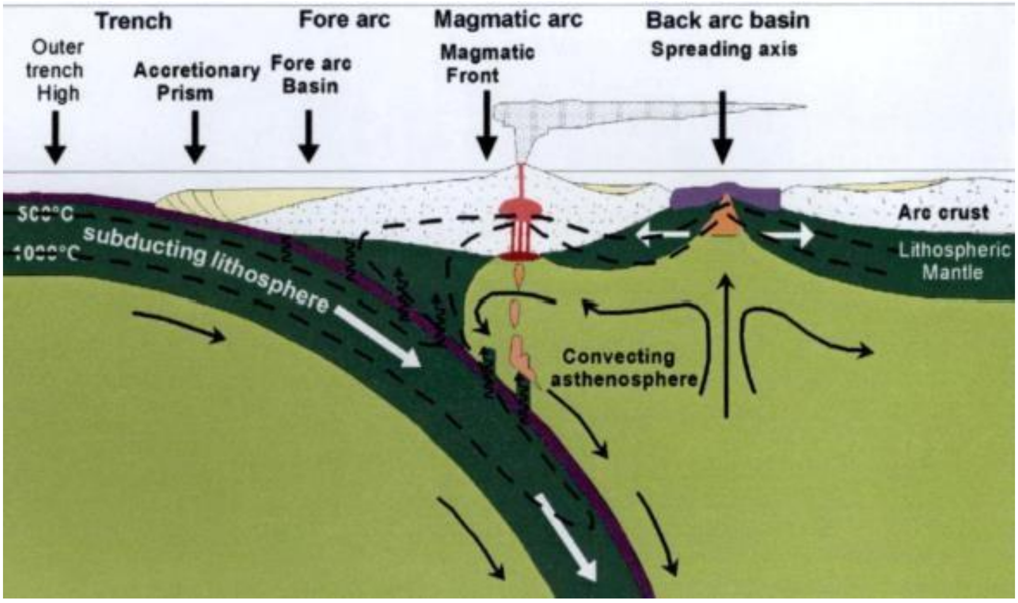

Figure 1: Tectonism mechanism for basin formation (Allen and Allen, 2013)

2.3.7. **Sedimentary Basins**

Sedimentary basins are low areas on the Earth's surface where sediments accumulate over time. These basins can be formed through various geological processes, including tectonic activity and subsidence.

a) Intracratonic Basins

- Formation Mechanism: Intracratonic basins are large, shallow depressions that form within stable continental interiors, often due to thermal subsidence, where the lithosphere cools and contracts.

- Example: The Michigan Basin in the United States is an intracratonic basin that has accumulated significant deposits of evaporites (salts), limestones, and shales.
- Significance: Intracratonic basins are important for studying long-term sedimentary processes and can host valuable resources like salt, gypsum, and oil.

b) Passive Margin Basins

- Formation Mechanism: Passive margin basins form along continental margins that are not associated with tectonic activity. They develop as the continent moves away from a spreading center, and the continental crust gradually subsides, allowing sediments to accumulate.
- Example: The Gulf of Mexico is a passive margin basin formed as North America drifted away from Europe and Africa during the breakup of Pangaea. Niger delta basin in Nigeria
- Significance: Passive margin basins are often rich in oil and gas deposits. The Gulf of Mexico is one of the most productive oil-producing regions in the world.

c) Transtensional Basins

- Formation Mechanism: These basins form where both extensional and strike-slip faulting occurs simultaneously, often at complex plate boundaries.
- Example: The Dead Sea Basin, located along the Dead Sea Transform fault system, is a transtensional basin.
- Significance: Transtensional basins can host unique sedimentary environments, such as evaporites, and may also be important for hydrocarbon exploration.

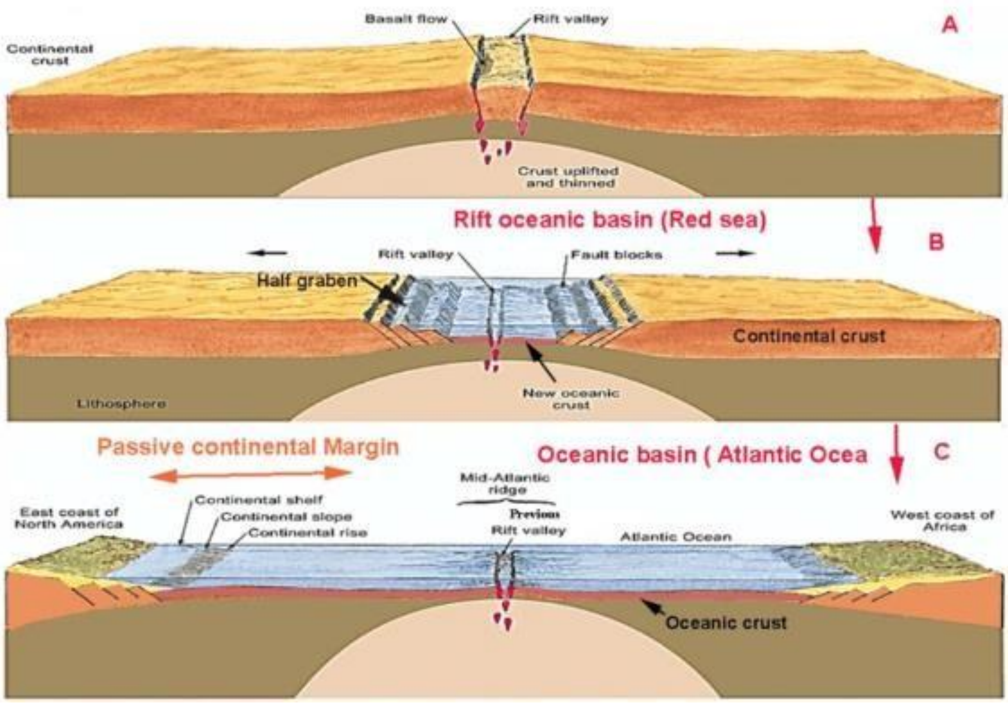

Figure 2: Sedimentary basin formation (Miall, 2016).

2.3.8. **Volcanic Basins**

Volcanic basins are formed by volcanic activity, often as a result of large eruptions that create depressions in the Earth's surface.

a) Caldera Basins

- Formation Mechanism: Calderas form when a large volcanic eruption causes the collapse of a magma chamber, creating a large circular depression. These depressions can later fill with sediments or water, forming lakes.
- Example: The Yellowstone Caldera in the United States is a well-known volcanic basin.
- Significance: Caldera basins are important for studying volcanic processes and are also sites of geothermal energy.

b) Volcanic Rift Basins

- Formation Mechanism: These basins form in regions of volcanic activity associated with rifting, where the crust is being pulled apart, allowing magma to rise to the surface.
- Example: The Afar Triangle in Ethiopia is a volcanic rift basin where tectonic rifting is accompanied by significant volcanic activity.
- Significance: These basins provide insights into the interplay between tectonics and volcanism and are often associated with

geothermal energy resources.

2.3.9. Impact Basins

Impact basins are created by the collision of extraterrestrial bodies, such as asteroids or meteorites, with the Earth's surface. These collisions create large depressions that can later fill with sediments.

a) Meteorite Impact Basins

- Formation Mechanism: These basins form when a large meteorite strikes the Earth's surface, causing an explosion that leaves a circular depression. Over time, this depression can fill with sediments or water, forming a lake.
- Example: The Chicxulub Crater in Mexico is one of the most famous impact basins, formed by the meteorite that contributed to the extinction of the dinosaurs.
- Significance: Impact basins are rare but provide valuable insights into planetary geology and the role of extraterrestrial events in shaping the Earth's surface.

2.3.10. Erosional Basins

Erosional basins are formed by the removal of material through wind, water, or glacial activity. These basins are typically formed in regions where erosion outpaces deposition.

a) Glacial Basins

- Formation Mechanism: Glacial basins are formed by the erosion of the Earth's surface by glaciers. As glaciers move, they carve out deep valleys and basins that are later filled with water or sediments.
- Example: The Great Lakes in North America are glacial basins formed by the action of glaciers during the last Ice Age.
- Significance: Glacial basins are important freshwater reservoirs and provide evidence of past glaciation.

b) Riverine Basins

- Formation Mechanism: Riverine basins form as rivers erode the surrounding landscape, creating wide, shallow depressions that can later fill with sediments.
- Example: The Amazon Basin is the largest river basin in the world, formed by the erosional action of the Amazon River and its tributaries.
- Significance: Riverine basins are essential for studying fluvial

processes and are often fertile regions for agriculture.

2.4. CONCLUSION

Basins are fundamental geological features formed through a variety of processes, including tectonic activity, sediment deposition, volcanic eruptions, and meteorite impacts. Each type of basin has unique characteristics and forms in specific geological settings, making them essential for understanding Earth's history and for the exploration of natural resources like oil, gas, and minerals. Rift basins, foreland basins, intracratonic basins, volcanic basins, and impact basins all represent different geological environments and processes, contributing to the diversity of Earth's surface features.

2.5. SUMMARY

- Tectonic basins include rift, foreland, strike-slip, and back-arc basins, formed by plate tectonics and crustal deformation.
- Sedimentary basins include intracratonic and passive margin basins, where sediments accumulate over time due to subsidence.
- Volcanic basins form through volcanic activity, such as the collapse of a magma chamber, creating a caldera.
- Impact basins are formed by the impact of meteorites or asteroids, such as the Chicxulub Crater.

2.6. REFERENCES

Allen, P.A., & Allen, J.R. (2013). Basin Analysis: Principles and Application to Petroleum Play Assessment. Wiley-Blackwell.

Miall, A.D. (2016). The Geology of Sedimentary Basins. Springer.

Schlumberger. (2023). "Basin Types and Their Formation Mechanisms." Schlumberger Oilfield Glossary.

North, F.K. (2012). Petroleum Geology. Allen & Unwin.

2.7. MULTIPLE CHOICE QUESTIONS

1. Which of the following is a type of sedimentary basin formed along passive continental margins?

A) Rift Basin
B) Foreland Basin
C) Passive Margin Basin
D) Intracratonic Basin

2. What type of basin forms due to the stretching and thinning of the Earth’s crust?

A) Forearc Basin
B) Rift Basin
C) Foreland Basin
D) Passive Margin Basin

3. Which of the following basins typically forms due to the bending of the Earth's crust in response to a nearby mountain belt?

A) Rift Basin
B) Foreland Basin

C) Intracratonic Basin
D) Passive Margin Basin

4. Which type of basin is associated with large, stable cratons and usually forms away from active plate boundaries?

A) Rift Basin
B) Forearc Basin
C) Intracratonic Basin
D) Back-arc Basin

5. What type of basin forms between an oceanic trench and a volcanic arc?

A) Forearc Basin
B) Rift Basin
C) Back-arc Basin
D) Foreland Basin

6. The Niger Delta Basin in Nigeria is an example of which type of basin?

A) Rift Basin
B) Intracratonic Basin
C) Passive Margin Basin
D) Foreland Basin

7. Which type of basin is typically found on the continental side of a volcanic arc, in regions where subduction occurs?

A) Forearc Basin
B) Back-arc Basin
C) Rift Basin
D) Intracratonic Basin

8. What type of basin forms within a continent due to localized subsidence, often far from tectonic boundaries?

A) Intracratonic Basin
B) Foreland Basin
C) Rift Basin
D) Back-arc Basin

9. The Benue Trough in Nigeria is an example of which type of basin?

A) Forearc Basin
B) Rift Basin
C) Intracratonic Basin
D) Foreland Basin

10. Which of the following describes a basin formed by the downward flexure of the Earth's crust as a result of tectonic compression?

A) Passive Margin Basin
B) Foreland Basin
C) Rift Basin
D) Back-arc Basin

ANSWER: 1C 2B 3B 4C 5A 6C 7B 8A 9B 10B

MODULE 4 FORMATION OF SEDIMENTARY ROCKS

UNIT 1 TYPES OF SEDIMENTARY ROCKS AND MECHANISM OF SEDIMENT DEPOSITION

Unit Structure

1.1 INTRODUCTION

Sedimentary rocks are formed through the gradual accumulation of "sediment" for example, sand on a beach or mud on a river bed. As the sediment is buried it is compacted as more and more materials are deposited on the top. They are derived from pre-existing rocks such as igneous rocks or metamorphic rocks. They are referred to as "derived rocks" or "sedimentary rocks". The parent rocks were altered by the forces of weathering which could be by wind, water, frost, or sun and were broken down. The rock materials were then carried away to some suitable locations, on the land, lake or sea. In this unit, we will be looking at the different sedimentary rocks and the medium at which sediment has been transported and deposited.

1.2 OBJECTIVES

By the end of this unit, you will be able to:

- identify the major classification of sediments and sedimentary rock;
- explain the different sources and deposition of sediments.
- discuss the different transport media responsible for sediment deposition.

1.3 TYPES OF SEDIMENT AND SEDIMENTARY ROCKS

1.3.1. Sediments

Sediments are rock fragments that are broken from the pre-existing rocks (igneous or metamorphic rocks) as a result of weathering. Sedimentary rocks are formed through the gradual accumulation of the sediments. These sediments can be classified based on their size, composition, and origin.

A. Clastic Sediments

- **Particle Size-based classification:**
  - **Gravel:** coarse-grained fragments/particles (larger than 2 mm).
  - **Sand:** medium-grained fragments/particles (0.0625-2 mm).
  - **Silt:** fine-grained fragments/particles (0.004-0.0625 mm).
  - **Clay:** very fine-grained fragments/particles (smaller than 0.004 mm).

- **Composition-based classification:**

  - **Detrital sediments:** derived from the weathering of rocks.
  - **Bioclastic sediments:** composed of fragments of organisms.
  - **Pyroclastic sediments:** derived from volcanic eruptions.

B. Chemical Sediments

- Precipitated from solutions, often in bodies of water.

Examples: limestone, dolomite, chert, halite, gypsum.

C. Organic Sediments

- Derived from the accumulation of organic matter.

Examples: coal, oil shale, peat.

These different types of sediments can be transported and deposited by various agents, such as water, wind, ice, or gravity, to form sedimentary rocks.

1.3.2. Sedimentary Rocks

Sedimentary rocks are grouped into two categories; they include (i) Clastic and (ii)Non- Clastic Sedimentary rocks.

(A) Clastic Sedimentary rocks: These are rocks that are made up of particles or clasts derived from pre-existing rocks.

(B) Non-clastic sedimentary rocks: These are biogenic or chemical-precipitated materials formed from the precipitation of salts.

