

Addis Ababa University
College of Natural and Computational Science
Freshman Course

Course Title:

Geography of Ethiopia and the Horn



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CHAPTER TWO:

THE GEOLOGY OF ETHIOPIA AND THE HORN

Objectives

- **After completing this chapter, the learners will be able to:**
 - **Analyze the geologic processes and the resultant land forms of Ethiopia and the Horn.**
 - **Examine the formation of the Rift Valley.**
 - **Recognize the current status of Ethiopian mineral endowment associated with geologic processes.**

Introduction

- **Geology** is an **Earth science** that studies about:
 - 1.the **evolution of the earth**,
 2. the **materials of which it is made of**, and
 - 3.the **processes acting** upon the earth's materials.
- **Geology** studies of **how Earth's materials, structures, processes and organisms have changed overtime**.
- **Much of Geology** is concerned with **events that took place in the remote past**.
- **A great deal of geological understanding** can be obtained by **inference using clues** from **what can be seen** and **what can be measured**. There are many **clues** which can be **observed** and **measured** from the **rocks** and **landforms**
- There are many **clues provided by indirect methods such as geophysics, geochemistry and geochronology**.

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- **Indirect methods** such as:
 - **Geophysics** - studying **earthquake waves** which can penetrate deep beneath the Earth's surface,
 - **Geochemistry** - analysis of the detailed **composition of rocks** which can give clues as to their **origin** and
 - **Geochronology** - methods for finding the **ages of rocks**, usually from the **radioactive elements** they contain.
 - **In short, a great deal of geological understanding** can be obtained by **inference using clues through:**
 - i. **Direct Observation and Measurement of rocks and landforms**
 - ii. **Indirect Methods such as geophysics, geochemistry and geochronology.**

Continental Drift Theory

- Australian Climatologist **Alfred Wegener** proposed the hypothesis that the **earth's continents** were **once assembled or bunched up together** in to a **single huge continent or as a supercontinent** called **Pangaea**. The Pangaea or large super continent was then **split into Gondwanaland and Laurasia**; and **later into smaller fragments** over the last million years; then **drifted apart to form the present arrangement of continents**.
- **Wegener's principal observations** were:
 1. **Fit of the continents:**
 - The **opposing coastlines** of continents often **fit together**.
 2. **Match of mountain belts, rock types:**
 - If the continents are reassembled as Pangaea, **mountains in West Africa, North America, Greenland, and Western Europe** match up.

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- **Distribution of fossils:**
 - The distribution of **plants and animal fossils** on separate continents forms **definite linked patterns** if the continents are reassembled.
- **Paleoclimates:**
 - **Rocks formed 200 million years ago** in **India, Australia, South America,** and **southern Africa** all exhibited **evidence of continental glaciations.**

The Geologic Processes:

- The **Geologic Processes** are divided into two major groups:

1. The Internal Processes (Endogenic Forces): -

It includes:

- **volcanic activity,**
- all the **tectonic processes** (folding, faulting, orogenesis, and epeirogenesis.

Orogenesis - mountain building Process

Epeirogenesis - slow rising and sinking of the landmass

- These processes result in building of structural and volcanic features like **Plateaus, Rift Valleys, Block Mountains, Volcanic**

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2. The External Processes (Exogenic Forces):

- are **geomorphic processes**.
- they include **weathering, mass transfer, erosion and deposition**.
- They act upon the **volcanic and structural landforms** by **modifying, roughening and lowering** them down.
- **The landmass of Ethiopia is the result of the combined effect of endogenic and exogenic processes.**

The Geological Time Scale and Age Dating Techniques

- **Geological Time Scale (GTS)** is a **system** of **chronological dating** (following the **order** in which the event occurred) that **relates geological strata or layer to time**.
- **GTS** describes the **timing** and **relationships of events** that have **occurred** during **earth's history**.
- **GTS** is **essential or needed** for **understanding** those events which have been happened on earth before million years ago.
- **GTS** gives the **information of sequence of events** which occurred in the **history of the earth**.
- The **first Geological Time scale** was proposed by **Giovanni Arduino** in **1760**, also known as the **father of GTS**.

