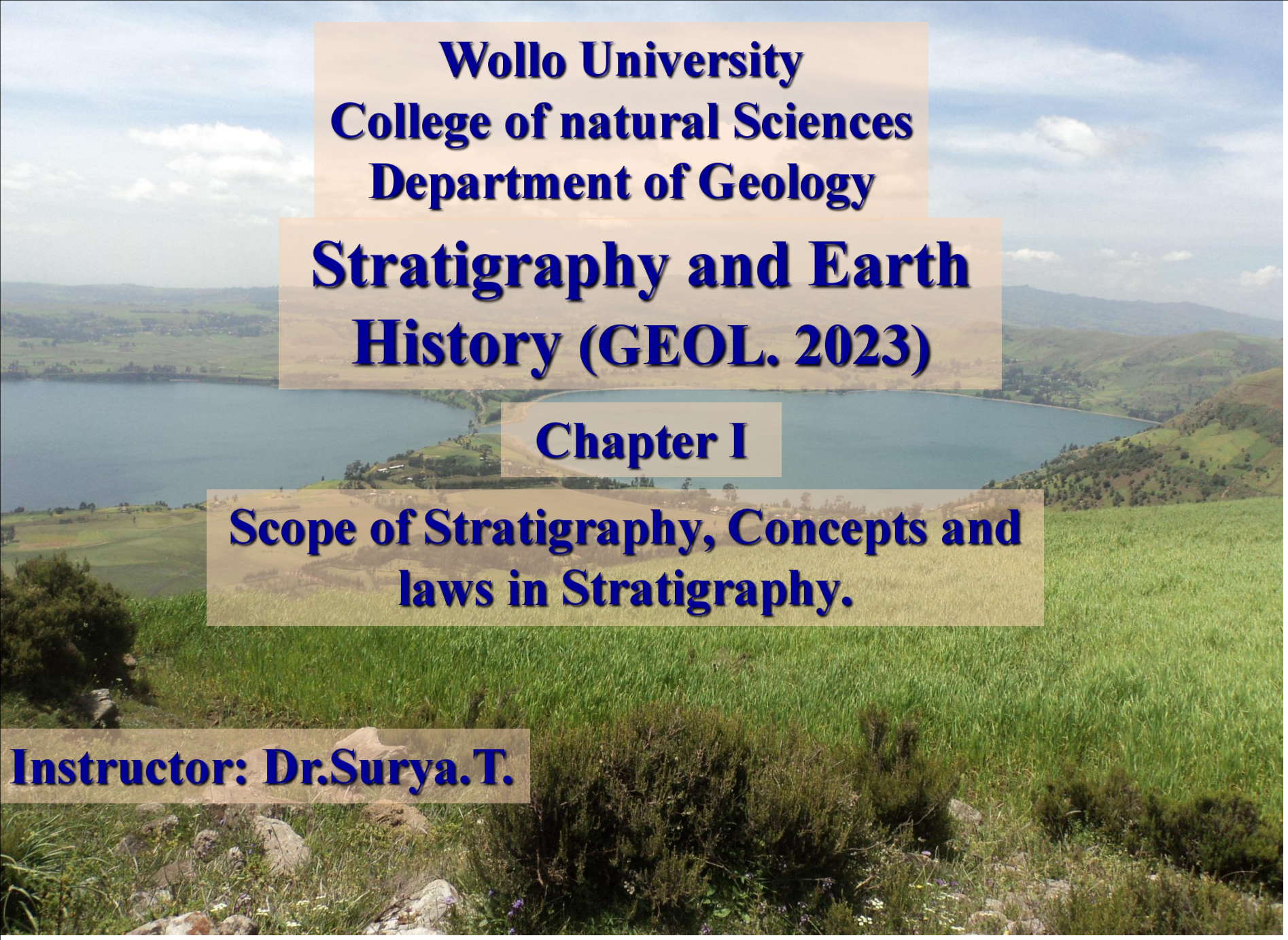


Wollo University
College of natural Sciences
Department of Geology

Stratigraphy and Earth History (GEOL. 2023)

Chapter I

Scope of Stratigraphy, Concepts and laws in Stratigraphy.

Instructor: Dr.Surya.T.

Introduction to Stratigraphy

- **Definition and Scope of Stratigraphy:**

✓ Stratigraphy is the science of rock strata.

✓ Stratigraphy is that branch of geology which treats all characteristics and attributes of rocks as *strata.*

✓ *Latin word - stratum ; Greek word: Graphia*

✓ Stratigraphy deals with the vertical and lateral relationships between rock units (i.e. stratigraphic units) that are defined on the basis of

✓ lithologic,

✓ paleontologic,

✓ geophysical properties,

✓ age relationships,

✓ sequences, event horizons, cycles and stable isotopes.

Subdisciplines of Stratigraphy

1. **Lithostratigraphy :** studies the vertical and lateral relationships between rock units (i.e. stratigraphic units) that are described on the basis of *lithologic or physical properties, such as*

rock type, color, mineral composition and texture.

2. **Biostratigraphy :** based on paleontological characteristics (fossil content)
3. **Chronostratigraphy** : based on ages of strata and their relationships (*chrono means time)*

✓ The above three are traditional branches of stratigraphy that existed long before the 1960s.

(Relatively new branches that emerged after 1960s.)

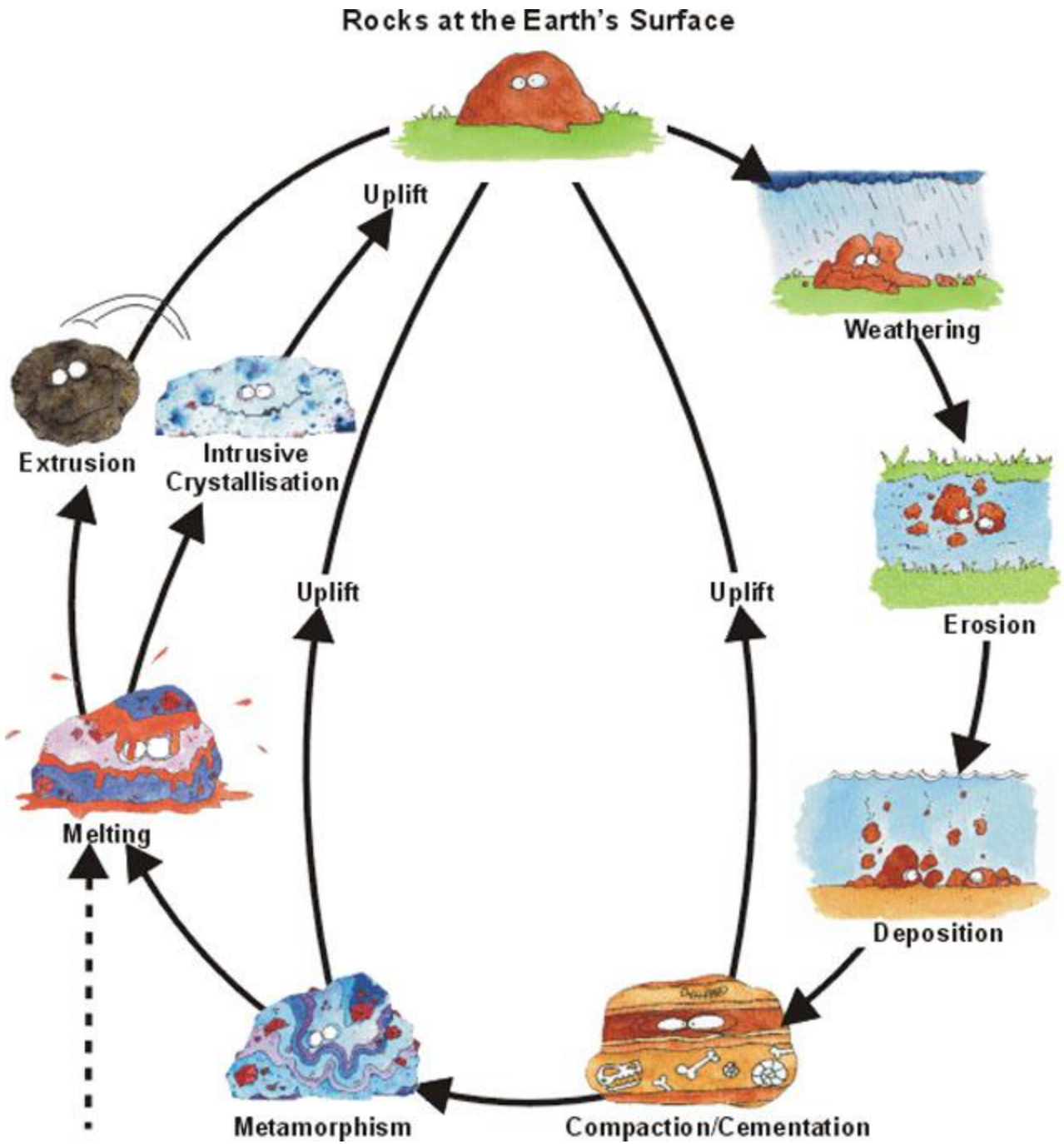
4. **Seismic Stratigraphy** : based on the response of strata to seismic waves (elastic waves).
5. **Sequence Stratigraphy** : based on depositional sequences (packages of strata that are bounded by unconformities).
6. **Allostratigraphy** : based on bounding discontinuities between units.
7. **Magnetostratigraphy** : based on magnetic properties of strata(magnetic polarity).

8. **Event Stratigraphy** : based on event horizons and marker beds.

9. **Cyclostratigraphy** : based on sedimentary cycles in the stratigraphic record.

10. **Chemostratigraphy** – based on stable isotopes (e.g. O, C, S, Sr).

J. Hutton
Rock cycle



- ✓ First usage: the term Stratigraphy was first used by William Smith (1817)
- ✓ Strata*: layers of (usually sedimentary) rock*
- ✓ Contact: a boundary that separates different strata or rock units.

❖ **Stratigraphic procedure includes:**

- ✓ Description
- ✓ classification
- ✓ naming and
- ✓ correlation of rock units

Basic Concepts

✓ Lithostratigraphy

Each layer is a different rock type

✓ Chronostratigraphy

Each layer is a different age.

✓ Biostratigraphy

Each layer contains a different fossil assemblage.

How do we Illustrate Stratigraphy?

- Stratigraphic Columns
- Cross Sections
- Geologic Maps

- ✓ **Geologic time**

  Absolute date/Absolute time

  Relative dating/Relative time

- ✓ Relative age dating is a way to use geometric relationships between rock
- ✓ Relative dating is different from **absolute dating.**
- ✓ **How we know time?**

  Process → Rate of process → Time

  Structural relations of rock bodies (lower or higher)

Nicolavs Steno (1638-1686)

- Noted that teeth of the shark are the same as the glossopetrae (tongue stones) so often found as fossils

Relative dating

Nicolavs Steno (1638-1686)

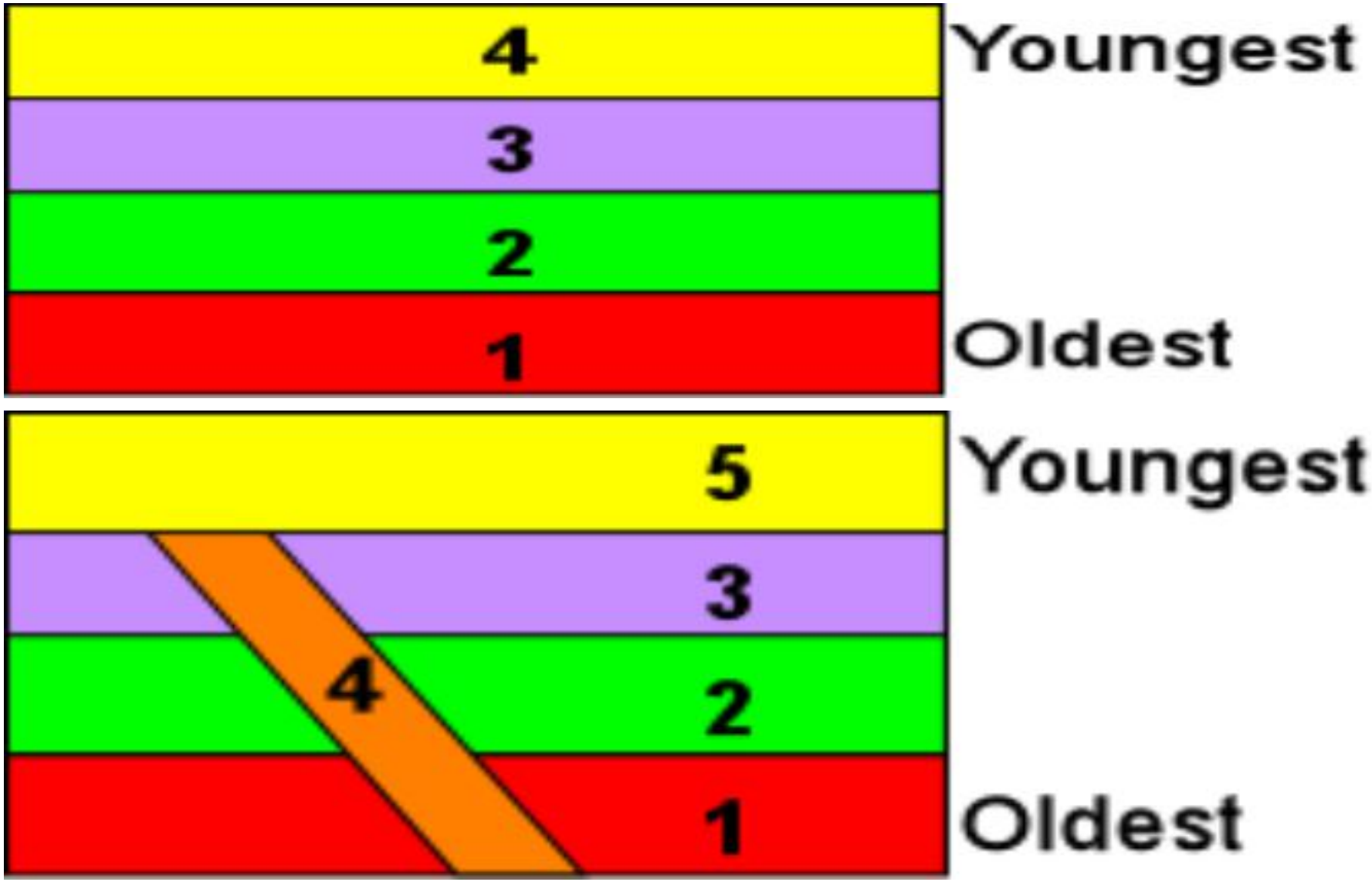
is the founder of relative dating

Concepts and Laws in Stratigraphy

- These laws were developed in the 17th to 19th centuries based upon the work of Nicolaus Steno , James Hutton and William Smith, among others.
- They are divided into Six major groups

1.The law of superposition: set forth by Nicolaus Steno in 1669 in his attempt to place a sequence of geologic events in proper order, known as *relative dating.*

- ”the law of superposition states that *in an undisturbed succession of sedimentary strata, unaffected by later folding, faulting, intrusion (dikes and sills) or any other physical disturbance, younger rocks lie above older rocks.”*


4
Youngest
3
2
1
Oldest
5
Youngest
3
4
2
1
Oldest

2.The law of original horizontality: Sediments are commonly deposited in approximately horizontal, flat-lying layers.

- ✓ Folded, faulted or dipping strata must have been deformed after deposition.

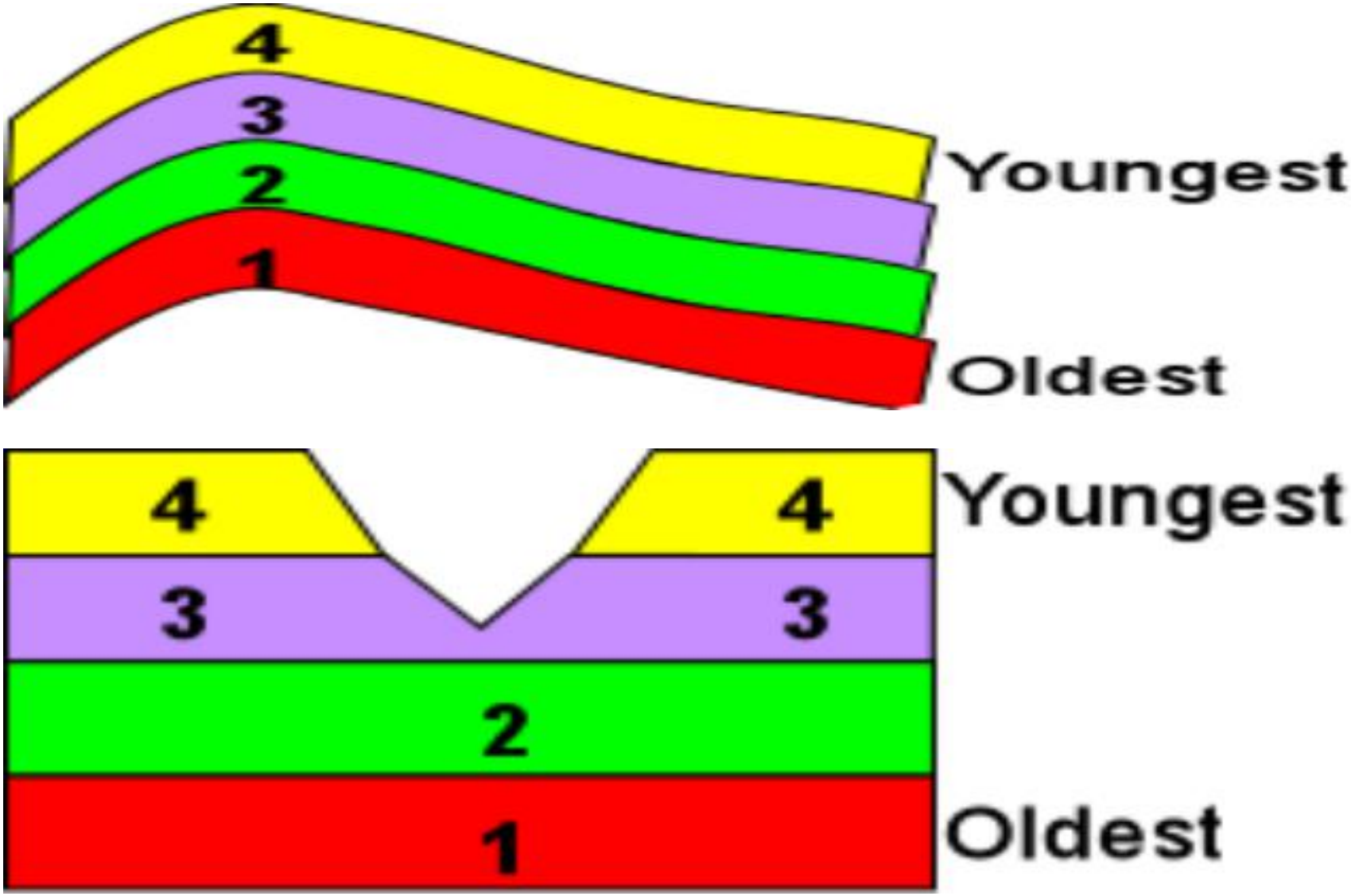
3.The law of lateral continuity: sedimentary strata will be continuous in all directions until it reaches the edge of the depositional basin.

✓ **4. Cross-Cutting Relations**

- "If a body or discontinuity cuts across a stratum, it must have formed after that stratum." Steno, 1669.

✓ **5. Law of Inclusions-** this law states that rock fragments (in another rock) must be older than the rock containing the fragments.

✓ **6.Law of Faunal Succession-** This law was developed by William "Strata" Smith who recognized that fossil groups were succeeded by other fossil groups through time.


4
3
2
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Youngest
Oldest
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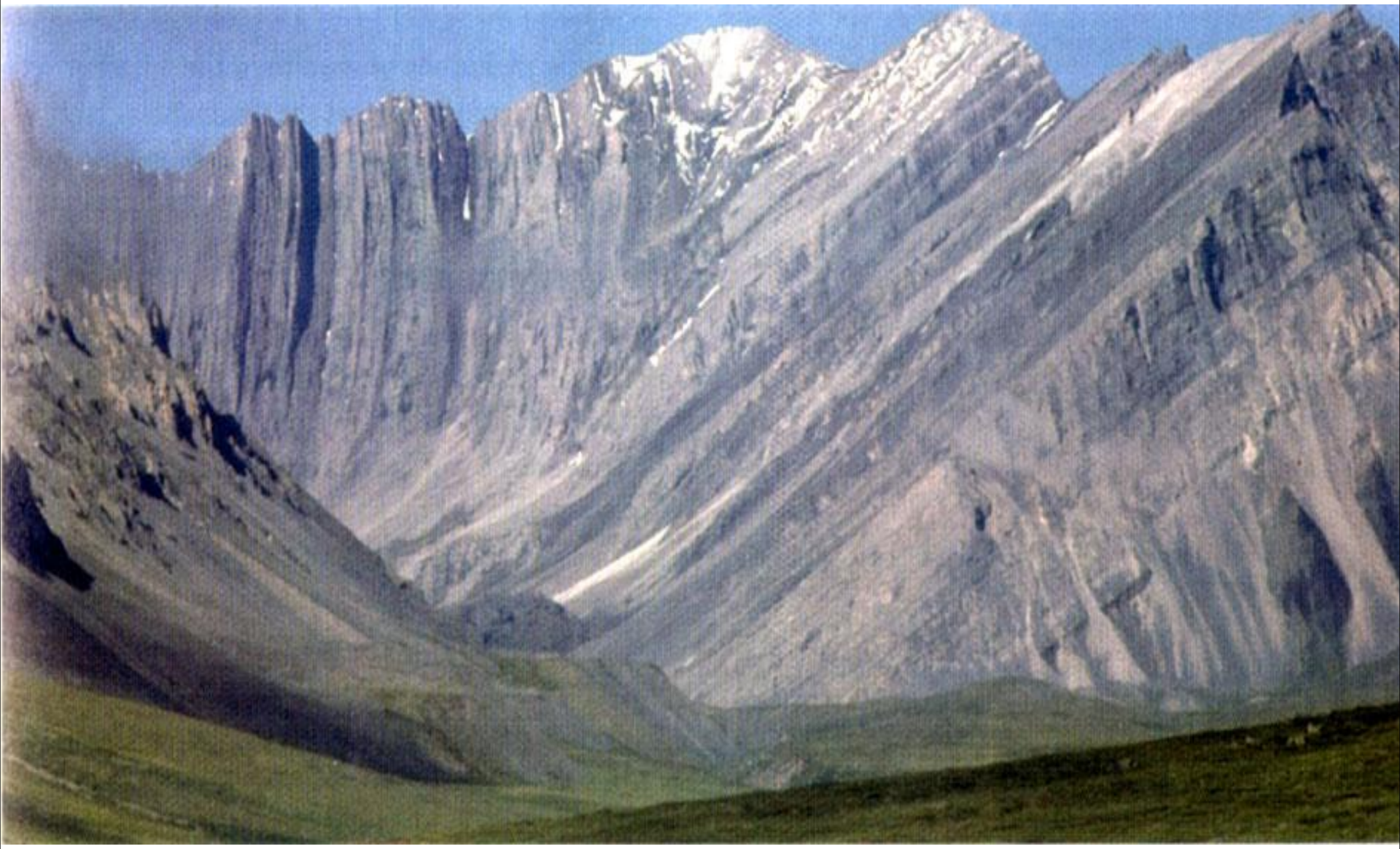
3
3
2
1
Youngest
Oldest