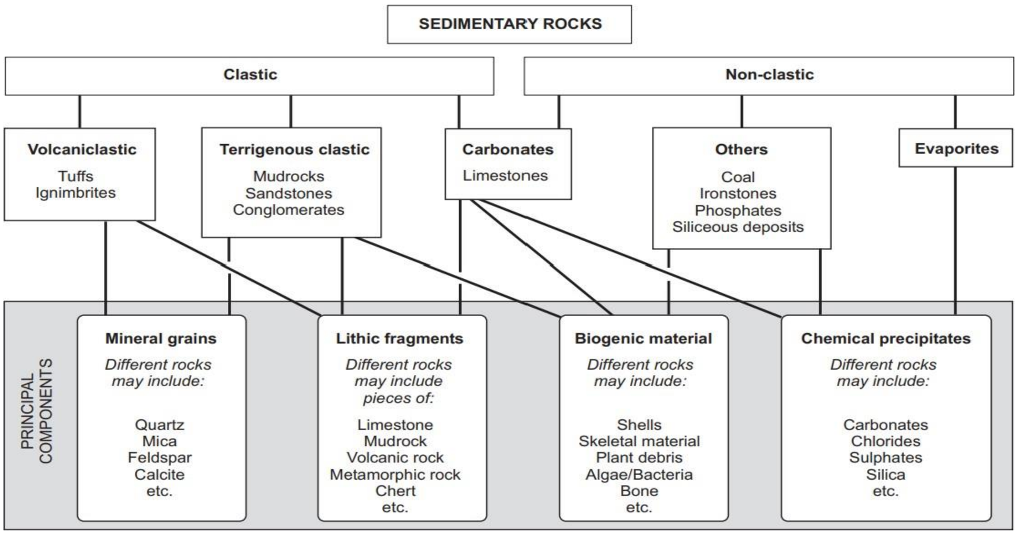

Fig. 1: A classification scheme for sediments and sedimentary rocks

A. Clastic Sedimentary Rocks

These are rocks formed by the breakdown or disintegration of preexisting rock during the process of mechanical weathering. Agents of erosion such as water, wind or glaciers then transport the materials. These materials are later deposited in the sea or on land where they are pressed together to become solid as rock by water or the weight of overlying deposits. This process of solidification is called “compaction or cementation”. The clastic sedimentary rocks can be divided into;

i. Volcaniclastic rocks: These are rocks that are composed of material of volcanic origin, mainly lava fragments, volcanic glass and crystals. Examples of volcaniclastic rocks are tuffs and ignimbrites.

ii. Terrigenous clastic rocks: These are rocks dominated by detrital grains (especially silicate minerals and rock fragments). Examples are sandstones, conglomerates, breccias and mudrocks.

iii. Carbonate rock: These are rocks that are dominated by biogenic materials such as shells, skeletal material and plant debris. Examples are limestones and dolomites.

B. Non-Clastic Sedimentary Rocks

The non-clastic sedimentary rocks can either be chemically formed or organically formed sedimentary rocks.

i. Chemically formed sedimentary rocks: These are rocks chemically precipitated from rocks before they solidified. Some sedimentary rocks are formed as a result of the precipitation of certain minerals from salt solutions. These are referred to as "evaporates". An example of chemical precipitation in sedimentary rocks is the precipitation of calcium carbonate from calcium bicarbonate. This is formed as water passes through limestone; it dissolves its mineral Unit Structure and carries it as a solution. Over a period, this mineral carried in solution is used to build "stalactites" and stalagmites in limestone caves.

ii. Organically Formed Sedimentary Rocks: Some sea animals extract calcium carbonate from the sea to build their shells and skeletons. This calcium carbonate accumulates after their death to form rocks such as limestone, chalk and dolomite. Buried coastal plants had been found along coastal land under clay and mud to form rock such as peat, lignite and coal after decay. The carbon content of the plant is especially common in coal plant remains which gives coal its black colour. Coal is mined as a fuel and it can be used in making a variety of plastic and medicines.

Other examples of non-clastic sedimentary rocks are ironstone, phosphates and siliceous deposits.

1.3.3 Transport Media Responsible for Sediment Deposition

Water: Transporting material in water is by far the most significant of all transport mechanisms. Water flows on the land surface in channels and as overland flow. Currents in seas are driven by wind, tides and oceanic circulation. These flows may be strong enough to carry coarse material along the base of the flow and finer material in suspension. Material may be carried in water hundreds or thousands of kilometres before being deposited.

Air: Wind blowing over the land can pick up dust and sand and carry it large distances. The low density of air limits the capacity of the wind to transport material.

Ice: This occurs mostly in the glacier environment (Ice region), it is considered a fluid because, over long periods, it moves across the land surface, albeit very slowly. Ice is, therefore, a rather high-viscosity fluid that is capable of transporting large amounts of plastic debris. The movement of detritus by ice is significant in and around polar ice caps and in mountainous areas with glaciers. The volume of material moved by ice has been very great at times of extensive glaciation.

1.4 CONCLUSION

In this unit, different classifications of sediments and sedimentary rock were highlighted. Also, the source and area of deposition. The unit also explains different mechanisms by which sediments can be transported.

1.5. SUMMARY

- Sedimentary rocks are formed through the gradual accumulation of "sediment".
- Sediments are rock fragments that are broken from the pre-existing rocks as a result of weathering or chemical precipitation. Examples are mineral grains, biogenic material etc.
- Sedimentary rocks are divided into clastic and non-clastic rocks.
- The clastic sedimentary rocks are formed from weathering of the pre-existing rocks e.g., Sandstone, tuff, breccia, conglomerate and limestone.
- The non-clastic sedimentary rocks are either chemically formed or organically formed sedimentary rocks. Examples are evaporites, shale, limestone, coal etc.
- The sediments can be transported through Water, Air and Ice.

1.6 REFERENCES

Chernicoff, S. & Whitney, D. (2007) Geology: An Introduction to Physical Geology (4th edition).

Pearson/Prentice Hall, New Jersey.

Grotzinger, J., Jordan, T.H., Press, F. & Siever, R. (2007) Understanding Earth (5th edition).

Freeman and Co., New York.

Lutgens, F.K. & Tarbuck, E.J. (2006) Essentials of Geology (9th edition). Pearson/Prentice Hall, New Jersey.

Allen, J.R.L. (1982) Sedimentary Structures: their Character and Physical Basis, Vol. 1.

Developments in Sedimentology. Elsevier, Amsterdam.

Collinson, J., Mountney, N. & Thompson, D. (2006) Sedimentary Structures. Terra Publishing, London.

Leeder, M.R. (1999) Sedimentology and Sedimentary Basins: From Turbulence to Tectonics.

Blackwell Science, Oxford.

Allen, J.R.L. (1985) Principles of Physical Sedimentology. Unwin-Hyman, London. Allen, P.A. (1997) Earth Surface Processes. Blackwell Science, Oxford, 404 pp.

1.7 MULTIPLE CHOICE QUESTIONS

1. The breaking down of rocks is called____
a. weathering
b. explosion
c. melting
d. compaction.

2. Rock fragments that are broken from the pre-existing rocks are ______
(a) sediments
(b) moulds
(c) boulders
(d) sand.

3. These are examples of sediments except (a) mineral grains (b) rock fragments (c) Sandstone (d) Plant debris.

4. All these are examples of terrigenous rock except (a) shale (b) sandstone (c) mudrock (d) conglomerate.

5. Example of biogenic materials (a) quartz (b) Mica (c) fossil (d) silica.

6. This rock belongs to non-clastic rocks (a) Sandstone (b) Tuff (c) Ironstone (d) Ignimbrites

7. One of the transport media for sediments are (a) water (b) Air (c) Ice (d) Magma

8. River belongs to what transport media for sediments (a) Ice (b) Magma (c) water (d) Hotspring

9. ______is an example of a carbonate rock (a) sandstone (b) Limestone (c) Tuff (d) evaporites.

10. ______is a rock formed chemical precipitated (a) Sandstone (b) limestone (c) Shale (d) evaporite

ANSWER: 1B 2A 3C 4A 5C 6C 7D 8C 9B 10D

UNIT 2 DIAGENESIS AND LITHIFICATION OF SEDIMENTS

Unit Structure

2.1 INTRODUCTION

Sediments, after being deposited through various geological processes like erosion, transport, and deposition, do not remain in their loose, unconsolidated form indefinitely. Over time, they undergo a series of changes through processes known as **diagenesis** and **lithification**. These processes are essential in converting loose sediments into solid sedimentary rocks. Diagenesis encompasses a wide range of chemical, physical, and biological transformations that sediments experience after their deposition, while lithification focuses on the hardening of these sediments into rock. These changes occur under relatively low temperature and pressure conditions, distinguishing them from metamorphism, which takes place at much higher temperatures and pressures. This unit will explore the various factors influencing these processes and the resulting sedimentary rock types.

2.2 OBJECTIVES

By the end of this unit, you will be able to:

- explain the basic concepts of diagenesis and lithification
- identify the key factors that influence these processes
- describe the different stages of sediment transformation
- analyse the role of diagenesis and lithification in geological history.

2.3 CONCEPT OF DIAGENESIS AND LITHIFICATION

2.3.1. Diagenesis

Diagenesis refers to the physical, chemical, and biological processes that occur in sediments after their initial deposition and during and after their lithification (conversion to rock). It encompasses all the changes that occur to sediments from the moment they are deposited until they are either turned into rock or destroyed. Diagenetic processes take place at relatively low temperatures and pressures, distinguishing them from metamorphic processes.

stages of diagenesis

Diagenesis can be broadly divided into early, middle, and late stages based on the depth and intensity of the processes involved:

- Early Diagenesis: Occurs at shallow depths shortly after sediment deposition, typically in unconsolidated sediments. The dominant processes here include compaction, bioturbation, the dissolution of unstable minerals, and the precipitation of minerals like calcite, silica, and iron oxides. Organic matter decomposition by microbial activity also plays a key role, especially in marine environments.
- Middle Diagenesis: Occurs at greater depths where temperature and pressure increase. In this stage, more significant changes occur, such as the transformation of unstable minerals into more stable forms. Clay minerals may begin to undergo significant alteration, and cementation can become a dominant process. Recrystallisation of some minerals, particularly carbonates, also begins.
- Late Diagenesis: Happens in deeply buried sediments and is characterized by even higher temperatures and pressures, sometimes bordering on the conditions of metamorphism. In this stage, there can be extensive mineralogical changes, further recrystallisation, and the growth of new mineral phases. Organic matter may undergo further thermal maturation, potentially generating hydrocarbons.

Processes In Diagenesis

- Compaction: As more sediments accumulate over time, the weight of the overlying layers exerts pressure on the lower layers, reducing the pore space between sediment grains. This results in the expulsion of pore water and increased density of the sediment.

- Cementation: Involves the precipitation of minerals from pore waters, binding the grains of sediment together. Common cementing agents include silica, calcite, and iron oxides. Cementation is critical in transforming loose sediments into solid rock.
- Recrystallisation: Occurs when minerals reorganize into more stable forms without a change in the overall chemistry of the rock. Carbonates, especially in limestones, often undergo recrystallisation during diagenesis, altering the size and texture of mineral grains.
- Dissolution: Some minerals are more soluble than others in water, particularly if the chemical conditions of the pore waters change. This process removes minerals from the rock, creating secondary porosity.
- Authigenesis: Refers to the formation of new minerals within the sediment from material already present. This can include the growth of clay minerals or the precipitation of minerals like quartz and calcite from pore fluids.
- Bioturbation: Organisms living within the sediment can physically disrupt the layering and structure of sediments, as well as chemically alter the sediment through biological activity.

Types Of Diagenetic Environments

- Marine Diagenesis: Occurs in oceans and seas, where sediments are in contact with seawater. Diagenetic processes in these environments are influenced by the chemistry of seawater, microbial activity, and the presence of organic material.
- Fluvial Diagenesis: Takes place in river systems where sediments are subject to fresh water. The interaction between river water and sediments affects processes like oxidation, organic matter decomposition, and mineral precipitation.
- Lacustrine Diagenesis: Found in lake environments, where freshwater conditions dominate. Diagenetic processes in lakes are influenced by the chemistry of the lake water, sedimentation rates, and biological activity.

2.3.2. Lithification

Lithification refers specifically to the process by which loose sediments are transformed into solid sedimentary rocks. It is a subset of the broader diagenetic processes, focusing on the hardening of sediments into rock. Lithification involves both compaction and cementation and can occur relatively quickly in geologic terms or over long periods, depending on environmental conditions.

Key Processes in Lithification

- Compaction: This is the primary mechanism in lithification, where the weight of overlying sediments compresses the grains in the sedimentary layer. Compaction leads to a reduction in pore spaces, causing sediments to become denser and more consolidated.
- Cementation: Following compaction, mineral-rich water percolates through the sediment deposits minerals in the pore spaces between sediment grains. Over time, these precipitated minerals (such as calcite, silica, or iron oxides) form a natural "glue" that binds the grains together into a solid mass. Cementation is crucial for the rock to attain the strength and coherence typical of sedimentary rocks.

Figure 1: A lithified Shale sediment (Boggs, 2016)

Factors Influencing Lithification

- Grain Size: Finer-grained sediments, like clay and silt, typically lithify more readily than coarse-grained sediments like sand, due to their smaller pore spaces. Sands and gravels require more extensive cementation to become rock.
- Sediment Composition: The mineral makeup of the sediment determines the types of cement that will form during lithification. For example, carbonates like limestone often lithify more quickly due to the solubility and precipitation of calcium carbonate in pore waters.
- Pure Water Chemistry: The chemistry of the water circulating

through the sediments plays a crucial role in cementation. Waters rich in dissolved minerals are more likely to deposit cementing agents within the pore spaces of the sediments.

Types of Lithified Sediments

- Clastic Sedimentary Rocks: Formed from the compaction and cementation of fragments of pre-existing rocks. Common clastic sedimentary rocks include sandstone, siltstone, and shale, each representing different grain sizes of sediment.
- Chemical Sedimentary Rocks: Formed from the precipitation of minerals from solution, these rocks include limestones (calcium carbonate) and evaporites like gypsum and halite, which form from the evaporation of mineral-rich water.
- Organic Sedimentary Rocks: These rocks, such as coal, form from the lithification of organic material, including plant debris. The compaction of organic material over time can create coal beds, while the compaction of shell fragments or other biological materials can form limestone.

2.3.3. Diagenesis and Lithification in Different Environments

- Fluvial and Alluvial Settings: In river or floodplain environments, sediments undergo rapid deposition, and lithification often follows quickly due to the compaction and cementation in sandstones and conglomerates.
- Marine Settings: In shallow marine environments, bioclastic sediments (like shell fragments) can undergo rapid diagenesis, especially in warm, tropical waters where calcium carbonate is abundant. Deep-sea sediments lithify more slowly due to the lower deposition rates and cooler temperatures.
- Lacustrine Environments: Lakes tend to accumulate fine-grained sediments like clays, which lithify into shales or mudstones. Diagenesis in lakes is influenced by the chemistry of lake water, often resulting in organic-rich sedimentary rocks.