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- **GTS** have some **division** or **units** like **Eon, Era, Period and Epoch**.

I. Eon:

- **Eon** is the **mega or biggest unit** in **GTS** (the **duration of Eon** is around **half a billion or more**)
- There are **two Eon**. These are:
 - 1 **Phanerozoic Eon** (Visible life)
 2. **Cryptozoic Eon** (No life)
- **NB:**
 - The word **ozoic** means **life** while **azoic** means **no life**
 - Our **GTS** is composed of **Phanerozoic Eon** since we will talk about life which were visible or existed in those time period. Thus, the Eon used in **GTS** is **Phanerozoic Eon**.

II. Eras:

- **Eons** are further divided in to **smallest units** called **eras**
- There are **four eras**. These are:
 1. **Precambrian Era (Primitive Life)**
 2. **Paleozoic Era (Ancient/Old Life)** is the **age of invertebrates**
 3. **Mesozoic Era (Middle Life)** is the **age of reptiles**
 4. **Cenozoic Era (Recent Life)** is the **age of mammals**.
- The **Eras** are given **names** that indicate the **kind of life that existed in them**.

III. Periods:

- **Each** era are further sub divided in to **smaller time units** called **periods**

IV. Epoch:

- **Periods** are further divided in to **smaller units** are called **Epoch**.
- **Rock units** corresponding to epochs are called **series**.

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- The **Earth** is believed to have been **formed** approximately **4.5 billion years ago**.
- The **earliest forms of life** were thought to have **originated** approximately **3.5 billion years ago**.
- To describe the **geology** and **history** of **life** on Earth, scientists have developed **the geological time scale**
- The **geological time scale** measures time on a scale **involving or relating with four main units**:

1. **Epoch** - smallest unit of time in a scale encompasses

a period of millions years

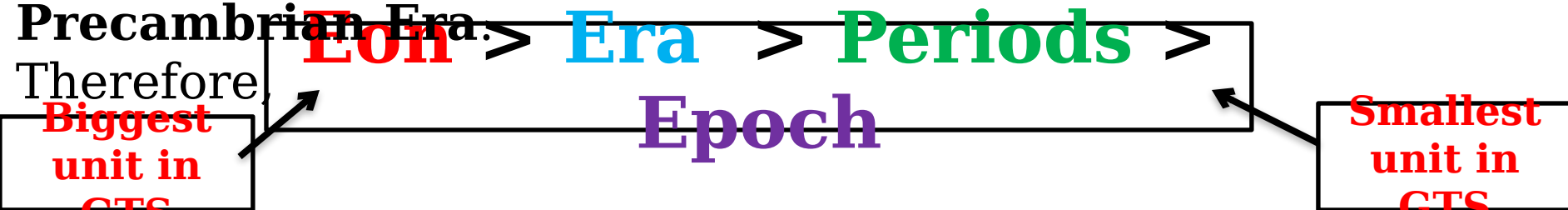
2. **Period**

3. **Era**

4. **Eon** is the largest period of geological time.

- The **span of time before life appeared** was termed the **Precambrian Era**.

Therefore,



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- The **geological time divisions** basically **differ** from each other based on the following **characteristics**:
 - the **relative position of land and sea**,
 - **the kind of climate** and
 - the **kind of animal and plant life that developed** and **existed** during that Era or period.
- The **division of time units in the geological time scale** is usually **based on the occurrence of significant geological events** (e.g. mass extinctions - process of being or becoming extinct). As such, the **geological time categories do not usually consist of a uniform length of time.**

The Geological Time Scale

Era	Period	Began (in Million Years)	End (my)	Major Events (million years ago)
Cenozoic	Quaternary	1.6	Present	Major glaciers in North America and Europe (1.5)
	Tertiary	70	1.6	Rocky Mountains (65), individual continents take shape.
Mesozoic	Cretaceous	146	70	Dinosaurs extinct (65), western interior seaway and marine reptiles (144 – 65)
	Jurassic	208	146	Pangaea (one land mass) begins to break up (200)
	Triassic	225	208	First mammals and dinosaurs
Paleozoic	Permian	290	225	Greatest extinction on Earth (245)
	Pennsylvanian	322	290	First reptiles
	Mississippian	362	322	Coal-forming forests
	Devonian	408	362	First land animals and first forests (408)
	Silurian	439	408	Life invades land
	Ordovician	510	439	First fish appeared
	Cambria	600	510	Great diversity of marine invertebrates
Precambrian	Proterozoic	2,500	600	Marine fossil invertebrates (600)
	Archean	4,500	2,500	Earliest fossils recorded (3,500), earliest rock formation (4,000)

