เอกสารประกอบการสอนรายวิชา
434376
Subsurface Geology
ธรณีวิทยาใต้พื้นผิว

โดย

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มหาวิทยาลัยเทคโนโลยีสุรนารี

สาขาวิชาเทคโนโลยีธรณี

สำนักวิชาวิศวกรรมศาสตร์

มหาวิทยาลัยเทคโนโลยีสุรนารี

สารบัญ

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Chapter 1

Introduction

Prerequisite: 434201 Structural geology

Interpretation of structural geology and basin analysis from drilling well and geophysical data, including subsurface mapping

Course Content

Chapter 1: Introduction

Chapter 2: Sedimentary environment

Purpose:

Subsurface analysis attempts to recognize the interrelationships among depositional systems through direct, indirect information and compare with modern sedimentary environment.

- Direct & Indirect Evidences
- Concepts & methods
    - 2.1 Sedimentary environment
    - 2.2 Sedimentary Facies
    - 2.3 Sedimentary Models
- Sequence/succession

Chapter 3: Environment indication

Purpose:

They are five basic parameters and make data source for over all methodology of subsurface analysis. Before drilling associated facies and geometry can be analyzed and after drilling lithology, sediment structure and palaeontology can be analyzed.

- General
- Associated facies
- Geometry
- Lithology
- Sedimentary structure
- Palaeontology

Chapter 4: Sources of information

Purpose:

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To analysis sedimentary environments, two types of information are in consideration. First is direct source of information such as outcrop, core and cutting. Second is indirect source of information such as wire line logging, seismic data and lab data.

- Cutting
- Core
- Wire line logs
- Seismic

Chapter 5: Subsurface mapping (6 hrs)
Purpose:

The subsurface correlation points is seen either as a surface of a mass of strata containing some property in common or as a tangible trace of as abstract correlation points and interpreting, it leads to subsurface structural contour mapping.

Correlation points of logged data

- Stratigraphic law
- Contour lines
- Nomograms
- Cross-sections
- Structural contour maps

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Chapter 2

Sedimentary Environment

1. Sedimentary environment

Purpose: Subsurface analysis attempts to recognize the interrelationships among depositional systems through direct, indirect information and compare with modern sedimentary environment.

1.Direct & Indirect Evidences
2.Concepts & methods
  2.1 Sedimentary environment
  2.3 Sedimentary Facies
  2.3 Sedimentary Models
3. Sequence/succession

Petroleum Exploration and Production

1. Surface Exploration:

  a. geological survey
  b. filed work
  c. mapping

2. Subsurface Exploration

  a) Geophysical Surveys: Seismic
  b) Core and cutting samples
  c) Wire line logging

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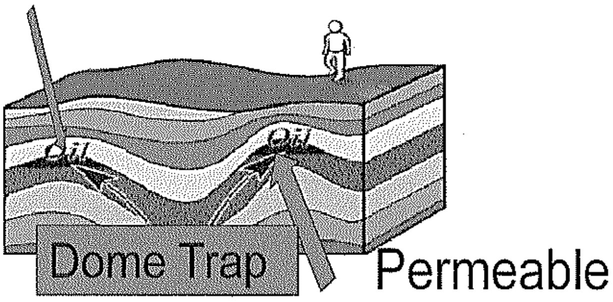
Reservoir rocks (Oil Traps)
Impermeable



Traps →→ Reservoir (Porosity & Permeability)

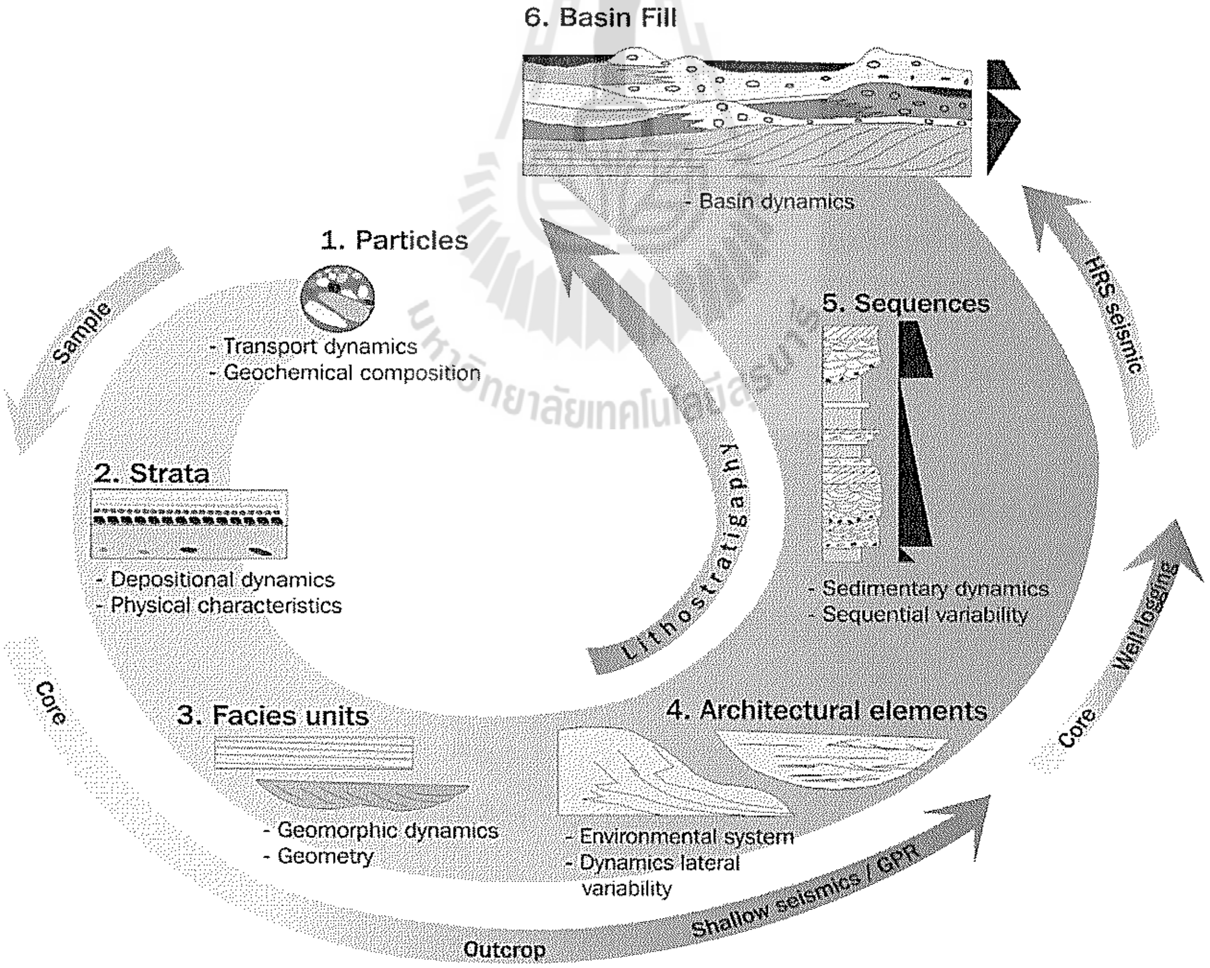
- The properties controlled by depositional process thus their prediction is base on facies analysis
- The facies analysis is accomplished chiefly through the construction of an ancient sedimentary environment model.

Diagram to show how sedimentary rocks may be differentiated by:

1. Facies
2. Lithostratigraphy
3. Chronostratigraphy
4. Sequence stratigraphy

These may then be interpreated as to environment and time

Sedimentary Facies analysis



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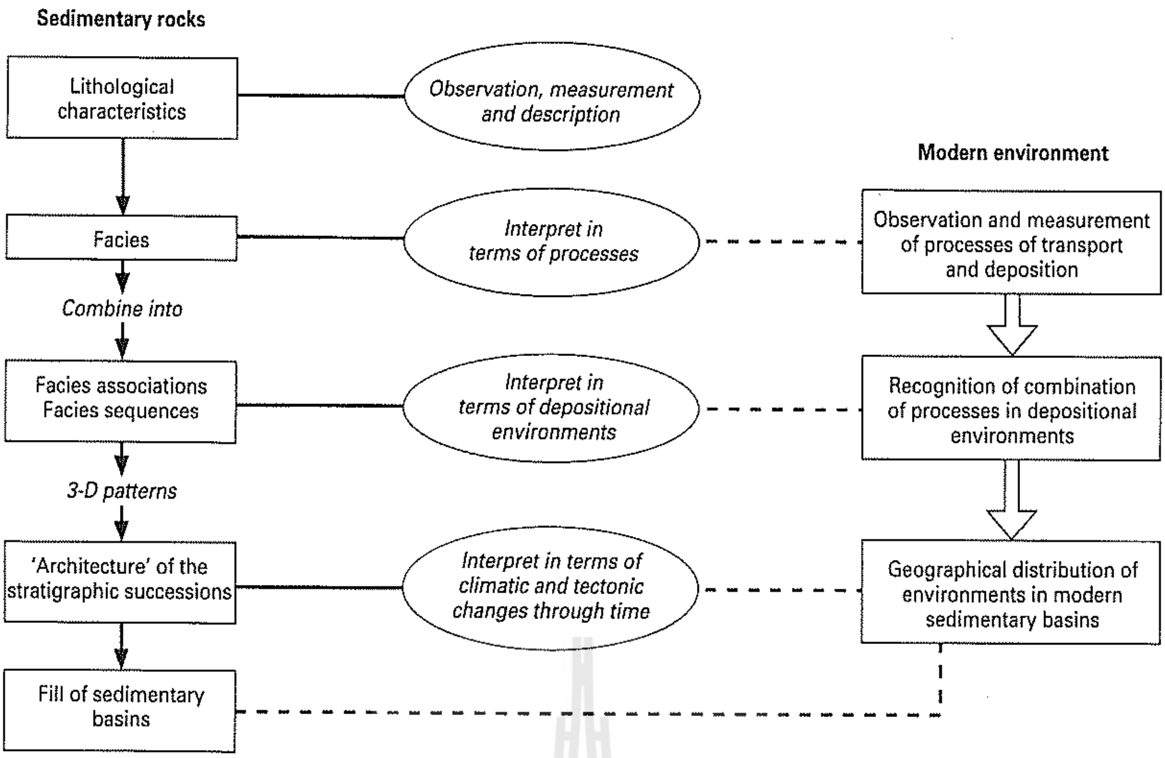

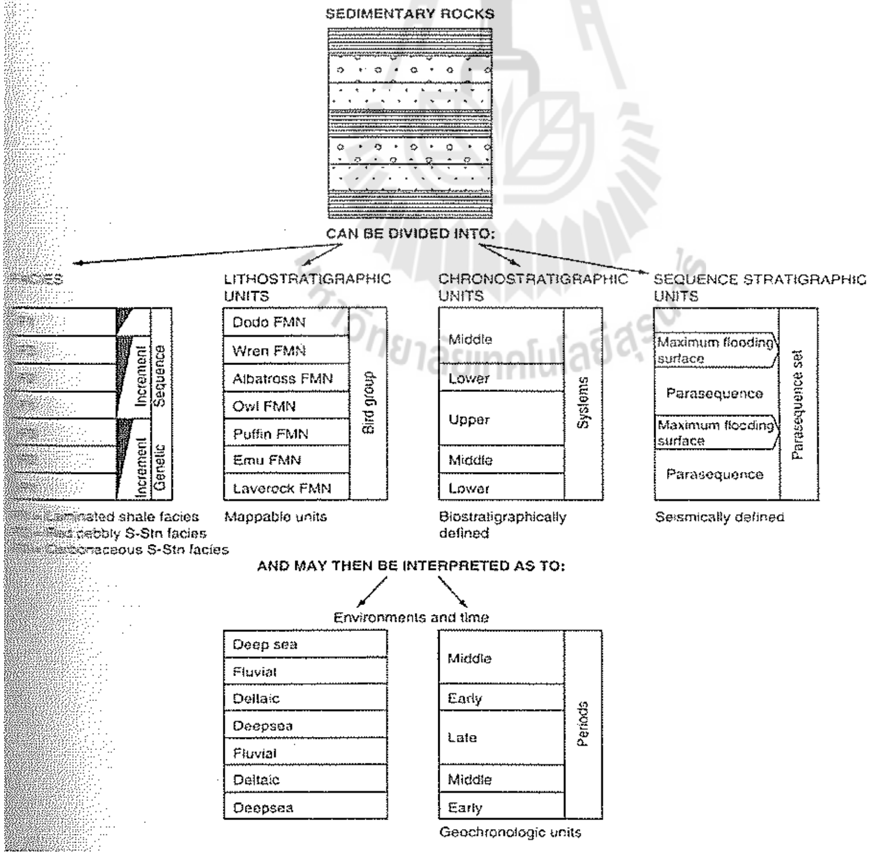

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1. Information for sedimentary environment analysis

There are two evidences:

1) Direct evidence: surface & subsurface information that can be use this data by do not interpretation;

- Outcrop
- Cutting
- Core samples
- Fluid samples

2) Indirect evidence: subsurface information that have to interpreting before to use this data;

- Electrical logs e.g. SP, Density, Resistivity, caliper, neutron, sonic logs etc.
- Seismic section
  - Both Direct & Indirect evident have to mix together to product geologic model

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ส่วนประกอบและขั้นตอนของการศึกษาลำดับชั้นหินโดยตรง

1.1 Direct evidence- study from outcrop, cutting samples and core samples

กาลำดับชั้นหินตามลักษณะหิน (Lithostratigraphy)	การลำดับชั้นหินตามชีวภาพ (Biosteatigraphy)
1. การสังเกตและการรวบรวม	
- แนวตั้งของการลำดับชั้นหินตามลักษณะหิน (Litgostratigraphic cloumn)	- แนวตั้งของการลำดับชั้นหินชีวภาพ (Biostratigraphic column)
-ศิลาวิทยาทางหินตะกอน (Sedimentary Perology)	- บรรพชีวินวิทยา (Paleontology)
- คุณสมบัติของเม็ดตะกอน	- สัณฐานวิทยา (morphology)
- การจำแนกหินตะกอน	- การจำแนกสิ่งมีชีวิต
- กระบวนการทางหินตะกอน	- กระบวนการทางชีวภาพ
2. การวิเคราะห์	
- การเทียบสัมพันธ์ตามลักษณะหิน (Lithologic correlation)	- การเทียบสัมพันธ์ตามชีวภาพ (Biostratigraphic correlation)
- การเทียบความสัมพันธ์ลำดับชั้นหินตามอายุกาล (Chronostratigraphic correlation)	
- ธรณีวิทยาแปรสัณฐานทางหินตะกอน (Lithologic correlation)	- วิวัฒนาการของสิ่งมีชีวิต (Organic evolution)
- การเทียบความสัมพันธ์ลำดับชั้นหินตามอายุกาล (Chronostratigraphic correlation)	
- การเทียบสัมพันธ์ตามลักษณะหิน (Sedimentary tectonics)	- การเทียบสัมพันธ์ตามชีวภาพ (Biostratigraphic correlation)
3. การแปลความหมายและการสังเคราะห์	
ลักษณะภูมิประเทศในอดีต (Paleogeography) และธรณีประวัติ (Geologic history)	

ประเภทการจำแนกลำดับชั้นหิน (Stratigrapsic Categories)	**ชื่อหน่วยลำดับชั้นหินที่สำคัญ** (Principal Stratigraphic Unit-Terms)
การลำดับชั้นหินตามลักษณะหิน (Lithostratigraphy)	กลุ่มหิน (Grorp) หมวดหิน (Formation) หมู่หิน (Member) ชั้นหิน (Bed (S))
การลำดับชั้นหินตามชีวภาพ (Biotratigraphy)	ส่วนชั้นชีวภาพ (Biozones): ส่วนชั้นกลุ่มชีวิน (Assmblage-zones) ส่วนชั้นช่วงชีวิน (Range-zones) ส่วยชั้นแอกมี (Acme-zones) ส่วนชั้นระหว่างแนวชั้นชีวภาพ (Interval-zones) เป็นต้น
การลำดับชั้นหินตามอายุกาล (Chronostratigraphy)	หินบรมยุค (Eonthem) หินมหายุค (Erathem) หินยุค (System) หินสมัย (Series) หินช่วงอายุ (Stage) หินรุ่น (Chronozone)
การลำดับชั้นหินตามลักษณะอื่นๆ ทางแร่ ทางสภาพแวดล้อม ทางความไหวสะเทือน (seismic) ทางสนามแม่เหล็กโลก (magnetic) เป็นต้น	ส่วนชั้น_______(zones)

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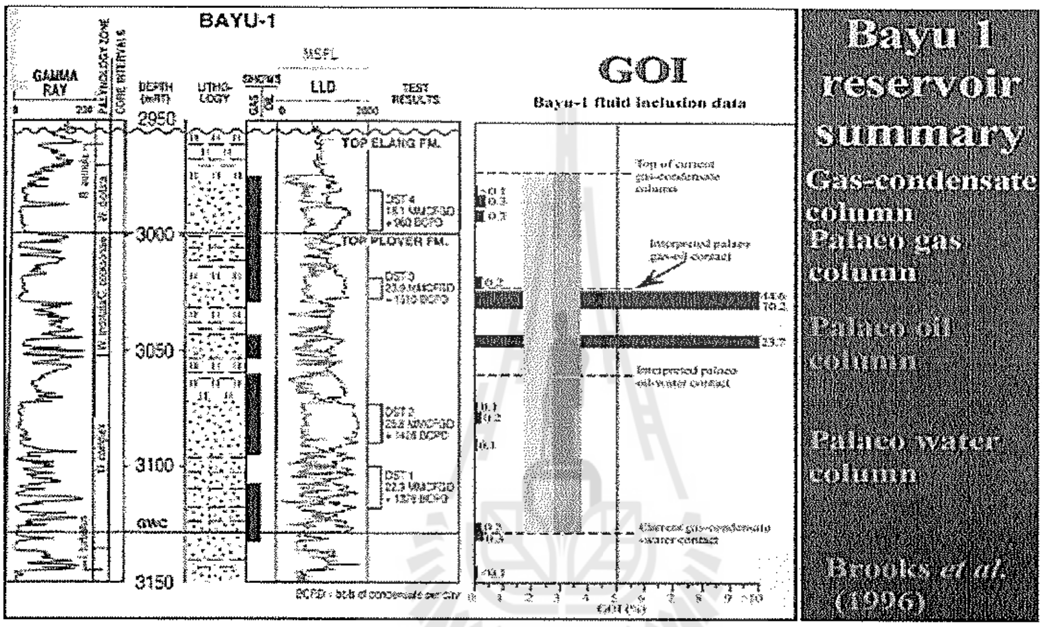
Stratigraphy แบ่งออกเป็น
1. Lithostratigraphy
การลำดับชั้นหินด้วยการรวมชั้นหินเข้าด้วยกันเป็นหมวดต่าง ๆ โดยอาศัยลักษณะทางกายภาพของหิน

2. Biostratigraphy
การลำดับชั้นหินด้วยการรวบรวมชั้นหินเข้าด้วยกันเป็นหน่วยต่าง ๆ โดยอาศัยซากดึกดำบรรพ์ที่ปรากฏอยู่ในชั้นหิน

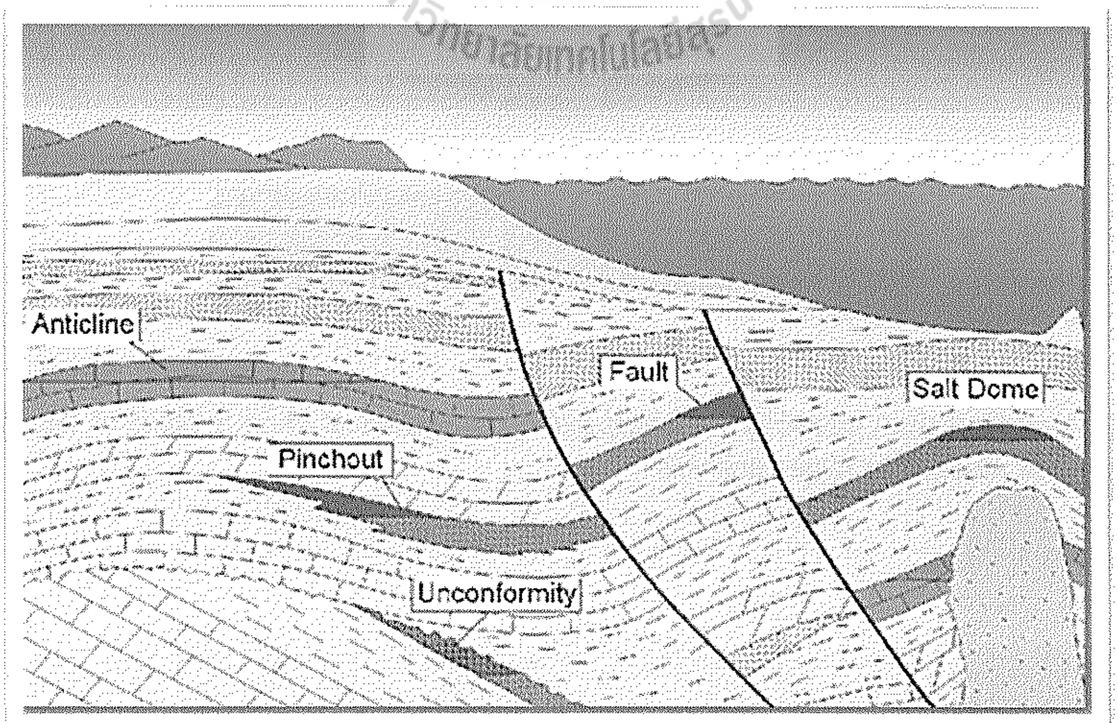
3. Chronostratigphy
การลำดับชั้นหินด้วยการรวมชั้นหินเข้าด้วยกันเป็นหน่วยต่าง ๆ โดยอาศัยอายุและความสัมพันธ์ทางกาลเวลาของหิน

1.2 **Indirect evidences:** Study from

- **Wireline Logs**



- **Seismic Section**



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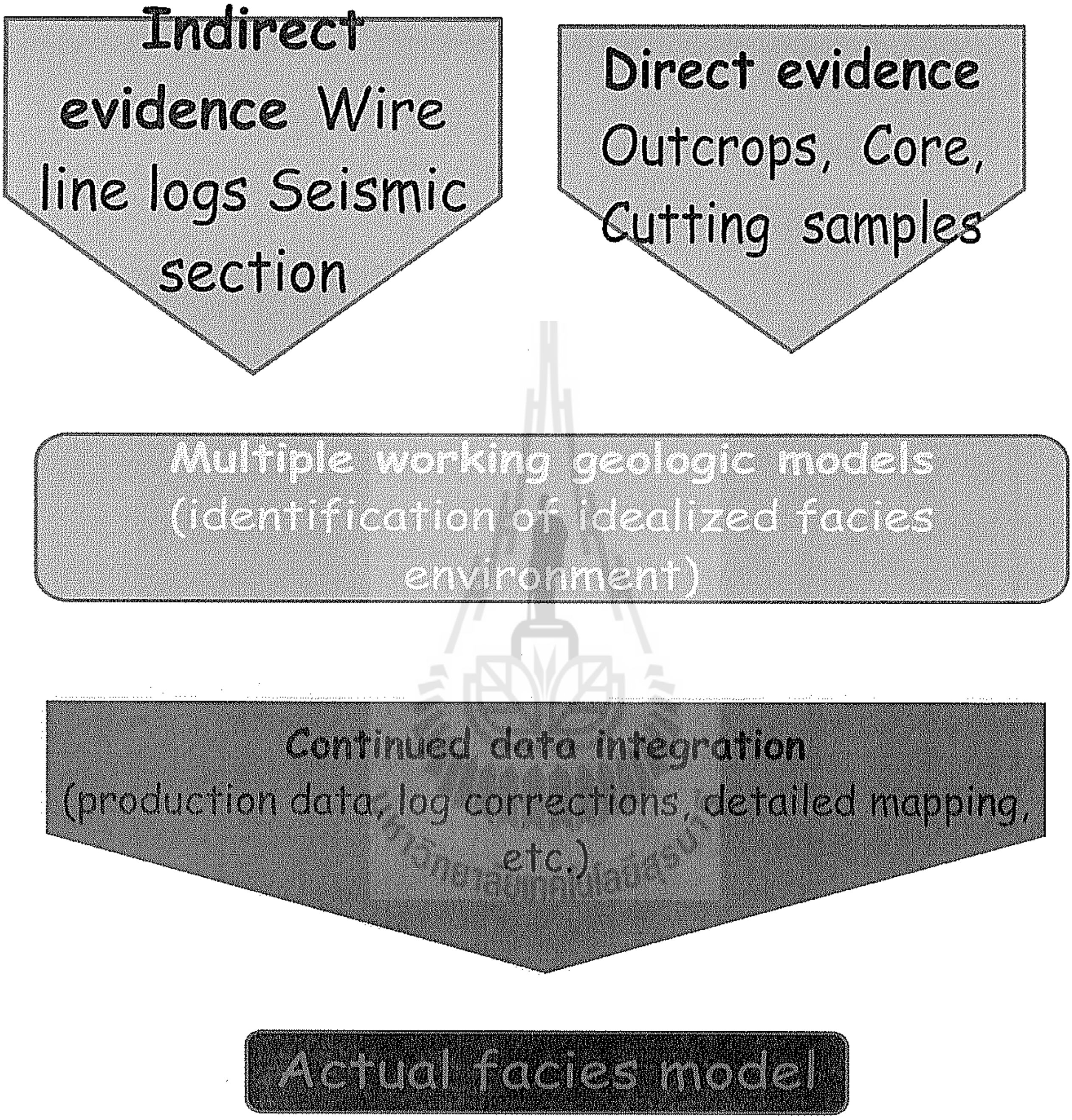


Idealized flow chart showing the incorporation of various of various types of data to generate models for facies analysis

2. Concepts and methods

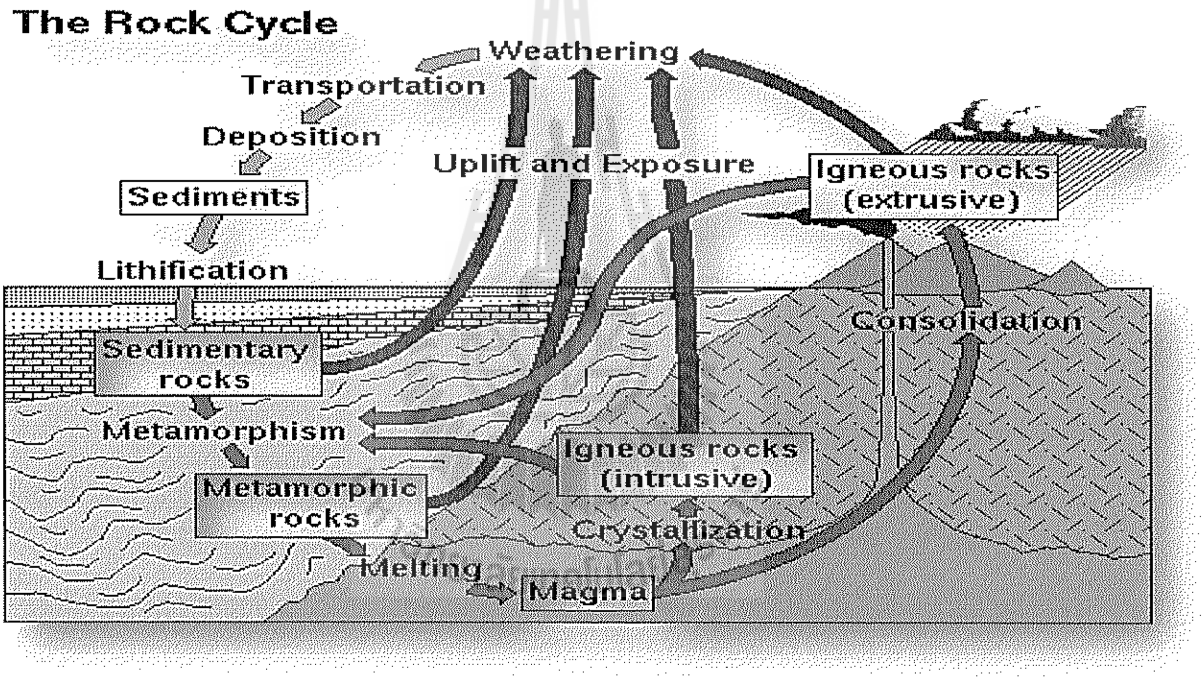
2.1 Sedimentary Environments
2.2 Sedimentary Facies
2.1 Sedimentary Models

2.1 Sedimentary Environment

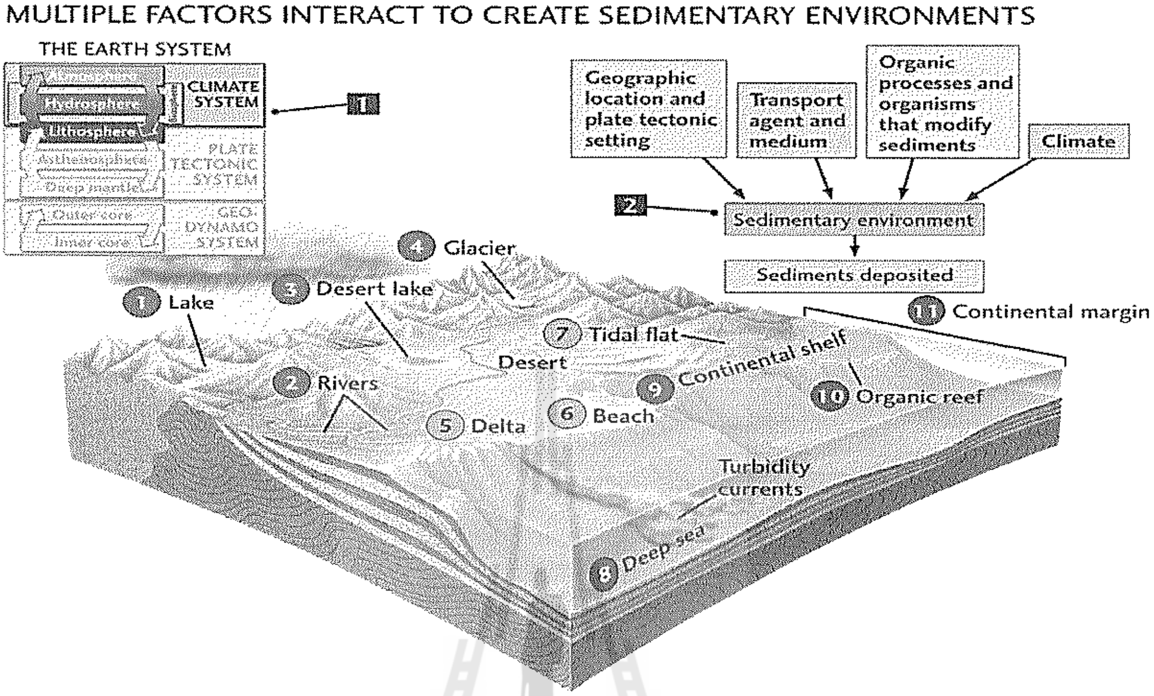
- **Sediments:** loose particulate material (clay, sand, gravel, etc.)

Sediment becomes sedimentary rock through lithification, which involves:

- Compaction
- Cementation
- Recrystallization (of carbonate sediment)



- **Environment:** part of earth's surface which can be distinguished from adjacent parts because of variations in conditions (physical, chemical, organic) that influence the surface
- **Sedimentary environment:** All of the physical, chemical, biological, and geographic conditions under which sediments are deposited.



Sedimentary Environment

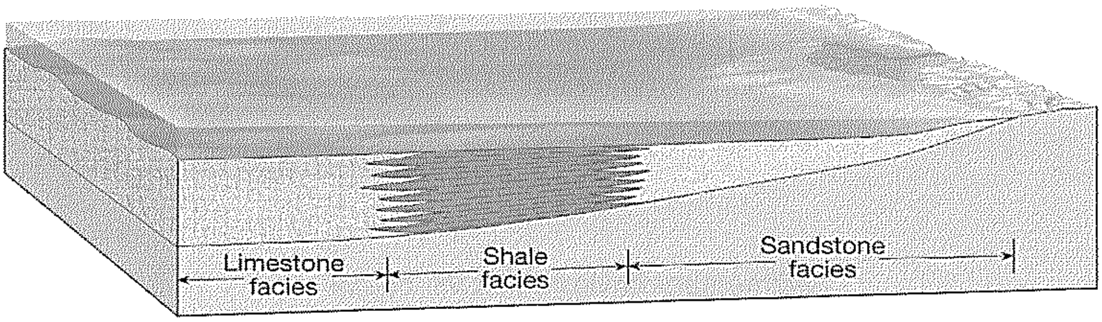
2.2 Sedimentary Facies

Facies: The overall characteristics (physical, chemical and biological) of a rock unit that reflect its origin and differentiate the unit from others around it.

The facies concept refers to the sum of characteristics of a sedimentary unit, commonly at a fairly small (cm-m) scale

- Lithology
- Grain size
- Sedimentary structures
- Color
- Composition
- Biogenic content

In a shallow marine setting, the different facies represent different depositional environments



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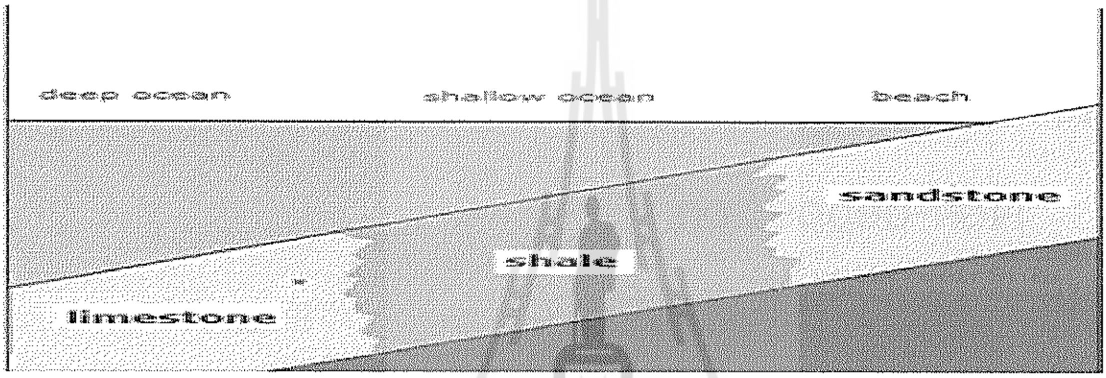
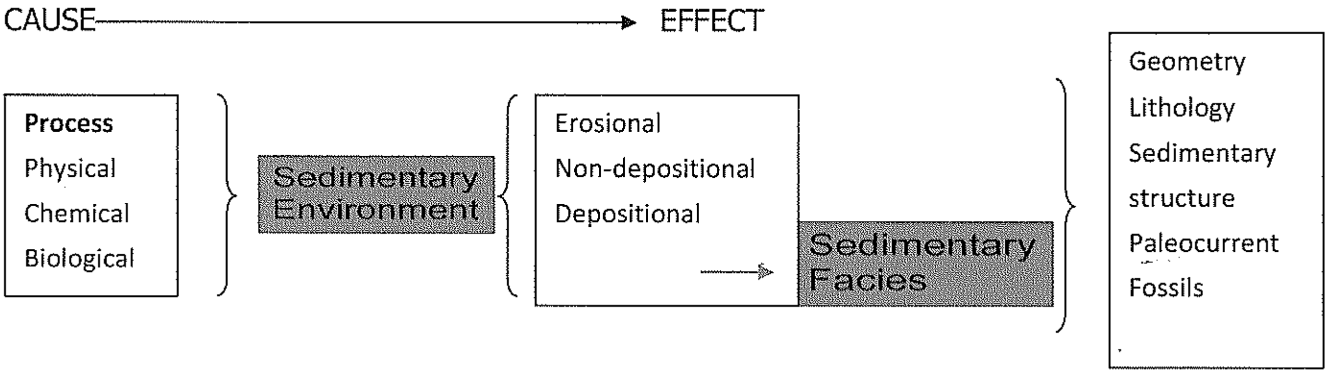


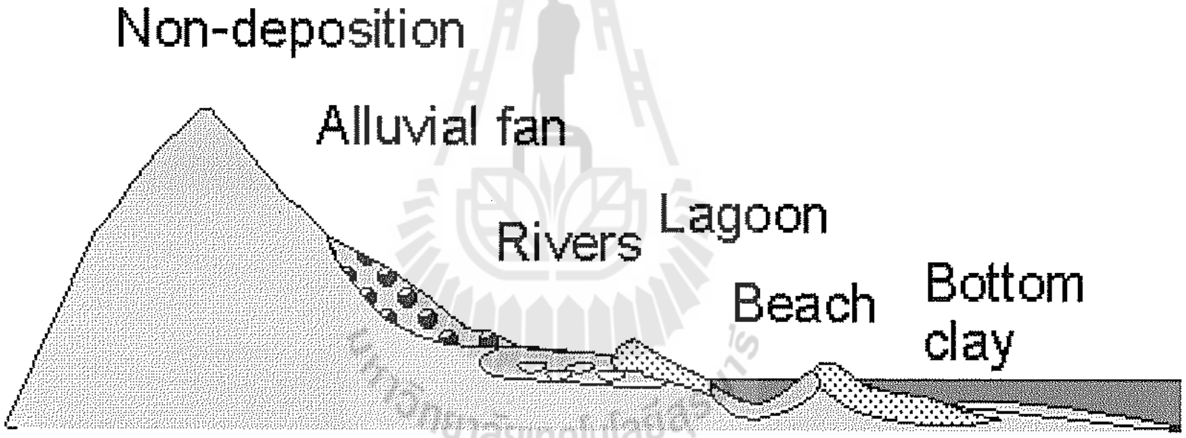
Example of sedimentary fancies



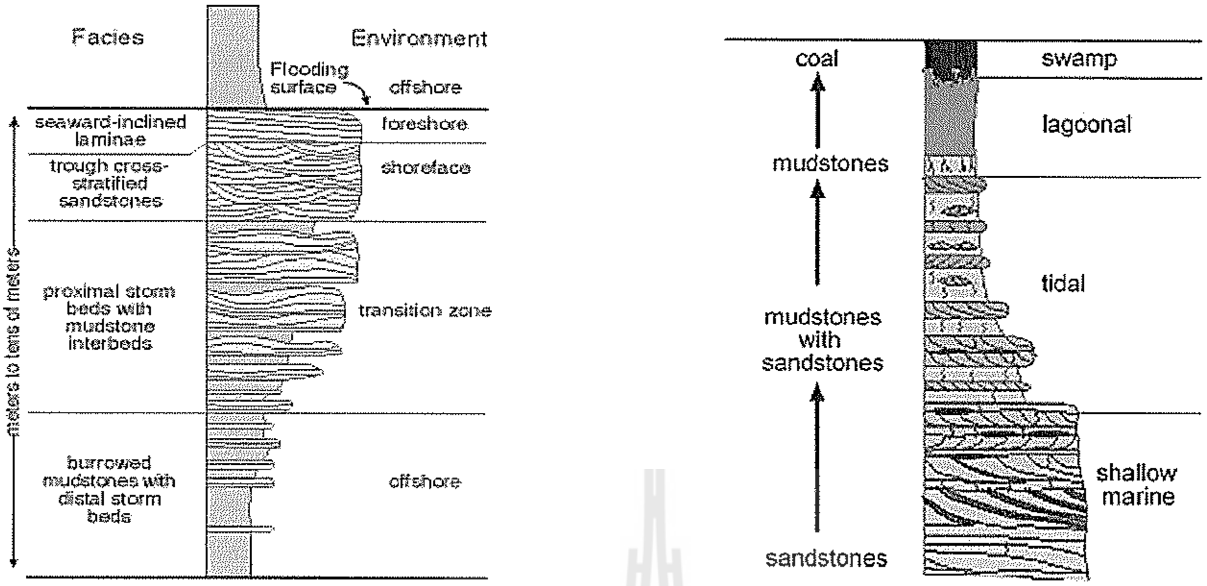
Sedimentary Environment vs. Facies

The relationship between sedimentary environments & facies, that sedimentary facies is the product of a depositional environment, a particular type of sedimentary environment

Different environments produce different sedimentary rocks or characteristics (facies)



- Facies analysis is the interpretation of strata in terms of depositional environments (or depositional systems), commonly based on a wide variety of observations
- Facies associations constitute several facies that occur in combination, and typically represent one depositional environment
- Facies Sequence (or successions) are facies associations with a characteristic vertical order
- Sequence: Relatively conformable (that is, containing no major unconformities), genetically related succession of strata bounded by unconformities or their correlative conformities.



Facies succession or Facies sequence

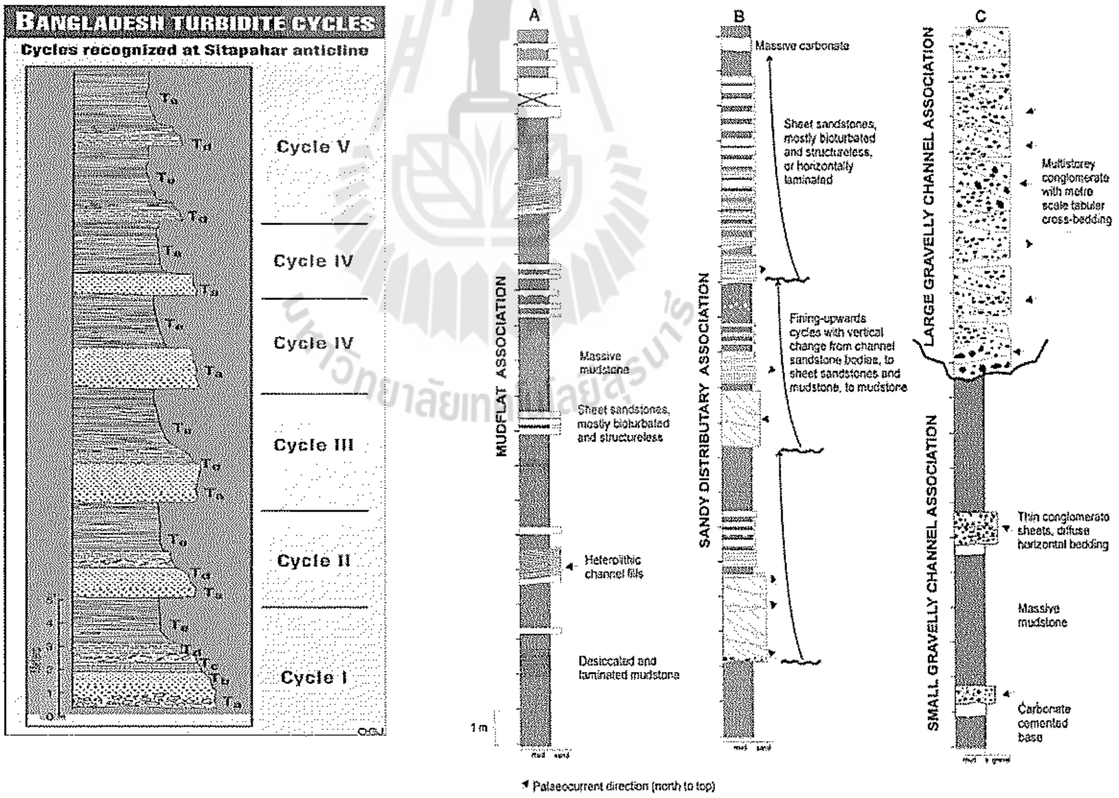
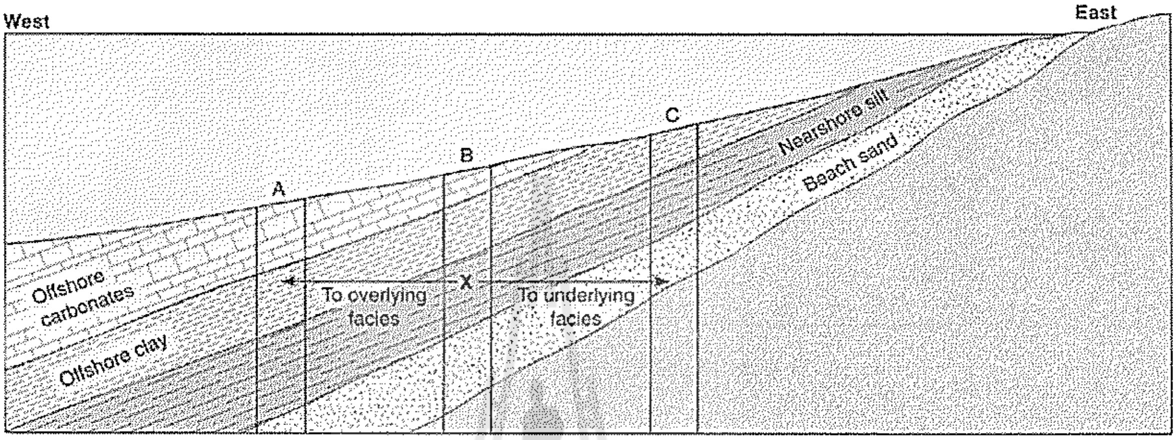


Fig 13. Facies Sequence/Cycle

Walther's Law

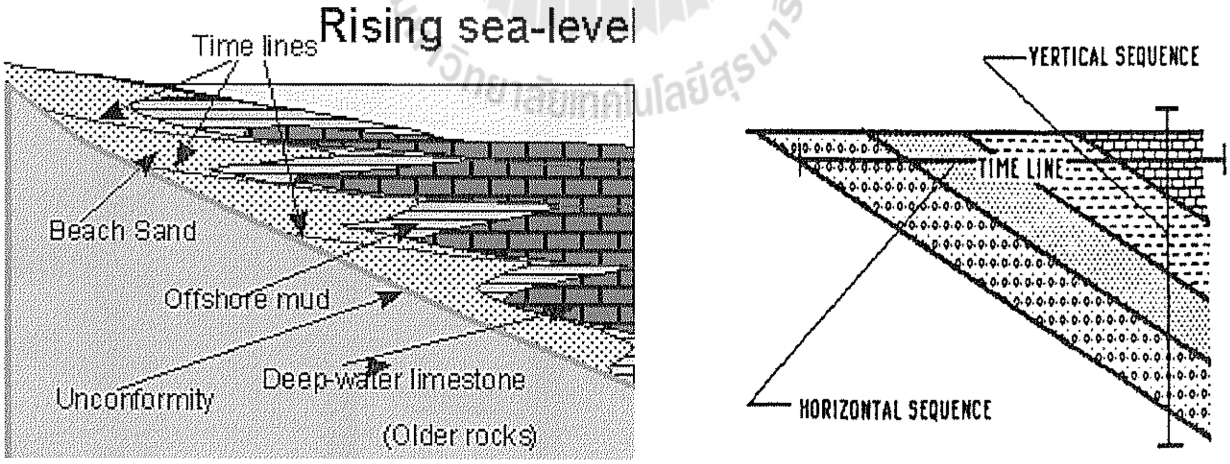
- Walther's Law (1894) states that " two different facies found superimposed on one another and not separated by an unconformity, must have been deposited adjacent to each other at a given point in time" (Fig. 14)
- The result is a vertical sequence of beds. The vertical sequence of facies mirrors the original lateral distribution of sedimentary environments.



Facies Change

Sedimentary rocks change laterally. These changes reflect the different environments where the rocks formed.

- caused by changes in sea-level, shifting climates, etc.
- Walther's law - vertical change in facies is the same as a horizontal one.



Facies Change

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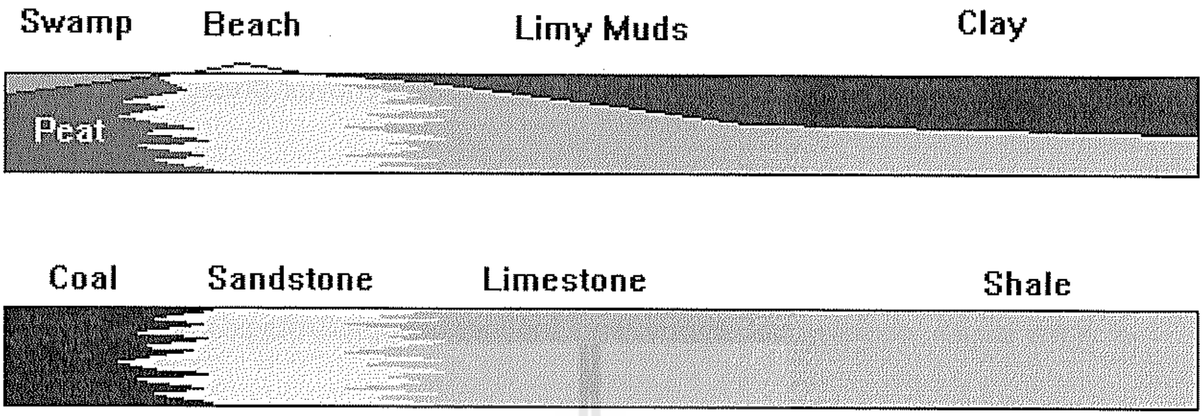
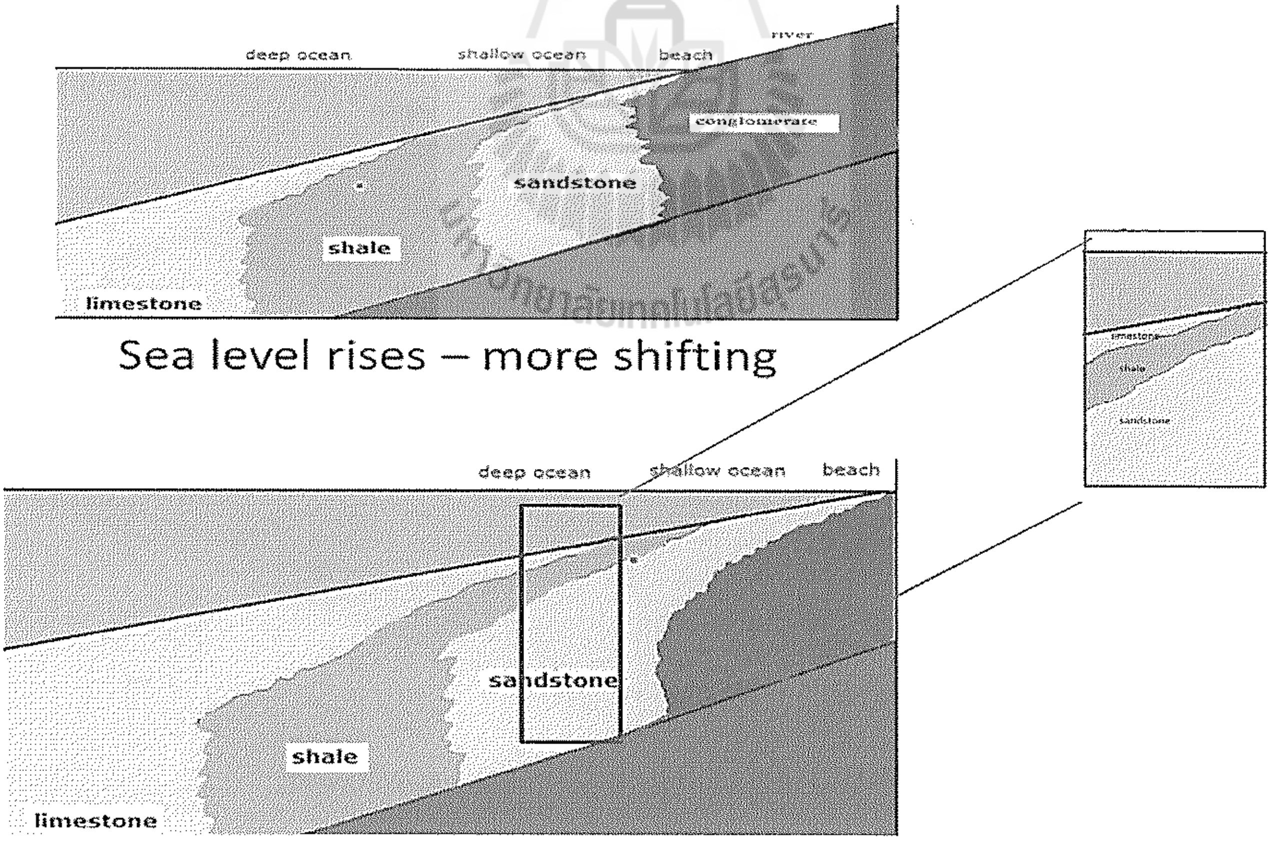
Sedimentary rocks change laterally



Shifting of facies



Sea level rises – more shifting

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Type of Sedimentary Facies can be devided into:

1. **Lithofacies** (physical and chemical characteristics of rocks)
2. **Biofacies**-Body fossils: the physical remains of an organism preserved in rock. (macrofossil and microfossil content)
3. **Ichnofacies** -Trace fossils: the record of organisms' behavior preserved in rock.

Lithofacies: the basic descriptive 3-D sedimentary rock elements that record in terms of their lithology, texture, geometry, sedimentary structure and paleology that related characteristics, a specific depositional setting or event and can be interpreted in terms of water depth, depositional energy, and sediment supply/biologic input.

Lithofacies concept

1. Sediment properties are directly derived from the sedimentary environment the deposits originated in. This includes lithology and sedimentary architecture
2. Unit scale depends on the model application, but is typically m-scal
3. Units are lithofacies associations rather than individual lithofacies
4. Sedimentary environments repeat itself in geological time.

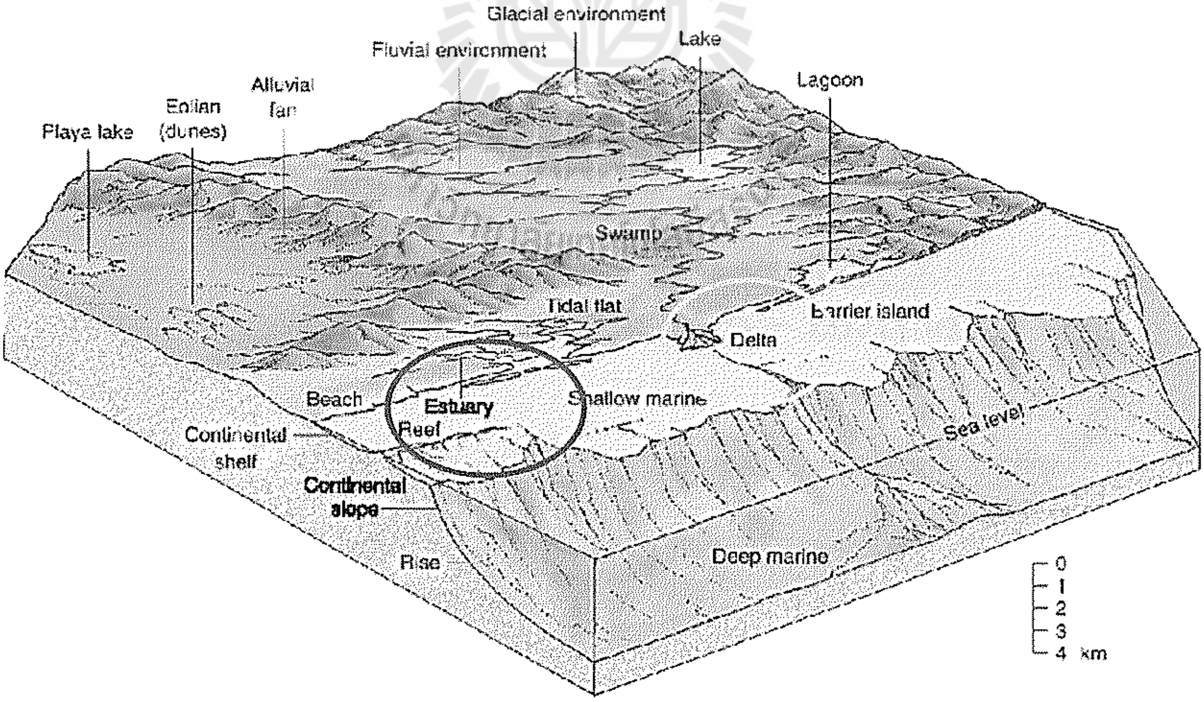
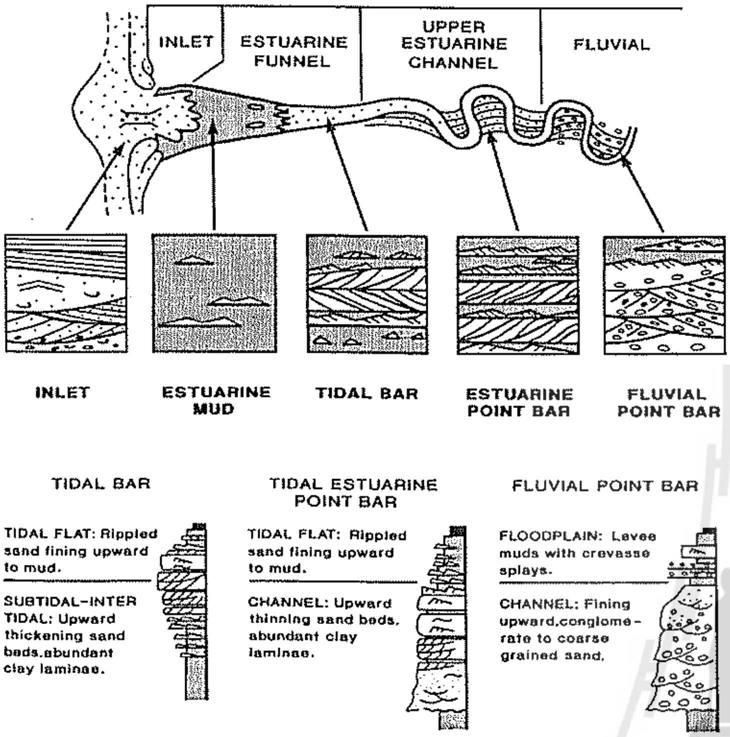


Diagram illustrating some depositional environments.