2.3.4. Significance Of Diagenesis and Lithification

These processes are vital in the formation of sedimentary rocks, which are key to interpreting Earth’s geological history. Fossils, which are often preserved within sedimentary rocks, provide critical information about past life. The diagenetic history of a sedimentary basin can also provide insight into past environments, fluid migration, and even potential hydrocarbon reservoirs.

2.4. CONCLUSION

Diagenesis and lithification are intimately related processes that play a crucial role in transforming loose sediments into solid rock. While diagenesis encompasses a broader range of post-depositional changes, lithification focuses on the physical processes of compaction and cementation that produce sedimentary rocks. Together, they shape much of the Earth's surface geology and preserve records of environmental conditions, biological activity, and geochemical processes over time. Understanding these processes helps geologists interpret past environments, assess the potential for natural resources like hydrocarbons and groundwater, and reconstruct ancient landscapes. Both diagenesis and lithification are vital components of the rock cycle and illustrate how sediments evolve over geological time.

2.5 SUMMARY

- Diagenesis is a broad term covering all post-depositional changes in sediments, while lithification specifically refers to the process of turning sediment into rock.
- The main processes of diagenesis include compaction, cementation, dissolution, recrystallisation, and bioturbation.
- Lithification focuses on the compaction and cementation that bind sediments together to form rocks.
- The formation of different types of sedimentary rocks depends on the sediment's grain size, mineral composition, and environmental conditions during diagenesis and lithification.

2.6 REFERENCES

Boggs, S. Jr. (2016). *Principles of Sedimentology and Stratigraphy*. Pearson.

Leeder, M. R. (2011). *Sedimentology and Sedimentary Basins: From Turbulence to Tectonics*. Wiley-Blackwell.

Prothero, D. R., & Andrews, F. N. (2004). *Sedimentary Geology*. W.H. Freeman.

Schultz, M. J. (Ed.). (1987). *The Diagenesis of Sedimentary Rocks*.

Academic Press.

Smith, M. L., & Hughes, K. J. (2011). "Role of Organic Matter in Diagenesis and Lithification of Shales." *Marine and Petroleum Geology*, 28(3), 779-790. **DOI:** 10.1016/j.marpetgeo.2010.08.002

Wilson, J. R., & Cohen, H. L. (2006). "Sediment Diagenesis: A Case Study of the Permian Basin." *AAPG Bulletin*, 90(3), 345-367.**DOI:** 10.1306/01290605147.

2.7 MULTIPLE CHOICE QUESTIONS

ATTEMPT ALL QUESTIONS

1. Which of the following processes is involved in diagenesis?
a) Weathering
b) Compaction
c) Sedimentation
d) Erosion

2. What is the primary factor that leads to the compaction of sediments during lithification?
a) Chemical alteration
b) Overlying pressure
c) Temperature change
d) Biological activity

3. Lithification is the process by which:
a) Sediments are deposited in layers.
b) Sediments are transformed into solid rock.
c) Rocks are eroded and transported.
d) Igneous rocks are formed.

4. Cementation during lithification involves the:
a) Dissolution of mineral grains.
b) Re-crystallisation of organic matter.
c) Precipitation of minerals between sediment grains.
d) Movement of sediments by wind and water.

5. Which of the following is NOT a typical mineral involved in cementation?
a) Quartz
b) Calcite
c) Hematite
d) Olivine

6. What happens to pore spaces between sediment grains during compaction?
a) They increase in size
b) They fill with water
c) They are reduced in size
d) They become larger due to chemical weathering

7. The transition from sediment to sedimentary rock occurs primarily due to:
a) Crystallisation of magma
b) Lithification
c) Metamorphism
d) Plate tectonics

8. Diagenesis differs from metamorphism in that it:
a) Occurs at higher temperatures and pressures.
b) Occurs at lower temperatures and pressures.
c) Involves melting of the material.
d) Only affects igneous rocks.

9. Which of the following is a common feature of chemical diagenesis?
a) Melting of sediment
b) Formation of new minerals
c) Increase in pore spaces
d) Dissolution of igneous rocks

10. Which of the following can be a product of biological diagenesis in sediments?
a) Fossil fuels
b) Metamorphic rocks
c) Igneous intrusions
d) Volcanic ash

ANSWER: **1B 2B 3B 4C 5D 6C 7B 8B 9B 10A**

UNIT 3 STRUCTURES AND TEXTURES OF SEDIMENTS AND SEDIMENTARY ROCKS

Unit Structure

3.1. Introduction
3.2. Objectives
3.3. Structures in sediments and sedimentary rocks
 3.3.1. Primary Sedimentary Structures
 3.3.2. Secondary Sedimentary Structures
 3.3.3. Textures of Sediments and Sedimentary Rocks
3.4. Conclusion
3.5. Summary
3.6. References
3.7. Multiple Choice Questions

3.1 INTRODUCTION

Sedimentary rocks and the sediments from which they form display a wide variety of **structures** and **textures** that are essential for interpreting past environments, depositional processes, and geological history. These features provide insights into the transportation, deposition, and lithification processes that formed the rocks. This unit will explain the various structures and textures found in sediments and sedimentary rocks, and how they can be used to interpret geological history.

3.2 OBJECTIVES

By the end of this unit, you will be able to:

- define and identify different types of sedimentary structures and textures
- explain the formation processes of various sedimentary structures.
- Relate sedimentary structures and textures to depositional environments
- analyze the impact of post-depositional processes on sedimentary structures and textures
- apply knowledge of sedimentary structures and textures to geological interpretation.

3.3 STRUCTURES IN SEDIMENTS AND SEDIMENTARY ROCKS

Sedimentary structures are the large-scale physical features seen in sedimentary rocks, created during or shortly after the deposition of sediments. These structures provide essential clues about the conditions of deposition, the environmental setting, and the geological processes that occurred. They are particularly useful for interpreting the Earth's sedimentary history and reconstructing past environments. Sedimentary structures can be categorized into primary (those formed during deposition) and secondary (those formed after deposition, such as through post-depositional processes like deformation or bioturbation). Below is the discussion of key sedimentary structures, their formation processes, and their geological significance.

3.3.4. **Primary Sedimentary Structures**

Primary structures are formed at the time of deposition and provide important information about the environment of sediment deposition.

1. Bedding and Stratification

- Description: Bedding refers to the layered arrangement of sediments, with individual beds (or strata) separated by bedding planes. These layers represent changes in sediment deposition over time, and the orientation and characteristics of the beds offer information about the depositional environment.

Types of Bedding:

- Planar (or Horizontal) Bedding: This is the most common form of bedding, characterized by horizontal layers of sediment. It forms in environments with minimal disturbance during sedimentation, such as lakes or deep marine basins.
- Cross-Bedding: Cross-bedding consists of inclined layers within horizontal beds. It forms from the migration of ripples or dunes in water or wind environments.
  - Trough Cross-Bedding: Curved, concave layers that form from migrating ripples or dunes in a fluvial or aeolian setting.
  - Tabular Cross-Bedding: Flat or gently inclined layers typical in windblown sand dunes or shallow marine environments.
- Graded Bedding: A type of bedding where the grain size gradually changes from coarse at the bottom to fine at the top within a single bed. Graded bedding often forms from turbidity currents in deep-sea environments.

- Normal Grading: Indicates a decrease in energy, typical in underwater landslides.
- Reverse Grading: Less common, where finer particles are at the base, forming in unusual settings like debris flows.

- Geological Significance: Bedding provides insights into sedimentary processes, depositional environments, and even tectonic settings. Cross-bedding, for instance, is common in fluvial, aeolian, and coastal environments, and it can be used to determine paleocurrent directions. Graded bedding is indicative of high-energy depositional events, such as turbidity currents in deep marine environments.

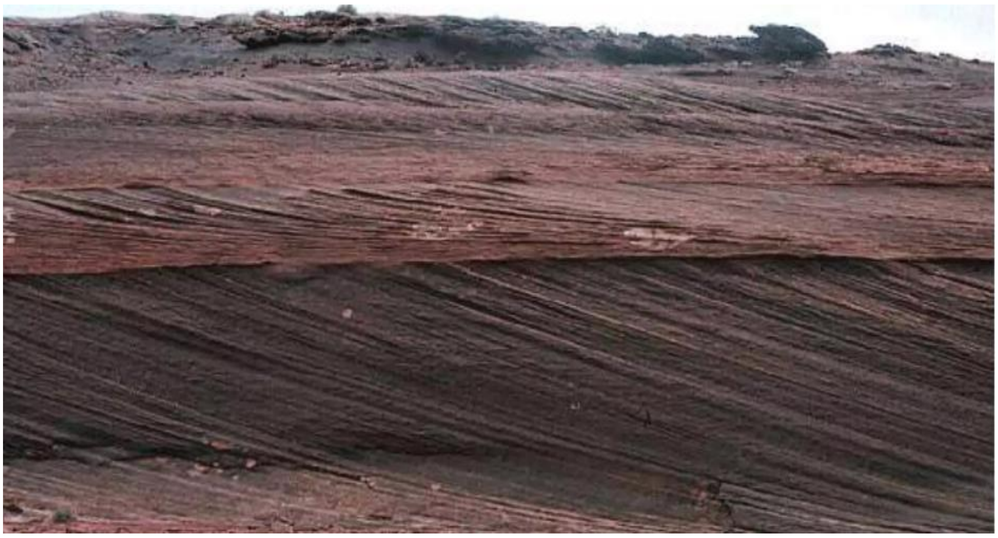

Fig. 1: Sedimentary structure showing cross bedding (Leeder, 2016)

2. Ripple Marks

- Description: Ripple marks are small-scale, wave-like structures formed on sediment surfaces by the movement of water or wind. They are typically found in sandstones and siltstones.

Types Ripple Marks

- Symmetrical Ripple Marks: These have a wave-like appearance and form in environments where water oscillates back and forth, such as beaches.
- Asymmetrical Ripple Marks: These have a steep slope on one side, formed by unidirectional currents, such as those found in rivers or on shallow marine shelves.

- Geological Significance: Ripple marks indicate the direction and nature of sediment transport. Asymmetrical ripples show the flow direction, while symmetrical ripples indicate a bidirectional movement, such as wave action in shallow waters.

Figure 2: Sedimentary structure showing ripple marks (Leeder, 2016)

3. Mud Cracks

- Description: Mud cracks form when fine-grained sediments, like clay or silt, are exposed to the air and dry out. The sediment contracts, creating a network of polygonal cracks.
- Formation: Mud cracks are commonly found in environments that experience periodic drying, such as tidal flats, floodplains, and desert playas.
- Geological Significance: Mud cracks suggest that the environment experienced alternating wet and dry conditions, such as in tidal zones or ephemeral lakes. They provide evidence of exposure to the atmosphere and indicate subaerial conditions.

Figure 3: Sedimentary structure showing mud cracks (Leeder, 2016)

4. Flute Casts

- Description: Flute casts are erosional features formed by turbulent water scouring the bed surface, creating elongated, bulbous depressions. These depressions are later filled by overlying sediments.
- Formation: Typically found in deep marine environments affected by turbidity currents, where the force of the current erodes the underlying sediments.
- Geological Significance: Flute casts are useful indicators of current direction and high- energy depositional environments. They are often used in conjunction with graded bedding to interpret deep-water turbidite deposits.

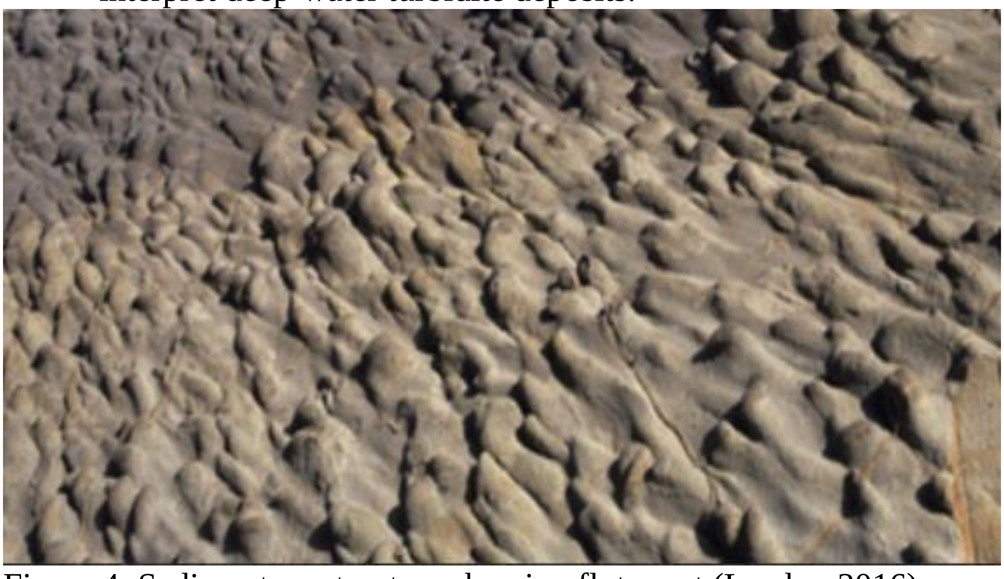

Figure 4: Sedimentary structure showing flute cast (Leeder, 2016)

5. Imbrication

- Description: Imbrication refers to the arrangement of flat or elongated sediment particles (such as pebbles or cobbles) where they lean against each other in a preferred direction.
- Formation: Commonly found in river environments where flowing water causes the clasts to align.
- Geological Significance: Imbricated clasts indicate the direction of water flow, as the clasts tilt upstream. This structure is commonly used to reconstruct paleocurrent directions in fluvial or river systems.

Figure 5: Sedimentary structure showing imbrications (Leeder, 2016)

6. Graded Bedding

- Description: Graded bedding consists of a gradual change in grain size from coarse at the base to fine at the top of a sedimentary bed.
- Formation: Typically, graded bedding forms in environments like deep-sea fans where turbidity currents deposit sediments. The coarsest particles settle first, followed by progressively finer particles as the current loses energy.
- Geological Significance: Graded bedding is a clear indicator of a decrease in flow velocity, often associated with turbidity currents. These beds can help geologists interpret underwater landslide events and the flow regime of ancient submarine environments.

Figure 6: Sedimentary structure showing graded bedding (Leeder, 2016)

7. Troughs and Channels

- Description: Troughs and channels are erosional features formed by the movement of water, which scours the sediment surface. These features are later filled with coarser sediments, creating a U- or V-shaped structure.
- Formation: Typically found in river channels, deltas, and submarine environments where high-energy flows erode the substrate.
- Geological Significance: These structures indicate erosional events and can be used to reconstruct the energy levels and depositional conditions of ancient environments. Channel structures suggest that the sediment was deposited in a high-energy environment, such as a river or deltaic system.