Original horizontality

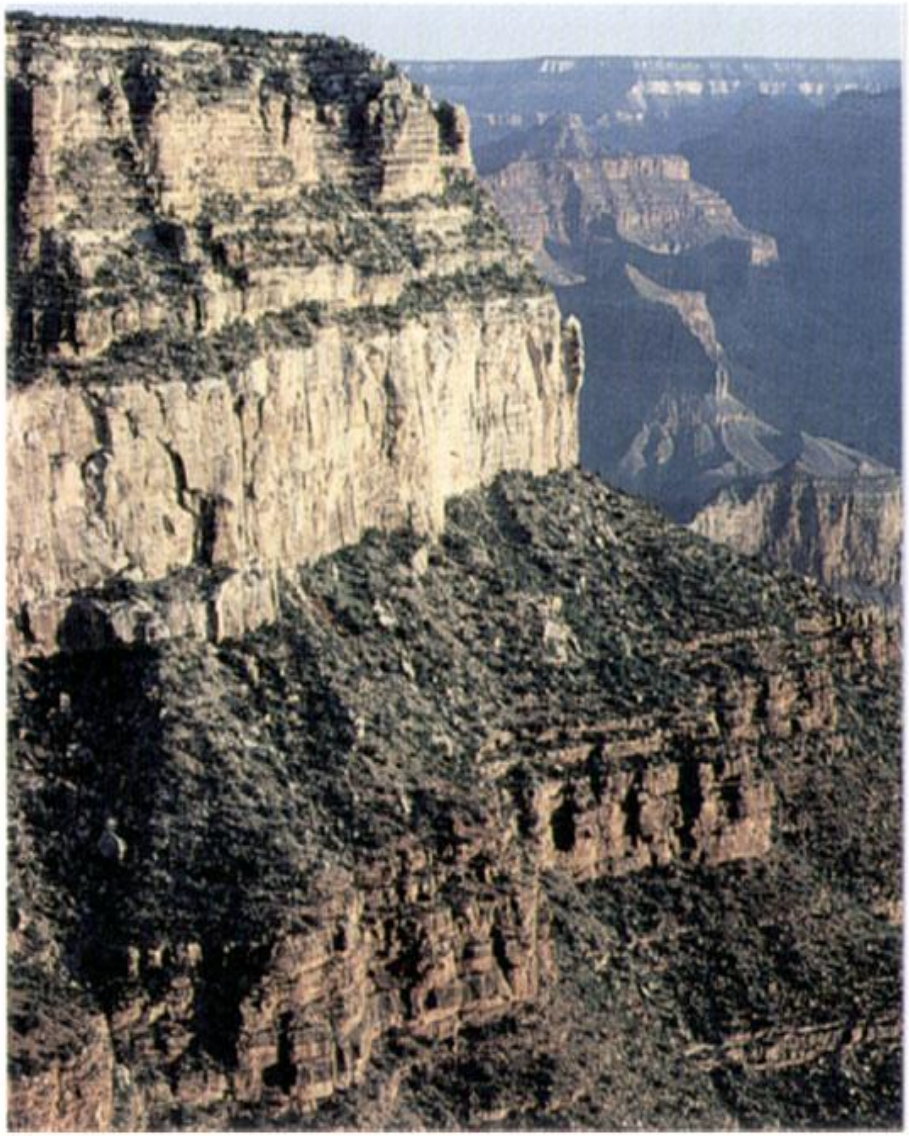
Original horizontality



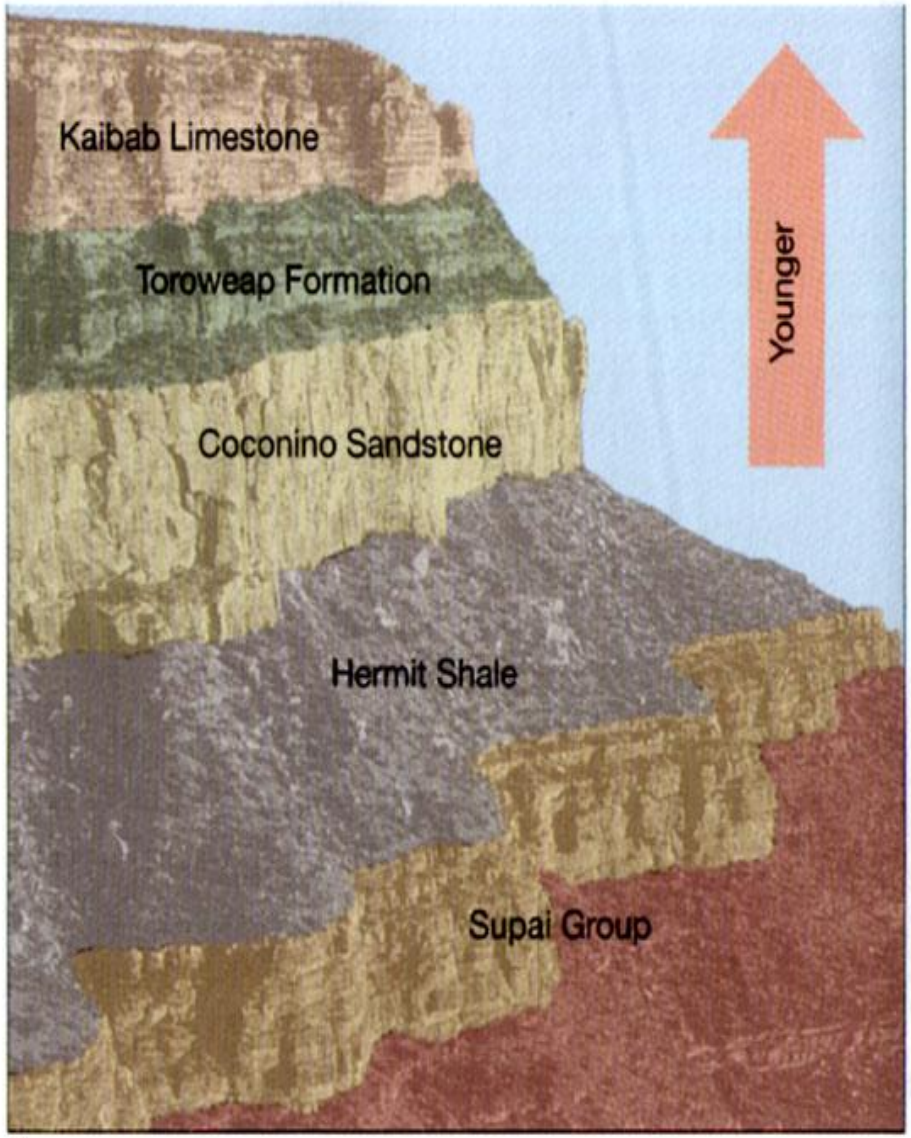
These folded rocks were originally horizontal

Original continuity

Law of superposition



A.



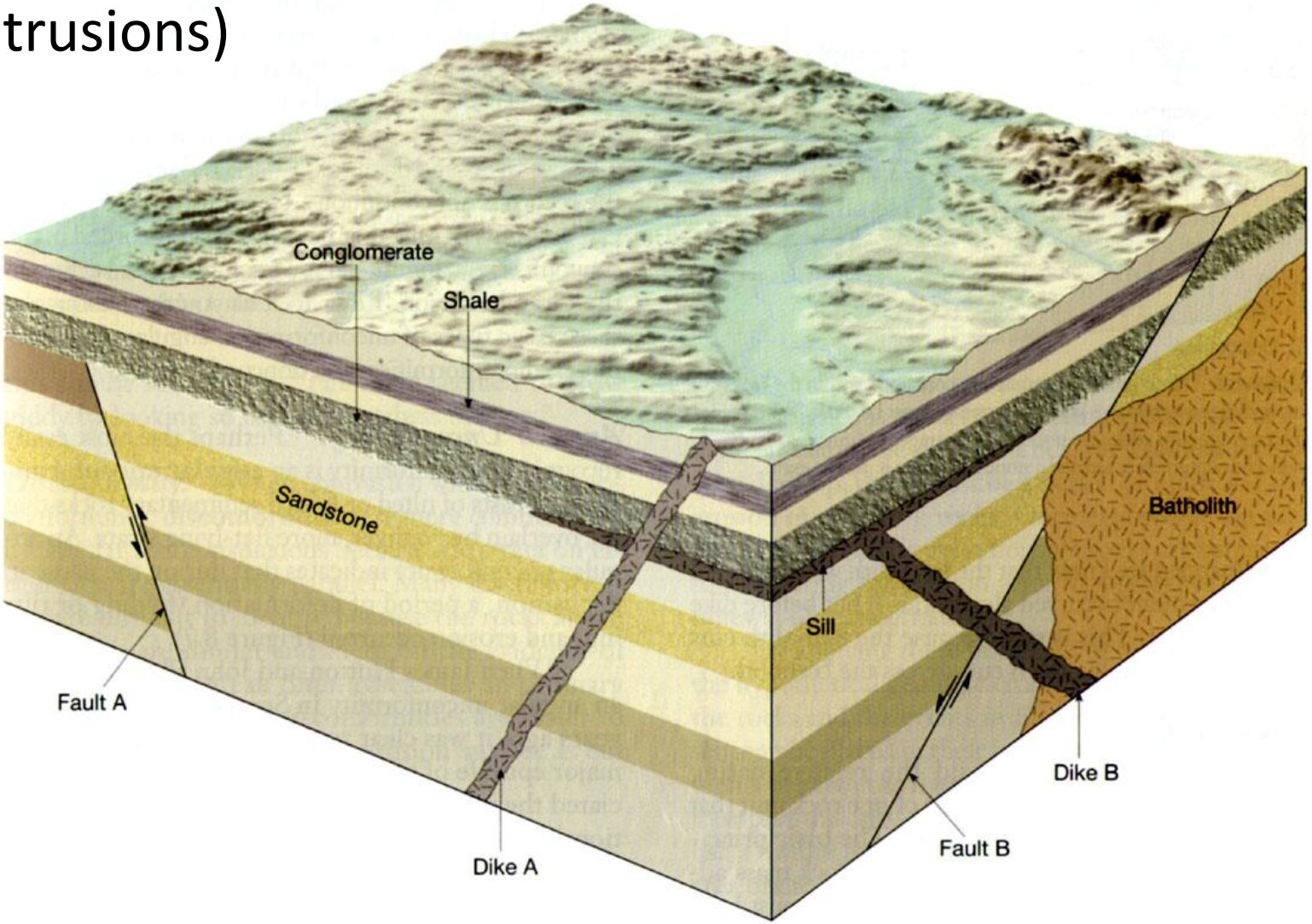
B.

Principle of cross-cutting relationships

Layers

Dykes (intrusions)

Faults



Fossils and correlation

- William Smith (1769-1839), the first professional geologist
- He invented the **Principle of faunal succession** (1796)

Chapter -2

Stratigraphic data Collection

- ✓**Source of data and Means of data collection**
- ✓**Completeness of stratigraphic data/ record**

STRATIGRAPHIC DATA

✓ **Stratigraphic Data**

Stratigraphic data may be obtained from two basic sources:

1.Surface outcrops **2.Subsurface data**

1.Surface outcrops

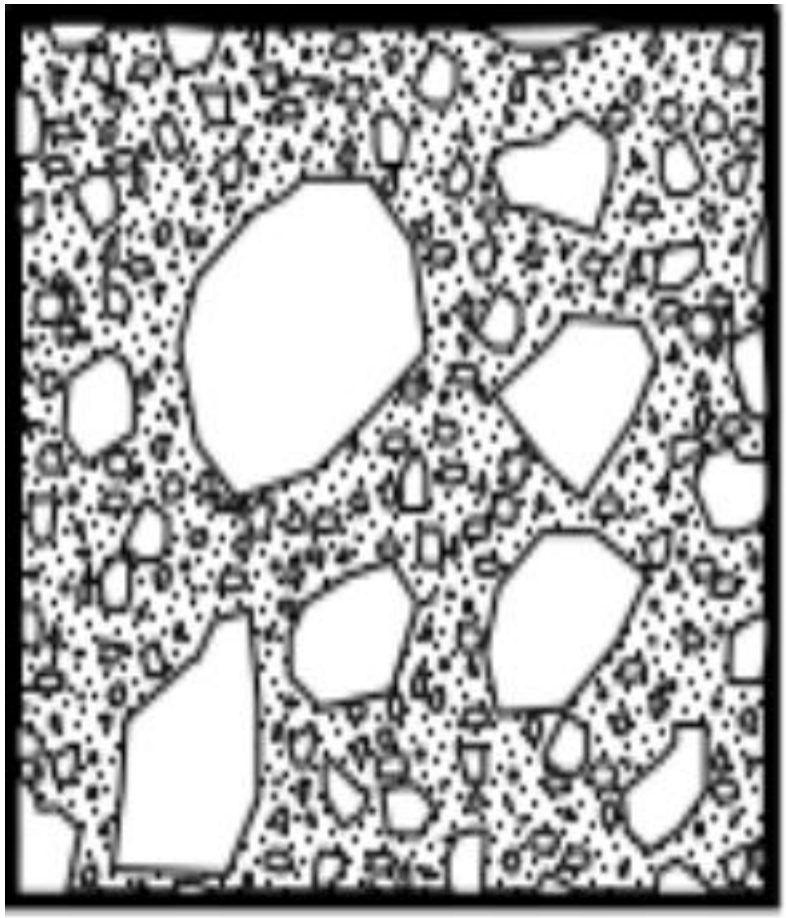
- Road side exposures
- Valley/stream side exposures
- Cliff exposures etc..

2.Subsurface data

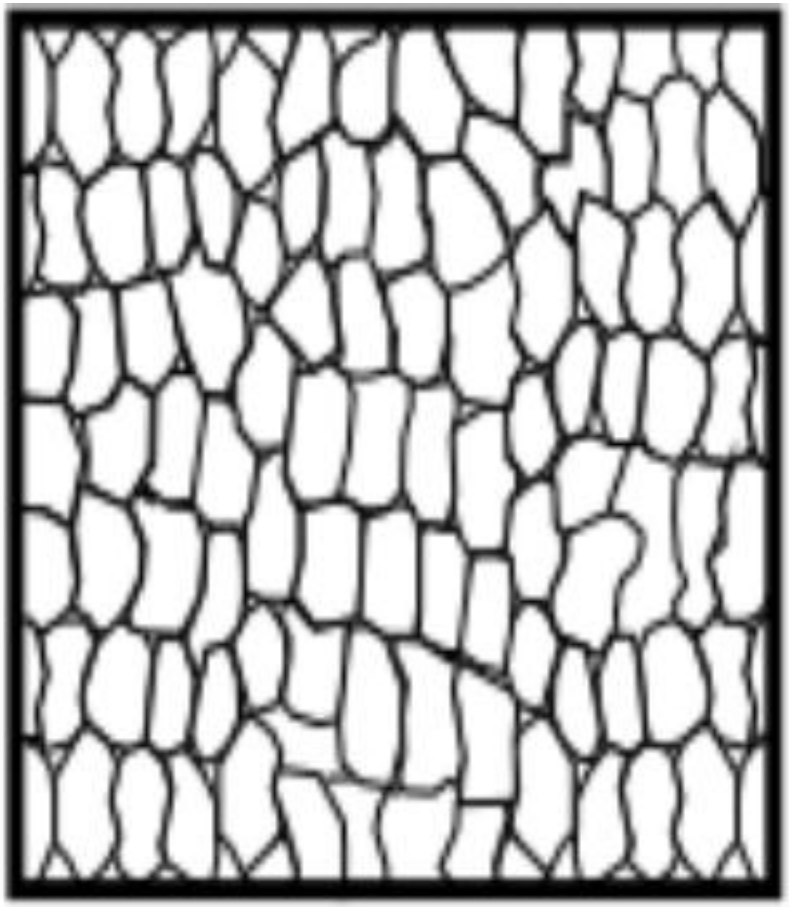
- core samples from drilling bore holes,
- well logs and
- seismic profile

- ✓ The main aspects of sedimentary rocks, which are likely to be recorded in the field are:
- ✓ **LITHOLOGY** - refers to the physical characteristics of rocks, i.e.
  - rock type,
  - color,
  - mineral composition

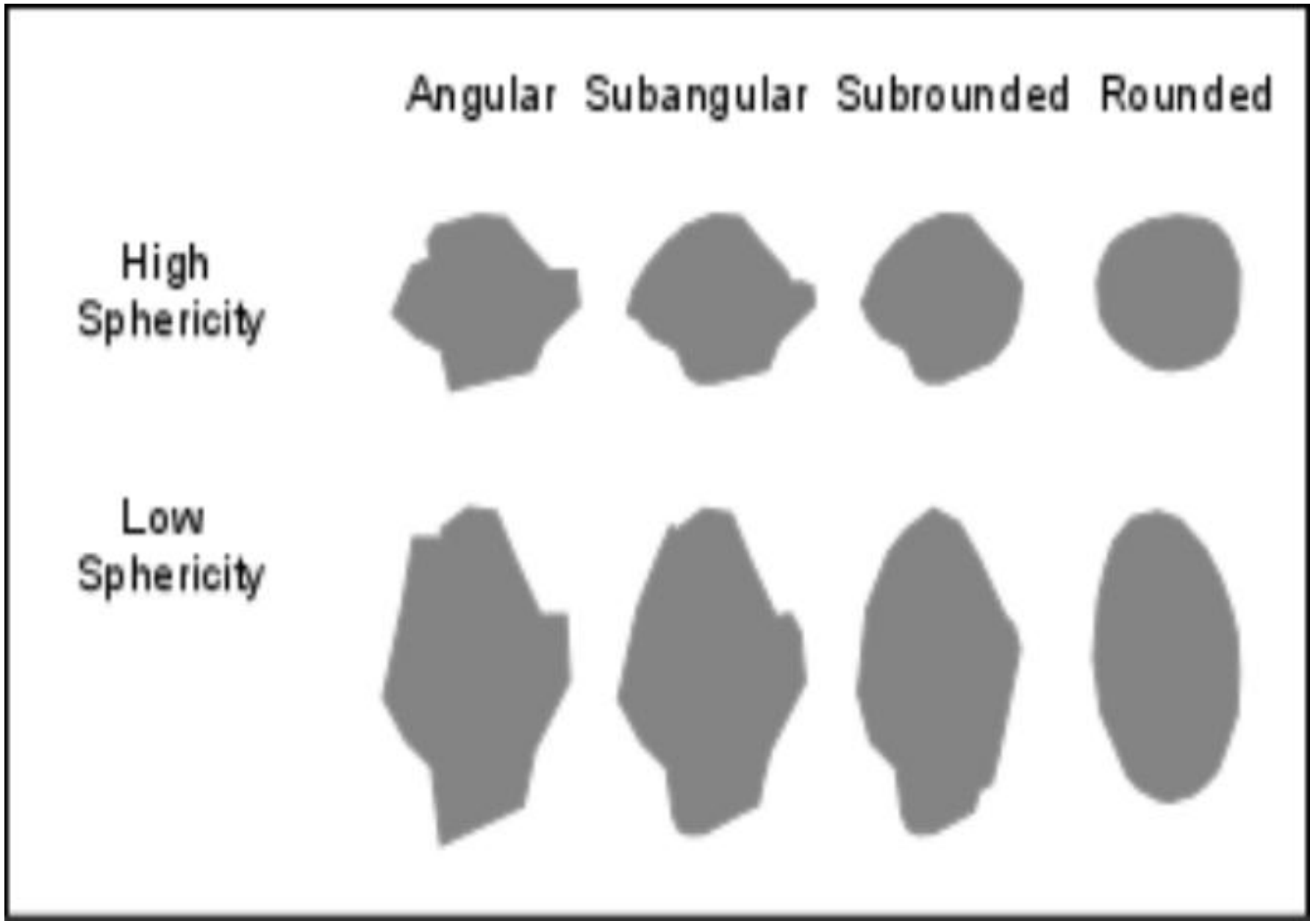
- ✓ **SEDIMENTARY TEXTURE**
  - grain size
  - grain shape (Sphericity)
  - sorting
  - roundness



Poorly Sorted Sediment



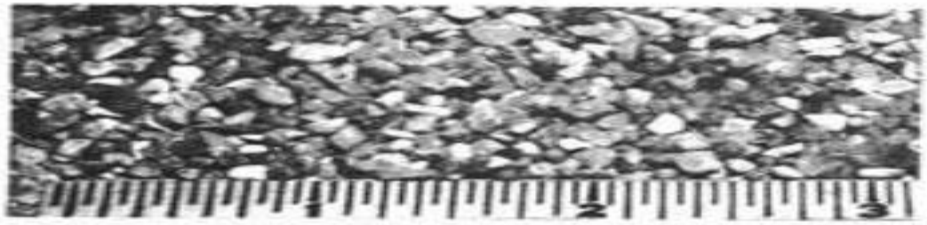
Well Sorted Sediment


Angular
Subangular
Subrounded
Rounded
High Sphericity
Low Sphericity

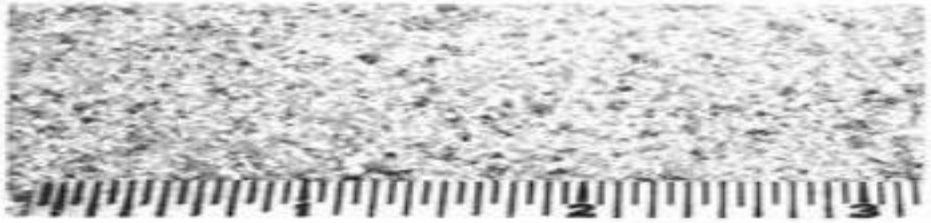
GRAIN SIZE PHOTOGRAPHS

19 mm — 3/4" — Fine GRAVEL

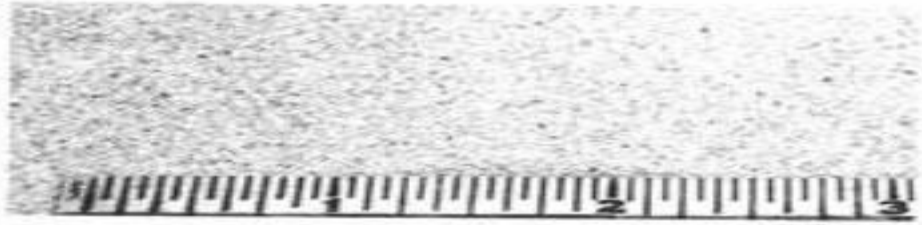
5 mm — 3/16" — No. 4 — Coarse SAND



2 mm — 3/32" — No. 10 — Medium SAND



0.42 mm — No. 40 — Fine SAND



0.074 mm — No. 200 — SILT & CLAY

SEDIMENTARY STRUCTURES

- ✓ Bed thickness, bed geometry, contacts between beds
- ✓ Internal structures of beds
- ✓ Structures on bedding surfaces
- ✓ Structures involving several beds
- ✓ Paleocurrent data (orientation of paleocurrent indicators, other structural information

Textures and Textures Analysis

- ✓ **Origin of the grains**
  - Clastic texture
  - Non- clastic texture

- ✓ **Size of the grain**
  - Fine grained :< 1/16mm diameter
  - Medium grained:1/16-2mm diameter
  - Coarse grained:>2mm in diameter
- ✓ **Sorting**
  - Unsorted
  - Well-sorted
- ✓ **Shape of the grains**
  - Rounded
  - Sub rounded
  - Angular
  - Sub angular

Clastic rock texture

What does texture mean?

Texture encompasses 3 fundamental properties.

- ✓Grain size
- ✓Grain shape
- ✓Fabric

➢ Sedimentary rock texture also affects:

- ✓ porosity,
- ✓ permeability,
- ✓ bulk-density,
- ✓ electrical conductivity and
- ✓ sound transmissibility.