Example: estuarine environment

Estuarine Lithofacies units

- Marine lithofacies units
- Coastal lithofacies units
  - "Tidal channel"
  - "Tidal flat"
  - "Salt marsh"
  - "Coastal lagoon"
- Fluvial lithofacies units



Lithofacies Unit of Estuary

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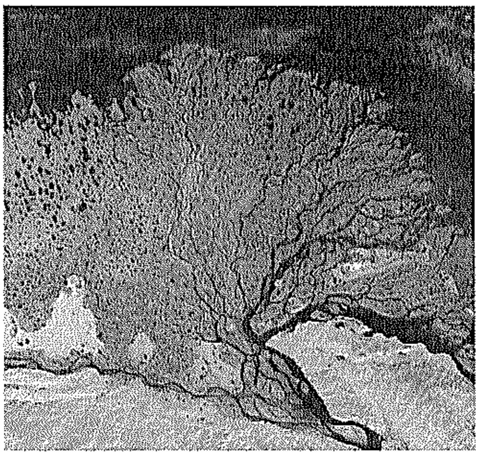
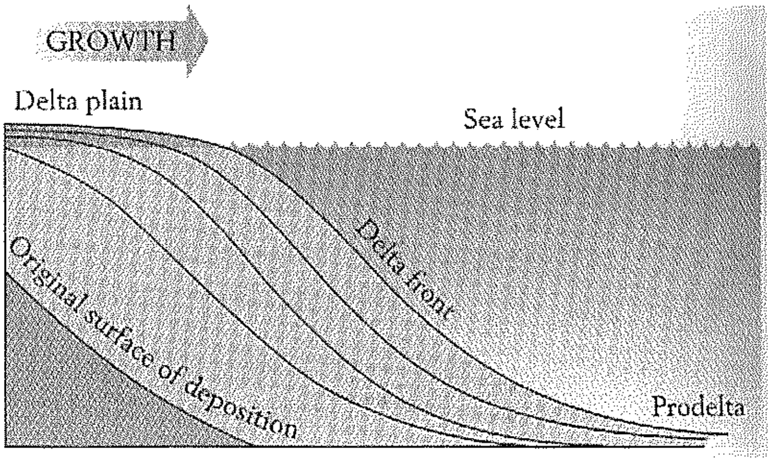
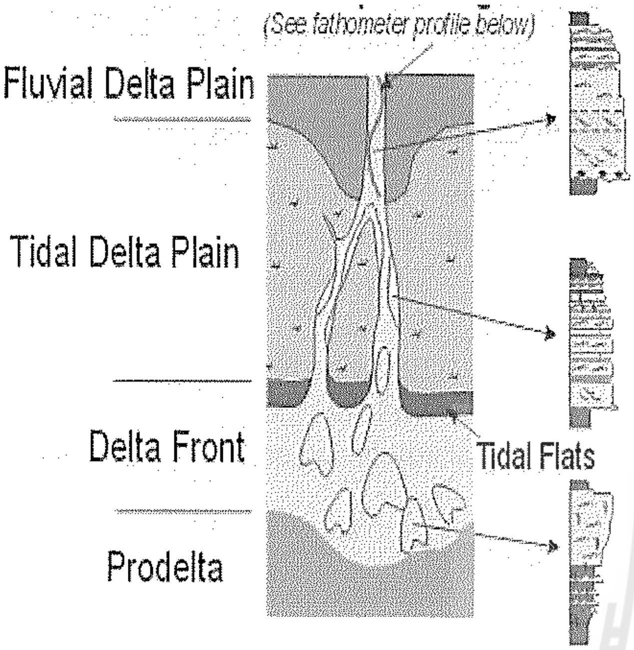
Example: Deltaic System

Deltaic system composed of

1. delta-plain silt & sand
2. delta front sand
3. prodelta shale facies.





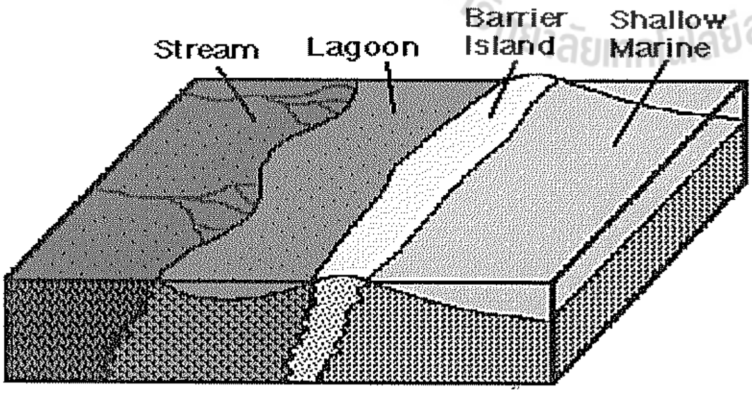


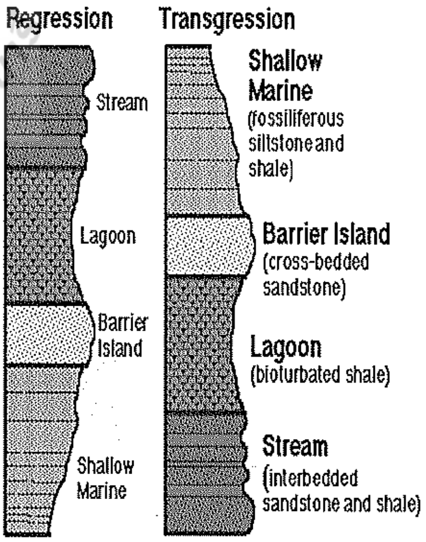
Fluvial Distributary Channel
- organic clay
- rippled sand-mud lamination
- cross bedded medium sand with
- carbonaceous laminae

Tidal Distributary Channel
- rippled sand-mud lamination with scattered burrows
- cross bedded and rippled fine to medium sand with mud laminae

Distributary Mouth Bar
- fine to medium bioturbated sand
- bioturbated mud with fine sand
- massive prodelta mud

Lithofacies Unit of Delta

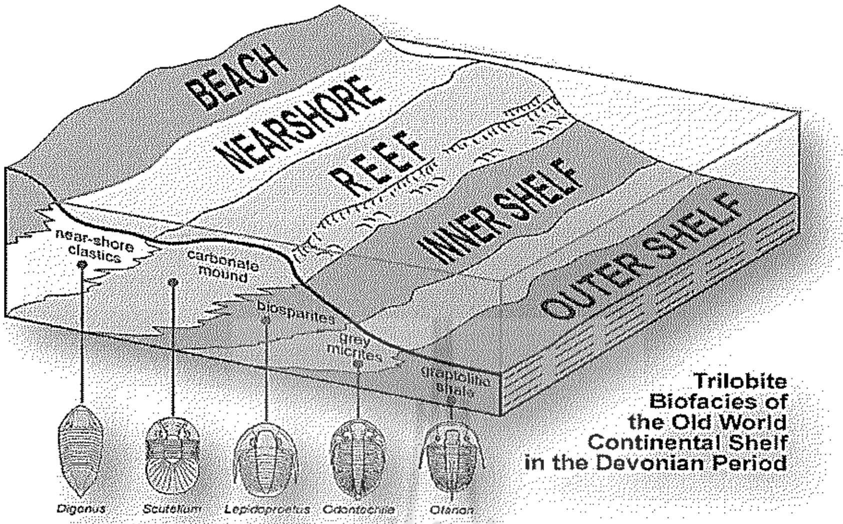


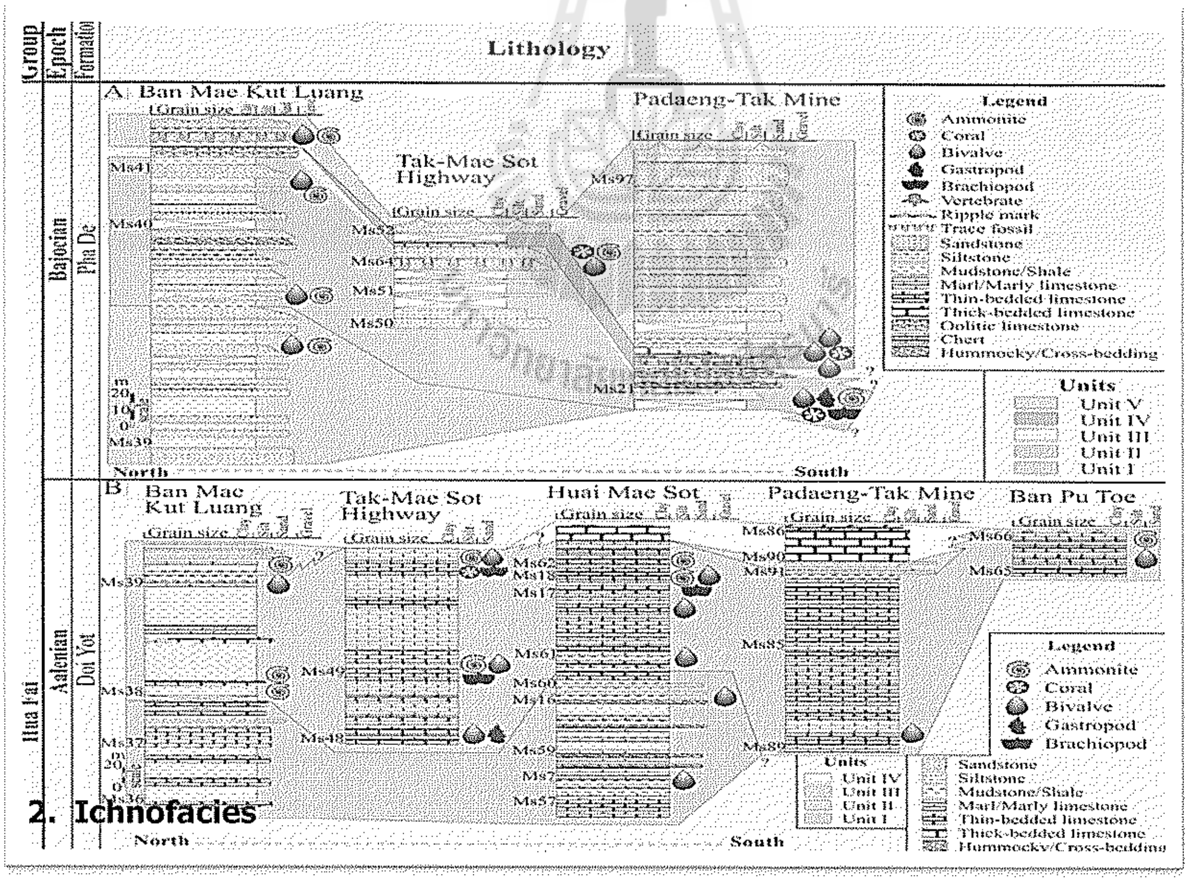


- Lagoon - quiet water, bioturbated shales
- Beach - high energy, cross-bedded sandstone

1. Biofacies

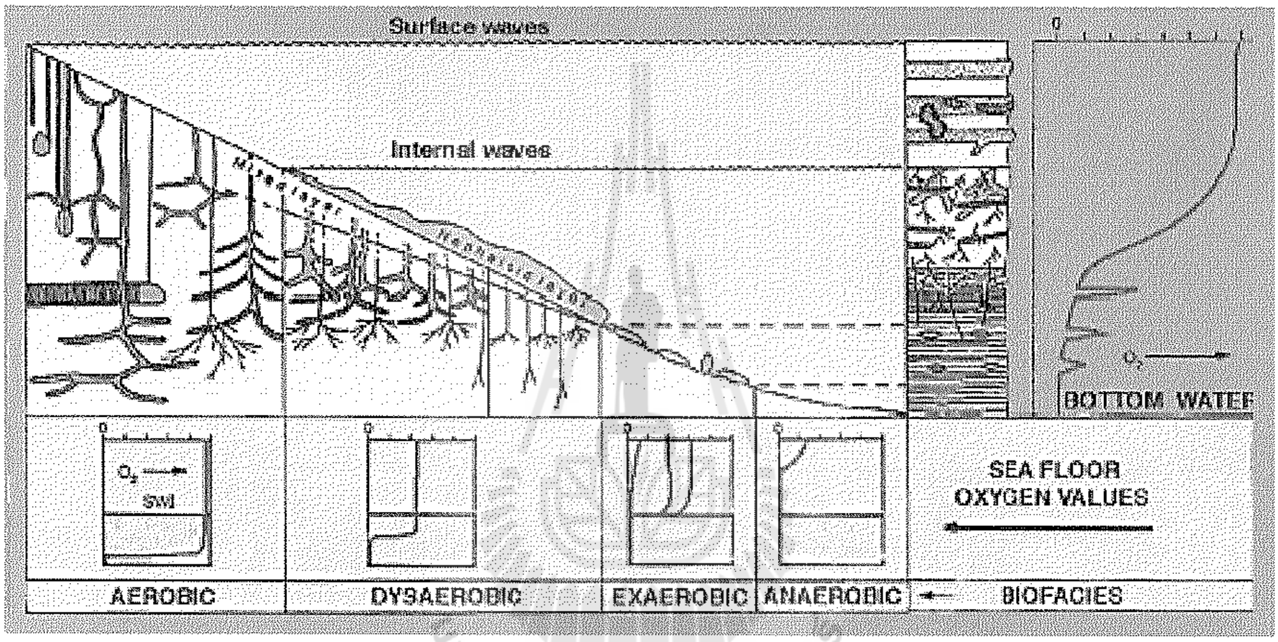
Biofacies: A rock unit differing in biologic aspect from laterally equivalent biotic groups. Lateral variation in the biologic aspect of a stratigraphic unit.





2. Ichnofacies

- The concept of Ichnofacies used as a paleontological tool to analyze assemblages of trace fossils to determine ancient depositional settings and facies of sedimentary rocks. The character determines the ichnofacies assemblage into:
- Soupground: Slurry
- Softground: Grains in contact, but wet Firmground: De-watered, compacted
- Hardground: Cemented



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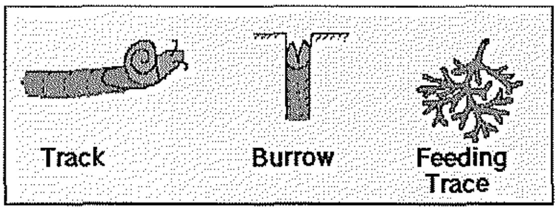
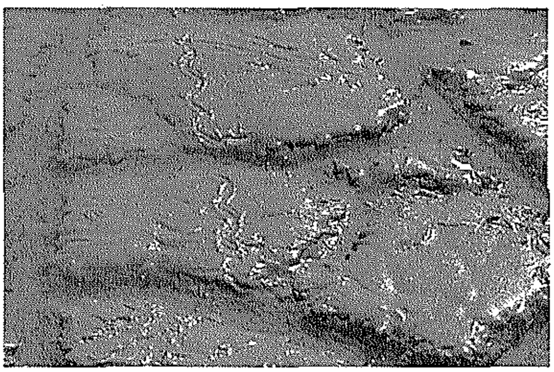
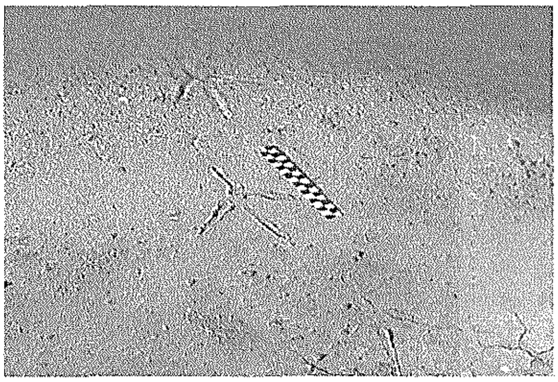
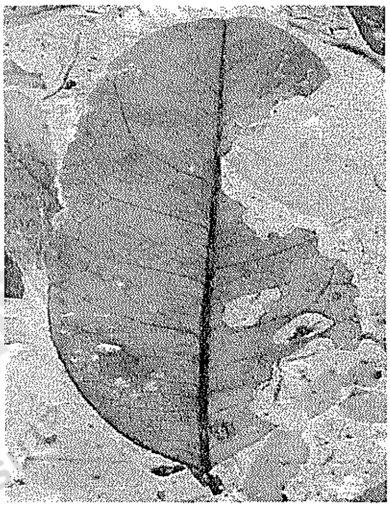






Bird Track

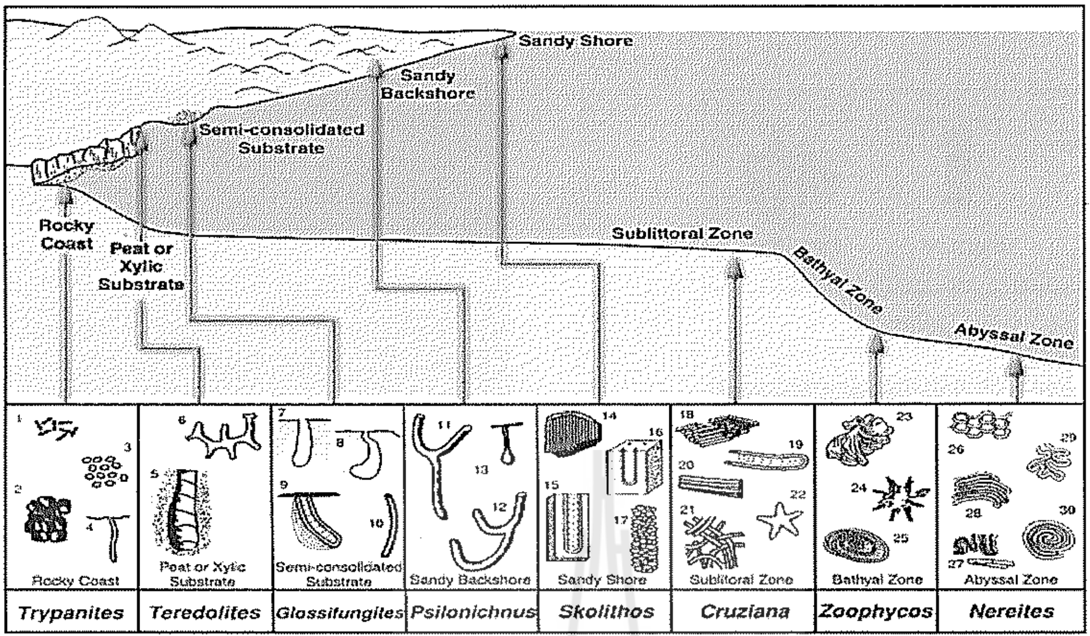
Snake Trail



Burrow

Feeding Trace

Example of ichnofacies



after Seilacher image from http://research.eas.ualberta.ca/ichnology/

Distribution of Common Marine Ichnofacies

Typical trace fossils include: *1) Caulostrepsis; 2) Entobia; 3) echinoid borings; 4) Trypanites; 5) Teredolites; 6) Thalassinoides; 7, 8) Gastrochaenolites or related genera; 9) Diplocraterion (Glossifungites); 10) Skolithos; 11,12) Psilonichnus; 13) Macanopsis; 14) Skolithos; 15) Diplocraterion; 16) Arenicolites; 17) Ophiomorpha; 18) Phycodes; 19) Rhizocorallium; 20) Teichichnus; 21) Planolites; 22) Asteriacites; 23) Zoophycos; 24) Lorenzinia; 25) Zoophycos; 26) Paleodictyon; 27) Taphrhelminthopsis; 28) Helminthoida; 29) Cosmorhaphe; 30) Spirorhaphe.*

Distribution of Common Marine Ichnofacies

2.3 Sedimentary Model

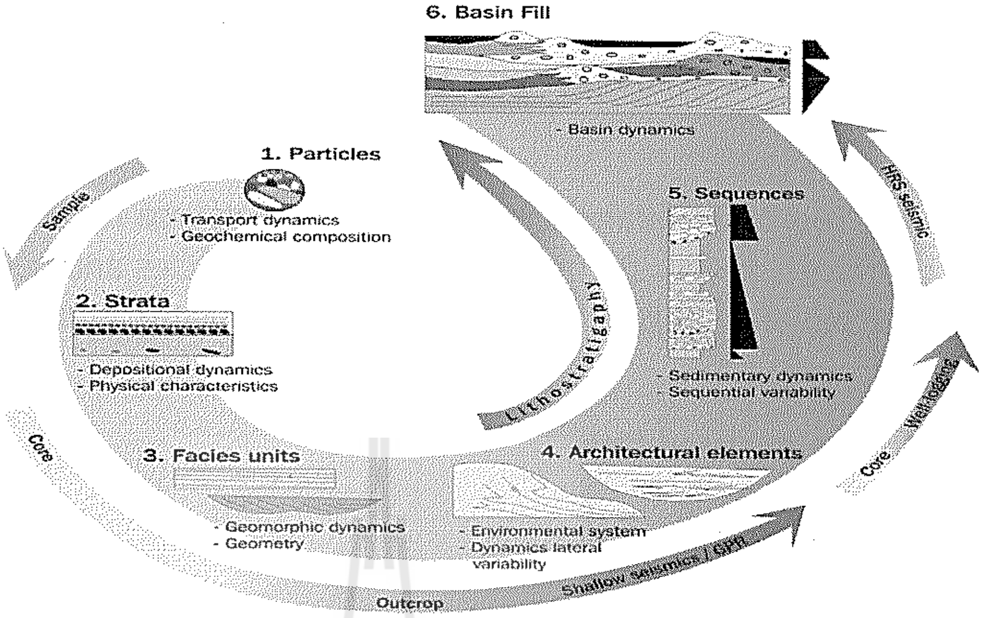
Sedimentary models serve many function can be used to predict:

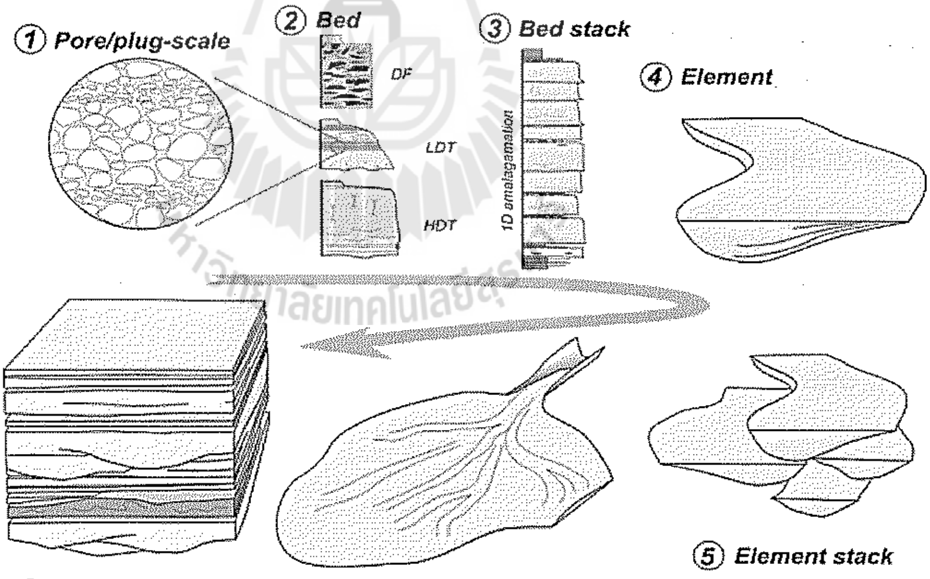
- the distribution of porosity and permeability within reservoirs
- the distribution of both syngenetic and epigenic ores sedimentary rock (ancient sedimentary environment)

Sedimentary Model

- Sedimentary logs are one-dimensional representations of vertical sedimentary successions
- Architectural elements are the two- or three-dimensional 'building blocks' of a sediment or a sedimentary rock
- The three-dimensional arrangement of architectural elements is known as sedimentary architecture
- Facies models are schematic, three-dimensional representations of specific depositional environments that serve as norms for interpretation and prediction

Architectural elements





Peter Haughton, 2007

Depositional Archtecture

Chapter 3

Sedimentary Environment indicators

Purpose:

There are five basic parameters and make data source for over all methodology of subsurface analysis. Before drilling associated facies and geometry can be analyzed and after drilling lithology, sediment structure and paleontology can be analyzed.

- Associated facies
- Geometry
- Lithology
- Sedimentary structure
- Paleontology

Methodology of Facies Analysis

There are five basic parameters:

1. Associated facies: stratigraphy
2. Geometry: seismic data

Early State

3. Lithology: core, cutting, wireline log, seismic data
4. Sedimentary structure: core, logs, Seismic
5. Palaeontology: cutting, core

After Drilling

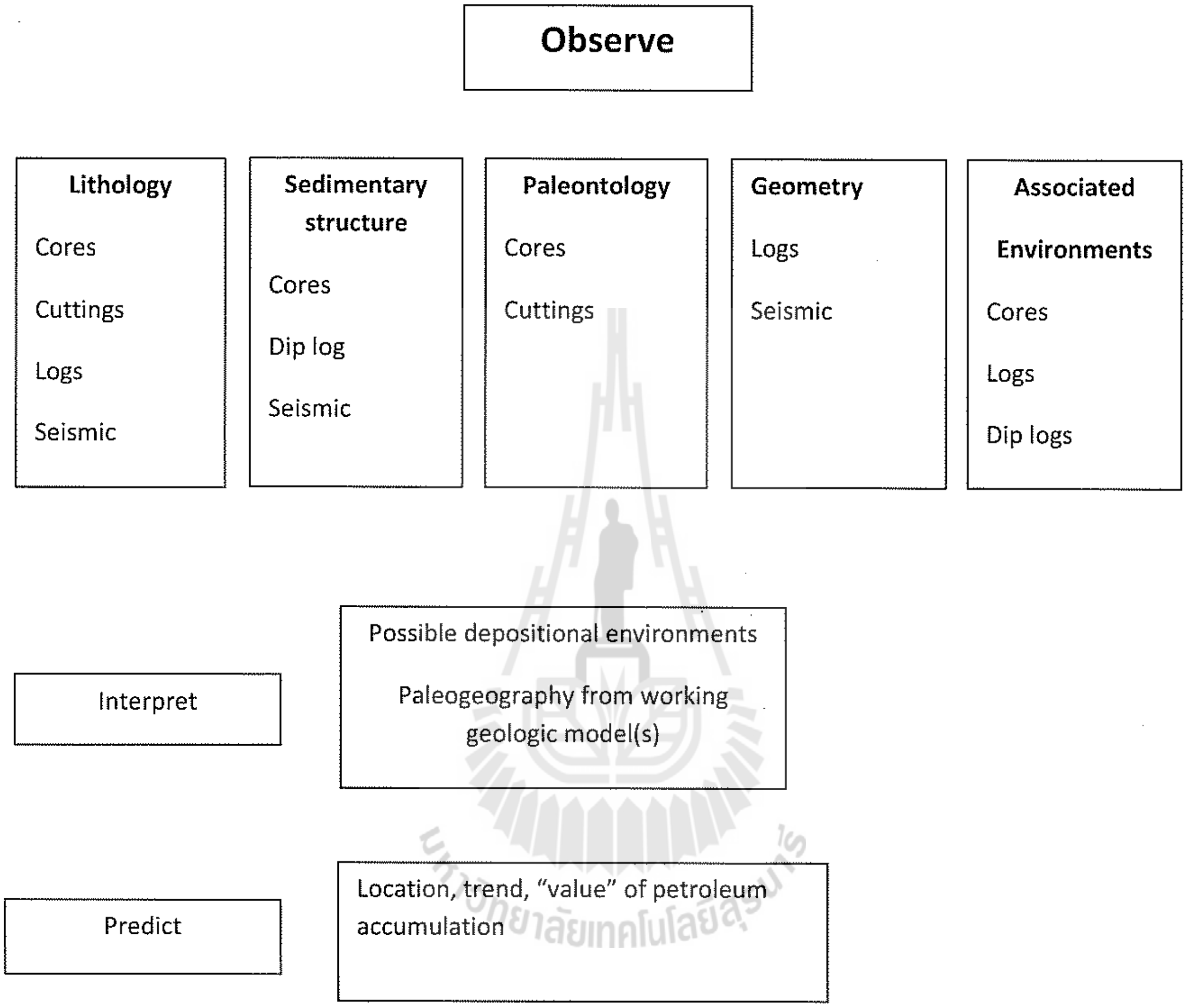


Figure 2-1. Basic parameters and the overall methodology of facies analysis

1. Associate facies

: The nature of laterally and vertically associated lithostratigraphic unit

1.1 Lateral associate facies

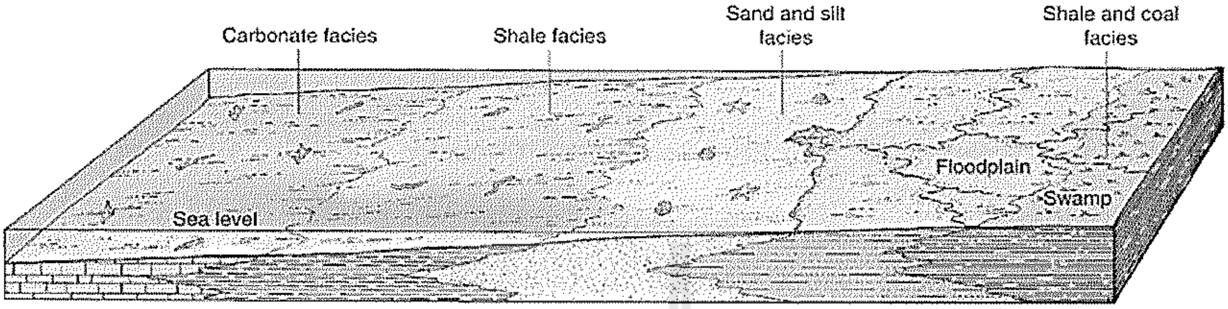


Figure 2-2: showing the lateral association facies

- **Facies** (or lithofacies) developed in the **marine environment**,
  :**Sand and silt facies** of the beach and nearshore environment
  :**Shale facies** in deeper, quieter water
  :Carbonate fancies are far from shore in warm shallow seas
  : **Shale and coal facies develops** in a **swamp** area on a **delta**

1.2 Vertical sequence

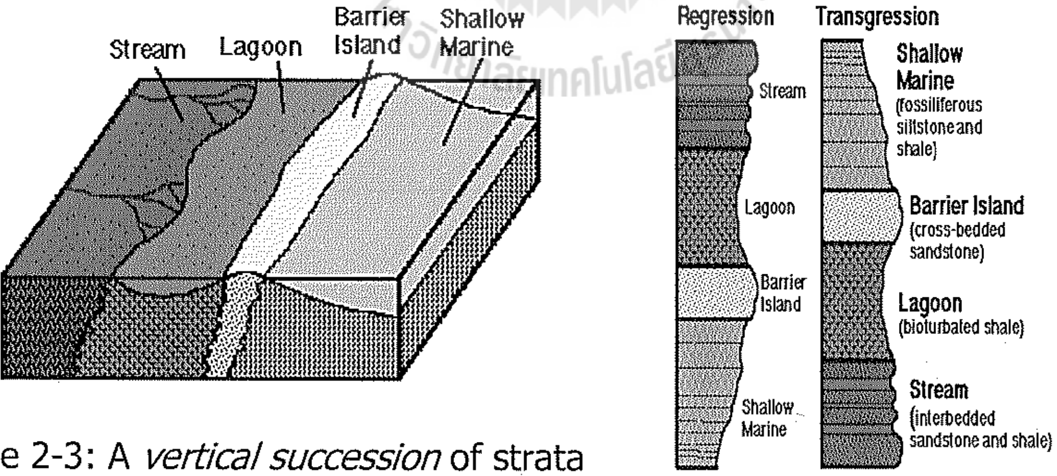


Figure 2-3: A *vertical succession* of strata represents progressive passage of time, either continuously at the scale of observation (conformable) or discontinuously (unconformable).

Walther's Law

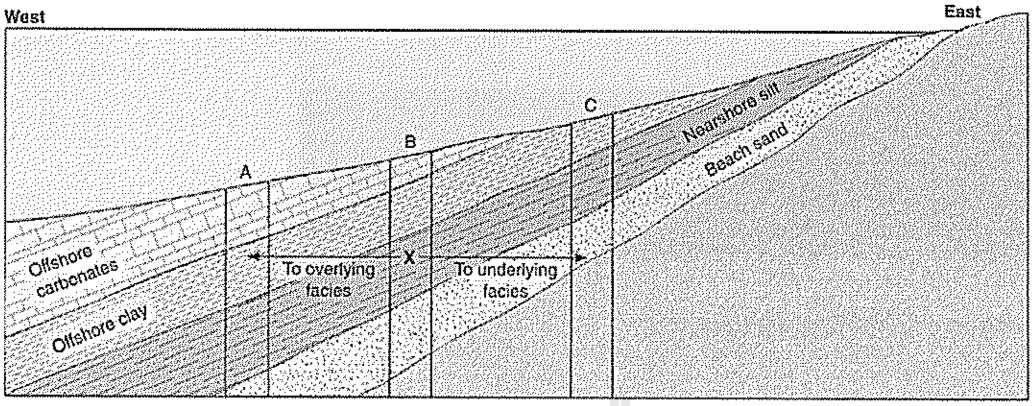


Figure 2-4: The vertical sequence of facies mirrors the original lateral distribution of sedimentary environments.

Laterally & Vertically Associated

The nature of laterally and vertically associated lithostratigraphic unit: The environment that show the completed depositional environment such coastal (Lateral) and shallow marine (Vertical):

- **Sea level Rise (Transgression)**
- **Sea level Drop (Regression)**

} Sea Level Change

Causes of Sea Level Change

1. **Changes in the size of the polar ice caps**, due to climatic changes

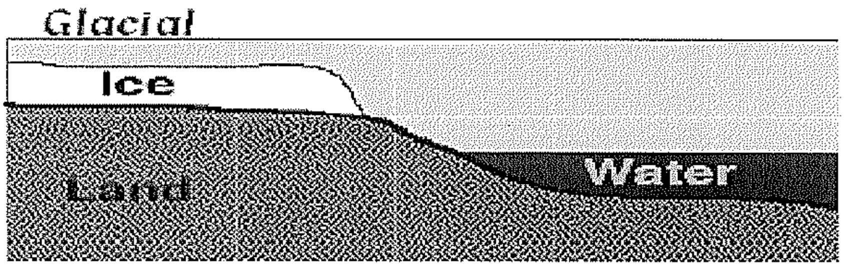


Figure 2-5: growth of ice cap- Regressive

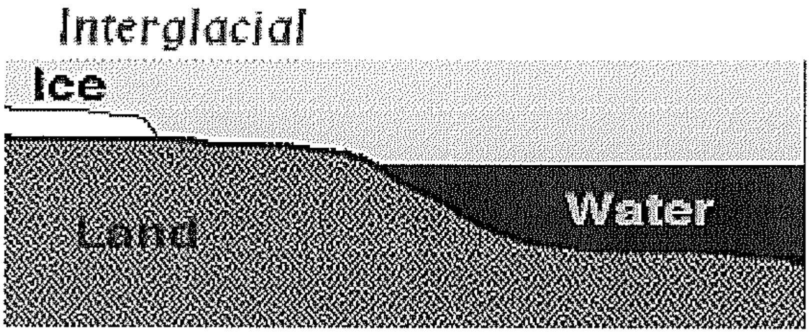


Figure 2-6: glaciers melt-Transgressive

2. Rate of seafloor spreading

When seafloor spreading is active the mid-oceanic ridges expand due to increased heat flow, resulting **displacing water onto the edges of the continents (transgression).**

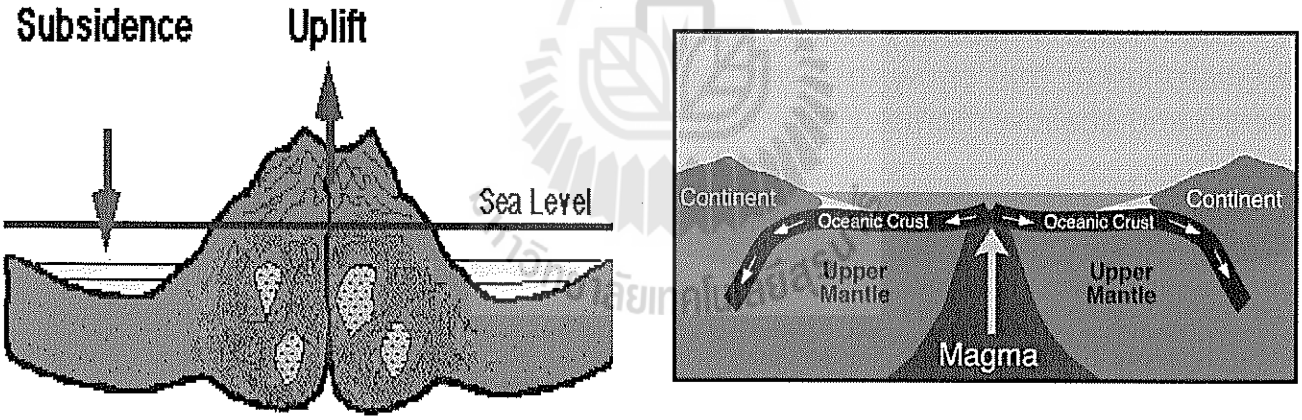


Figure 2-7: seafloor speading in mid oceanic ridges (left) and displacement of water onto the edges of the continents (right)-cause to the transgressive

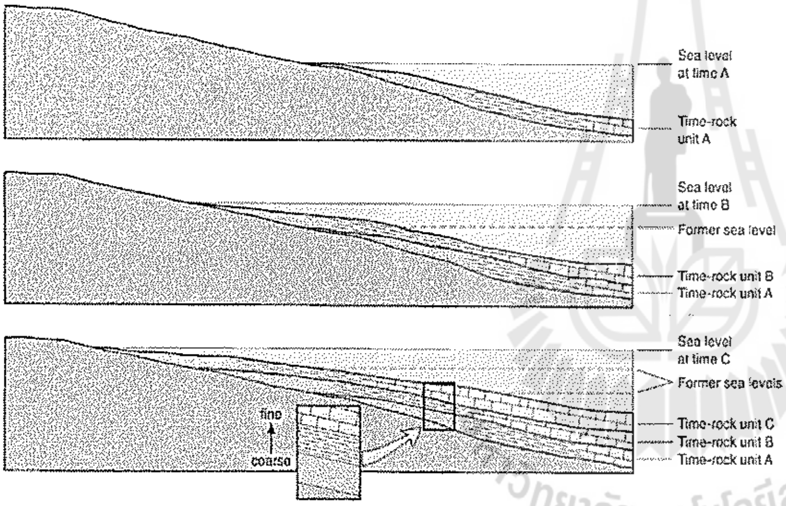
3. Localized subsidence (Transgressive) or Uplift of the land (Regressive)

Facies vs. sea level changes

1. Transgression (sea level **rise)**

- produce a vertical sequence of facies representing progressively **deeper** water environments
  (a **deepening-upward** or **fining upward sequence**)-**Onlap sequence**

: offshore facies deposited over nearshore facies (Landward)



Caused by

1. melting of polar ice-caps
2. displacement of ocean water by undersea volcanism
3. subsidence of the land in coastal areas.

2. **Regressive** (Sea level **drop)**

: produce a sequence of facies representing progressively shallower water environments

(**shallowing-upward or coarsening-upward** sequence-**Offlap** sequence.

: nearshore facies deposited over offshore facies. (Seaward)

Caused by

1. buildup of ice in the polar ice caps
2. uplift of the land in coastal areas

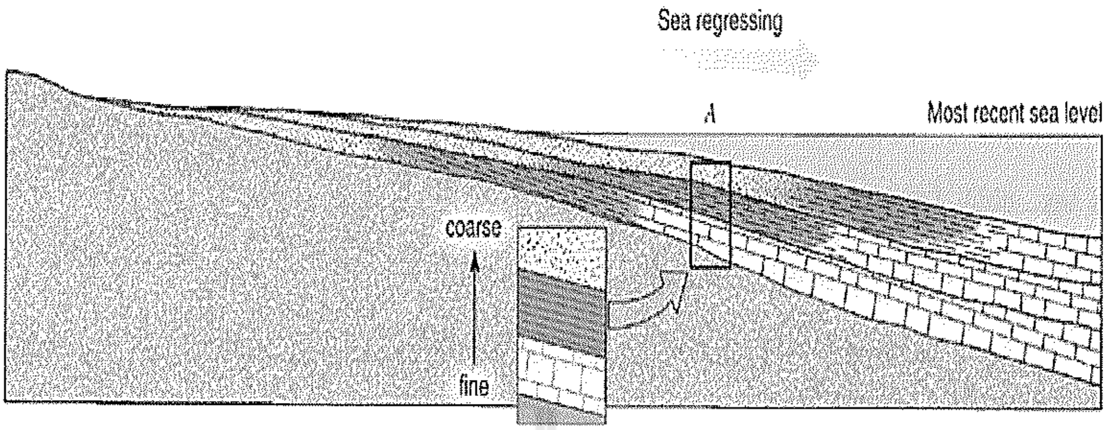
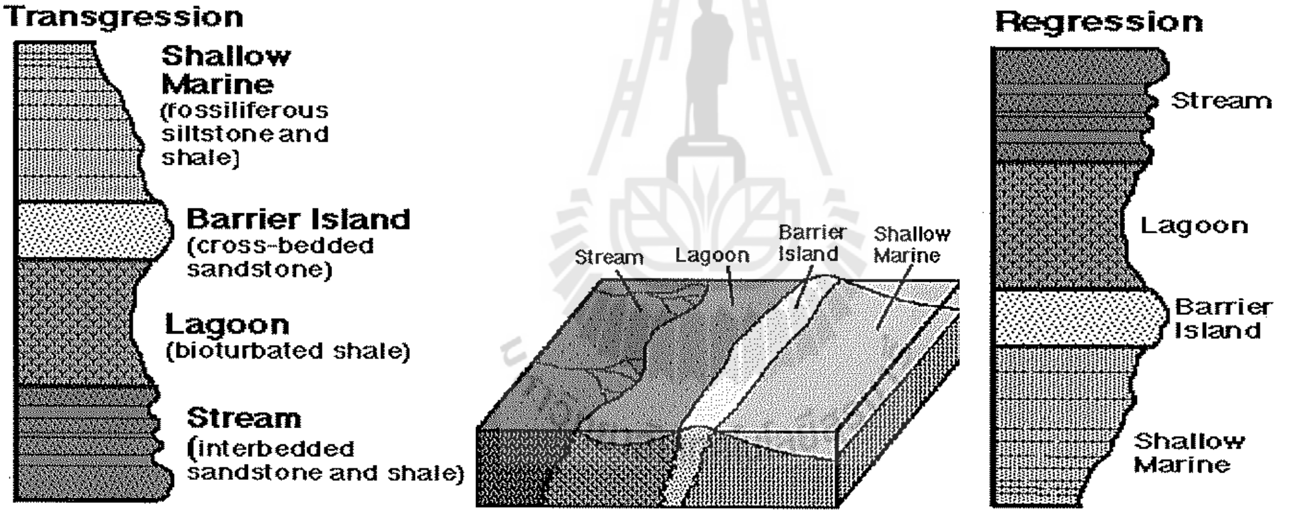


Figure 2-8: Facies of Regressive Sequences along the coastal



Transgressive sequence

Deepening upward.

Fining upward.

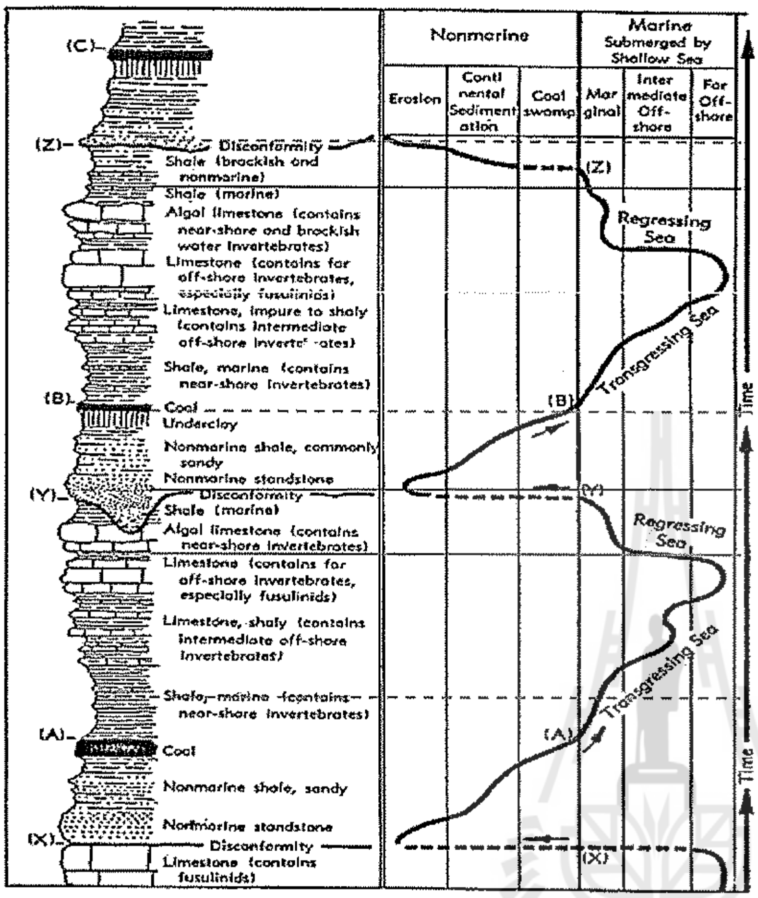
Regressive sequence

Shallowing upward.

Coarsening upward.

Figure 2-9: Facies of Transgressive and Regressive Sequences

Example: Nonmarine and Marine facies



Coarsening upward

Fining upward

Coarsening upward

Fining upward

Figure 2-10: example of nonmarine and marine facies

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2. Geometry

The overall shape of lithofacies maybe deformed controlled by:

1) Depositional Surface (Original)
2) Sedimentary Supply (nature & amount)
3) Depositional Currents (Intensity & Direction)
4) Climate
5) Paleoslope

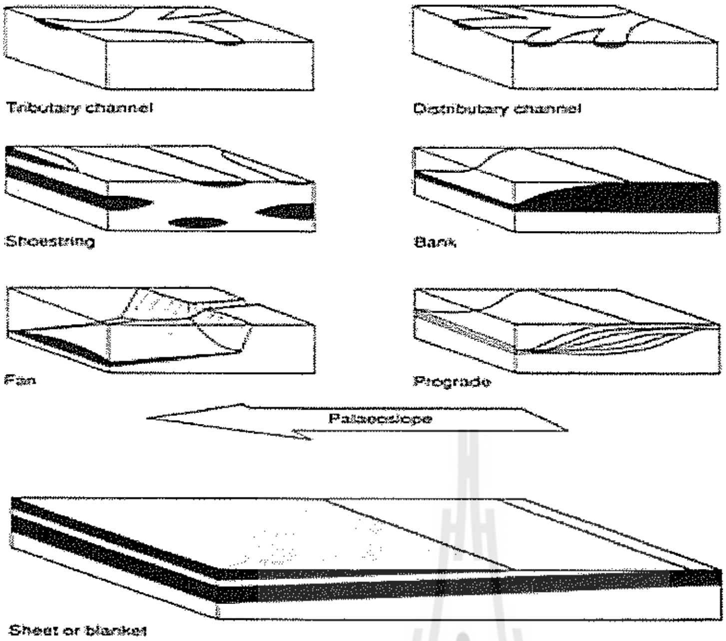


Figure 2.1 Cartoons of various facies shapes. Note that shape alone may not be diagnostic. Channels and fans occur in a range of environments from fluvial to deep sea. Shoestring sands may be beaches, barrier islands or tidal sand waves.

Figure 2-11: Shape of lithofacies controlled by Depositional Currents

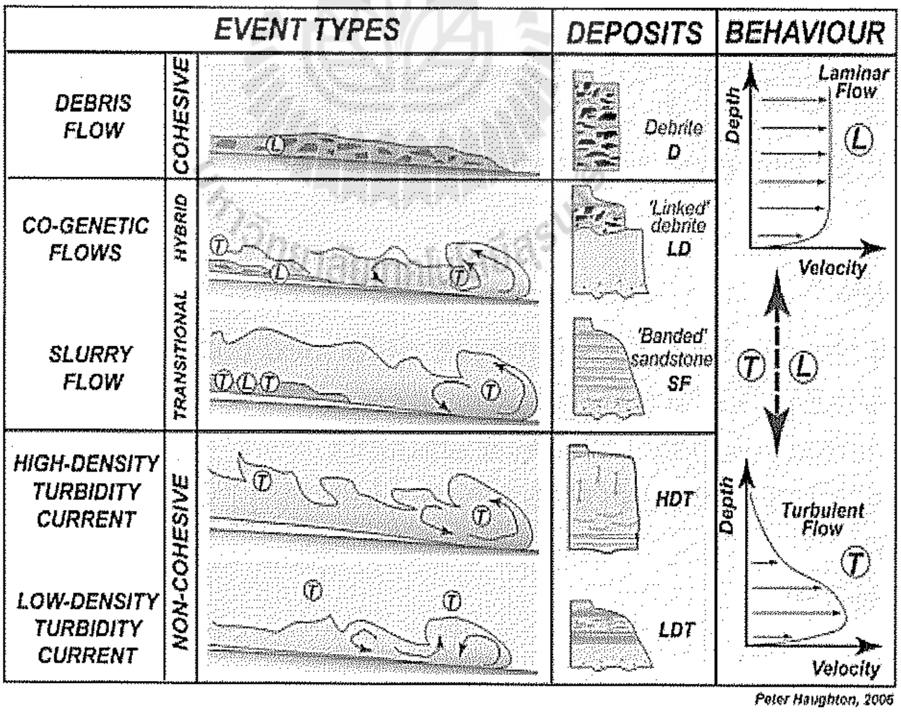
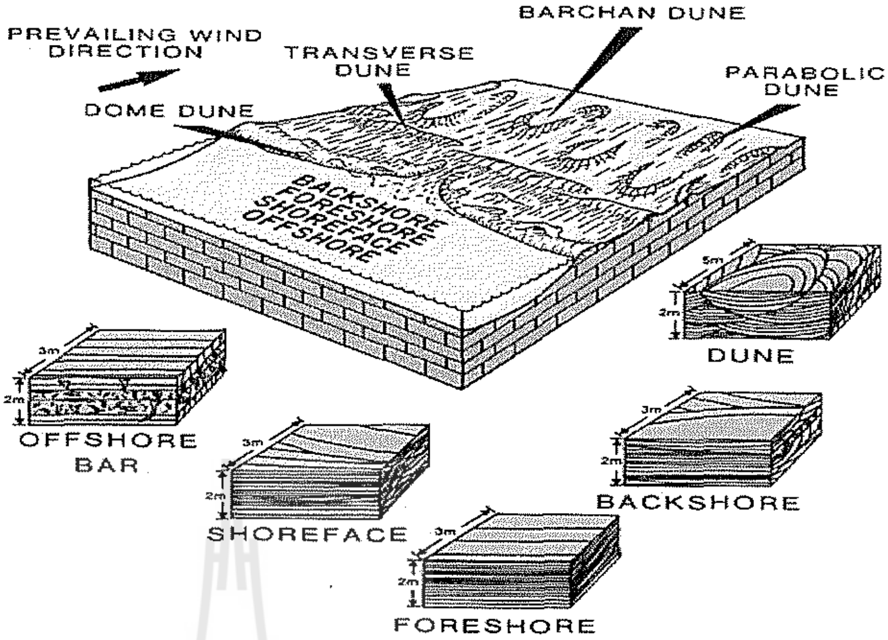


Figure 2-12: Shape of lithofacies controlled by Depositional Currents and fluid flow

Depositional Geometry

Shape of lithofacies
may be referred to each of
depositional environment



Some case of geometry & depositional environment

Same geometry but different environment

- **Channel**: Fluvial/Deltaic/Tidal/Submarine
- **Fan**: Alluvial/Deltaic/ Submarine

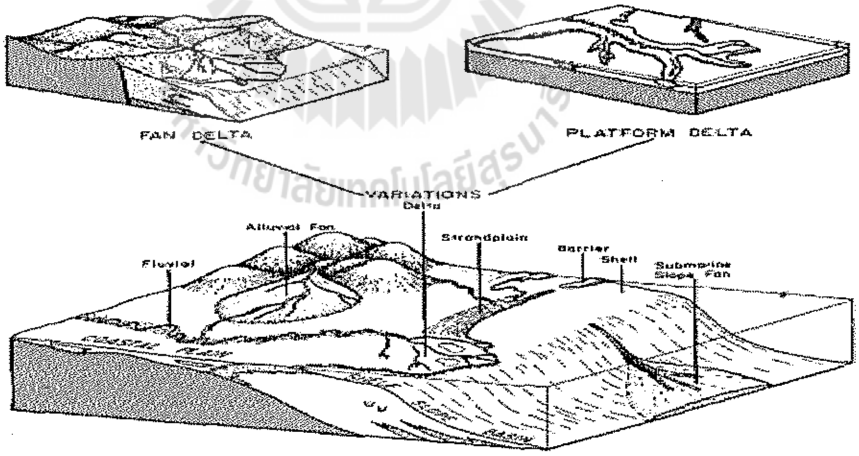


Figure 2-14: Fan Geometry: Alluvial/Deltaic/Submarine

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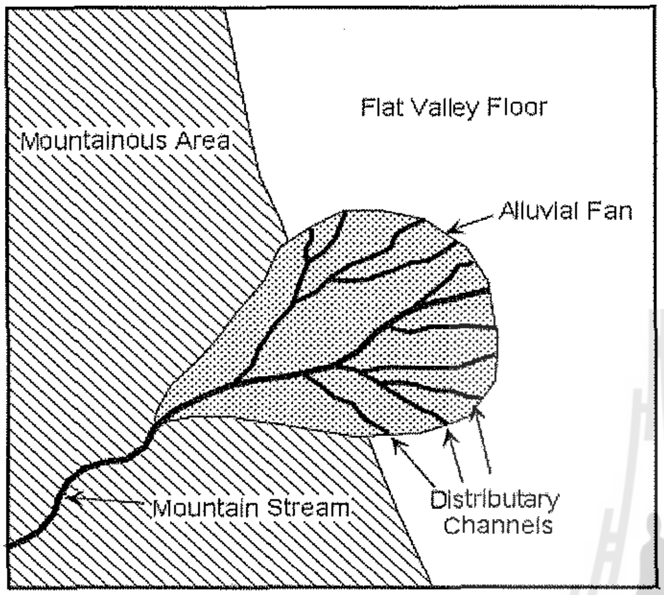
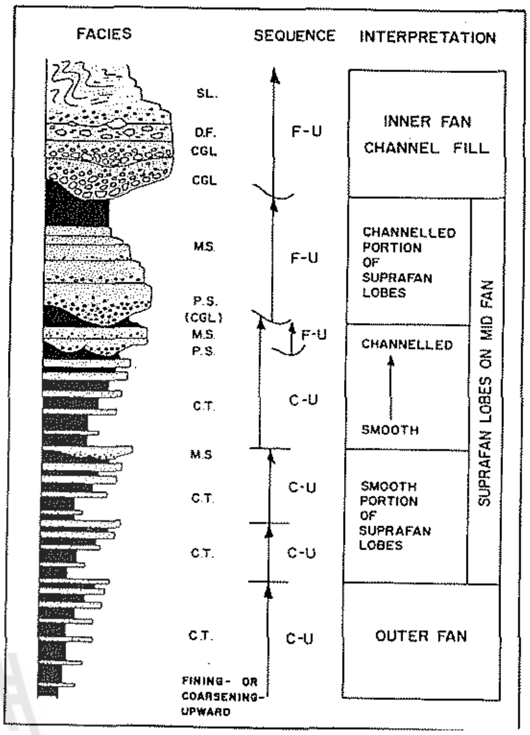


Figure 2-15: Alluvial fan geometry



Delta Fan Geometry

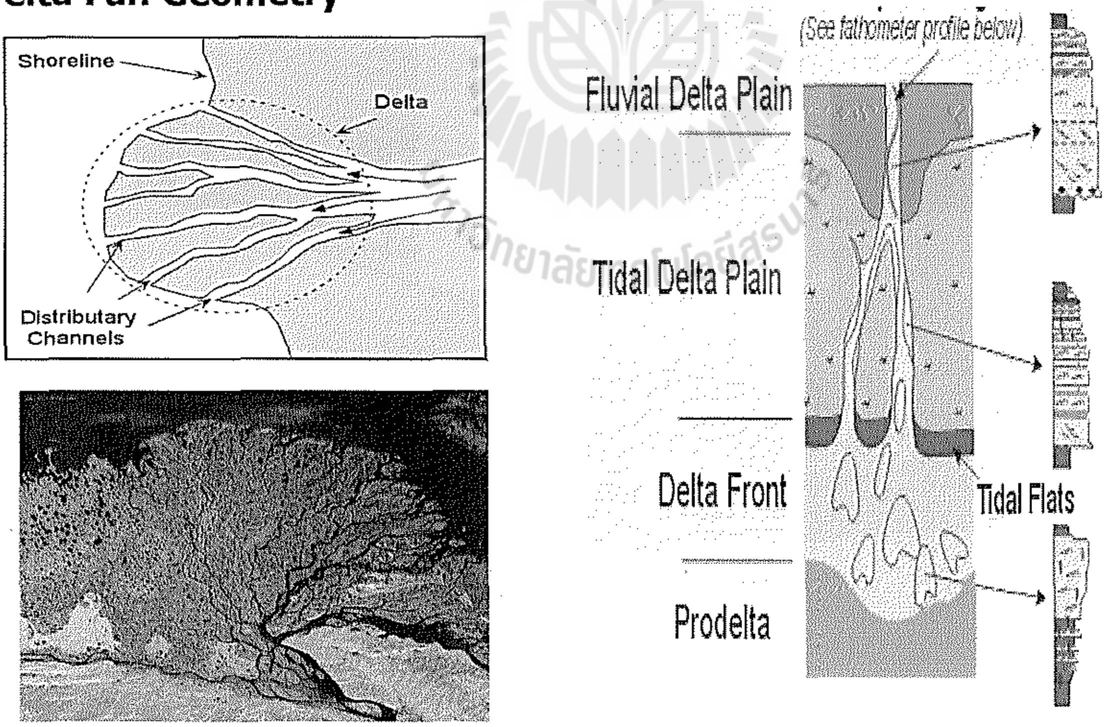


Figure 2-16: Delta Fan Geometry

3. Lithology

Lithology: *The systematic description of rocks,* in terms of mineral composition, grain size, color and texture.