Geological Time Scale

Eon Age (in Million Years)		Era	Period	Epoch	Evolutionary Changes/Development
<u>Phanerozoic Eon</u>	Present	Cenozoic	Quaternary	Holocene	Age of Man
	2 (in between)			Pleistocene	Extinction of Large Mammal
	12		Tertiary	Pliocene	Man Evolving (man was in developmental stage) , Mammals Abundant
	2.6			Miocene	First Man like Apes (apes very much similar to man were appeared)
	37			Oligocene	Appearance of Modern Mammals
	53			Eocene	Diversification of Placental Mammals (different species of mammals appeared)
	65			Paleocene	Evolutionary Explosion of Mammals (fast changes or development were observed)
	136	Mesozoic	Cretaceous		Dinosaurs reached peak and became extinct, Modern Bird common, Rise of Flowering Plants
	190		Jurassic		Appearances of first toothed/sharp birds, dominance of dinosaur, first flowering plants appeared
	230		Triassic		Extinction of primitive amphibians, change/transition of reptile to mammals, gymnosperms dominant.
	290	Paleozoic	Permian		Extinction of Ammonites and trilobites, dwindling of ancient plants (to become smaller or weak),
	345		Carboniferous		Amphibians dominant on land, rise of insects, seeds, ferns, gymnosperm dominant
	395		Devonian		First forest, first gymnosperm, diversification in fishes
	430		<u>Silurian</u>		Arthropods abundant, first land plants
	500		Ordovician		First true corals, <u>bryozoan</u>, it is the age of graptolites
	2500		<u>Proterozoic</u>		Age of trilobites
	3800		<u>Archeozoic</u>		Rock transformation belonging to <u>Proterozoic</u> group show traces of primitive life – they are fossilized rocks
	4500		<u>Hadean</u>		Rocks of this periods are <u>unfossiliferous</u> (no fossils in the rocks)

Age Dating Techniques

- **There are two techniques of knowing the age of rocks:**

- 1. Relative age dating.**

- 2. Absolute age dating**

1. Relative dating:

- **It uses geological evidence to assign comparative ages of fossils.**
- **we can use two ways to know the relative age of a rock:**
 - i. by looking at any fossils the rock may contain.**
 - ii. by looking layers of rocks**
- **The two methods only give the relative age of rocks -which one is younger and which is older.**

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2. Absolute Dating:

- It is known as **Radiometric techniques**
 - i. **Carbon-14 Technique**
 - ii. **Potassium-Argon Technique**

Geological Processes and the Resulting Landforms of Ethiopia and the Horn

1. The Precambrian Era (4.5 billion - 600 million years ago)

- It covers **5/6th** of the Earth's history
- Our **knowledge** of the events is **limited** due to its **remoteness in time** and **the absence of well-preserved fossils**
- Some **general description** of the main geologic **processes** includes:
 - **Orogenesis**: the **land** was subjected to **intense folding** which was associated **with intrusive igneous activity**. The result was the **formation of huge mountain ranges/gigantic mountains**
 - There were **long periods of denudation** which finally **reduced these mountains to near-level (peneplained) rock surfaces**.
 - The formation of the **basement rocks or crystalline rocks**

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- In Ethiopia the **Precambrian rock or the basement/crystalline rocks** are found exposed in the following areas:

- **In the Western Part:**

Gambella, Benishangul-Gumuz (Metekel and Asossa), western Gojjam, western Wellega, Illuababora, and Abay gorge.

- **In the Southern Part:**

Guji, southern Omo, and parts of southern Bale and Borena.

- **In the Eastern part:**

Eastern Hararghe.