  - **They are of particular interests to**
    - ✓ Petroleum Geologists,
    - ✓ Hydro geologists and
    - ✓ Geo-physists

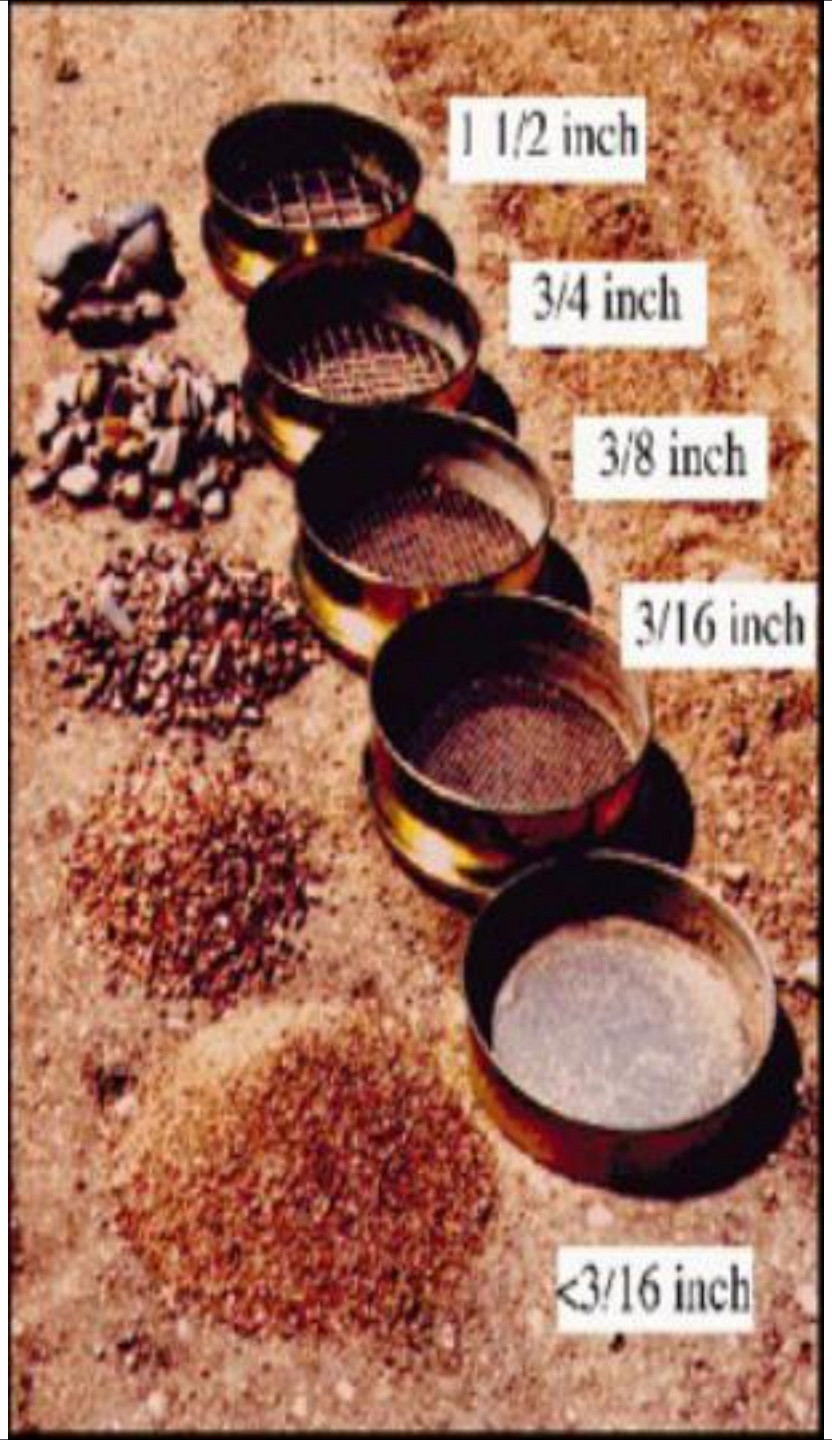
❖A.Grain size:

- ✓It is about properties of individual grains.
- ✓Range in size **< 1/256 mm to 2mm**
- ✓ particles range in size from clay to boulders.

✓Clay, silt, sand, gravel

- Grain size can be measured in different ways.

Type of sample	Sample grade	Method of analysis
Unconsolidated sediment and disaggregated sedimentary rock	Boulders Cobbles Pebbles	Manual measurement of individual clasts
	Granules Sand Silt	Sieving, settling-tube analysis, image analysis
	Clay	Pipette analysis, sedimentation balances, Sedigraph, laser diffractometry, electro-resistance size analysis (e.g. Coulter Counter)
Lithified sedimentary rock	Boulders Cobbles Pebbles	Manual measurement of individual clasts
	Granules Sand Silt	Thin-section measurement, image analysis
	Clay	Electron microscopy


1 1/2 inch
3/4 inch
3/8 inch
3/16 inch
<3/16 inch

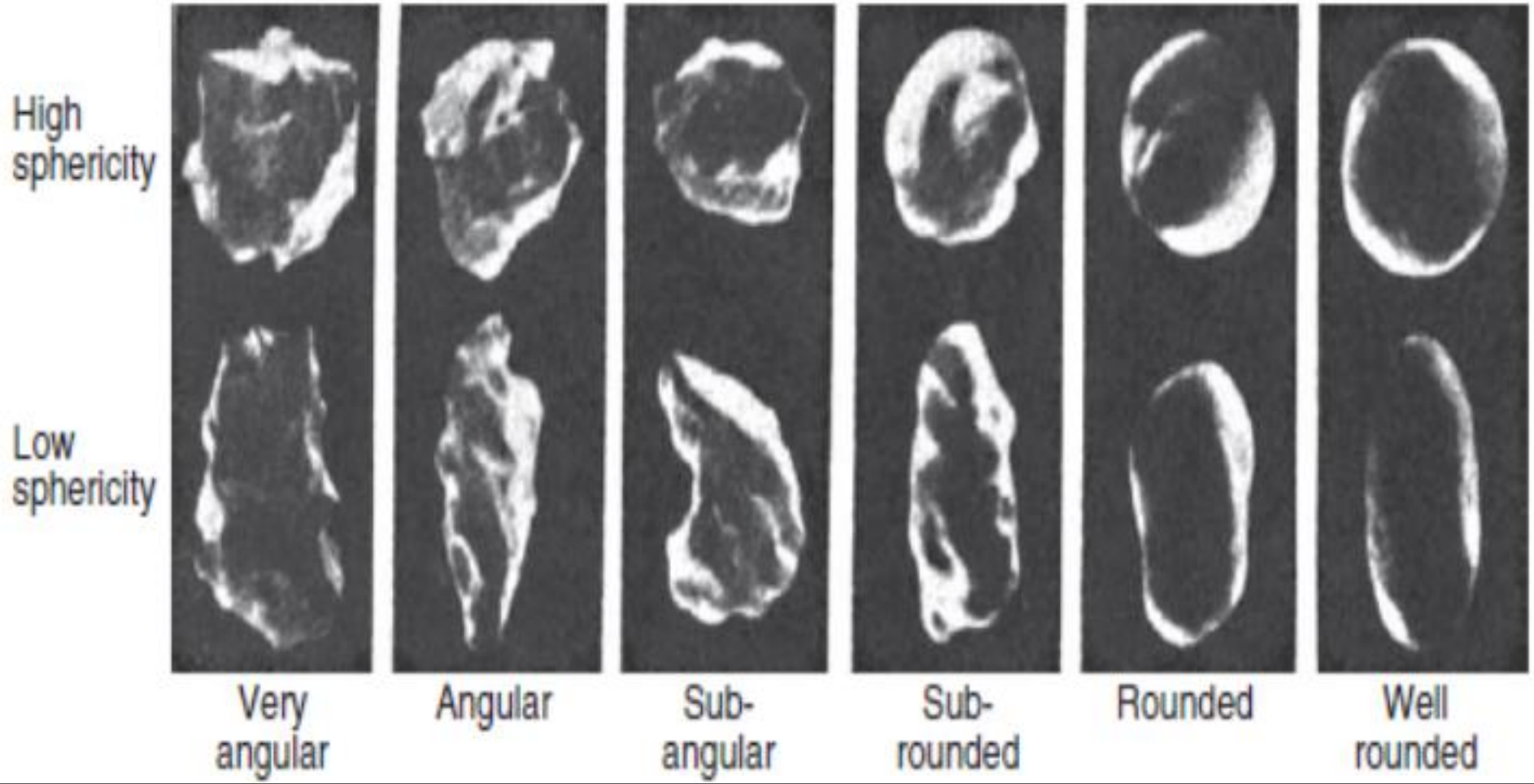
granular
flocculent
disperse

- **Grain-size data can be used:**

  - ✓ To interpret some aspect of earth's history
  - ✓ Evaluating economic significance
  - ✓ To understand the history of transportation and sediment source.

b.Grain shape

- Refers to all aspects of external **morphology** (form, roundness and surface texture)



- **Grain shape affects the transportability of particles.**

  e.g. Roller shaped

  blade shaped

  disc-shaped particles

Porosity

- Defined as the ratio of pore space in a sediment or sedimentary rock to the total volume of the rock.
- It is commonly expressed in percent as:

$$\textbf{Porosity (\%)} = V_p/V_b * 100$$

$$\textbf{Effective Porosity (\%)} = IV_p/V_b * 100$$

Permeability

Commonly defined as the ability of a medium to transmit water.

- **Darcy's law**. This equation is expressed as

$$Q = K\, h/l$$

Where

✓Q is discharce for unit area

✓K is permeability

✓h/l the hydraulic gradient.

PETROLOGY OF CLASTIC ROCKS

- Clastic sediments are named based on particle size.

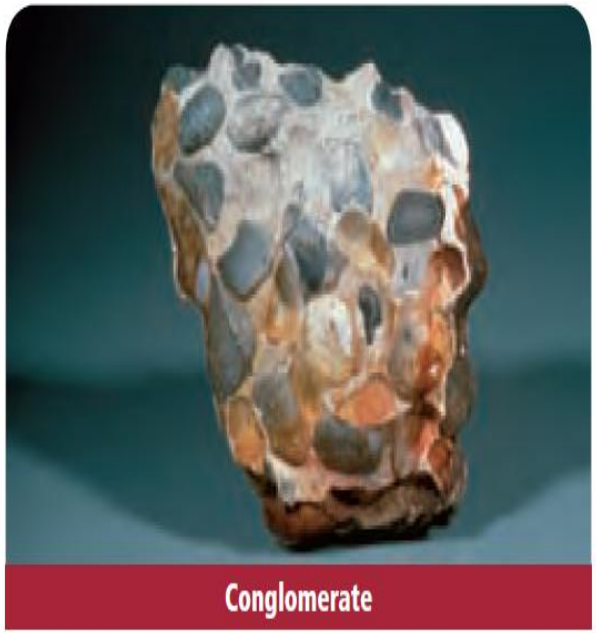
DIAMETER (mm)	SEDIMENT		CLASTIC SEDIMENTARY ROCK	
256–	Boulders	Gravel (rubble)	Conglomerate (rounded particles) or breccia (angular particles)	
64–	Cobbles			
2–	Pebbles			
	Sand		Sandstone	
1/16–				
	Silt	Mud	Siltstone	Mudstone
1/256–	Clay		Claystone or shale	

Clastic sedimentary rocks are mainly

- Sandstone
- Siltstone
- Shale
- Mudstone
- Conglomerate
- Breccia
- Kaolin

Conglomerate and Breccia

- ✓ **Conglomerates** are poorly-sorted composites of a wide range of rounded grain sizes ranging from **sand to cobbles (> 2mm).**
- ✓ **Breccia** is a poorly-sorted composite of a wide range of grain sizes ranging from **clays to gravels (> 2 mm).**
- ✓ coarse-grained clastic rocks



Sandstone

- ✓ Sand stone contain abundant Medium Course clastics.
- ✓ The word *sandstone* refers to any clastic sedimentary rock comprising primarily sand-sized grains.
- ✓ **Arkose 25% feldspar**
- ✓ The sand grains in arkose are commonly coarse and angular.

Clay stone

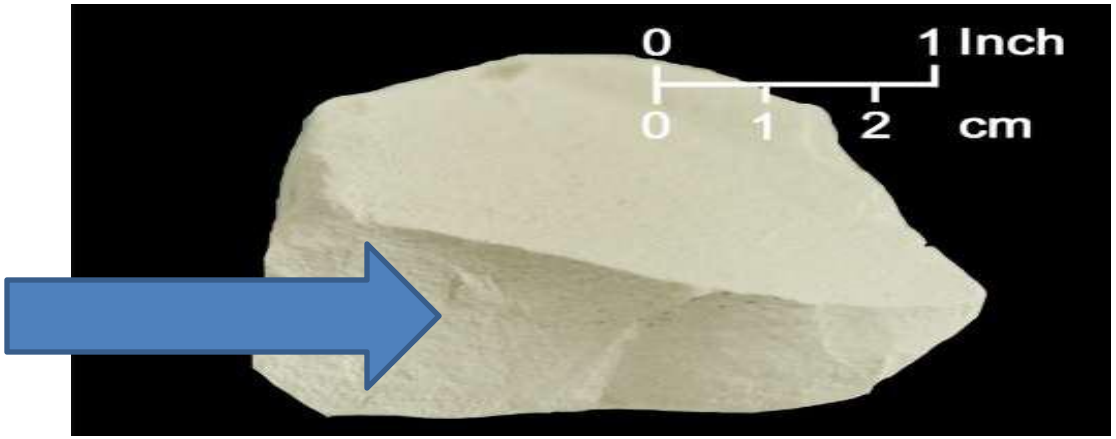
- fine grained clastic rocks
- composed predominantly of clay minerals and small amounts of quartz

Kaolin

- Kaolin consists of very fine-grained kaolinite.
- clay weathered from feldspar minerals in metamorphic and igneous rocks.
- Kaolin is generally very light colored to off-white.

.

kaolin



❖ **Shale**

fine grained clastic rocks

has a finely layered structure called **fissility**

the source of most oil and natural gas.

❖**Mudstone:Mudstone** consists of **very silt-sized** and **clay-sized grains** (<0.0625 mm) and are often well consolidated with little pore space.

✓non-fissile rock

✓composed of clay and silt

✓ In some mudstone and clay stone,

✓layering is absent

❖**Siltstone:**

- Silt stone and Shales
- contain Fine grained clastics.
- is lithified silt
- main component of most siltstones is quartz

Identifying Chemical, Biological Sedimentary Textures

Chemical, Biological Sediments have a variety of Textures that are also subdivided into 3 groups, they are

1. Crystalline Texture: Dominated minerals
2. Skeletal Texture: Interlock to from a dense rock.
3. Oolitic Texture: Found in limestone formation.

Classification of sedimentary textures

- **Two reasanable ways of classifying are**

(A) Physical sedimentary structure,

(B) Chemical sedimentary structure, and

(C) Biogenic sedimentary structures and

(1) Primary sedimentary structures, and

(2)Secondary sedimentary structures.

	Physical	Chemical	Biological
Primary	Stratification Sole marks	Stratification	Bioturbation (Tracks, Tails)
Secondary	Deformation intrusion desiccation	Nodules Concretation Deformation stylolites	Bioturbation (Burrows)

Sedimentary Structures (clastic rocks)

Sedimentary structures are the larger-scale features of sedimentary rocks.

Two types

1. physical (inorganic) structures These are sedimentary features formed by physical processes without the influence of organisms

Two types :-

- **primary structures** -are the most important. They are mechanical structures formed during deposition of the sediments.
  - ✓ **Graded bedding, lamination, ripple marks, stratification, tool marks etc.**
- **Secondary structures** – are structures formed after deposition during burial and diagenesis.

  e.g. concretion

2.Biogenic sedimentary structures

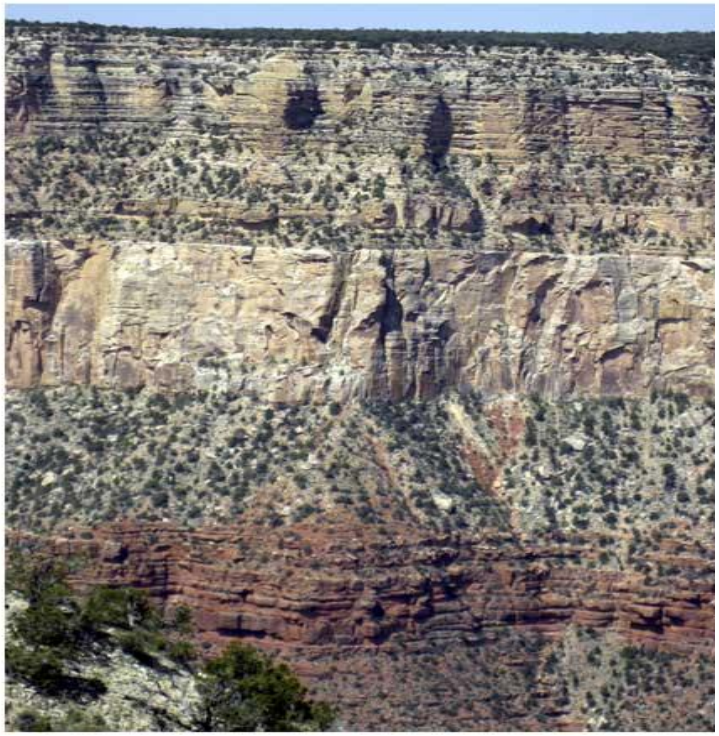
These are structures formed by organisms (trace fossils).

e.g. borings, burrows etc.

physical (inorganic) structures

Plane bedding

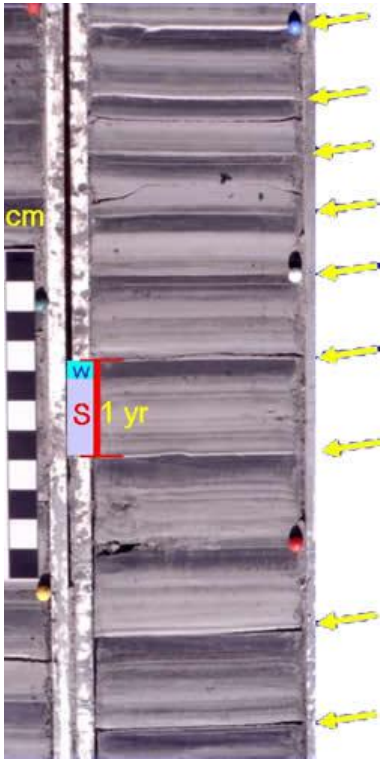
- Layering thicker than 1cm



laminations

- Finer scale layering (<1cm)

laminations



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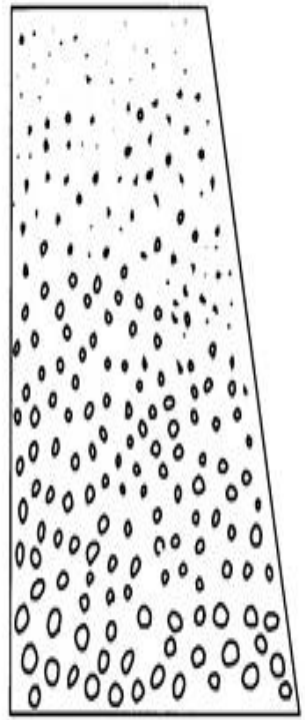
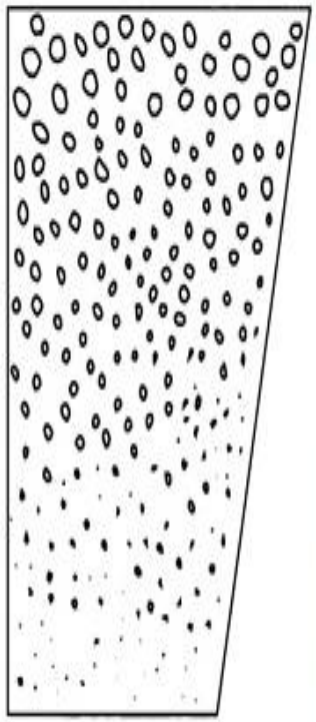
Graded bedding

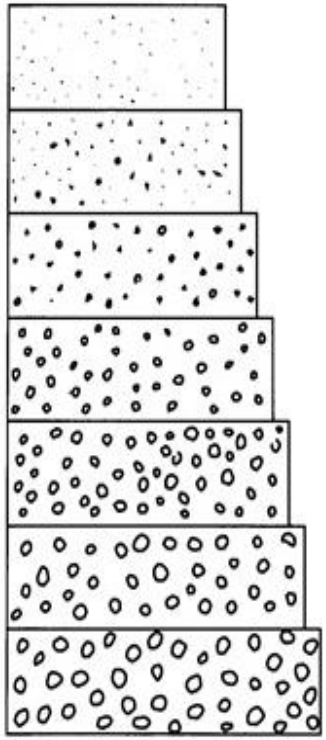
Graded beds are strata characterized by gradual but distinct vertical changes in grain size(particles are sorted according to density, size and shape.)



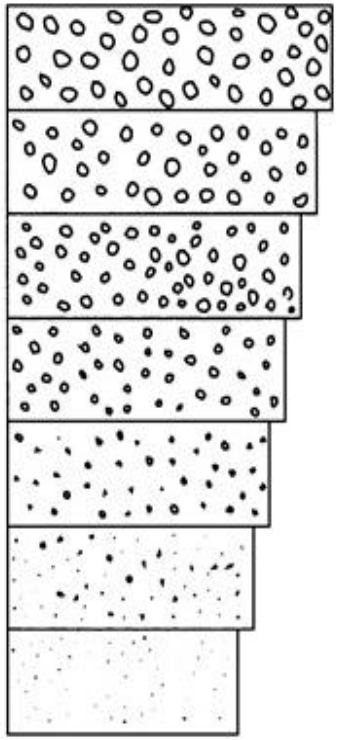
Normal grading in a bed



Reverse grading in a bed



Fining-up of a series of beds



Coarsening-up of a series of beds

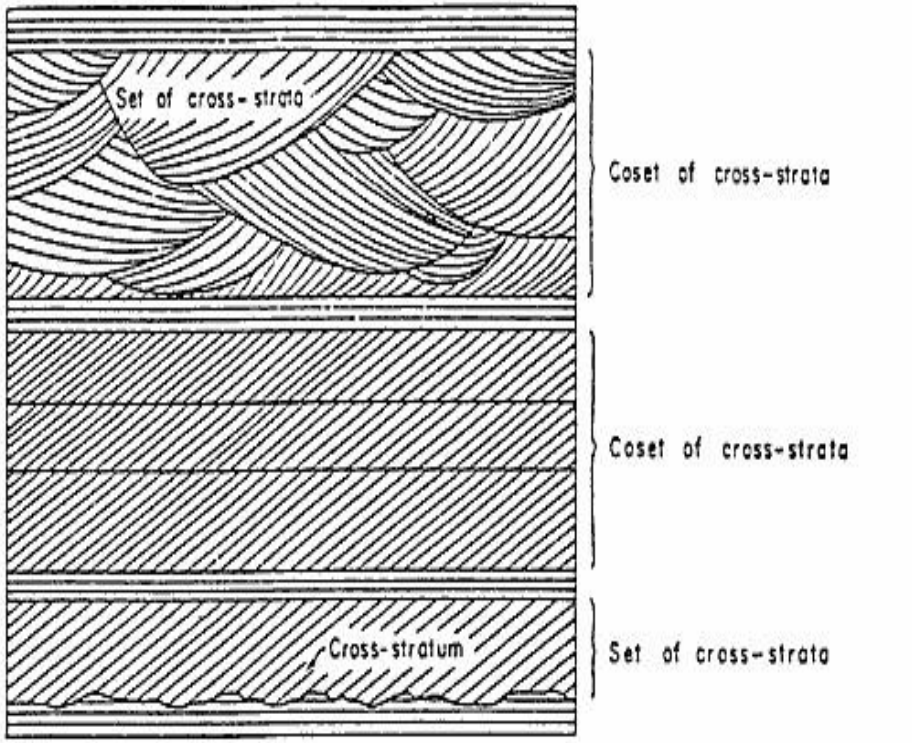
Bedforms generated by multidirectional flow

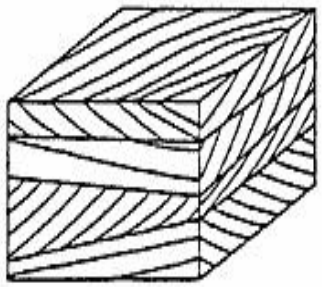
Cross bedding(stratification)

- Cross-beds are strata in which internal layers dip at distinct angle to the surfaces that bound the sets of cross-beds.

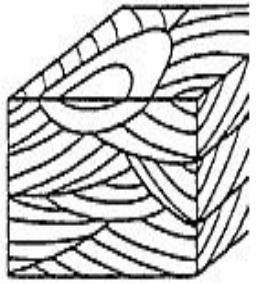
Two types

- **Planar cross bedding** – have bounding surfaces that are planar
- **Trough cross bedding** – having bounding surfaces that are curved





Planar
Cross-stratification



Trough
Cross-stratification

Mud cracks

- Structures form when the clay rich sediments found in muds dry and shrink
- As the sediment shrinks crack begin to form in the sediment creating polygonal patterns called mud cracks
- Indicate that the mud accumulated in shallow water that periodically dried up and form in semi arid areas

Concretion

- A hard, compact mass of matter formed by the precipitation of mineral cement with in the spaces between particles
- Are often ovoid or spherical in shape although, irregular shape also occur

Biological sedimentary structures

Tracks

- are impressions on the surface of a bed of sediment produced by the feet of animals.