3.3.5. **Secondary Sedimentary Structures**

Secondary sedimentary structures form after the initial deposition of sediments, often during early diagenesis or as a result of biological, chemical, or physical processes.

1. Bioturbation Structures

- Description: Bioturbation refers to the disruption of sedimentary layers by the activities of organisms, such as burrowing, feeding, or crawling.
- Formation: Organisms such as worms, mollusks, and other infaunal creatures disturb the sediment, creating burrows, tubes, and tracks.

- Geological Significance: Bioturbation structures provide information about the biological activity in the depositional environment, including oxygen levels and the nature of the substrate. Extensive bioturbation can obliterate original sedimentary structures, making it challenging to interpret depositional environments.

Figure 7: Sedimentary structure showing bioturbation (Leeder, 2016)

2. Concretions and Nodules

- Description: Concretions are hard, compact masses of mineral matter that form within the sediment after deposition. They often have a different composition than the surrounding sediment.
- Formation: Concretions form as minerals precipitate around a nucleus, such as a fossil, in the sediment. This typically occurs due to changes in pore water chemistry during diagenesis.
- Geological Significance: Concretions can preserve fossils and provide clues to the diagenetic history of the sediment. They also indicate changes in chemical conditions during or after deposition.

Figure 8: Sedimentary structure showing concretions (Leeder, 2016)

3.3.6. Textures Of Sediments and Sedimentary Rocks

The texture of sedimentary rocks refers to the size, shape, sorting, and arrangement of grains or clasts, which provide clues to the history of sediment transportation and deposition.

A. Grain Size

Grain size is one of the most fundamental characteristics of sedimentary texture, determining how sediments and sedimentary rocks are classified and providing insights into the energy of the depositional environment.

1. Classification of Grain Size

- **Gravel**: Particles larger than 2 mm in diameter.
  - Subtypes include **cobbles** (64–256 mm) and **boulders** (>256 mm).
- **Sand**: Particles between 0.0625 mm and 2 mm.
  - Subtypes include **very coarse sand** (1–2 mm), **coarse sand** (0.5–1 mm), **medium sand** (0.25–0.5 mm), **fine sand** (0.125–0.25 mm), and **very fine sand** (0.0625–0.125 mm).
- **Silt**: Particles between 0.0039 mm and 0.0625 mm.
- **Clay**: Particles smaller than 0.0039 mm.

2. Significance of Grain Size

- **Energy of the Depositional Environment**: The grain size of sediments reflects the energy of the transporting medium (water, wind, or ice). Coarser grains like gravel and sand are deposited in high-energy environments such as rivers, beaches, and deserts. Fine-grained sediments like silt and clay settle out in low-energy environments like deep marine basins, lakes, and floodplains.
- **Transport Distance**: Generally, the finer the grain size, the farther the sediment has traveled from its source. Clay and silt-sized particles can remain suspended in water and travel great distances before settling, while larger particles like gravel and boulders are deposited closer to their source.

Particle Size (mm)	Particle Name		Name of Rock Formed	
<0.004	Clay*	Mud	Shale	Mudstone
0.004–0.063	Silt		Siltstone	
0.064–2	Sand		Sandstone	
2–4	Granule	Gravel	Breccia (if particles are angular)	
4–64	Pebble			
64–256	Cobble		Conglomerate (if particles are rounded)	
>256	Boulder			

Figure 9: Grain size (Tucker, 2011)

3. Methods of Measurement

- **Sieving**: For sand and larger particles, sieving is a common method to measure grain size.
- **Sedimentation Techniques**: For finer particles such as silt and clay, sedimentation methods (such as pipette or hydrometer analysis) are used to determine particle size based on settling rates.

B. Grain Shape

Grain shape refers to the overall geometry of sediment particles and is influenced by their original form and the degree of mechanical weathering during transport.

1. Roundness

- **Definition**: Roundness describes the degree to which the edges and corners of a grain are smoothed or rounded off. It is a result of physical abrasion during transport.

- **Classification**:

  - **Angular**: Grains with sharp edges and corners.
  - **Sub-angular**: Slightly worn edges.
  - **Sub-rounded**: Moderately worn edges.
  - **Rounded**: Well-rounded grains with smooth edges.

- **Geological Significance**: More rounded grains indicate longer transportation distances or more intensive reworking by wind or water. Angular grains suggest minimal transport, as they retain their sharp edges. Thus, the roundness of grains can be used to interpret the distance from the source and the transport mechanism (e.g., river, wind, or glacier).

2. Sphericity

- **Definition**: Sphericity measures how closely a grain's shape approaches that of a sphere.

- **Classification**:

  - **High Sphericity**: Grains that are nearly spherical in shape.
  - **Low Sphericity**: Grains that are elongated, flattened, or irregularly shaped.
- **Geological Significance**: Sphericity is influenced by the composition of the grain and the nature of its source material. While less indicative of transport distance than roundness, it can provide insights into the original form of the material and its resistance to weathering.

3. Fabric

- **Definition**: Fabric refers to the orientation and arrangement of grains within a sedimentary rock.

- **Types of Fabric**:

  - **Grain-Supported Fabric**: Grains are in direct contact with each other, typically indicating a higher-energy environment where finer sediments are winnowed away.
  - **Matrix-Supported Fabric**: Grains are surrounded by finer sediment, often indicating deposition in lower-energy environments where finer particles settle around larger grains.

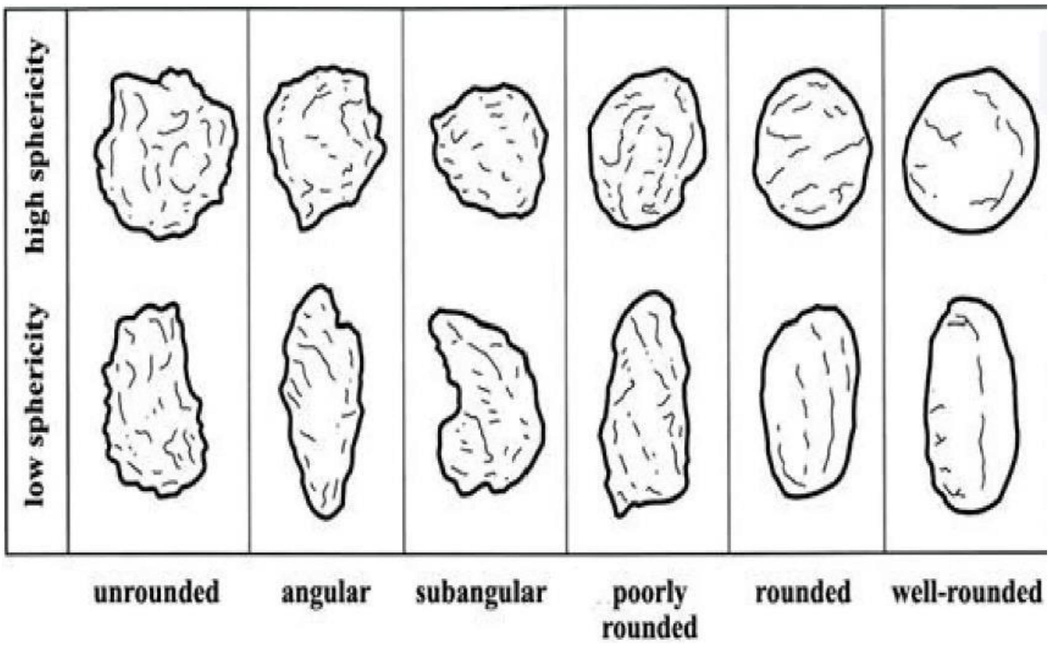

Figure 10: Grain shape (Tucker, 2011)

C. Sorting

Sorting refers to the distribution of grain sizes within a sediment or sedimentary rock. It describes how uniform the grain sizes are and is controlled by the transport medium.

1. Types of Sorting

- **Well-Sorted Sediments**: Grains are of nearly uniform size, indicating deposition by a steady transport medium like wind or water. Windblown sands, for example, are typically well-sorted.
- **Poorly-Sorted Sediments**: Grains vary widely in size, indicating deposition by turbulent or high-energy processes like glaciers, debris flows, or landslides, which do not sort sediments by size.

2. Significance of Sorting

- **Depositional Environment**: Well-sorted sediments are common in environments with consistent energy conditions, such as deserts, beaches, and river channels. Poorly sorted sediments indicate more erratic energy levels, as in glacial deposits or alluvial fans.

- **Transport History**: Sorting can also reflect the distance from the source. As sediments are transported over longer distances, the finer particles are carried further away, leaving coarser material behind, leading to better sorting in more distant deposits.

D. Grain Orientation

Grain orientation describes the alignment of sediment particles in a sedimentary rock, especially in cases where elongated or flat grains show a preferred direction of alignment.

1. Imbrication

- **Definition**: In a flowing medium (such as water), elongated clasts (e.g., pebbles) may align themselves so that they overlap each other in the direction of the current, producing a pattern known as **imbrication**.
- **Geological Significance**: Imbrication is commonly observed in fluvial environments and can be used to infer paleocurrent directions, revealing the orientation of ancient river flows.

2. Compaction and Fabric Orientation

- **Description**: Grains can become aligned due to compaction during burial or by forces exerted by water or wind currents. This alignment reflects the dynamics of the depositional environment.
- **Significance**: Grain orientation is valuable in reconstructing paleocurrent directions, depositional slopes, and flow regimes in sedimentary environments like rivers and deltas.

E. Cementation and Matrix

Sedimentary rocks are formed through the process of **lithification**, where sediments are turned into rock. This process involves **compaction** and **cementation**.

1. Cementation

- **Description**: Cementation occurs when minerals precipitate from groundwater and fill the spaces between sediment grains, binding them together.
- **Common Cements**: The most common minerals acting as cement include **calcite**, **quartz**, and **hematite**.

- **Significance**: The type of cement reflects the geochemical conditions present during the diagenetic process, and the amount of cementation influences the porosity and permeability of sedimentary rocks, which is important for oil, gas, and water reservoirs.

2. Matrix

- **Description**: The **matrix** refers to the fine-grained material (typically silt or clay) that fills the spaces between the coarser grains.
- **Significance**: The presence or absence of a matrix can be used to interpret depositional processes. Matrix-supported textures typically form in lower-energy environments, while grain-supported textures form in higher-energy conditions.

3.4. CONCLUSION

The study of sedimentary structures and textures offers valuable insights into past environments and the geological processes that shaped the Earth's surface. By analyzing these features, geologists can interpret the history of sediment transportation, deposition, and lithification, as well as predict the occurrence of natural resources. Structures like bedding, cross-bedding, ripple marks, and mud cracks, along with textural properties such as grain size, shape, sorting, and cementation, collectively contribute to the understanding of sedimentary rock formation and the dynamic processes that influence them.

3.5. SUMMARY

- The study of structures and textures in sediments and sedimentary rocks is vital for interpreting the geological past. Sedimentary structures such as bedding, cross-bedding, ripple marks, and mud cracks reflect the depositional environment, energy conditions, and flow dynamics during sediment deposition.
- Sedimentary textures, including grain size, shape, sorting, and orientation, provide additional clues about sediment transport. Grain size is directly related to the energy of the depositional environment, with coarser grains indicating high-energy settings and finer grains suggesting low-energy environments. Grain shape and roundness offer insights into

- the distance sediments have traveled, while sorting indicates the consistency of the transport medium. Cementation and matrix material influence the lithification process and provide information about the geochemistry of pore waters during diagenesis.
- Together, sedimentary structures and textures offer a window into the processes that shaped the Earth's surface over time. They help geologists reconstruct ancient environments, understand sediment transport mechanisms, and identify depositional settings, which is crucial for resource exploration. By analyzing these features, we can interpret past geological events, reconstruct ancient landscapes, and predict the distribution of economically important resources like hydrocarbons and groundwater.

3.6. REFERENCES

Boggs, S. Jr. (2016). *Principles of Sedimentology and Stratigraphy*. Pearson.

Leeder, M. R. (2011). *Sedimentology and Sedimentary Basins: From Turbulence to Tectonics*.
Wiley-Blackwell.

Prothero, D. R., & Andrews, F. N. (2004). *Sedimentary Geology*. W.H. Freeman.

Reading, H. G. (2009). *Sedimentary Environments: Processes, Facies and Stratigraphy*. Wiley- Blackwell.

Tucker, M. E. (2001). *Sedimentary Petrology: An Introduction*. Blackwell Science.

Allen, J. R. L. (1982). *Sedimentary Structures: Their Character and Physical Basis*.
Developments in Sedimentology. Elsevier.

Internal Structures of Earth [Online] http://www.**rauias.com/blog/internal-structure-of-earth**, Retrieved on the 3rd September, 2024.
Yuan, H. and Romanowicz, B. (2019). "Introduction - Lithospheric Discontinuities". Pp 1 – 3. In: Geophysical Monograph 239, First Edition. Yuan, H. and Romanowicz, B. (Eds.). © 2019 American Geophysical Union. Published 2019 by John Wiley & Sons, Inc. DOI:10.1002/9781119249740.ch0

3.7. MULTIPLE CHOICE QUESTIONS

ATTEMPT ALL QUESTIONS

1. Which of the following is NOT a primary sedimentary structure?
A. Cross-bedding
B. Ripple marks
C. Mud cracks
D. Concretions

2. Which of the following grain sizes represents the boundary between sand and silt? A. 0.0625 mm
B. 0.2 mm
C. 0.5 mm
D. 2 mm

3. What does well-sorted sediment indicate about the depositional environment?
A. It was deposited in a high-energy environment like a fast-moving river.
B. It was deposited in a low-energy environment like a deep ocean.
C. It was transported by a consistent, steady energy medium like wind or water.
D. It was transported by glaciers, which carry a wide range of particle sizes.

4. Which of the following best describes poorly sorted sediments?
A. Sediments with grains of uniform size
B. Sediments with a wide range of grain sizes
C. Sediments deposited in a desert environment
D. Sediments primarily composed of fine clay

5. What is the primary control on the roundness of sedimentary grains?
A. The chemical composition of the grains
B. The energy of the environment
C. The transport distance and abrasion
D. The rate of sedimentation

6. What does a matrix-supported sedimentary rock indicate about the depositional environment?

A. It was deposited in a high-energy environment.
B. It was deposited in a low-energy environment where finer materials accumulated around larger grains.
C. It was formed by biological activity.
D. It was cemented by carbonate minerals.