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2. The Paleozoic Era (600 million - 225 million years ago)

- The major geological process was **intense and prolonged denudation followed by peneplanation (peneplained surface)**.
- **The formation of undulating plains or inselbergs.**
- The **sediments** were **transported southward and eastward to form continental (in Africa) and marine deposit.**
- Rocks belonging to paleozoic Era are **rare** in Ethiopia because of the **limited deposition.**

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3. The Mesozoic Era (225-70 million years ago):

- It was an era of **epeirogenesis or alternate slow sinking and rising** of the landmass.
- This **process affected the whole present-day Horn of Africa and Arabian landmass**. At the same time **the land was tilted eastward** and therefore **lower in the southeast and higher in the northwest**.
- Due to **gradual subsidence or sinking of land**, the **sea invaded** the land starting from **Somalia and Ogaden** and **slowly spreading northwestward**, this was began during **Triassic period** and continued up to **Jurassic Period**.
- As the **shallow sea** spread towards the land, **sands** were **deposited** over the peneplained Precambrian rock surface. As the depth of the sea increased, **mud (shale), gypsum** and **later lime** were **deposited due to** decomposition and precipitation of marine life; this makes the Mesozoic rocks to have a great potential of oil and gas deposit

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- Through time, **compression** by the **overlying rocks** and by **cementing minerals**, the **sands** and **lime** were **compacted** to **form sandstone** and **limestone layers** respectively. These are known as **the Adigrat sand stone** and **Hintalo limestone layers**.
- In the **Horn of Africa** and **Ethiopia**, the **slow rise** of the **land** and **consequently the regression/drop of the sea began** in the **Upper Jurassic**. It continued throughout the Cretaceous period, and hence, due to **uplift of the landmass**, the **sea began to retreat** and thus another process of **deposition** occurred.
- By the **end of the Mesozoic Era**, when the **land emerged out of the sea**, **three major sedimentary formations** were laid and formed upon the Precambrian rock surface. These were:
 - i. **Adigrat or lower sandstone,**
 - ii. **Hintalo limestone and**
 - iii. **Upper Sandstone.**

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- Due to the **tilting/sloping of the landmass** during the **transgression** and **regression** of the sea, and due to **the direction of the invading and retreating sea**, the **age** and **thickness** of the **Sandstone layers** vary in a **Southeast - Northwest direction**.
- The **Adigrat sandstone** is **older** and **thicker** in the **southeast** and **progressively decreases** in **age** and **thickness** **northwestward**.
- The **Upper sandstone**, is **thicker** and **younger** in the **Southeast**, while in the **Northwest** it is **older** and **thinner**.
- The **transgressing sea** and **Mesozoic sediments** nearly **covered the whole of Ethiopia**.
- As **surface rocks**, these **old marine sediments** are **extensively found in the Southeast lowlands**. Other exposures include **central Tigray**, and **along the gorges of Abay and Wabishebele rivers**.

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4. The Cenozoic Era (70million years ago - Present)

- The **tectonic** and **volcanic activities** that **took place** in this era have an important **effect** in the **making of the present-day landmass of Ethiopia** and the **Horn of Africa**.
- The **major geologic events/activities** were:
 - a. **Uplifting of the Arabo-Ethiopian landmass and outpouring of huge quantity of lava** (i.e Trappean lava or Trap Series lava formed volcanic mountains)
 - b. **Formation of the Rift Valley**
 - c. **Quaternary volcanism and deposition**

A. Tertiary Period:

- The **Red Sea** and the **Gulf of Aden** were connected as a result of the **rifting** and **faulting**, the **Afar depression** (including the Gulf of Zula) was **down-faulted**, **thick saline materials accumulated**; the area **between the Danakil Depression** and the **Red Sea** was uplifted to form the **Afar Block Mountains**.

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- The **spatial extent of the rift valley-**
 - **Great East African Rift system** extends from **Palestine-Jordan** in the north to **Malawi-Mozambique** in the south, with a **distance** of about **7,200 kilometers**. Of these, **5,600 kilometers** is in **Africa**, and **1,700 kilometers** in **Eritrea and Ethiopia**.
 - the **widest part of the Rift Valley** is the **Afar Triangle (200-300 km)**.
- The **Red Sea**, the **Gulf of Aden**, and the **East African System** **meet** and form the **triangular depression of the Afar** where the **Kobar Sink** lies about **125 meters below sea level (the lowest place)**.
- The **formation of the Gulf of Aden** and the **separation of the Arabian Peninsula** from the **Horn of Africa** also took place during the **Tertiary period**.