Tracks

Trails

- Are groove like impressions on the surface of a bed produced by an organisms which crawls or drags their body parts through the sediment

Trails

Burrow marks

- any organism that borrows in to a soft sediment can disturb the sediment and destroy many of the structures
- Such burrow marks can be excellent top and bottom indicators

Burrow marks

Biological sedimentary structures

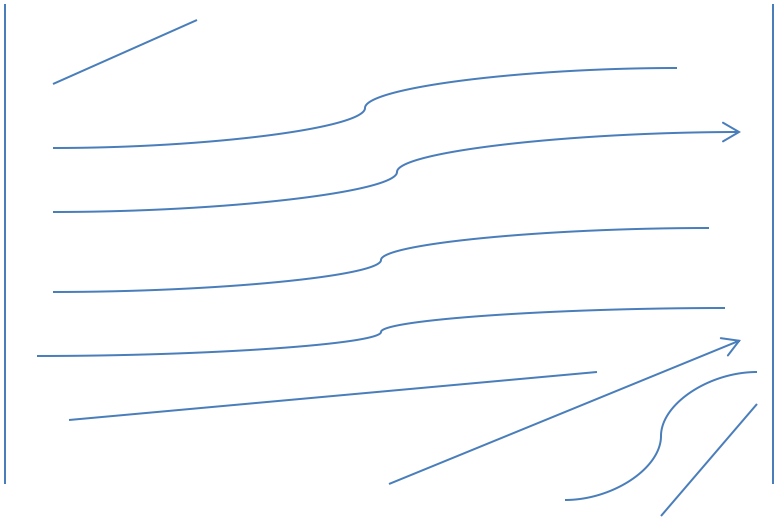
Borings

- are holes made by animals in to hard materials, such as wood, shells, rock or hard sediment and are usually circular in cross section.

Root marks

- are the traces left by the roots of plants in ancient soil zones(called paleosols)

- **Stratification** : Stratification is by far the most importants sedimentary structures. S rocks are stratified in one way or another.
- The term layering being more generally used for any arrangement of rocks.
- **Cross- Stratification:** Cross- stratification is stratification that is locally at some angle to the overall Stratification.
- **A common examples of a cross- stratification deposits.**

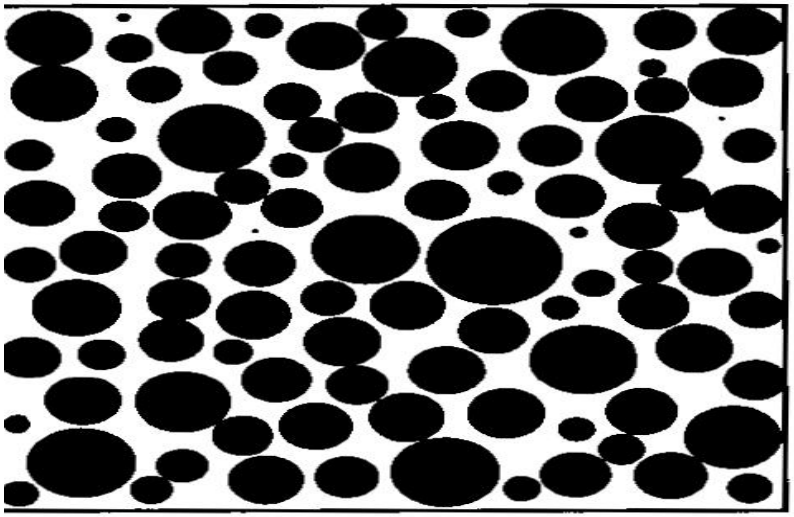


❖ Sorting

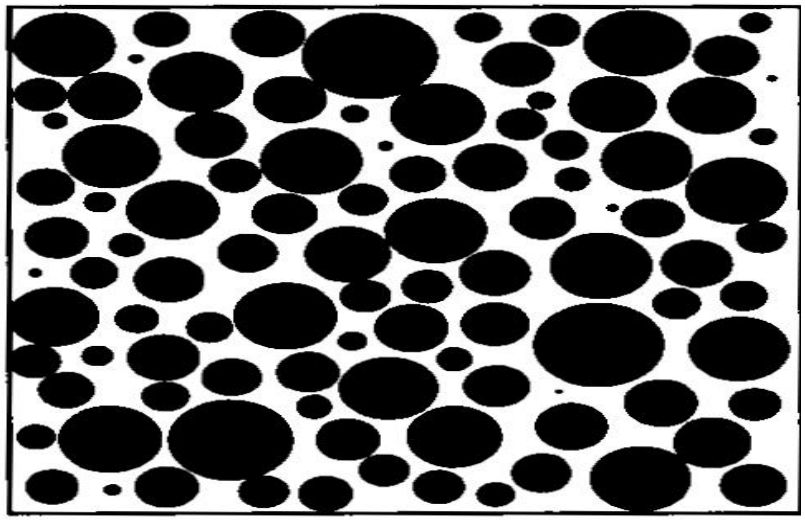
- ✓ Sorting can be estimated in the field or laboratory by use of a hand lens or microscope.
- ✓ More accurate determination of sorting requires mathematical treatment of grain-size data.
  - The mathematical expression of sorting is **standard deviation**.

❖**Fabric:** The fabric of sedimentary rocks is a function of grain orientation and packing.

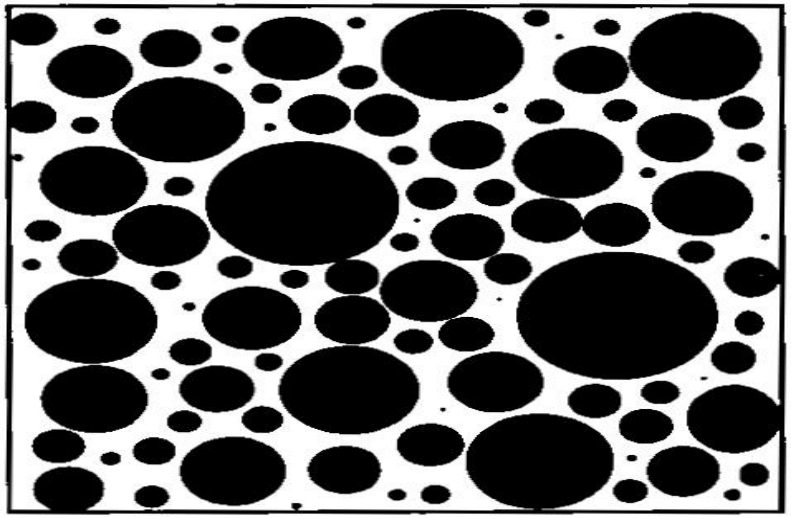
- ✓ It is thus a property of grain aggregates



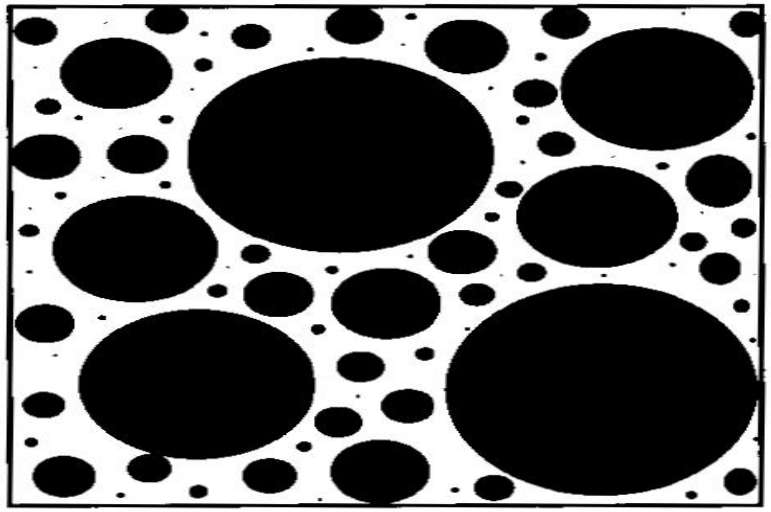
Well Sorted (0.35 phi)



Moderately Well Sorted (0.50 phi)



Poorly Sorted (1.00 phi)



Very Poorly Sorted (2.00 phi)

Visual images for estimating grainsize sorting.

This information is then enriched by data from ***the laboratory:***

- Sieve analysis
- Thin-section analysis
- Micropaleontological preparation & identification of samples
- SEM *(Scanning Electron Microscope)*
- Chemical Analysis
- XRD *(X-Ray Diffraction)*
- XRF *(X-Ray Flouroscence)*
- ICP – MS *(Inductively coupled plasma-mass spectrometer)*

Completeness of the Stratigraphic Record

- Similar to the record we have of life through fossils, the stratigraphic record is also incomplete!
- The incompleteness of the stratigraphic record is mainly because of: erosion

- But our lack of information of geologic history of stratified sequences can also be a result of :
- non-depositionor even
- non-exposure

Chapter -3

❖ The Geologic Time Scale

- ✓ History and development of the geologic time scale
- ✓ Division of the geologic time scale

History and development of the geologic time scale

- The time span of Earth's History is about 3000my.
- It is roughly represented by the column of S rocks

The geologic time scale subdivided into smaller units. On this basis a standard Geological time scale(Table 1)has been prepared which is used universally for the correlation of rock formations.

Age M Y	Era	Period	Epoch
	CENOZOIC	Quaternary	Recent
2 –			Pleistocene
12 –		Tertiary	Pliocene
26 –			Miocene
37 –			Oligocene
53 –			Eocene
65 –			Paleocene
136 –	MESOZOIC	Cretaceous	
190 –		Jurassic	
230 –		Triassic	
280 –	PALAEOZOIC	Permian	
345–		Carboniferous	
395 –		Devonian	
430 –		Silurian	
500 –		Ordovician	
570 –		Cambrian	

❖**Eras:** The major units of the Geological time are called “Eras". in the Geological Time Scale

There are Four Eras:

(1)Precambrian

(2)Palaeozoic

(3)Mesozoic

(4)Cenozoic

❖**Periods:** Each era has been subdivided into smaller time units are called “Periods”.

The stratigraphic breaks which subdivide eras are relatively of lesser significance.

✓for examples, in the Palaeozoic era, there are **six periods.**

(i)Cambrian

(ii)Ordovician

(iii)Silurian

(iv)Devonian

(v)Carboniferous

(vi)Permian.

- ✓ A succession of rocks deposited during a period constitutes a “System”.

❖**Epochs:** The periods are further divided into smaller parts called “Epochs”.

✓ The rock units corresponding to epocha are called **“Series”.**

✓ For examples, in the **Triassic period**, there are Three epochs:

- Lower Triassic
- Middle Traissic
- Upper Traissic

❖**Stage:** A part of the series is called “Stage”.

✓ it is characterized by a typical assemblage of Fossils.

❖**Zone**: The basic unit of a stage is called “Zone”

✓ It is recognized mainly on the basis of the most characteristics Fossil form.

✓ On the basis of Paleontology, The precambrian era has been divided into two groups:

(i)Archaeozoic

(ii)Proterozoic

Geologic Time Scale

Eras	Periods	Life
Quaternary	Recent Pleistocene	Man, Modern plants, and Animals. Many mammals die.
Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	Mammals, Birds, Mollusk and Flowering Plants.
Mesozoic	Cretaceous Jurassic Triassic	Dinosaurs, Flowering plants. Ammonites, Dinosaurs Ammonites, Reptiles, Amphibians
Paleozoic	Permian Carboniferous Devonian Silurian Ordovician Cambrian	Reptiles, Nonflowering plants Amphibians, Nonflowering plants Corals,Brachiopods,Early land plants Freshwater fishes, Graptolites Trilobites, Graptolites Trilobites,
Precambrian	Proterozoic Archaeozoic	Soft bodied animals and plants Lifeless

Naming of Eras, Periods and Systems

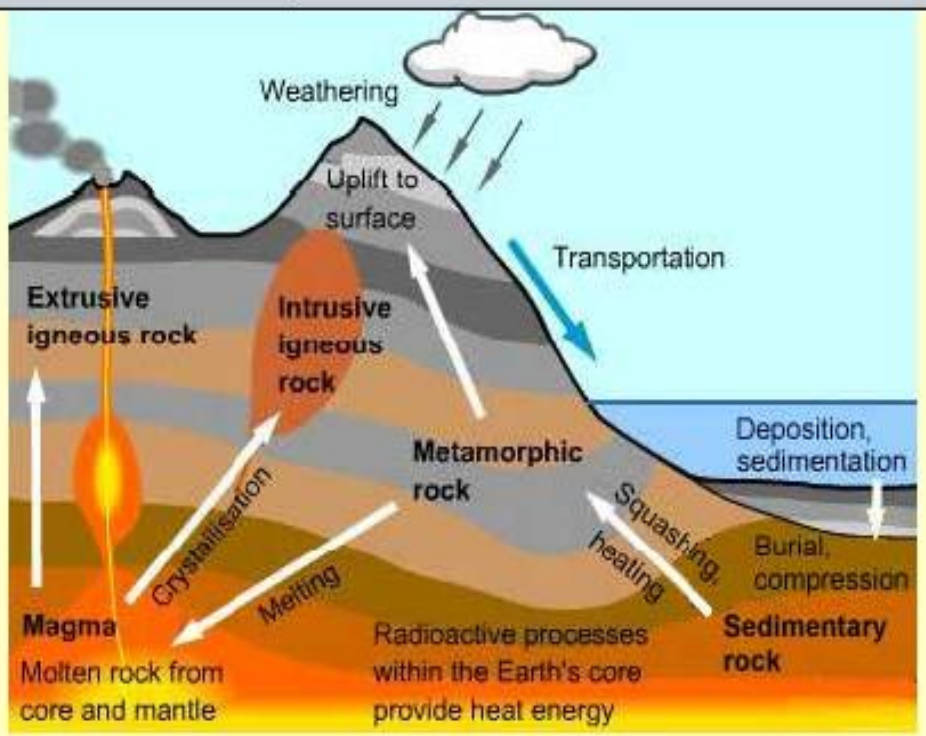
- ✓ Paleozoic era – Adam Sedgwick (1839)
- ✓ Mesozoic era – John Phillips (1840)
- ✓ Cenozoic (Kainozoic) – John Phillips (1840).
- ✓ These names and usage of fossils as time interval measure **pre-dated** Darwin's *Origin of Species* (1859).

Chapter -4

❖ Depositional environments and Facies

- ✓ Concept of Facies
- ✓ Continental, Transitional and Marine Environment

- **Definition of D E**: D E is part of Earth surface that has certain Chemical, Biology, and Physical characteries, They are 3 kinds of Environments, They are **1.Continental Environmental 2.Marginal Marine Environment 3.Marine Environments.**
- S rocks are formed by 5 processes, there are **Erosion, Weathering, Transport, and Deposition, Diagenesis**.
- It is introduced by (Boggs in 1991)
- These 5 processes with 3 types of rocks make up a cycle that is known as **Sedimentary Cycle**.



The rock cycle

1. Existing mountain ranges are worn down by **weathering** and **erosion**, and the pieces of eroded rock may eventually be deposited and form **sedimentary** rocks.

2. Sedimentary rocks may become buried and compressed, or alternatively uplifted by large scale movements of the Earth's crust. If they are subjected to heat and pressure, they may be transformed into **metamorphic** rocks.

3. The metamorphic rocks may continue to be uplifted to form mountain ranges. Alternatively, they may sink deeper into the hot **mantle**, and melt to form **magma**.

4. Molten magma is pushed up towards the crust by pressure and convection, eventually cooling and solidifying to form **igneous** rock. If the magma is extruded from the crust by volcanic activity it will form **extrusive igneous rock** on the surface. If it cools below the surface it will crystallize into **intrusive igneous rock**.

5. Rocks of any type may eventually reach the surface as a result of mantle or crust movements, and themselves become subject to weathering and erosion - thus beginning the cycle again.

❖ The properties of S rocks such as **Sediment Textures and Structures** are formed by **Chemical, Physical, and Biological Processes.**

1. **Continental Environments:** Deposited on Land or in Fresh Water.

✓ There are 4 Major kinds of Terrestrial Environments. They are **Fluvial, Desert, Lacustrine, and Glacial.**

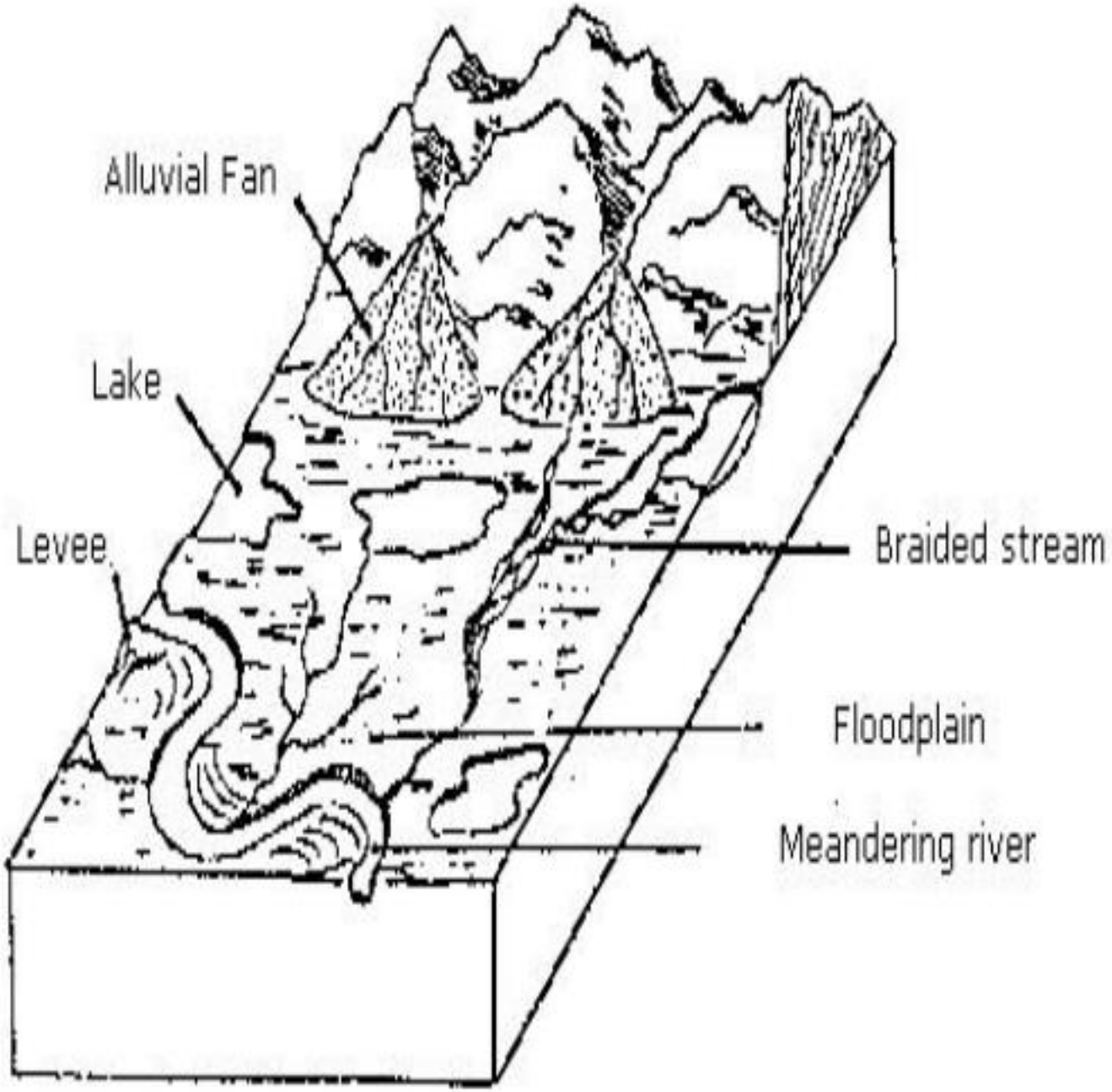
(a)Fluvial E: F E is close-connected to the activity of river.

(b) Desert E: D E is close-connected to the role of Wind.

(c) Lacustrine E: From lake.

(d) Glacial E: From ice.