Source of data (Subsurface geology):

1. **Direct information**: cutting and core sample
2. **Indirect information**: Wire line log and seismic data

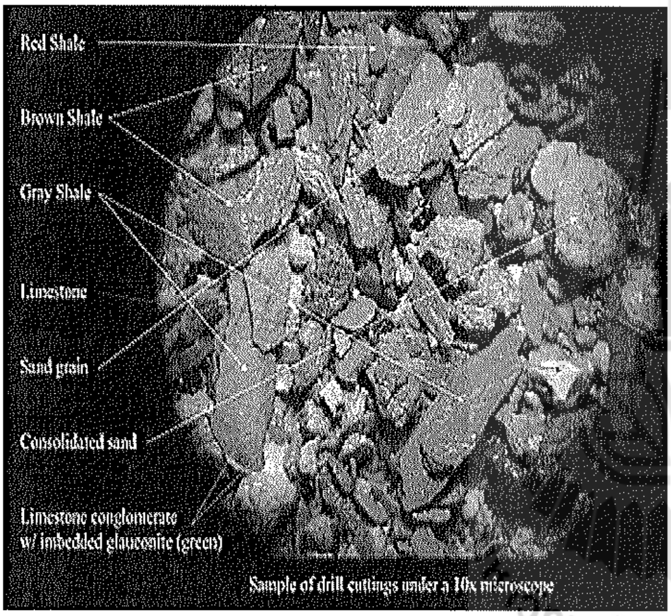
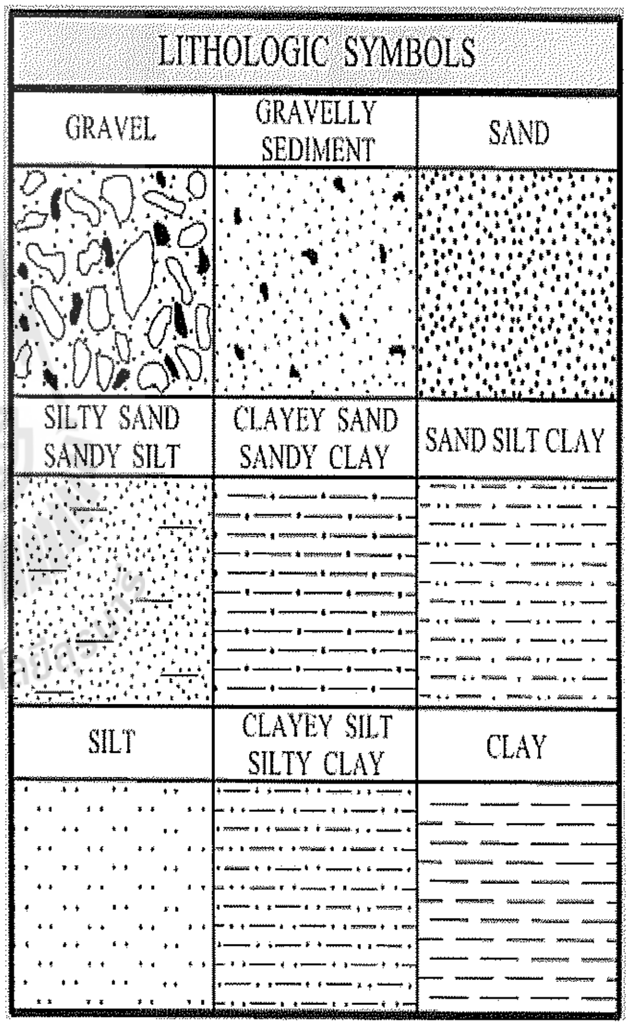


Figure 2-17: Lithologic symbols from cutting sample



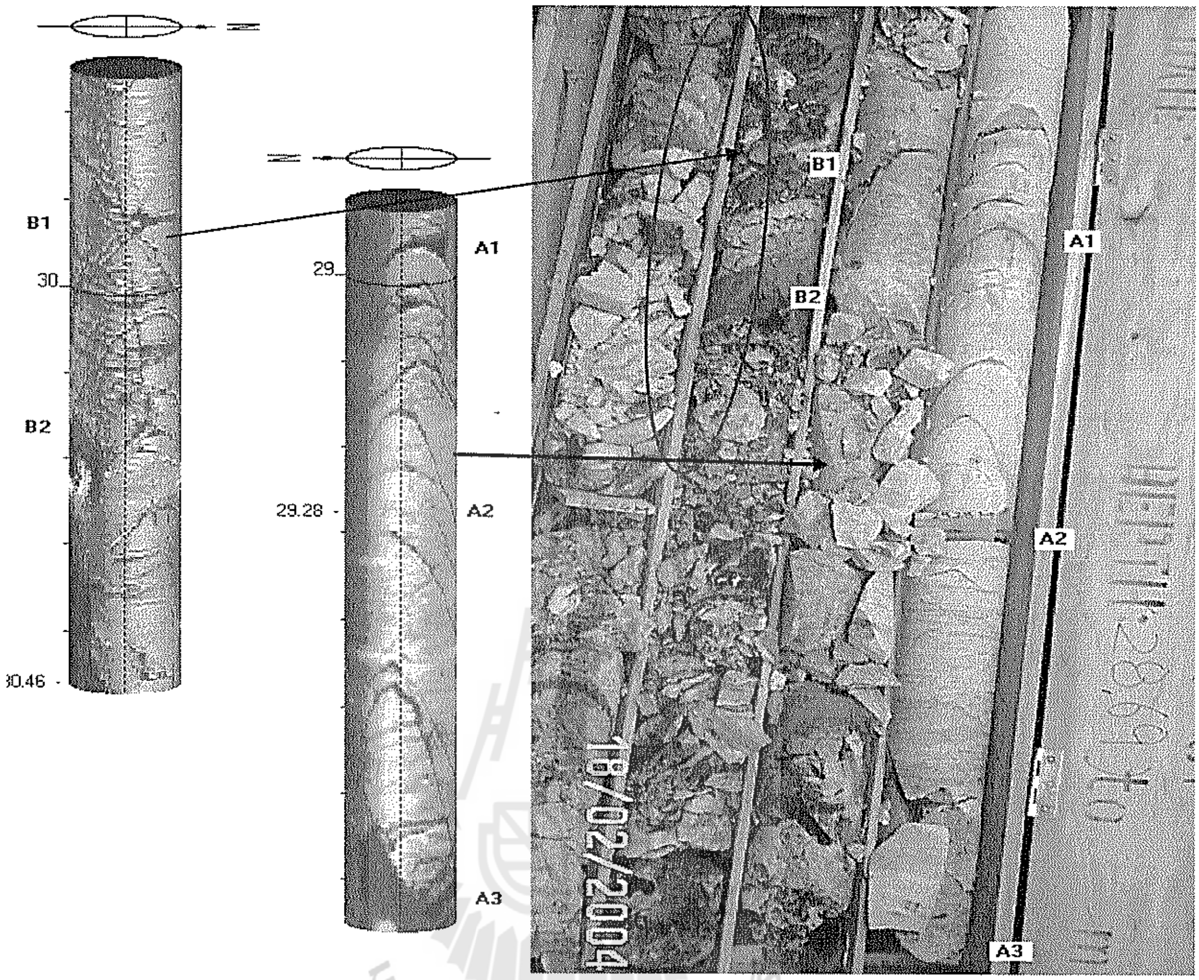


Figure 2-18: Lithology from Core sample

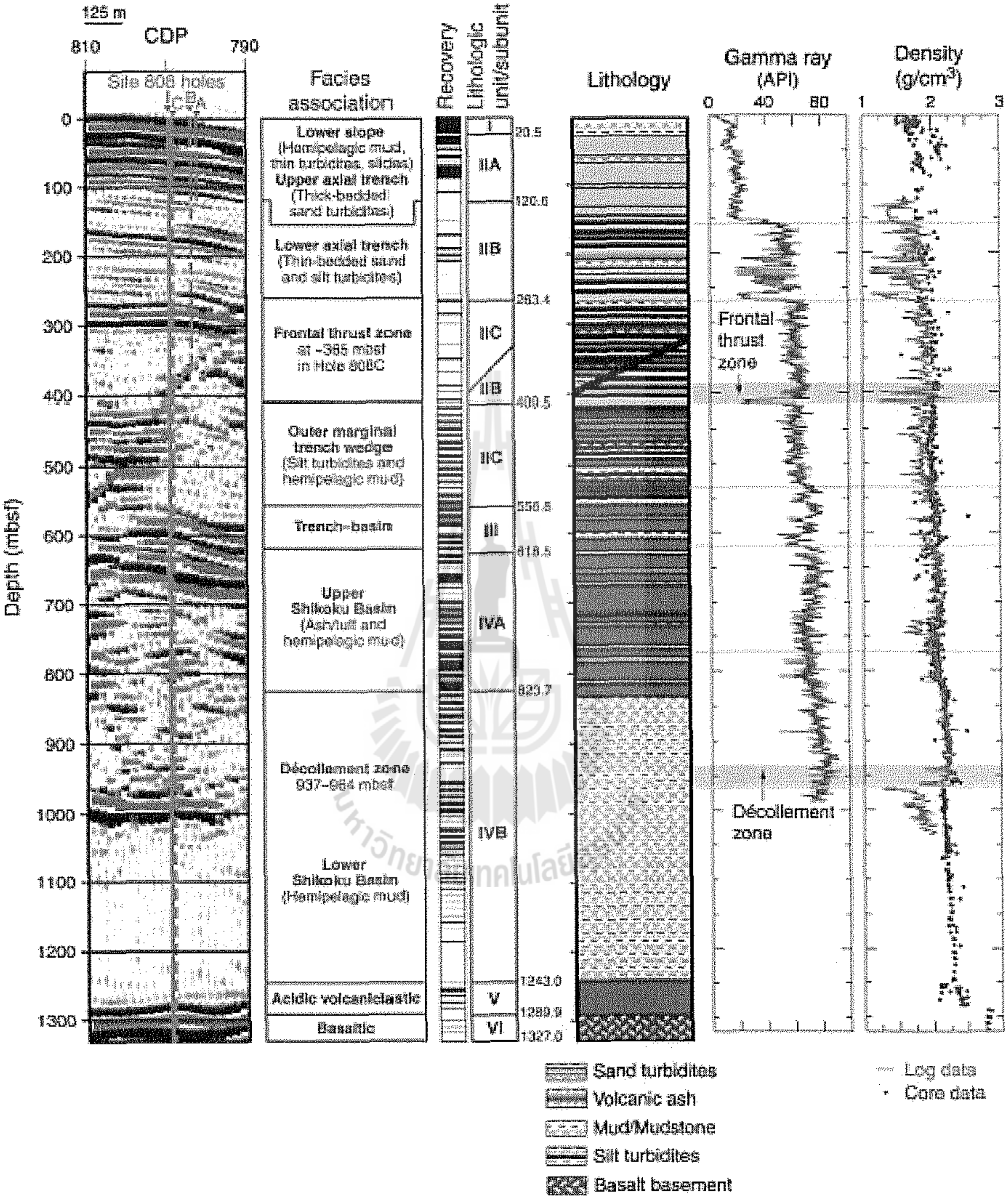


Figure 2-19:Seismic data, well log vs. lithology

Lithology Interpretation

Sedimentary rocks give important clues to the *geologic history* of an area

1. Source area

Study of direction and distance

: Sediment composition, shape, size and sorting are indicators of source rock type and relative location

2. Environmental Deposition:

Location where sediment came to rest

: Sediment characteristics and sedimentary structures (including fossils)

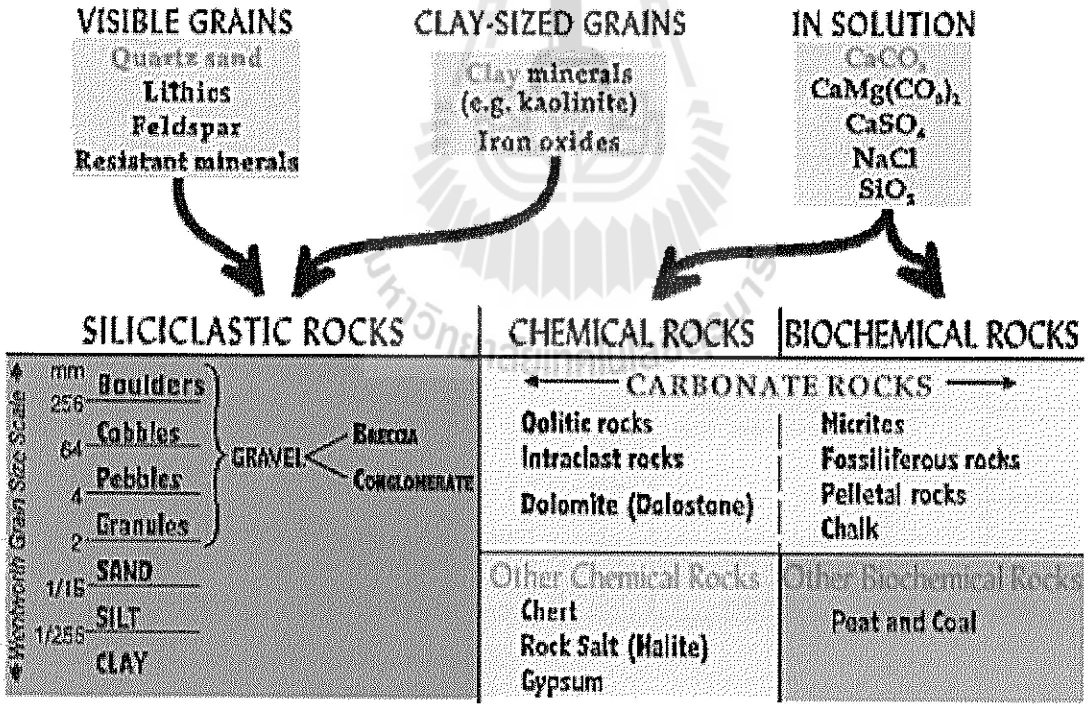


Figure 2-20:Classification of Sedimentary Rocks

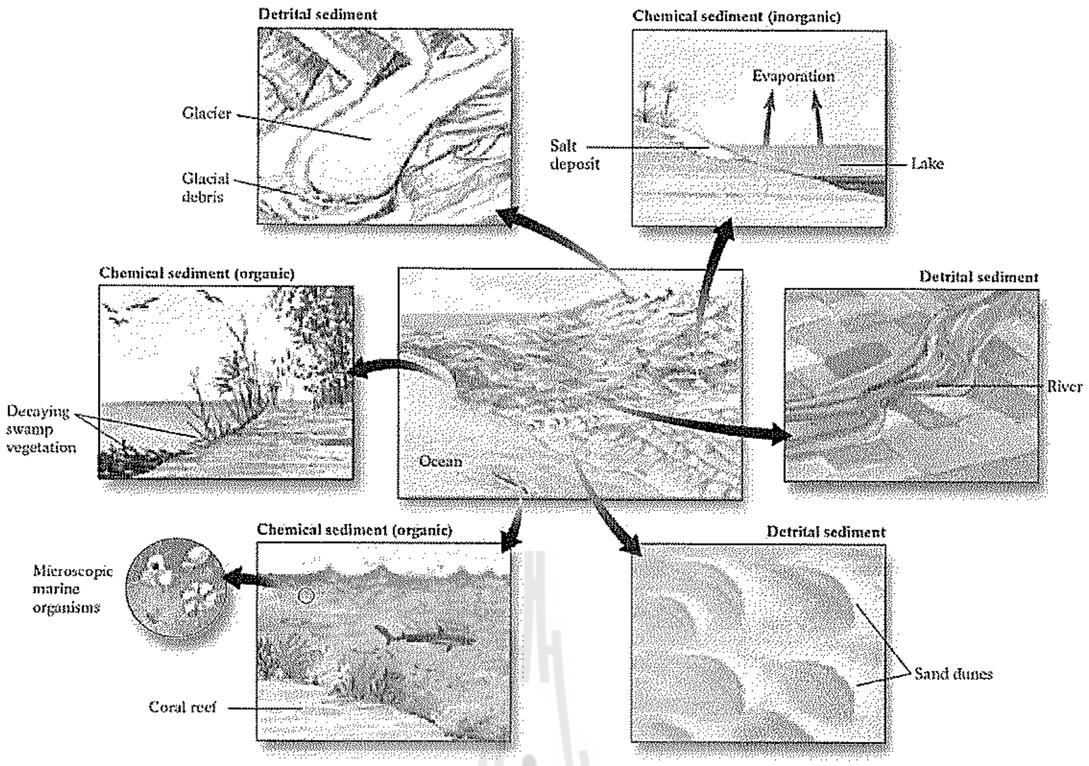


Figure 2-21: Types of Sediments

Clastic or Detrital Sediments

- Weathering & erosion from host rock
- Visible grains: texture
- Qtz, Feldspar, other resistance minerals

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Clastic sediements: Source area interpretation

Texture

- **Grain Size:** Power of Transport
- **Grading:** Coarse or fine grain –energy level
- **Grain Shape:** Rounding – distant from origin
- **Sorting:** selecting of the grained size-energy level
- **Orientation:** current of water or wind, or flow direction
- **Transport, Reworking**: energy level
- **Color and Chemistry**

- Red Beds - Often Terrestrial, high oxygen (Oxidization)
- Black Shale - Oxygen Poor, Often Deep Water (reducing)

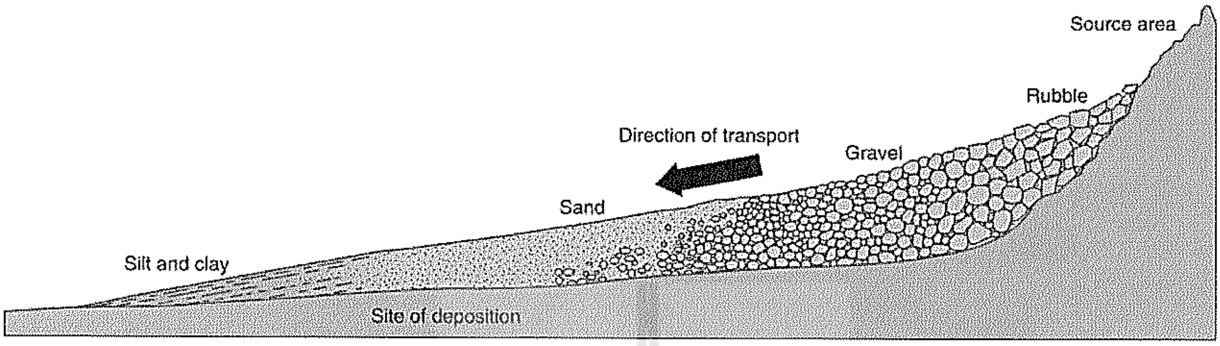

Figure 2-22: Texture of sediment indicates the depositional environemt

Textural Interpretation of Clastic Sedimentary Rocks

Texture refers to the size, shape, sorting, and arrangement of grains in a sedimentary rock.

1. Clasts - larger grains in the rock (gravel, sand, silt).
2. Matrix - fine-grained material surrounding clasts (often clay/silt).
3. Cement - the "glue" that holds the rocks together.

Silica (quartz, SiO_2) , Calcite ($CaCO_3$) , and Iron oxide Other minerals

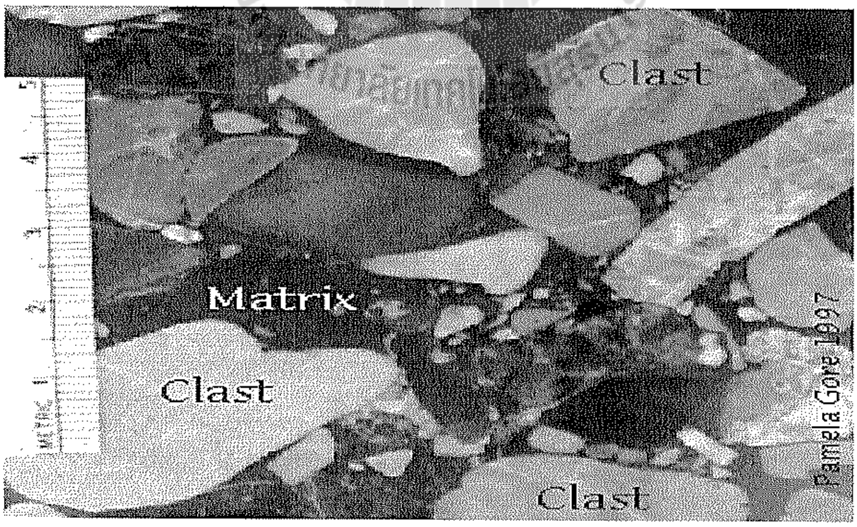

Figure 2-23: Clasts and matrix (labelled), and iron oxide cement (reddish brown color)

Clastic Sediment Textures

Maturity:

Chemical and physical weathering gradually breaks down rock to quartz and clay minerals. Maturity is a measure of this process.

Depends on: Time, Climate, Transport History, Depositional Environment.

1. **Immature**: poorly sorted, clays + mineral fragments (olivine, pyroxene, amphibole, etc.), rock fragments. Grains are angular and vary in size.
2. **Mature**: well sorted, no clays, mostly made up of rounded quartz grains.

Process:

- **Transportation**: Rounding - increases with length of transportation history.
- **Sorting**: increases with length of transportation history (weaker minerals broken down).
- **Deposition**: any process that lays down *material*.
- **Environment of Deposition**: location in which deposition occurs.
- **Preservation**: deposition and burial in a basin. Reworking degrades preservation.

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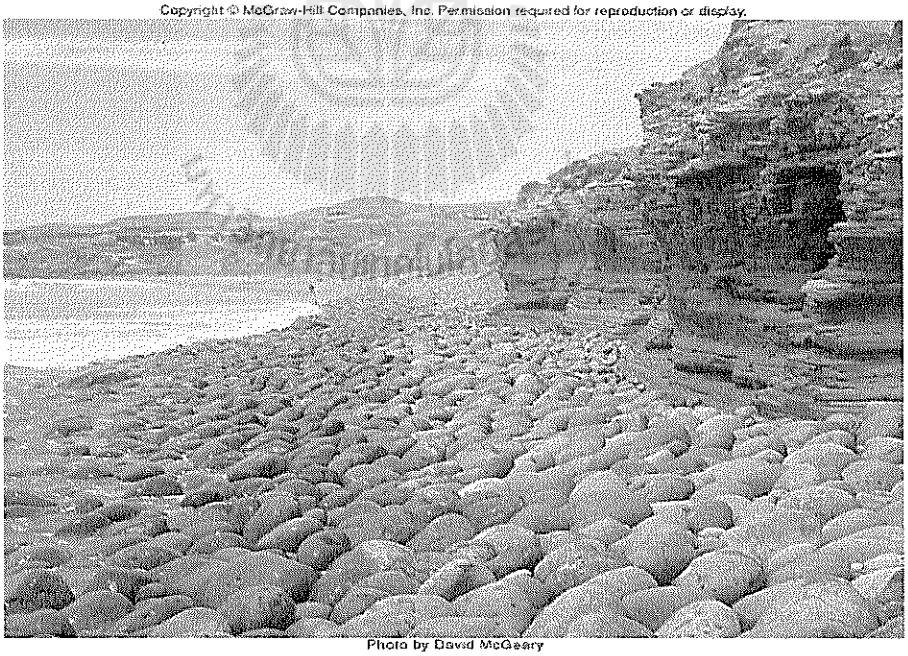

Photo by David McGeary

Figure 2-24: Transportation: Rounding - increases with length of transportation history.

Transportation
Silt & Clay
Low energy

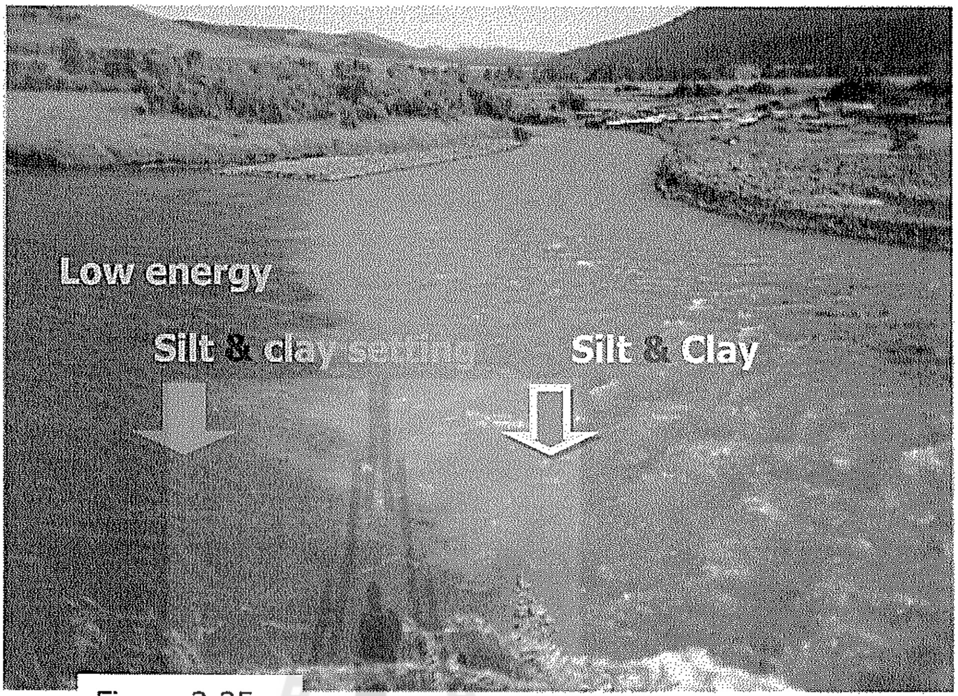

Figure 2-25

The river on the right is carrying only silt and clay as it enters the clear river on the left. This fine sediment may come to rest at the mouth of a river where it enters a lake or the sea.

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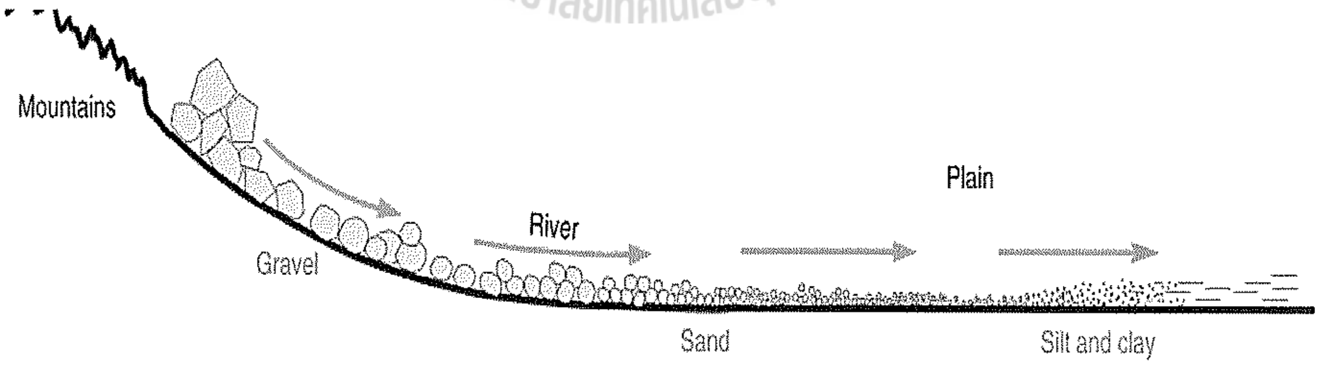

Figure 2-26: Sorting increases with length of transportation history (weaker minerals broken down).

Deposition: any process that lays down material.

Environment of Deposition: location in which deposition occurs.

Figure 2-27: Deposition of river sediments depend on the water energy

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Example of clastic sedimentary rocks

Figure 2-28: Conglomerate: coarse (> 2 mm), rounded clasts (gravel) + finer groundmass.

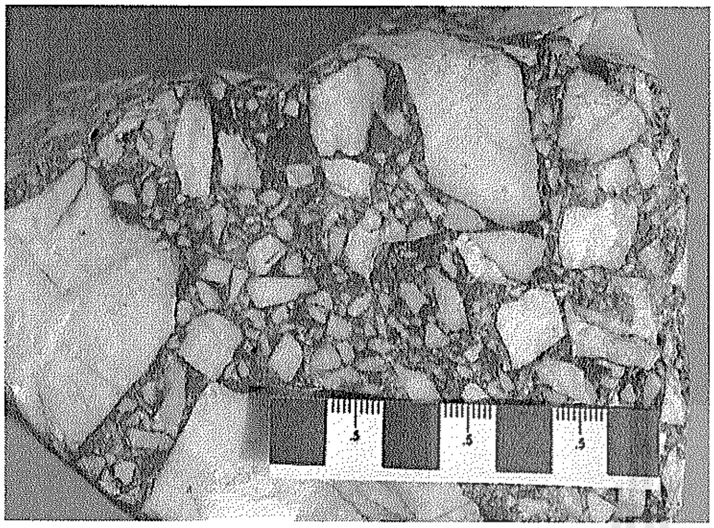
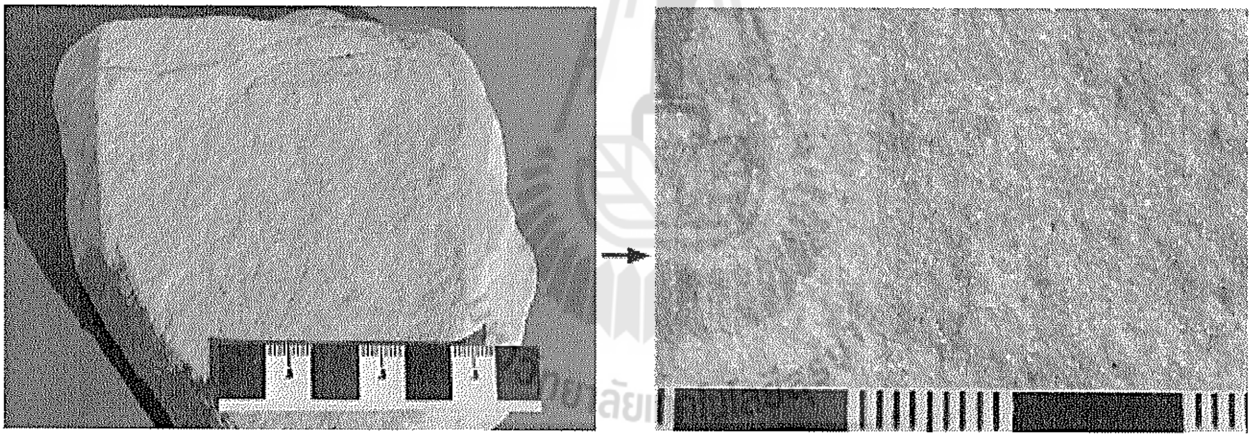


Figure 2-28: Breccia: coarse (> 2 mm), angular clasts (gravel) + finer groundmass.

Figure 2-29: Sandstone: medium (1/16-2 mm), 90% quartz + matrix.



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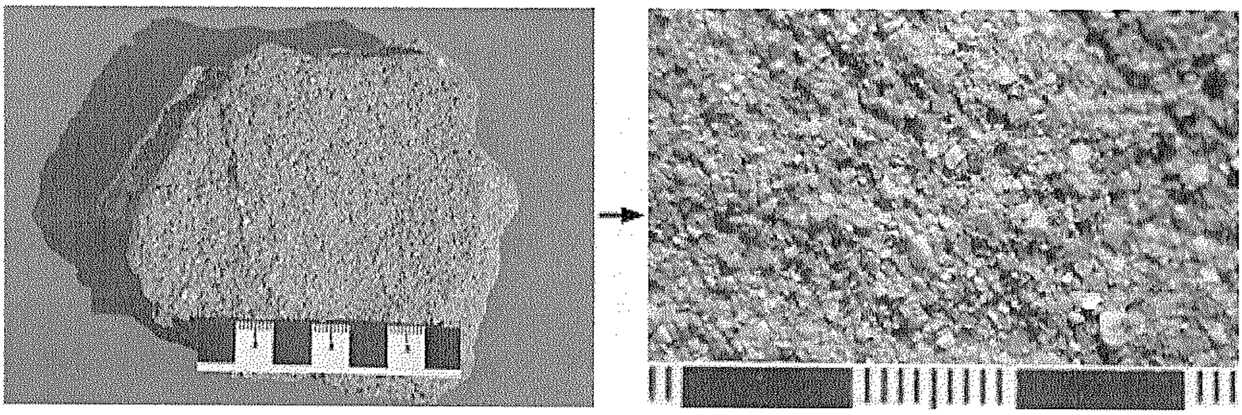
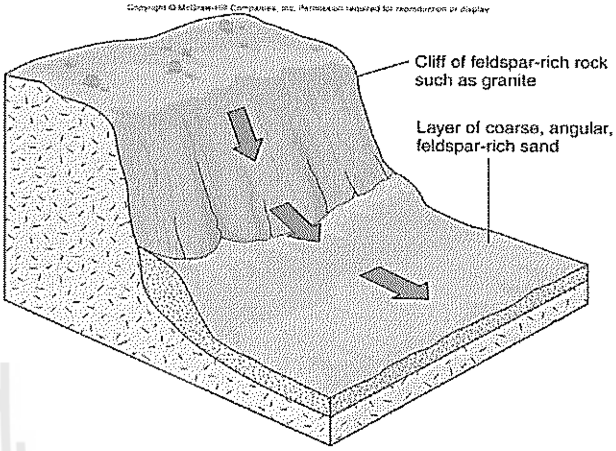
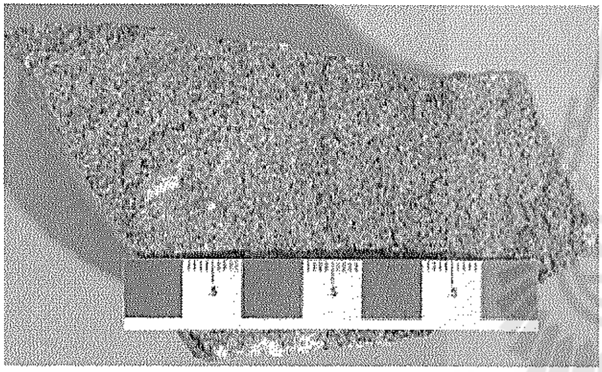


Siltstone: fine (1/256 – 1/16 mm), fine-grained sandstone, feels gritty.

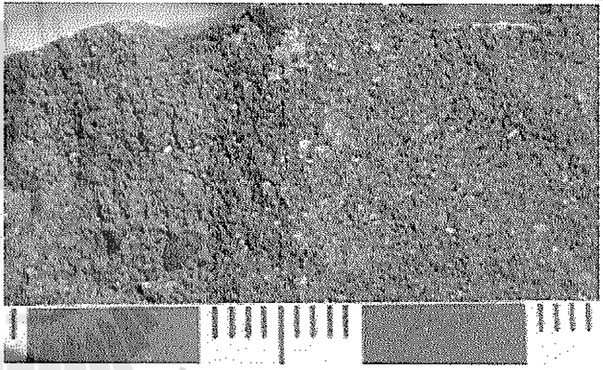
Figure 2-30: Area of deposition close to area of erosion - feldspar weathers



Greywacke



turbidity



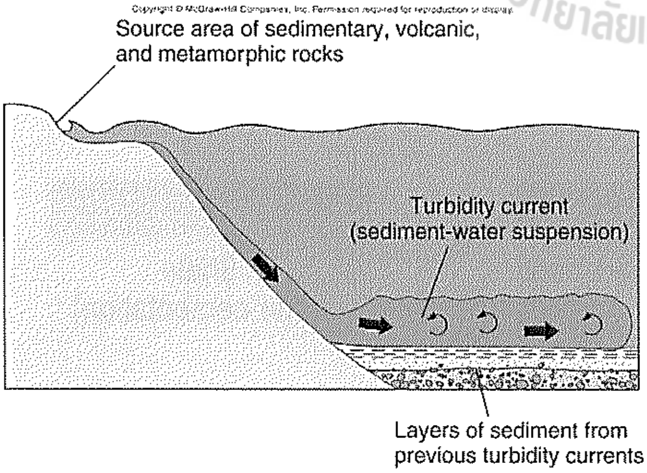


Figure 2-31: Earthquake triggers slumping of sediments down continental slopes. Can form V-shaped

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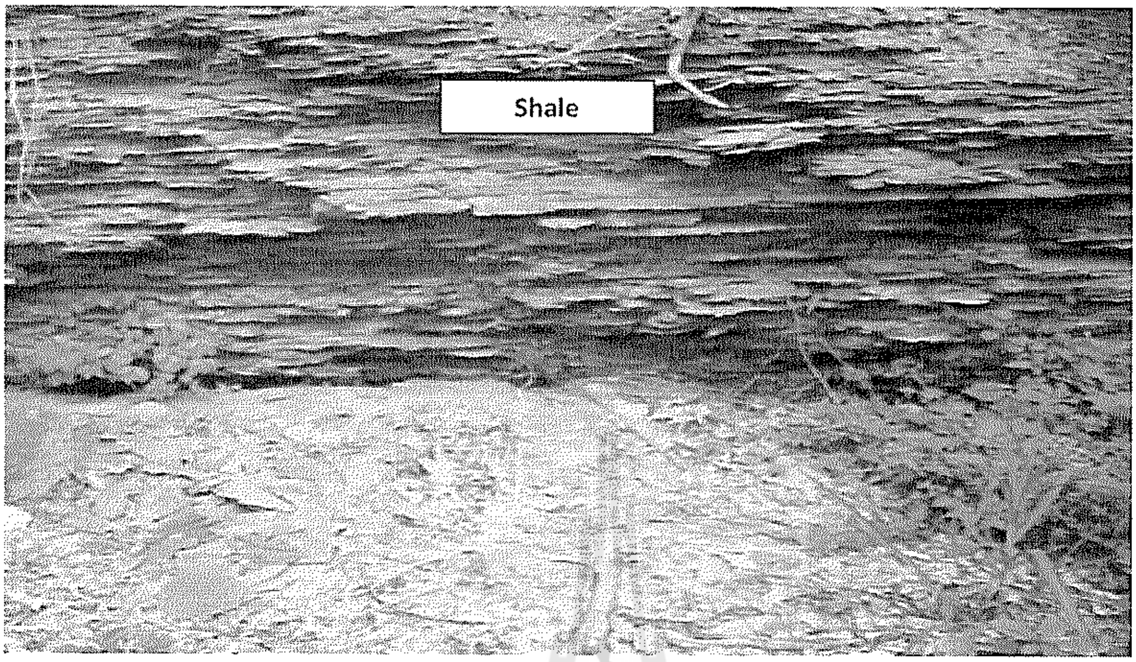

Figure 2-32: shale bed show the high organic matter

Shale: mostly clay, ***fissile*** (splits because of preferred orientation of clays. Feels smooth. Quiet deposition.

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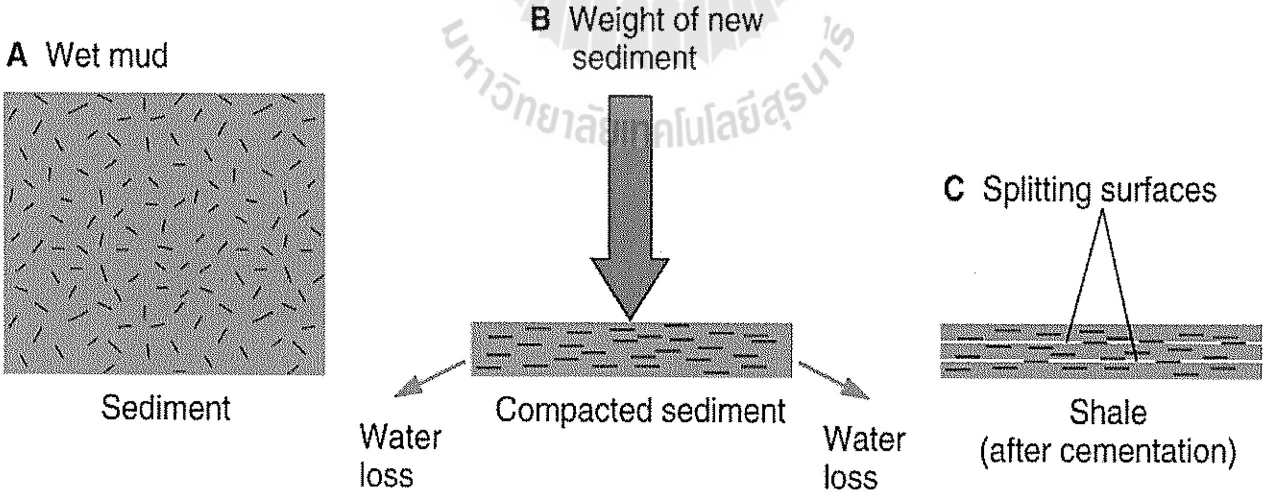


Figure 2-33: Stage of shale forming

Grain size

The **texture** of a sedimentary rock can provide clues to the **depositional environment.**

- **Fine grain: <u>quiet water </u>(low energy).**
- **Coarse grain: <u>higher energy </u>(higher water velocity)**

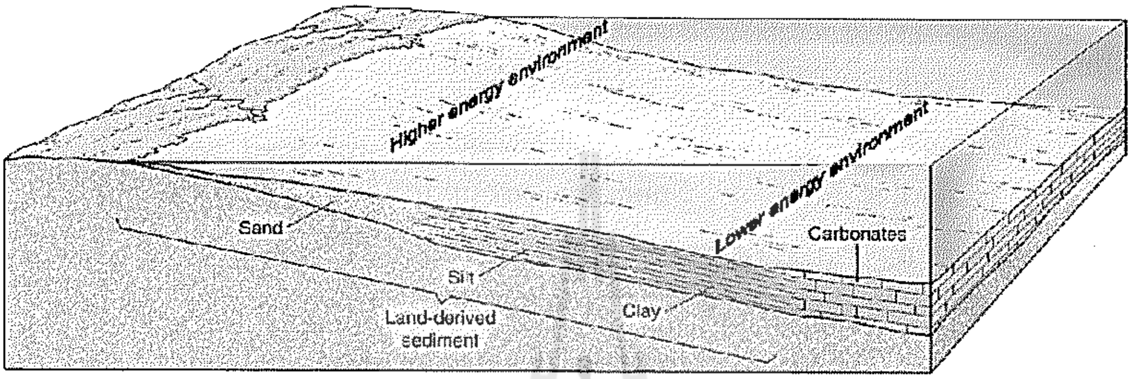
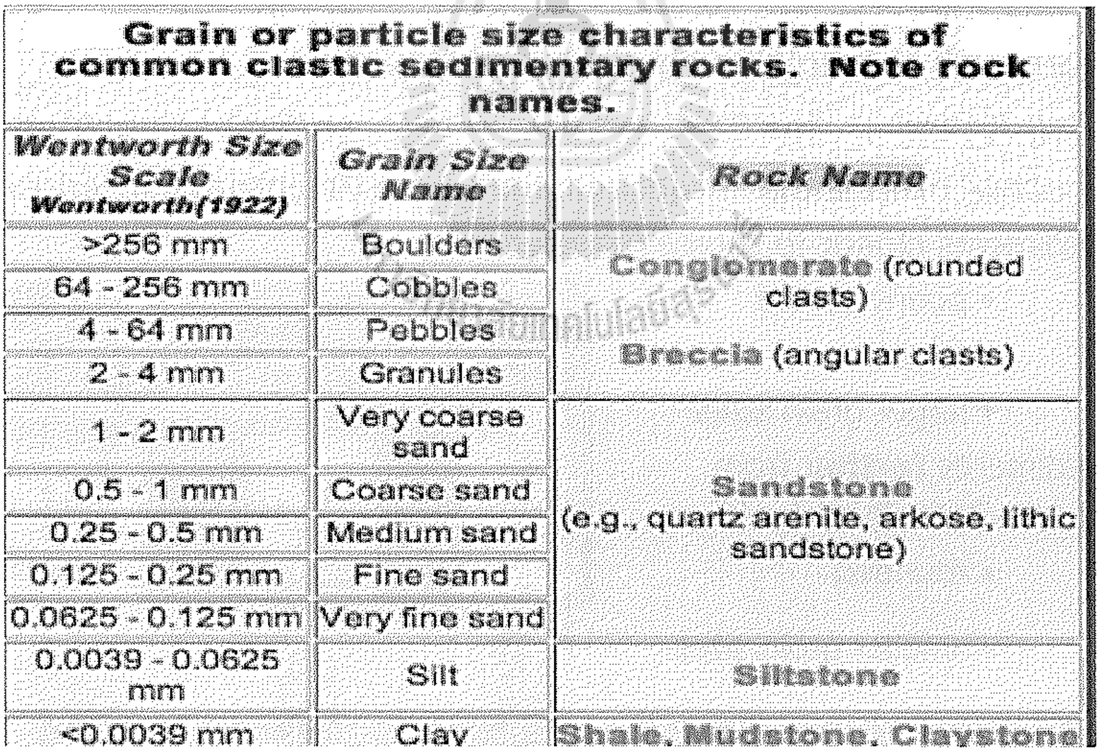


Figure 2-34: Relationship of grain size and energy current

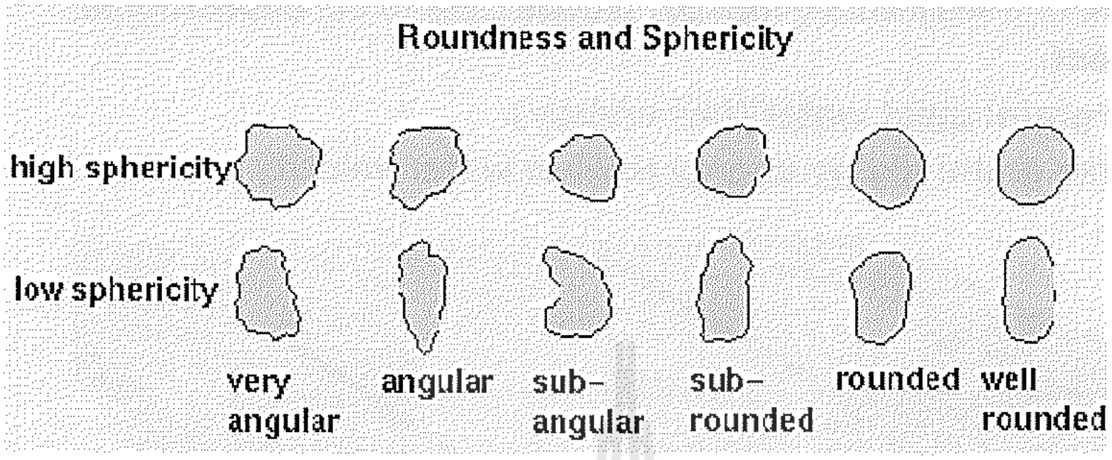


Grain or particle size characteristics of common clastic sedimentary rocks. Note rock names.

Wentworth Size Scale *Wentworth(1922)*	*Grain Size Name*	*Rock Name*
>256 mm	Boulders	**Conglomerate** (rounded clasts) **Breccia** (angular clasts)
64 - 256 mm	Cobbles	
4 - 64 mm	Pebbles	
2 - 4 mm	Granules	
1 - 2 mm	Very coarse sand	**Sandstone** (e.g., quartz arenite, arkose, lithic sandstone)
0.5 - 1 mm	Coarse sand	
0.25 - 0.5 mm	Medium sand	
0.125 - 0.25 mm	Fine sand	
0.0625 - 0.125 mm	Very fine sand	
0.0039 - 0.0625 mm	Silt	**Siltstone**
<0.0039 mm	Clay	**Shale, Mudstone, Claystone**

Figure 2-35:table show the clastic sedimentary rock classification with grain size

Grain Shape



Sphericity: refers to shape of grain
Roundness: refers to the roughness of surface

- **Angular** ขอบและมุมยังเป็นหยักและคมอยู่
- **Subangular** ผิวยังไม่ถูกขัด ขอบและมุมมนเข้ามาหน่อย
- **Subrounded** ผิวถูกขัดบางส่วน ขอบและมุมมนและโค้ง
- **Rounded** ผิวเดิมถูกขัดเกือบหมดยกเว้นบางส่วน
- **Well Rounded** ไม่มีผิวเดิมเหลืออยู่เลยเพราะถูกขัดจนมนและกลหมดแล้ว

Grain shape indicate the distant from the source (Roundness/Sphericity)

- Sediments **closer** to source (traveled less)
    - poorly sorted
    - angular
    - larger grain sizes
- Sediments **farther** from source (traveled more)
    - rounded
    - smaller grain sizes

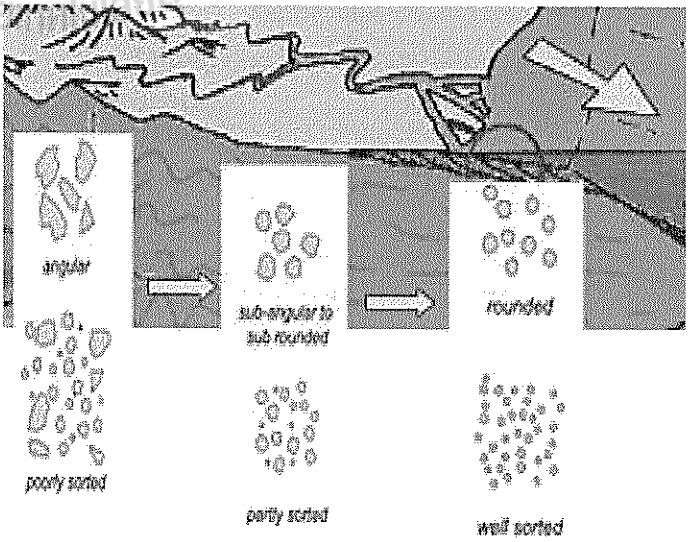
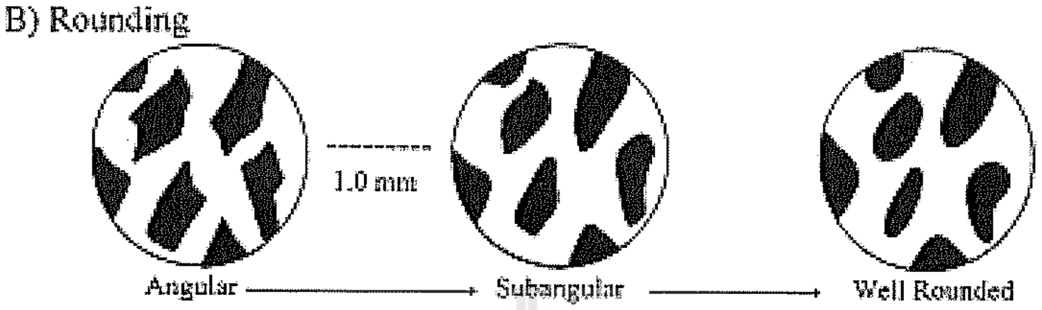


Figure 2-36: Grain shape indicate the distant from the source

: Roundness/Angularity:

Transport by **wind or water** – rounding occurs.

Transport by **ice or gravity** – angular.



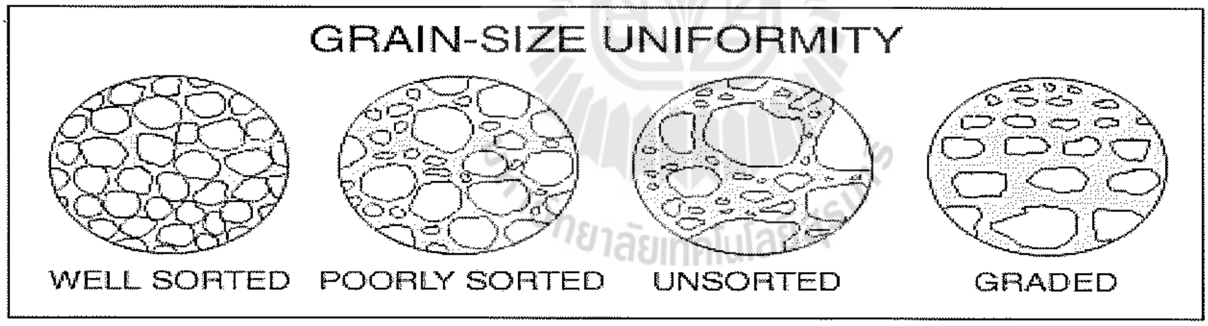
: Sorting (Grain relationship)

Degree of Sorting

Selection/separation of grains is on the basis of size, shape, specific gravity.

Poorly sorted: fast deposition, high energy.

Well sorted: slow deposition, less chaotic, low energy



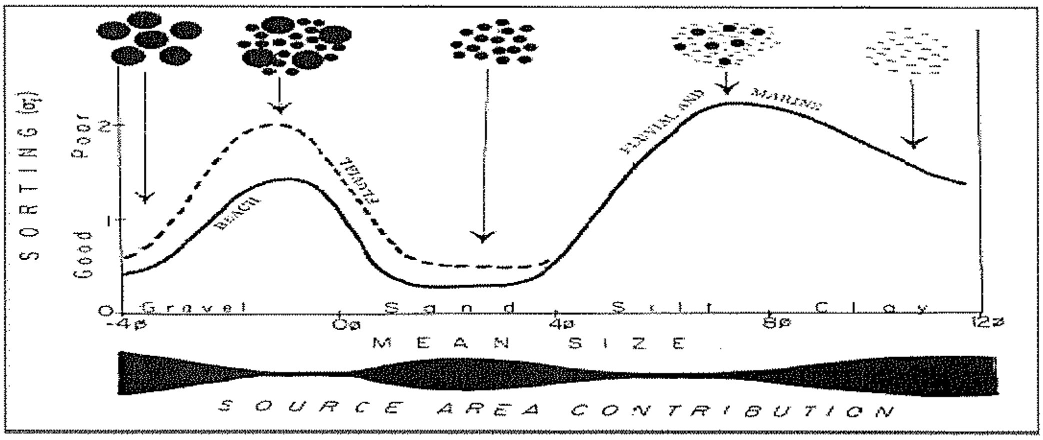
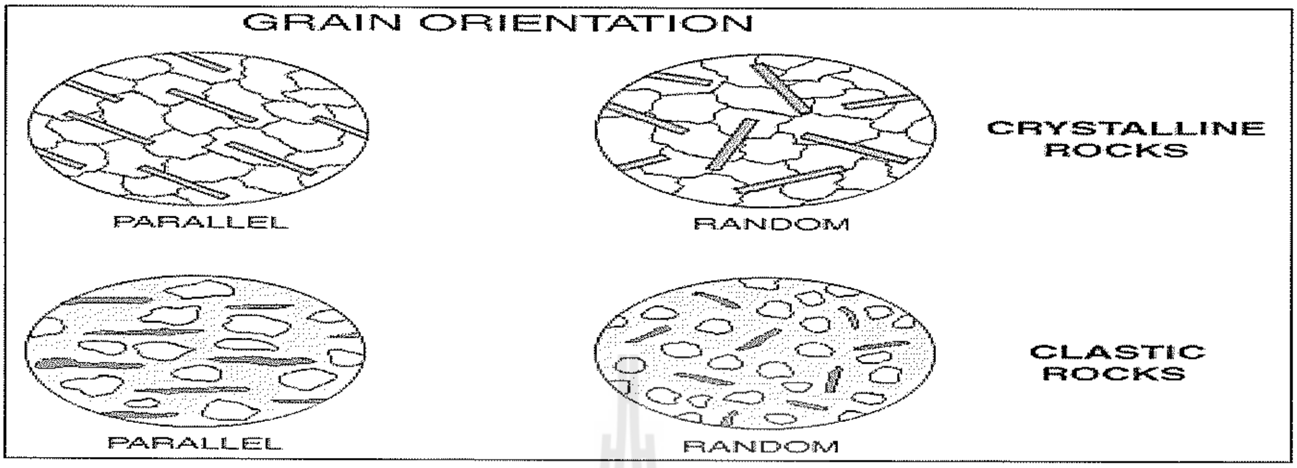


Figure 2-37: Environment vs. Sorting

: Orientation of Grains



- Indicate the *grains are mixed up* into zones.
- Relates to the *method of transport and deposition* of the grains.
- Interpret *ancient current or wind directions.*
- The long axis of the grain indicated the *flow direction.*

: Chemistry and mineralogy

- Depositional environment may provide by minerals which conditioniginally precipitated at the time of deposition
- They are extremely sensitive to diagenetic change and can possibly be more of an indicator of post deposition
    - Diagenetic: The physical, chemical or biological alteration of sediments after deposition.
    -

: Oxidation – Reduction (Redox Potential, Eh)

- **Reduction potential** (also known as **redox potential, oxidation / reduction potential**) is a measure of the tendency of a chemical species to added/reduced electron.

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- Relate to the **oxygen content** of water.