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- The **Rift Valley region** of Ethiopian is the **most *unstable*** part of the country; in this region, there are **numerous hot springs, fumorales, active volcanoes, geysers, and frequent earthquakes**
- **The formation of the Rift Valley has the following structural (physiographic) effects:**
 - **It divides the Ethiopian Plateau into two.**
 - **It separates the Arabian landmass from African landmass.**
 - **It causes the formation of the Dead Sea, Red Sea and the Gulf of Aden troughs/channels.**
 - **It creates basins and fault depressions on which the Rift Valley lakes are formed.**

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- **Quaternary Volcanic Eruptions and Depositions**
 - **Quaternary Deposition:** During the Quaternary period of the Cenozoic Era, **the Earth experienced a marked climatic change**, where **warmer** and **dry** periods were **alternating with cooler** and **wet periods**. This is the time of “**Ice Age**” in the **middle** and **high latitude** areas and the time of the “**Pluvial Rains**” in Africa.
 - The **heavy Pluvial Rains** **eroded** the **Ethiopian plateau** and the **eroded materials** were **deposited in the Rift Valley lakes**.

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- According to **the place** and **manner of deposition** and **depositing agents** these **deposits** are divided as follow.
- a. **Lacustrine deposits**: Deposits on former **lakebeds**, and **swampy** depressions.
- b. **Fluvial deposits**: Deposits on the **banks of rivers**, **flood plains** both in plateau, foothills etc.
- c. **Glacio-fluvial deposits and erosional features**: These are occurred **on high mountains**, such as Bale and Kaka Mountains.
- d. **Aeolian deposits**: are **windblown deposits**.
- e. **Coastal and marine deposits**: Deposits on sea invaded and **sea-covered places**.

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- The **quaternary deposits** are mainly found in the **Rift Valley (Afar and Lakes Region)**, **Baro lowlands**, **southern Borena**, and **parts of northwestern low lands**.

Rock and Mineral Resources of Ethiopia

- The occurrence of **metallic minerals** in Ethiopia is associated with the **Precambrian rocks**.
- **Gold production and utilization, the mining and working of iron for the manufacture of tools, utensils and weapons and the use of salt and salt-bar** indicates the long mining tradition in Ethiopia.

Brief Facts and Current State of Main Minerals in Ethiopia

- Geological surveys proved that Ethiopia has abundant mineral resources of metals and precious metals, coal, and