7. Which sedimentary structure is characteristic of drying and cracking in fine-grained sediment?
A. Graded bedding
B. Mud cracks
C. Ripple marks
D. Cross-bedding

8. Which grain size category is typical of sediments transported and deposited in a high-energy river environment?
A. Clay
B. Silt
C. Sand
D. Gravel

9. What is the term for sediment particles that are supported primarily by a fine-grained matrix rather than direct contact with other grains?
A. Well-sorted fabric
B. Matrix-supported fabric
C. Imbricated fabric
D. Grain-supported fabric

10. Which sedimentary structure commonly forms as a result of alternating wet and dry conditions in environments like tidal flats or deserts?
A. Cross-bedding
B. Flute casts
C. Mud cracks
D. Graded bedding

ANSWER: 1D 2A 3C 4B 5C 6B 7B 8D 9B 10C

MODULE 5 GRAIN SIZE ANALYSIS

UNIT 1 PEBBLE MORPHOMETRY

Contents

1.1 INTRODUCTION

Pebble morphometry is a branch of sedimentology that focuses on the measurement and analysis of pebble shapes and sizes within sedimentary deposits. This unit will provide valuable insights into the processes that transport and deposit sediment, the provenance of pebbles, and the conditions of the depositional environment. By examining pebbles' physical characteristics, geologists can infer various aspects of sedimentary environments, including the energy and dynamics of transport systems, the distance of sediment transport, and the nature of the source area.

1.2 OBJECTIVES

By the end of this unit, you will be able to:

- explain the basic concepts and parameters of pebble morphometry.
- state the methods for measuring and analyzing pebble characteristics.
- explore the geological significance of pebble morphometry in interpreting sedimentary processes and environment.

1.3. KEY PARAMETERS OF PEBBLE MORPHOMETRY

A. Grain Size

- Definition: Refers to the diameter or longest axis of a pebble, typically ranging from 4 mm to 64 mm.
- Measurement Methods:
  - Calipers: Measure the diameter of pebbles directly.
  - Digital Image Analysis: Utilize high-resolution images and software to measure grain size.
- Significance: Grain size helps determine the energy of the transporting medium and the distance traveled by the sediment.

B. Shape

- Definition: Describes the general form and geometry of the pebble.
- Types of Shapes:
  - Spherical: Round, ball-like shape.
  - Elongate: Longer than it is wide.
  - Platy: Thin and flat.
  - Irregular: Non-uniform, with no clear geometric pattern.
- Significance: Pebble shape provides clues about the depositional environment and the processes that have acted upon the sediment.

C. Roundness

- Definition: The degree to which the edges and corners of a pebble have been smoothed or rounded.
- Classification:
  - Angular: Sharp edges and corners.
  - Sub-angular: Slightly rounded edges.
  - Sub-rounded: Moderately rounded edges.
  - Rounded: Smooth, well-rounded edges.
- Significance: Roundness indicates the degree of abrasion and transport distance. Well-rounded pebbles suggest long transport distances and significant wear.

D. Sphericity

- Definition: Measures how closely the shape of a pebble approaches that of a sphere.
- Classification:
  - High Sphericity: Nearly spherical shape.

- Low Sphericity: Elongated, flattened, or irregular shape.
- Significance: Sphericity reflects the original form of the pebble and the processes of transport and abrasion it has undergone.

E. Surface Texture

- Definition: The texture of the pebble's surface, including features such as scratches, pits, or polish.
- Types of Surface Textures:
- Frosted: Rough surface from wind action.
- Striated: Grooves or scratches from glacial movement.
- Polished: Smooth surface from abrasion.
- Significance: Surface texture provides information about the transport mechanism and the environmental conditions.

1.3.1 Methods of Measurement

1. Manual Measurement

- Calipers: Used for direct measurement of pebble diameters.
- Microscope: For detailed examination of shapes and surface textures**.**

2. Photogrammetry

- Digital Images: Capture high-resolution images of pebbles.
- Image Analysis Software: Tools like ImageJ are used to measure and analyze shapes and sizes from digital images.

3. Statistical Analysis

- Shape Factors: Calculating aspect ratios, elongation indices, and roundness.
- Distribution Analysis: Analysing grain size distributions and shape parameters to interpret transport processes and depositional environments.

1.3.2 Geological Significance

1 Transport History

- Roundness and surface texture indicate the distance and nature of transport. Rounded and polished pebbles suggest long transport distances and significant abrasion, while angular pebbles indicate minimal transport.

2 Source and Provenance

- Shape and sphericity help determine the origin of the pebbles. Different geological environments produce pebbles with distinctive shapes and sphericity.

3 Depositional Environment

- Sorting and size distribution of pebbles reveal the energy of the depositional environment. Well-sorted pebbles are typically found in high-energy environments, while poorly sorted pebbles indicate variable energy conditions.

4. Paleocurrent Analysis

- Imbrication and alignment of pebbles can indicate the direction of ancient currents, helping reconstruct past flow directions in river channels and other sedimentary environments.

5. Reconstructing Geological Processes

- Differences in pebble shape and surface texture provide clues about whether pebbles were transported by glaciers, rivers, or wind. For instance, glacial pebbles often show striations and irregular shapes, while river pebbles are more rounded.

1.4. CONCLUSION

Pebble morphometry is a crucial aspect of sedimentology that involves analysing the size, shape, roundness, sphericity, and surface texture of pebbles. By understanding these characteristics, geologists can infer a wide range of information about sediment transport, provenance, and depositional environments. The methods and measurements of pebble morphometry provide valuable insights into the geological processes that shaped sedimentary deposits and help reconstruct past environmental conditions.

1.7 SUMMARY

Pebble morphometry encompasses the study of pebbles' physical attributes to understand their transport and deposition history. Key parameters include grain size, shape, roundness, sphericity, and surface texture. Measurement methods involve manual tools, digital imaging, and statistical analysis. The geological significance of pebble morphometry includes interpreting transport history, source and provenance, depositional environments, paleocurrent directions, and geological processes. This field of study provides essential information for reconstructing past environments and understanding sedimentary processes.

1.8 ERENCES

Blair, T. C., & McPherson, J. G. (1994). *Sedimentary Processes, Environments, and Basins: A Practical Perspective*. Springer.

Folk, R. L. (1980). *Petrology of Sedimentary Rocks*. Hemphill Publishing Company.

Sneed, E. D., & Folk, R. L. (1958). "Pebbles in the Lower Colorado River, Texas: A Study in Particle Morphology." *Journal of Geology*, 66(2), 114-150.

Miall, A. D. (1996). *The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis, and Petroleum Geology*. Springer.

Tucker, M. E., & Wright, V. P. (1990). *Carbonate Sedimentology*. Blackwell Science.

Leeder, M. R. (1982). *Sedimentology and Sedimentary Basins: From Turbulence to Tectonics*. Wiley-Blackwell.

1.9 MULTIPLE CHOICE QUESTIONS

1. What does pebble roundness measure?

A. The diameter of a pebble
B. The smoothness of the pebble's edges and corners
C. The colour of the pebble
D. The weight of the pebble

2. Which tool is commonly used for measuring the diameter of pebbles directly?

A. Micrometer
B. Calipers
C. Sieve
D. Digital camera

3. Which characteristic of pebbles helps determine the distance of transport?

A. Color
B. Roundness
C. Surface texture
D. Weight

4. What type of surface texture would you expect on a pebble transported by wind?

A. Polished
B. Striated
C. Frosted
D. Pitted

5. Which measurement method involves using high-resolution images to analyse pebbles?

A. Manual measurement with callipers
B. Digital image analysis
C. Microscopic examination
D. Sieve analysis

6. What type of pebble shape is characterised by a length greater than its width?

A. Spherical
B. Platy
C. Elongate
D. Irregular

7. Which feature is NOT commonly used to describe pebble shape?

A. Sphericity
B. Aspect ratio
C. Roundness
D. Color

8. Which parameter is used to describe the elongation of pebbles?

A. Roundness
B. Sphericity
C. Aspect ratio
D. Surface texture

9. Which of the following characteristics helps determine the energy of the depositional environment?

A. Pebble colour
B. Pebble size distribution
C. Mineral composition
D. Pebble origin

10. Which feature indicates that pebbles have been transported by a river?
A. Striated texture
B. Frosted surface
C. Well-rounded shape
D. Angular edges

ANSWERS 1B 2B 3B 4C 5B 6C 7D 8C 9B 10C

UNIT 2 MINERAL COMPOSITION OF THE SEDIMENTARY ROCKS

Unit Structure

2.1. INTRODUCTION

Sedimentary rocks are formed from the accumulation, compaction, and cementation of sediments, which can include mineral grains, organic material, and chemical precipitates. The minerals present in sedimentary rocks are key to understanding the conditions under which these rocks formed, their source, and their subsequent geological history. Each mineral provides insights into the environmental conditions at the time of deposition and the processes involved in sediment transport and diagenesis.

2.2 OBJECTIVES

By the end of this unit and the relevant readings, candidates of this course should be able to:

- Understand what is a mineral
- Understand the importance of mineral composition in sedimentary rocks.
- Learn about the common minerals found in sedimentary rocks and their significance.
- Interpret geological processes based on mineralogical

2.3 K MINERAL

2.3.1. Definition Of A Rock Mineral

Rock mineral is defined as a naturally occurring, inorganic solid with a definite chemical composition and a crystalline structure. Rock minerals have specific characteristics which are color, luster, hardness, density, and streak. The crystal systems (e.g., cubic, tetragonal, orthorhombic) affects the mineral's external crystal shape. Examples of common rock minerals are Quartz (SiO_2), Calcite, feldspar and mica.

2.3.2. Common Rock Minerals In Sedimentary Rocks

A. Quartz

- Description: Quartz is a highly stable and common mineral composed of silicon dioxide (SiO_2). It is characterized by its hardness (7 on the Mohs scale) and resistance to weathering.
- Occurrence: Quartz is abundant in sandstones, siltstones, and conglomerates. It often constitutes a significant portion of these rocks.
- Significance: The high stability of quartz means that it survives long transport distances and extensive weathering. Its presence indicates a stable environment with minimal chemical alteration.

B. Feldspar

- Description: Feldspar is a group of silicate minerals that include potassium feldspar (orthoclase) and plagioclase. These minerals are less stable compared to quartz and have varying hardness.
- Occurrence: Feldspar is commonly found in sandstones and shales. It can be a significant component in rocks formed from less extensively weathered sediments.
- Significance: The presence of feldspar indicates less transport and weathering compared to quartz. It can also provide information about the source rocks, often being derived from granitic or volcanic terrains.

C. Clay Minerals

- Description: Clay minerals, such as kaolinite, illite, and smectite, are fine-grained and formed from the weathering of silicate minerals. They have low hardness and high surface area.
- Occurrence: These minerals are predominant in shales and

mudstones, where they contribute to the rock's fine texture.

- Significance: The abundance of clay minerals reflects low-energy depositional environments, such as floodplains, lake beds, and deep marine settings. Their presence can also indicate chemical weathering processes.

D. Calcite

- Description: Calcite is a carbonate mineral composed of calcium carbonate ($CaCO_3$). It is commonly found in sedimentary rocks as a result of biological and chemical processes.
- Occurrence: Calcite is a major component of limestone and marl. It forms in marine and lacustrine environments where carbonate precipitation occurs.
- Significance: The presence of calcite suggests that the sediments were deposited in a marine or lacustrine environment with sufficient carbonate supply. Calcite is also used as an indicator of past climate conditions.

E. Gypsum and Halite

- Description: Gypsum ($CaSO_4 \cdot 2H_2O$) and halite (NaCl) are evaporite minerals formed from the evaporation of saline waters.
- Occurrence: These minerals are found in evaporitic environments, such as salt flats, salt mines, and arid basin deposits.
- Significance: The presence of gypsum and halite indicates arid climatic conditions and high evaporation rates. They are often associated with evaporite deposits and saline lake environments.

F. Mica

- Description: Mica is a group of sheet silicate minerals, including muscovite (potassium mica) and biotite (iron-magnesium mica). These minerals are characterized by their sheet-like crystal structure.
- Occurrence: Mica is found in certain sandstones and shales, often derived from metamorphic and igneous source rocks.
- Significance: Mica provides information about the source rock and can indicate specific depositional environments, such as those influenced by nearby metamorphic or igneous activity.

2.3.3. Geological Significance

1. Sediment Transport and Sorting

- Quartz vs. Feldspar: The ratio of quartz to feldspar in sedimentary rocks can indicate the extent of transport and weathering. A high quartz content with low feldspar suggests long transport distances and extensive weathering, while a higher feldspar content suggests shorter transport distances.

2. Depositional Environments

- Marine vs. Continental: Mineral composition can indicate the depositional environment. For example, limestone with high calcite content suggests a marine environment, while evaporites like gypsum and halite indicate arid, evaporitic conditions.

3. Weathering and Diagenesis

- Mineral Stability: Changes in mineral composition due to diagenesis (e.g., the transformation of feldspar to clay minerals) provide insights into the diagenetic history of the rock and the conditions it has undergone since deposition.

4. Climate Reconstruction

- Mineral Indicators: Certain minerals, such as calcite and gypsum, can help reconstruct past climatic conditions. For example, the presence of gypsum indicates arid climates, while the presence of calcite can suggest warmer, wetter conditions.

5. Economic Resources

- Mineral Deposits: Sedimentary rocks can be economically significant due to their mineral content. For instance, limestone is used in construction and as a source of lime, while evaporites are important for salt production.

2.4 CONCLUSION

The mineral composition of sedimentary rocks is a key factor in understanding their formation, transport, and depositional history. By analyzing the types and abundances of minerals, geologists can infer information about past environments, climatic conditions, and geological processes.

2.5. SUMMARY

The study of mineral composition in sedimentary rocks involves analyzing the types and quantities of minerals present to understand their formation and history. Common minerals include quartz, feldspar, clay minerals, calcite, gypsum, halite, and mica.

2.6. REFERENCES

Boggs, S. Jr. (2016). *Principles of Sedimentology and Stratigraphy*. Pearson. Pettijohn, F. J., Potter, P. E., & Siever, R. (1987). *Sand and Sandstone*. Springer. Tucker, M. E. (2001). *Sedimentary Petrology: An Introduction*. Blackwell Science.

Dunham, R. J. (1962). *Classification of Carbonate Rocks According to Depositional Texture*. AAPG Bulletin, 46(5), 797-825.

Miall, A. D. (1996). *The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis, and Petroleum Geology*. Springer.

Grotzinger, J. R., & Jordan, T. E. (2003). *Understanding Earth*. W.H. Freeman.