  Application of Eh for environmental analysis
- **: <u>Oxygen content</u>**

  High Eh: high oxygen, shallow water depth

  Low Eh: low oxygen, deep water depth

  <u>Depositional environment</u>: color, chemical facies

  Dark, green or grey: reducing environment, high organic matter (marine or deep water)

  Red, Yellow. Brown: oxidization environment (terrestrial)

: Colors depend on:

- Mineral, cement, and matrix colors
- Common color from ferruginous, carbonaceous, siliceous, calcareous
  - Limonite (Yellow) & hematite (Red, Brown)
  - Carboraceous &phosphatic = Grey to Black
  - Iron sulfide, manganese, **glauconite**, ferrous iron, serpentine, chlorite, epidote = Green

Color vs. Environment

- **Red, Brown**: Ferric iron indicate to an oxidizing environment
- **Green, blueyish gray**: Ferric iron indicate to a reducing environments.
- **Dark brown**, **Black** colors: organic matter indicate to a potential petroleum source, reducing environments.
- **Black** color of sulfides indicate to anaerobic environment conductive to the production of hydrocarbon

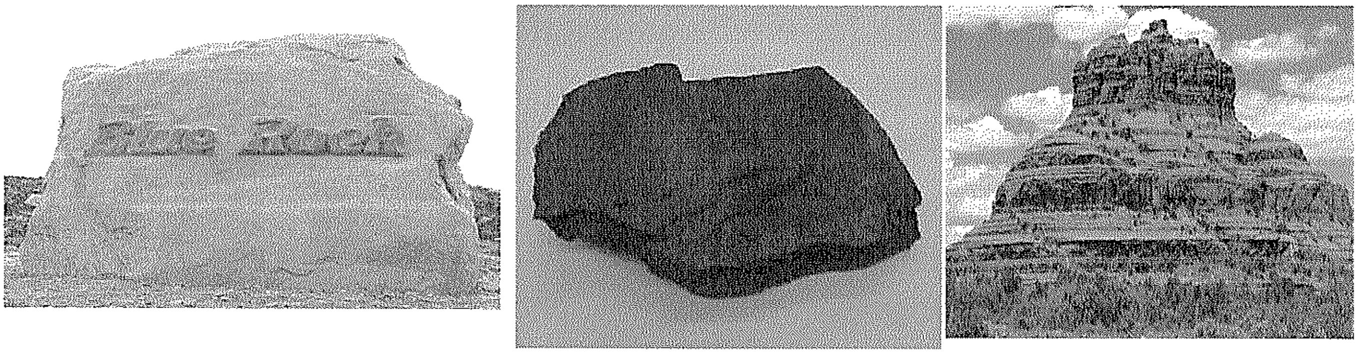

Figure 2-38: Difference color in the rock

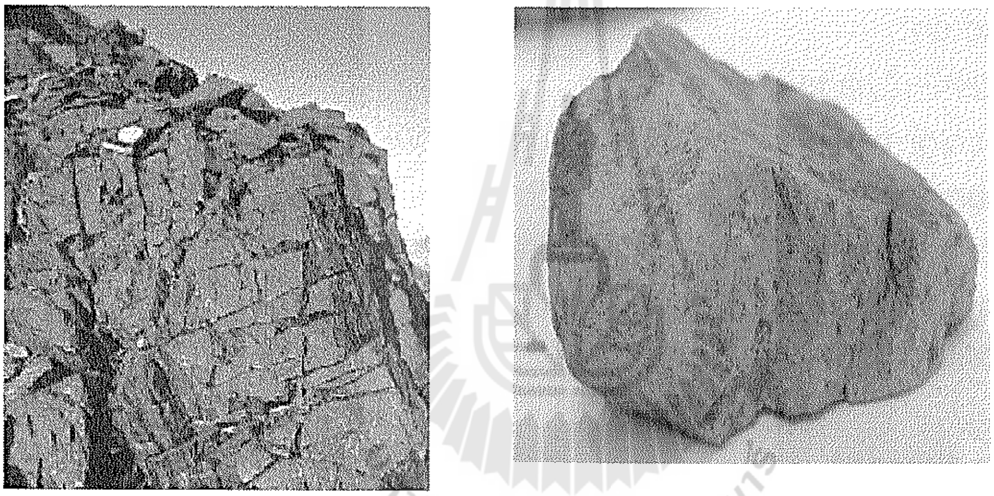

Figure 2-39: Banded Iron Formation. The red bands are hematite, and are interbedded with chert.

Common Minerals & Depositional Environment

1. Glauconite
2. Mica flakes
3. Carbonaceous materials (lignite & coal)
4. Shell fragment
5. Clay minerals
6. Trace Element Content

: Glauconite $(K,Na,Ca)(Fe^{+3},Al,Fe^{+2},Mg)_2(Si_2Al_4O_{10})(OH)_2$

- Green mineral (reducing environment)
- very low weathering resistance
- Continental shelf marine environment

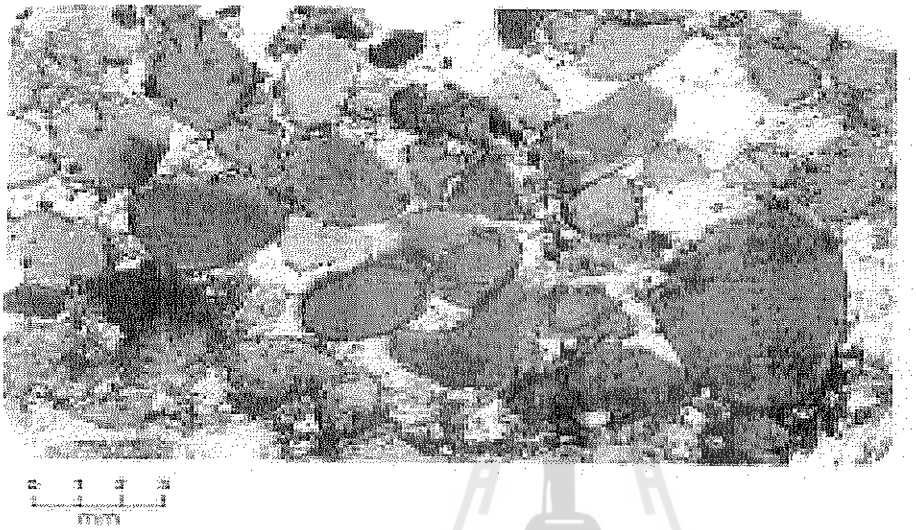

Figure 2-40: Glauconite mineral showing the reducing environment

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: Mica flakes (Muscovite) $K_2Al_4(Si_6Al_2)O_{20}(OH,F)_4$

Trend to be winnowed out of high energy of deposition (HE) by strong current and carried away to be deposited in lower energy of deposition (LE)

HE	LE
• Barrier island bar • Shallow shelf bar • Eolian dunes	• Outer delta slopes • Outer shelf • Submarine channels and fans

: Carbonaceous material

- Lignite & coal
- Most from land plants and commonly found in fluvial, lacustrine, delta sands

: Shell fragment

- Mostly indicates a marine deposit and quite limited in continental deposition due to leaching by acidic meteoric water

: Clay minerals

- Illite & Montmorillonite: marine rocks
- Kaolinite: continental rocks

: Trace Element Content

- Continental= Titanium, Thorium
- Marine (slightly anaerobic)= Chromium
- Marine (Highly anaerobic)= Boron, Copper, Vanadium, Gallium

2.Organic Sediments

Derived due to organic activity.

: fossils + calcite/dolomite.

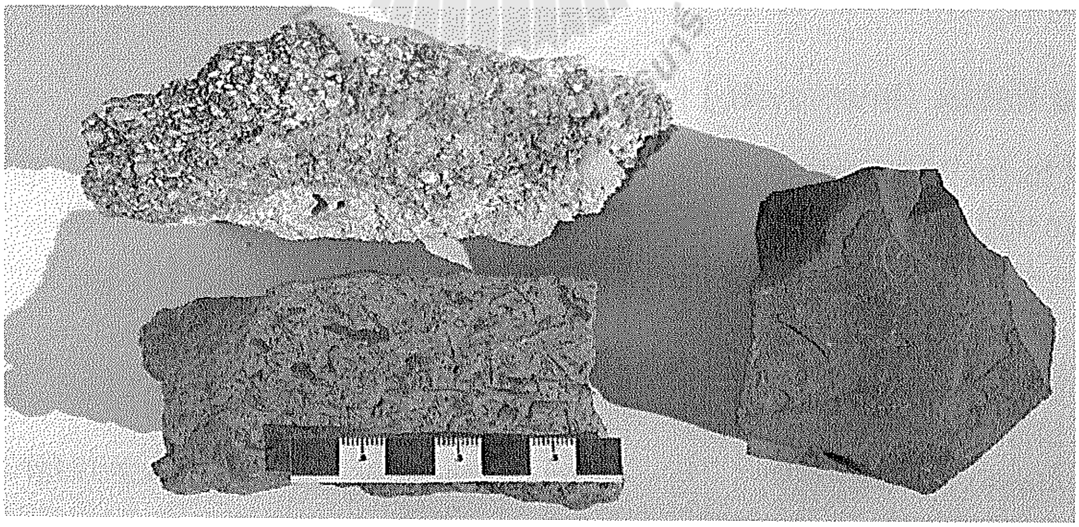
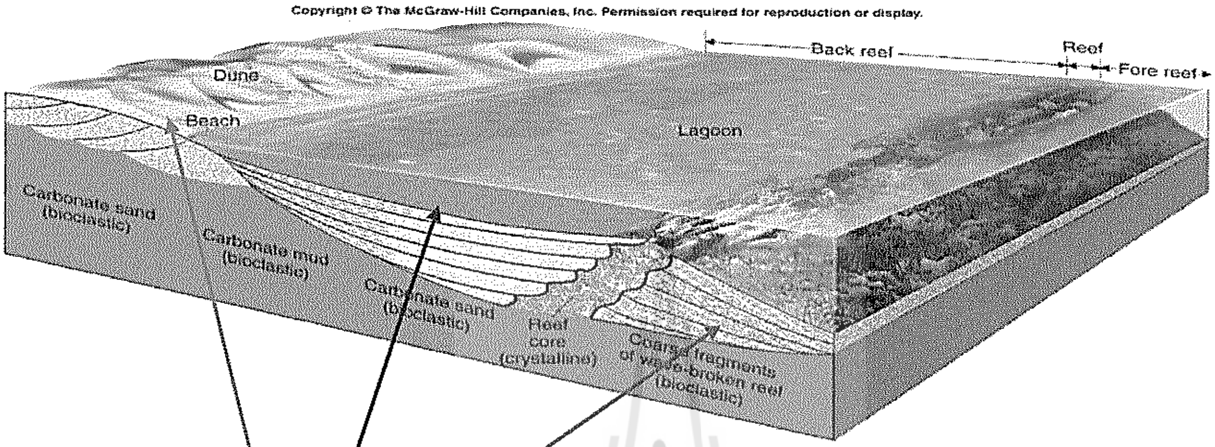


Figure 2-41: Organic sedimentary rocks

Figure 2-42: A living coral-algal reef sheds bioclastic sediment into the fore-reef and back-reef environments.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The fore reef consists of coarse, angular fragments of reef.

Coralline algae are the major contributors of carbonate sand and mud in the back-reef environment.

Beaches and dunes = **bioclastic sand.**

The sediments in each area can lithify to form highly varied LS.

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Figure 2-43: Corals precipitate $CaCO_3$ to form limestone in a r

Water depth about 25 feet. Warm and clear water.

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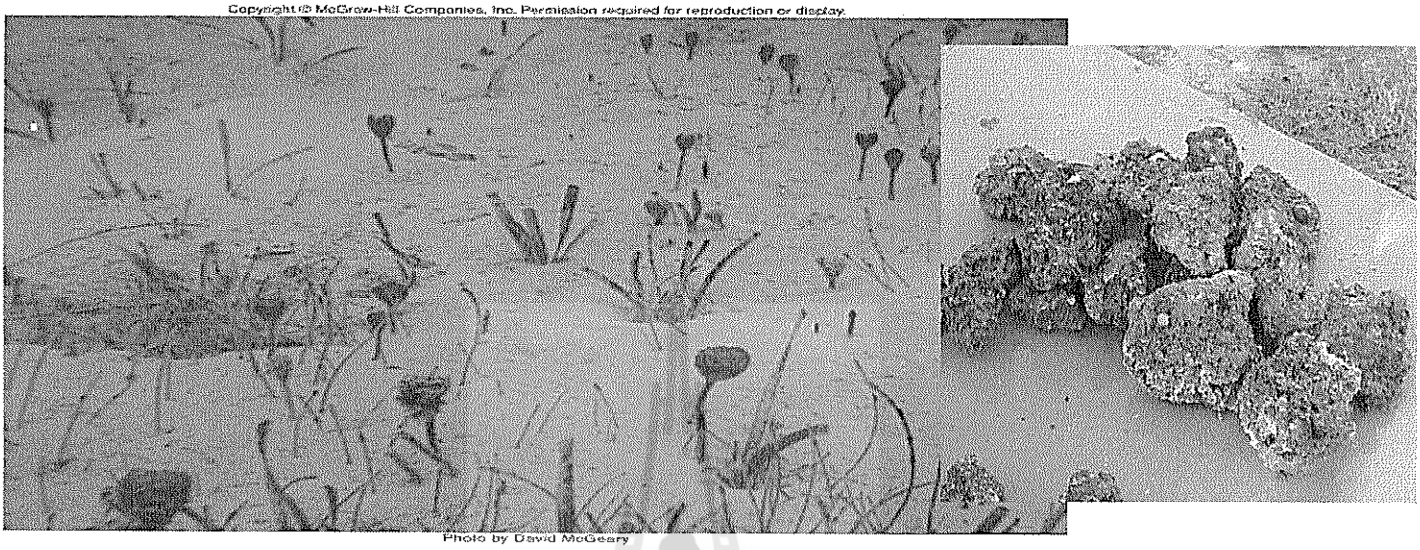

Photo by David McGeary

Figure 2-44: Coralline algae on the seafloor off the Bahamas can produce large quantities of carbonate mud

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Example of Organic Sediments

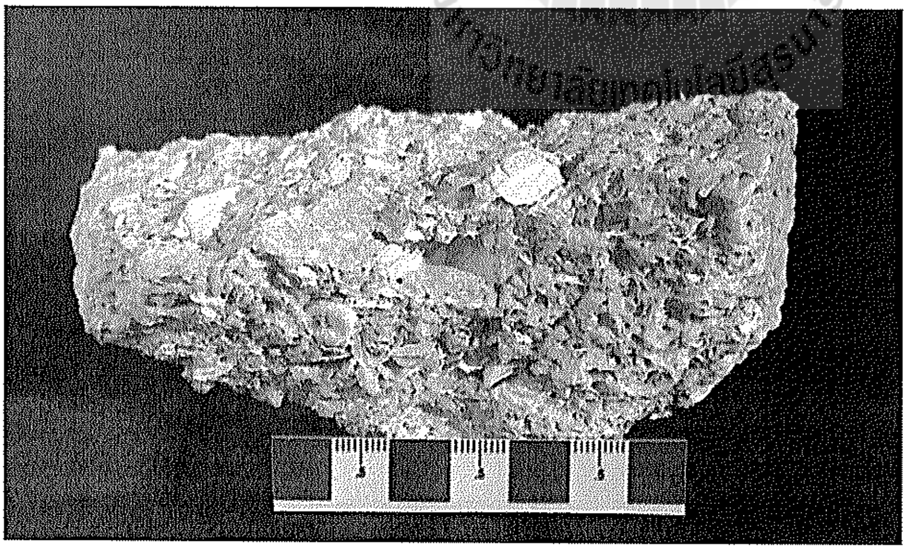


Figure 2-45: Coquina: rock composed of shell fragments only.

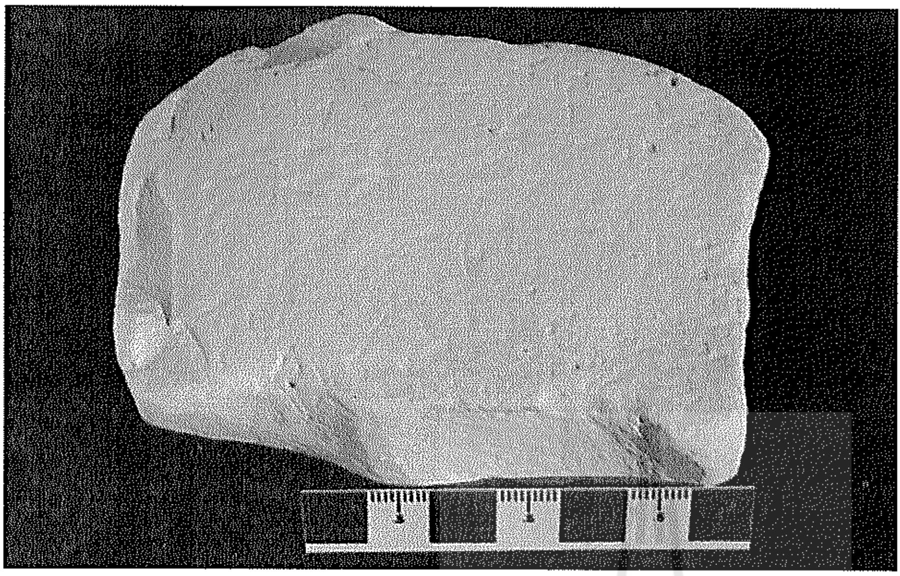
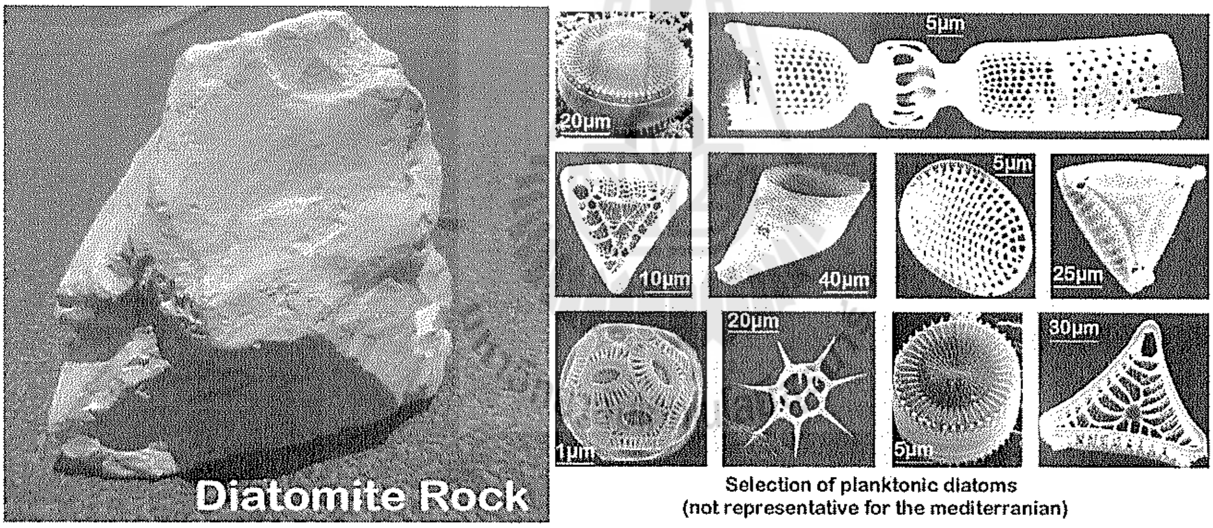
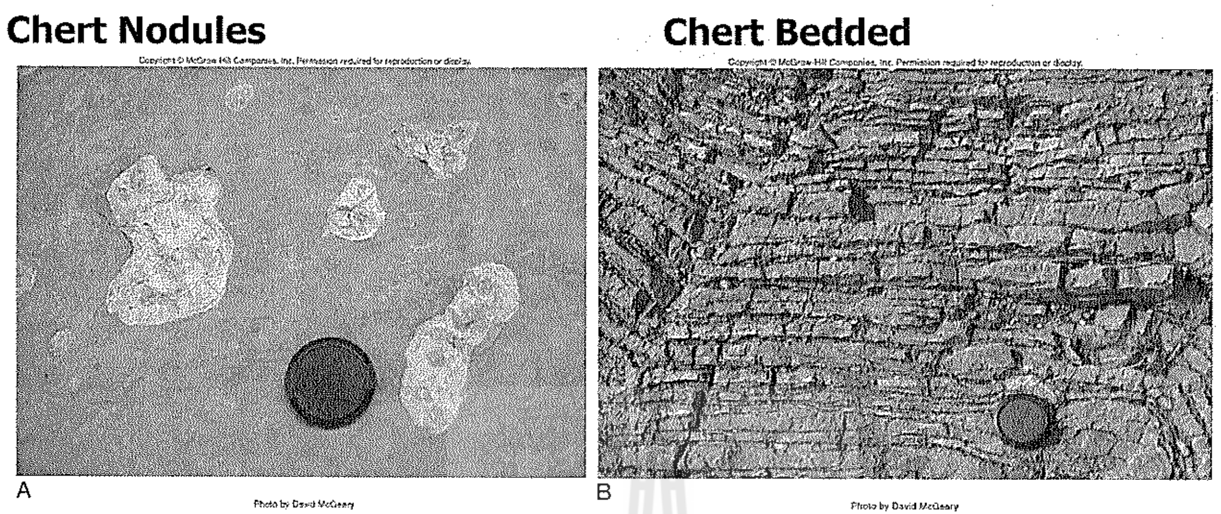


Figure 2-46: **Chalk**: made up of calcareous fine grained planktonic micro-organisms.



Selection of planktonic diatoms
(not representative for the mediterranian)

Figure 2-47: Diatomite: Siliceous fine grained planktonic organisms (*diatoms*). **(Marine enviromnet)**


Chert Nodules

Chert Bedded

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Photo by David McGeary

Figure 2-48**: Chert: cryptocrystalline** siliceous which may be of organic (radiolaria) or inorganic origin (chalcedony)-**deep marine environment**

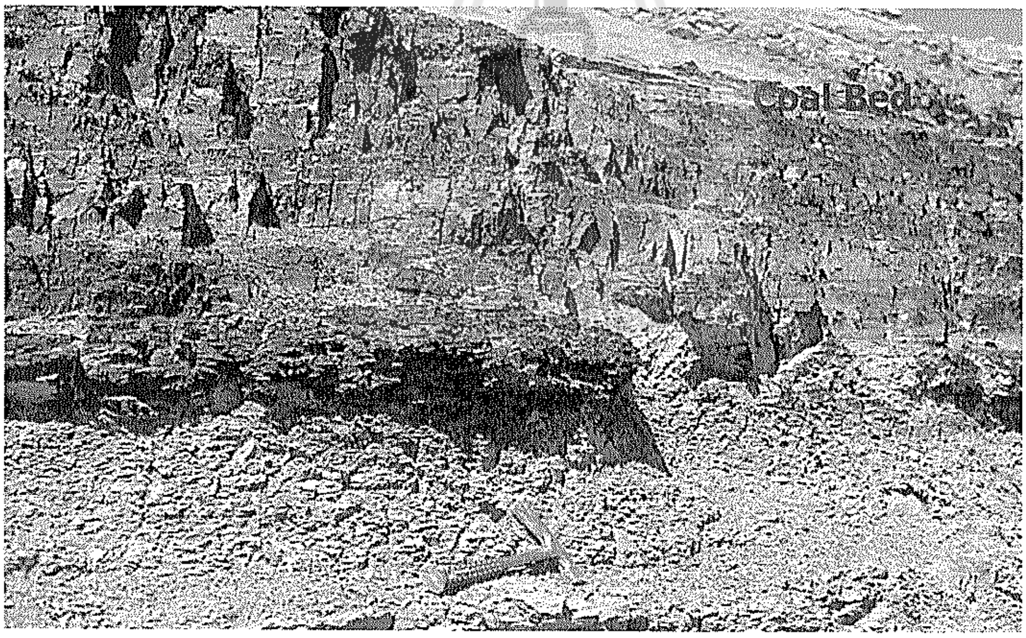

Figure 2-49: Coal: modified plant material (continental Environment)

3. **Inorganic/Chemical Sediments**

Formed by chemical precipitation from solution.

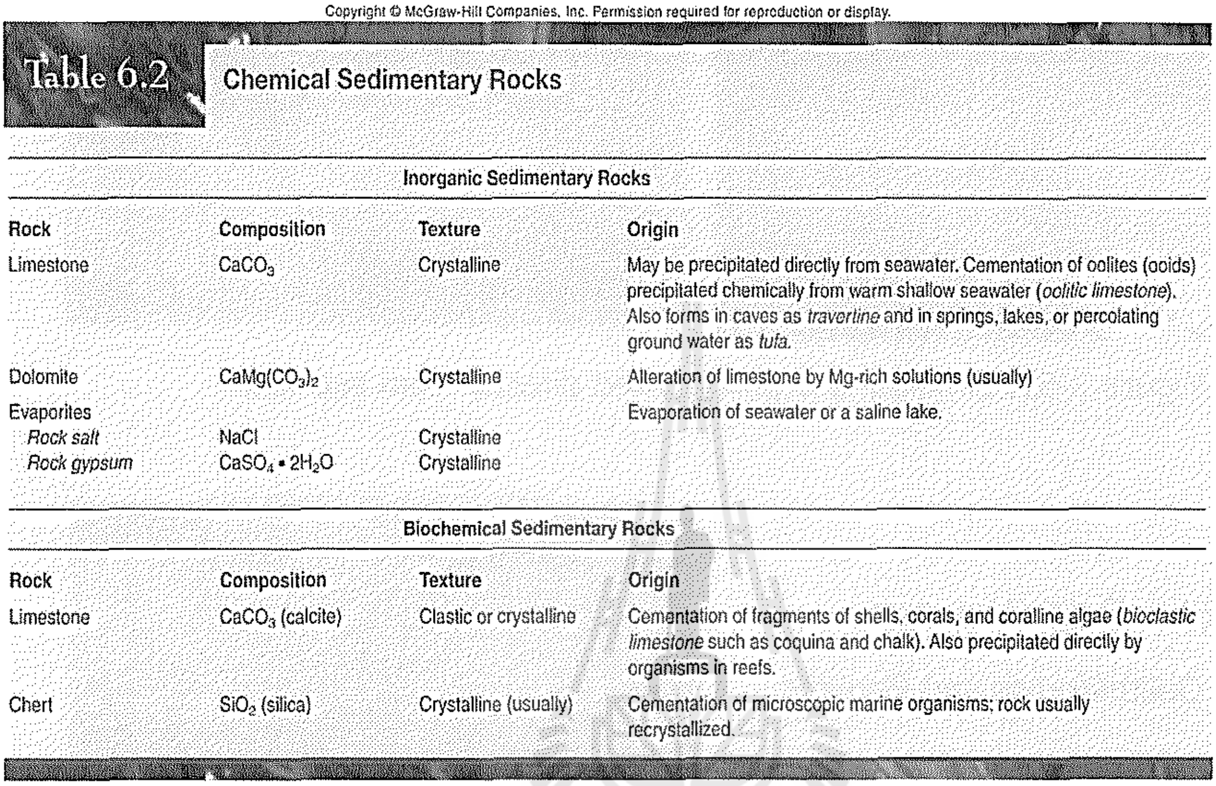

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Table 6.2 Chemical Sedimentary Rocks

Inorganic Sedimentary Rocks

Rock	Composition	Texture	Origin
Limestone	$CaCO_3$	Crystalline	May be precipitated directly from seawater. Cementation of oolites (ooids) precipitated chemically from warm shallow seawater (*oolitic limestone*). Also forms in caves as *travertine* and in springs, lakes, or percolating ground water as *tufa*.
Dolomite	$CaMg(CO_3)_2$	Crystalline	Alteration of limestone by Mg-rich solutions (usually)
Evaporites			Evaporation of seawater or a saline lake.
Rock salt	NaCl	Crystalline	
Rock gypsum	$CaSO_4 \cdot 2H_2O$	Crystalline	

Biochemical Sedimentary Rocks

Rock	Composition	Texture	Origin
Limestone	$CaCO_3$ (calcite)	Clastic or crystalline	Cementation of fragments of shells, corals, and coralline algae (*bioclastic limestone* such as coquina and chalk). Also precipitated directly by organisms in reefs.
Chert	SiO_2 (silica)	Crystalline (usually)	Cementation of microscopic marine organisms; rock usually recrystallized.

Figure 2-50: Chemical Sedimentary rock classification

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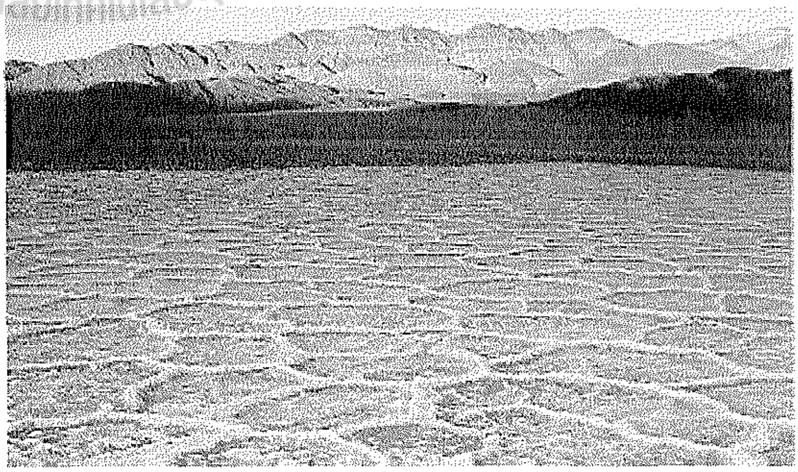
Precipitation sequence from seawater:

Calcite ($CaCO_3$)
Anhydrite ($CaSO_4$)
Gypsum ($CaSO_4.H_2O$)
Halite (NaCl)
Sylvite (KCl)



Example of Inorganic/Chemical Sediments

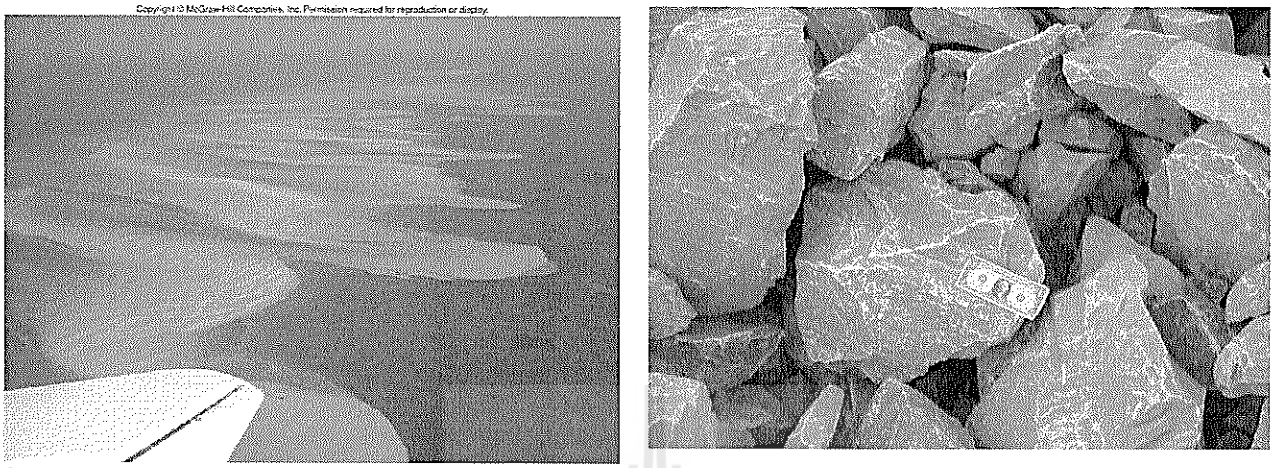

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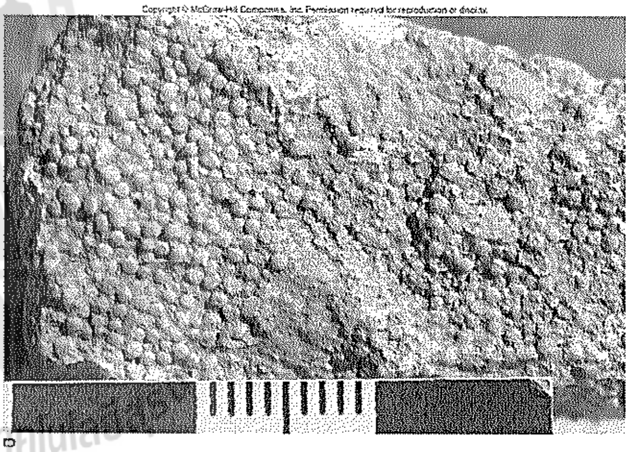
Figure 2-51: Limestone is precipitated directly from seawater.

Figure 2-52: Oolitic Limestone:

Ooliths/ooids and Pisoliths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4. Sedimentary Structure

Sedimentary structure can be divided into 2 studies:

1. **Primary** (physical) study: inorganic (mineral) & organic (trace fossil)
2. **Secondary** (chemical) study: diagenetic concretions (การเปลี่ยนแปลงสภาพไปหลังจากที่สิ่งแวดล้อม เปลี่ยนแปลงไป)

Kinds of sedimentary structure

1. Erosional structures: unconformity, cut and fill bedding
2. Depositional structures: cross bedding, graded bedding
3. Post-depositional structures: concretion, fracture, fault, curve, sinkhole
4. Biogenic structures: trace fossils, fossils

Sedimentary Structures

Clastic sediments display a wide variety of bed structures that help in determining:

1. **Way-up** of a rock sequence
2. **Depositional environment**

Paleocurrent pattern & paleogeography

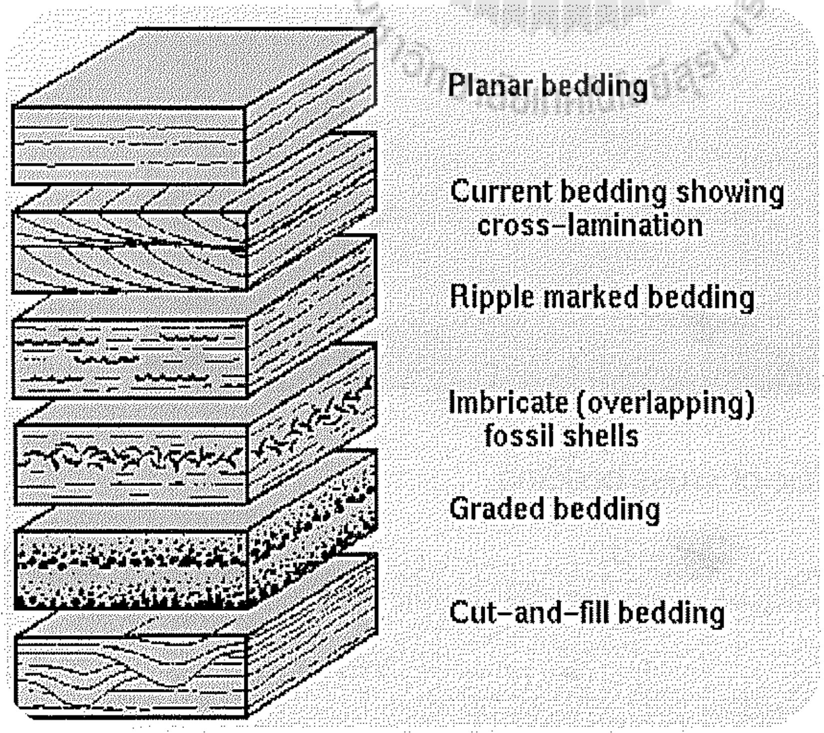

Figure 2-53: Characteristic of sedimentary structure

Sedimentary Structures indicate to

: Give evidence of depositional environments.

: Sedimentary rocks are deposited originally in horizontal beds.

: Later deformation causes the beds to be inclined.

: Which was the original way up? Structures can give that information.

: Sedimentary structures can give idea of ***paleocurrents and paleography***.

Type of Sedimentary Structures

1. Bedding

:Series of visible layers within a rock

: Horizontal sheets differing in composition

: Most common sedimentary structure

2. Cross-bedding

: Series of thin, inclined layers within a horizontal bed of rock

: Common in sandstones

: Indicative of deposition in ripples, bars, dunes, deltas

Figure 2-55: Characteristic of cross bedding

3. Ripple marks

Small ridges formed on surface of sediment layer by moving wind or water in shallow environments.

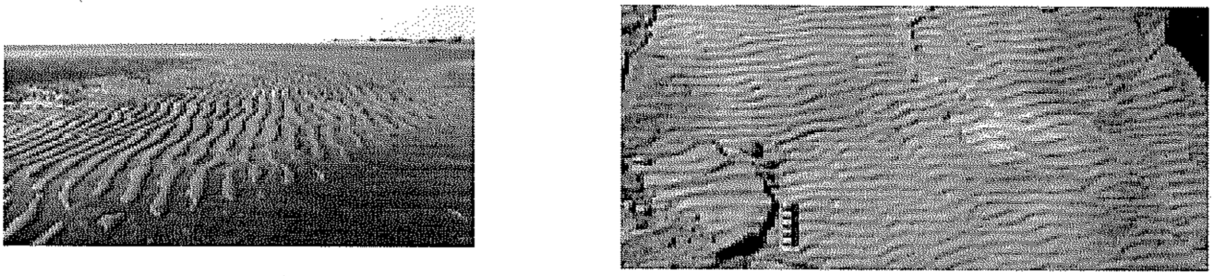

Figure 2-55: Ripple mark in recent (left) and in ancient (right)

4. Graded bedding

Progressive change in grain size from bottom to top of a bed as they enter a body of water that is standing still.

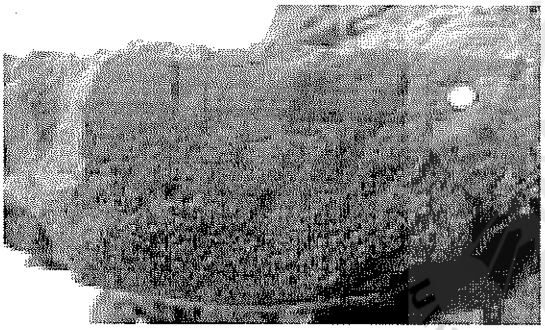

Figure 2-56: Gradded bedding

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5. Mud cracks

Polygonal cracks formed in drying mud

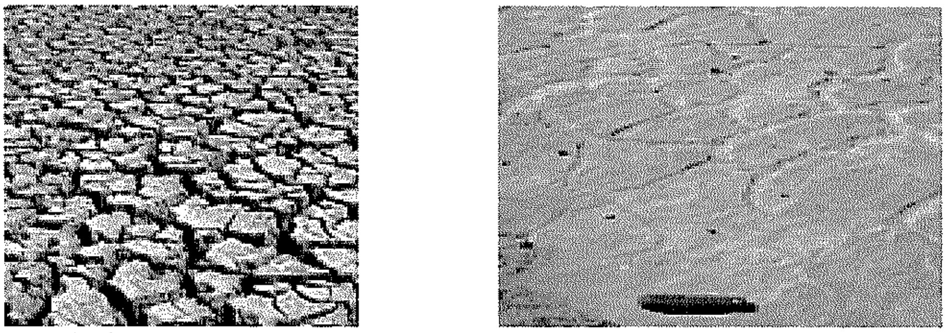
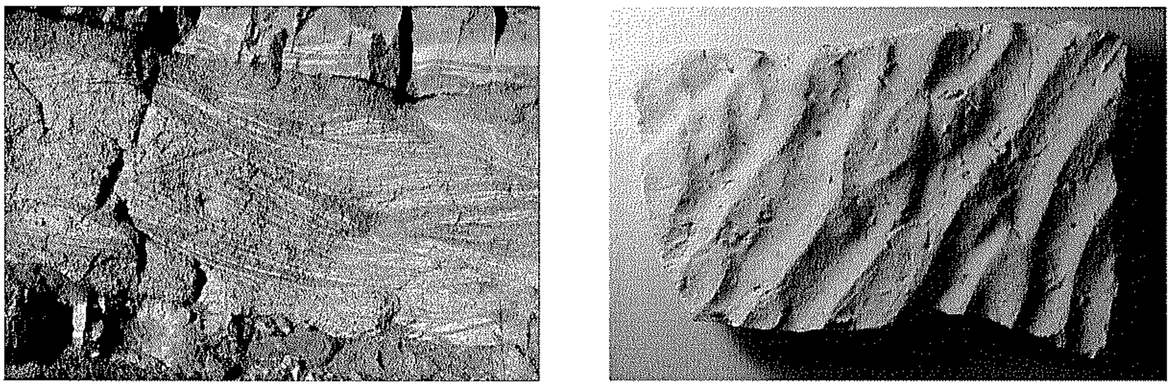


Figure 2-57: Mud cracks

Cross-bedding

Ripple mark



Mud cracks

Concretion

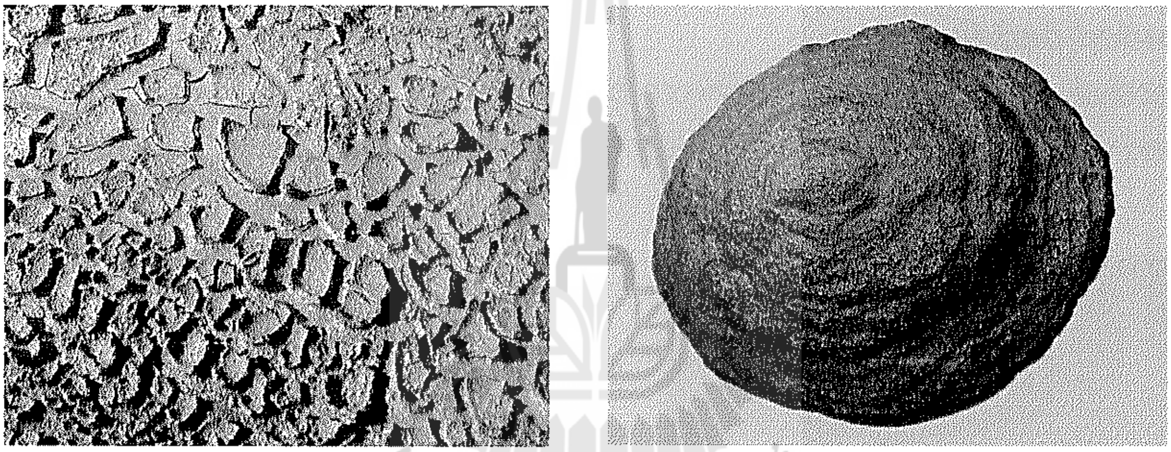


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Figure 2-58: summarize of sedimentary structure

Bedding or Stratification

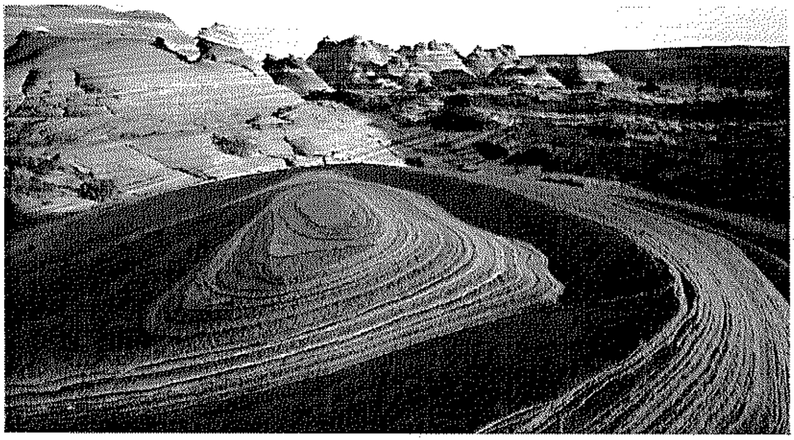


Figure 2-59: Bedding and stratification

Sedimentary layering or strata, or a primary sedimentary structure; Structures formed during deposition

Stratification

Stratification is the layering of sedimentary rock.

It occurs when the conditions of sedimentary deposit change.

What Changes?

: Velocity of water or wind

: Rise in Sea Level

: Change in source of sediments

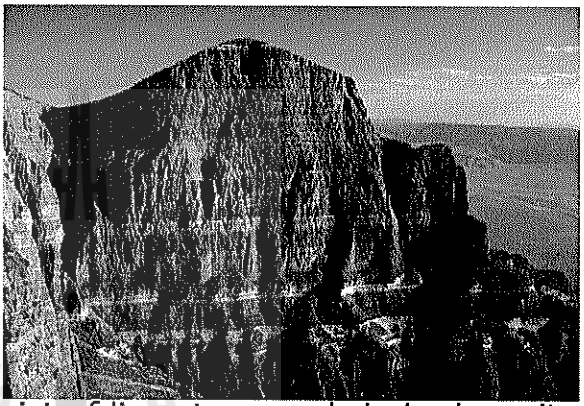


Figure 2-60: The different layers consist of limestone and shale deposited in shallow marine settings.

Horizontal Bedding: Beds get younger upward.

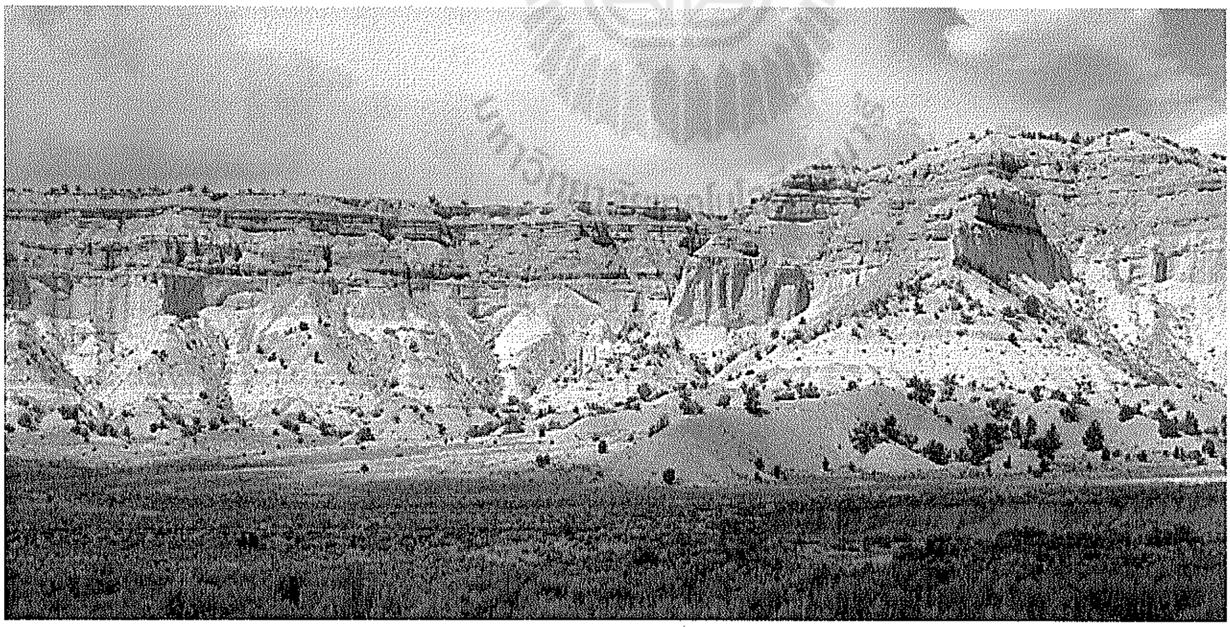


Figure 2-61: Deposited in water (no wave affect)

Cross Bedding

Series of thin, inclined layers in a horizontal bed or rock

Deposition in dunes, sand bars, deltas

Figure 2-62: Cross bedding show the direction of current

Development of Cross Bedding

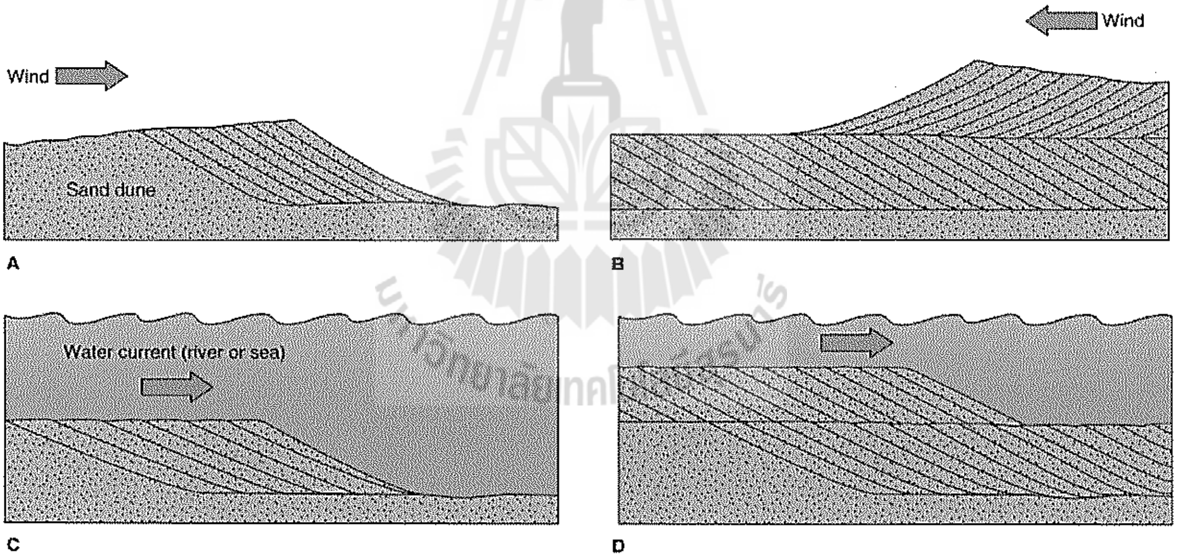


Figure 2-63: Form when particles drop from a moving current (water/air)

Graded bedding

- Change in grain size from coarse at bottom of bed to fine at the top of the beds

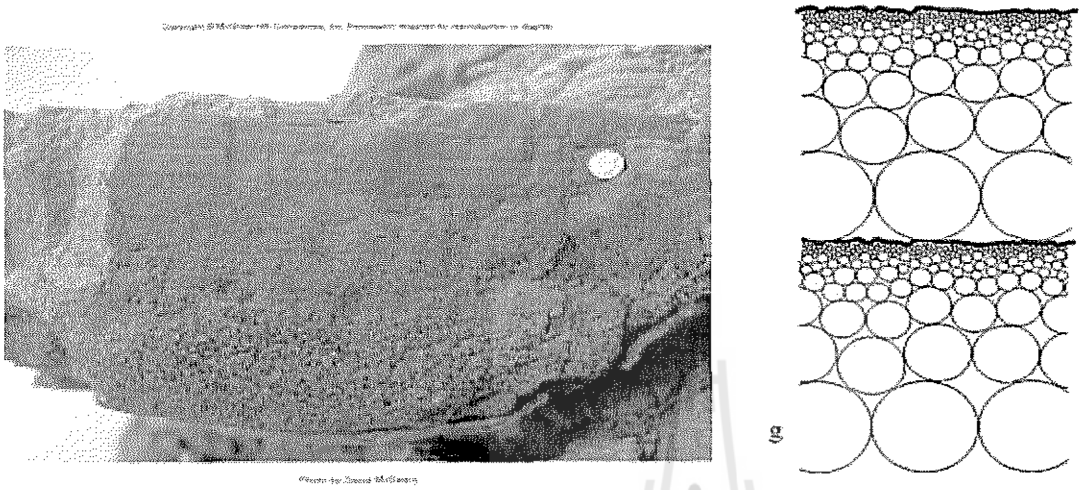
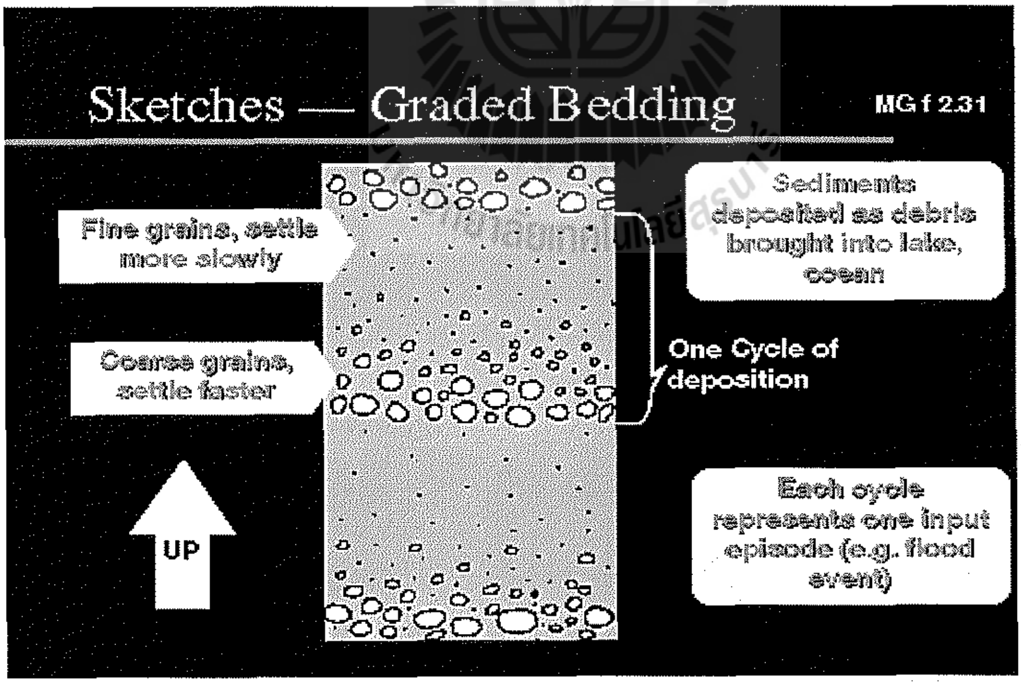


Figure 2-64: Gradded bedding show the change ofgrain size



Sketches — Graded Bedding

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Fine grains, settle more slowly

Coarse grains, settle faster

UP

Sediments deposited as debris brought into lake, ocean

One Cycle of deposition

Each cycle represents one input episode (e.g. flood event)

Figure 2-65: Sketches of the gradded beding

Turbidity current

– beds grade from coarse grained at the bottom to fine grained at the top.

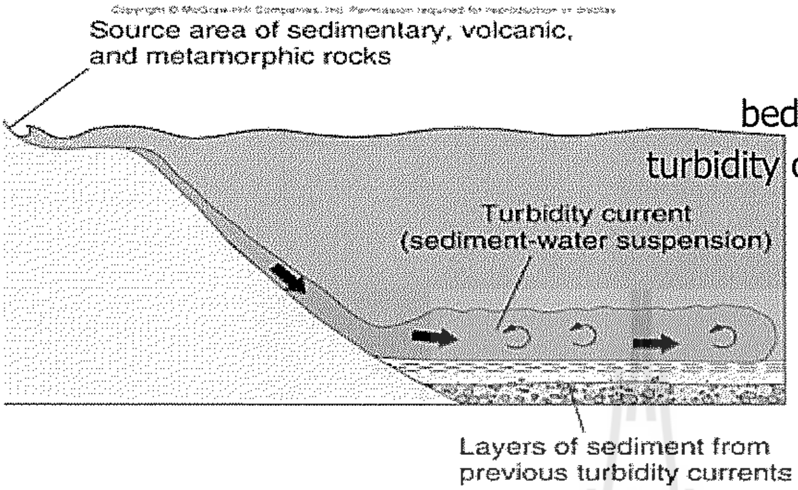

Figure 2-66: Gradded bedding form from the turbidity current

Ripple Marks

Ripple Marks – wave action, form on top of beds.

Ripple marks for during deposition through water flow. Different types of ripple marks record different types of water currents, and thus depositional environments.

Small ridges formed on surface of sediment by moving wind or water

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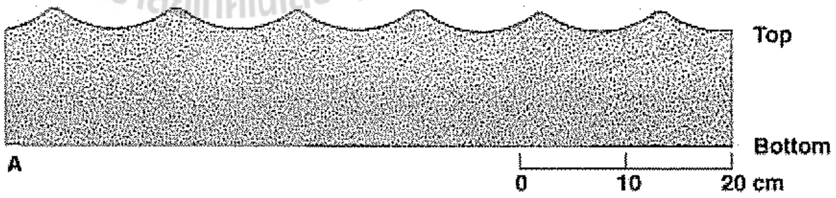
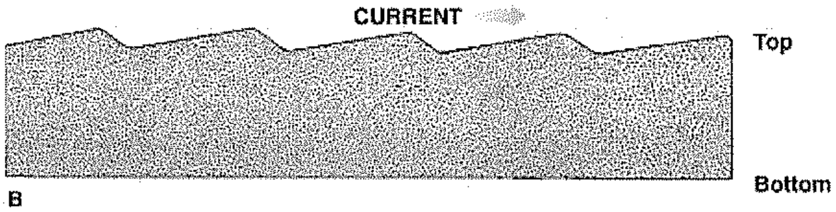
Symmetric (Beaches)



Asymmetric



(Rivers and wind)

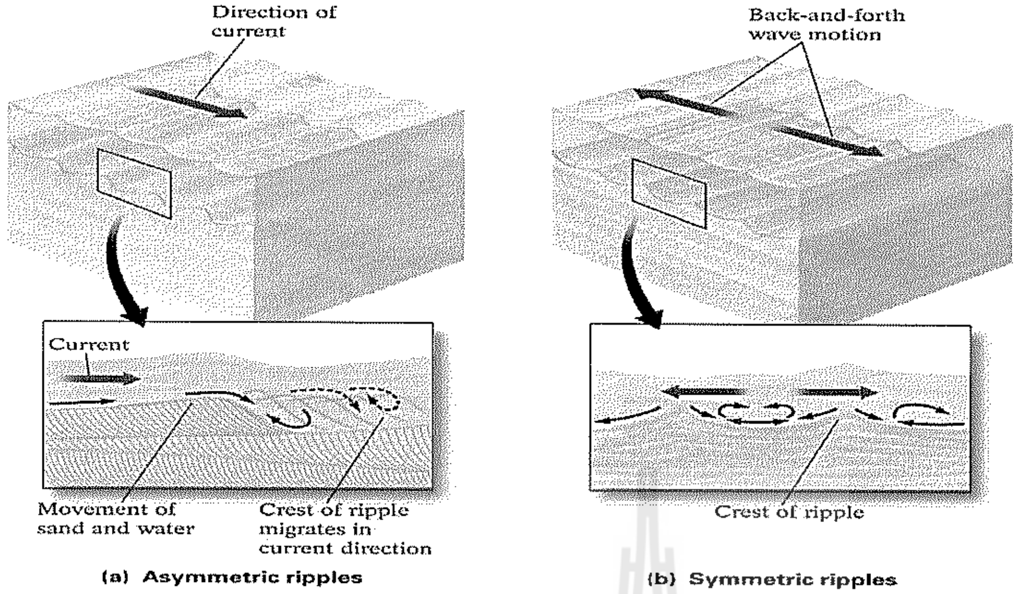
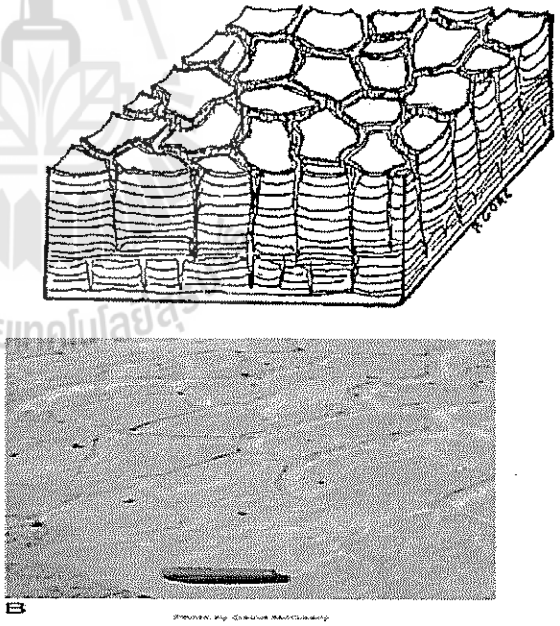


Figure 2-67: Asymmetric and Symmetric Ripples

Mud cracks

- Polygonal cracks formed in drying mud on top of bed

Recent mud cracks



Mud cracks in rock

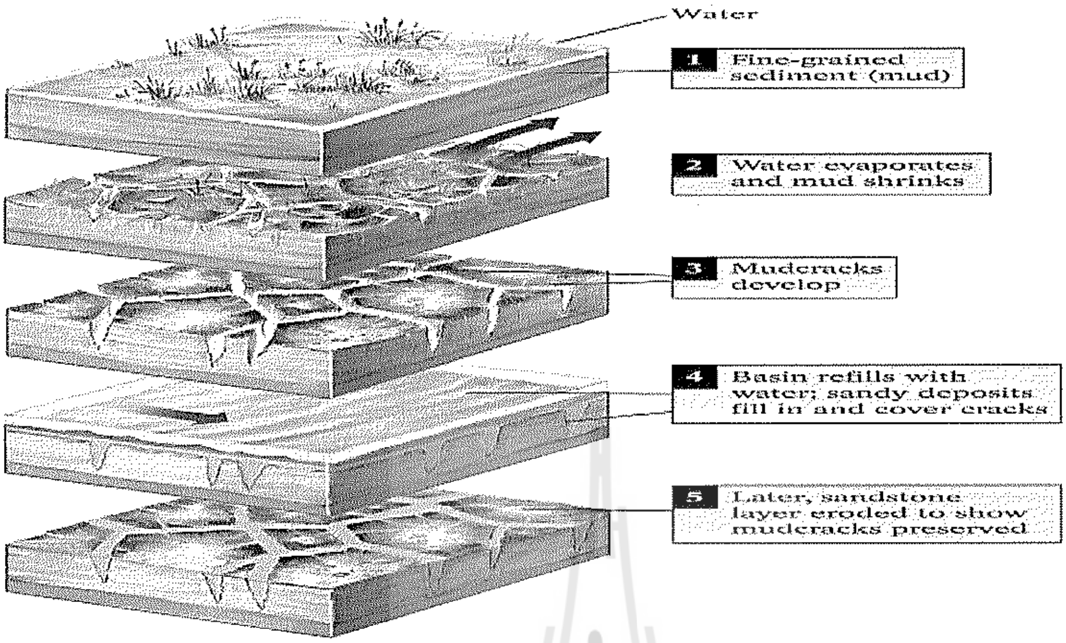


Figure 2-68: Origin of Mud Cracks

Formations

- Extremely thick body of rock with characteristics that distinguish it from adjacent rock units and is large enough to map.
- Formations are based on rock type or sedimentary structure
- Can be a single thick bed, several thin beds of the same rock type, or an alternating sequence of two rock types.