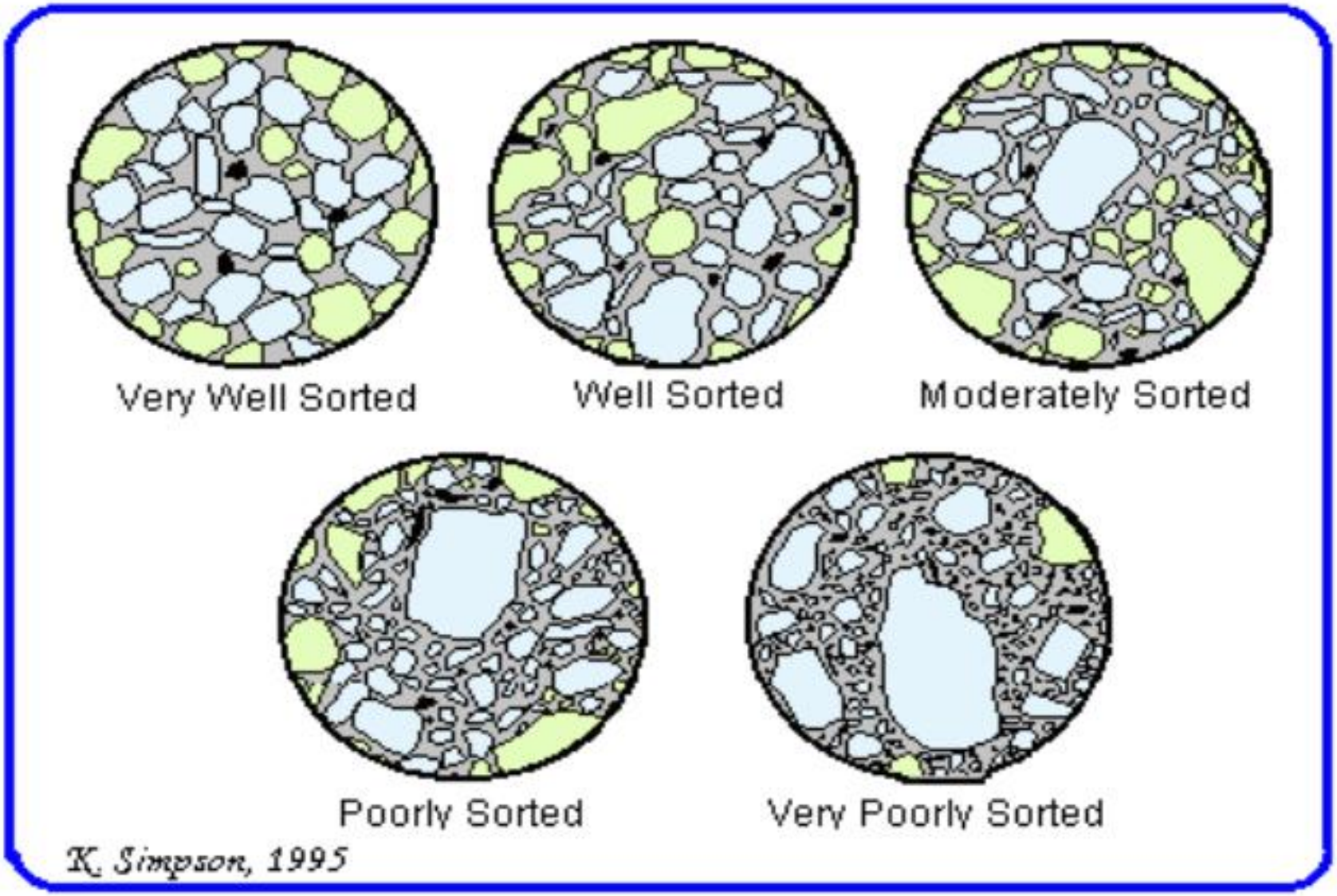
Continental Sedimentary Environments

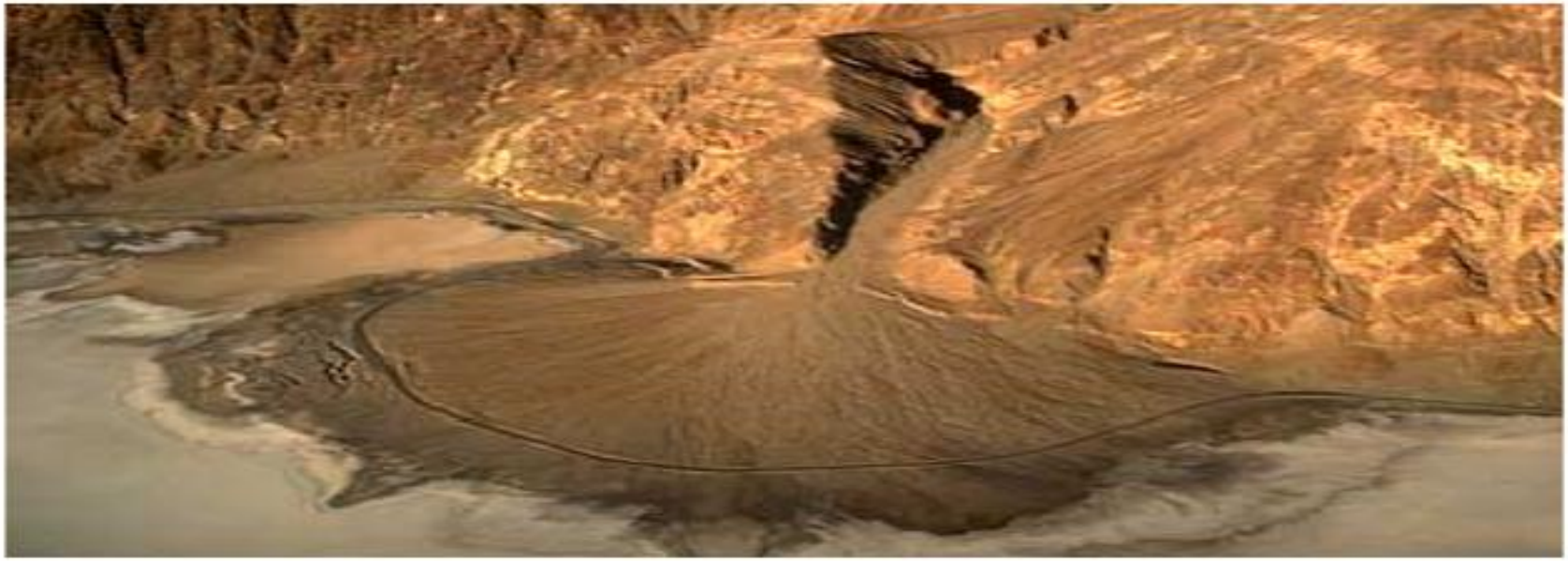


Alluvial Fans

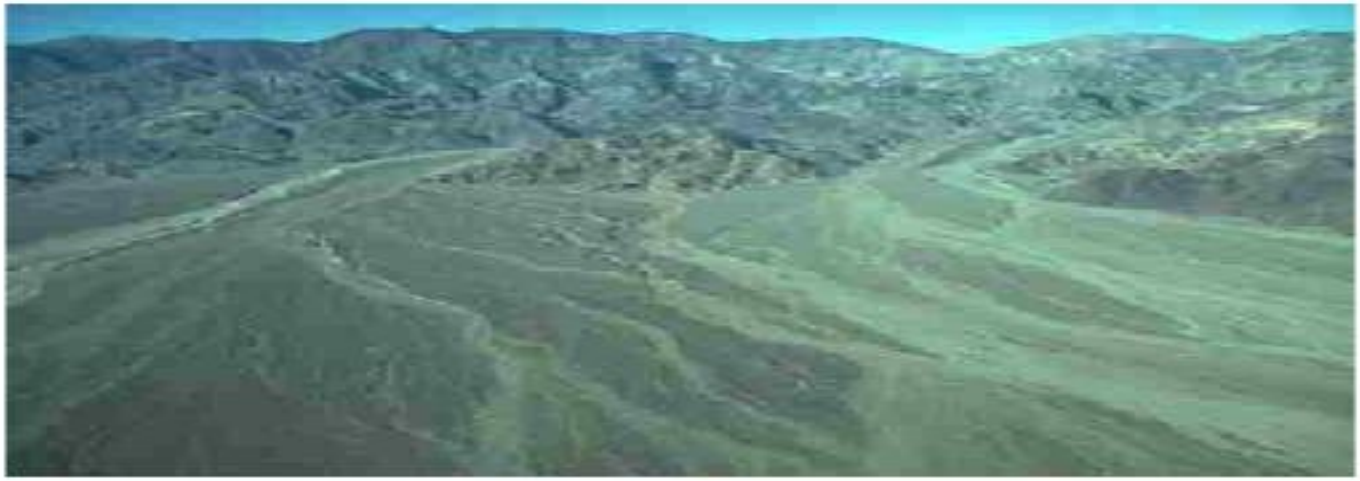
- Alluvial fans are **sedimentary deposits** that typically form at the margins of a dry basin.
- **They typically contain coarse**
  - ✓ boulders and gravels and are poorly sorted.
  - ✓ Fine-grained sand and silt may be deposited near the margin of the fan in the valley, commonly in shallow lakes.

Grain Size Distribution





Alluvial fans are fan-shaped deposits of water-transported material break in slope. Consequently, alluvial fans tend to be coarse-graine



Here's another alluvial fan. It's actually two fans that have grown tog coarsest sediment.

Phi Units*	Size	Wentworth Size Class	Sediment/Rock Name
-8	256 mm	Boulders	Sediment: GRAVEL Rock RUDITES: (conglomerates, breccias)
-6	64 mm	Cobbles	
-2	4 mm	Pebbles	
-1	2 mm	Granules	
0	1 mm	Very Coarse Sand	Sediment: SAND Rocks: SANDSTONES (arenites, wackes)
1	1/2 mm	Coarse Sand	
2	1/4 mm	Medium Sand	
3	1/8 mm	Fine Sand	
4	1/16 mm	Very Fine Sand	
8	1/256 mm	Silt	Sediment: MUD Rocks: LUTITES (mudrocks)
		Clay	

* Udden-Wentworth Scale

Transitional Environment : Deposited is an Environment showing Influence of both **Fresh Water or Air and Marine Water.**

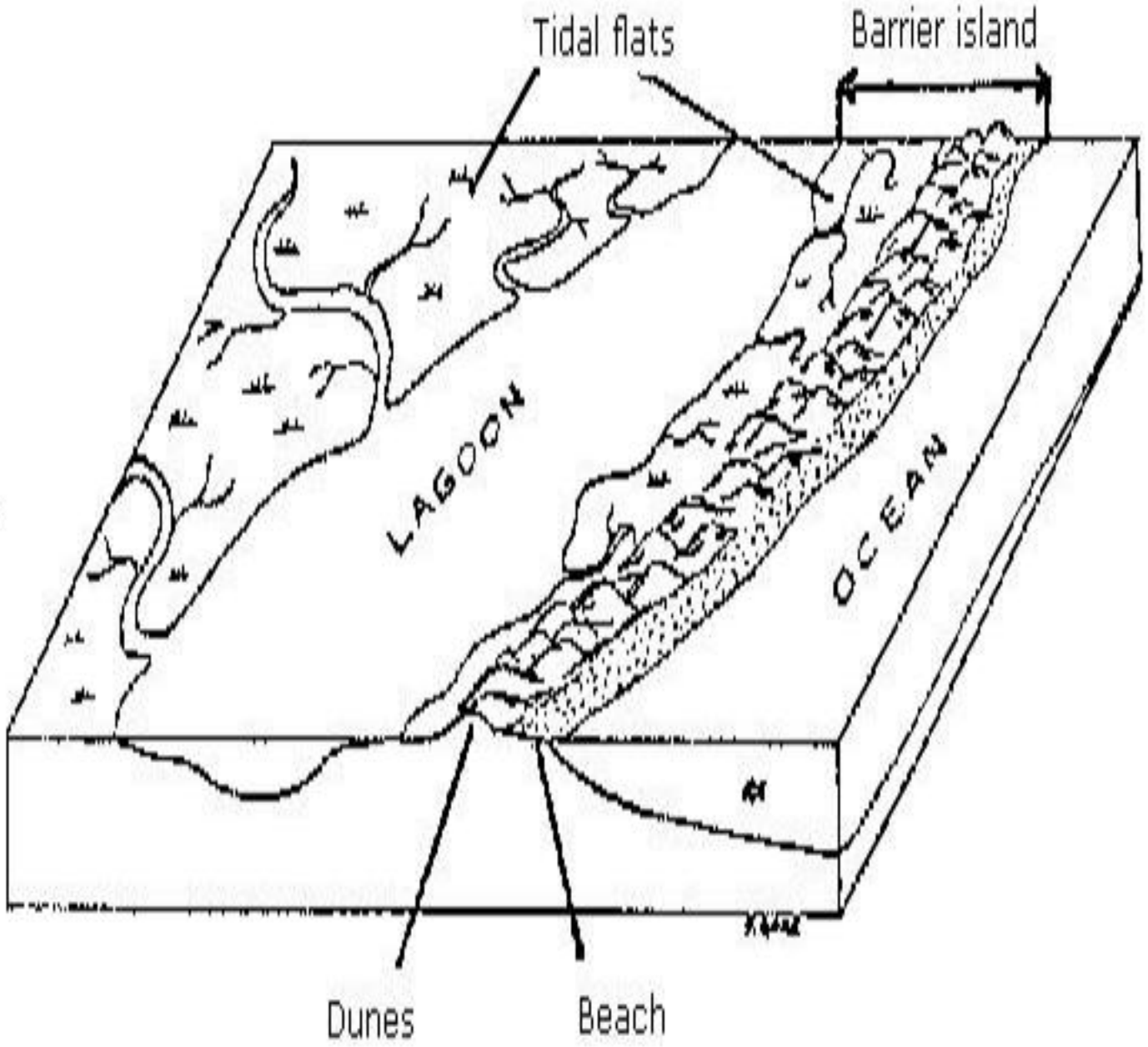
Ex: **Deltaic :** Deposit as mouths of the Large River.

Easturine: Deposit in Sea level.

Logoonal: Deposit in the Water

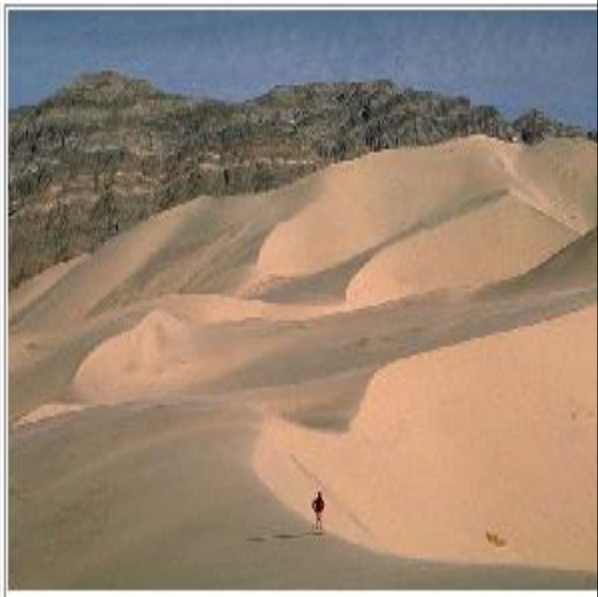
Beach: Deposit in Shallowest marine Water

Transitional environments

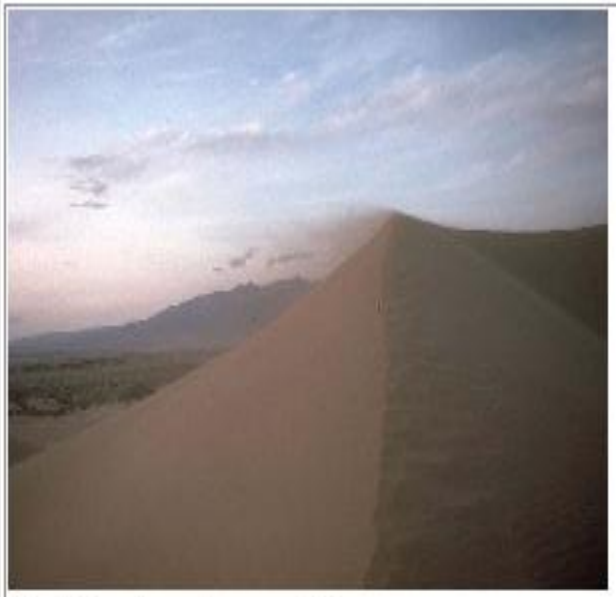


Dunes and Ripples; Mesquite Flat, Death Valley, CA

Dunes and Ripples, Mesquite Flat, Death Valley, CA.

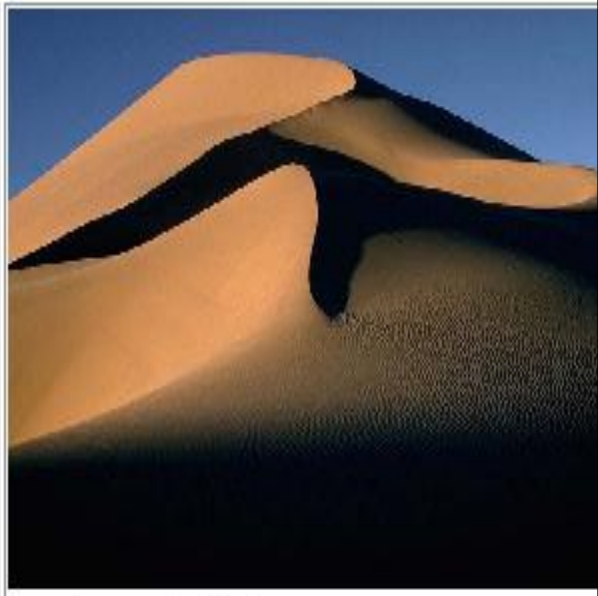


Eureka Sand Dunes, California



Sand blowing off crest of dune.

Great Sand Dunes National Monument, Colorado



Ibex Dunes, California

Shoreline

- ***Lagoons*** are bodies of water on the landward side of barrier islands.
- They are protected from the pounding of the ocean waves by the barrier islands, and
- contain finer sediment than the beaches (usually **silt and mud).**.
- ***Tidal flats*** border lagoons. They are periodically flooded and drained by tides.
- Tidal flats are areas of low relief, cut by meandering tidal channels. Laminated or rippled **clay, silt, and fine sand**

Gravel Beach, SW Alaska

Sandy Beach and incoming waves, central California

Oblique incoming waves to cause longshore drift, OR

Rivers

- ✓ **River channels, bars, levees, and floodplains** are parts (or subenvironments) of the fluvial environment.
- ✓ River Channel deposits consist of **coarse, rounded gravel, and sand**.
- ✓ Bars are made of **sand or gravel.**
- ✓ Levees are made of **fine sand or silt.**
- ✓ Floodplains are covered by **silt and clay.**

Lakes

- ✓**Lacustrine environments (or) lakes:** they may be
- ✓**large or small,**
- ✓**shallow or deep, and**
- ✓**filled with terrigenous, carbonate, or evaporitic sediments.**

Lake Eliza, S. Australia

Ephemeral pond near the Great Salt Lake, Utah. Note shoreline terraces of the Great Salt Lake on mountains at left (light colored horizontal line).

2. Marginal marine Environment: The M M E is located around the boundary between the continental and the marine depositional realms.

- ✓ The marginal marine is dominated by **waves, rivers, and Tidal processes.**
- ✓ **The depositional setting in M M sediment are**
- ✓ Deltas,
- ✓ Beach,
- ✓ Barries island esturine
- ✓ Lagoonal and
- ✓ Tidal Flats.
- ✓ **Deltas** are large accumulations of sediment that are deposited where a **river empties into a standing body of water.**

Delta building into lake. SE Alaska.

Delta and alpine lake. Banff National Park, Alberta

3.Marine Environment: Only influenced by **Sea Water**.

Ex:Shallow marine clastic: Near the mouths of rivers.

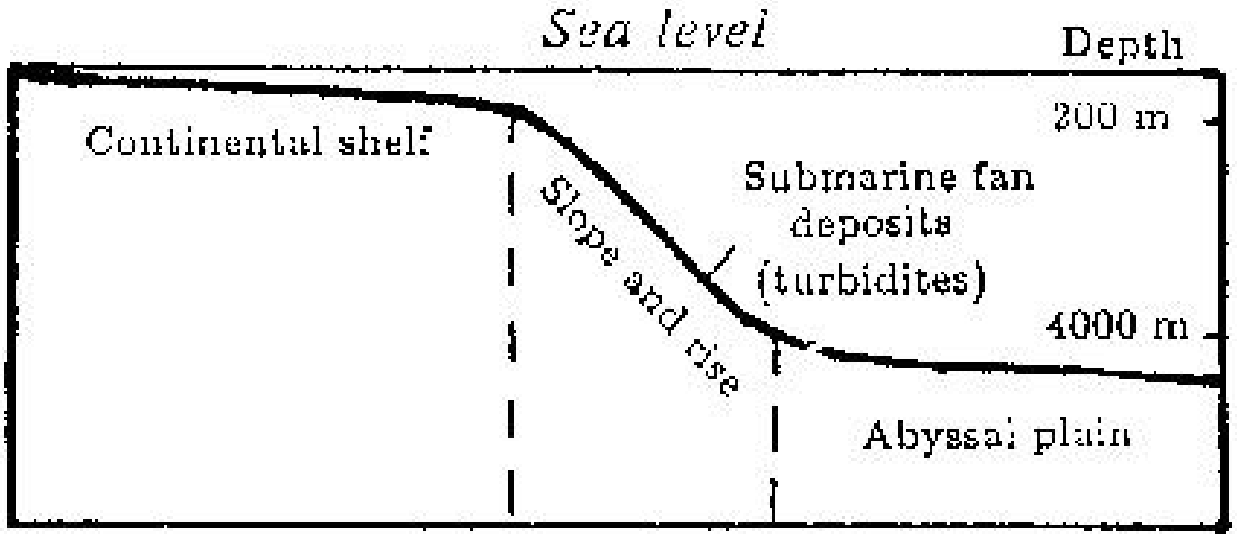
- **Carbonate Shelf:** clear water.
- **Continental Slope:** Dominated by the deposition of submarine Landslides.
- **Deep marine:** Very thin Sediments.
- **Fluvial system:** Stream- related processes are called "**Fluvial**"

(From the Latin word **Fluvial= River**)

- **Alluvial system:** Fluvial deposits also known as "**Alluvial Deposits**"

MARINE

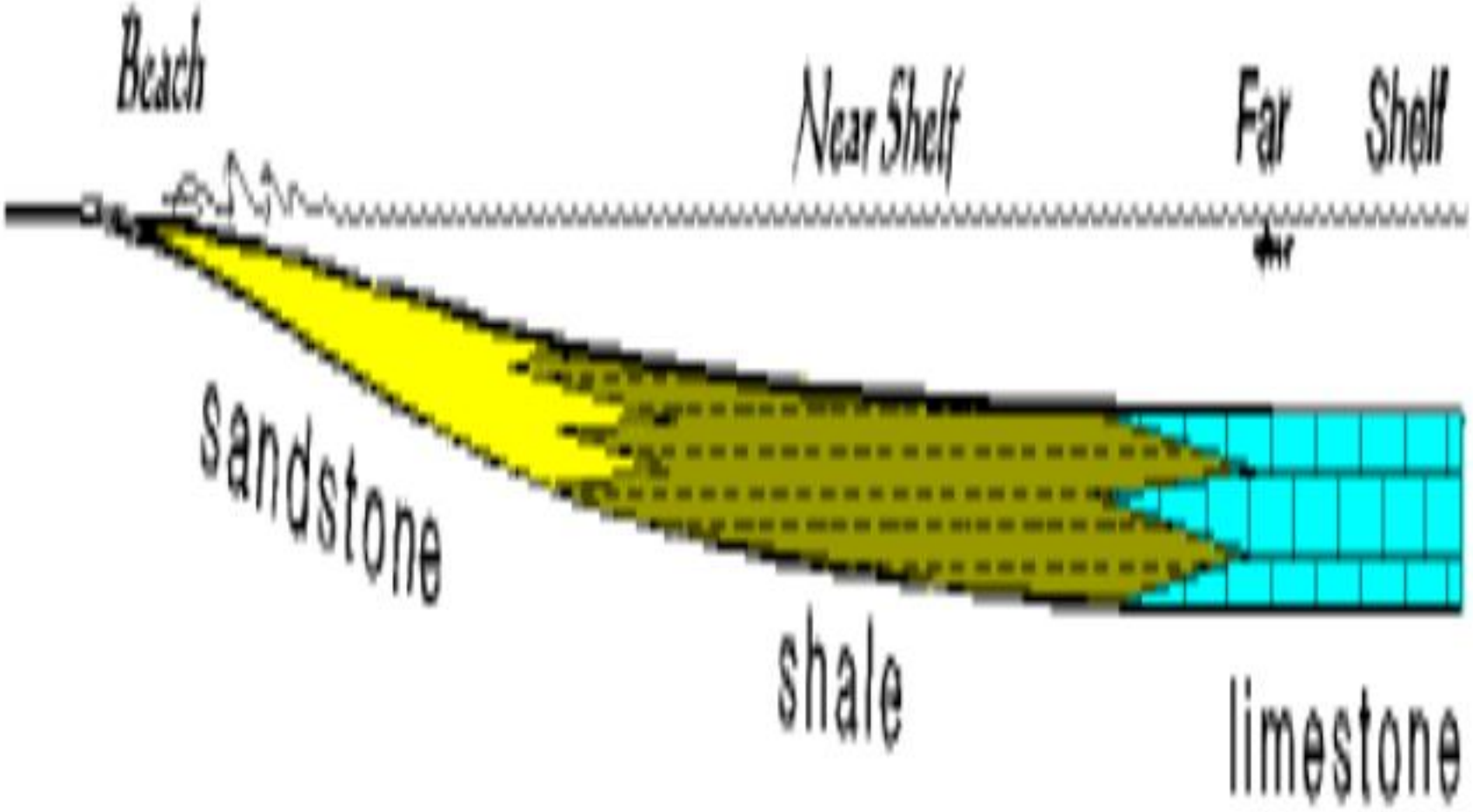
ENVIRONMENTS



- ✓ The ***continental shelf*** is the flooded edge of the continent.
- ✓ The ***continental slope and continental rise*** are located seaward of the continental shelf.
- ✓ The ***abyssal plain*** is the deep ocean floor.