2.7 MULTIPLE CHOICE QUESTIONS

1. Which of the following minerals is the most abundant in sandstones?

A) Feldspar
B) Calcite
C) Quartz
D) Clay minerals

2. The presence of which mineral indicates a carbonate sedimentary environment?

A) Quartz
B) Feldspar
C) Gypsum
D) Calcite

3. Which mineral is commonly found in evaporitic environments and forms from the evaporation of saline waters?

A) Mica
B) Halite
C) Feldspar
D) Kaolinite

4. In sedimentary rocks, high levels of which mineral suggest minimal weathering and short transport distances?
A) Quartz

B) Feldspar
C) Calcite
D) Clay minerals

5. Which of the following minerals is typically associated with fine-grained sedimentary rocks like shales and mudstones?
A) Quartz
B) Feldspar
C) Gypsum
D) Clay minerals

6. What does the presence of gypsum in sedimentary rocks typically indicate about the depositional environment?
A) Arid and evaporitic conditions
B) Marine environment with high biological activity
C) Glacial environment
D) High-energy river environment

7. Which mineral is characterized by its sheet-like structure and is commonly found in some sandstones and shales?
A) Calcite
B) Gypsum
C) Mica
D) Quartz

8. Which mineral is a key component in limestone and is often formed from the shells of marine organisms?
A) Feldspar
B) Quartz
C) Calcite
D) Halite

9. What type of mineral is feldspar classified as?
A) Silicate
B) Carbonate
C) Sulfate
D) Halide

10. Which of the following is true about the mineral composition of sedimentary rocks?

A) High quartz content indicates extensive chemical weathering.
B) Presence of clay minerals suggests high-energy depositional environments.
C) The mineral composition can provide insights into past environmental conditions.
D) Gypsum and halite are common in high-latitude, glacial environments.

ANSWER: 1C 2D 3B 4B 5D 6A 7C 8C 9A 10C

UNIT 3 PETROGRAPHIC CLASSIFICATION OF SANDSTONES.

Unit Structure

3.1 INTRODUCTION

Sandstone is one of the most common types of sedimentary rocks, formed by the cementation of sand-sized particles of minerals, rocks, or organic materials. Petrographic classification is a method of categorizing sandstones based on their mineral composition, texture, and grain characteristics. This classification helps geologists in understanding the origin, depositional environment, and potential reservoir properties of sandstones. Petrographic classification is particularly important in fields such as petroleum geology, hydrology, and environmental geology, where sandstones often serve as reservoirs for hydrocarbons and groundwater.

3.2 OBJECTIVES

By the end of this unit and the relevant readings, candidates of this course should be able to:

- Understand the mineralogical and textural composition of sandstone.
- Explore various petrographic classification schemes for sandstone.
- Examine the role of sandstone classification in interpreting depositional environments.
- Appreciate the significance of sandstone in natural resource exploration, such as hydrocarbons and groundwater reservoirs.

3.3 COMPOSITION OF SANDSTONE

Sandstones are mainly composed of three primary components:

- Framework Grains: These are sand-sized particles (0.0625–2 mm in diameter), which usually consist of quartz, feldspar, and rock fragments.
- Matrix: The finer-grained material (clay or silt) that fills the spaces between the larger grains.
- Cement: The mineral material that precipitates in the pore spaces between grains, binding them together. Common cements include quartz, calcite, and hematite.

The primary framework minerals are:

- Quartz: The most common mineral in sandstone, highly resistant to weathering.
- Feldspar: Less resistant to weathering than quartz, feldspar grains are often present in younger or less mature sandstones.
- Lithic Fragments: Pieces of pre-existing rocks that are not fully weathered, often present in tectonically active settings.

3.3.1. Factors In Petrographic Classification

Petrographic classification of sandstone depends on:

- Mineral Composition: Proportions of quartz, feldspar, and lithic fragments.
- Texture: The degree of grain size sorting, rounding, and matrix content.
- Cementation and Diagenesis: The nature and type of cement and the diagenetic processes that affect the sandstone after deposition.

3.3.2. Petrographic Classification Systems

Several classification systems have been proposed by geologists for classifying sandstones. The most commonly used are those developed by Folk (1974), Pettijohn (1975), and Dott (1964).

A. Folk's Classification (1974)

Folk's classification system is one of the most widely accepted methods for categorizing sandstones. It is based on the relative proportions of three major components in the framework grains: quartz, feldspar, and rock fragments (lithics). This classification is best visualized using a ternary diagram, which illustrates the following types of sandstone:

- Quartz Arenite: Sandstone with more than 90% quartz grains. These sandstones are highly mature and typically form in stable environments with extensive weathering.
- Arkose: Sandstone containing more than 25% feldspar grains. Arkoses often form in tectonically active areas where there is little time for feldspar to weather into clay minerals.
- Lithic Sandstone (Litharenite): Sandstone containing more than 25% lithic (rock) fragments. These sandstones are common in tectonically active regions where the source rocks are being rapidly eroded.
- Subarkose and Sublitharenite: These are intermediate types, with smaller proportions of feldspar or lithic grains.

Folk’s system focuses on mineralogy and provides insights into the sandstone's source area and the maturity of the sediment.

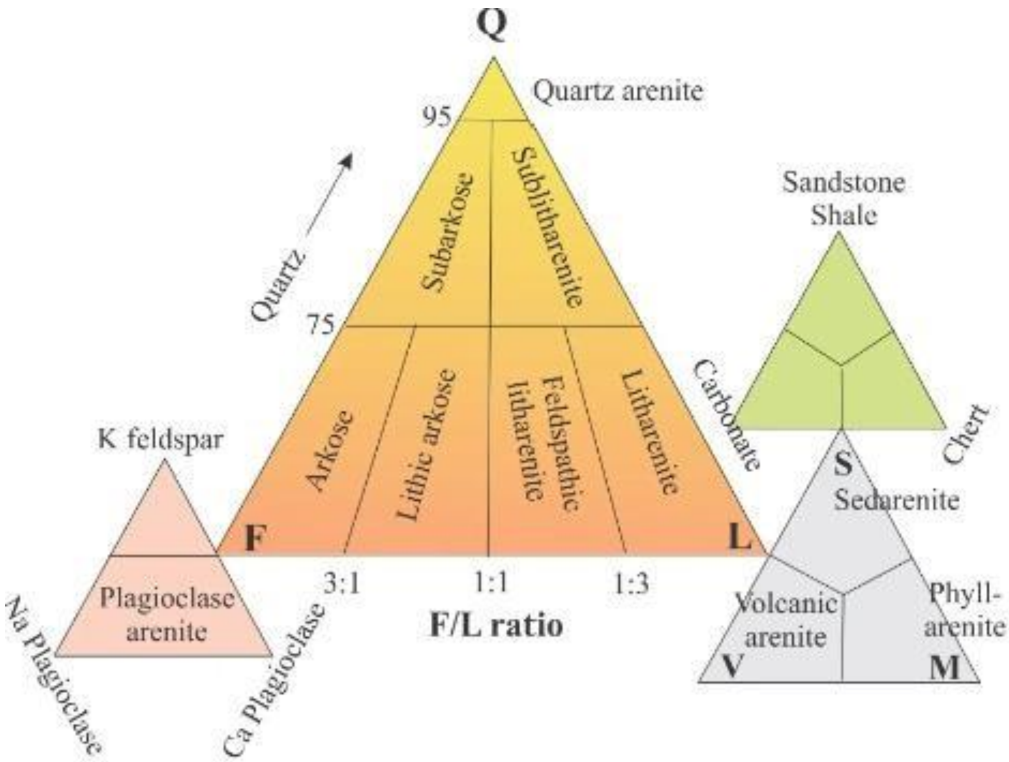

Figure 1: Classification of sandstone according to Folk, 1972. Q = quartz, F = feldspar, L = Lithic

B. Pettijohn’s Classification (1975)

Pettijohn's classification, another widely used system, is based on the relative proportions of quartz, feldspar, and rock fragments but also takes into account the matrix content (the amount of clay or silt-sized particles). Sandstones in this classification are divided into two broad categories:

- Arenites: Sandstones with less than 15% matrix. Arenites are further classified into quartz arenites, feldspathic arenites (arkoses), and lithic arenites based on the proportions of quartz, feldspar, and lithic grains.
- Wackes: Sandstones with more than 15% matrix. Wackes are also subdivided into quartz wackes, feldspathic wackes, and lithic wackes.

Pettijohn's classification is more comprehensive because it includes the textural aspect (matrix content), which affects the porosity and permeability of the sandstone, critical for understanding its potential as a reservoir.

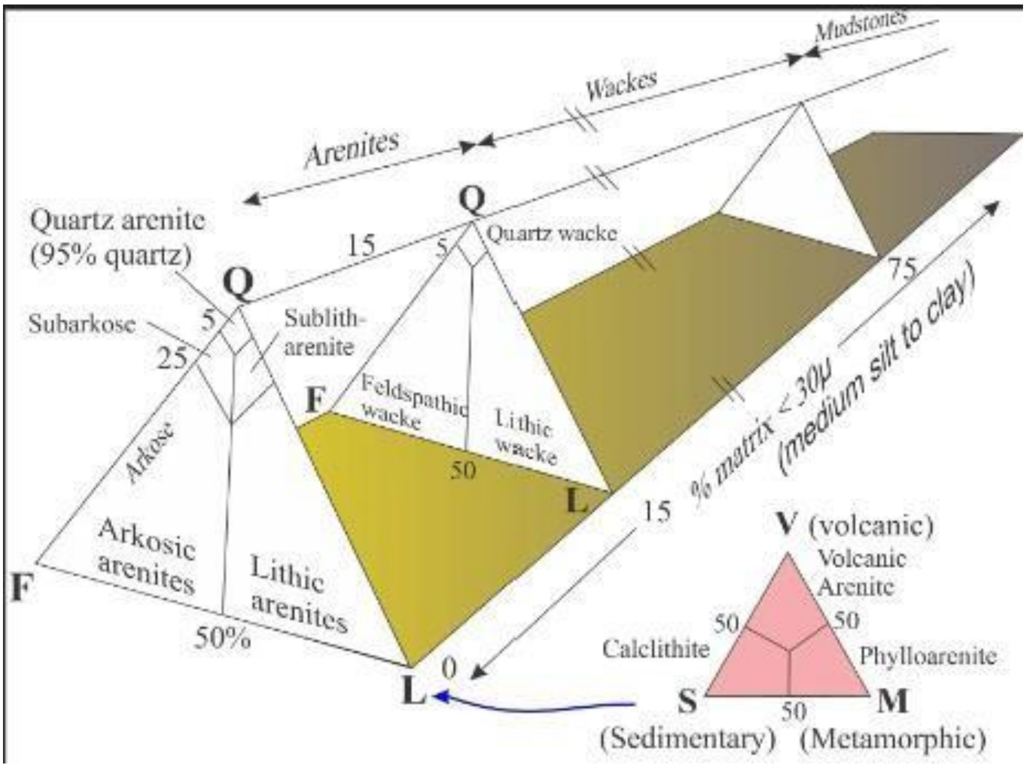

Figure 2: Classification of sandstone according to Pettijohn's (1975). Q = quartz, F = feldspar, L= Lithic

C. Dott's Classification (1964)

Dott's classification combines both the mineralogical composition and the textural maturity of sandstones. This system is similar to Pettijohn's but places more emphasis on grain size, sorting, and matrix content.

- Quartz Arenites: Clean sandstones with high quartz content and low matrix.
- Feldspathic Arenites (Arkoses): Sandstones with a significant amount of feldspar but less than 15% matrix.
- Lithic Arenites: Sandstones with abundant rock fragments.
- Feldspathic Wackes: Sandstones with feldspar grains and more than 15% matrix.

- Lithic Wackes: Sandstones with high rock fragment content and a significant matrix component.

Dott's classification provides a useful way of understanding the depositional environment because the sorting and grain size reflect the energy of the depositional medium (e.g., rivers, beaches, deep marine environments).

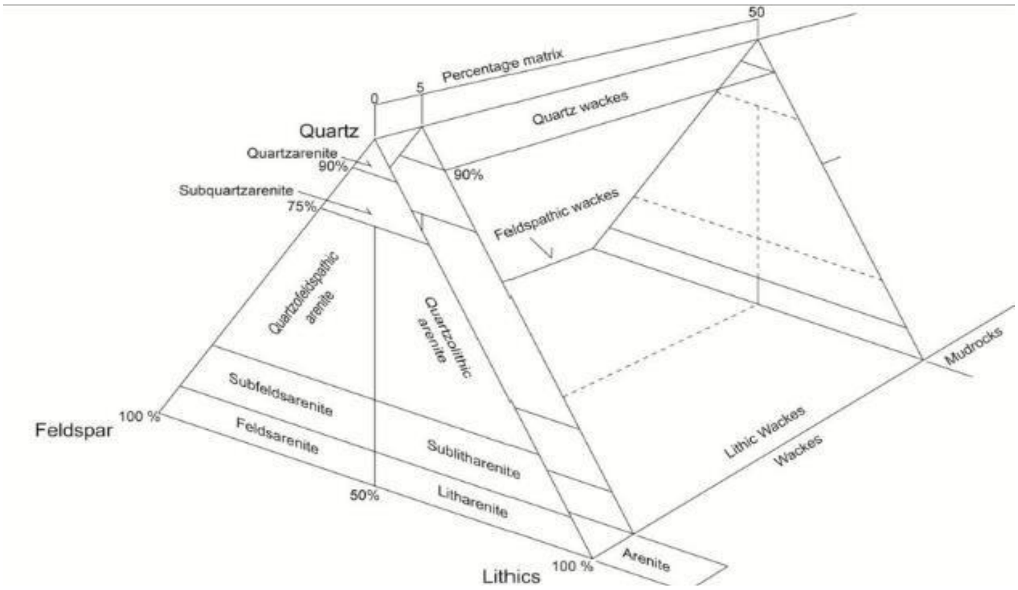

Figure 3: Classification of sandstone according to Dotts (1964). Q = quartz, F = feldspar, L = Lithic

3.3.3 Applications Of Sandstone Classification

The petrographic classification of sandstones has several important applications:

- Depositional Environment Analysis: The composition and texture of sandstones provide clues about the depositional environment. For example, quartz arenites typically form in stable, long-term environments like beaches, while lithic sandstones form in tectonically active settings like deltas or foreland basins.
- Tectonic Setting Interpretation: Different types of sandstone form in different tectonic settings. For example, arkoses are common in rift basins, while lithic sandstones are associated with foreland basins.
- Reservoir Quality Prediction: The porosity and permeability of sandstones depend on their composition and texture. Clean quartz arenites are often good reservoir rocks, while matrix-rich wackes tend to have poor permeability.
- Source Rock Identification: By analyzing the composition of sandstone, geologists can infer the types of source rocks and the processes of erosion and transport involved.

3.4. CONCLUSION

The petrographic classification of sandstone is crucial for understanding the geological history and economic potential of sedimentary basins. Systems like those developed by Folk, Pettijohn, and Dott provide frameworks for categorizing sandstones based on their mineral composition, texture, and diagenetic features. These classifications are not only important for academic research but also for practical applications in fields such as petroleum geology, hydrogeology, and environmental science. Understanding the petrography of sandstones allows geologists to reconstruct past environments, identify source areas, and predict the reservoir potential of sedimentary formations.