  : Sedimentary layer: limestone beds, can be separated by fossil types, and igneous or metamorphic layer.

  Contact – is the boundary surface between the two different rock types.

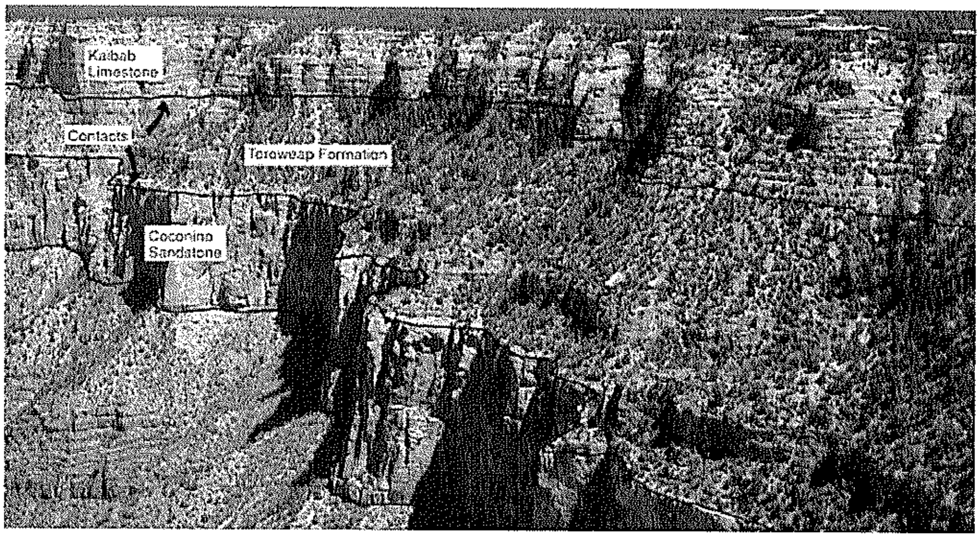
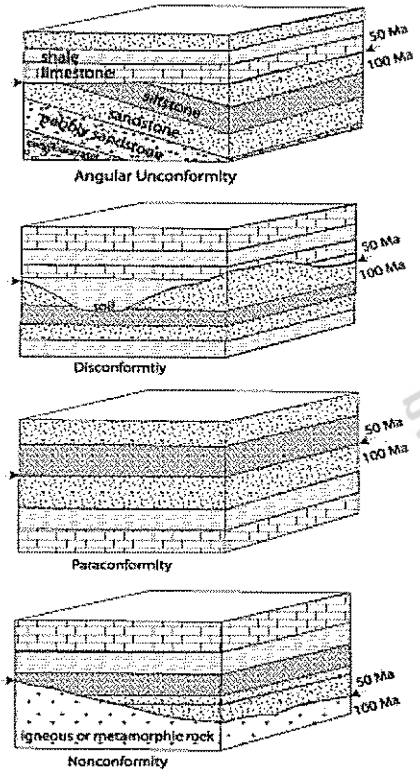


Figure 2-69: Contact of formation depent on sedimentary rock type and sedimentary structure

Unconformity



Unconformities (redrawn from Boggs, 2001)

1. **Angular conformity**: younger sediments rest upon the eroded surface of tilted or folded older rocks.
2. **Disconformity**: contact between younger and older beds is marked by a visible, irregular or uneven erosional surface.
3. **Paraconformity**: beds above and below the unconformity are parallel and no erosional surface is evident; but can be recognized based on the gap in the rock record.
4. **Nonconformity**: develops between sedimentary rock and older igneous or metamorphic rock that has been exposed to erosion.

Figure 2-70: Type of unconformity

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Example of Unconformity

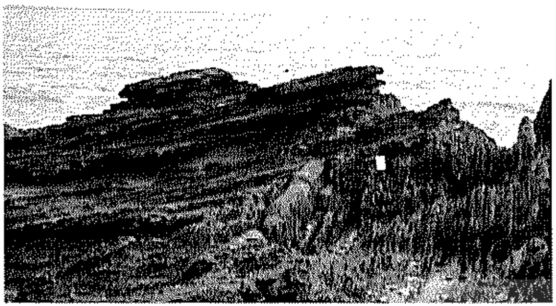

Figure 2-71: Angular unconformity at Siccar Point in Scotland. *Yellow notebook for scale.*

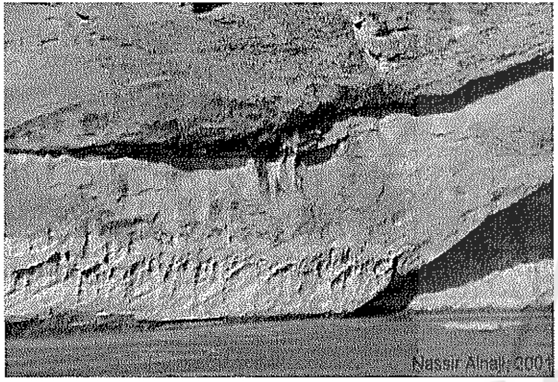

Figure 2-72: **Disconformity** exposed in the cliffed bank of the San Juan River, Paradox Basin, Southeastern Utah.

5. Paleontology (Fossils)

Type of Fossil

Fossils found in sedimentary rocks include:

1. The tracks and trails of animals
2. Microscopic fossils of:
    2.1 continental animal and plants (spores and pollen)
    2.2 marine animal and plants (diatoms, coccolithophores, radiolarians, foraminifera, ostracods, dinoflagellates, etc.)
3. invertebrates (shell, sponges, corals, pelecypods, brachiopods, algea etc.)
4. vertebrates (fish, amphibians, reptiles, and mammals)
5. plants (root, leaf, branch etc.)

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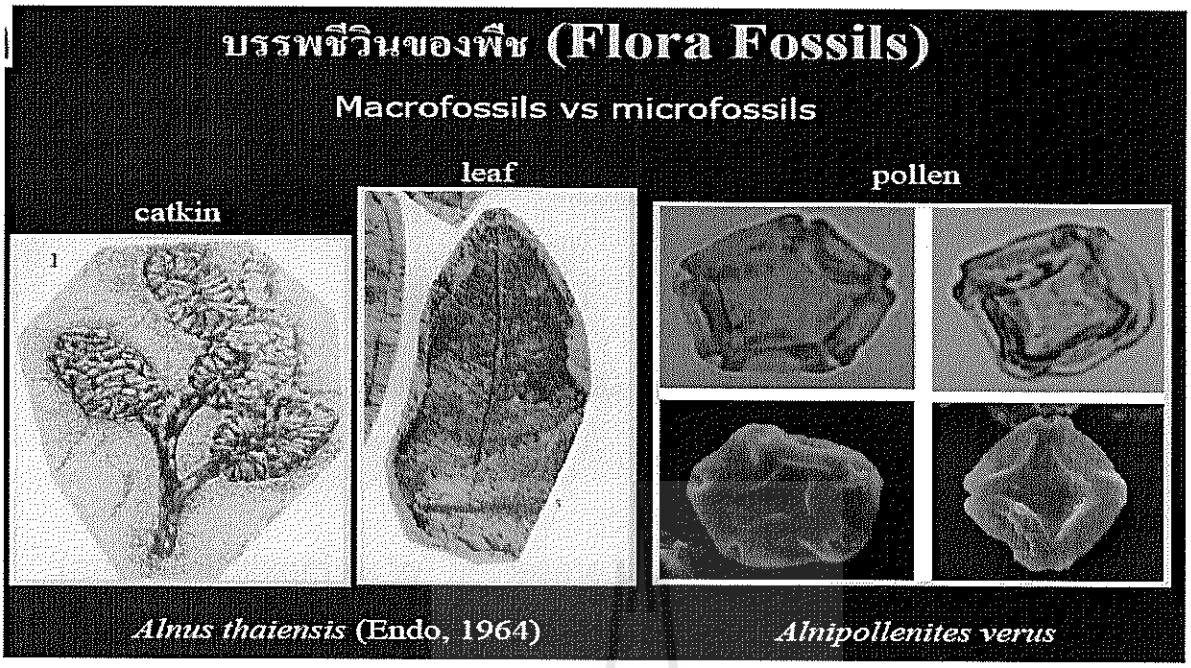


บรรพชีวินของพืช (Flora Fossils)

Macrofossils vs microfossils

Figure 2-73: Flora fossils; leaves spore and pollen

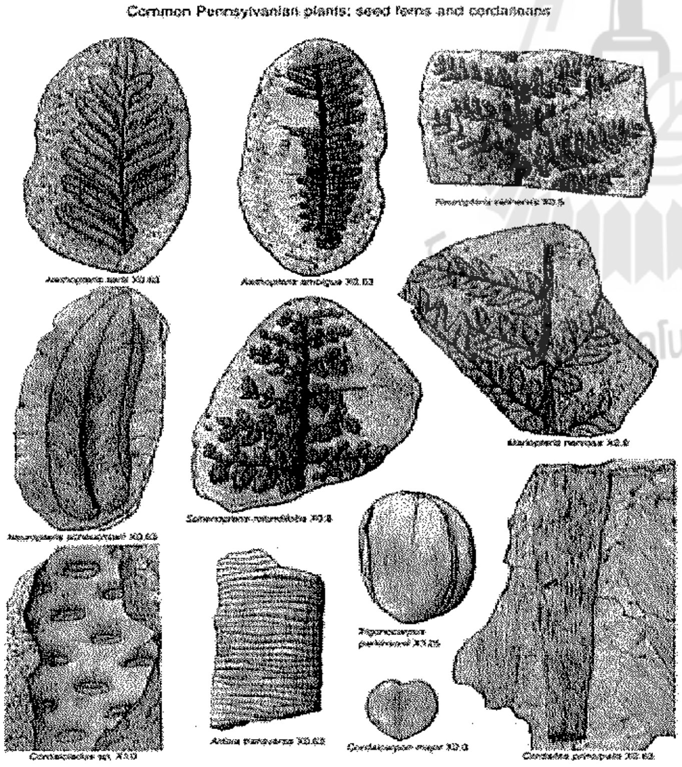


Figure 2-74: Seed ferns and leaves

What characteristics of fossils make them useful for interpreting past environments:

1. They have a distinct geographic range
2. Their distribution was influenced by:

- Water or atmospheric temperature
- Climate variability
- Elevation
- Oceanic salinity, nutrients, oxygen content, turbidity, etc

Fossilization

1. Body Fossils - some part of the body preserved (or as molds and casts).

:Typically hard parts of organisms preserved (such as bone, shell, teeth, etc.).

1.1 Macrofossils: Dinosaur, mammals, primate

1.2 Microfossils: Faraminifera, ostacods, spore& pollen

2. Trace Fossils - tracks, trails, burrows, nests, even fossilized feces (coprolites).

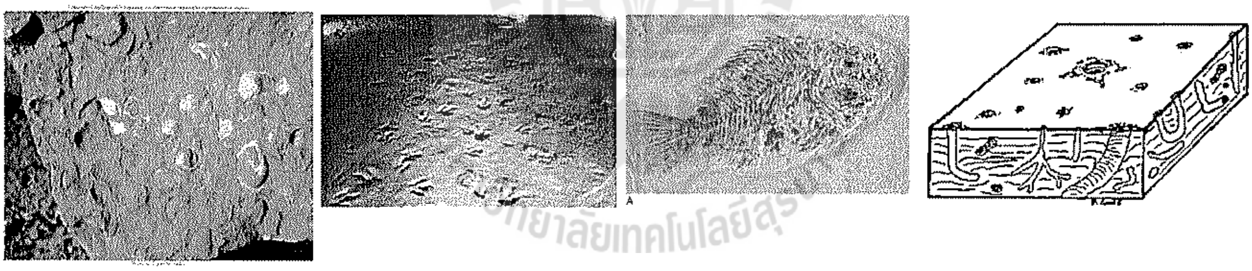


Figure 2-75: trace fossills

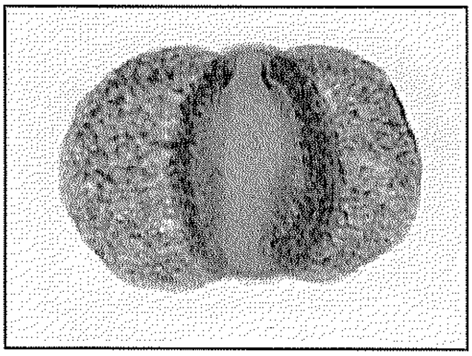


Figure 2-76: Spore& pollen use for indicating the **paleoclimate** and environment i.e. Fossil pine pollen. The abundance of pine pollen, along with the rock moss, indicates a dry climate (temperate)

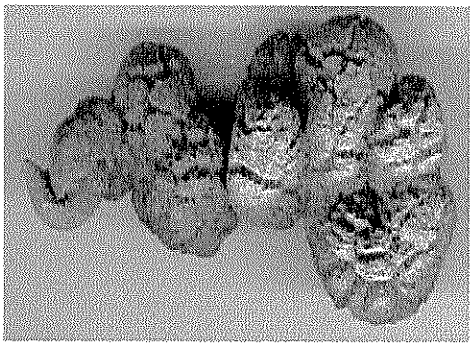


Figure 2-77: a turtle **coprolite** from the Eocene of Madagascar

Types of Preservation

1. Unaltered Remains (ไม่มีการเปลี่ยนแปลงสภาพ, คงสภาพเดิมให้เห็น)

1.1 hard part (shells, teeth, bone)

1.2 mummification (dessication),

1.3 frozen remains (example: Wooly Mammoth),

1.4 tar pits (La Brea Tar Pit of California - mammoths, saber tooth tigers, and other Pleistocene fossils).

2. Altered Remains - changed structurally or chemically or both (การแปรสภาพทางลักษณะโครงสร้างหรือเคมีของซาก fossil หรือแปรสภาพทั้งสองแบบ)

2.1 Permineralization - pores filled with mineral matter.

การที่แร่ธาตุต่างเข้าไปแทรกในช่องว่าง

2.2 Recrystallization - no change in basic composition, but crystals grow larger and are reoriented.

การที่มีการตกผลึกใหม่ของแร่โดยอาจมีขนาดใหญ่ขึ้นหรือการจัดเรียงตัวใหม่ แต่ส่วนประกอบพื้นฐานไม่มีการเปลี่ยนแปลง

Eg. Aragonite ($CaCO_3$) ------> Calcite ($CaCO_3$)

Silica (as microcrystalline quartz - SiO_2 recrystallizing to larger crystals.

Recrystallization may destroy some or all of the fine structure, but will retain the overall shape of the fossil.

2.3 **Replacement** - another mineral replaces the original hard parts.
(การเข้าไปแทนที่ของแร่ใหม่แทนแร่เดิมที่อยู่ในโครงสร้าง)

Example: **silicification** of calcareous, phosphatic (Dinosaurs bones are often silicified or partially silicified, Petrified wood is commonly silicified), or woody fossil material is fairly common.

FeS_2 (Pyrite) often replaces calcite or silica.

- **Silicification:** Introduction of replacement by silica

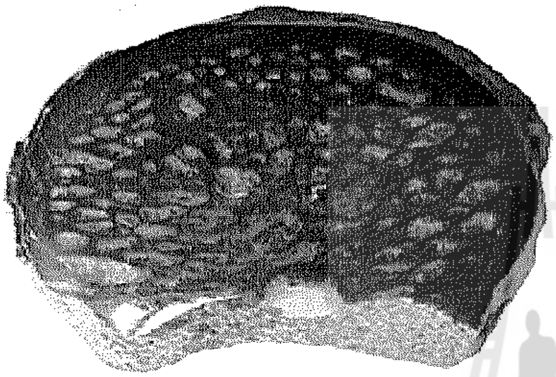
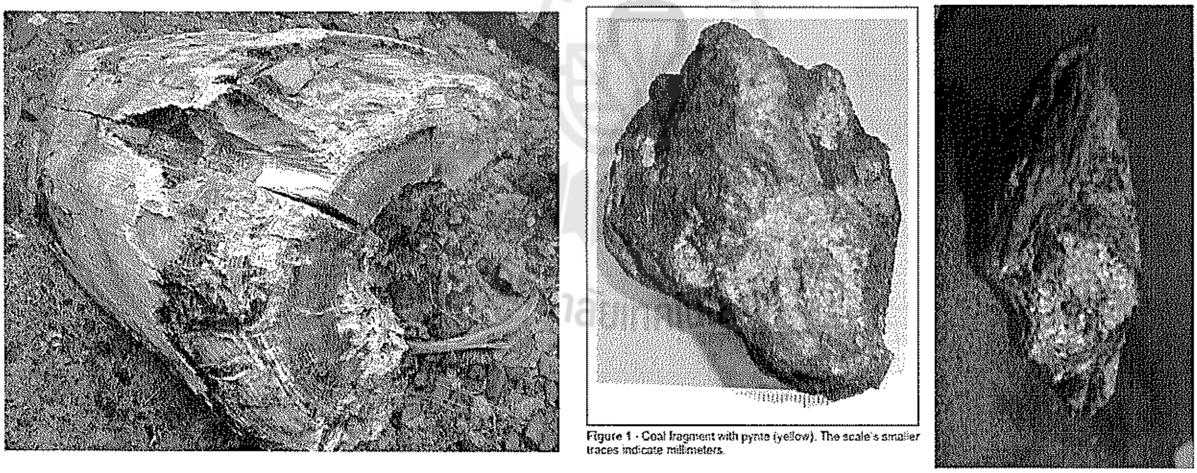


Figure 2-78: Permineralization



Petrified wood **Pyrite on coal**

Figure 2-79: Mineral replaces in the wood (silica) and coal (pyrite)

Fossils in Environmental Analyses

1. Did the organisms in question live where they were buried?
   - Or where their remains or fossils transported there?

Example:

- Fossil dinosaurs usually indicate deposition in a land environment such as a river floodplain
- But if their bones are found in rocks with clams, corals and sea lilies,
- we assume a carcass was washed out to sea

Fossils in Environmental

What kind of habitat did the organisms originally occupy?

- Studies of a fossil's structure
  - and its living relatives, if any, help environmental analysis

For example: clams with heavy, thick shells (deep water)

- typically live in shallow turbulent water whereas those with *thin shells* are found in low-energy environments
- Most corals live in warm, clear
  - shallow marine environments where symbiotic bacteria can carry out photosynthesis

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Deposition Environments can be classify into:

1.Non-marine environment

- พบ Fossil น้อยกว่าใน Marine environment
  - Land environment สภาพแวดล้อมบนบก
  - Aquatic environment (Lacustrine environment) สภาพแวดล้อมในน้ำจืด เช่น ทะเลสาบ, หนอง, บง เป็นต้น

2. Marine environment

2.1 Benthonic environment สภาพแวดล้อมของพื้นทะเลหรือท้องทะเล สัตว์ที่อยู่ในสภาพแวดล้อมแบบนี้ เรียกว่า Benthos ซึ่งสามารถแบ่งเป็น 2 ชนิดคือ

- Vagile เป็น benthos ที่เคลื่อนที่ได้ เช่น ปู กุ้ง
- Sessile เป็น benthos ที่อยู่กับที่ เช่น พลับพลึงทะเล (Crinoid)

2.2 Pelagic environment (Nektoplanktonic) สภาพแวดล้อมของพื้นน้ำ สัตว์ที่อยู่ในสภาพแวดล้อมแบบนี้ แบ่งเป็น 2 ชนิดคือ

- Nekton เป็นพวกที่ว่ายน้ำได้เช่น ปลา
- Plankton เป็นพวกที่ว่ายน้ำไม่ได้แต่ลอยตัวอยู่ตามกระแสน้ำ

Index Fossils

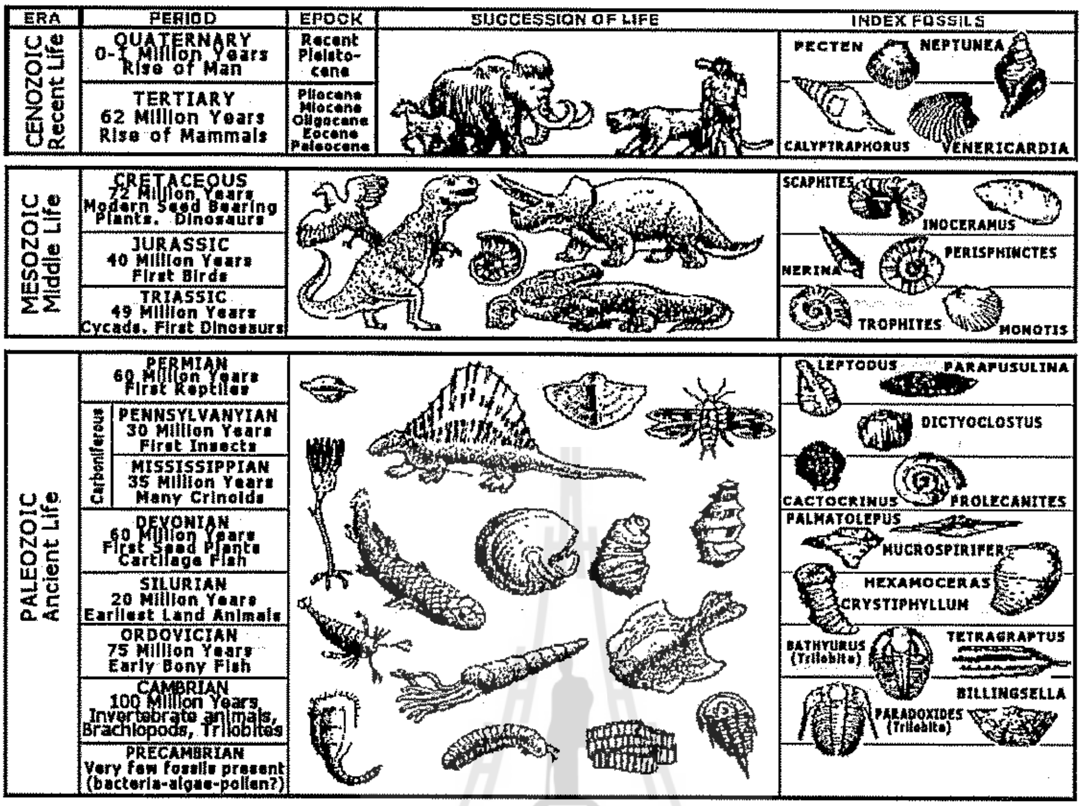
- **Index fossils** are fossils used to define and identify geologic periods (or **faunal/floral** stages) , some case it can be indicate the *depositional environment* at that time.

CHARACTERISTICS OF INDEX FOSSILS

1. Short geologic time range.
2. Wide geographic distribution (implies ecologic tolerance).
3. Abundant (relatively easy to find in rocks)
4. Easily recognizable to a trained paleontologist

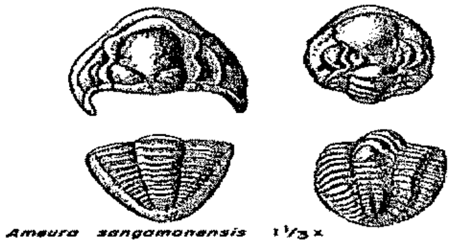
EX.: **Ammonites and Trilobites** are examples of index fossils.

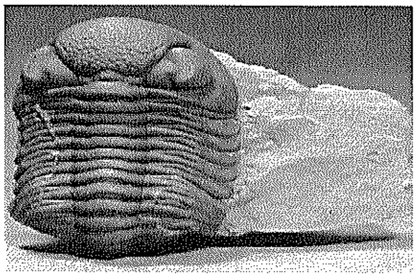
GEOLOGIC TIME SCALE

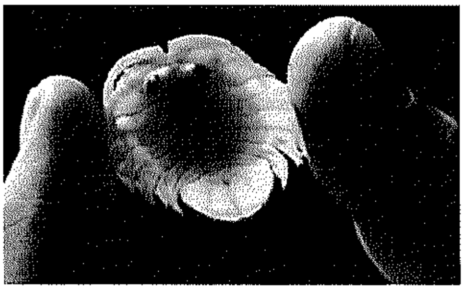


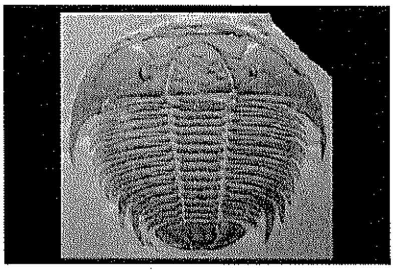
Trilobites

- Cousins of crabs or insects.
- They used to be very common and came in many different and bizarre shapes.
- They are now extinct—totally gone! They died out <u>before the dinosaurs</u> ever lived!


Ameura sangamonensis 1 1/3 ×







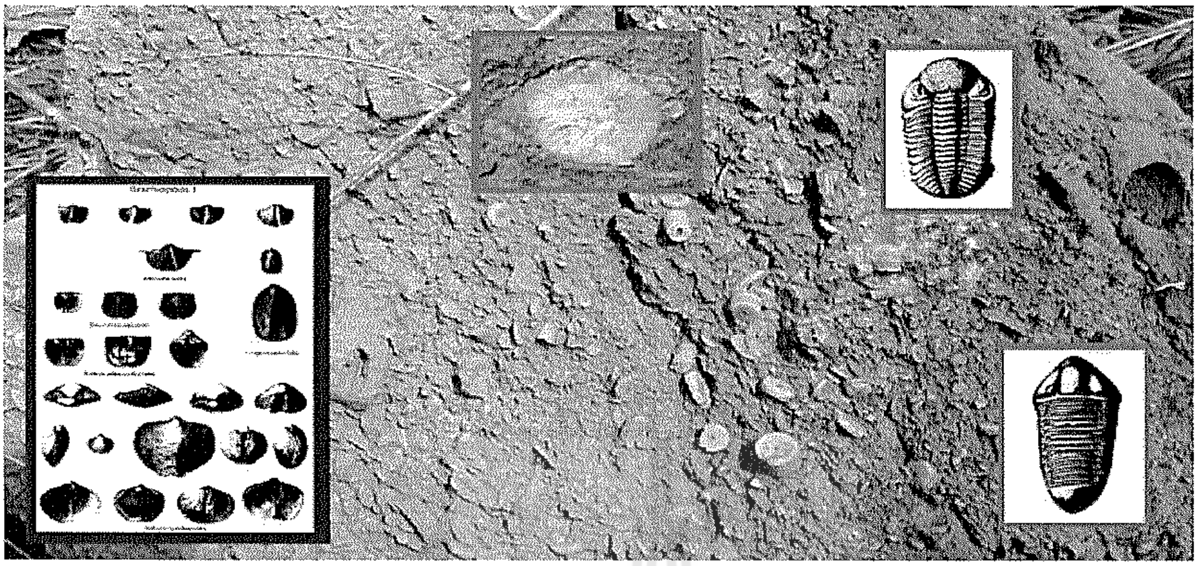
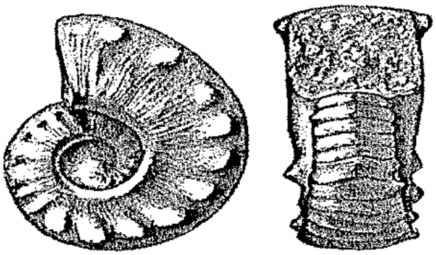


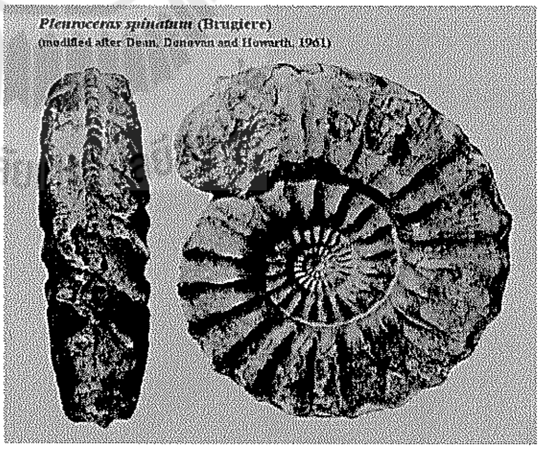
Figure 2-81: Some of the fossils that might be collected on the trip. The background is made by a slab of limestone crowded by crinoid stem fragments. Brachiopods (left) and trilobites (right) are common, as are corals (rugose coral on photo in center).

AMMONITE

Glophrites welleri 2/3 x



Metacoceras cornutum 1 1/2 x



- Cephalopoda (Gastropod)
- Late Silurian/early Devonian (400 Ma) to end Cretaceous (65 Ma)
- Marine envi.

Crinoids

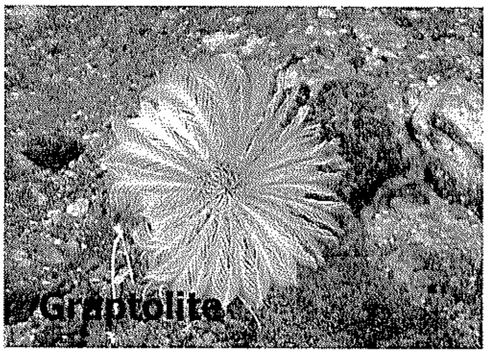
: Sometimes called **"sea lilies" and "feather stars"** but they're not plants!

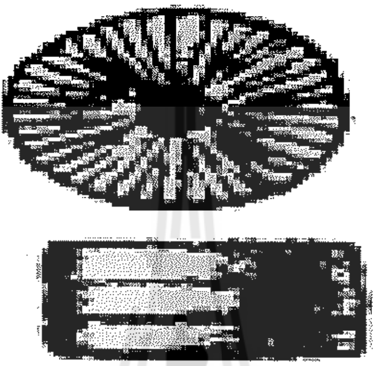
: They are class of **Echinoderms,** cousins of the **starfish.**

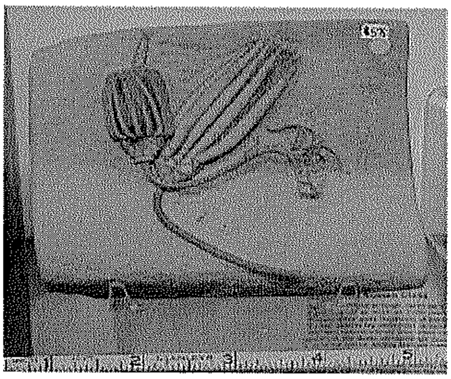
: When they died, their hard skeletons (calcium carbonate) broke apart

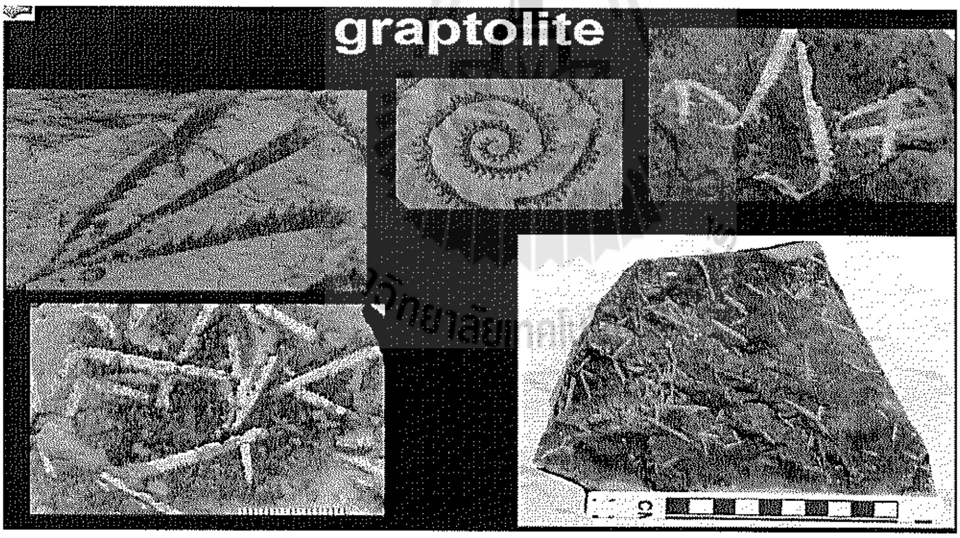
: The "stems" that held them up became many little round pieces sometimes called "Indian beads!"

: Marine environment

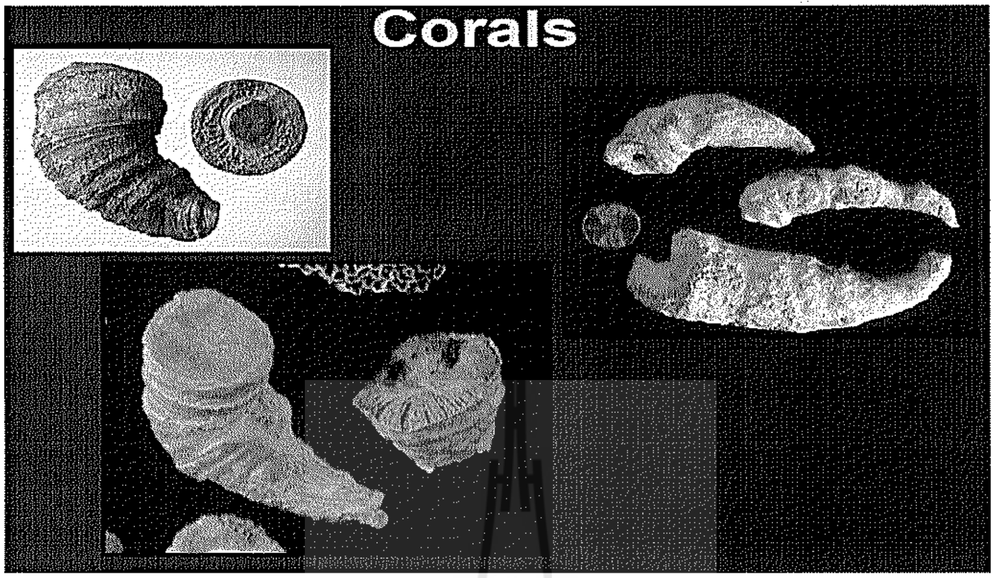






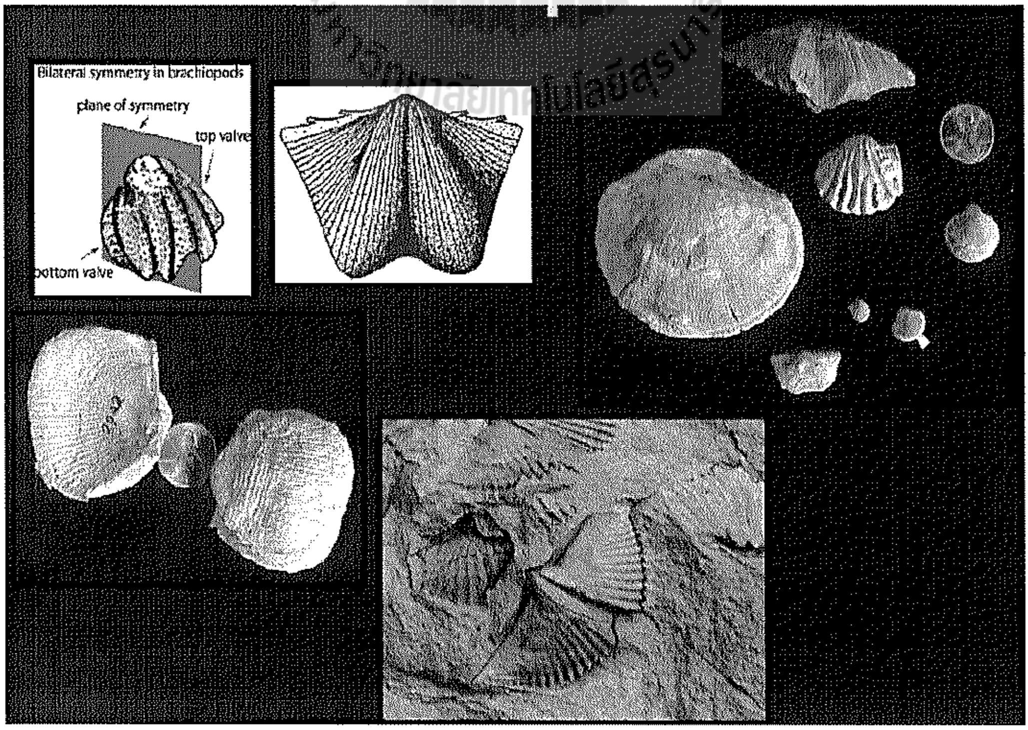


Corals



Brachiopods

- หอย 2 ฝาที่ไม่เท่ากัน
- ประโยชน์ใช้ indicate ลำดับชั้นหิน และหาอายุเปรียบเทียบทางธรณีวิทยา
- เกิดในทะเล ซึ่งอยู่ใกล้ชายฝั่ง (shallow marine)ที่อากาศร้อนชื้น (tropical)
- หลาย Species ตายไปที่ช่วงปลายของ Paleozoic



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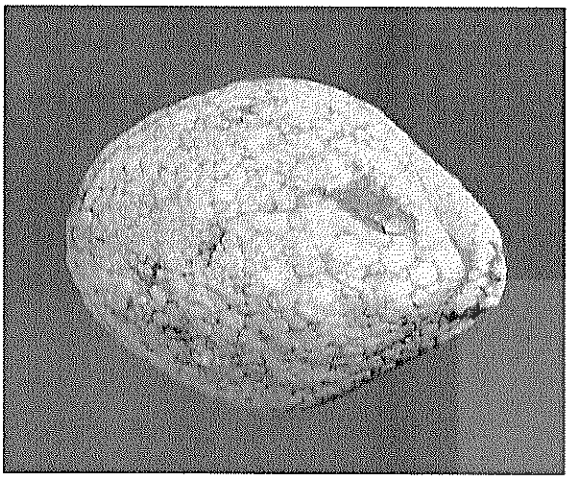
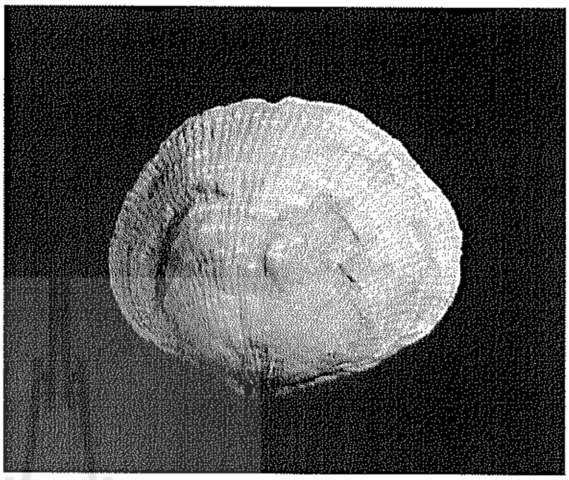
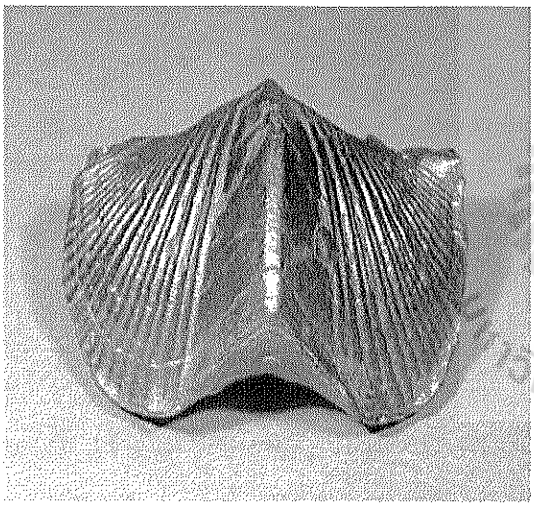
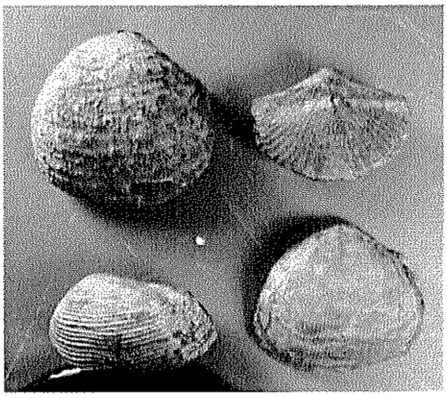
Brachiopoda is a phylum of shelled invertebrate
: Marine animals, i.e., they lived in salt water. (Shallow to deep waters)
: Cold or warm water/ silt laden or clean water

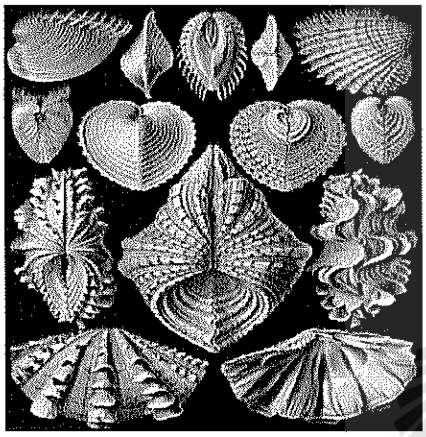

Replaced with pyrite Replaced with quartz & hematite (red color).

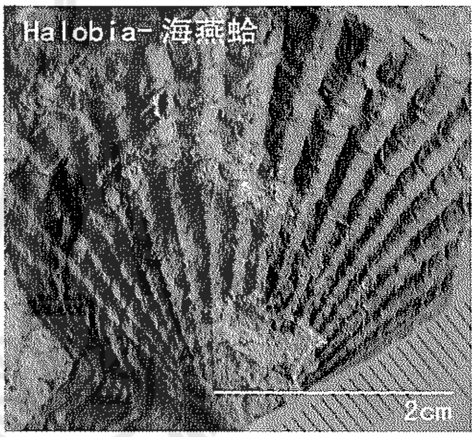
"The present is the key to the past"

Pelecypods



- หอยสองฝาๆเท่ากันทั้งขนาดและรูปร่าง ได้แก่ Clam (หอยกาบ), scallop, oyster
- พบได้ทั้ง Marine and Non-marine (ระดับน้ำตื้น)
- เมื่อตาย ฝาสองด้านจะแยกจากกัน
- พบได้กว้าง ปลายยุค Paleozoic to Cenozoic
- Thailand: genus Daonella, Halobia, Posidonis (Late Triassic)
- Anatoconcha (ที่เขาสมโภชน์) จ,ลพบุรี)





Gastropods

- หอยฝาเดียว เปลือกอาจจะปิด หรือขดเป็นวง
- พบใน marine-non marine
- เป็นสัตว์กินพืชหรือกินสัตว์
- Ex. หอยทาก (100,000 sp.)พบในทุกสภาวะอากาศ ทุกแห่ง (ที่ลุ่มถึงเขาสูง)
- Paleozoic to Cenozoic
- Thailand: Genus Viviparus (Pliocene)

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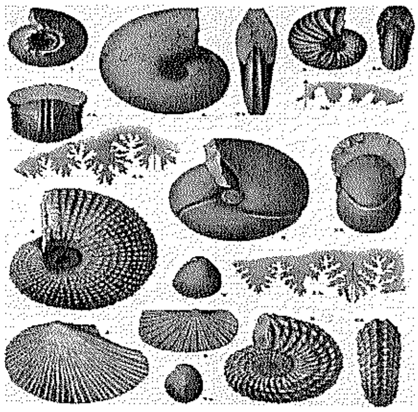
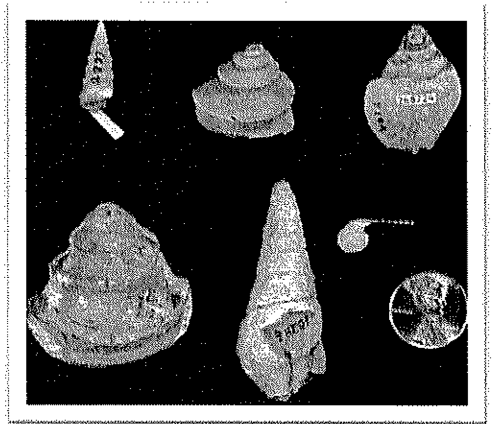
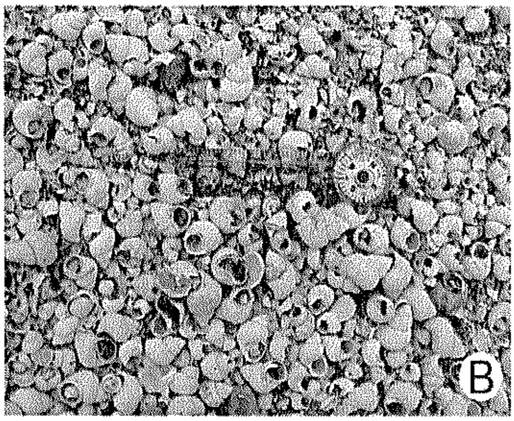




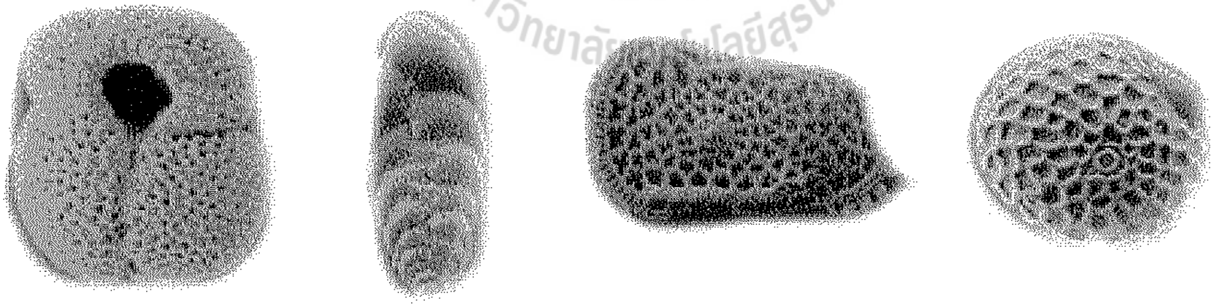


Microfossils

- Microfossils are particularly useful
    - because many individuals can be recovered from small rock samples
- In oil-drilling operations, small rock chips
    - called ***well cuttings*** are brought to the surface
- These cuttings rarely
    - contain complete fossils of large organisms,
      but they might have thousands of microfossils
    - that aid in relative **dating** and environmental analyses

Micropalaeontology

- Micropalaeontology is the study of the fossilised remains of foraminifera (single cell protozoans), ostracods (bivalved crustaceans) and associated microfossils (such as radiolaria and diatoms).
- **Foraminifera** are of great importance as stratigraphic markers and indicators of marginal to fully marine environments.
- Cenozoic and Mesozoic foraminifera (planktonic (ว่ายน้ำ), benthonic and larger benthonic (อยู่ตามพื้น)), ostracods (marine and non-marine)

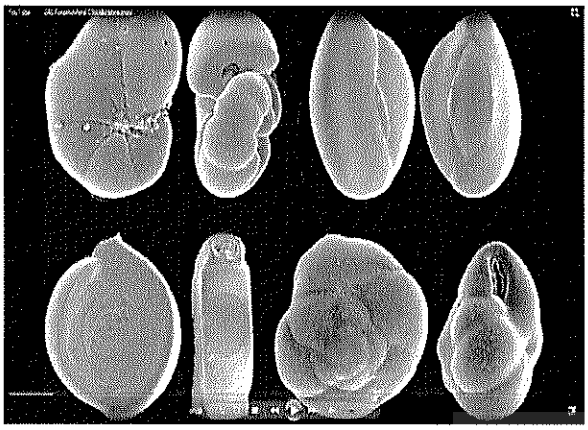


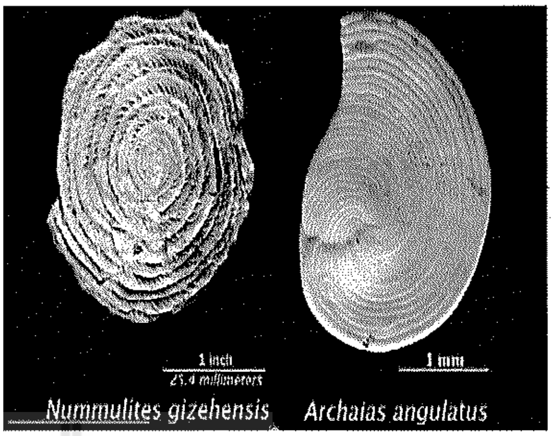
Foraminifera

Foremen = hole   Ferre = bear

Test

Testa= shell





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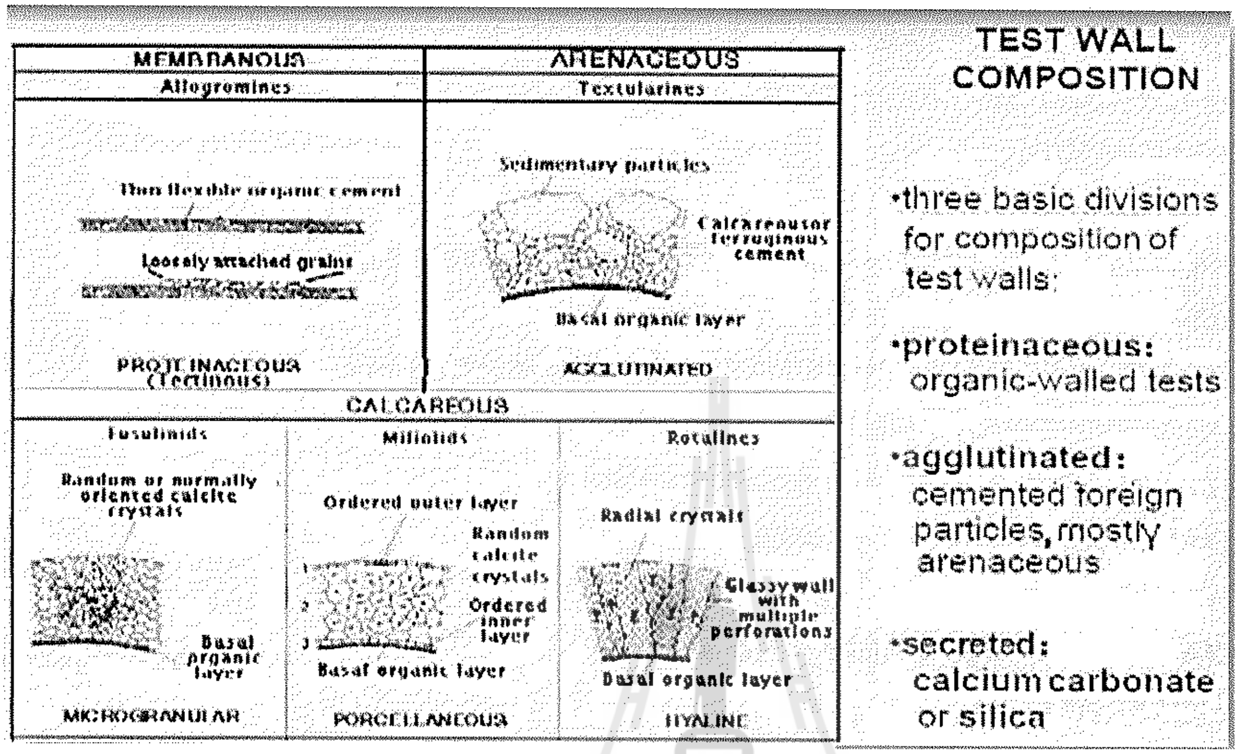
Foraminifera

- Small, one-cell animal
- Phylum Protozoa, planktonic (free-floating)
- Calcareous shells
- Early Paleozoic to Recent
- Use for zoning wells, age of sediments, paleoecological indicators
- Common indicating marine environment

It can be separated three type of foraminifera:

1. Microforaminifera
2. Small foraminifera
3. Large foraminifera

Test Well composition



TEST WALL COMPOSITION

- three basic divisions for composition of test walls:
- proteinaceous: organic-walled tests
- agglutinated: cemented foreign particles, mostly arenaceous
- secreted: calcium carbonate or silica

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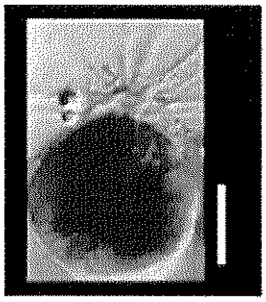
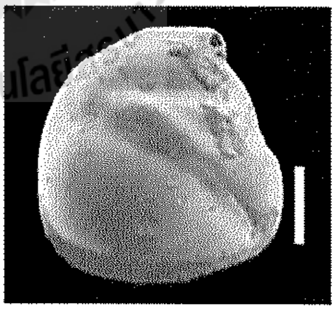
Proteinaceous & Siliceous Tests





Proteinaceous

- Oldest type of foraminifer
- Test consists of thin layer of organic material
- Found in low salinity envi.
- Entirely benthic

Siliceous

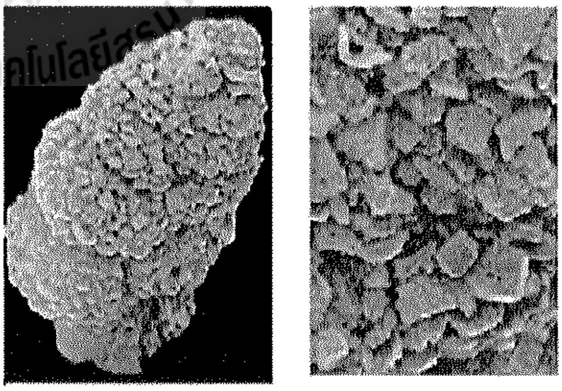
- First discovered in 1970's
- Test consists of siliceous material
- Found in deep sea envi. (below CCD)
- Entirely benthic

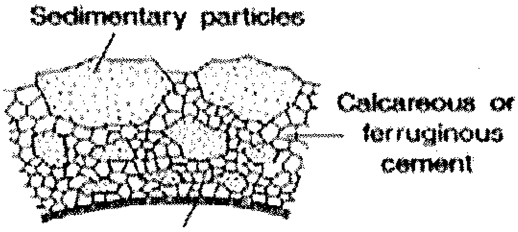
Foraminifera Test (Skeleton/shell) composition vs. Environment

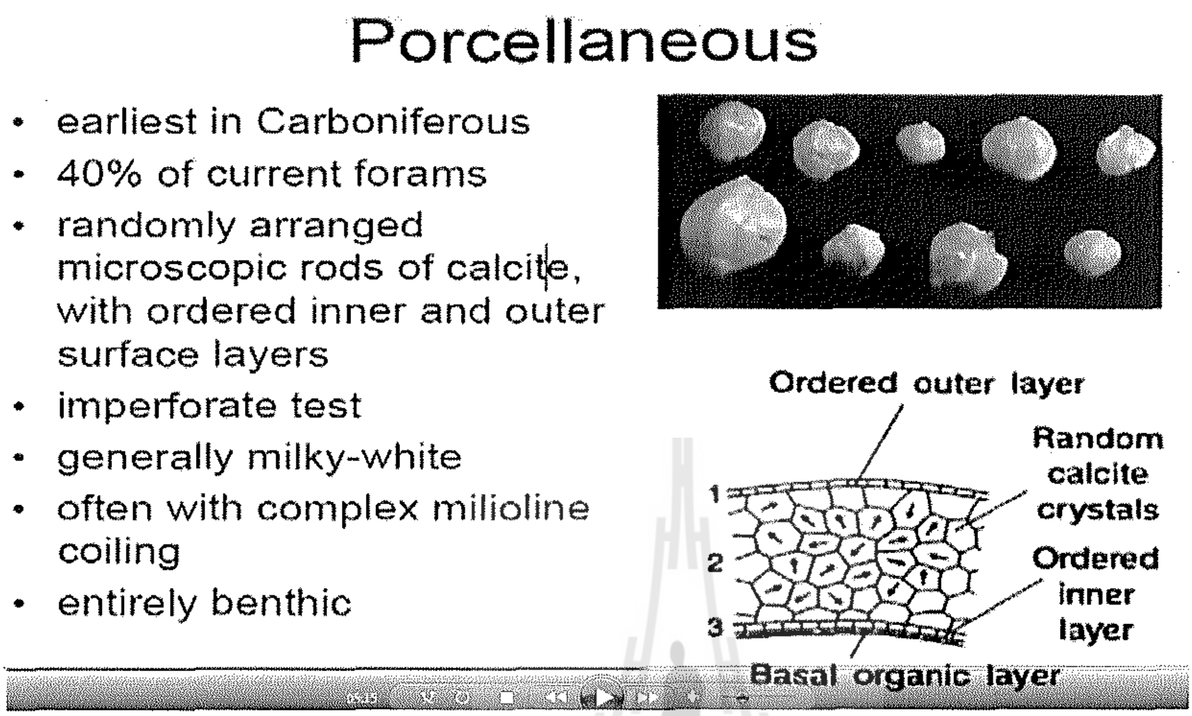
1. **Agglutinated test**
   - **Qtz grn:** mica, flake-clay skeleton debris **(arenaceous)**
   - Brackish lagoon & Estuaries
   - **Shallow-deep water but non-calcareous**
2. **Porcelaneous Opaque (Secreted)**
   - **Calcareous:** white & brilliant in reflected light
   - **Hyper saline Lagoon (shallow water)**
3. **Hyaline (Secreate)**
   - **Calcareous:** Glass like transparency (โปร่งใส)
   - **Shallow to deep water but in deepest water**

Agglutinated test

- Cambrian-Recent
- selective incorporation of foreign particles (commonly sand grains) onto organic test wall
- particles cemented by iron or carbonate cements secreted by foram
- entirely benthic
- variable test form
- widest geographical distribution

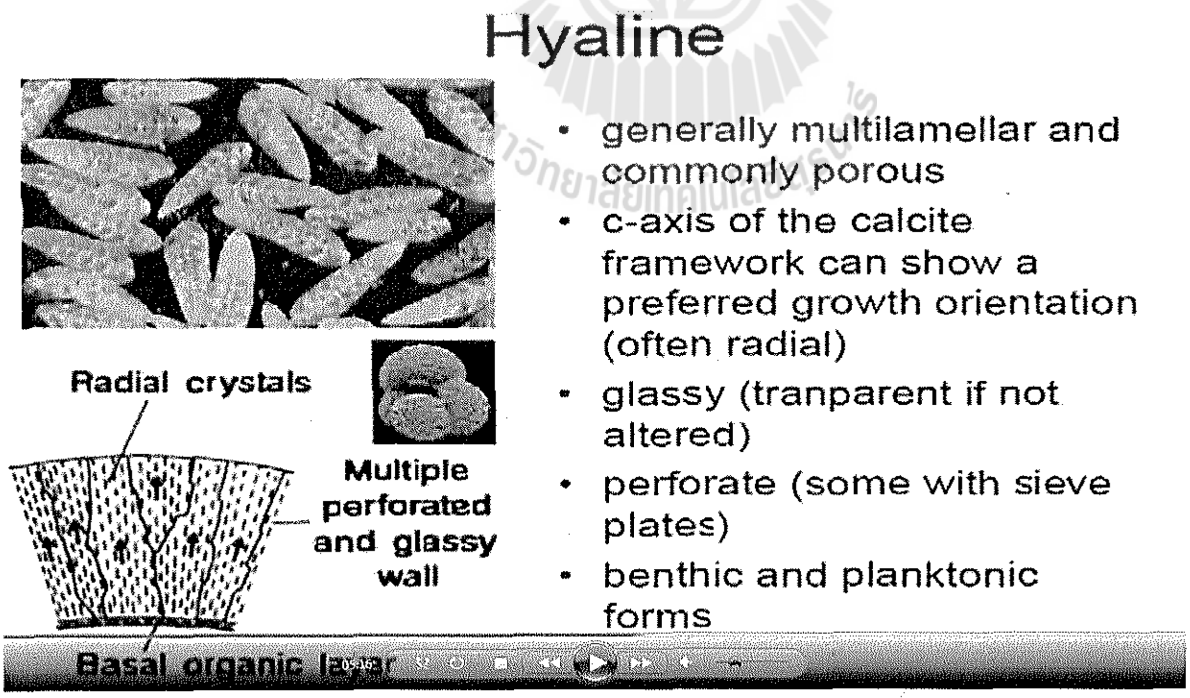






Porcellaneous

- earliest in Carboniferous
- 40% of current forams
- randomly arranged microscopic rods of calcite, with ordered inner and outer surface layers
- imperforate test
- generally milky-white
- often with complex milioline coiling
- entirely benthic



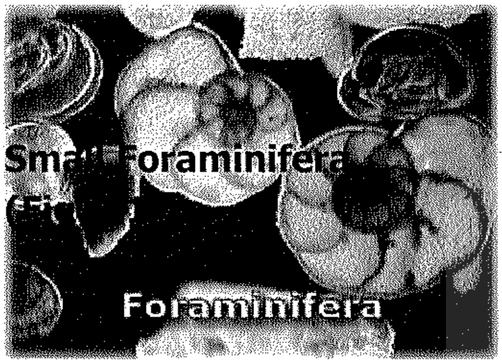
Hyaline

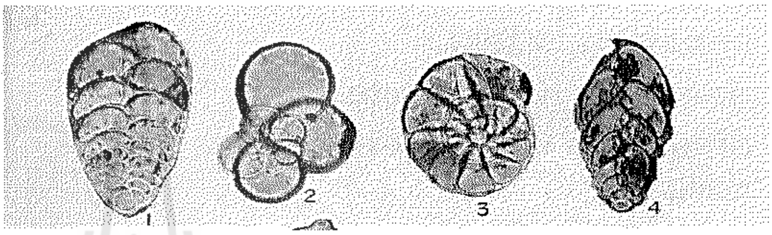
- generally multilamellar and commonly porous
- c-axis of the calcite framework can show a preferred growth orientation (often radial)
- glassy (tranparent if not altered)
- perforate (some with sieve plates)
- benthic and planktonic forms

Microforaminifera

Figs 1-4

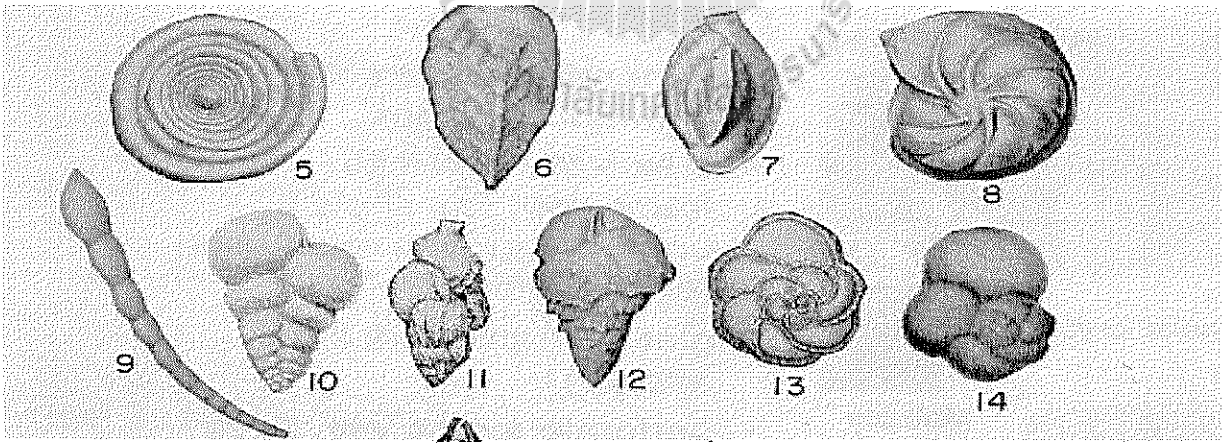
- Size avg. 500 microns (0.5 mm), ranges from 50-150 microns
- abundant in sedimentary rocks of marine origin.