Shallow Marine

- ✓ Shallow seas are widespread along continental margins.
- ✓ Sediments deposited in these **shallow marine waters** from extensive layers of **well-sorted**
- ✓ **sand,**
- ✓ **shale,**
- ✓ **limestone, and**
- ✓ **dolomite**


Beach
Near Shelf
Far Shelf
sandstone
shale
limestone

Spit at Mission Bay, San Diego

	ALLUVIAL FAN	FLUVIAL	LACUSTRINE	DESERT (DUNES)	PALUDAL
Rock Type	Breccia, conglomerate, arkose	Conglomerate, sandstone, siltstone, shale	Siltstone, shale, limestone, or evaporites (gypsum)	Quartz arenite (sandstone) or gypsum	Peat, coal, black shale, siltstone
Composition	Terrigenous	Terrigenous	Terrigenous, carbonate, or evaporite	Terrigenous or evaporite	Terrigenous
Color	Brown or red	Brown or red	Black, brown, gray, green	Yellow, red, tan, white	Black, gray, or brown
Grain Size	Clay to gravel	Clay to gravel (Fining upward)	Clay to silt or sand (Coarsening upward)	Sand	Clay to silt
Grain Shape	Angular	Rounded to angular	---	Rounded	---
Sorting	Poor	Variable	Variable	Good	Variable
Inorganic Sedimentary Structures	Cross-bedding and graded bedding	Asymmetrical ripples, cross-bedding, graded bedding, tool marks	Symmetrical ripples, lamination, cross-bedding, graded bedding, mudcracks, raindrop prints	Cross-bedding	Laminated to massive

	DELTA	BARRIER BEACH	LAGOON	TIDAL FLAT
Rock Type	Sandstone, siltstone, shale, coal	Quartz arenite, coquina	Siltstone, shale, limestone, oolitic limestone or gypsum	Siltstone, shale, calcilutite, dolostone or gypsum
Composition	Terrigenous	Terrigenous or carbonate	Terrigenous, carbonate, or evaporite	Terrigenous, carbonate, or evaporite
Color	Brown, black, gray, green, red	White to tan	Dark gray to black	Gray, brown, tan
Grain Size	Clay to sand (Coarsening upward	Sand	Clay to silt	Clay to silt
Grain Shape	---	Rounded to angular	---	---
Sorting	Poor	Good	Poor	Variable
Inorganic Sedimentary Structures	Cross-bedding, graded bedding	Cross-bedding, symmetrical ripples	Lamination, ripples, cross-bedding	Lamination, mudcracks, ripples, cross-bedding
Organic or Biogenic Sedimentary	Trails, burrows	Tracks, trails, burrows	Trails, burrows	Stromatolites, trails, tracks, burrows

	REEF	CONTINENTAL SHELF	CONTINENTAL SLOPE AND RISE	ABYSSAL PLAIN
Rock Type	Fossiliferous limestone	Sandstone, shale, siltstone, fossiliferous limestone, oolitic limestone	Litharenite, siltstone, and shale (or limestone)	Shale, chert, micrite, chalk, diatomite
Composition	Carbonate	Terrigenous or carbonate	Terrigenous or carbonate	Terrigenous or carbonate
Color	Gray to white	Gray to brown	Gray, green, brown	Black, white red
Grain Size	Variable, frameworks, few to no grains	Clay to sand	Clay to sand	Clay
Grain Shape	---	---	---	---
Sorting	---	Poor to good	Poor	Good
Inorganic Sedimentary Structures	---	Lamination, cross-bedding	Graded bedding, cross-bedding, lamination, flute marks, tool marks (turbidites)	Lamination
Organic or Biogenic	---	Trails, burrows	Trails, burrows	Trails, burrows

- **Deltaic System:** D system is important because Delta told as the host of **Petroleum, Gasses, and Coals.**
- ✓ It is introduced by **Herodotus.**
- ✓ The **morphology** of delta can be **classified** as
- ✓ **Delta plain,**
- ✓ **Delta front, and**
- ✓ **Prodelta.**
- **Deep sea system**: DSS are the widest sedimentation area in the **World.**

Facies

- **All the properties of a body of rock.**
- Properties include
  - Lithology – rock type, including color, etc.
  - Composition – mineral content
  - Texture – grain size, sorting, roundness
  - Sedimentary structures
  - Fossils
- Facies means aspect – same Latin root as "face"
- **Facies are the products of depositional environments**
- **Examples:**
  - Planar laminated fine quartz **arenite facies**
  - Bioturbated, poorly sorted muddy skeletal **limestone facies**
  - Cross-stratified arkosic **conglomerate facies**

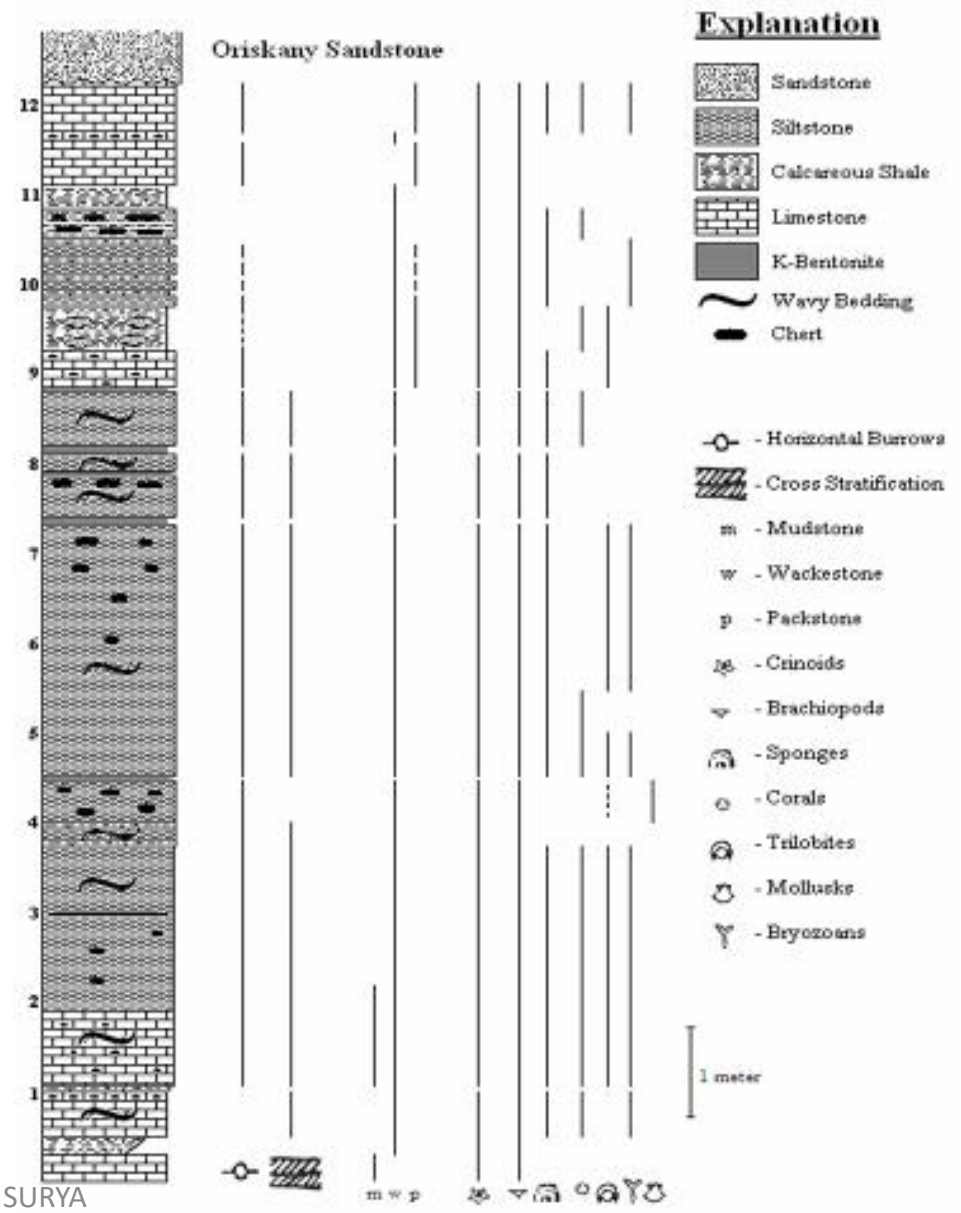
Facies Model

- ✓ Facies model **(Walker, 1992):**
- ✓ An idealized description of a facies
- ✓ Constructed from modern environments.
- **Facies Patterns:** Groups of facies commonly show patterns
- ✓ **Proximal Facies** (near the source) tend to be coarse grained
- ✓ **Distal Facies** (far from source) tend to be finer grained
- ➢ This pattern is displayed upstream and down in rivers and onshore to offshore in coastal areas

Facies Migration

- ✓ Facies migrate through space and time
- ✓ Migration is in response to environmental factors
  - – Sediment supply
  - – Sea level change
  - – Subsidence
- ✓ Facies become stacked during migration

Representing Facies: Stratigraphic Sections



FACIES

❖ **Facies**: In Geology, a facies is a body of rock.

✓ The term facies was introduced by **swiss in 1838.**

✓ Facies are divided into 4 groups, they are

- 1.Sedimentary facies
- 2.Walther's law of facies
- 3.Metamorphic facies
- 4.Sciesmic facies

1. **Sedimentary facies**: S facies is a distinctive rock unit and conditions of sedimentation.

- ✓ Facies based on Petrological characters such as Grain size, and Mineralogy)
- ✓ Ex: cross bedded Oolitic limestone facies, or a shale facies.

2. **Walther's law facies**:Walther's law facies simply Walther's law.

- ✓ It is introduced by **Johannes walther's (1860-1937)**

3. **Metamorphic facies:** Higher T and P.

4. **Scismic facies:** Scismic facies are mappable three dimentional scismic units.

Chapter -5

- **Stratigraphic Relationship: Event and Sequence Stratigraphy**
- ✓ **Stratigraphic Boundaries**
- ✓ **Event Bedding, Cycles and Sequence**
- ✓ **Geologic & Stratigraphic Cross- Sections and their Use correlation**

Stratigraphic Boundaries

- **Stratigraphic boundaries separate rocks of significantly different environments or lithology.**

✓ **A) Stratigraphic Surface - Continuous Physical Boundary**

(i) Stratal Surface

(ii) Discontinuity surface

(iii) Diachronous surface

✓ **(B) Stratigraphic Boundaries**

(iv) Synchronous: Parallel to Stratal surfaces

(v) Diachronous: Step across strata surfaces

- ✓Stratigraphic boundaries separate different lithologies resulting from different depositional environments.
- ✓They are of two types of continuous physical boundaries:

(A) Physical stratigraphic surfaces

(B) Lithofacies or biozone boundaries

(1) Physical stratigraphic surfaces are of three types:

(i) Stratal surfaces

(ii) Stratal discontinuities

(iii) Diachronous surfaces

- (i) Stratal surfaces are physical depositional surfaces separating sedimentary rock layers.
- ✓ They bound laminae, bed and large stratal units and represent periods of non deposition or abrupt shifts in depositional environment.

- ✓ They are the physical boundaries of sedimentary strata and form practical geologic time-horizons, consequently these are synchronous surfaces that represent (within the limitations of practical subsurface technology) the same instant in geologic time over large areas.

Time-gaps (hiatuses)

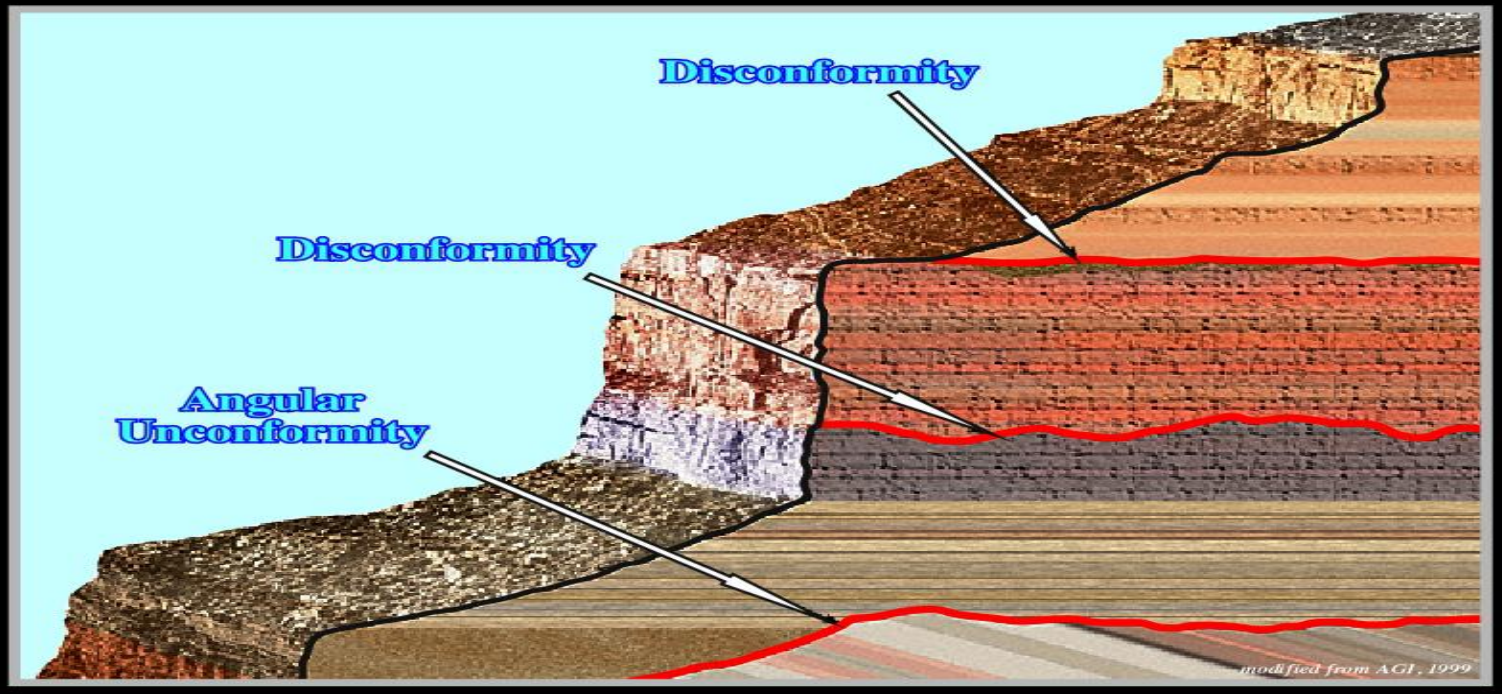


Plate 139 - Time-gap surfaces can be bedding planes, when the time-gap is small, and unconformities or disconformities when the time-gap is significant. As you will see later, unconformities can be tectonically enhanced (angular unconformities) or not. When they are not tectonically enhanced, unconformities are sometimes named disconformities as illustrated above. On these notes, the term unconformity will be used for all erosional surfaces induced by significant relative sea level falls.

✓(ii) Stratal discontinuities are physical surfaces caused by erosion or by non deposition.

- They include (1) unconformities, (2) disconformities and (3) depositional hiatuses.
- Unconformity time-gaps may simply represent prolonged periods of subaerial exposure with minimal erosion, possibly with local valley or channel down-cutting, or they may represent periods of uplift and major subaerial erosion of strata, or they may represent submarine erosion by turbidites, slump or submarine currents. Classical subaerial unconformities are of two major types:

(a) Angular unconformities (Plate 140), with the discontinuity surface created by truncated strata beneath the boundary.

(b) Disconformities (Plate 139) with beds parallel above and below the boundary.

Angular Unconformity

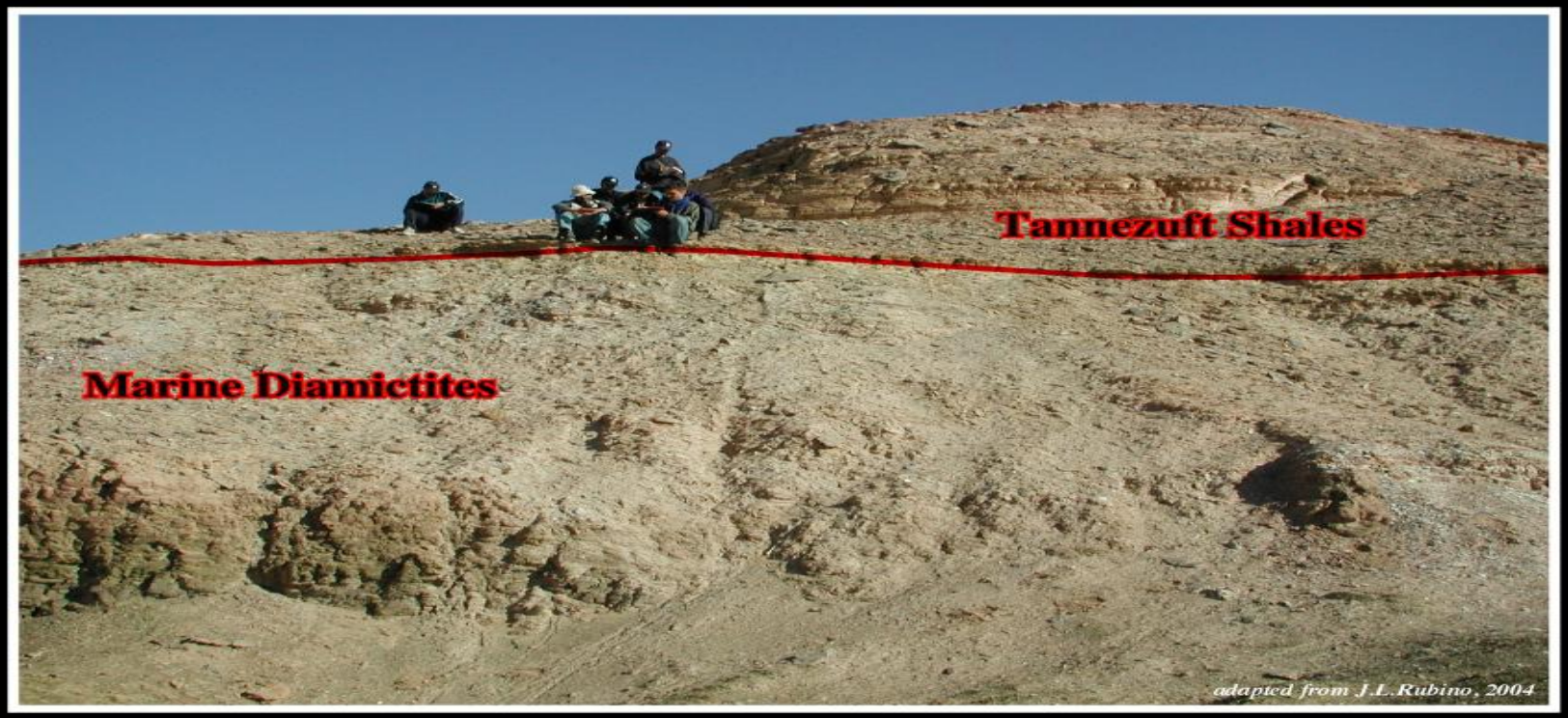


Plate 140 - The stratal relationships (reflection termination on seismic lines), between the Marine diamictites and the Tannezuft shales characterize an erosional surface, which created a large time-gap or hiatus, i.e., an unconformity between the sedimentary intervals. In addition, as we will see in next chapter (geometrical relationships) the stratal relationships are those associated with an angular unconformity.

- Disconformities do not show discontinuity patterns, consequently they are recognized either by paleontological evidence of a time-gap or by tracing regional discontinuity surfaces into the disconformity.
- These classic unconformity types remain significant, but we also find discontinuity patterns of onlap (marine, or lacustrine, transgression of the old subaerially exposed and gently tilted surface) and toplap (rapid progradation of deltaic or bank-edge sediments into the basin from a common depositional surface) commonly associated with subaerial unconformities.

- Submarine unconformities have many of the same discontinuity patterns. Truncation is created by turbidite and gravity-slump erosion of submarine valleys and canyons. High energy submarine currents may also produce truncation patterns, although this is usually local and rarely removes consolidated sediments.
- Subaqueous nondepositional discontinuities are time-gaps caused by nondepositional or very slow deposition.

- (iii) Diachronous surfaces are continuous physical boundaries that cross and are essentially independent of stratal boundaries. These are generally not stratigraphic surfaces and are mentioned here because they are sometimes confused with stratal surfaces. Lithofacies and biozone boundaries may be synchronous, i.e., the particular lithofacies or biozone assembly is laterally continuous within synchronous stratigraphic surfaces. They may also be diachronous, i.e., they may step across stratal surfaces in a transgressive or regressive pattern.

Stratigraphic cycles

- **Stratigraphic cycles** refer to the transgressive and regressive sequences bounded by unconformities in the stratagraphic record on the cratons. These cycles represent a large scale eustasy cycle since the Cambrian period with further sub-divisions of those units
- 1Divisions
  - 1.1First-order cycles
  - 1.2Second-order cycles
  - 1.3Third-order cycles
  - 1.4Fourth order cycles
- 2Event stratigraphy

- **Stratigraphic Cycle Order**
- First-order Supercycle
- 200-400
- Second-order Sequence or Synthem
- 10-100
- Third-order
- Mesothem
- 1-10
- Fourth-order
- Cyclothem
- .2-.5

- Divisions
- The division of these sequences were originally constructed in the Appalachian Basin and Cordilleran Basin of North America. Eventually these sequences were correlated in Russia and South America.
- The transgressive-regressive units show gaps in the rock records which indicate times of continual erosion and very little deposition. Local tectonics did not play a role in these global events, rather, a worldwide rise and fall of sea level.
- Smaller orders in stratigraphic cycles have also been proposed. Fifth-order cycles and sixth order cycles have also been described in much of the Absaroka sequence. The time scale is much smaller and instead of Wilson cycle controlled sea-level change, these shorter cycles were controlled by glaciers (also called glacio-eustasy).

- **First-order cycles**
- This cycle is most likely caused by the break-up and formation of super-continents. The earth went through major climatic swings over the course of 200 to 400 million years. From the late Pre-Cambrian to the late Cambrian, late Devonian to the Triassic-Jurassic border, and since the Miocene until the present time, the earth was an "icehouse", with icesheets covering the poles. In the intervening years, the earth was a "greenhouse", with high global temperatures and elevated atmospheric CO_2. Volcanic activity was also high in the greenhouse years. These long periods of continental emergence helped produce changes in ocean currents and the distribution of atmospheric heat.
- **Second-order cycles**
- There are two competing arguments for second-order sea-level changes. The first states the sea level can be affected by the number of and the volume of the magma being produced at mid-ocean ridges.[6] During times of increased sea floor spreading, more magma is being produced and the volume of the ocean basins are displaced by this. This would result in a higher sea level. This increase in magmatic activity corresponds to increased mantle activity and the Earth's magnetic field.

- **Third-order cycles**
- This order of sea-level change has yet to be fully explained. It was originally thought that glaciers controlled these sea-level changes. But glaciers form and retreat far too rapidly, only tens of thousands of years instead of over a million years. Instead, short-term changes in earth's surface due to volcanics and tectonic events could change global sea levels over a million years. This change to earth's shape could produce "bulges" or "sags" that contribute to ocean level fluctuations.[3]
- **Fourth order cycles**
- Again, there are two competing theories for what controls fourth order cycles. Often called cyclothems, the relative short time period in which individual layers of rock are never more than 1 million years. Glaciers are capable of causing quick changes in sea level that can show up in the rock record. Some think that many of the Carboniferous-aged coal deposits were due to glaciers retreating and advancing over a few million years.
- Others propose that delta switching produced the cyclothems. A modern analogue to describe delta switching would be the Mississippi embayment. As the Mississippi River carries its sediment load into the Gulf of Mexico, the delta lobe can become sediment-choaked and the river will look for a new channel to follow the path of least resistance.

- Event stratigraphy
- This can refer to accumulation of sediments in one specific event. This event could be a large storm, landslide, volcanic eruption, or flood. The thickness of the bed could sometimes be over 50 feet in length. The uniform (or often the erratic) nature of the sediments in relation to the surrounding sediments is the only clue that a particular bed might have been deposited in a single event. A sandstone, for instance, that is well-sorted, contains erratic fossils (like brachiopods) and is wedged between sandstones that are generally poorly-sorted and contain minor siltstone layers and contains no fossils, can be interpreted as "tempestite". Other event indicators could be lava flows, lahars, and glacial ice-dam breaks- all of which have been identified in the rock record.

Cross section

- Geological cross sections are graphical representations of vertical slices through the earth used to clarify or interpret geological relationships with or without accompanying maps. As with other tools applied to petroleum development, cross sections are used to portray geological information in a visual form so that reservoir characteristics can be readily interpreted. For example, a thorough understanding of regional structural and stratigraphic relationships may lead to better characterization of reservoir flow units (see Flow units for reservoir characterization).
- There are two major classes of cross sections used in understanding petroleum reservoirs.
- *Structural cross sections*, which show the present day geometry of an area
- *Stratigraphic cross sections*, which show prior geometric relationships by adjusting the elevation of geological units to some chosen geological horizon.
- A third type of cross section called a *balanced cross section* is a combination of these two. This type attempts to portray the form of geological units prior to some episode of deformation (see Evaluating structurally complex reservoirs). It can provide important conclusions about present day geometry and past stratigraphic relationships.

- 1 Stratigraphic cross sections
  - 1.1 Choice of datum
  - 1.2 Orientation and layout of the cross section
  - 1.3 Selection of data
  - 1.4 Vertical and horizontal scale
  - 1.5 Labeling
- 2 Structural cross section
  - 2.1 Choice of datum
  - 2.2 Orientation and layout of a cross section
  - 2.3 Selection of data
  - 2.4 Vertical and horizontal scale

- 3 Cross sections in three dimensions
- 4 Computer generation of cross sections
- Stratigraphic cross sections
- Stratigraphic cross sections show characteristics of correlatable stratigraphic units, such as reservoir sandstones or sealing shales. They may also be vital in understanding the timing of deformation by showing the drape of sediment over developing folds or the thickening of the section across growth faults. The following elements of cross section design are presented as if they were a sequence. In practice, however, each choice affects and is affected by the others.