3.5 SUMMARY

- Sandstones are sedimentary rocks classified based on mineral composition, texture, and cementation.
- The most common classification schemes are those by Folk (1974), Pettijohn (1975), and Dott (1964).
- These classifications focus on the proportions of quartz, feldspar, and lithic fragments, as well as the matrix content.
- Sandstone classification helps geologists interpret depositional environments, tectonic settings, and reservoir quality.
- Understanding sandstone petrography is important for resource exploration, including hydrocarbons and groundwater.

3.6 REFERENCES

Folk, R. L. (1974). Petrology of Sedimentary Rocks. Hemphill Publishing Company. Pettijohn, F. J., Potter, P. E., & Siever, R. (1975). Sand and Sandstone. Springer-Verlag.

Dott, R. H. (1964). Wacke, Graywacke and Matrix—What Approach to Immature Sandstone Classification? Journal of Sedimentary Research.

3.7 MULTIPLE CHOICE QUESTIONS

1. What is the primary component in most sandstones?

A) Feldspar
B) Quartz
C) Calcite
D) Hematite

2. Which classification system is widely known for using a ternary diagram to classify sandstones based on quartz, feldspar, and lithic fragments?
A) Dott's classification
B) Pettijohn's classification
C) Folk's classification
D) Wentworth's classification

3. A sandstone with more than 90% quartz grains is classified as:

A) Arkose
B) Litharenite
C) Quartz Arenite
D) Wacke

4. In which classification scheme are sandstones divided into arenites and wackes based on their matrix content?
A) Folk's classification
B) Pettijohn's classification
C) Dott's classification
D) All of the above

5. Sandstones containing more than 25% feldspar grains are called:
A) Litharenites
B) Quartz Arenites
C) Arkoses
D) Wackes

6. What is the main distinction between arenites and wackes in sandstone classification?

A) Grain size
B) Mineral composition
C) Matrix content
D) Cementation

7. Dott’s classification focuses on grain size, sorting, and matrix content. Sandstones with less than 15% matrix are called:
A) Wackes
B) Arenites
C) Litharenites

D) Arkoses

8. A sandstone with more than 25% rock fragments (lithic grains) is classified as:

A) Arkose
B) Quartz Arenite
C) Litharenite
D) Wacke

9. Which classification system includes consideration of diagenetic processes that affect sandstone composition after deposition?
A) Folk's classification
B) Pettijohn's classification
C) Dott's classification
D) All of the above

10. Which mineral in sandstone is typically the most resistant to weathering and dominates in mature sandstones?
A) Feldspar
B) Calcite
C) Quartz
D) Hematite

ANSWER: 1B 2C 3C 4B 5C 6C 7B 8C 9D 10C

UNIT 4 HEAVY MINERALS IN SEDIMENTARY ROCKS

Unit Structure

4.1. Introduction
4.2. Objectives
4.3. Concept of heavy minerals
4.4. Conclusion
4.5. Summary
4.6. References
4.7. Multiple Choice Questions

4.1 INTRODUCTION

Heavy minerals in sedimentary rocks play a crucial role in understanding the provenance (origin) of the sediments, the processes involved in transportation, and the environmental conditions at the time of deposition. Unlike the more common light minerals such as quartz and feldspar, heavy minerals are denser and generally less abundant in sedimentary deposits. They are essential tools for sedimentologists and geologists because they often retain characteristics of the parent rocks and provide important clues about past geological processes. This unit will covers the definition of heavy minerals, their significance in sedimentology, types of heavy minerals, methods of analysis, and their applications in geological studies.

4.2 OBJECTIVES

By the end of this unit and the relevant readings, candidates of this course should be able to:

- Understand the definition and classification of heavy minerals in sedimentary rocks.
- Learn the importance of heavy minerals in geological studies.
- Identify common heavy minerals in sedimentary rocks and their uses in provenance analysis.
- Explore the methods for heavy mineral separation and analysis.
- Apply heavy mineral data to interpret sedimentary processes and depositional environments.
- Appreciate the economic significance of certain heavy minerals in industrial applications.

4.3 CONCEPT OF HEAVY MINERALS

4.3.1 Definition Of Heavy Minerals

Heavy minerals are defined as minerals with a specific gravity greater than 2.9, making them denser than most of the common rock-forming minerals like quartz and feldspar. They constitute a small fraction of sedimentary rocks (typically less than 1% of the total mineral composition), but they offer valuable information about the source and history of sediments.

Key Characteristics:

- High Specific Gravity: Greater than 2.9, often ranging between 3.0 to 7.5.
- Low Abundance: Typically found in trace amounts (less than 1%) within sedimentary deposits.
- Resistant to Weathering: Many heavy minerals are chemically and physically resistant, making them useful in tracing the origin of sediments**.**

4.3.2. Importance Of Heavy Minerals In Sedimentary Rocks

1. Provenance Determination:

- Heavy minerals are resistant to weathering and preserve the characteristics of their parent rocks. By analyzing the heavy mineral assemblage in a sedimentary rock, geologists can infer the type of source rock (igneous, metamorphic, or sedimentary) and the tectonic setting of the sediment's origin.

2. Transport History:

- The diversity and roundness of heavy minerals can provide insights into the transport processes. For example, angular heavy minerals suggest short transport distances, while well-rounded grains indicate longer transport and reworking.

3. Paleoenvironmental Reconstruction:

- The presence of certain heavy minerals can indicate specific depositional environments. For example, the mineral zircon is common in fluvial (river) environments, while the presence of glauconite suggests a marine setting.

4. Economic Significance:

- Some heavy minerals, like gold, platinum, titanium (in the form of rutile and ilmenite), and zircon, have significant economic value. They are often concentrated in placer deposits and can be mined for industrial and ornamental purposes.

4.3.3. Common Heavy Minerals In Sedimentary Rocks

1. Zircon ($ZrSiO_4$):

- Description: Highly resistant to weathering and often found in fluvial, beach, and marine environments.
- Significance: Zircon is a key mineral in provenance studies due to its durability. It also provides important geochronological information through uranium-lead (U- Pb) dating.

2. Rutile (TiO_2):

- Description: A red or brown mineral rich in titanium, with high specific gravity.

- Significance: Rutile is commonly found in sediments derived from high-grade metamorphic rocks and is used to track sediment transport and deposition.

3. Ilmenite ($FeTiO_3$):

- Description: A black or brownish-black mineral composed of iron titanium oxide.

- Significance: Ilmenite is a key mineral for identifying sedimentary deposits that originated from volcanic or high-grade metamorphic rocks.

4. Tourmaline:

- Description: A group of complex boron silicate minerals that occur in various colors.
- Significance: Tourmaline is highly resistant to weathering and is commonly found in sediments derived from igneous and metamorphic rocks.

5. Garnet:

- Description: A group of silicate minerals typically red, brown, or green in color.

- Significance: Garnet is often used as an indicator of high-grade metamorphic provenance, and its chemical composition can provide information about the pressure-temperature conditions of the source rock.

6. Magnetite (Fe_3O_4):

- Description: A magnetic iron oxide mineral that is black in color.
- Significance: Magnetite is often derived from igneous or metamorphic rocks and is useful for tracing sediments deposited near volcanic or tectonic activity.

7. Glauconite:

- Description: A green, iron-rich silicate mineral typically found in marine environments.
- Significance: The presence of glauconite indicates deposition in slow sedimentation, marine environments such as continental shelves or shallow marine settings.

8. Hornblende:

- Description: A common amphibole mineral that is dark green to black.
- Significance: Hornblende is commonly found in sediments derived from igneous or metamorphic rocks, especially in volcanic arcs and active tectonic margins.

4.3.4. METHODS FOR HEAVY MINERAL ANALYSIS

1. Grain Separation:

- Heavy Liquids: The most common method of heavy mineral separation involves using heavy liquids like bromoform or tetrabromoethane (TBE), which have a higher density than light minerals like quartz and feldspar. This allows heavy minerals to settle, leaving lighter minerals in suspension.
- Magnetic Separation: Magnetic minerals like magnetite can be separated from non- magnetic heavy minerals using magnets.

2. Microscopy:

- Petrographic Microscopy: A common tool for identifying and analyzing the optical properties of heavy minerals in thin sections under polarized light.
- Scanning Electron Microscopy (SEM): This provides detailed surface imagery and allows for compositional analysis of individual grains.

3. X-Ray Diffraction (XRD):

- Used to identify and quantify the mineralogical composition of heavy mineral fractions.

4. Geochemical Techniques:

- Electron Microprobe: This technique provides chemical composition data of individual mineral grains, which is useful for distinguishing between different heavy mineral species (e.g., various types of garnet).

5. U-Pb Zircon Dating:

- The U-Pb dating method on zircon grains allows geologists to determine the age of the source rocks from which the sediments were derived. This method is highly accurate and is widely used in provenance studies.

4.3.5. APPLICATIONS OF HEAVY MINERALS IN GEOLOGICAL STUDIES

1. Provenance Analysis:

- Heavy minerals are used to trace the origin of sedimentary materials. By identifying specific mineral assemblages, geologists can reconstruct the history of the sediments, including the type of source rocks and the tectonic setting in which they formed.

2. Sedimentary Basin Analysis:

- Heavy minerals help in understanding the evolution of sedimentary basins by providing insights into changes in sediment supply, tectonic activity, and depositional environments over time.

3. Economic Geology:

- Heavy minerals are important in the exploration of economically valuable placer deposits, such as those containing gold, zircon, and titanium-bearing minerals (rutile and ilmenite). These deposits often form in riverbeds, beaches, and other high-energy environments where heavy minerals are concentrated by flowing water.

4. Paleoenvironmental Reconstruction:

- Certain heavy minerals, like glauconite and zircon, are used to infer past environmental conditions. For example, the presence of glauconite suggests a marine setting, while zircon-rich deposits may indicate fluvial systems.

4.4. CONCLUSION

Heavy minerals in sedimentary rocks provide valuable information about the origin, transport, and deposition of sediments. They are vital tools for provenance analysis, economic geology, and environmental interpretation. Through advanced analytical techniques, geologists can trace the geological history of sedimentary deposits and gain insights into the tectonic and climatic conditions that influenced sedimentation. Understanding the distribution and composition of heavy minerals is key to unraveling the complexities of the Earth's sedimentary systems.

4.5. SUMMARY

Heavy minerals, due to their density and durability, offer important insights into the provenance, transport, and depositional environments of sediments. Common heavy minerals like zircon, rutile, and garnet are used to trace sediment origins, while others like glauconite can indicate specific depositional settings. Through methods like heavy liquid separation, microscopy, and geochemical analysis, geologists can unlock the geological history embedded within sedimentary rocks. Their study has both academic and economic applications, particularly in the field of resource exploration.

4.6 REFERENCES

Blatt, H., Middleton, G., & Murray, R. (1980). **Origin of Sedimentary Rocks**. Prentice-Hall.

Tucker, M. E. (2001). **Sedimentary Petrology: An Introduction to the Origin of Sedimentary Rocks**. Wiley-Blackwell.

Mange, M. A., & Maurer, H. F. W. (1992). **Heavy Minerals in Colour**. Springer-Verlag.

Morton, A. C., & Hallsworth, C. R. (1999). "Processes Controlling the Composition of Heavy Mineral Assemblages in Sandstones." **Sedimentary Geology**, 124(1–4), 3–29.

Pettijohn, F. J. (1975). **Sedimentary Rocks**. Harper & Row.

4.7 MULTIPLE CHOICE QUESTIONS

ATTEMPT ALL QUESTIONS

1. What is the primary characteristic that defines a heavy mineral?

A) High silica content
B) Specific gravity greater than 2.9
C) Abundance in sedimentary rocks
D) Occurrence in igneous rocks

2. Which of the following is a common method used for separating heavy minerals from lighter minerals?

A) Filtration
B) Heavy liquid separation
C) Centrifugation
D) Sieving

3. Which heavy mineral is most commonly used for U-Pb dating?

A) Tourmaline
B) Garnet
C) Zircon
D) Glauconite

4. The presence of glauconite in sedimentary rocks typically indicates a depositional environment associated with:

A) Deep-sea trenches
B) Fluvial settings
C) Shallow marine environments
D) Desert dunes

5. Which heavy mineral is most likely to be found in sediments derived from high-grade metamorphic rocks?

A) Rutile
B) Ilmenite
C) Glauconite
D) Zircon

6. Which of the following minerals is magnetic and can be separated using a magnet?

A) Garnet
B) Magnetite
C) Zircon
D) Tourmaline

7. Which heavy mineral is commonly found in placer deposits and has significant economic value?

A) Ilmenite
B) Quartz
C) Feldspar
D) Kaolinite

8. Which technique is most useful for analyzing the surface structure and elemental composition of heavy minerals?

A) Heavy liquid separation
B) Petrographic microscopy
C) Scanning electron microscopy (SEM)
D) X-ray diffraction (XRD)

9. Which of the following heavy minerals is commonly associated with high-grade metamorphic and igneous sources and is used in industrial ceramics?

A) Glauconite
B) Garnet
C) Zircon
D) Rutile

10. The presence of well-rounded heavy mineral grains in a sedimentary rock suggests:

A) Limited transport from the source
B) Intense chemical weathering
C) Long-distance transport or reworking
D) Deposition in an arid environment

E) ANSWER: **1B 2B 3C 4C 5A 6B 7A 8C 9C 10C**

MODULE 6 PROVENANCE AND DEPOSITIONAL ENVIRONMENT RECONSTRUCTION

UNIT 1 PROVENANCE OF SEDIMENTS

Unit Structure

1.1 INTRODUCTION

The provenance of sediments refers to the origin and history of the materials that compose sedimentary rocks. Understanding sediment provenance helps geologists trace the source rocks from which sediments are derived, identify the tectonic settings of sediment deposition, and reconstruct past geological environments. Provenance studies rely on analysing mineralogical, chemical, and isotopic compositions of sediments to deduce information about their sources and the processes that have affected them during transport and deposition. This unit is critical for understanding sedimentary basins, tectonic evolution, and sedimentary processes.

1.2 OBJECTIVES

By the end of this unit, you will be able to:

- discuss the concept of sediment provenance and its importance in geological studies
- identify the methods used for determining sediment provenance
- analyse the significance of mineral composition, grain size, shape, and sorting in provenance studies
- relate sediment provenance to tectonic settings and depositional environments
- apply knowledge of provenance to interpret geological history.