Small Foraminifera
(Fig 5-14)

- Use more in oil company lab
- Use widely for correlation age, paleoecologic determination

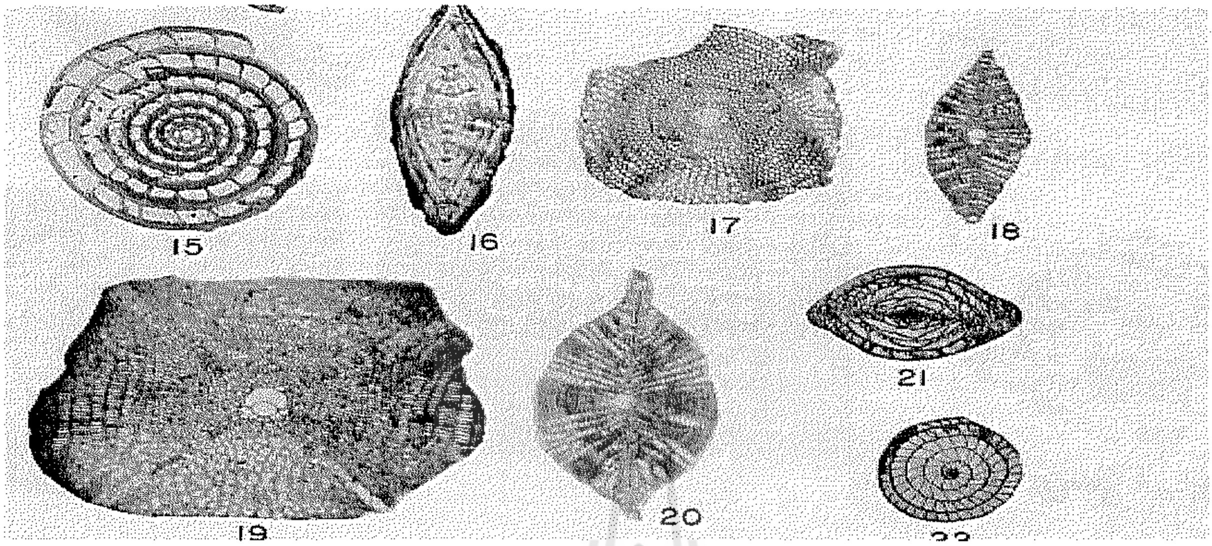


Large Foraminifera

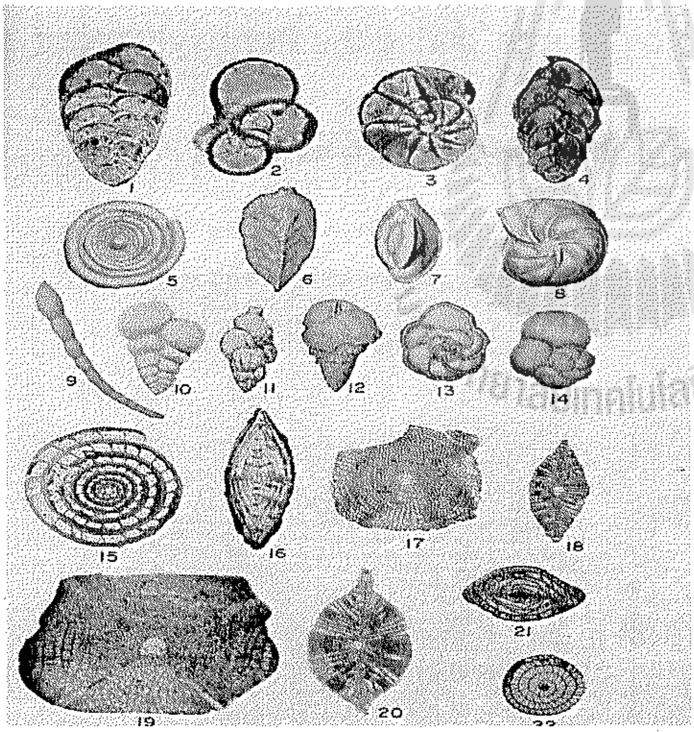
(Figs. 15-22)

- Families: *Orbitoidae, Discocyclinidae, Miogypsinidae* ***and Fusulinidae***

- Common found in carbonate rocks
- *Fusulinids- Late Paleozoic foraminifera*



Micro-foraminifera

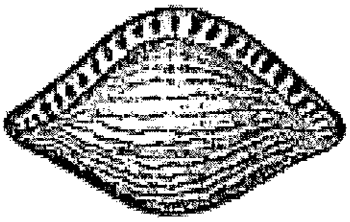


Small-foraminifera

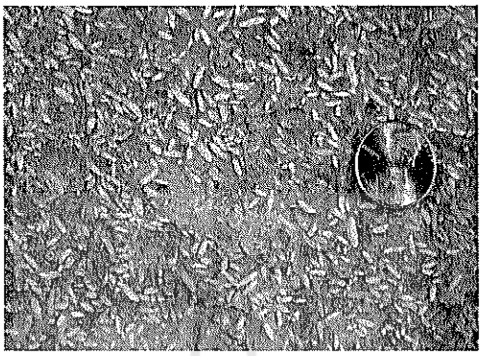
Large-foraminifera

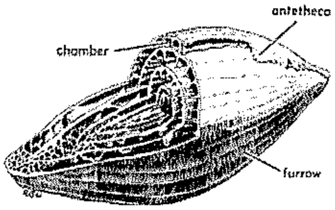
Fusulinids (large foraminifera)

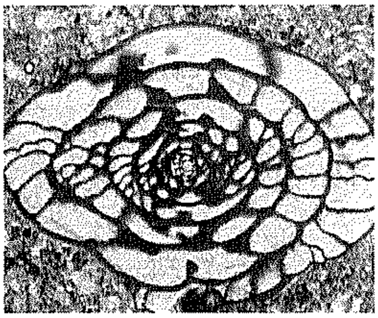
Fusulina acme 5x



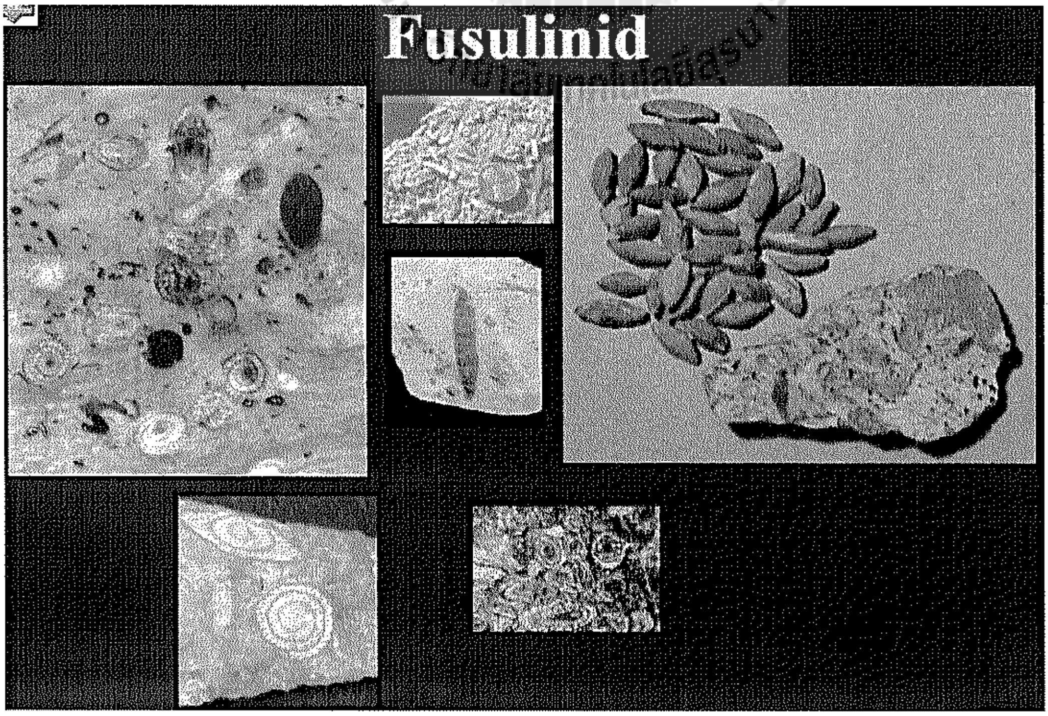
Fusulina girtyi 5x







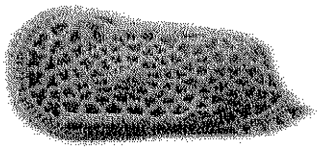
- Fusulinids were small, marine organisms, during the **Pennsylvanian and Permian** periods.
- **Mass extinction** at the **end of the Permian Period**



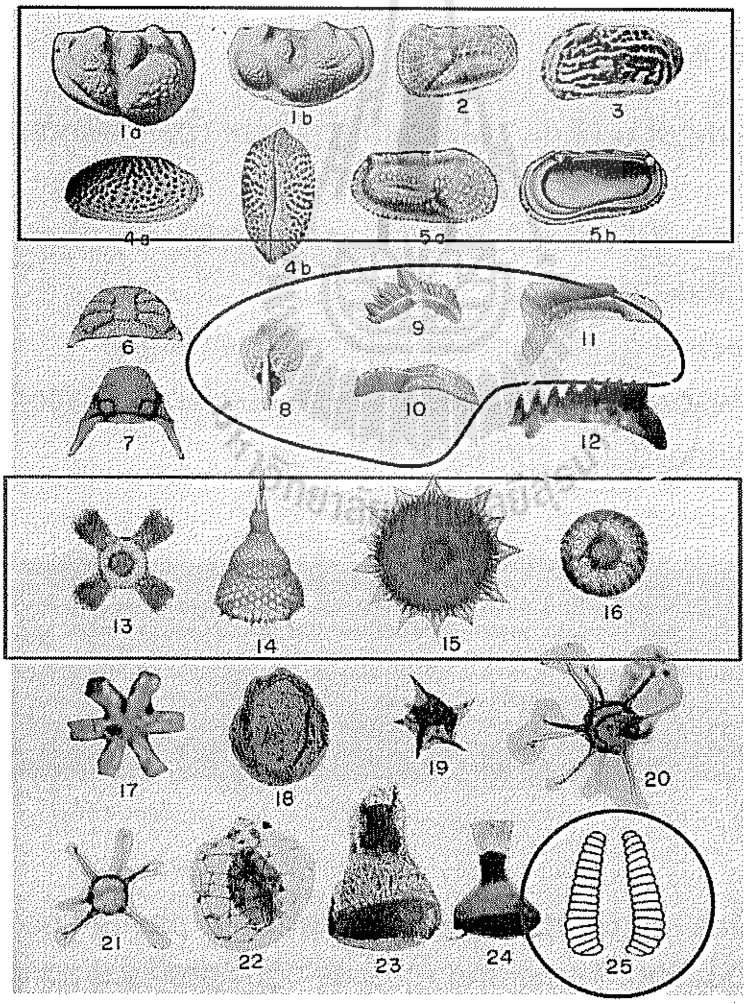
Fusulinid

Ostracods

- Small Bivalve Crutacea (สัตว์ซึ่งมีเปลือกหุ้ม)
- More Marine environments (เปลือกหนา) than fresh water(เปลือกค่อนข้างบาง) and brackish water (เปลือกหนาปานกลางแต่จะมีรอยขีดข่วนเนื่องจากโดนขัดถูและกระแทก)
- 0.5 to more 20 millimeters in length
- Ordovician to Recent
- Found in shales, marls, and limestone
- (Low energy)



Ostracods



Ostracods
Figs 1-5

Conodonts
(Ordovician to Triassic)
Marine
Figs 8-11

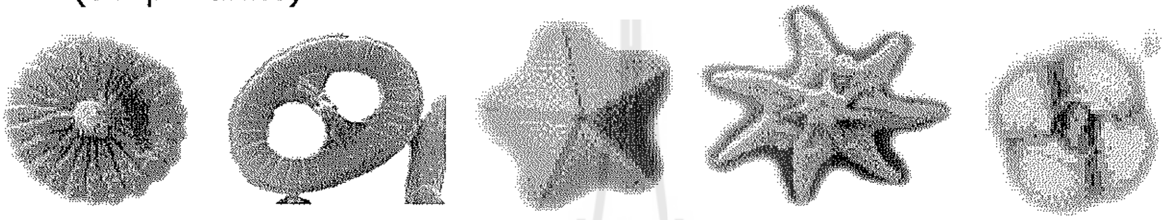
Radiolaria
(Cambrian to Recent)
silica or strontium sulfate sediment
Figs 13-16

Scolecodonts
(Ordovician to Recent)
Brackish to marine
Figs 12

Nannoconus
(Cretaceous marine sediment)
Figs 25

Nanopalaeontology

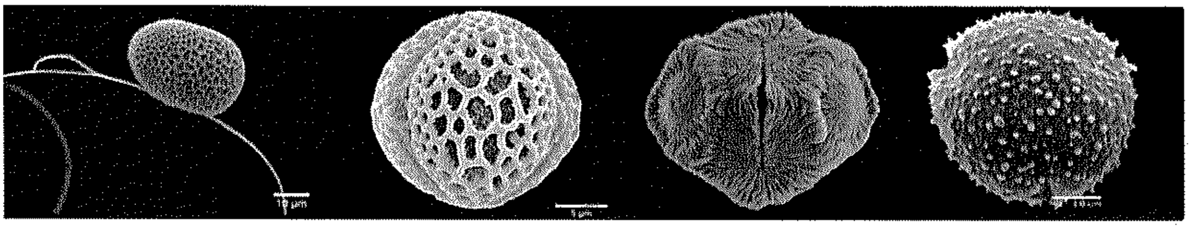
- The ultra-microsopic calcareous remain of calcite secreting (size 1-35 micron)
- Unocellular marine phytophankton (nanoplankton) (shape: rosette-star-Button (coccolite คล้ายกระดุม)
- Upper Triassic-Recent
- Marine Environment
- (deep marine)



Palynology (Spore & Pollen)

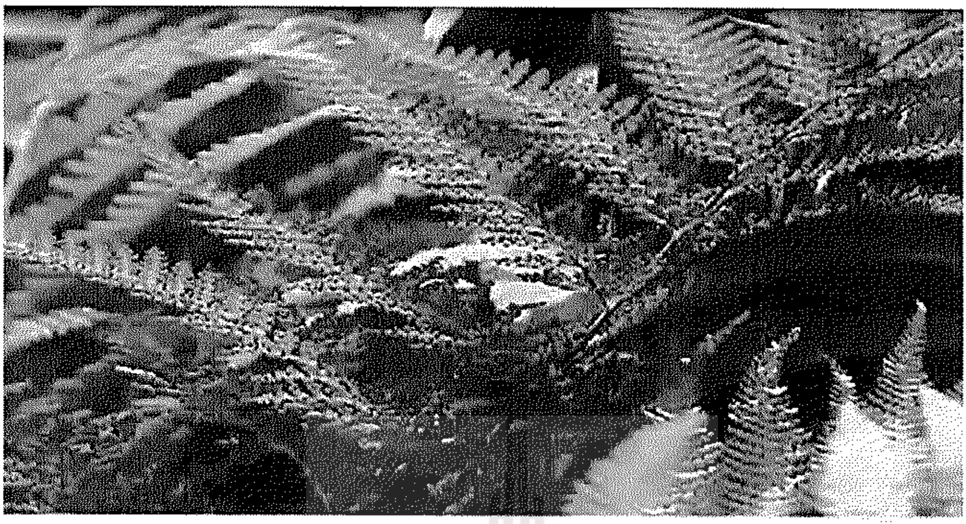
Palynology is the study of organic walled microfossil (palynomorphs), Precambrian-Recent

  - **Marine group :** dinoflagellate cysts, acritarch, prasinophycean algae, chitinozoans
  - **Non-marine group:** pollen, spore, fresh algae
- Tertiary and Mesozoic: dinoflagellate cysts, pollen and spores
- Palaeozoic: chitinozoans, spores and pollen



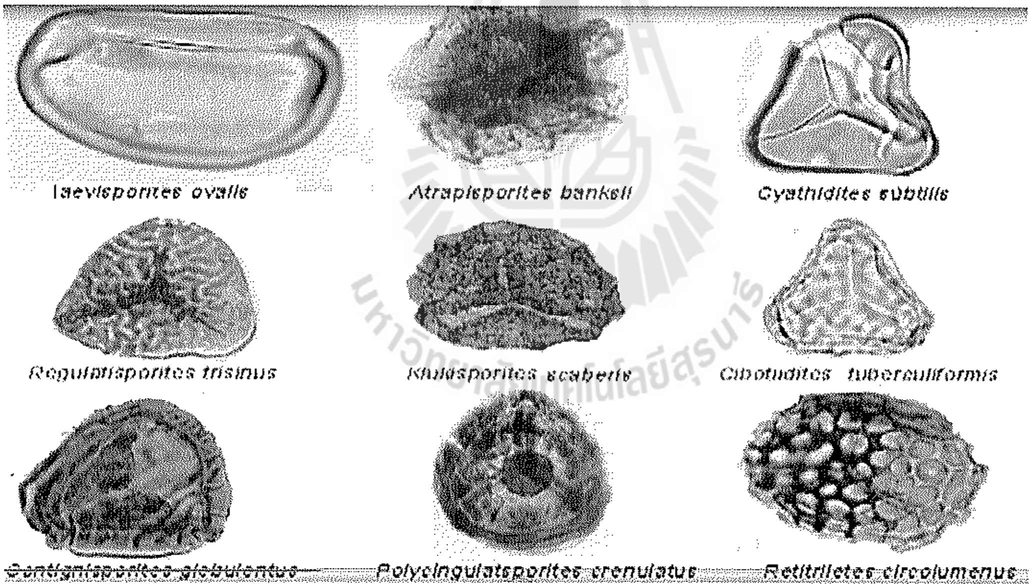
Spore

Spores are used by groups of ancient plants and fungi in one stage of their reproduction. Ferns and mosses both produce spores.



Back dots are spores on fern

Fossil spore from New Zealand



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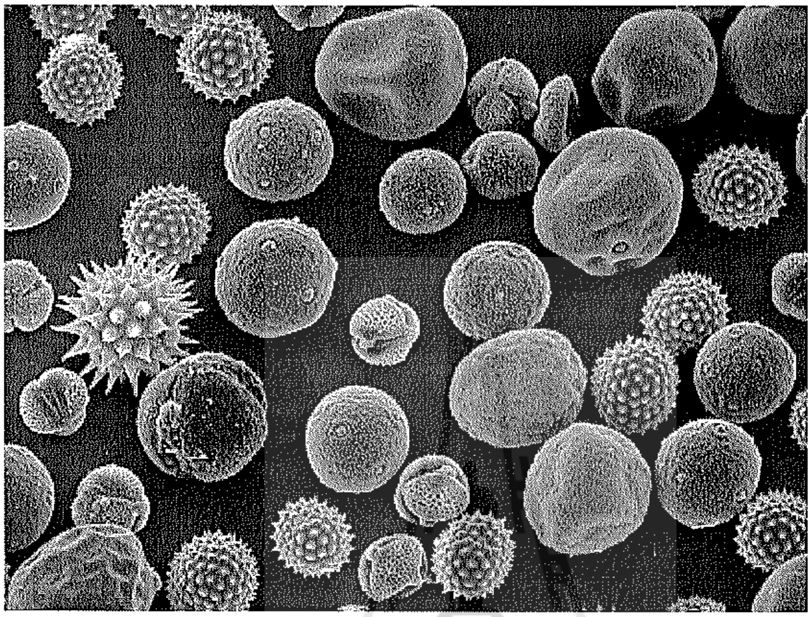
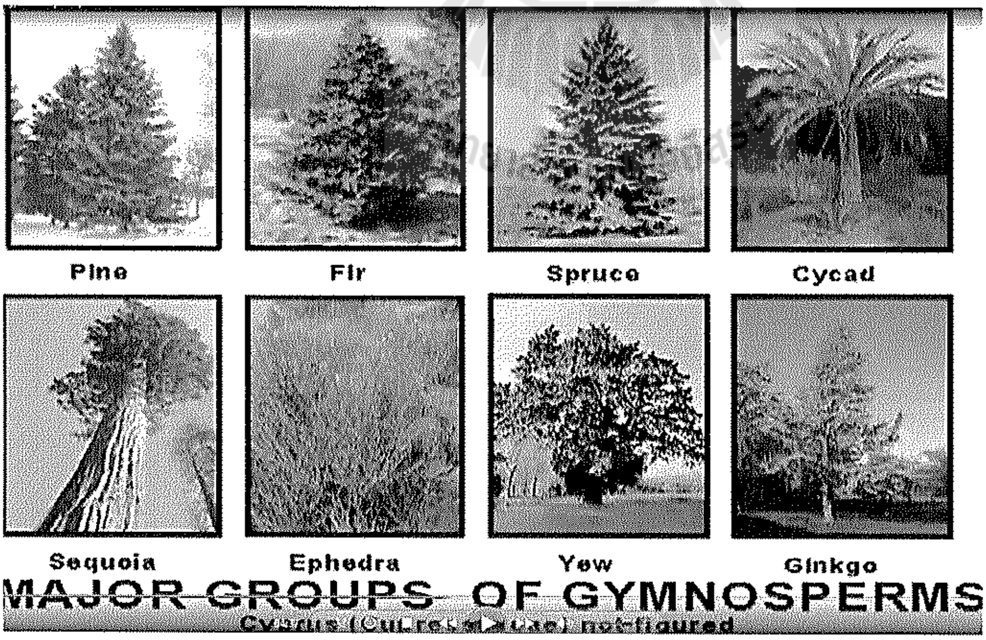
Pollen

Pollen is used by flowering plants to fertilize seeds. Fertilized seeds grow into adult plants. (pollen size larger than spore)



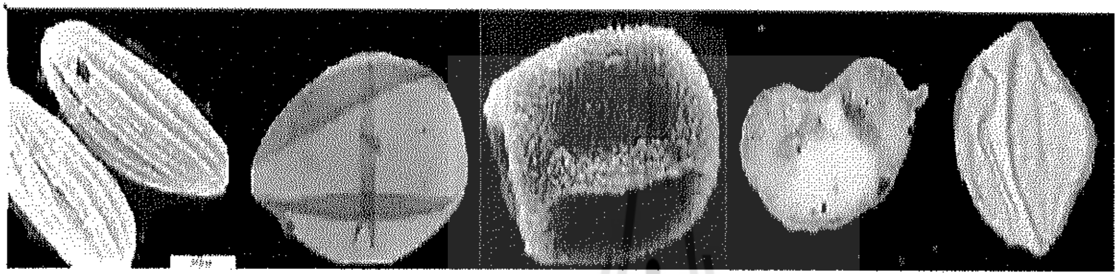


Pinus ponderosa Ponderosa pine

Sequoia sempervirens Coast Redwood

Pinus echinata Shortleaf Pine

Gingko biloba maidenhair tree



Ephedra trifurca Longleaf jointfir

Pseudotsuga menziesii Douglas Fir

Taxus baccatus English Yew

Picea englemanni *Englemann spruce*

Cycadopites sp. *Fossil(Triassic)N.Z.*

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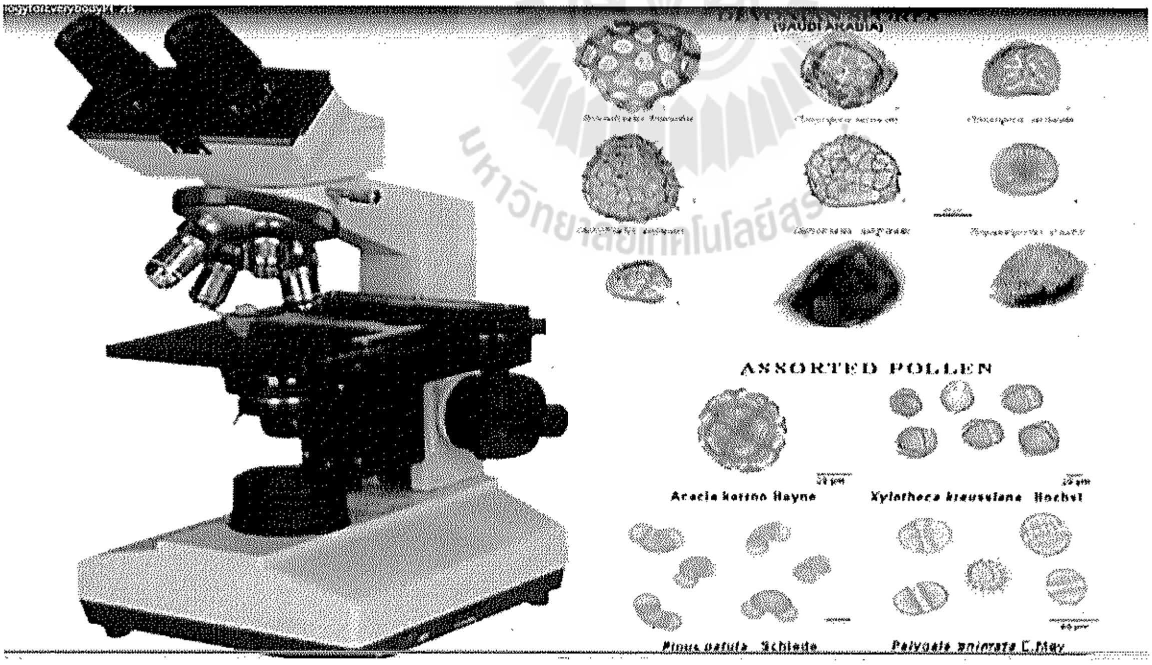


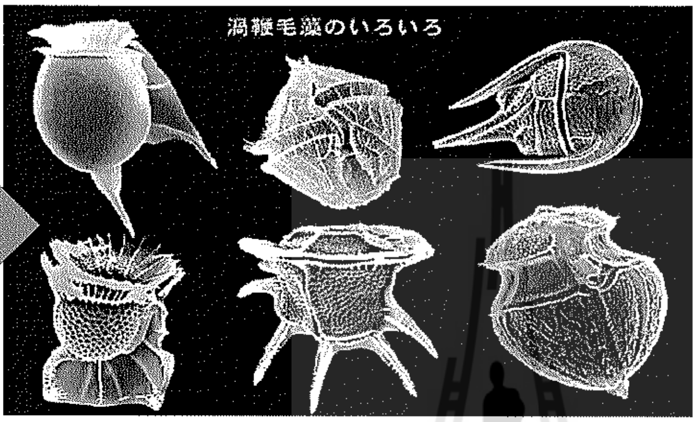
ประโยชน์ในการศึกษา Fossil กับ Petroleum

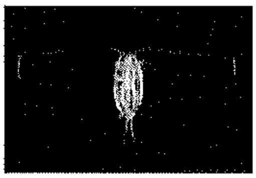
1. Depositional environment
2. Age of formation
3. Source rocks==Plankton

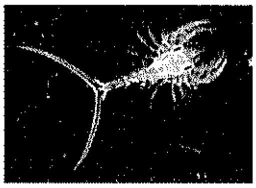
Plant plankton

Animal plankton

10,000 of these bugs would fit on a pinhead!

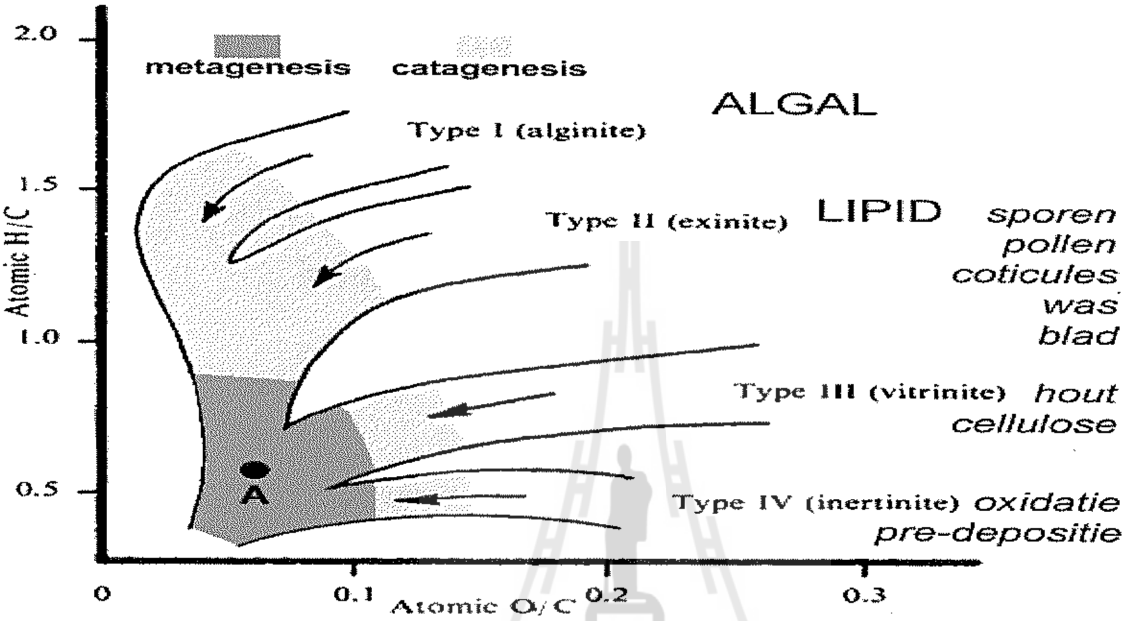






Presenter notes: It may come as a surprise but most of the world's oil and gas is made up of the fossil remains of microscopic marine plants and animals. That's why oil and gas are often referred to as a fossil fuel. One of the most important group of plankton involved in the formation of oil and gas are single-celled marine 'plants' called dinoflagellates, though many types of animal plankton are also important. Some oil and gas may have also originated from the remains of land plants, but we will not discuss these types of deposits in this talk.

Kerogen Type



Van Krevelen diagrams are a graphical-statistical method that cross-plots the O/C and H/C ratios of

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Trace fossils or ichnofossils

- Trace fossils or ichnofossils represent the effects of organismal activity **upon** or in the **substrate**.
- Not preserving the body or the morphology of the original organism
- Not transported from their original place of origin, and are thus good indicators of the original sedimentary environment.

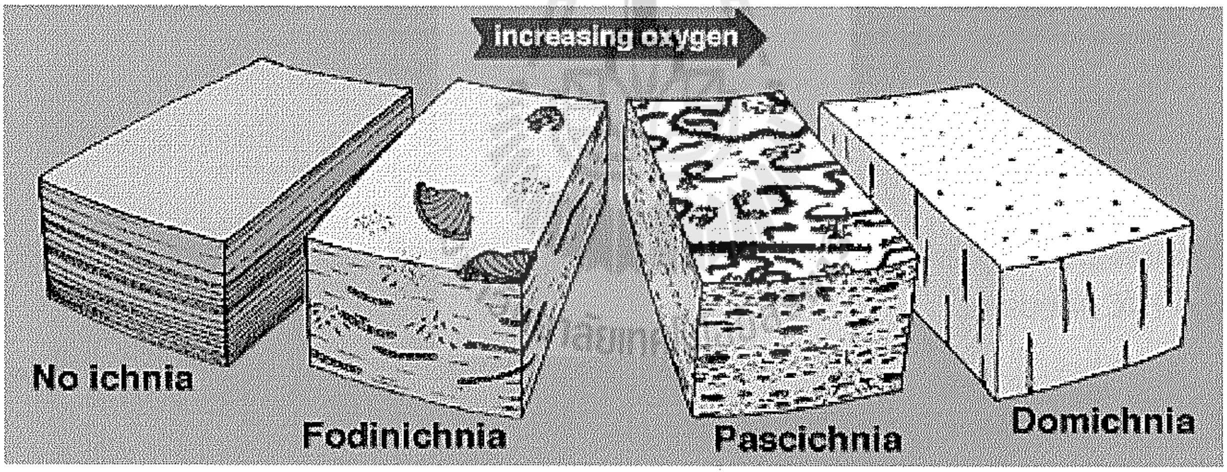
Ichnofacies

- The concept of Ichnofacies used as a paleontological tool to analyze assemblages of trace fossils to determine ancient depositional settings and facies of sedimentary rocks.

  The character determines the ichnofacies assemblage into:
  - **Soupground: Slurry**
  - **Softground: Grains in contact, but wet**
  - **Firmground: De-watered, compacted**
  - **Hardground: Cemented**

Slurry ผสมของเหลวกับวัสดุที่เหนียวๆ เช่นโคลน ดิน ซีเมนต์

Trace fossils or ichnofossils



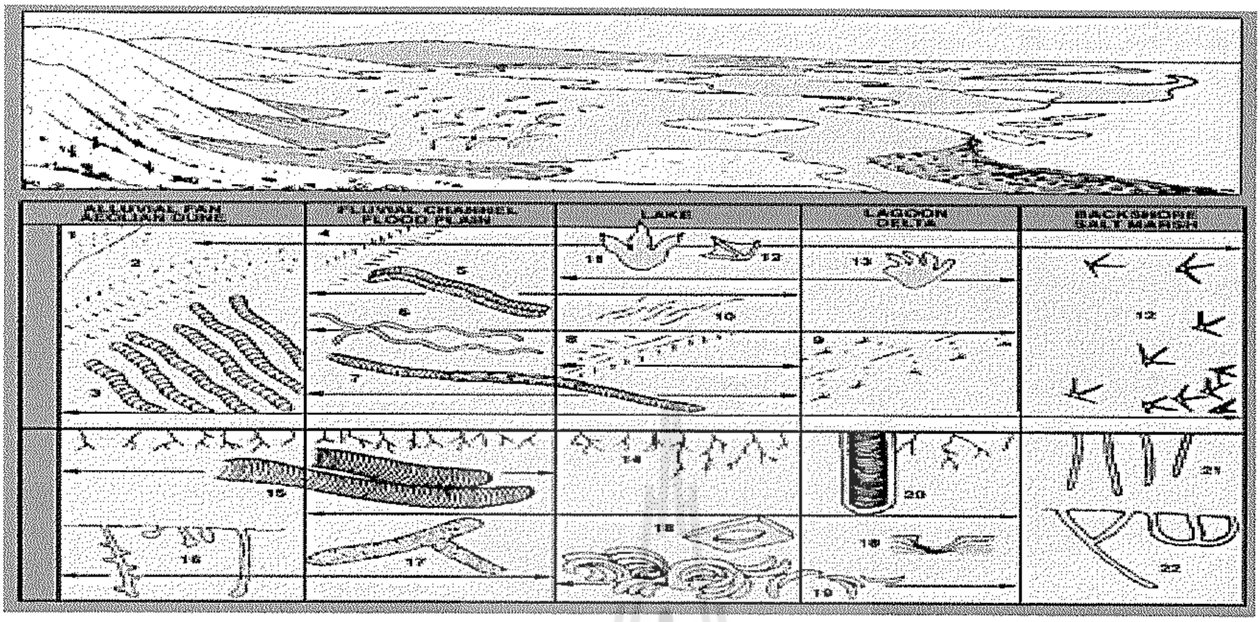
No trace fossil
Very deep marine
No O2

More horizontal burrow
Deep marine
Low O2

horizontal burrow
& crawling trace
marine
moderate O2

Vertical burrow
& crawling trace
Shallow marine
high O2

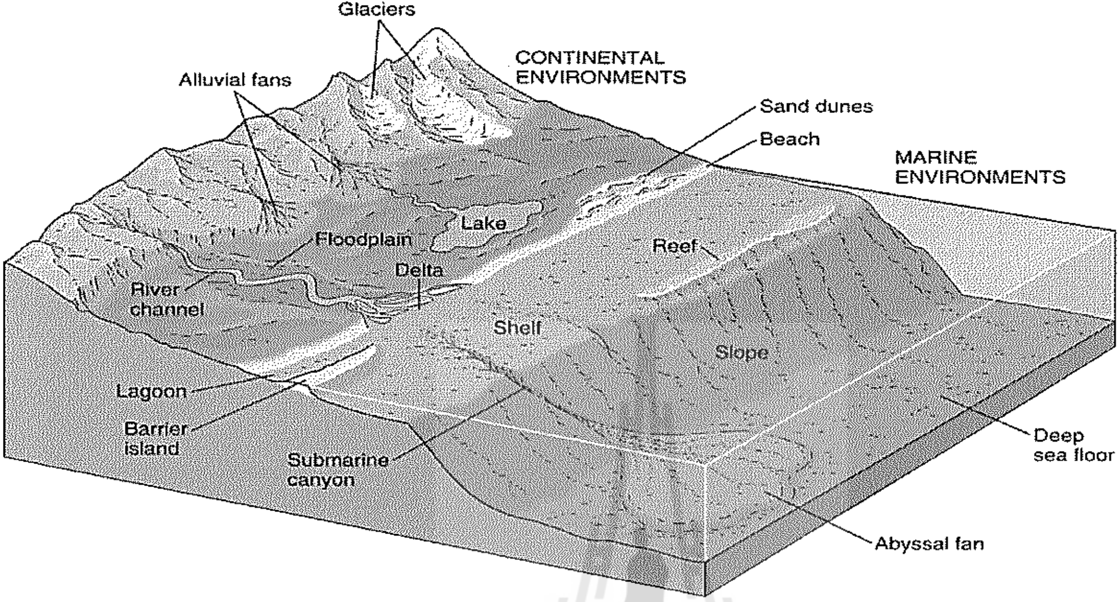
Distribution of trace fossils in marine environments



Distribution of trace fossils in non-marine environments:

Palaeohelcura (scorpion trackway); 2. *Mesichnium* (insect trackway); 3. *Entradichnus* (exogenic insect traces); 4. *Acripes* (crustacean trackway); 5. *Cruziana problematica* (branchiopod crustacean burrow); 6. *Cochlichnus*; 7. *Scoyenia gracilis*; 8. *Siskemia* (arthropod trackway); 9. *Kouphichnium* (xiphosuran trackway); 10. *Undichnus* (fish swimming traces); 11. reptile track; 12. bird tracks; 13. amphibian track; 14. roots; 15. *Beaconites*; 16. insect burrows; 17. *Spongeliomorpha carlsbergi* (insect burrow); 18. *Lockeia siliquaria*; 19. *Fuerschichnus communis*; 20. *Diplocraterion paralellum*; 21. *Skolithos*; 22. *Psilonichnus* and other crab burrows. (after Bromley, 1996)

Depositional Environment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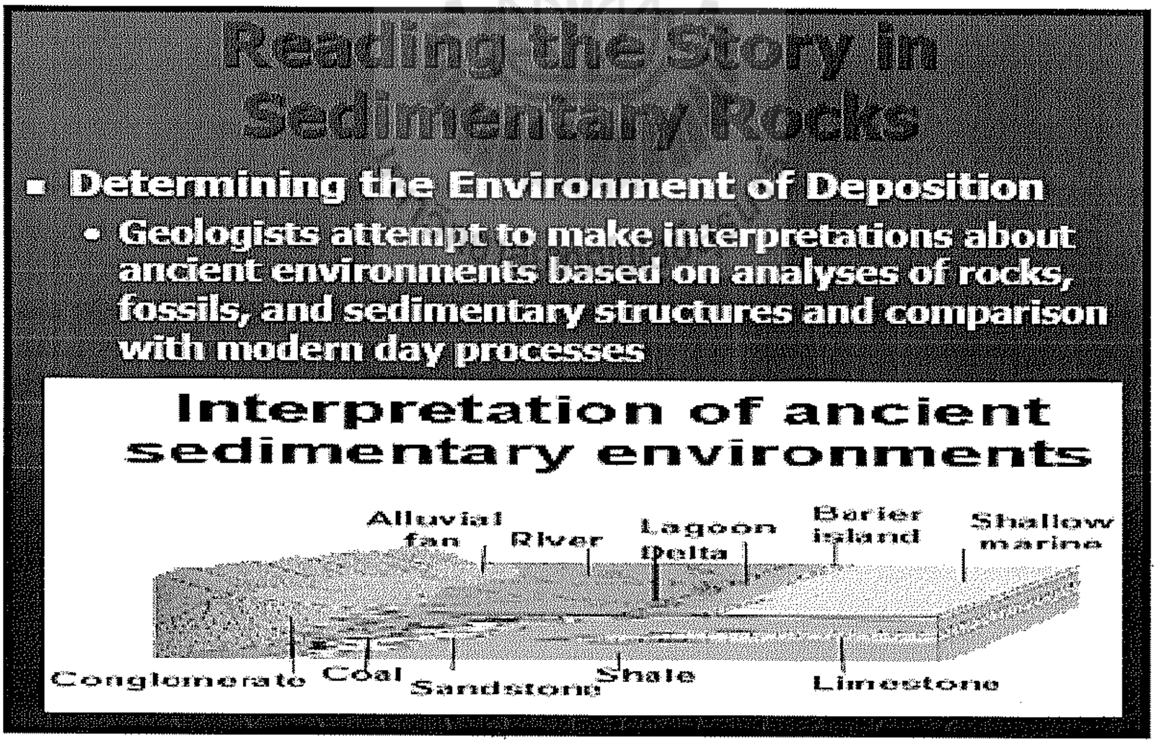
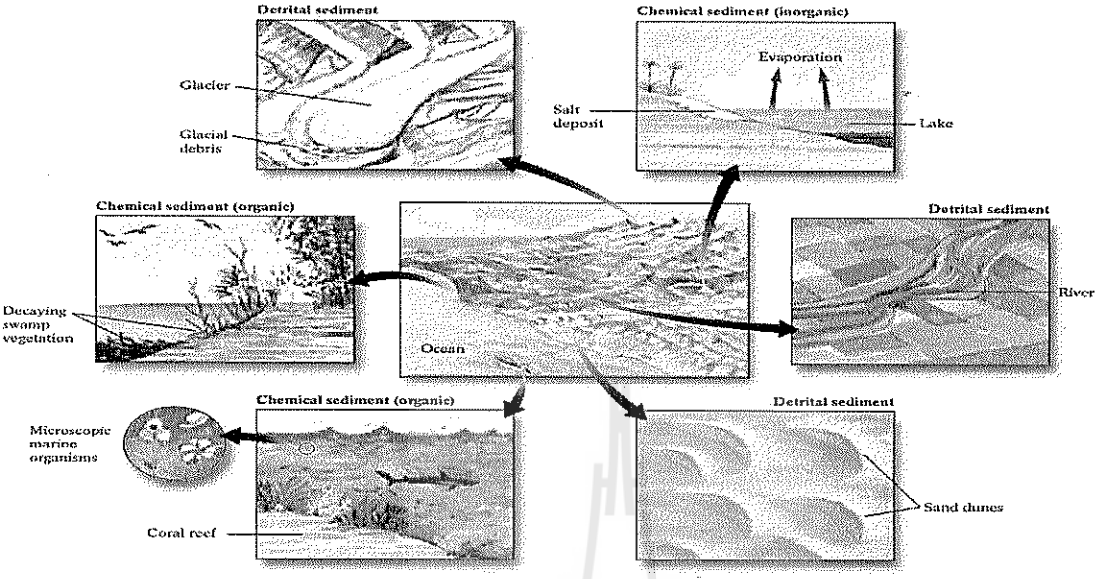


Reading the Story in Sedimentary Rocks

- **Determining the Environment of Deposition**
  - Geologists attempt to make interpretations about ancient environments based on analyses of rocks, fossils, and sedimentary structures and comparison with modern day processes

Interpretation of ancient sedimentary environments

Types of Sediment



Environments Where Deposition Occurs

Sedimentary rocks may be:

1. Extrabasinal in origin - Sediments formed from the weathering of pre-existing rocks outside the basin, and transported to the environment of deposition.

2. Intrabasinal in origin - Sediments form inside the basin; includes chemical precipitates, most carbonate rocks, and coal.

By comparing modern sedimentary deposits with ancient sedimentary rocks, the depositional conditions can be interpreted

General Environmental Indicators

1. Grain size

Fine grain size: low energy mechanisms (e.g. standing water)

Course grain size: higher energy mechanisms (running water or wave action).

2. Grain composition

Rock fragments & feldspars: close to source

Quartz: generally far from source but depends on source itself

3. Rounding

Angular fragments: close to source

Rounded fragments: generally far from source but, depends on source

3. Sorting

Well sorted: constant or small range of energy at deposition

Poorly sorted: erratic energy or very high energy environment (e.g. glaciers or high gravitational forces such as near mountains)

4. Color

Red: oxidizing environments- at or near surface, not in oceans.

Special Environmental Indicators

1. Sedimentary Structures

Bedding & lateral continuity, Ripple marks, Mudcracks, Scours, Cross-bedding, graded bedding, Rip-ups

2. Fossils

Dfn: fossils are the remains or traces of once living organisms

Fish live in water, for example. Different species can indicate the environments where they live

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Classification of Sedimentary Environments

Continental Environments (Terrigenous)	Transitional Environments (Shoreline)	Marine Environments
• Alluvial or Fluviatile (Running Water) • Lacustrine (lake) • Paludal (Swamp and Marshes) • Eolian (Deserts) • Glaciers	• Alluvial or Fluviatile (Running Water) • Lacustrine (lake) • Paludal (Swamp and Marshes) • Eolian (Deserts) • Glaciers	• Continental shelf • Reef • Continental slope and rise • Abyssal Plain

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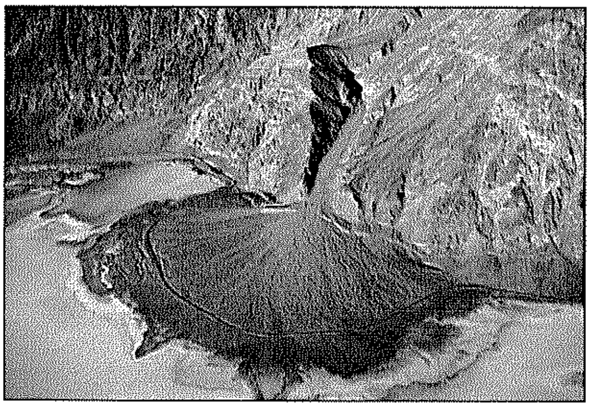
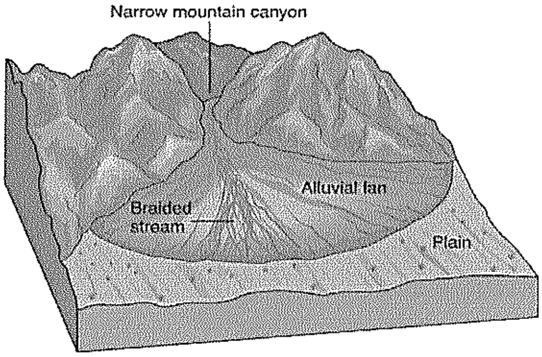
Interpretation of Ancient Depositional Environments from sedimentary rocks

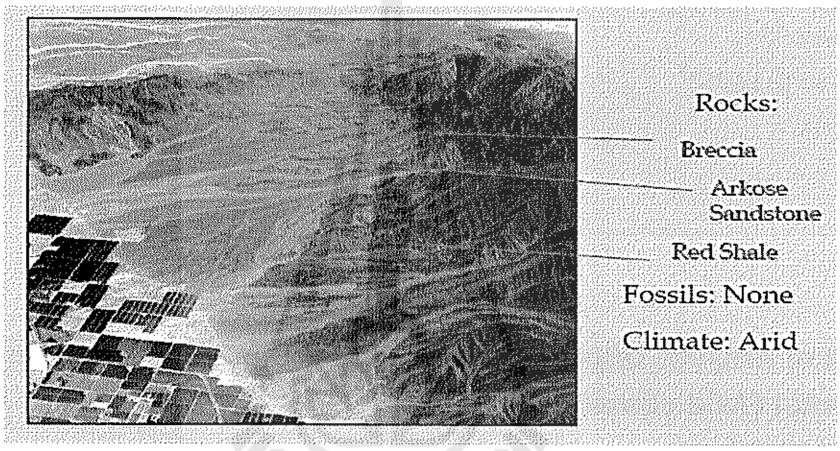
- **Continental (Arid climate)**
  1. Alluvial Fans
  2. Playa Lakes
  3. Deserts
- **Continental (Normal climate)**
  1. Glacial
  2. River Systems: meandering and braided
  3. Lakes or lacustrine
  4. Swamps or marsh

1. Alluvial Fan

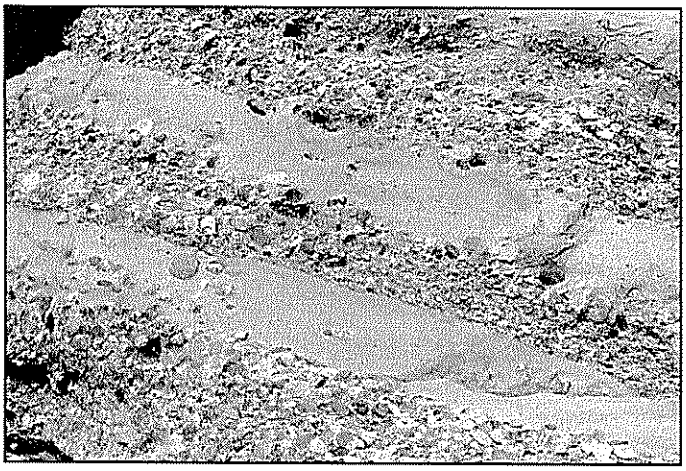
- Fan-shaped deposits formed at the base of mountains.
- Most common in arid and semi-arid regions where rainfall is infrequent but torrential, and erosion is rapid.
- Sediment is typically coarse, poorly- sorted gravel and sand.
- cross-bedding and lens-shaped channel deposits.