- **Choice of datum**
- The *datum* is the level or reference horizon from which elevations and depths are measured in the cross section. In a stratigraphic cross section, the geologist takes advantage of the principle of original horizontality to produce an interpretation of what the chosen slice of the earth might have looked like at some time in the past. By “hanging” all the available vertical information on a stratigraphic horizon or datum that can be correlated along the full length of the cross section, the data are transformed to reflect a different horizontal plane, one that existed at an earlier time . The assumption that this surface was horizontal when deposited assumes no original depositional slope.
- The purpose of the cross section is to determine which horizon can serve as the datum. Because it is shown as horizontal, the thickness variations of the units directly above and below the datum are most simply interpretable on the cross section. The cross section uses the horizon labeled F as a datum because this has been interpreted as the top of a chronostratigraphic sequence.
- An unconformity is commonly used as a datum. In many circumstances, unconformities represent relatively uniform and geologically important time horizons and are therefore useful features on which to hang cross sections. However, caution must be used since the sedimentary layers may reflect paleotopographic relief.

Orientation and layout of the cross section

- The orientation of a cross section must be chosen to balance the need for a clear representation of the features of interest with the availability of appropriate information. In development geology, this information comes largely from well data (geophysical logs, mudlogs, and cores), but in some places, outcrops and seismic reflection data can be used to constrain interpretations.

- **Selection of data**
- Once the choices of datum and orientation have been made, the next step is to decide what data must be displayed.
- If the object of the cross section is to show lateral and vertical details of the stratigraphy, log properties are of utmost importance.
- Typically the SP or gamma ray log and one resistivity log are displayed Porosity logs may also be important, and if seismic data are part of the cross section, the sonic log is a critical tool to demonstrate the velocity structure, and consistency of conversion of time to depth.

- **Vertical and horizontal scale**
- To show significant details of stratigraphic variation, it is usually necessary to exaggerate the vertical scale with respect to the horizontal scale on a stratigraphic cross section.
- It is important to realize the effect that this distortion has on reservoir geometry and angular relationships of geological surfaces. The small angular differences between stratigraphic horizons that account for thickness variations are strongly exaggerated in such a section. The apparent dip of a bed in a vertically exaggerated cross section is related to true dip by the following equation.

- where
- δ_E = apparent dip in exaggerated section
- δ = true dip
- V = vertical exaggeration, or
- , the ratio of vertical scale (I_v) to horizontal scale (I_h)
- As a result of this relationship, low dips are exaggerated and appear larger, whereas higher dips all appear close to vertical. The effect is illustrated in Table 1, where selected values of true and apparent dip are shown for vertical exaggerations of five and ten times. Note that two horizons differing in dip by only 3° appear to differ by 14° and 22°, respectively, for the two values of vertical exaggeration. Any attempt to render structural form on a stratigraphic cross section is schematic but should take into account this effect. It is also important to remember that the image one creates with a stratigraphic cross section is a distortion of reality.

Computer generation of cross sections

- Cross sections are now routinely and rapidly constructed by computers. Computers process input data to construct cross sections in two ways, each of which has a pitfall. The more sophisticated method involves the use of program algorithms to interpolate and extrapolate from the limited available data to a complete cross section, such as the connecting of stratigraphic tops with straight lines. This process can go wrong when a well does not have a full set of tops picked such that false correlations are created. Thus, one pitfall to be aware of is the indiscriminate application of software to computer generation of cross sections.

Chapter -6(part-1)

- ❖ **Classification and Nomenclature of Stratigraphic units**
- ✓ **Stratigraphic Code and formal StratigraphUnits**

1. Lithostratigraphy
2. Biostratigraphy
3. Chronostratigraphy
4. Magnetostratigraphy
5. Seismostratigraphy
6. Chemostratigraphy

- ✓ The stratigraphic code was first developed in 1933, and later revised 1961, 1970 and 1983 by the **North American Commission on Stratigraphic Nomenclature** (NACSN).
- ✓ Formal Lithostratigraphic Units are defined in accordance with the procedures and requirements of the Stratigraphic Code established by NACSN.
- ✓ **These procedures include the following five requirements:**

1. requirements for picking a name,
2. requirements for designating a stereotype or type section,
3. requirements for describing the units,
4. requirements for specifying the boundaries between units, and
5. requirements for publishing in a recognized scientific medium.

1.LITHOSTRATIGRAPHY

- ✓ **Lithostratigraphy:** a traditional branch of stratigraphy that involves recognition, subdivision and correlation of sedimentary rocks on the basis of *lithology.*
- ✓ **Lithology:** refers to study and description of the physical characteristics of rocks, i.e. rock type, color, mineral, composition, texture and fossil content.
- ➢ Texture: refers to grain size, grain shape, grain sorting and roundness.
- ➢ rock type : sandstone, mudstone, shale, limestone, etc
- ➢ color : reddish brown sandstone, yellowish sandstone, black shale, greenish mudstone, etc
- ➢ mineral composition: quartz sandstone (quartzarenite), lithic sandstone (lithic arenite)

- texture : fine-grained, well-sorted and well-rounded sandstone; coarse-grained, poorly sorted and angular sandstone
- fossil content : fossiliferous limestone/sandstone, non-fossiliferous limestone/sandstone, etc
- A Lithostratigraphic Unit: a body of rock distinguished on the basis of lithologic characteristics
- The sedimentary rock unit that is defined on the basis of the above mentioned physical properties is referred to as a lithostratigraphic unit

Nomenclature and classification of lithostratigraphic units is necessary:

- to bring order or systematic organization to strata
- to understand to the geologic history record.
- The basis of relative age, which was started by Steno in 1669, evolved gradually throughout the 18th and 19th centuries and eventually culminated in the formulation of the internationally used **Geologic Time Scale and the Geologic (Stratigraphic Column).**

2.Biostratigraphy

- Biostratigraphy : is a traditional and highly useful method for characterizing, subdividing , and correlating sedimentary rocks into identifiable stratigraphic units on the basis of their fossil content.
- Stratigraphy based on the paleontologic characteristics of sedimentary rocks or the study of fossils and their distributions in various geologic formations is also referred to as Stratigraphic paleontology.

Biostratigraphic units

- **A biostratigraphic unit:** is a body of rock strata characterized and distinguished from adjacent strata by its fossil content.
- **The zone, or biozone:** is the fundamental biostratigraphic unit that does not have any prescribed thickness or geographic extent.
- They may range in thickness from thin beds **a few meters thick to units thousands of meters.**

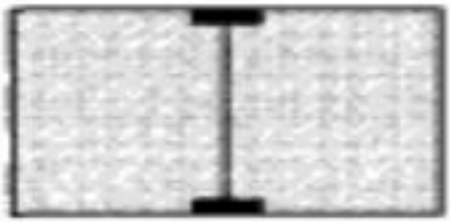
Kinds of biozones

- There are **five principal kinds of biozones to subdivide a biostratigraphic unit. These are:**

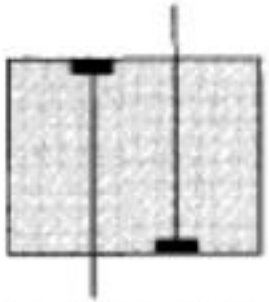
1. **Range biozone**
2. **Lineage biozone**
3. **Interval biozone**
4. **Assemblage zone**
5. **Abundance biozone**

- Each biozone is distinguished by different criteria, and they are explained below:

- **1. Range biozone:** is a body of rock representing the known stratigraphic and geographic range of occurrence of a single taxon.
- A concurrent range biozone is a body of rock that includes the concurrent, coincident, or overlapping part of the ranges of two specified taxa.

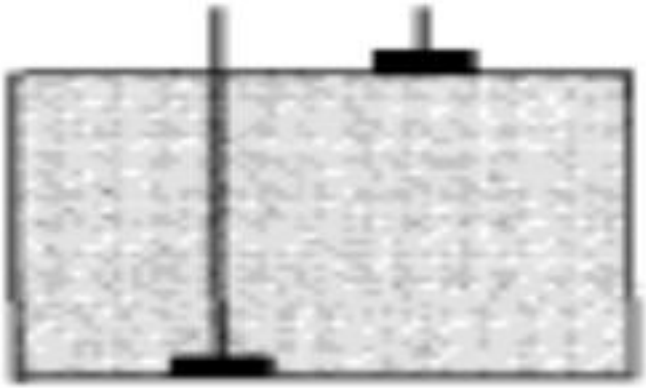


Taxon-range Biozone (based on the range of a taxon)



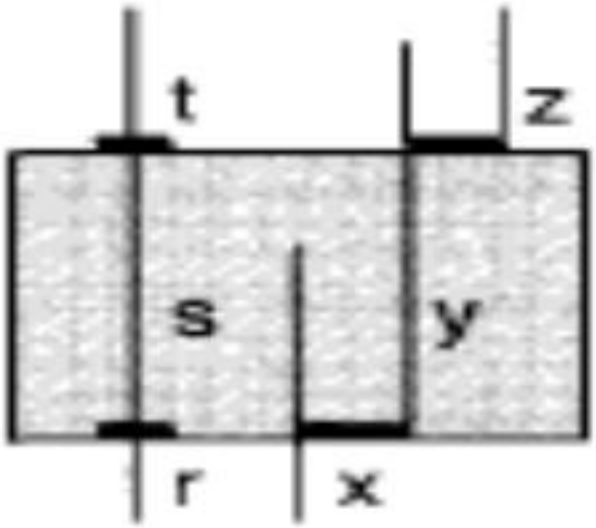
B - Concurrent-range Biozone (based on range of concurrent occurrence of two taxa)

- **2. Interval biozone (or subzone):** is the body of rock between two specific biostratigraphic surfaces (or biohorizons).
- Biohorizons are surfaces of lowest or highest occurrence.



C - Interval biozone (based on lowest occurrences of taxa)

- **3. A lineage biozone:** is a body of rock containing species representing a specific segment of an evolutionary lineage.

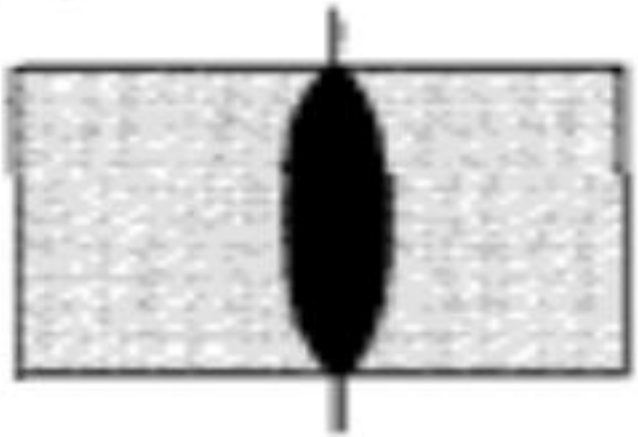


E - Lineage Biozone (based on successive species in a segment of an evolutionary lineage)

- **4. Assemblage biozone:** is a body of rock characterized by a unique association of three or more taxa,
- the association of which distinguishes it in biogeographic character from adjacent strata.

F - Assemblage Biozone (based on overlapping ranges of an assemblage co-occurring taxa)

- **5. Abundance biozone:** is a body of rock in which the abundance of a particular taxon or specified group of taxa is significantly greater than in adjacent parts of the section.



G - Abundance Biozone (thickened line denotes range of increased abundance of the taxon).

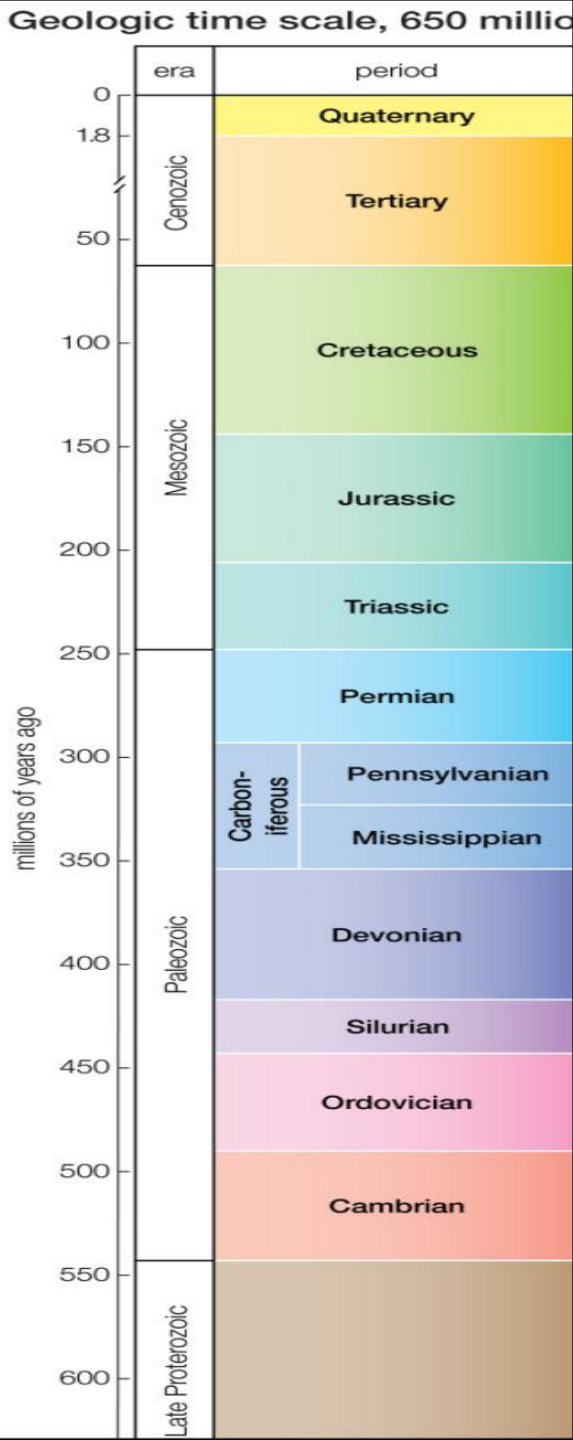
3.Chronostratigraphic Units

- Chrononstratigraphic unit is a body of rock strata that is unified by being formed during a specific interval of geologic time.
- Stratigraphic units based on the time of formation of the rock bodies.
- Chronostratigraphy is the element of stratigraphy that deals with the relative time relations and ages of rock bodies.
- Chronostratigraphic classification is the organization of rocks into units on the basis of their age or time of origin.

Geochronologic Units

- Geochronology is the science of determining the numerical age of rocks, fossils, and sediments by measuring the amount of decay of a radioactive isotope with a known half-life.“

- Geochronologic units are units of time which we subdivide the Geologic time
- Eon
- Era
- Period
- Epoch
- Age



- The rank and relative magnitude of the units are a function of the length of time.

- **The Hierarchy of Chrononstratigraphic units**

✓ Eonothem

✓ Erathem

✓ System

✓ Series

✓ Stage

- **Stage:** The basic working unit of the Chrononstratigraphy.
- A stage is normally the lowest ranking unit in the chronostratigraphic.
- It is a subdivision of a series.
- Stages are variable in time span (Average 3-10 M.Y).
- Thickness may range from few meters to thousands of meters

- A system is a unit of major rank above a series and below an erathem.
- The geochronologic equivalent of a system is a period.
- The average time span of a systems ranges from 30 to 80 million years, except for the Quaternary System that has a time span of only about 1.64 million years.

Geochronology Vs. Chronostratigraphy

- Geochronology is concerned with geological time units.
- Chronostratigraphy refers to material stratigraphic units.
- The difference is that Geochronology is an interval of time that is expressed in years, whereas Chronostratigraphy is unit of rock.
- Chronostratiigraphic terminologies **(Stage, series..)**are used when speaking about Sediments
- Geochronologic terminologies **(Period, Epoch,…)** are used when speaking about the time.

Geochronology Vs Chronostratigraphy

Chronostratigraphic units have equivalent geochronologic units

Chronostratigraphic Name	Geochronologic Name
Eonthem	Eon
Erathem	Era
System	Period
Series	Epoch
Stage	Age
Chronozone	Chrone

- Position within a **Chronostratigraphic unit** is expressed by adjectives indicative of position such as: **basal, lower, middle, upper, etc.;**

- Position within a **Geochronologic unit** is expressed by temporal adjectives such as: **early, middle, late, etc.**

Eonothem (Eon)	Erathem (Era)	System and Subsystem (Period and Subperiod)		Series (Epoch)	Numerical Age (Ma) (2)	(3)	(4)
PHANEROZOIC	Cenozoic	Quaternary		Holocene			
				Pleistocene	1.60		1.64
		Tertiary	Neogene	Pliocene			
				Miocene	23.7	23.	23.3
			Paleogene	Oligocene			
				Eocene			
				Paleocene	66.4	65	65
	Mesozoic	Cretaceous		Upper			
				Lower	144	135	145.8
		Jurassic		Upper			
				Middle			
				Lower	208	205	208
		Triassic		Upper			
				Middle			
				Lower	245	250	245
	Paleozoic	Permian		Upper			
				Lower	286	300	290
		Carboniferous (5)			360	355	362.5
		Devonian		Upper			
				Middle			
				Lower	408	410	408.5
		Silurian			438	438	439
		Ordovician		Upper			
				Middle			
				Lower	505	510	510
		Cambrian			570	570	570
PRECAMBRIAN	PROTEROZ.				2500		2500
	ARCHEAN						

Elements of Stratigraphy

LithostratigraphY	Lithostratigraphic Unit	Lithology
Pedostratigraphy	Pedostratigraphic Unit	Buried Soils
Biostratigraphy	Bio Zones	Fossil Content
Chronostratigraphy	Chronostratigraphic Units (System, Series, Stage)	Time Relationships
Geochronology	Geochronologic Units (Period, Epoch, Age)	Time Relationships

Chapter -6(part-2)

- 4.Magnetostratigraphy
- 5.Seismostratigraphy
- 6.Chemostratigraphy

4.Magnetostratigraphy

- **Magnetostratigraphy:** is a relatively new branch of stratigraphy that deals with vertical and lateral relationships of strata *on the basis of magnetic properties of sedimentary rocks and layered volcanic rocks.*

- It is a relatively new branch of stratigraphy developed largely since about the middle 1960s.

➢ The Earth's Magnetic Field:

➢ The Earth has two north poles:

1. The Geographic north pole, and

2.The magnetic north pole

- ✓ The magnetic North Pole has an angle of declination with respect to the Geographic North Pole .
- ✓ Studies of magnetism in igneous and sedimentary rocks show that the dipole of Earth's magnetic field.

- ✓ When Earth's magnetic field has the present orientation it is said to have **normal polarity**
- ✓ When Earth's magnetic field rotates by 180° and changes its orientation it is said to have **reversed polarity.**

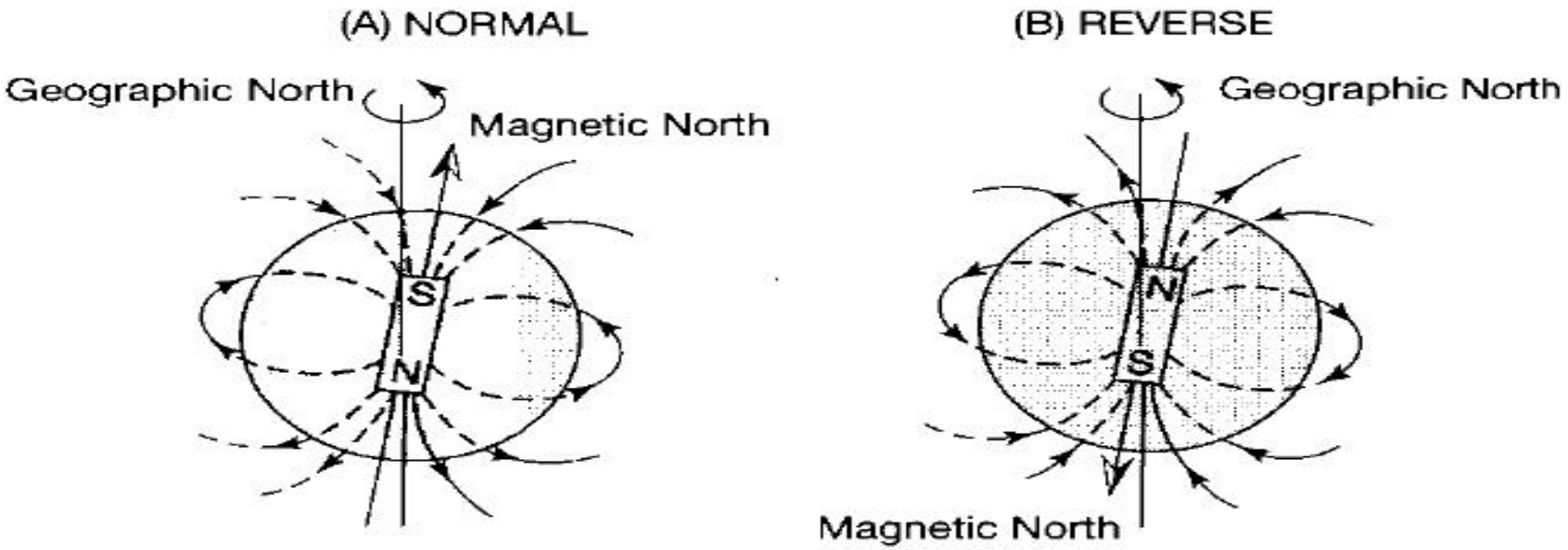
➢ **How volcanic rocks are magnetised - *Thermal remanent magnetism (TRM)***

- During the cooling of molten rock, iron-bearing minerals become magnetized in alignment with Earth's magnetic field as they cool through a critical temperature of about 500°C-600°C (for magnetite).

- **How sedimentary rocks are magnetised - *Detrital Remanent Magnetism (DRM)***
- During deposition of sediments, small magnetic mineral grains are able to rotate in the loose, unconsolidated sediment on the depositional surface and thus align themselves mechanically with Earth's magnetic field.
- This (statistically) preferred orientation of magnetic minerals in sedimentary rocks imparts bulk magnetic properties to the rocks, referred to as ***depositional remanent magnetism*** or ***detrital remanent magnetism***.

➢ Normal and Reversed Polarity in the Geo*magnetic Field of the Earth*

- The significance of primary remanent magnetism for stratigraphic studies stems from the fact that Earth's magnetic field has not remained constant throughout geologic history but has frequently reversed.
- The geomagnetic field is generated in some poorly understood way by the motion of highly conducting nickel-iron fluids in the outer part of Earth's core; When Earth's magnetic field has the present orientation, it is said to have normal polarity. when this orientation changes 180°, it has reversed polarity.



Schematic representation illustrates diagrammatically the magnetic lines of force around Earth during normal and reversed polarity epochs. Note that during a time of normal polarity the magnetic lines of force appear to "flow" out of Earth at the geographic South Pole, bend around Earth, and re enter at the geographic North Pole. Thus, a compass needle hinged vertically (swings up and down) would point down (into Earth) at the North Pole and up (out of Earth) at the South Pole. The flow direction of the magnetic lines of force, and the direction of a compass needle, would reverse during an episode of reversed polarity.