Table: Available Minerals and their Location in Ethiopia

Mineral	Location
Gold	Primary sources: <u>Benishangul-Gumuz (Metekel) and Adola.</u> <u>Demi-dama, Sakoro and Lega-dembi.</u> Secondary Source/Deposit: <u>Adola, Murmur Basin, Shakiso, Awata Basin, Dawa Basin, Ghenale Basin, Ujama Basin, Mekanisa (Guba and Wombera), Kaffa, In Gambella and Illuababora (Akobo River), in Sidama (Wondo), Borena (Negele-Yabelo area) and in Benishangul-Gumuz (Sherkole), west Wellega, Mengi-Tumat-Shangul areas to the Sudanese border, and the drainage of the Didessa and Birbir.</u>
Platinum	- <u>The Yubdo area in Wellega, is the only active Ethiopian Platinum mine,</u> - <u>Platinum occurrences have been reported from Delatti in Wellega, and the valley of Demi-Denissa and Bone Rivers as well as Tullu Mountain area in Sidama.</u>
Tantalum	- <u>In Southern Ethiopia - Adola.</u> - <u>Extensive lignite deposits in Ethiopia are found in Nedjo (Wellega), and in small amounts in Chilga (Gonder)</u> - <u>Important Lignite (lowest ranked coal) occurred in Beressa Valley and Ankober (North Shewa), Sululta (near Addis Ababa), Muger Valley (West Shewa), Aletu valley (near Nedjo), Kariso and Selmi Valleys (Debrelibanos), Zega wodem gorge (near Fiche), Didessa Valley (southwest of Nekemte), Kindo and Challe Valley (Omo confluence), Adola, Wuchalle (north of Dessie), Chukga area (on Gonder-Metema road), Dessie area (near Borkena River).</u>
Gemstones including amethyst, aquamarine, emerald, garnet, opal, peridot, sapphire, and tourmaline	- <u>Occurred in mainly in Amhara and Oromia Regional States;</u> - <u>Quality Opal was first discovered by local people in Wadla and Dalanta woredas, North Wello in Amhara Regional State.</u>
Potash	<u>Danakil (Dallol Depression) of the Afar region</u>
Gypsum and Anhydrite	<u>Large deposits are known to occur in sedimentary formations of the Red Sea coastal area, Danakil Depression, Ogaden, Shewa, Gojjam, Tigray, and Hararghe</u>
Clay: Industrial Clay Material	- <u>Alluvial clay deposits for bricks and tile, pottery and pipe industry occur in Adola, Abay gorge, and the Rift Valley lakes region.</u> - <u>Ceramic clay for the production of glasses, plates, bricks is found at Ambo and Adola; Hawasa.</u>
Marble	<u>Found in west of Mekelle and south of Adwa in Tigray. In the east in Galetti, Soka, Ramis, Rochelle, Kumi and other valleys of Chercher Mountain in West Hararghe. In the northwestern also in areas built of Precambrian schist in Gonder, and the Dabus River and other neighboring river basins in Benishangul-Gumuz and Gojjam.</u>
Construction stones: Basalt, granite, limestone, sandstone and scoria are important building stones	<u>Found in Dire Dawa and Muger Valley, Abay gorge (Dejen), Tigray (Messebo)</u>

- According to the **Ethiopian geological survey**, the **geologic formations** that host most **mineral potentials of Ethiopia** includes **three major**

Table: Mineral Potential Sites of Ethiopia

Greenstone Belt	Minerals and their Location
The Western and South-western-greenstone belt	- Primary gold occurrences (<u>Dul Tulu-Kape</u>, <u>Oda-Godere</u>, <u>Akobo</u>, <u>Baruda</u>, <u>Bekuji-Motish</u>; - <u>Yubdo</u> Platinum; - Base metals of <u>Azali Akendeyu</u>, <u>Abetselo</u> and <u>Kata</u>; <u>Fakushu Molybdenite</u> - The iron deposits of <u>Bikilal</u>, <u>Chago</u>, <u>Gordana</u> and <u>Korre</u>, <u>Benshagul-Gumuz</u>- <u>Marble</u>, <u>Akobo</u> - <u>Asosa</u> placer gold deposits
The Southern greenstone belt	- It is known as the <u>Adola</u> belt, which comprises the primary gold deposits and occurrences of <u>Lega-dembi</u>, <u>Sakaro</u>, <u>Wellena</u>, <u>Kumudu</u>, <u>Megado-Serdo</u>, <u>Dawa Digati</u>, <u>Moyale</u> and <u>Ababa River</u>; - The <u>columbo-tantalite</u> of <u>kenticha</u> and <u>Meleka</u>, and - The <u>Adola</u> nickel deposit and other industrial minerals.
The Northern greenstone belt (Tigray):	- This belt comprises of the primary gold occurrences of <u>Terakemti</u>, <u>Adi-Zeresenay</u>, and <u>Nirague</u>. - The base metals of <u>Terer</u>, <u>Tsehafiembra</u> and other parts of <u>Tigray</u>, - Placer gold occurrences of <u>Tigray</u>.

Discussion Question

- **Answer the following questions briefly.**
- 1. What were the major geologic processes of the Precambrian and Paleozoic Eras in the Horn of Africa?**
- 2. Explain the formation of the oldest sedimentary rocks in Ethiopia and the Horn.**
- 3. Discuss the major geologic events of Ethiopia that took place during the Cenozoic Era.**
- 4. Where are the major mineral potential sites of Ethiopia? Discuss each of them with the help of examples.**

Thank You!