- Sediment is typically coarse (mix of bounder), poorly- sorted gravel and sand (high energy)
- There are fine sediments (Siltstone & claystone) interbedded with coarse grain (low energy)



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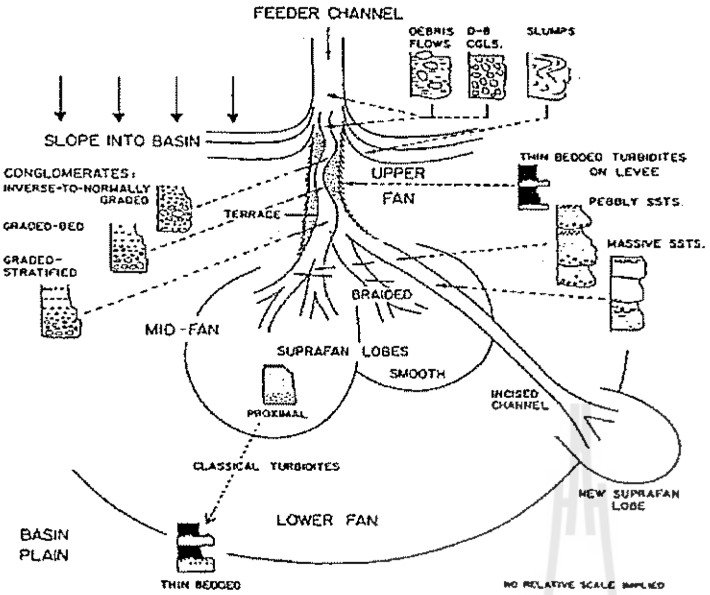
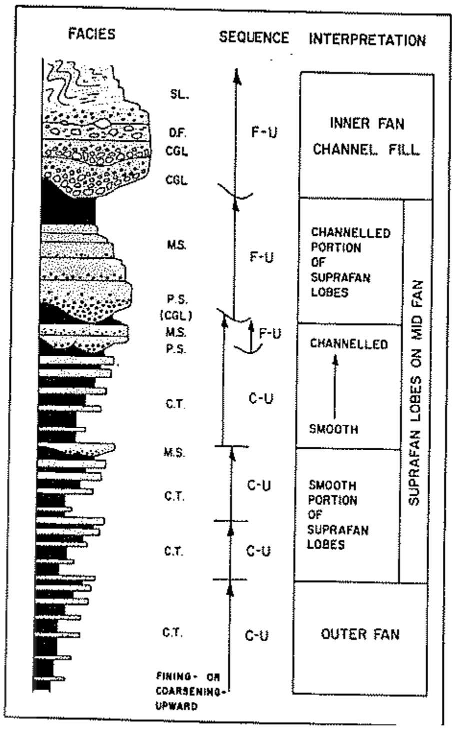
Alluvial Facies



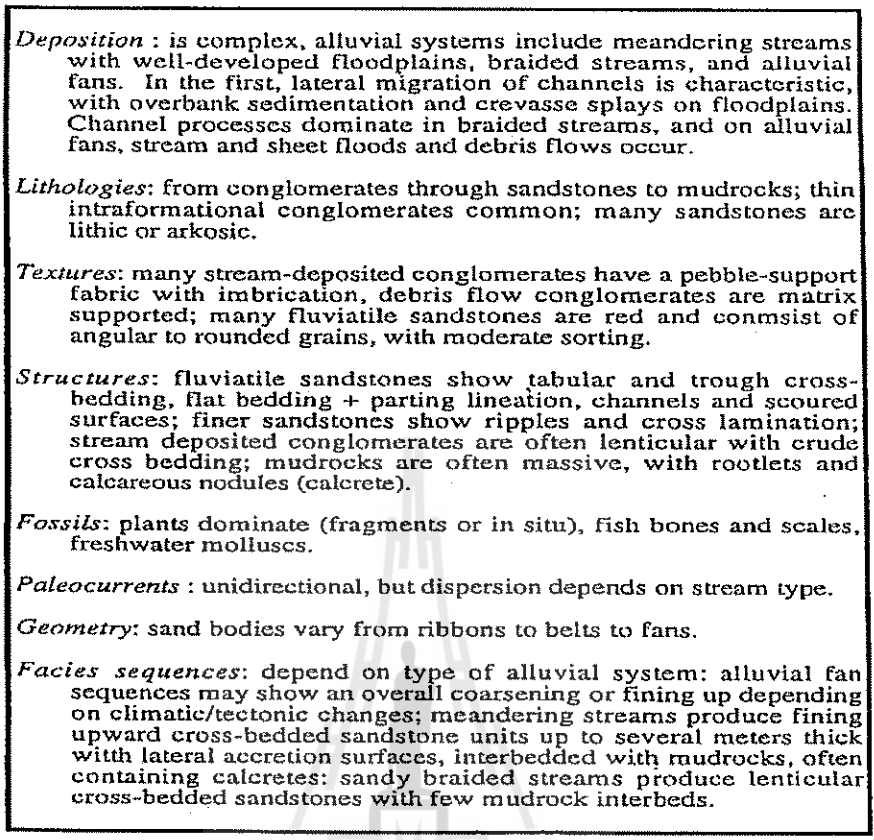


Alluvial fan and petroleum production

- Are not generally reservoir rocks because of abrupt and erratic changes in both laterally and vertically facies
- No source rocks
- No seal
- Reservoir rocks are usually found within the stream-flow deposits, providing migration path of hydrocarbon and source rocks are available

มหาวิทยาลัยเทคโนโลยีสุรนารี

ตารางที่ 11-8 ลักษณะเด่นของ alluvial facies (จาก Tucker, 1982)



Deposition : is complex, alluvial systems include meandering streams with well-developed floodplains, braided streams, and alluvial fans. In the first, lateral migration of channels is characteristic, with overbank sedimentation and crevasse splays on floodplains. Channel processes dominate in braided streams, and on alluvial fans, stream and sheet floods and debris flows occur.

Lithologies: from conglomerates through sandstones to mudrocks; thin intraformational conglomerates common; many sandstones are lithic or arkosic.

Textures: many stream-deposited conglomerates have a pebble-support fabric with imbrication, debris flow conglomerates are matrix supported; many fluviatile sandstones are red and conmsist of angular to rounded grains, with moderate sorting.

Structures: fluviatile sandstones show tabular and trough cross-bedding, flat bedding + parting lineation, channels and scoured surfaces; finer sandstones show ripples and cross lamination; stream deposited conglomerates are often lenticular with crude cross bedding; mudrocks are often massive, with rootlets and calcareous nodules (calcrete).

Fossils: plants dominate (fragments or in situ), fish bones and scales, freshwater molluscs.

Paleocurrents : unidirectional, but dispersion depends on stream type.

Geometry: sand bodies vary from ribbons to belts to fans.

Facies sequences: depend on type of alluvial system: alluvial fan sequences may show an overall coarsening or fining up depending on climatic/tectonic changes; meandering streams produce fining upward cross-bedded sandstone units up to several meters thick witth lateral accretion surfaces, interbedded with mudrocks, often containing calcretes: sandy braided streams produce lenticular cross-bedded sandstones with few mudrock interbeds.

2. Fluvial

- **Fluvial environments** include **braided** and **meandering** river and stream systems.
- River channels, bars, levees, and floodplains are parts (or subenvironments) of the fluvial environment.
- 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.**

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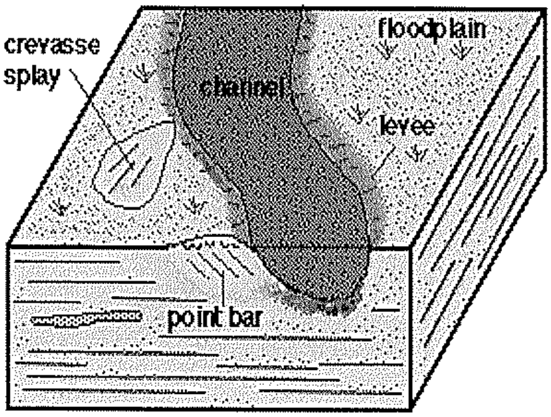
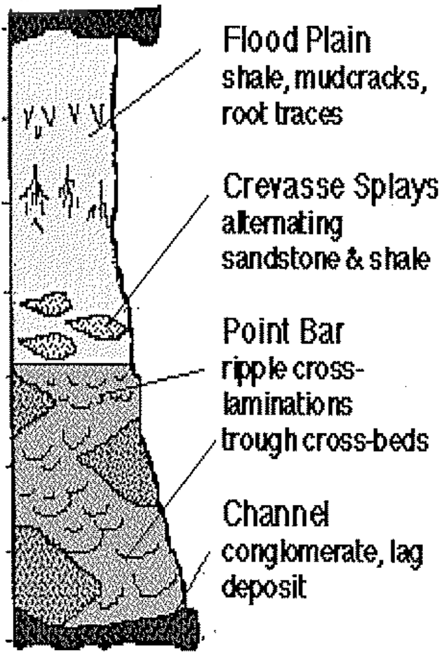
Fluvial System





2.1 Meandering system

Occurrence: low gradient permanent streams in temperate humid climates.

Physical processes: sedimentation of sand by traction currents. Sedimentation of fines from suspended load on flood plain

Lithology: Medium-fine sand & shales in about equal proportions, minor conglomerates, coals and concretionary limestones

Sedimentary structures: spore & pollen, Rare plant debris, vertebrate remains & freshwater mollusc shells.

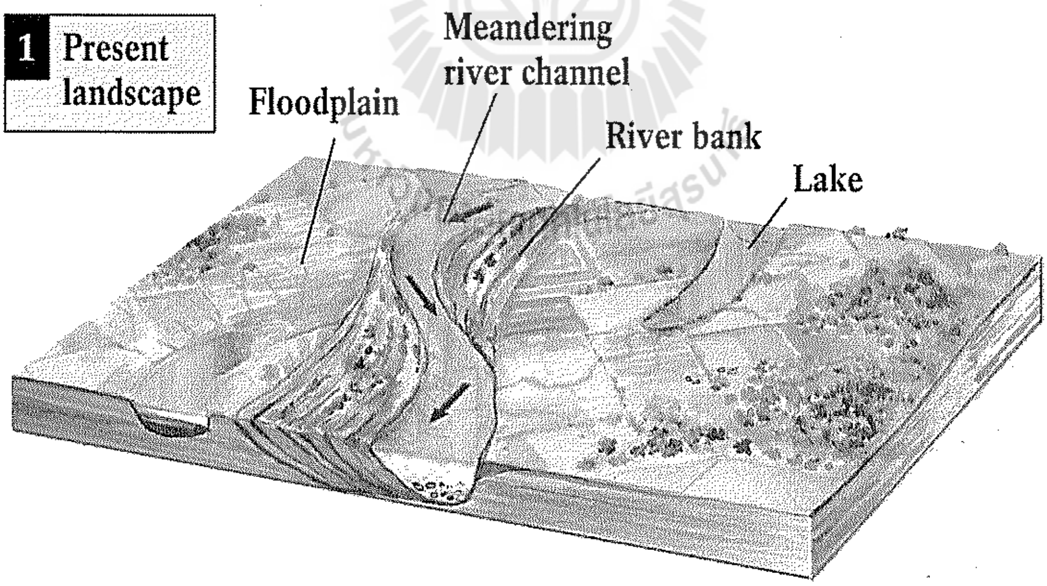
Meandering river facies

There are two main types of meandering river facies:

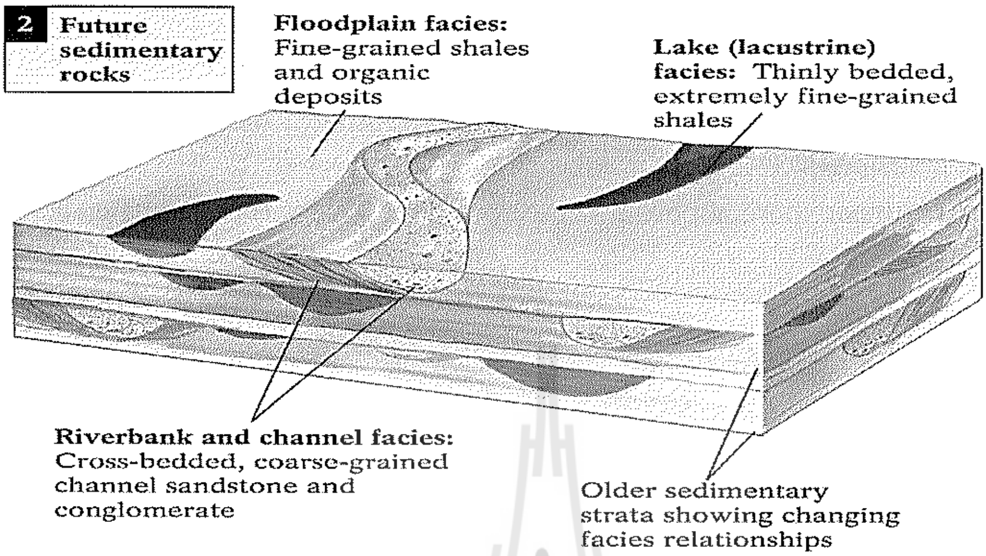
1) Rippled, cross-bedded, fining-upward sequences of gravel and sand (bars)

2) Fine-grained sediments, such as silt and clay, containing burrows and plant debris (overbank or flood deposits). In a vertical section through an ancient meandering system, these will tend to alternate.

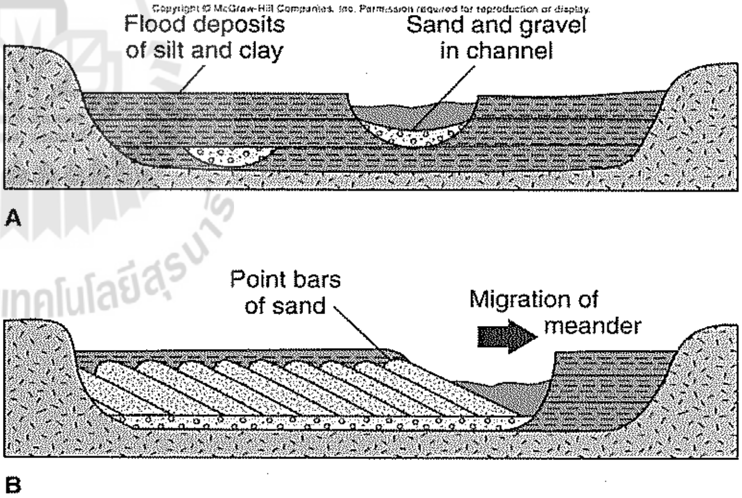
Sedimentary Facies Formation: Meandering



Sedimentary Facies Formation



Floodplains: thin-bedded shales with mud-cracks & fossil footprints. Hematite may color the floodplain deposits red.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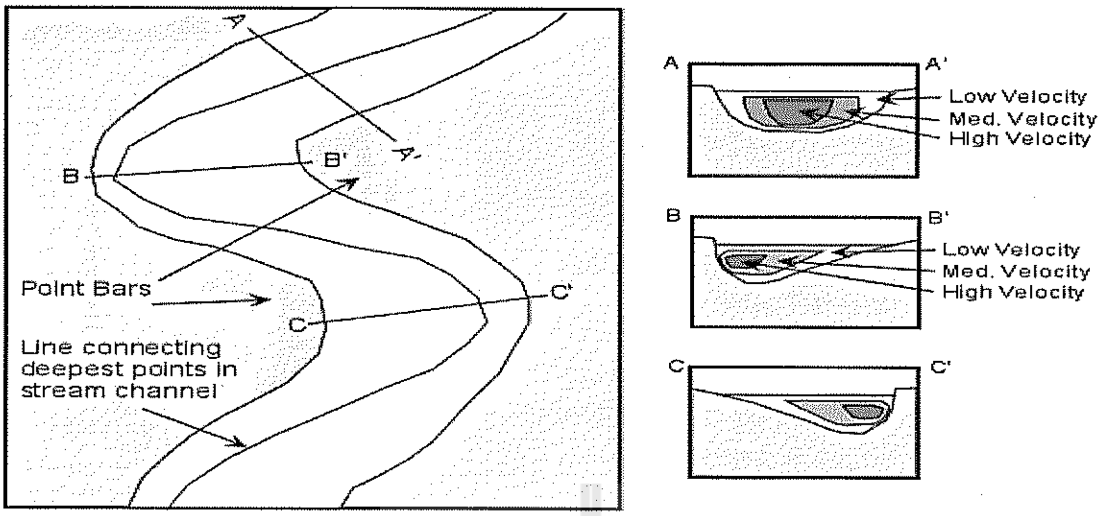
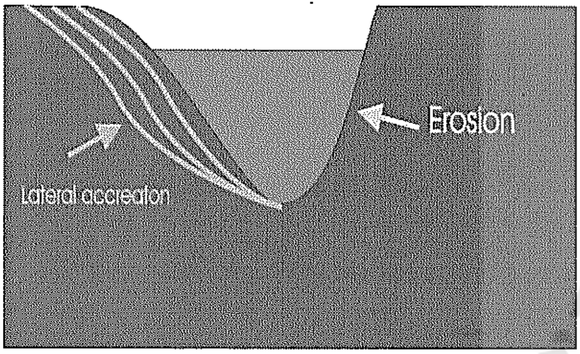
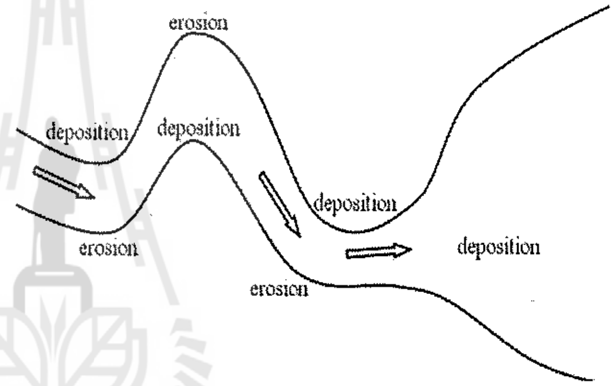
ลัยเทคโนโลยีสุรนาร

Meandering Channels







Meandering Stream

- Erosion on the Outside and Deposition on the inside.
- The two sides of the meander erode into each other.
- Water slows in the outside loop causing deposition.

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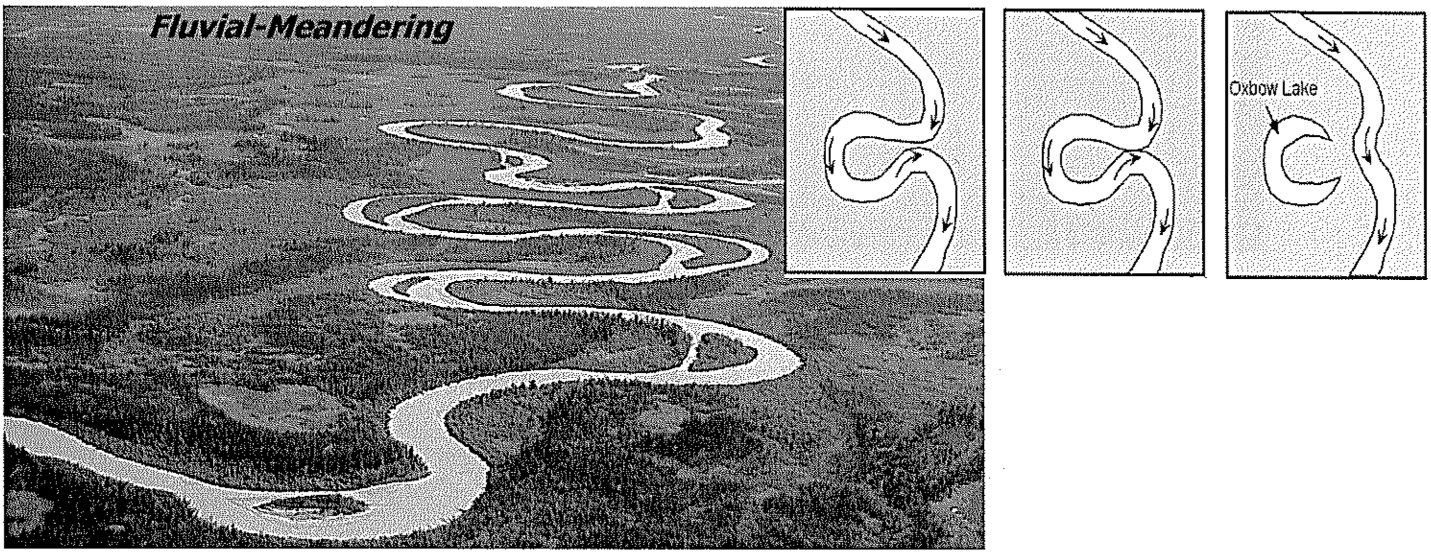
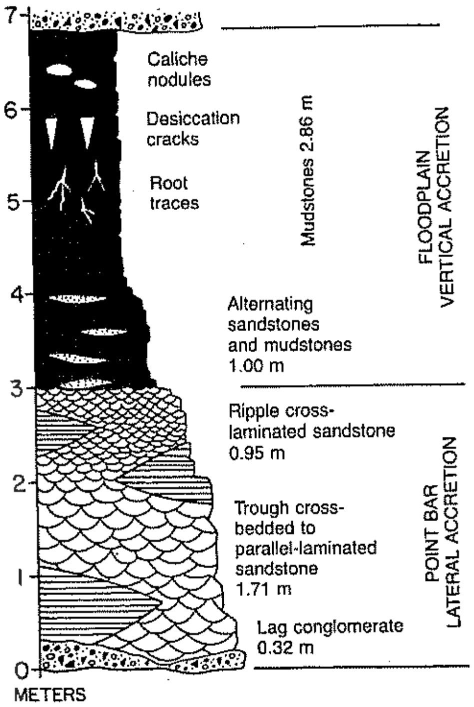


Meandering Facies

Fluvial Subenvironment	Subfacies
Channel - Active - Abandoned (Oxbow lake)	Upward fining upward channel sand Shales and fine sands, bounded by conglomerates above & below
Overbank-Floodplain	Shales, rippled sand, desiccation cracks, soils & peats (coal) transitional base, eroded on top



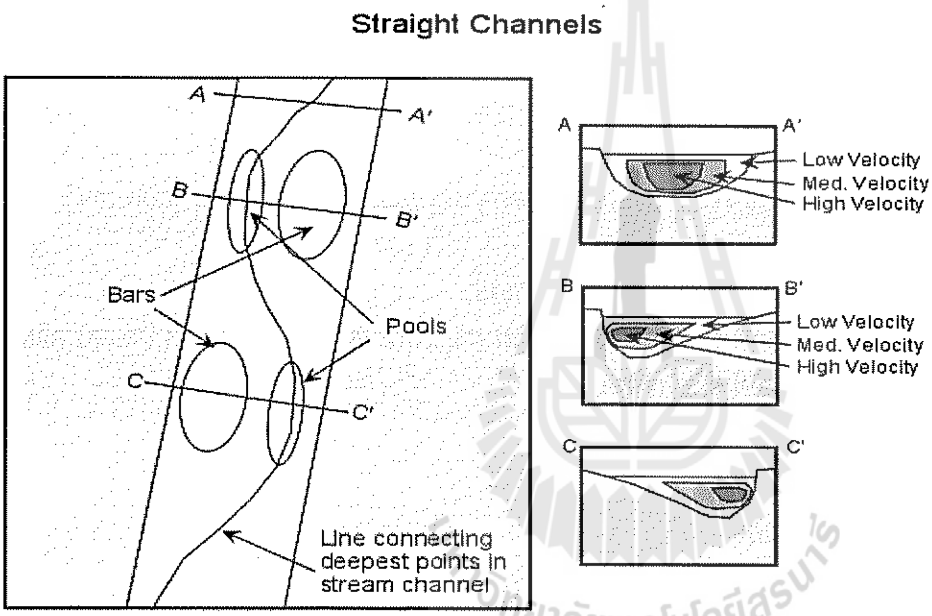
River Channel: lenses of conglomerate or sandstone (arkosic or sand-size rock fragments). Typically cross-bedded with ripple marks.

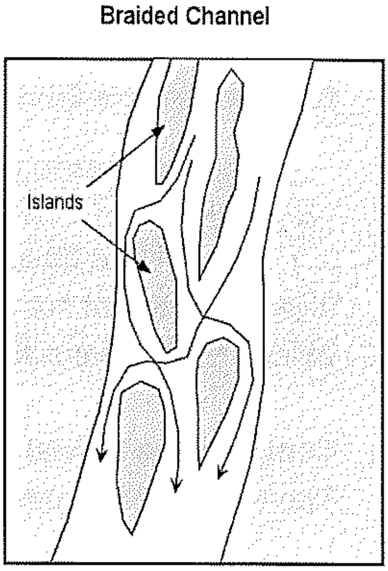
2.2 Braided River

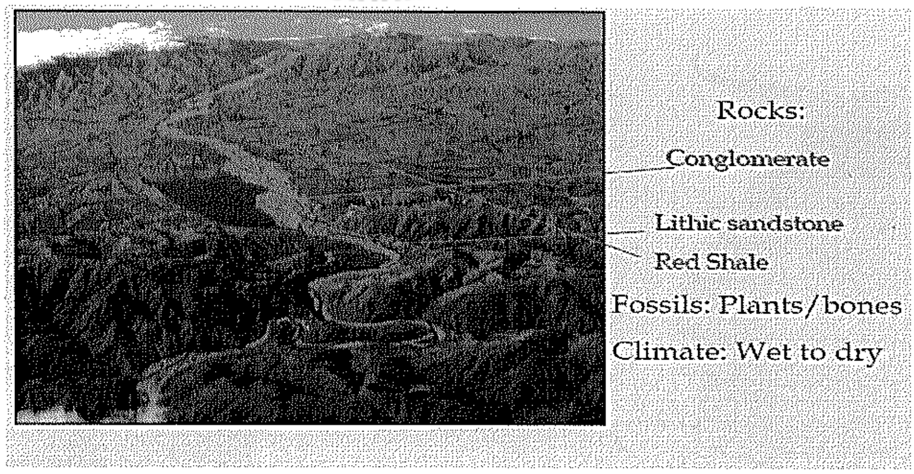
Braided Rivers - characterized by many channels separated by bars or small islands. Braiding results from rapid, large fluctuations in the volume of river water, and an abundance of coarse sediment.

There are two main types of braided river facies:

1) **Rippled,** cross-stratified gravels and coarse sandstones (bars) and
2) **Horizontally stratified,** fine to coarse sands (channels). In a vertical
3) section through an ancient braided river these will tend to alternate.







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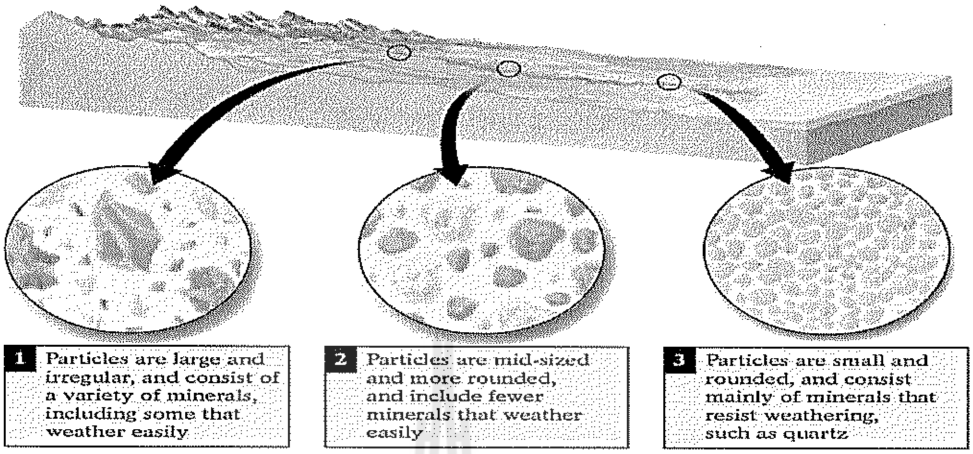
Sediment in a Stream



Braided Stream Environments

- Braided streams are high-energy river systems carrying coarse-grained sands and gravels
- Alluvial fans often grade laterally into a braided river

River channels are not well defined and tend to shift and migrate laterally over a broad alluvial valley ➡ rivers separate into vein like channel

Comparative Fluvial Deposits

Two types of fining upwards sequences

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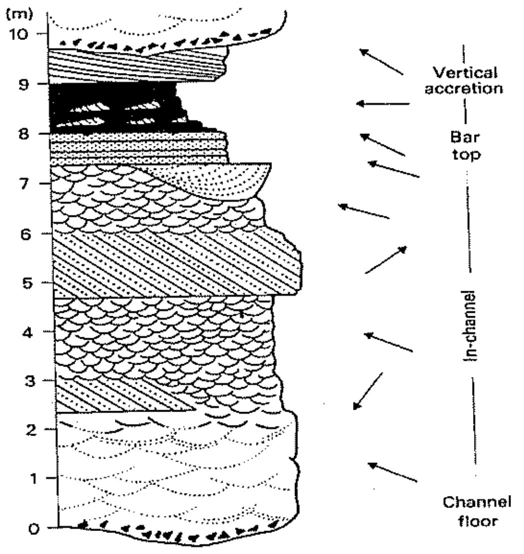
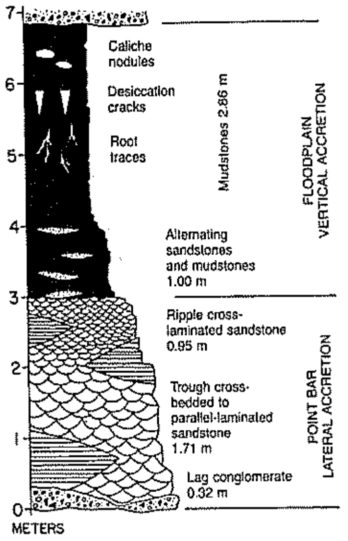
Braided



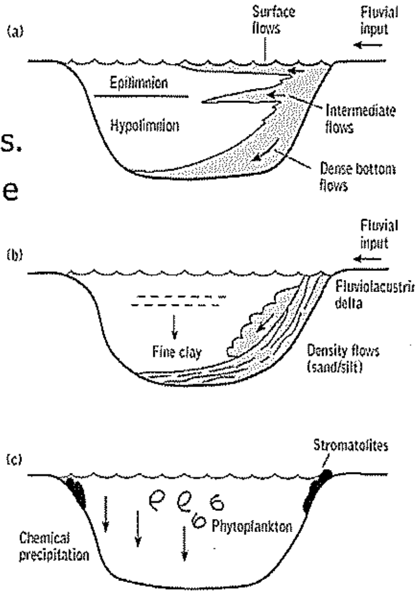
Meandering



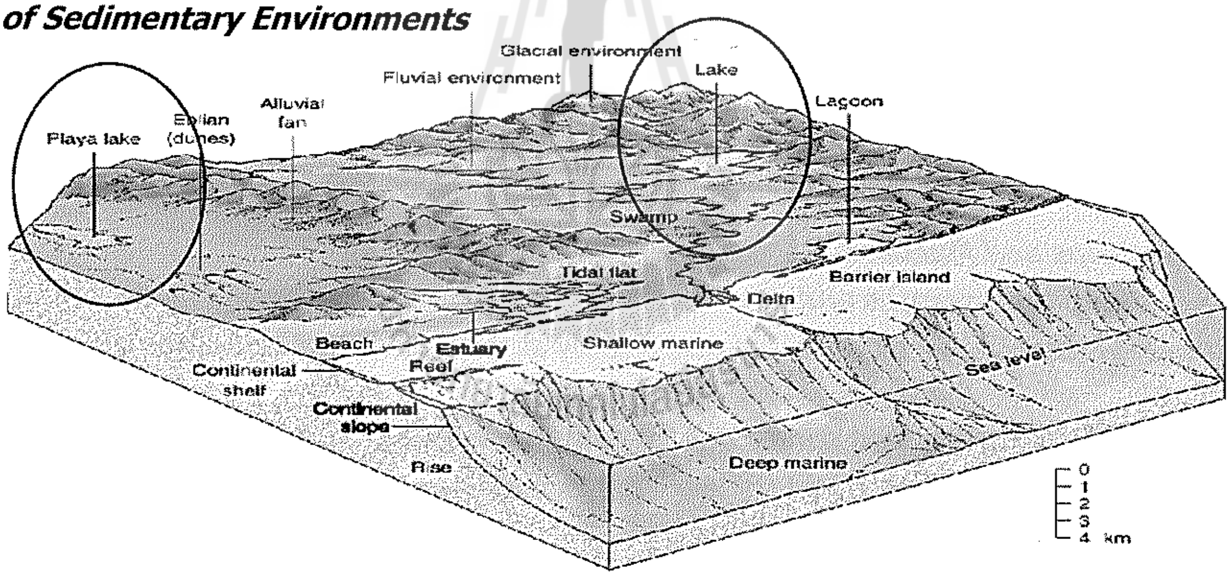
3. Lacustrine or Lake

Lake: Thin-bedded shales, possibly with fish fossils. May contain mud-cracks and interbedded evaporates, if it periodically dried up.

- **Lacustrine**
  - May be large or small, shallow or deep.
  - Fine grained sediments but may be coarse near the edges.
  - Fine grained sediment and organic matter settling in some lakes produced laminated **oil shales.**
  - **Playa lakes** are shallow, temporary lakes that form in arid regions.
  - They periodically **dry up as a result of evaporation.**



Type of Sedimentary Environments



ตารางที่ II-10 ลักษณะเด่นของ lacustrine facies (จาก Tucker, 1982)

Deposition : in lakes which vary in size, shape, salinity and depth. Waves and storm currents important in shallow water, turdibity currents, often river underflows, in deeper water. Biochemical and chemical precipitation common. Strong climatic control on lake sedimentation.

Lithologies : diverse including conglomerates through sandstones to mudrocks, limestones, marls, evaporites, cherts, oil shales and coals.

Structures : wave-formed ripples, desiccation cracks and stromatolites common in lake shoreline sediments; rhythmic laminations, possibly with synaeresis cracks, typical of deeper water lake deposits, together with interbedded graded sandstones of turbidity current origin.

Fossils : non-marine invertebrates (especially bivalves and gastropods); vertebrates (footprints and bones); plants, especially algae.

Facies sequences : often reflect changes in water level through climatic or tectonic events.

Facies associations : fluviatile and aeolian sediments often associated, soil horizons may occur within lacustrine sequences.

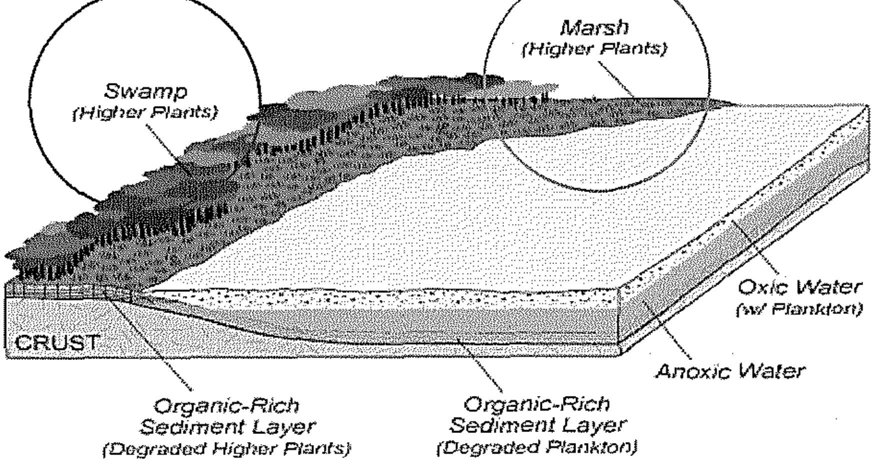
4. Swamps and Marshes

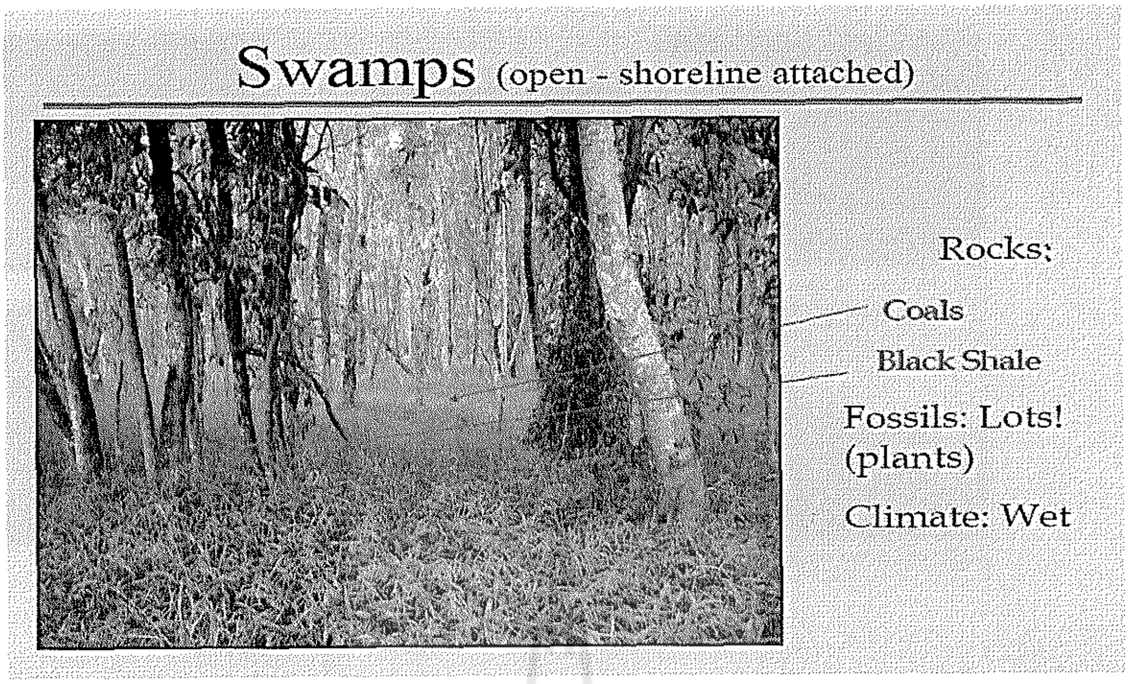
- **Paludal (swamps and marshes)**

: areas where water is more or less permanently at the surface and/or causing saturation of the soil.

: Organic-rich shale and sandstone or coal deposits with thin of siltstone and shale.

: Plant fossils are common in all stages of preservation (e.g. swamp plants, fern, peatlands).





Swamps (open - shoreline attached)

Rocks:

Coals

Black Shale

Fossils: Lots! (plants)

Climate: Wet

5. Deserts Aeolian or eolian environments

- Wind is an effective sorting agent and will selectively transport sand.
- Areas of windblown sand near beaches or in arid, desert environments.
- Gravel is left behind and dust-sized particles are lifted high into the atmosphere and transported great distances.
- Windblown sand forms dunes that are characterized by well-sorted grains showing large-scale cross bedding.
- Show ripple marks
- Good reservoirs

ตารางที่ II-9 ลักษณะเด่นของ aeolian facies (จาก Tucker, 1982)

Deposition : wind-blown sand is typical of deserts but also occurs along marine shorelines.

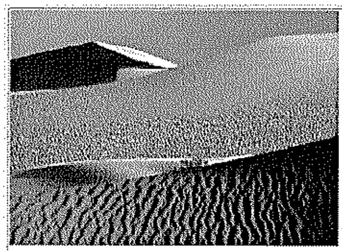
Lithology : clean (matrix-free) quartz-rich sandstones, no mica.

Textures : well-sorted, well-rounded sand grains ('millet-seed'); possibly with a frosted (dull) appearance; sandstones often stained red through hematite; any pebbles may be wind-faceted.

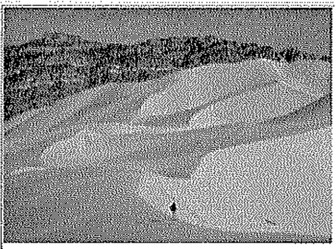
Structures : dominantly large-scale cross-bedding (set heights several to several 10's of meters); cross-bed dips up to 35°

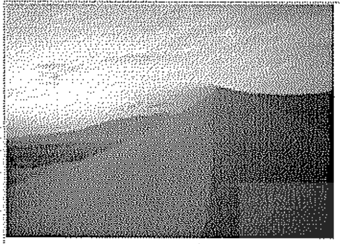
Fossils : rare, occasional vertebrate footprints and bones.

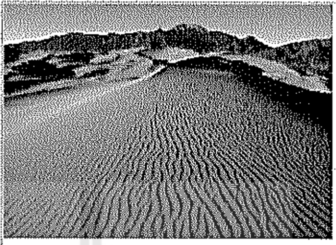
Facies associations : water-lain sandstones and conglomerates may be associated; also playa-lake mudrocks and evaporites and arid-zone soils.

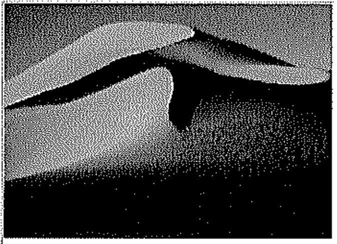

Dunes and Ripples; Mesquite Flat, Death Valley, CA.

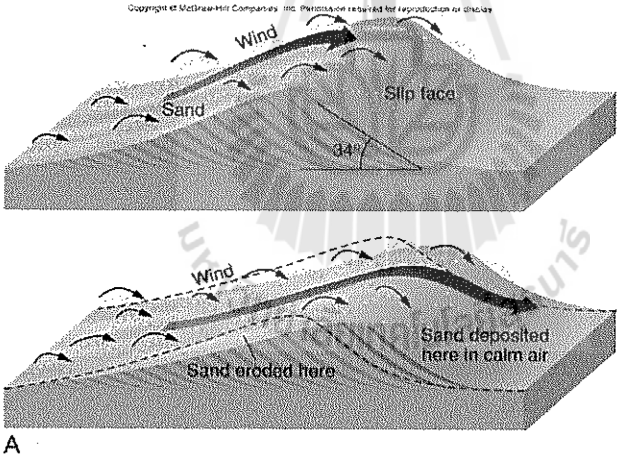

Dunes and Ripples, Mesquite Flat, Death Valley, CA.


Eureka Sand Dunes, California

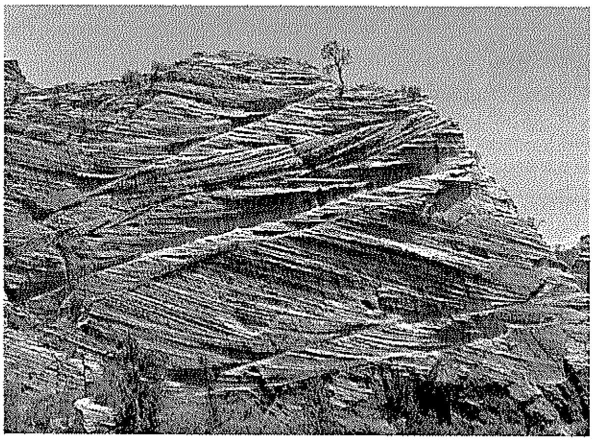

Sand blowing off crest of dune.


Great Sand Dunes National Monument, Colorado


Ibex Dunes, California



Dune Deposits

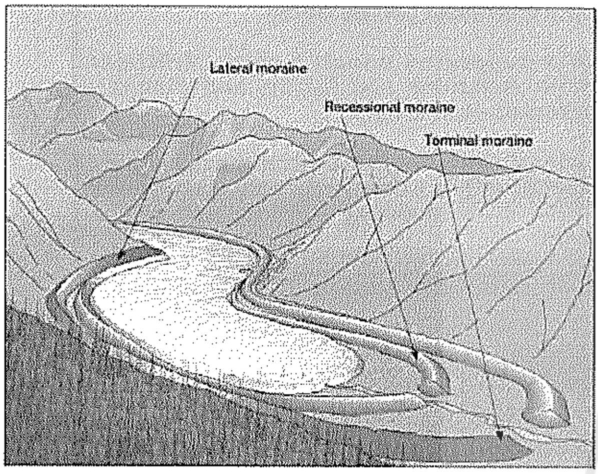


Cross-bedded Sandstone.

6. Glaciers

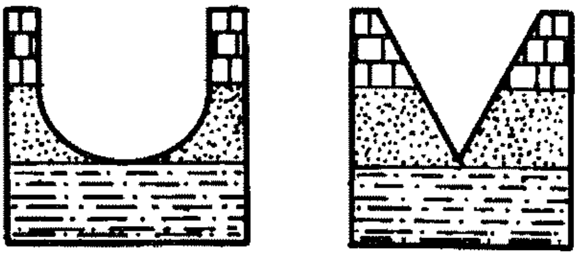
Glacial environments

- Sediment is eroded, transported, and deposited by ice (glaciers).
- Glacial deposits called **till** contain large volumes of unsorted mixtures of boulders, gravel, sand, and clay.



Ice (glaciers)

Another U-Shaped Valley in Alaska



The U-shaped Valley on the left was made by a glacier

V-shaped valley on the right was made by running water.

ตารางที่ II-11 ลักษณะเด่นของ glacial facies (จาก Tucker, 1982)

Deposition : takes place in a variety of environments: beneath glaciers of various types, in glacial lakes, on glacial outwash plains and glaciomarine shelves and basins, and by a variety of processes including moving and melting glaciers, melt-water streams, melt-water density currents and icebergs.

Lithologies : polymictic conglomerates termed tillite, sandstones, muddy sediments with dispersed clasts (dropstones).

Textture : poorly-sorted, matrix-supported conglomerates (tillites), angular clasts possibly with striations and facets, and elongate clasts possibly showing preferred orientation.

Structures : tillites generally massive but some layering may occur; rhythmically laminated ('varved') muddy sediments common; fluvioglacial sandstones show cross-bedding and lamination, flat bedding, scours and channels.

Fossils : generally absent (or derived), except in glaciomarine sediments.

Geometry : tillites laterally extensive.

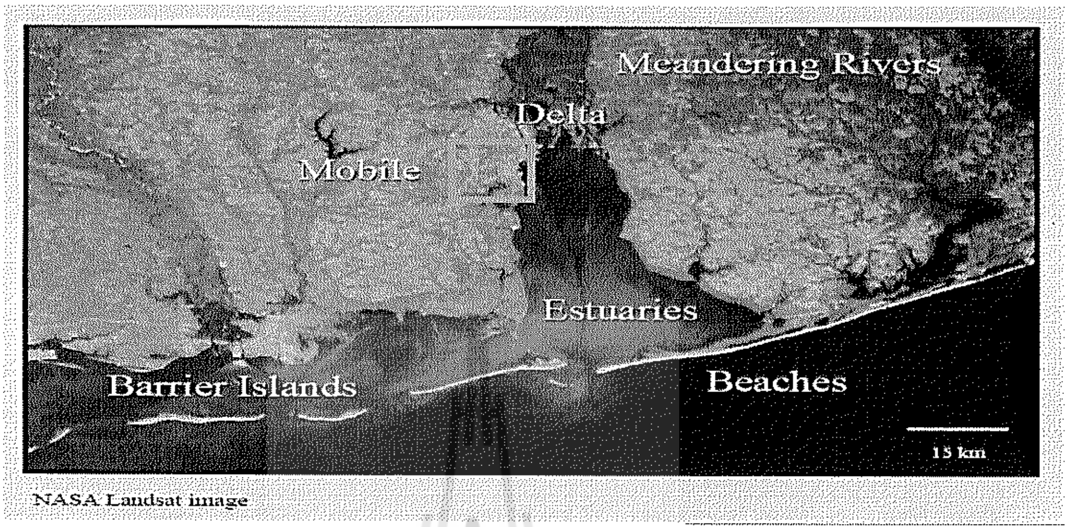
Facies sequences : no typical sequence.

มหาวิทยาลัยเทคโนโลยีสุรนารี

Summary of Continental Sedimentary Environments

	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
Organic or Biogenic Sedimentary Structures	---	Tracks, trails,burrows	Tracks, trails, burrows, rare stromatolites	Tracks, trails	Root marks, burrows
Fossils	---	Rare freshwater shells, bones, plant fragments	Freshwater shells, fish, bones, plant fragments	---	Plant fossils, rare freshwater shells, bones, fish

Transitional Environments



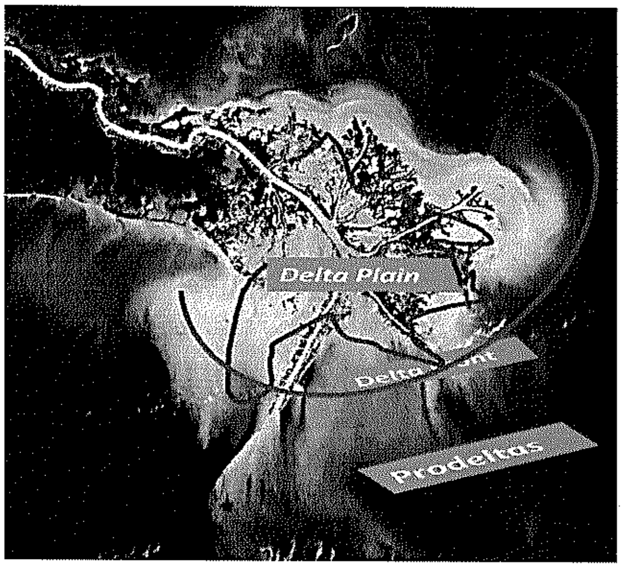
NASA Landsat image

1. Deltaic Environmemt

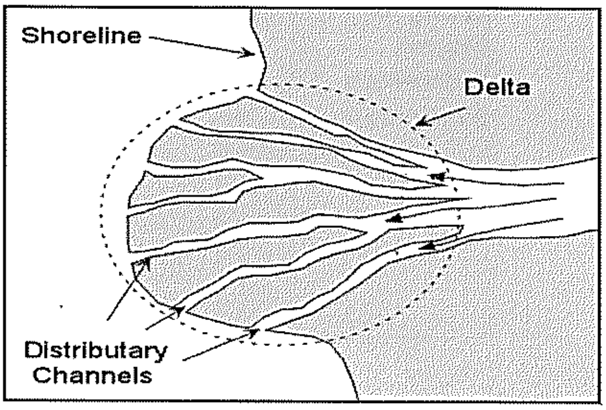
- Delta is formed when a sediment carrying stream enters a lake or sea, its velocity decreases and some of the sediment settles to form a delta
- Forces involved are:
  - **Forces of river**
  - **Tidal**
  - **Wave**

Control the geometry and distribution of the deposit ⇨ variation, deposition, depending on which of this forces is dominant

Delta: Mostly thick sequences of [illegible] gle cross-bedding, cut by coarse-grained channel deposits. It can contain peat/coal beds as well as marine fossils (Delta plain).



Birds- foot Deltas= Delta plain



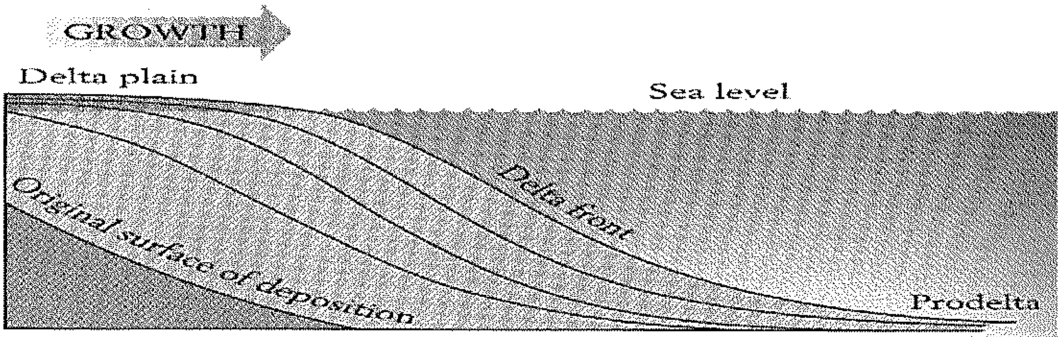
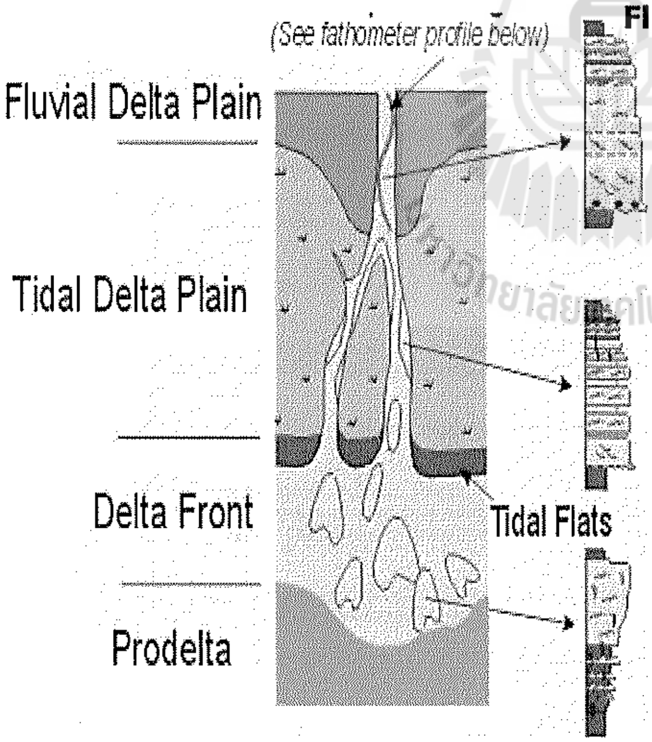


Figure 5-17 Cross section of a delta. As river water flows into the sea, it slows down. First sand drops from suspension in the delta plain; then silt and clay settle on the delta front (the slope is greatly exaggerated in the diagram); and finally clay settles in the prodelta. As the delta grows seaward, the sandy shallow-water sediments build out over the finer-grained sediments deposited in deeper water.



Fluvial Distributary Channel organic clay

- Rippled sand-mud lamination
- Cross bedded medium sand with carbonaceous laminae

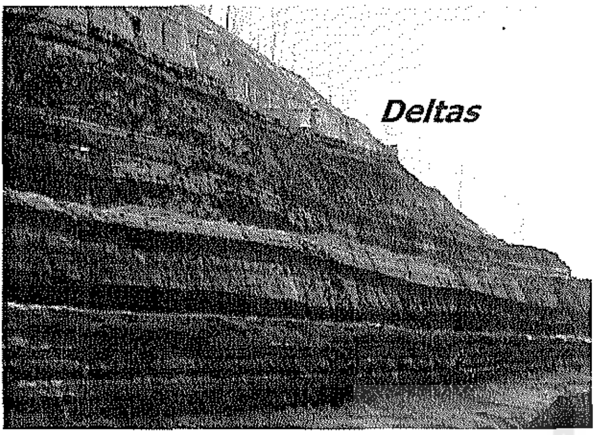
Tidal Distributary Channel

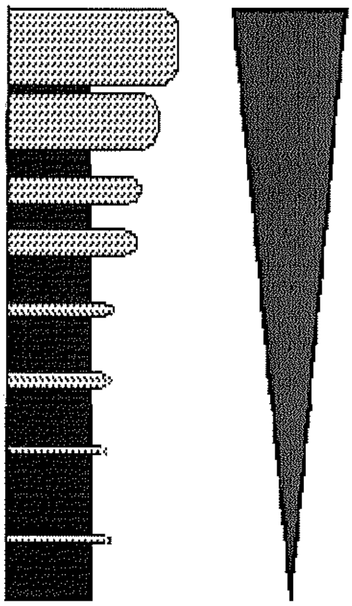
- Rippled sand-mud lamination with scattered burrows
- Cross bedded and rippled fine to medium sand with mud laminae

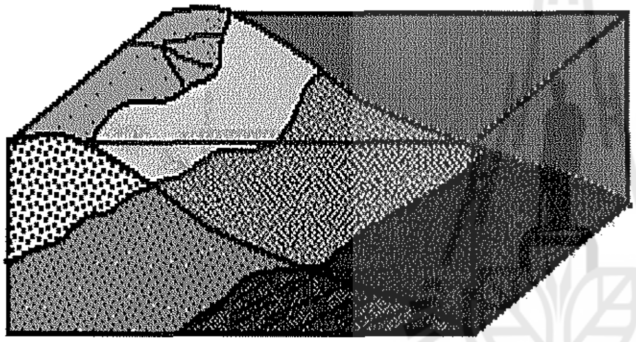
Distributary Mouth Bar

- Fine to medium bioturbated sand (trace fossil)
- Bioturbated mud with fine sand

Massive prodelta mud







ตารางที่ II-12 ลักษณะเด่นของ deltaic facies (จาก Tucker, 1982)

Deposition : complex, there are several types of delta (lobate and birdfoot especially), and many deltaic subenvironments (distributary channels and levees, swamps and lakes, mouth and distal bars, interdistributary bays and prodelta slope). Many deltas are river dominated but reworking and redistribution by marine processes can be important.

Lithologies : mainly sandstones (often lithic) through muddy sandstones, sandy mudrocks to mudrocks; also coal seams and ironstones.

Textures : not diagnostic, typically average sorting and rounding of sand grains.

Structures : cross-bedding of various types in the sandstones, flat bedding and channels common. Finer sediments show flaser and wavy bedding. Some mudrocks contain rootlets; nodules of siderite common.

Fossils : marine fossils in some mudrocks and sandstones, others with non-marine fossils, especially bivalves, Plants common.

Paleocurrents : mainly directed offshore but may be shore-parallel or onshore if much marine reworking.

Geometry : sand bodies vary from ribbons to sheets depending on delta type.

Facies sequence : these typically consist of coarsening upward units (mudrock to sandstone), through delta progradation, capped by a seatearth and coal; there are many variations however, particularly at the top of such units.