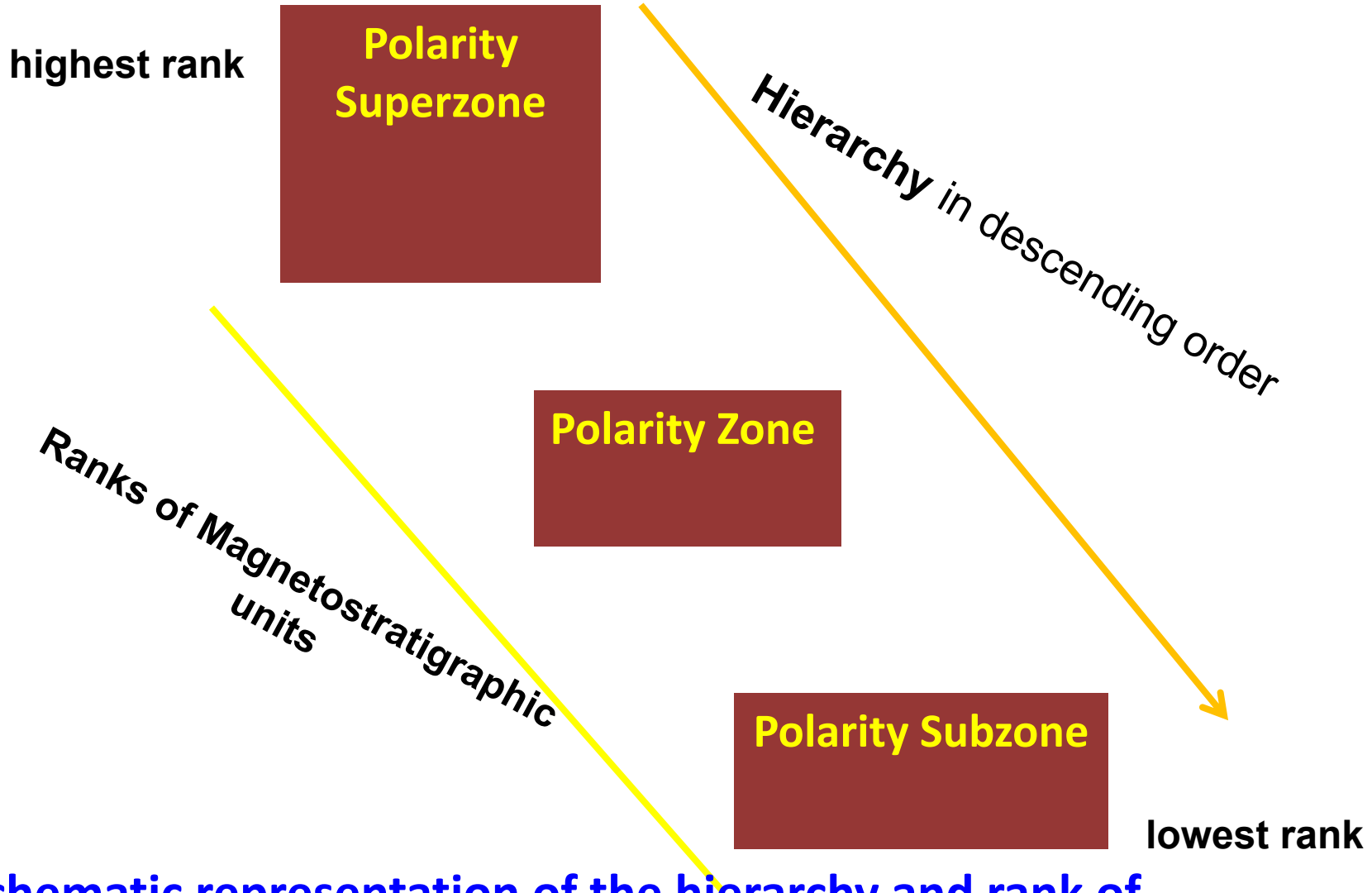
- **How to define the direction of magnetisation of a rock**
- Reversals of Earth's magnetic field are recorded in sediments and igneous rocks by patterns of normal and reversed remanent magnetism. The direction of magnetization of a rock is defined by its ***north-seeking magnetization***.
- If the north-seeking magnetization of rocks *points toward Earth's present magnetic north pole*, the rock is said to have normal-polarity magnetization.

Nomenclature of Magnetostratigraphic Units

- **Magnetostratigraphic Polarity Unit** is the fundamental unit of magnetostratigraphy that represents a body of rock .It has commonly a duration that ranges from 10^4-10^7 years.
- **Hierarchy and Rank of Magnetostratigraphic Units**

• Magnetostratigraphic Polarity Units are formally subdivided into polarity zones on the basis of their duration.

- **Polarity Zone:** is the fundamental formal magnetostratigraphic polarity unit used for subdivision of stratigraphic sections.
- **Polarity Superzone:** is the highest rank magnetostratigraphic unit composed of two or more polarity zones and has a duration of 10^6-10^7 years.
- **Polarity Subzone:** is the lowest rank magnetostratigraphic unit expressed as a subdivision of a polarity zone and has a duration of 10^4-10^5 years .



Schematic representation of the hierarchy and rank of magnetostratigraphic units.

➢ Naming Magnetostratigraphic Units

- Magnetostratigraphic Polarity Units are formally named by the geographic localities.

e.g: **Geographic name** plus **Rank** -

Northern Spain Polarity Zone

Southern Poland Polarity Zone

- They can also be formally named for a distinguished scientist who contributed to development of the field of geomagnetism (e.g. Gilbert Polarity Zone or Gauss Polarity Zone in Fig. 1).

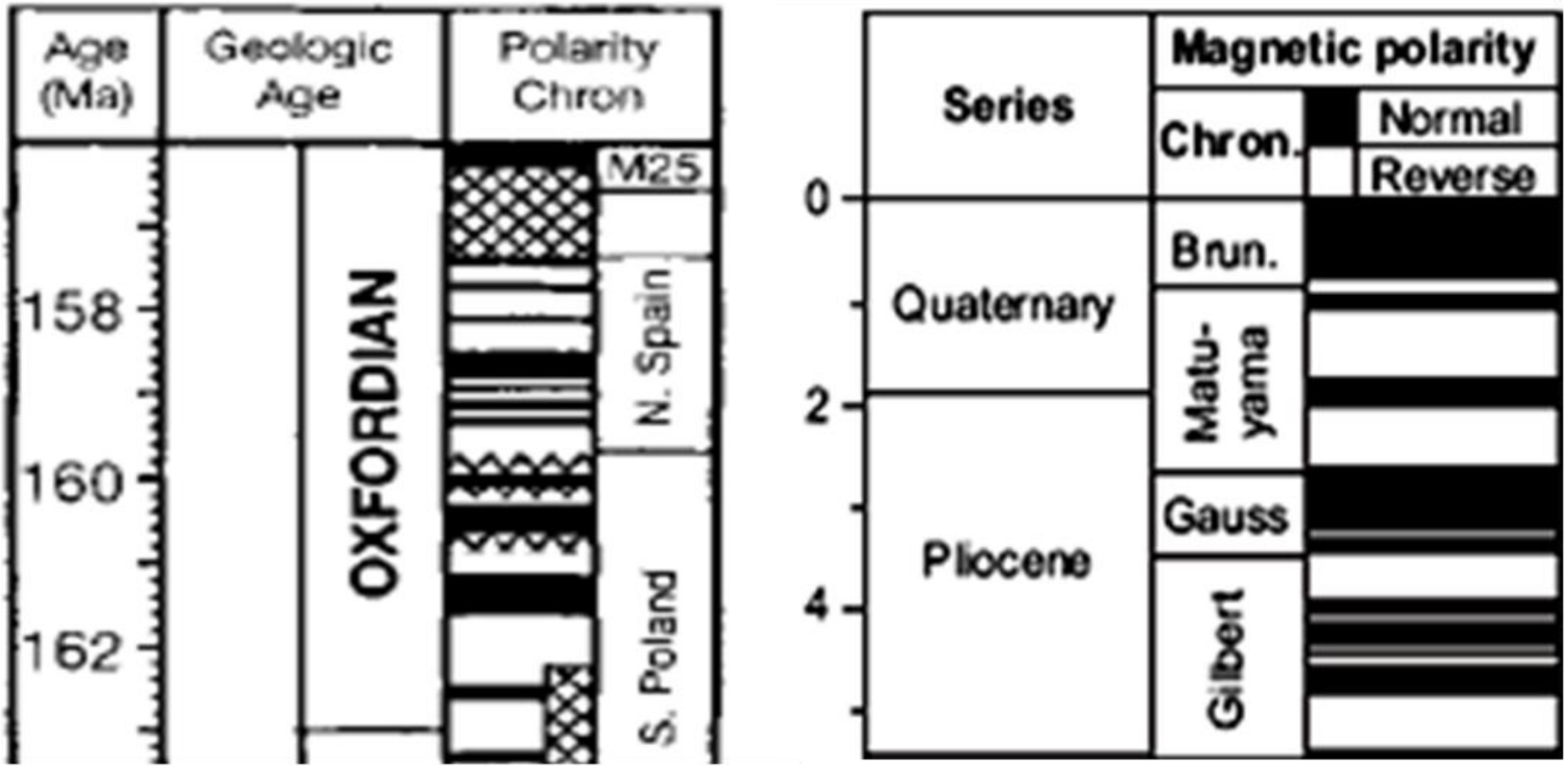


Fig 1. Schematic representation of naming magnetostratigraphic units.

The magnetic polarity time scale

- The magnetic polarity time scale (also called the geomagnetic time scale) was achieved by measuring the magnetic polarities of volcanic rocks on land and sea (i.e. polarity zones) and determining their age intervals of polarities by using radiometric dating (i.e. polarity chrons).
- **For example,** potassium-argon (K-Ar) techniques were used to estimate the ages of the rocks younger than about 5 million years.
- The magnetic polarity time scale is subdivided into polarity chrons and formally designated by the first capital letter of the Era they were identified and numbering them in sequential order from young to old.
- **For example,** C1, C2, C3,... for the polarity chrons of the Cenozoic Era, and M1, M2, M3,... for the polarity chrons of the Mesozoic Era.

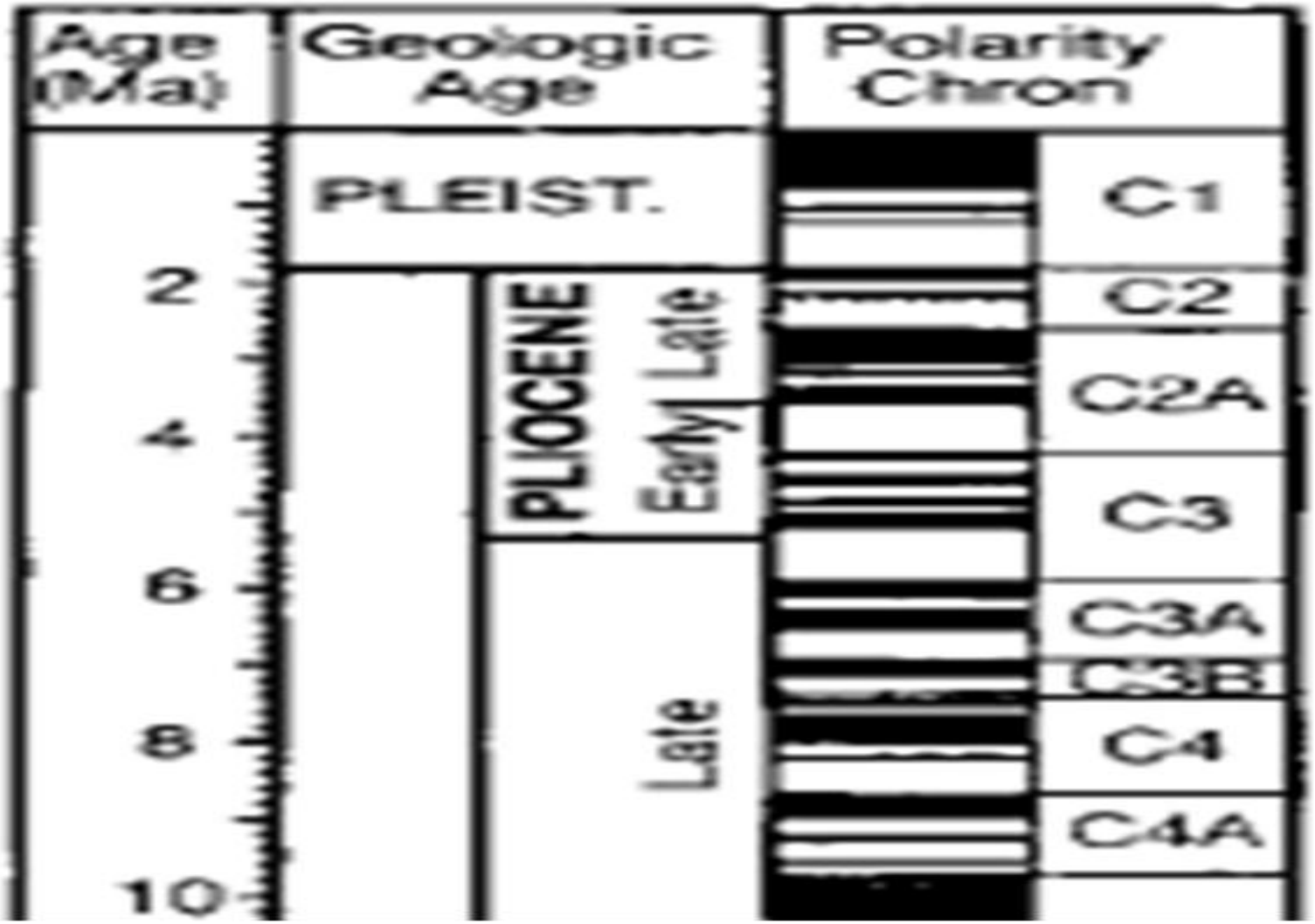


Fig 2. Schematic representation of the magnetic polarity time scale for the Upper Neogene Period.

5.SEISMIC STRATIGRAPHY

- **What is seismic stratigraphy?**
- **The principle of Seismic Stratigraphy** involves the use of artificially generated seismic waves (elastic waves) to obtain information about the vertical and lateral relationships of strata and the geologic structures, like faults and folds.

➢ These artificially generated elastic waves pass downward into Earth until they encounter a discontinuity and are reflected back to the surface, where they can be picked up by detectors (geophones or hydrophones).

- Seismic waves travel at velocities ranging from less than 2 km/s (some sediments) to more than 8 km/s (some igneous rocks).
- This means that the velocity of seismic waves varies depending upon the kinds of rocks through which they pass and their depth below Earth's surface.

➢ What is a reflection seismic data ?

- Reflection Seismic data is a *record of the variations in the acoustic properties of rocks.*
- A sound wave is partially reflected when it encounters a boundary between two materials of *different density and sonic velocity* (the speed of sound in the material).
- In geological terms, there is a strong reflection of the sound waves at the contact between two rocks that have different acoustic properties, such as a limestone and a mudstone.
- In general, crystalline or well-cemented rocks have a higher sonic velocity than clay-rich or porous lithologies.

Parameters Used in Seismic Stratigraphic Interpretation

- The important characteristic features of seismic reflection (referred to as *seismic parameters*) that have stratigraphic significance are:

- *reflection configuration,*
- *reflection continuity,*
- *reflection amplitude,*
- *reflection frequency,*
- *interval velocity and external form*.

Table 1. Seismic reflection parameters commonly used in seismic stratigraphy, and the geologic significance of these parameters.

Seismic facies parameters	Geologic interpretation
Reflection configuration	Bedding patterns
	Depositional processes
	Erosion and paleotopography
	Fluid contacts
Reflection continuity	Bedding continuity
	Depositional processes
Reflection amplitude	Velocity-density contrast
	Bed spacing
	Fluid content
Reflection frequency	Bed thickness
	Fluid content
Interval velocity	Estimation of lithology
	Estimation of porosity
	Fluid content
External form and areal association of seismic facies units	Gross depositional environment
	Sediment source
	Geologic setting

- **1.Reflection configuration**: refers to the gross stratification patterns identified on seismic records that can be interpreted in terms of primary depositional characteristics, such as
- bedding patterns,
- depositional processes,
- erosion and
- paleotopography.

2. **Reflection continuity**: refers to the continuity of the density-velocity contrast along bedding surfaces or unconformities.

- it can be classified as laterally continuous and discontinuous reflection patterns.
- ***Laterally continuous reflections*** indicate stratified deposits that are continuous over large areas.
- ***Discontinuous reflections*** terminate discordantly on the overlying or underlying strata.

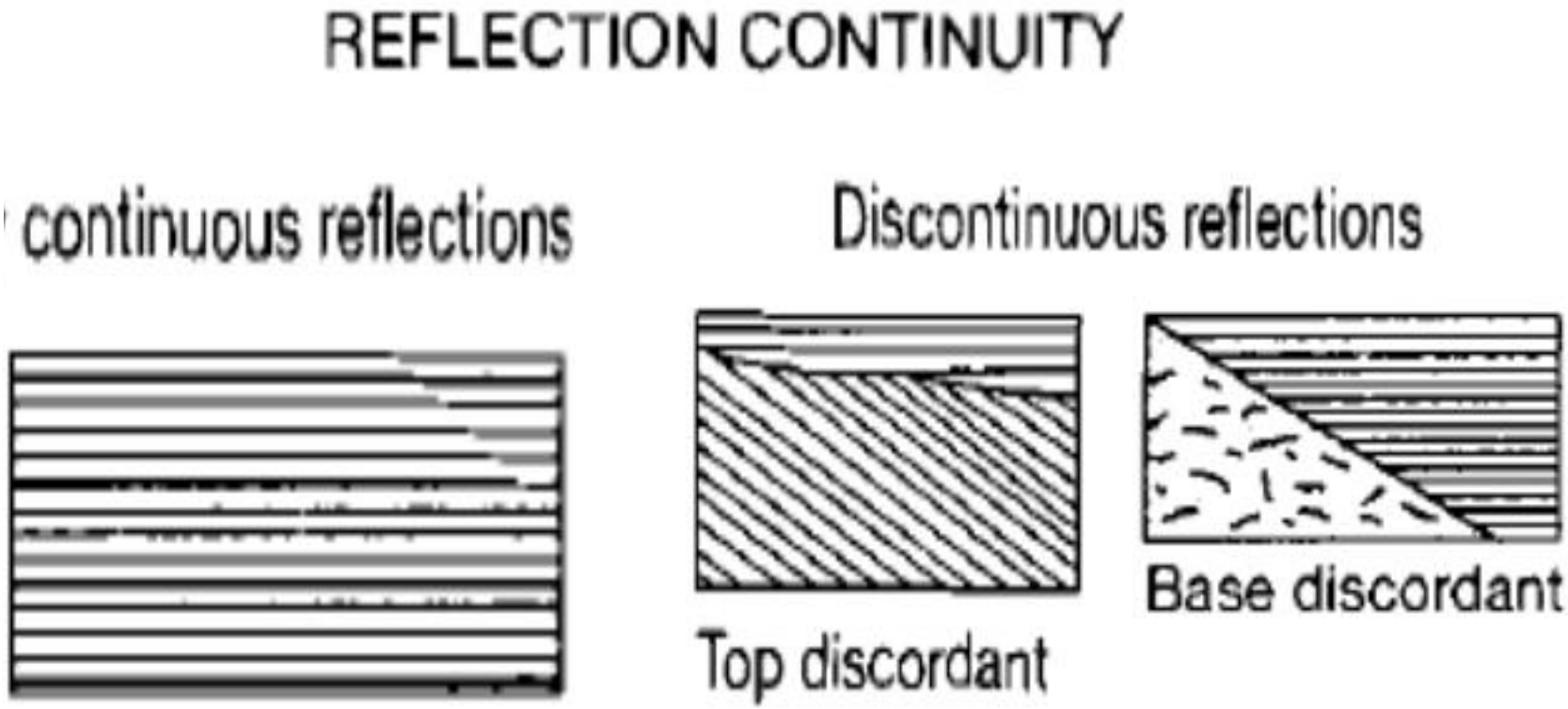


Fig . Schematic illustration of seismic reflection continuity.

3. **Reflection amplitude:** indicates velocity-density contrast, and thus, is used to calculate ***bed thickness*** and ***spacing***. It is also used to identify ***fluid content***.

- The presence of petroleum or natural gas can produce a marked increase in reflection amplitude of seismic waves that appears on seismic records as so-called ***"bright spots."***
- These bright spots are used for ***direct detection of petroleum or natural gas deposits***.

REFLECTION CONFIGURATION

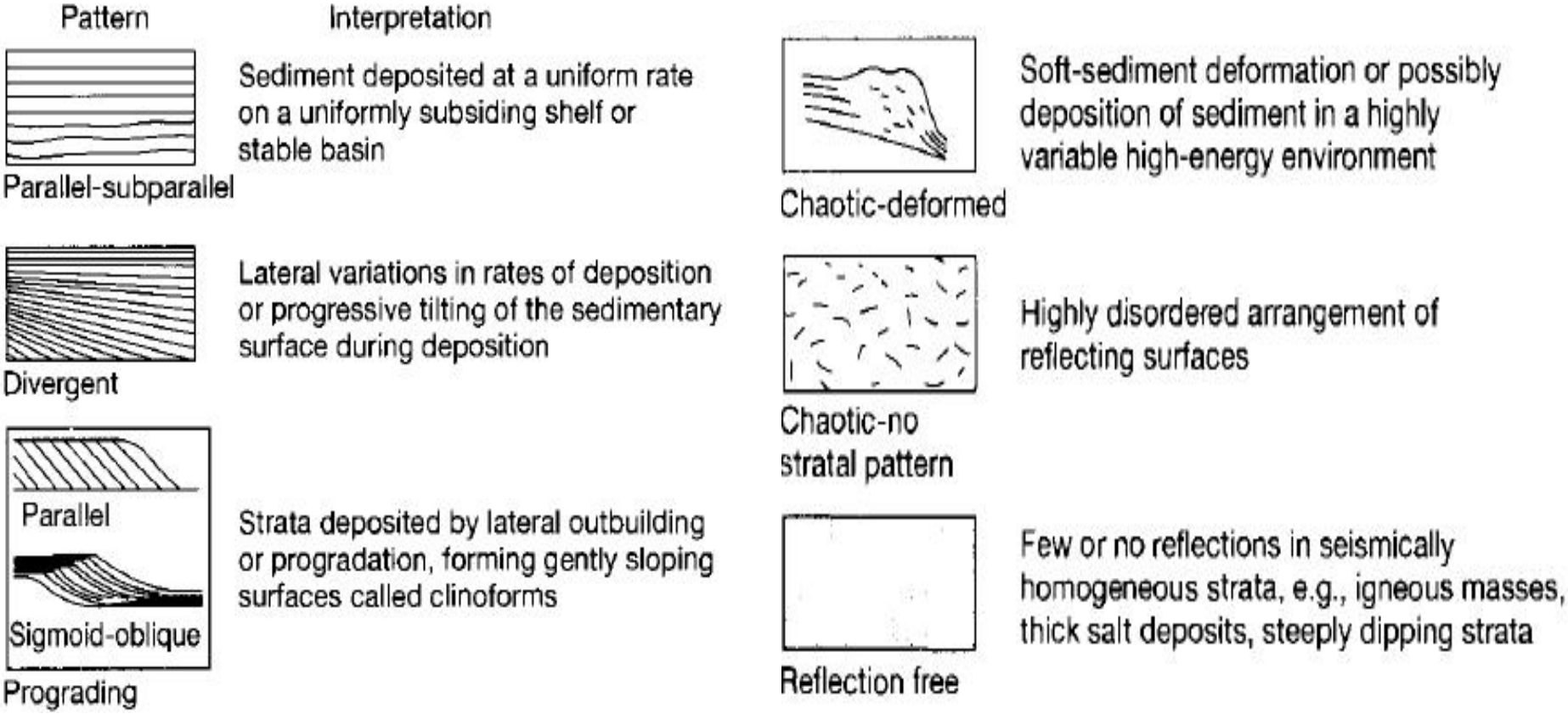


Fig 2. Schematic illustration of seismic reflection configuration.

4. **Reflection frequency**: is also the other important parameter used to calculate ***bed thickness*** and ***fluid content***.

5. **Interval velocity:** is used for ***estimation of lithology, estimation of porosity*** and ***fluid content***.

6. **External form:** is used identify ***the areal association of seismic facies units.***

6.Chemostratigraphy

- **Chemostratigraphy** – based on stable isotopes (e.g. O, C, S, Sr).

Chapter -7

- **Principles and Application of Stratigraphic Correlations**
- ✓ **Use of Stratigraphic Units and Cross-sections in Correlation**
- ✓ **Relative and Absolute Dating**
- ✓ **Log and Fence Diagram**

- **Absolute date**

- Newton time – time and space are independent aspects of objective reality
- Einstein time – time and space are related

Absolute date pinpoints the time in history when something took place.
Absolute time is the same for everyone, everywhere.

- **Relative dating**

Rocks are placed in their proper sequence of the formation.

How we know time?

- **Absolute time:** Process → Rate of process → Time
- **Relative time:** Structural relations of rock bodies (lower or higher).

Relative dating

Nicolaus Steno (1638-1686)

is the founder of relative dating

Principle of cross-cutting relationships

Layers

Dykes (intrusions)

Faults