1.3 SEDIMENT PROVENANCE

1.3.1. Definition of Sediment Provenance

Sediment provenance is the study of the origin of sediments, including the type of parent rocks, tectonic setting, and erosional processes that contributed to the formation of the sedimentary deposit. Provenance analysis investigates the composition of sediments, their transport history, and post-depositional alterations to reveal information about the source area.

1.3.2. Importance Of Provenance Studies

- Tectonic Insights: Provenance studies help understand tectonic settings by identifying the geological formations that contributed to sediment supply.
- Source Identification: Geologists can determine the type of rocks (igneous, metamorphic, or sedimentary) that produced the sediment through mineralogical, chemical, and isotopic analysis.
- Reconstruction of Past Environments: By tracing the origin and transport history of sediments, provenance studies help reconstruct past environmental conditions, including climate, erosion, and weathering patterns.
- Economic Geology: Knowledge of sediment provenance is important in natural resource exploration, including hydrocarbons, minerals, and heavy metals.

1.3.3. Methods of Provenance Analysis

Several techniques are used to study sediment provenance:

- **Mineralogical Composition:** The identification and analysis of minerals within sediments, particularly heavy minerals such as zircon, tourmaline, and rutile, provide information about the source rock types. These minerals are often resistant to weathering and can travel long distances without altering their original characteristics.
- **Geochemical Analysis:** Elemental and isotopic compositions of sediments can be analysed to infer source rocks. Techniques like X-ray fluorescence (XRF) and mass spectrometry can reveal trace element and isotopic signatures, linking sediments to their parent rocks.

- **Petrographic Analysis:** Thin sections of sedimentary rocks can be studied under a petrographic microscope to identify the types of minerals and rock fragments present. This provides direct evidence of the rock types in the source area.
- **Grain Size, Shape, and Sorting:** These physical characteristics of sediments provide clues about the distance of transport and the energy of the depositional environment. For example, well-rounded and well-sorted grains typically indicate long transport distances and high-energy environments like rivers and beaches.
- **Heavy Mineral Analysis:** The presence of specific heavy minerals in sediments, such as zircon, garnet, and rutile, can provide information about the source rocks and geological conditions at the source.
- **Detrital Zircon U-Pb Dating**: Zircon is a common and durable mineral used in provenance studies. Its uranium-lead (U-Pb) isotopic system is used to date the age of the zircon grains, providing insight into the geological history of the source rocks.

1.3.4. Transport Processes and Provenance

The distance and processes involved in sediment transport affect the mineral composition and texture of the sediment. Transport processes include:

- Fluvial Transport: Sediments transported by rivers are often well-sorted and rounded due to repeated collisions and abrasion during transport.
- Aeolian Transport: Wind-transported sediments, such as those in deserts, tend to be very well-sorted and rounded.
- Marine Transport: Coastal and deep-sea environments receive sediments from both rivers and marine processes. Heavy minerals like zircon and rutile are often concentrated in beach environments due to wave action.

1.4 CONCLUSION

Sediment provenance analysis is a fundamental tool in sedimentology, allowing geologists to trace the origin and history of sediments and understand the geological processes that shaped them. By studying mineral composition, isotopic signatures, and physical properties, geologists can reconstruct tectonic settings, depositional environments, and climatic conditions that influenced sedimentary basins. Provenance studies are essential for understanding the dynamics of sedimentary systems and their broader geological contexts.

1.5 SUMMARY

- Sediment provenance focuses on identifying the origin and history of sedimentary materials.
- It helps reconstruct tectonic settings, depositional environments, and transport processes.
- Methods of provenance analysis include mineralogical, geochemical, and isotopic studies, as well as examining grain size, shape, and sorting.
- Transport processes, like fluvial, aeolian, and marine, influence the composition and texture of the sediments.
- Provenance studies are important for understanding sedimentary basin evolution and resource exploration.

1.6 REFERENCES

Boggs, S. (2009). *Principles of Sedimentology and Stratigraphy*. Prentice Hall.

Tucker, M.E. (2001). *Sedimentary Petrology: An Introduction to the Origin of Sedimentary Rocks*. Wiley-Blackwell.

Blatt, H., Middleton, G., & Murray, R. (1980). *Origin of Sedimentary Rocks*. Prentice Hall.

Garzanti, E., Andó, S., & Vezzoli, G. (2008). "Provenance and Dispersal of Sand and Sandstone." *Earth-Science Reviews*, 85(3-4), 97-116.

1.7 MULTIPLE CHOICE QUESTIONS

1. What is the primary focus of sediment provenance studies?

A) Understanding the depositional environment
B) Identifying the source of sediments
C) Dating the age of sedimentary rocks
D) Determining the chemical composition of minerals

2. Which method is commonly used to date detrital zircon grains in provenance studies?

A) Carbon-14 dating
B) U-Pb dating
C) Potassium-argon dating
D) Optical dating

3. Well-rounded and well-sorted sediment grains typically indicate:

A) Deposition near the source
B) Long transport distance
C) Chemical alteration
D) Presence of heavy minerals

4. Which mineral is commonly used to trace sediments derived from volcanic arcs?

A) Glauconite
B) Feldspar
C) Zircon

5. Which process is responsible for concentrating heavy minerals like zircon and rutile in beach environments?

A) Wind action
B) Tectonic activity
C) Fluvial transport
D) Wave action

ANSWER: 1B 2B 3B 4C 5D

UNIT 2 RECONSTRUCTION OF PALEOENVIRONMENT, PALEOCLIMATE AND PALEOECOLOGY

Unit Structure

2.1 INTRODUCTION

Paleoenvironmental studies, paleoecology, and paleoclimate are interrelated fields that focus on understanding the Earth's past environments, ecosystems, and climate. These fields help scientists reconstruct the conditions under which ancient organisms lived, how ecosystems functioned, and how climate has changed over geological time. They are crucial for understanding how the Earth's climate system and biosphere have evolved, providing insights into modern environmental challenges and offering a window into how ecosystems and climates may respond to future changes.

- **Paleoenvironmental Studies**: Focus on reconstructing past environments by analysing geological and biological evidence.
- **Paleoecology**: Examines the interactions between ancient organisms and their environments, using fossil evidence and sediment records to reconstruct past ecosystems.
- **Paleoclimate**: Investigates Earth's climate in the past, relying on proxies such as ice cores, sedimentary records, and fossil isotopic data to infer temperature, precipitation, and atmospheric composition over time.

2.2 OBJECTIVES

By the end of this unit, will be able to:

- explain the key principles of paleoenvironmental studies, paleoecology, and paleoclimate

- analyse the different methods used to reconstruct past environments, ecosystems, and climates
- explain the importance of these fields in understanding Earth's history and predicting future environmental changes
- apply paleoecological and paleoclimatic principles to interpret past environmental and ecological changes.

2.3 PALEOENVIRONMENTAL STUDIES

Paleoenvironmental studies aim to reconstruct past physical, biological, and chemical environments by analysing the geological record. Understanding paleoenvironmental conditions provides insights into the natural processes that have shaped the Earth, including sedimentation, tectonics, erosion, and climate dynamics.

- Fossil Record: Fossils of plants, animals, and microorganisms preserved in sedimentary rocks are key indicators of past environments. Different species are associated with specific environmental conditions (e.g., marine, freshwater, or terrestrial).
- Sedimentary Structures: The nature of sedimentary deposits, such as grain size, sorting, and layering, provides clues about the depositional environment (e.g., river, desert, or deep- sea). Cross-bedding, ripple marks, and mud cracks are examples of features that help infer ancient depositional settings.
- Geochemical Signatures: The chemical composition of rocks and sediments, including stable isotopes (e.g., oxygen, carbon, nitrogen), can reveal information about ancient environmental conditions. These geochemical proxies are critical for reconstructing paleoenvironmental parameters such as temperature, salinity, and oxygen levels.

- **Paleoenvironmental Indicators**:

  - **Pollen Analysis**: Fossilized pollen grains are often used to reconstruct past vegetation and climate. The presence of specific pollen types can indicate whether the climate was cool or warm, wet or dry.
  - **Marine Microfossils**: Foraminifera, diatoms, and coccolithophores are common in marine sediments and provide information on past ocean temperatures, salinity, and nutrient levels.

2.3.1 Paleoecology

Paleoecology is the study of the relationships between ancient organisms and their environments. It seeks to understand how ancient ecosystems functioned, how organisms interacted, and how ecosystems responded to environmental changes.

- **Fossil Assemblages**: Fossils are often found in clusters known as fossil assemblages, which represent communities of organisms that lived in a particular environment. By examining these assemblages, paleoecologists can infer food chains, predator-prey relationships, and ecosystem structure.
- **Ecological Niches**: Each species in an ecosystem occupies a specific niche, defined by its role in the ecosystem (e.g., herbivore, carnivore, decomposer). Paleoecology uses fossil evidence to reconstruct these ecological roles and interactions within ancient ecosystems.
- **Taphonomy**: The study of how organisms decay and become fossilized is essential in paleoecology, as it helps understand biases in the fossil record. For example, some organisms are more likely to be preserved than others, influencing how complete the picture of an ancient ecosystem may be.

- **Paleoecological Case Studies**:

  - **The Eocene Epoch**: Fossil evidence from this warm period (about 56 to 33.9 million years ago) reveals lush, tropical ecosystems with diverse flora and fauna. By studying plant fossils and isotopic data, paleoecologists have reconstructed the ecosystems that existed during this time.
  - **The Late Quaternary Extinctions**: Paleoecology helps explain the extinction of large mammals (megafauna) such as mammoths and saber-toothed cats around 12,000 years ago. A combination of climate change and human activity is thought to have contributed to these extinctions.

2.3.2 Paleoclimate

Paleoclimate refers to the study of Earth's past climate conditions. It relies on various proxies, including ice cores, tree rings, marine sediments, and fossil evidence, to reconstruct temperature, precipitation, and atmospheric composition over time. Paleoclimate research is essential for understanding the natural variability of Earth's climate and for placing modern climate change into a long-term context.

- **Climate Proxies**:
  - **Ice Cores**: Ice cores drilled from glaciers and ice sheets contain trapped air bubbles that record past atmospheric compositions, including levels of greenhouse gases like carbon dioxide and methane. Isotopic analysis of the ice itself reveals past temperature fluctuations.
  - **Marine Sediments**: Deep-sea sediments preserve chemical signatures of past ocean temperatures and salinity, often recorded in the shells of foraminifera and other microorganisms.
  - **Tree Rings (Dendrochronology)**: Tree rings provide annual records of climate conditions. The width and density of tree rings reflect variations in temperature and precipitation.

- **Paleoclimatic Events**:
  - **The Last Glacial Maximum (LGM)**: Around 20,000 years ago, ice sheets covered large parts of North America and Eurasia. Paleoclimate data from ice cores, marine sediments, and fossil pollen reveal how temperatures were much cooler during the LGM and how ecosystems adapted to glacial conditions.
  - **The Paleocene-Eocene Thermal Maximum (PETM)**: A rapid warming event around 55 million years ago caused a dramatic rise in global temperatures, leading to widespread changes in ecosystems. Paleoclimate studies show that carbon dioxide levels rose significantly, possibly due to volcanic activity or methane release from ocean sediments.

2.3.3 Techniques In Paleoenvironmental, Paleoecological, And Paleoclimate Studies

- **Stable Isotope Analysis**: Stable isotopes, especially oxygen (O18/O16) and carbon (C13/C12), are powerful tools in paleoclimate studies. Oxygen isotope ratios in marine fossils help reconstruct past ocean temperatures, while carbon isotopes provide insights into past vegetation and atmospheric carbon levels.
- **Radiometric Dating**: Techniques like uranium-lead (U-Pb) dating and potassium-argon (K-Ar) dating are used to determine the ages of rocks and fossils, helping to place paleoenvironmental and paleoclimate changes in a chronological framework.
- **Palynology (Pollen Analysis)**: Fossilized pollen grains found in sediments can be used to reconstruct past vegetation and climate conditions. Different types of plants produce distinctive pollen, making it possible to identify past ecosystems.
- **Microfossil Analysis**: Microorganisms such as foraminifera,

diatoms, and radiolarians are sensitive to environmental changes and serve as valuable indicators of past marine and freshwater conditions.

2.4 CONCLUSION

Paleoenvironmental studies, paleoecology, and paleoclimate are interconnected fields that allow scientists to piece together Earth’s environmental, ecological, and climatic history. By analysing fossils, sediments, and isotopic signatures, researchers can reconstruct ancient ecosystems, study long-term climate trends, and understand the interactions between life and the environment throughout geological time. These studies are critical for understanding how ecosystems and climates have changed over millions of years, providing a foundation for predicting future changes in the face of ongoing environmental and climatic shifts.

2.5 SUMMARY

- **Paleoenvironmental studies** focus on reconstructing past environments through geological and fossil evidence.
- **Paleoecology** examines the interactions between ancient organisms and their environments, reconstructing past ecosystems and their functioning.
- **Paleoclimate** studies aim to reconstruct Earth's past climate using proxies such as ice cores, marine sediments, and isotopic data.
- These fields are essential for understanding how Earth's ecosystems and climate have evolved and for providing insights into modern environmental and climate issues.
- Methods such as stable isotope analysis, radiometric dating, and microfossil analysis are crucial tools in these studies.

2.6 REFERENCES

Armstrong, H. A., & Brasier, M. D. (2005). *Microfossils*. Blackwell Publishing.

Bradley, R. S. (1999). *Paleoclimatology: Reconstructing Climates of the Quaternary*. Academic Press.

Smol, J. P., Birks, H. J. B., & Last, W. M. (Eds.). (2001). *Tracking Environmental Change Using Lake Sediments*. Springer.

Zachos, J. C., Dickens, G. R., & Zeebe, R. E. (2008). "An Early Cenozoic Perspective on Greenhouse Warming and Carbon-Cycle Dynamics." *Nature*, 451(7176), 279-283.

2.7 MULTIPLE CHOICE QUESTIONS

1. What is the primary focus of paleoecology?

A) Reconstructing ancient climates
B) Studying ancient organisms and their environments
C) Mapping modern ecosystems
D) Determining the age of fossils

2. Which of the following is a common climate proxy used in paleoclimate studies?

A) Fossilized bone
B) Tree rings
C) Volcanic ash
D) River sediments

3. Which stable isotope is commonly used to reconstruct past ocean temperatures?

A) Carbon (C12/C14)
B) Oxygen (O18/O16)
C) Nitrogen (N15/N14)
D) Hydrogen (H2/H1)

4. What type of climate event was the Last Glacial Maximum (LGM)?

A) A period of extreme global warming
B) A period of maximum ice coverage
C) A volcanic eruption
D) A mass extinction event

5. Which field of study focuses on the chemical and physical conditions of past environments?

A) Paleobiology
B) Paleoecology
C) Paleoenvironmental studies
D) Paleoclimatology

ANSWER: 1B 2B 3B 4B 5C