2. Linear Shoreline

1. Barrier Island
2. Beach
3. Tidal Flat
4. Lagoon
5. Estuary

2.1 Barrier Island Environments

- **Barrier Island and Beaches**
  - Shoreline deposits
  - Exposed to wave energy
  - Dominated by sand
  - Marine fauna (animals)
  - A few km or less in width but may be more than 100 km long
  - Separated from the mainland by a lagoon (or salt marsh)
  - Commonly associated with tidal flat deposits

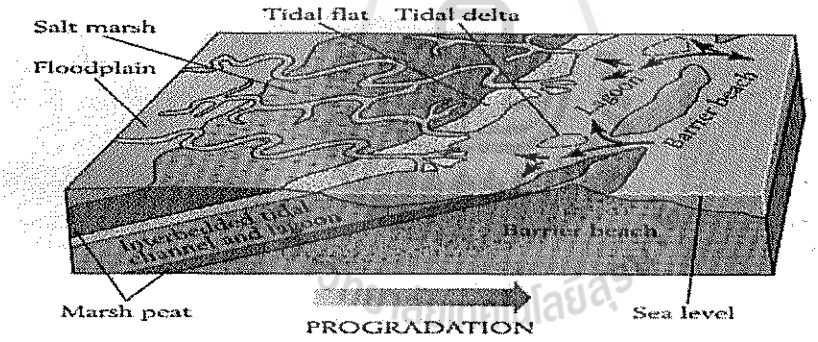
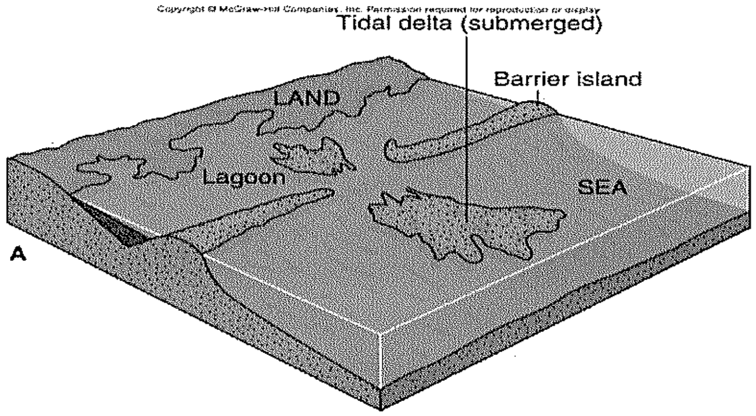


Figure 5-22 The stratigraphic sequence produced when a barrier island–lagoon complex progrades. Sediments of the lagoon and of the adjacent marshes and tidal flats are superimposed on beach sands of the barrier island.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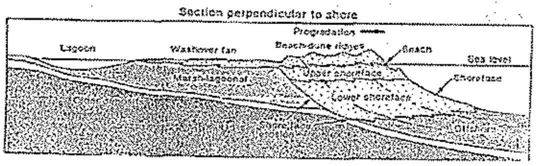
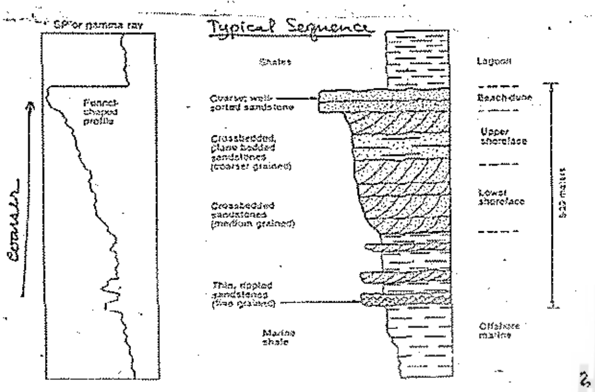
Barrier Island





2

Barrier Island Environment

- **Chain of sand bodies running parallel to the shoreline**
- **Occur as long, narrow, avg. thickness 50 ft**

Beach

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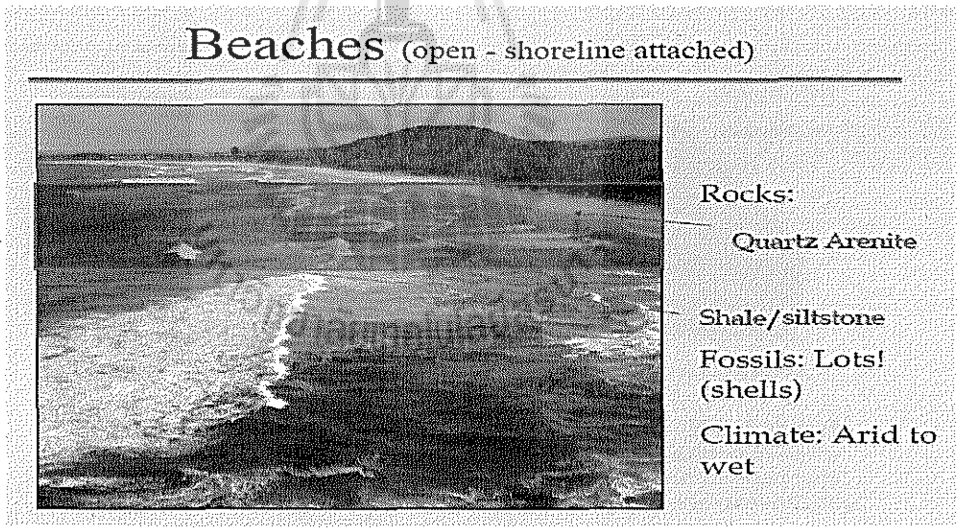
B

Photo by Diane Carlson



Beaches (open - shoreline attached)

Rocks:

Quartz Arenite

Shale/siltstone

Fossils: Lots! (shells)

Climate: Arid to wet

Beach, Barrier Island, Dune: a ***Barrier Island*** is an elongate sand bar built by wave action. All are comprised of well-sorted quartz sandstones with rounded grains.

Beach and Barrier Island: low angle cross-bedding and marine fossils.

Dune: high-angle and low-angle cross-bedding and occasional fossil footprints.

All 3 environments can also contain carbonate sand in tropical areas producing cross-bedded clastic limestone.

2.3 Tidal Flats

Tidal flats: Behind the beach area of this sand spit lies another transitional environment, is border lagoons.

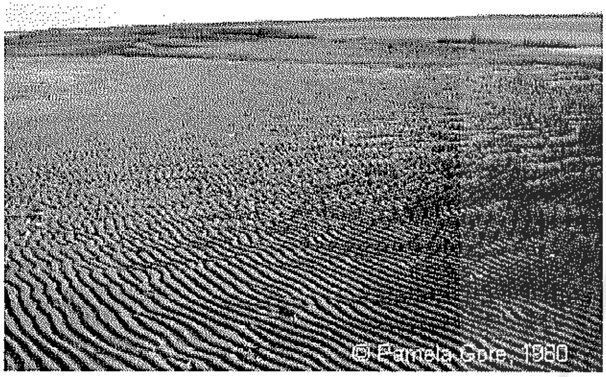
: They are periodically ***flooded and drained by tides*** (usually twice each day).

: **Low relief**, cut by ***meandering tidal channels.***

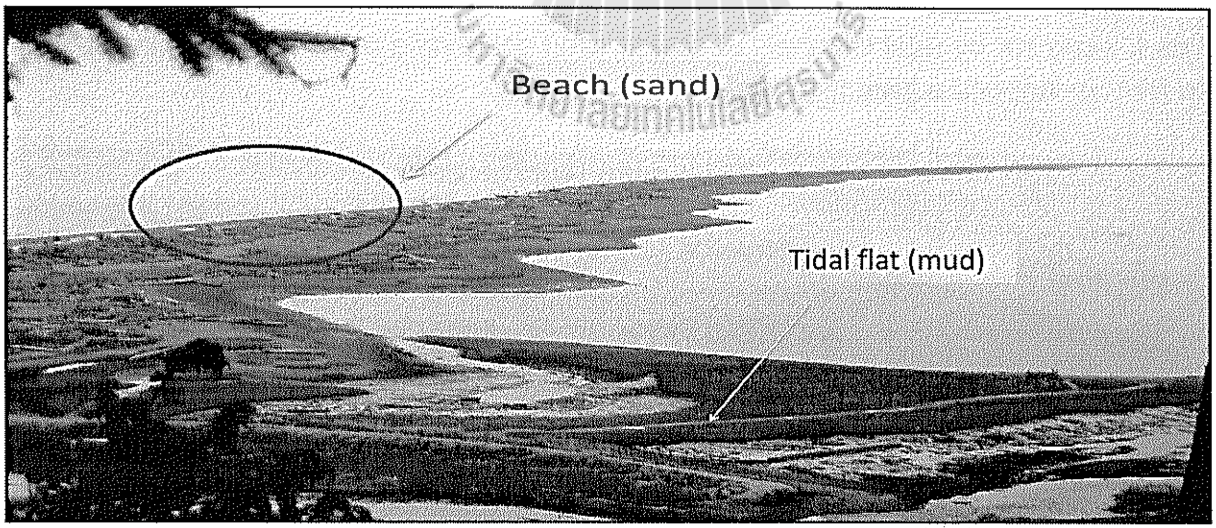
: Laminated or **rippled clay, silt, and fine sand** (either terrigenous or carbonate) may be deposited.

: Intense burrowing is common.

: Stromatolites (สาหร่ายสีเขียว)



Sandy Tidal flats



Spit

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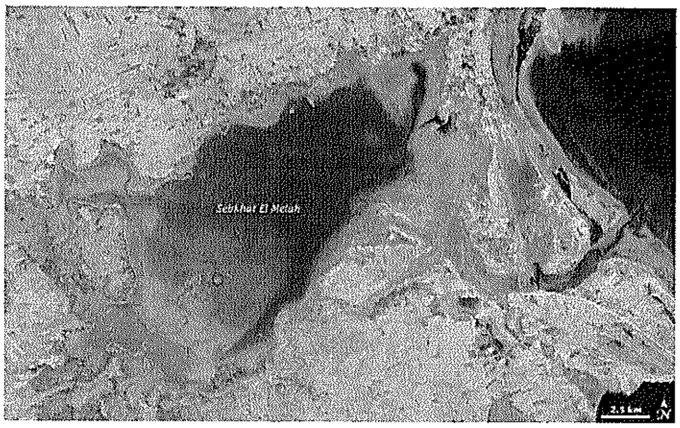

Sabkhas are another transitional environment that, although rare today, are important to the geologic past of Utah.

Sabkhas only occur in, hot, arid climates where sea water can evaporate rapidly.

White material is halite and gypsum.

Sabkhas : can occur with tidal flats or pools that are periodically
inundated with water.
: Evaporate minerals: halite (salt) or gypsum.

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2.4 Lagoon Deposits

Lagoon: semi-enclosed body of water between a barrier island and the mainland. Fine grained dark shale cut by tidal channels of coarse sand containing marine fossils. Limestones may also form in lagoons adjacent to reefs.

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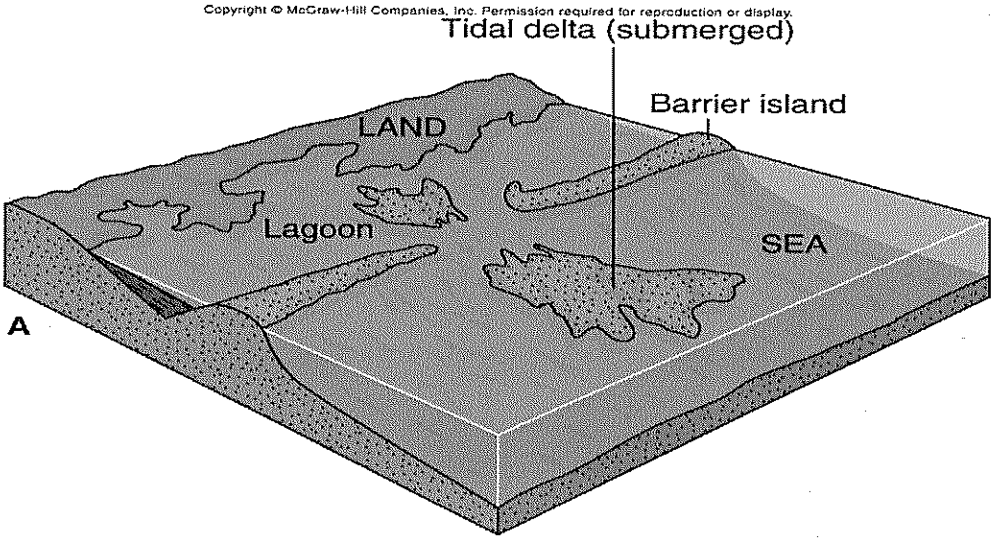
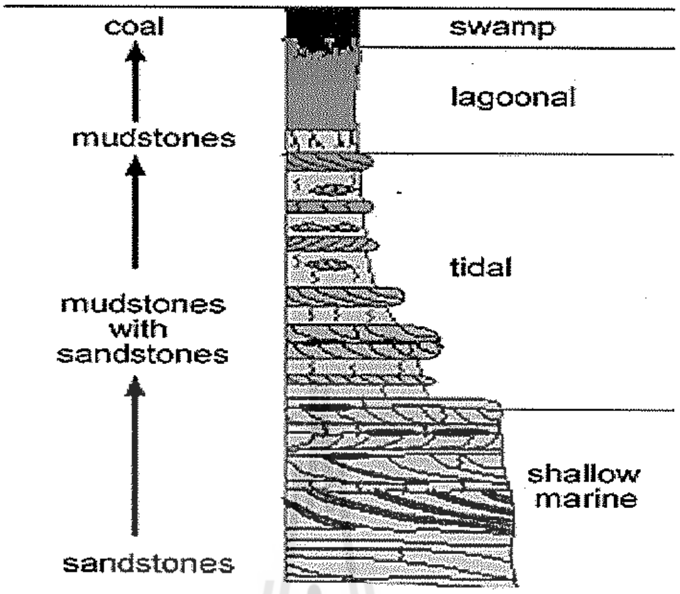


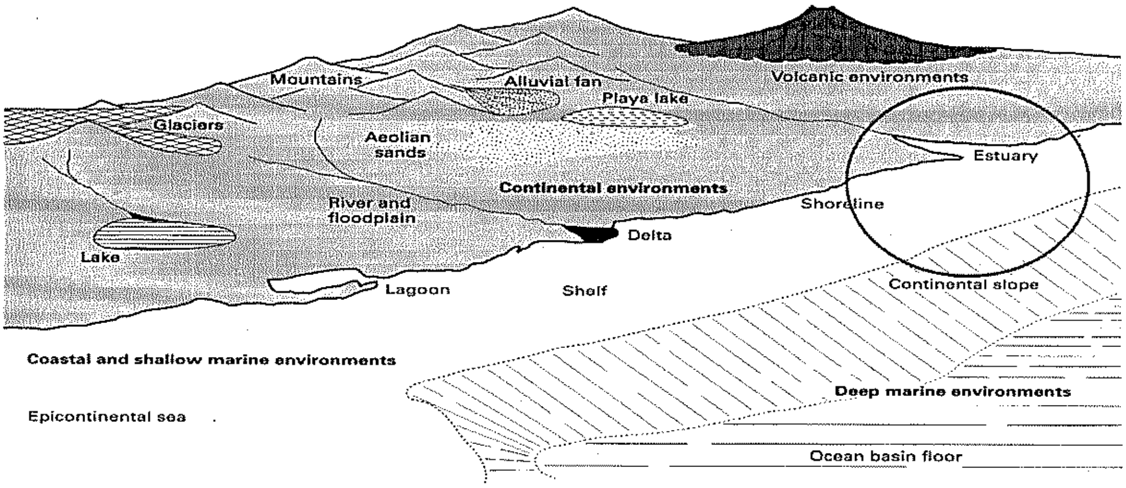
Facies sequence of coastal



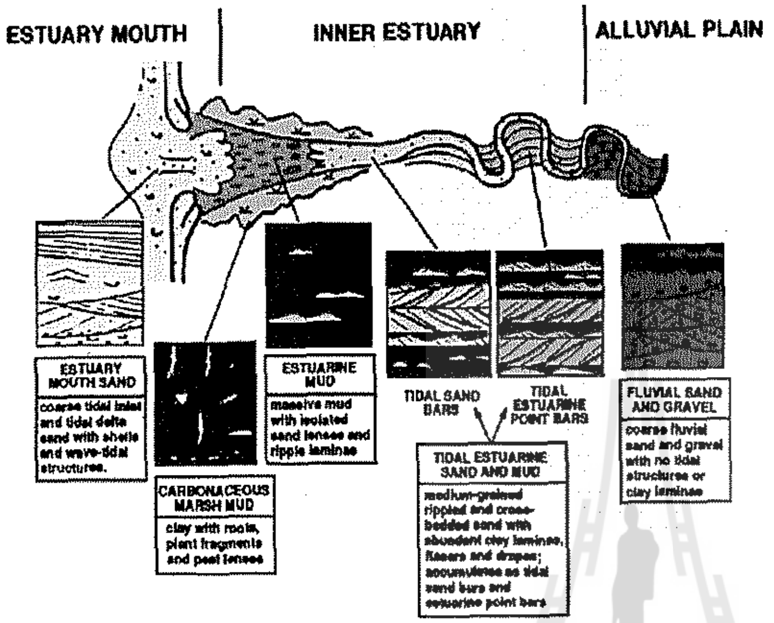
2.5 Estuaries

- Mouth of a river drowned by the sea
- Brackish water (mixture of fresh and salt water)
- May trap large volumes of sediment
- Sand, silt, and clay may be deposited depending on energy level
- Many estuaries formed due to sea level rise as glaciers melted at end of last Ice Age
- Some formed due to tectonic subsidence, allowing sea water to migrate upstream

Coastal and shallow marine environments



Estuarine environment



Lithofacies units:

- Marine lithofacies units
- Coastal lithofacies units

Tidal channel”

“Tidal flat”

“Salt marsh”

“Coastal lagoon”

Fluvial lithofacies units

ตารางที่ II-13 ลักษณะเด่นของ shallow-marine siliciclastic facies
(จาก Tucker, 1982)

Deposition : takes place in a variety of environments and subenvironments including tidal flat, beach, barrier island, lagoon and nearshore to offshore shelf. Waves, tidal and storm currents are the most important processes.

Lithologies : mainly sandstones (often quartz arenites) through muddy sandstone, sandy mudrocks to mudrocks: also thin conglomerates.

Textures : not diagnostic although sandstones often have well-rounded and well-sorted grains.

Structures : in the sandstones: cross-bedding, possibly herring-bone in character and with reactivation surfaces, flat bedding (in truncated sets if beach), wave-formed and current ripples and cross-lamination, flaser and lenticular bedding, desiccation cracks, thin graded sandstones of storm current origin; mudrocks may contain pyrite nodules, bioturbation and various trace fossils common.

Fossils : marine faunas with diversity dependent on salinity, level of turbulence, substrate, etc.

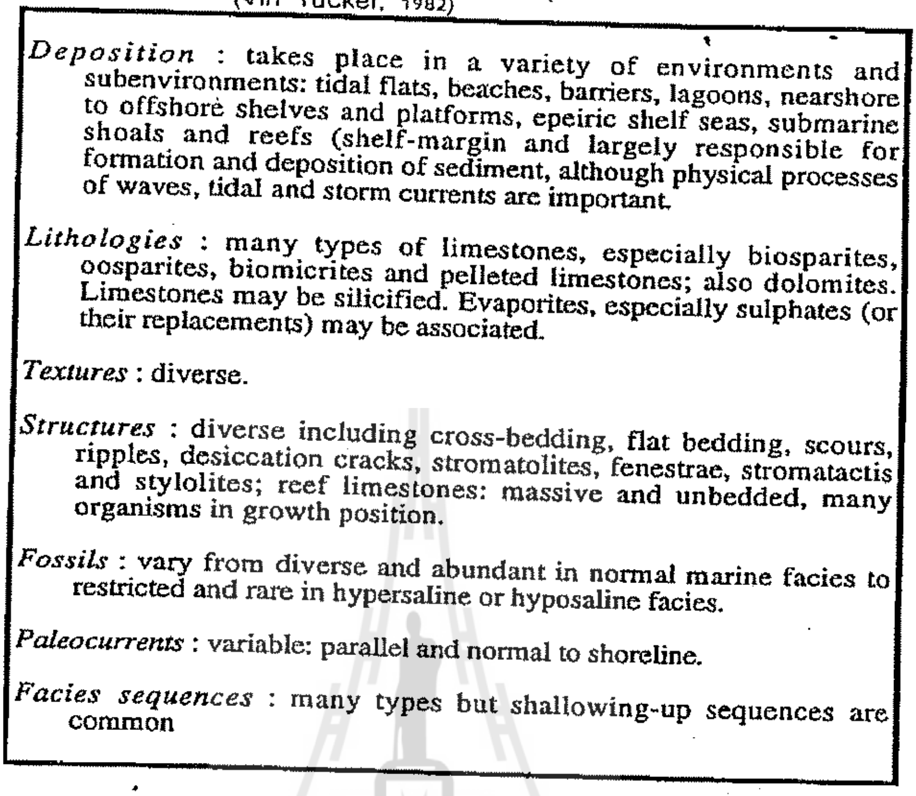
Paleocurrents : variable, parallel to and normal to shoreline, unimodal, bimodal or polymodal.

Geometry : linear and bodies if barrier or beach, sheet sands if extensive epeiric-sea platform.

Facies sequcnces : vary considerably depending on precise environment and sea-level history (rising or falling); both fining up and coarsening up units occur.

Facies associations : limestones, ironstones and phosphates may occur within shallow-marine siliciclastic facies.

ตารางที่ II-15 ลักษณะเด่นของ shallow-marine carbonate facies (จาก Tucker, 1982)



Deposition : takes place in a variety of environments and subenvironments: tidal flats, beaches, barriers, lagoons, nearshore to offshore shelves and platforms, epeiric shelf seas, submarine shoals and reefs (shelf-margin and largely responsible for formation and deposition of sediment, although physical processes of waves, tidal and storm currents are important.

Lithologies : many types of limestones, especially biosparites, oosparites, biomicrites and pelleted limestones; also dolomites. Limestones may be silicified. Evaporites, especially sulphates (or their replacements) may be associated.

Textures : diverse.

Structures : diverse including cross-bedding, flat bedding, scours, ripples, desiccation cracks, stromatolites, fenestrae, stromatactis and stylolites; reef limestones: massive and unbedded, many organisms in growth position.

Fossils : vary from diverse and abundant in normal marine facies to restricted and rare in hypersaline or hyposaline facies.

Paleocurrents : variable: parallel and normal to shoreline.

Facies sequences : many types but shallowing-up sequences are common

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Potential Reservoir & Source rocks vs. Transitional Deposits

Reservoir rocks: Delta, Beach sand, Barrier Island

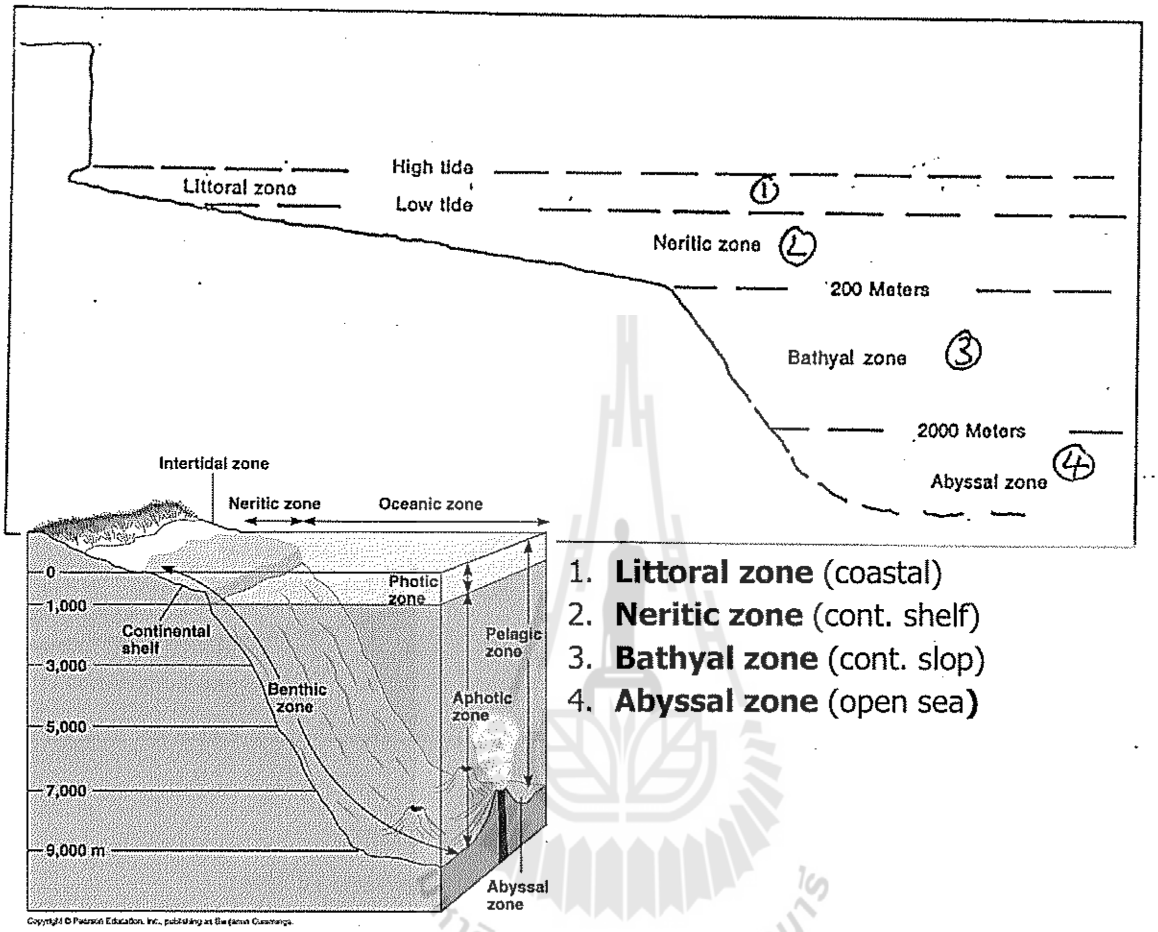
Source rocks: Lagoon, Tidal flat, Estuary, deltas

Summary of Transitional Environment

	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 Structures	Trails, burrows	Tracks, trails, burrows	Trails, burrows	Stromatolites, trails, tracks, burrows
Fossils	Plant fragments, shells	Marine shells	Marine shells	Marine shells

Marine Environments

Marine Depth Zones



1. **Littoral zone** (coastal)
2. **Neritic zone** (cont. shelf)
3. **Bathyal zone** (cont. slop)
4. **Abyssal zone** (open sea**)**

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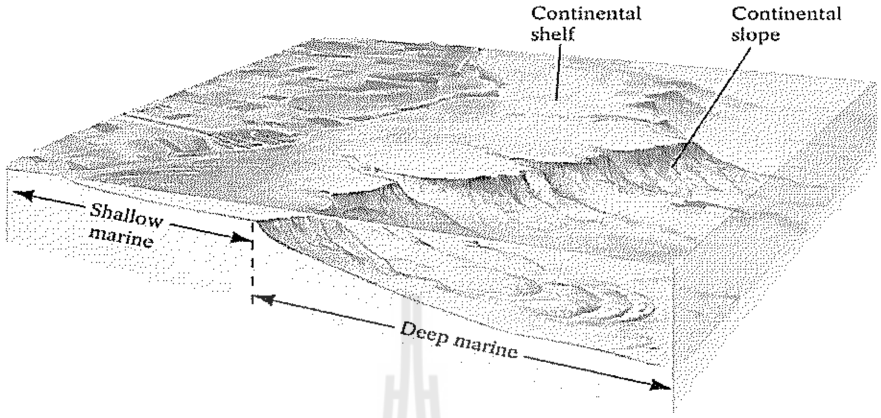
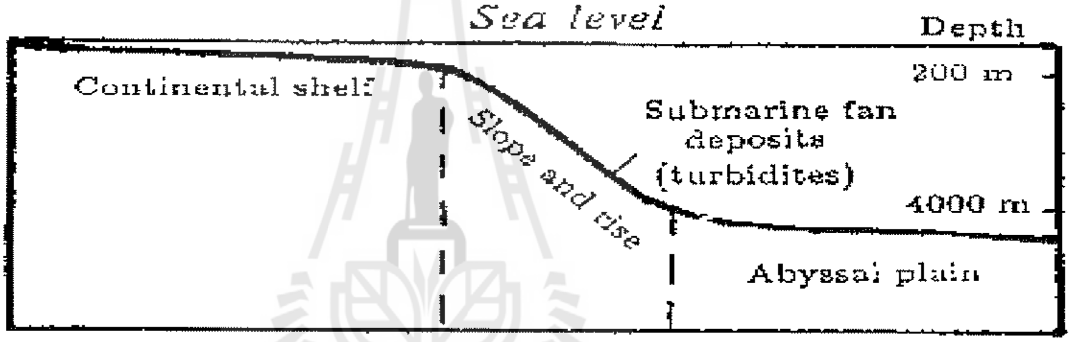
Marine environment can be subdivided into 4 depth zones:

1. **Littoral zone** max. erosion, life (animals & plants) forms that live in both marine and terrestrial environments
2. **Neritic zone** (intertidal and subtidal)- -below littoral zone to water depth 200 m., approximate edge of the continental shelf, contains majority of marine life, coral, algae etc.
3. **Bathyal zone** from 200 m to 2,000 m., continental slope, varies in abundance of life and depositional environment between the top and bottom-submarine canyon are often developed
4. **Abyssal zone**-below 2,000 m. to ocean floor, sediments are deposited by turbidity currents from the shelf and slope-no light

Marine sedimentary environment





Marine environment can be divided in to 4 parts:

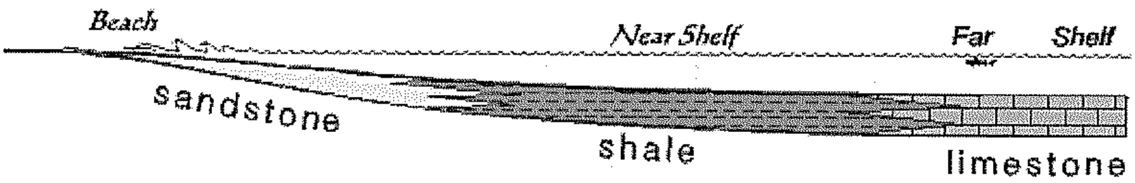
1. The ***continental shelf*** is the flooded edge of the continent.
2. The ***continental slope*** } are located seaward of the
3. The ***continental rise*** continental shelf.
4. The ***abyssal plain*** is the deep ocean floor.

Marine Environments

1. **Continental Shelf** or **Shallow Marine Shelf**:

Grain size decreases offshore. Widespread sandstones, siltstones, shales. Sandstone & siltstone contains ripple marks, low-angle cross-beds, & marine fossils. If tidal flats near shore are alternately covered & exposed, mud-cracked marine shales form

- Relatively flat (slope < 0.1°).
- Shallow water (less than 200 m deep).
- Exposed to waves, tides, and currents.
- **Coral reefs** and **carbonate sediments** may accumulate in tropical areas.

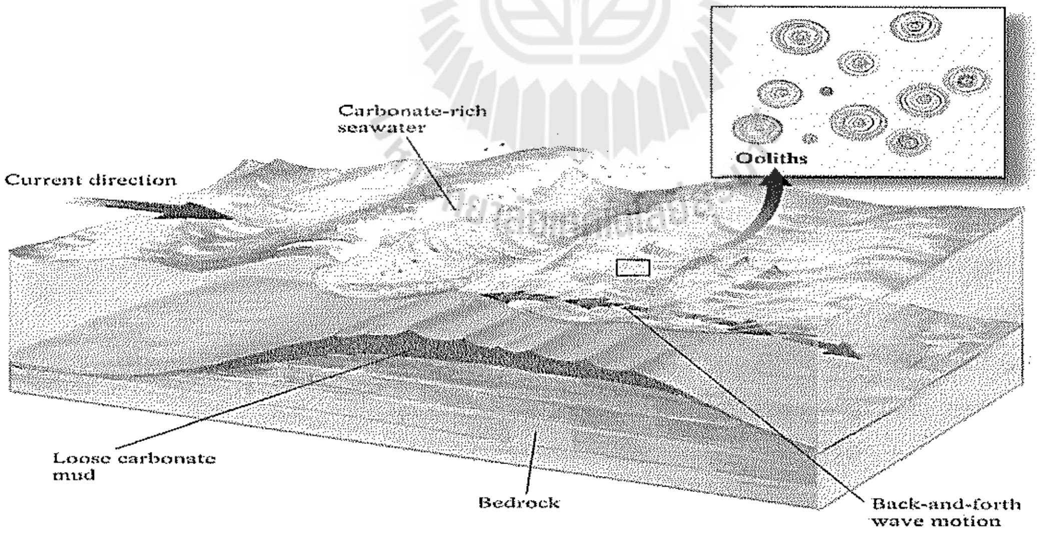


Carbonate Reservoir

- Carbonate sediments are born
    - Organisms==Corals, Bivalves or Gastropods, Algae
    - Direct precipitation
- Require special marine environment (Clear-warm-fairly shallow-agitated water)

Example of some modern carbonate forming organisms and type of sediments they produce

Organisms	**Sediment produced**
Corals	Reefs
Bivalves, Gastropods	Sand & Gravel- Sized particles
Algae	Sand, Lime, Mud



- **Oolitic carbonate sand** (High-energy shelf)-excellent reservoir rocks if porosity & permeability are not destroyed by subsequent diagenesis
  e.g. Oil field in Saudi Arabia

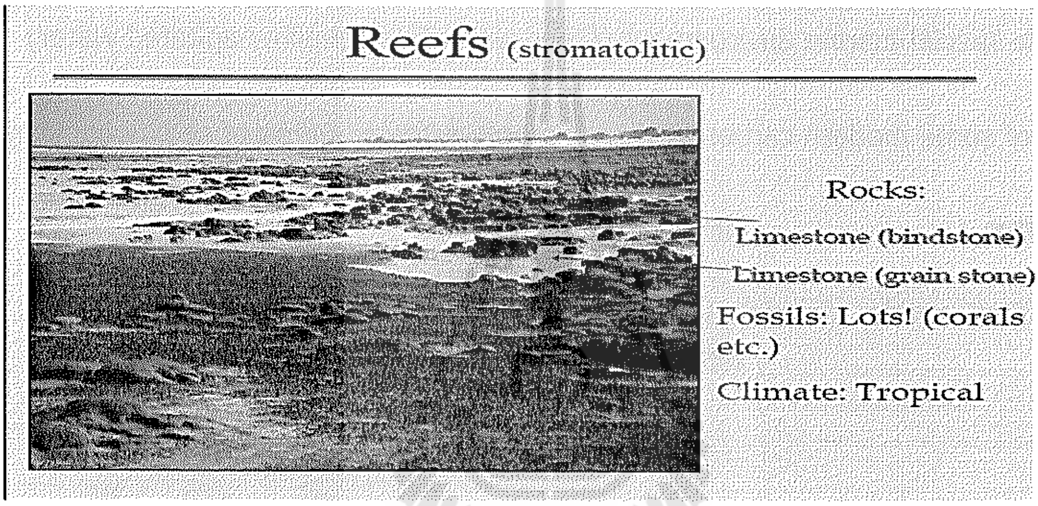
Reefs

Wave-resistant, mound-like structures made of the calcareous skeletons of organisms such as corals and certain types of algae.

: Most modern reefs are **in warm, clear, shallow (25 ft), tropical seas** (latitudes of **30°N and 30°S** of the equator)

: Massive limestone in core of reef, with steep beds of limestone breccia forming seaward (ออกสู่ทะเล), horizontal beds of sand-sized and finer-grained limestones form landward (เข้าสู่ฝั่ง).

: All are full of fossil fragments (coral, shells, etc.).



Reefs (stromatolitic)

Rocks:
Limestone (bindstone)
Limestone (grain stone)
Fossils: Lots! (corals etc.)
Climate: Tropical

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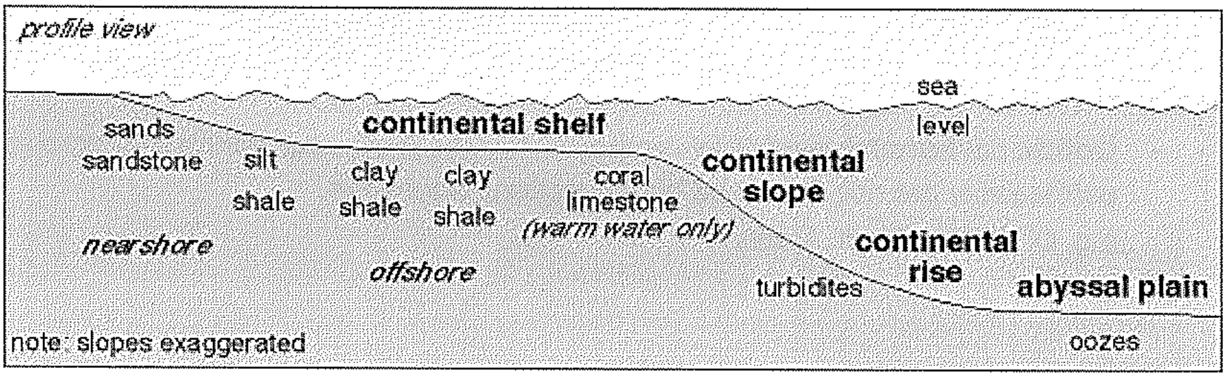
2. **Continental slope**-The steeper slope at edge of the continent.
   - Located seaward of the continental shelf.
   - Boundary between continental and oceanic crust.
   - Deeper water.
   - More steeply inclined (3 - 6°).
   - Rapid sediment transport down the slope by dense, muddy **turbidity currents.**
   - Passes seaward into the continental rise.



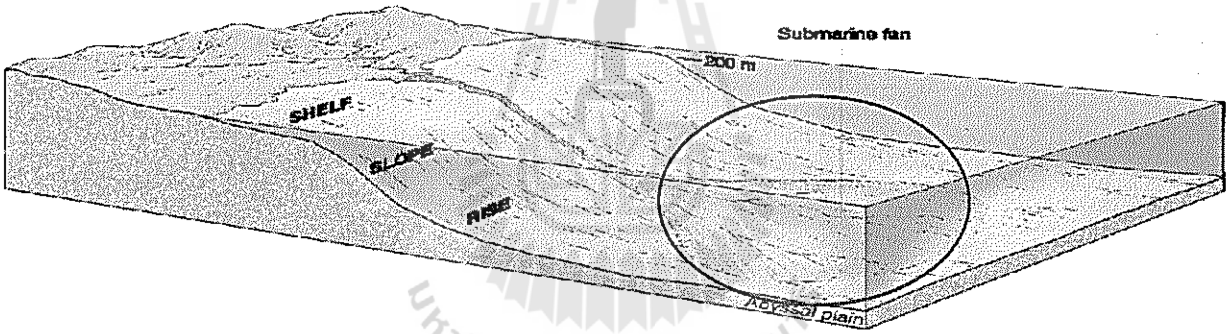
3. Continental rise

Continental rise - At the base of the continental slope.

- More gradual slope.
- Water depths of 1400 to 3200 m.
- **Submarine fans** form at mouth of submarine canyons.
- **Turbidity currents** deposit thick accumulations of sediment (called **turbidites**), transported downslope from continental shelf.
- Passes seaward into the abyssal plain.

Submarine-fan deposition

- The concept of submarine fan is similar to alluvial fan deposits-sediment overloading, storms, and possibly earthquake, coarse material periodically avalanches down canyons is the continental slope==Fan development
- ✓ **Channel deposits** in the upper part of the lobe, near canyon mouth, are dominated by massive conglomeratic and very coarse-grained sands==good reservoir



Deep-sea fan deposited by turbidity currents on the continental rise

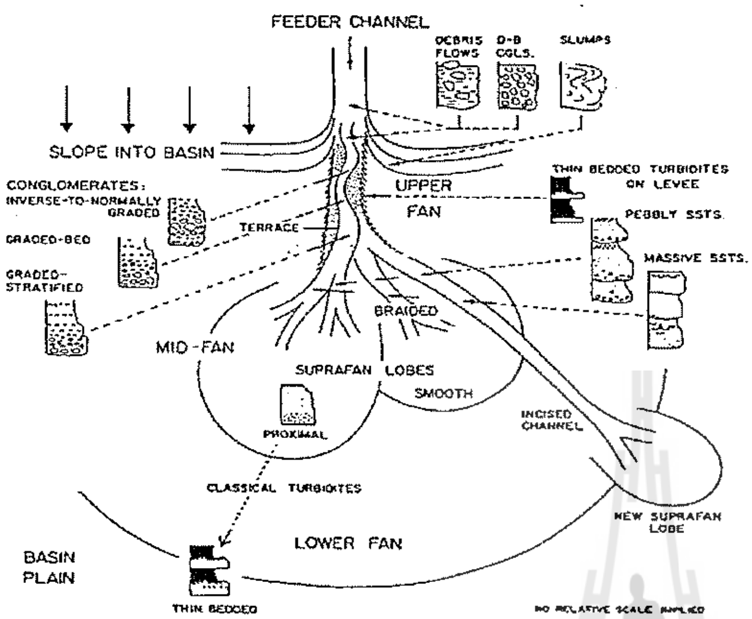
Submarine-fan deposition

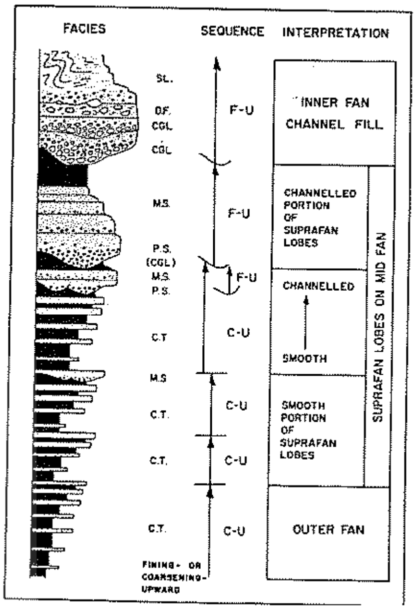
1. **Mid fan**-channels branch into braided distributaries deposits show a feature called graded bedding

e.g. A single layer with coarser material at the base and progressively finer sand above-imply that when one suprafan lobe is active, other lobes and their former distributary channels are being blanketed by mud==forming stratigraphic traps over potential suprafan oil and gas reservoirs

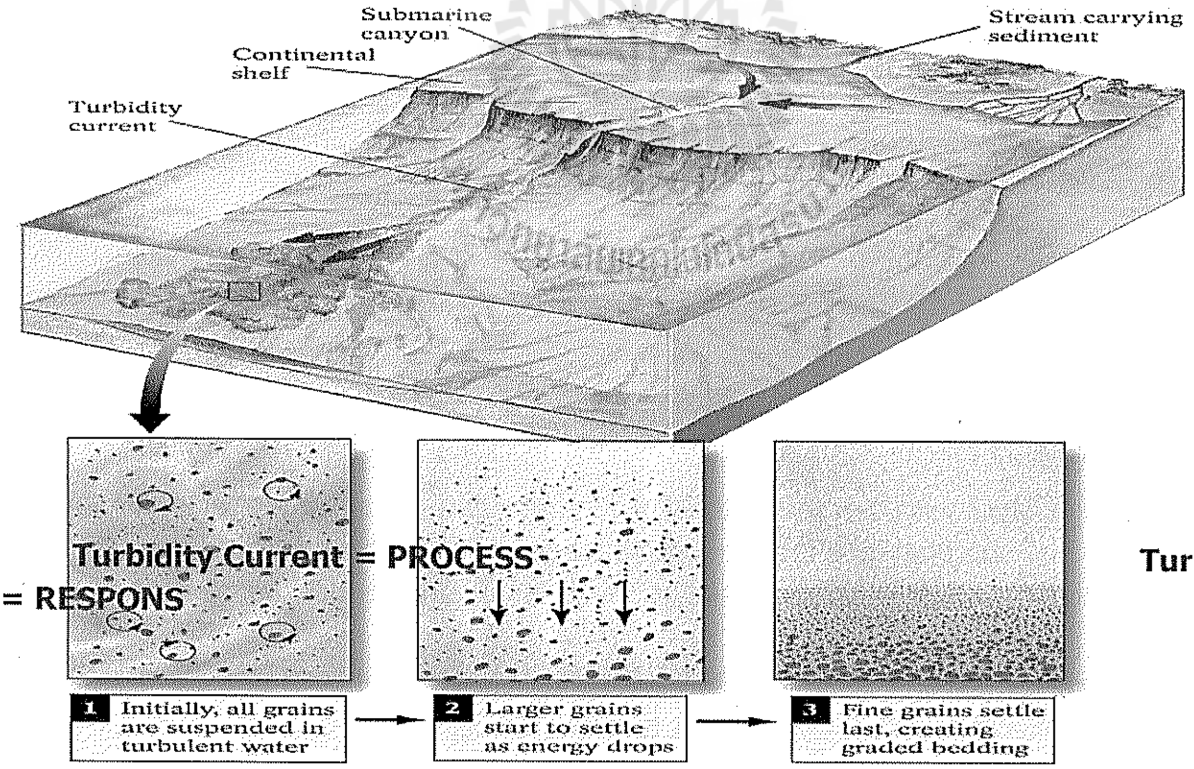
2. **Lower fan**-consist of a series of thin, laterally extensive sand beds deposited in broad lobes separated by muds==referred as turbidite deposit

Submarine-fan sequence





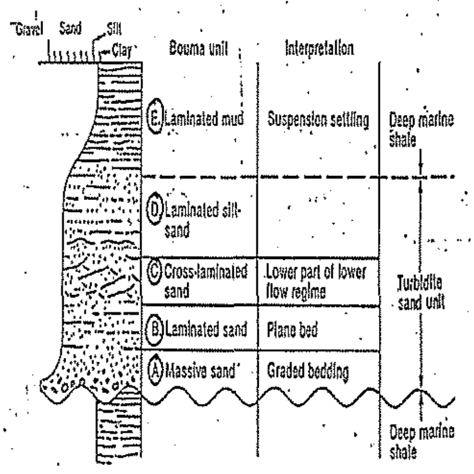
Graded Bedding = Vertical Decrease of Sediment Size



Turbidity Current = PROCESS

= RESPONS

Turbidite

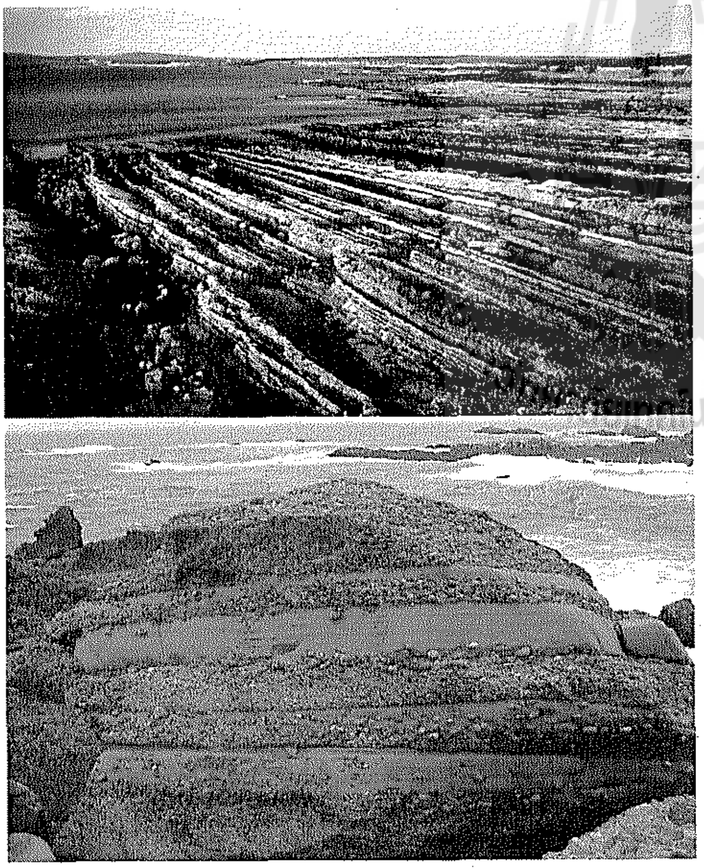


Complete turbidite sequence showing Bouma progression

Finning-upward deposits (coarse to fine grains) that were transported seaward in deep-sea channels and canyons by high-density, sediment laden currents.

The deposit of a turbidity current is called a turbidite

Turbidites



4. Abyssal plain

Abyssal plain - The deep ocean floor.

- Nearly flat.
- Water depths of 3 to 5 km (2 - 3 miles), or more.
- Covered by very fine-grained sediment and shells of microscopic organisms.
    - Clay.
    - Chalk (calcareous limestone)
    - Volcanic ash. (red colors)
    - Foraminifera (calcareous).
    - Radiolarians (siliceous).
    - Diatoms (siliceous).

Pelagic - fine-grained sediments deposited far from land influence by slowly settling particles suspended in the water column.

- ***Red Terrigenous Clay:***
- the abyssal floor is red clay
- Origin from blown dust, meteoritic dust, volcanic ash, and possible clay sized terrigenous material.
- The red colour relate to oxidizing nature of the cold abyssal waters, which are poor in organic material.
- ***Calcareous Oozes:***
- water depths less than 3500 m
- the accumulated skeletons of the floating foraminifera
- Sediments are not found in deeper water, below the carbonate compensation depth, because $CaCO_3$ is undersaturated in these colder deep waters, and the skeletons dissolve.
- ***Siliceous Oozes:***
- deeper 3500 m
- formed by the settling of the silica skeletons of diatoms (aquatic algae) and radiolarian (planktonic protozoan).
- Diatoms occur preferentially in the colder waters of high latitudes.

ตารางที่ II-18 ลักษณะเด่นของ volcaniclastic facies (จาก Tucker, 1982)

Deposition : takes place in subaerial and submarine (shallow or deep) environments by pyroclastic fall-out, volcaniclastic flows such as ignimbrites, lahars and base surges, and reworking and resedimentation by waves, tidal, storm and turbidity currents.

Lithlolgies ; tuffs, lapillistones, agglomerates and breccias.

Textures : diverse, include welding in ignimbrites and matrix-support fabric in lahar deposits.

Structures : include grading in air-fall tuffs, current and wave structures in reworked and redeposited tuffs, planar and cross-bedding in base surge tuffs.

Fossils : do occur although may be rare.

Facies associations : submarine volcaniclastics frequently associated with pillow lavas, cherts and other pelagic sediments.

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ตารางที่ II-14 ลักษณะเด่นของ deeper-marine siliciclastic facies (จาก Tucker, 1982)

Deposition : takes place on submarine slopes, submarine fans and in basins of many types, particularly by turbidity currents, debris flows, contour currents and deposition from suspension.

Lithlolgies : sandstones (often graywacke in composition) and mudrocks; also conglomerates.

Texture : not diagnostic; sandstones often matrix-rich; conglomerates mostly matrix-supported and of debris flow origin.

Structures : in sandstones of turbidity current origin: graded beds (interbedded with hemipelagic mudrocks) wich may show 'Bouma' sequence of structures (Fig.II-13); sole marks common, channels perhaps large-scale, also slump and dewatering structures. Some sandstones may be massive. Mudrocks may be finely laminated.

Fossils : mudrocks chiefly contain pelagic fossils; interbedded sandstones may contain derived shallow water fossils.

Paleocurrents ; variable, may be downslope or along basin axis.

Facies sequences : turbidite successions may show upwards coarsening and thickening of sandstone beds, or upwards fining and thinning.

√ ตารางที่ II-17 ลักษณะเด่นของ deeper-water carbonates and other pelagic facies (จาก Tucker, 1982)

Deposition : takes place in deeper-water epeiric seas, outer shelves and platforms, submarine slopes, in basins of many types and on ridges and banks within basinal areas. Deposition is from suspension and by resedimentation processes.

Lithologies : pelagic limestones are usually fine grained with dominantly pelagic fauna; limestone turbidites are coarser grained and consist largely of shallow water fossils; cherts, phosphorites, iron-manganese nodules and enrichments, hemipelagic mudrocks.

Structures : pelagic limestones: often nodular, hardgrounds common together with sheet cracks and neptunian dykes, stylolites common; turbidite limestones: grade bedding and other structures (sole and internal) as in Fig. II-13 although often less well developed; bedded cherts: may be graded and laminated. Pelagic sediments may be slump folded and brecciated.

Fossils ; pelagic fossils dominate; derived shallow-water fossils in limestone turbidites.

Facies sequences : no typical sequences; pelagic facies may overlie or underlie turbidite successions or follow platform carbonates. Pelagic facies may be associated with volcaniclastic sediments and pillow lavas.

Summary of Marine Sedimentary Environments

	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 Sedimentary Structures	---	Trails, burrows	Trails, burrows	Trails, burrows
Fossils	Corals, marine shells	Marine shells	Marine shells, rare plant fragments	Marine shells (mostly microscopic)

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Sedimentary Depositional Environments

	Depositional Environment	Environmental Characteristics	Organisms	Sediment	Sedimentary Structures	Sedimentary Rocks
non-marine	**river channel**	variable stream current (high- to low-E), water may dry-up, oxidation	land-freshwater plants & critters	gravel, sand, mud; variable sorting & rounding	crossbeds, ripple marks, graded beds, mudcracks, plant & animal fossil fragments	**conglomerate** **sandstone** **mudstone**
	flood plain	floods (low-E), drying, oxidation, soil formation	land-freshwater plants & critters	mud, sand; well-sorted	bedding, ripple marks, graded beds, mudcracks, abundant fossils	**mudstone (red beds)** **sandstone**
	river delta	stream current, tides low-E	land-freshwater plants & critters	sand, mud; well-sorted	bedding, cross beds, ripple marks, graded beds, abundant fossils	**sandstone** **mudstone**
	alluvial fan	periodic flash floods, mudflows high-E	land plants & critters	gravel > sand; poorly-sorted & angular	plant & animal fossil fragments	**sedimentary breccia** **arkose**
	desert dune	variable wind current (high- to low-E), dry, oxidizing	small insects & reptiles; sparse plants	sand; well-sorted & well-rounded	cross beds, ripple marks, trace fossils	**sandstone**
	playa	low-E, high evaporation, floods periodically, dry	small insects, reptiles; few plants	evaporites, mud	mud cracks, ripple marks, trace fossils	**evaporite** **mudstone**
	lake	low-E, shallow-deep standing water	land-freshwater plants & critters	mud, sand, carbonate sediment	bedding, ripple marks, graded beds, abundant fossils	**mudstone** **sandstone** **limestone**
	glacier	ice, bare rock, cold	sparse plants & critters	gravel; angular & poorly sorted	few	**till**
transitional	**beach**	waves (high- to low-E), tides, currents, wind	marine & non-marine critters	gravel, sand, mud, carbonate sediment; well-sorted & well-rounded	ripple marks, crossbeds, abundant fossils & fossil fragments	**conglomerate** **samdstone** **mudstone** **limestone & coquina**
	lagoon	low-E, tides, not very oxidized	marine & non-marine plants & critters	mud	bedding, ripple marks, abundant fossils	**mudstone (green-black, not red)**
marine	**shallow marine**	waves (high- to low-E), tides, strong ocean currents, wind	marine plants & critters	sand, mud, carbonate sediment; well-sorted & well-rounded	bedding, crossbeds, ripple marks, abundant marine fossils	**sandstone** **mudstone** **limestone**
	reef	waves (high- to low-E), tides, strong ocean currents, wind	marine plants & critters	gravel, sand, mud; carbonate sediment; variable sorting	abundant marine fossils	**limestone breccia** **sandstone** **mudstone**
	deep marine	low-E, variable currents	weird marine plants & critters	mud, carbonate & siliceous ooze	abundant marine fossils	**mudstone** **limestone** **chert**

Chapter 4
Sources of information

Purpose:

To analysis sedimentary environments, two types of information are in consideration.

- First is direct source of information such as outcrop, core and cutting.
- Second is indirect source of information such as wire line logging, seismic data and lab data.
    - Cutting
    - Core
    - Wire line logs
    - Seismic

1. Core and cutting

- **Core and drilling cuttings** are normally first examined with:

1. A low-power binocular microscope which will indentify most of the important features of the sample.

2. Petrographic microscope may be used to indentify some pore surface and microscorosity feature.

3. Scanning electron microscope (SEM) can magnify from low power up to magnifications of about 2000X, which enables clay mineral texture, microporosity, and pore coating to be dramatically revealed.

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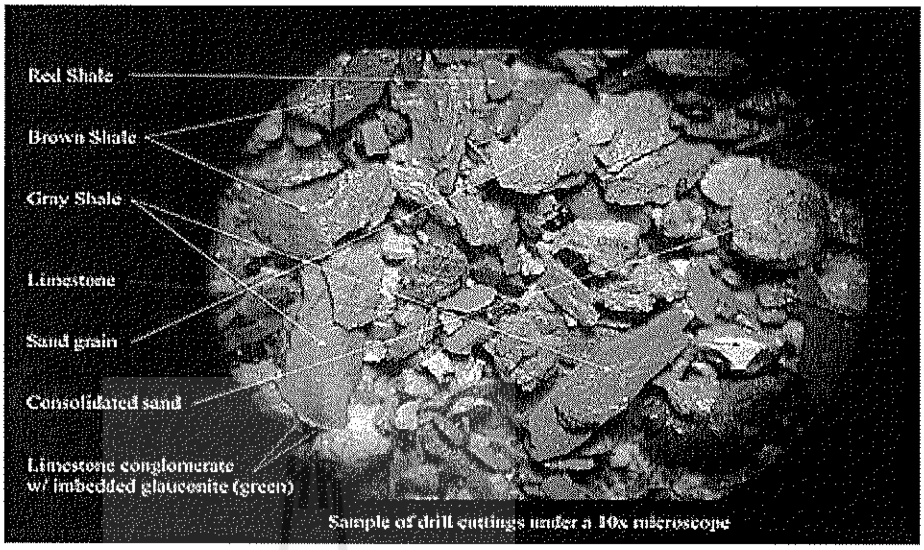
- **Drill Cuttings**
    - **Drill cuttings** refers to any material (typically called **solids**) removed from a borehole while drilling petroleum well.
    - Sand and shale make up the majority of the cuttings

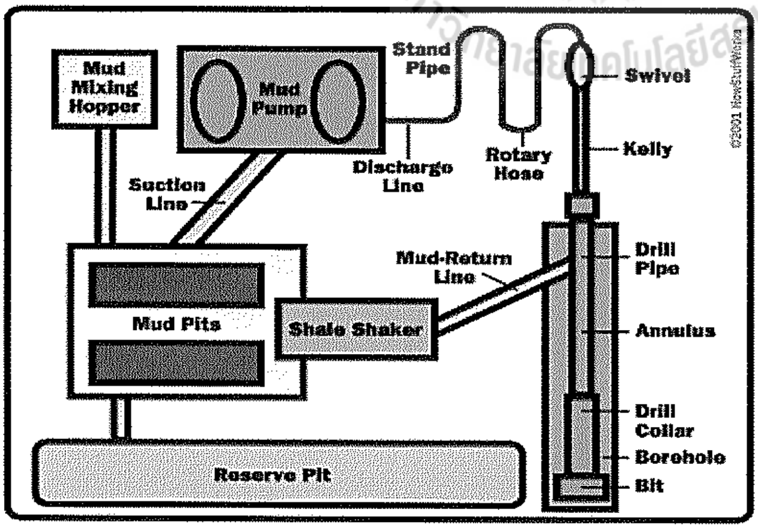
These include but are not limited to: anhydrite, calcite, chalk, chert, clay, dolomite, feldspar, glauconite, granite, gypsum, hematite, iron, kaolinite, lime, marlstone, mica, mudstone, pisolite, pyrite, quartz, sandstone, silica, silt and sulfur.

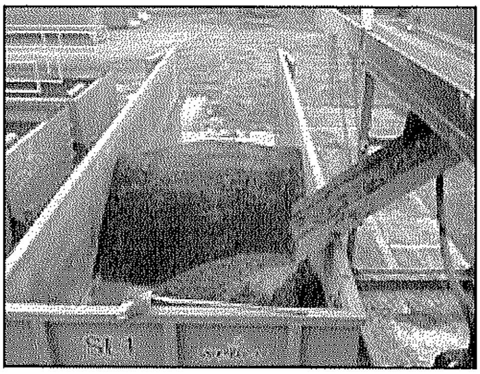
Sample of drill cutting



Why drilling cutting?

1. Drill cutting are the first and most obvious source of information obtained from the formation being drilled.
2. Drill cuttings are usually removed by circulating the drilling fluid over shale shakers
3. Cutting may reveal the first physical evidence of oil or gas.
4. Cutting can be indicator of increased pore pressure and can reveal formation.

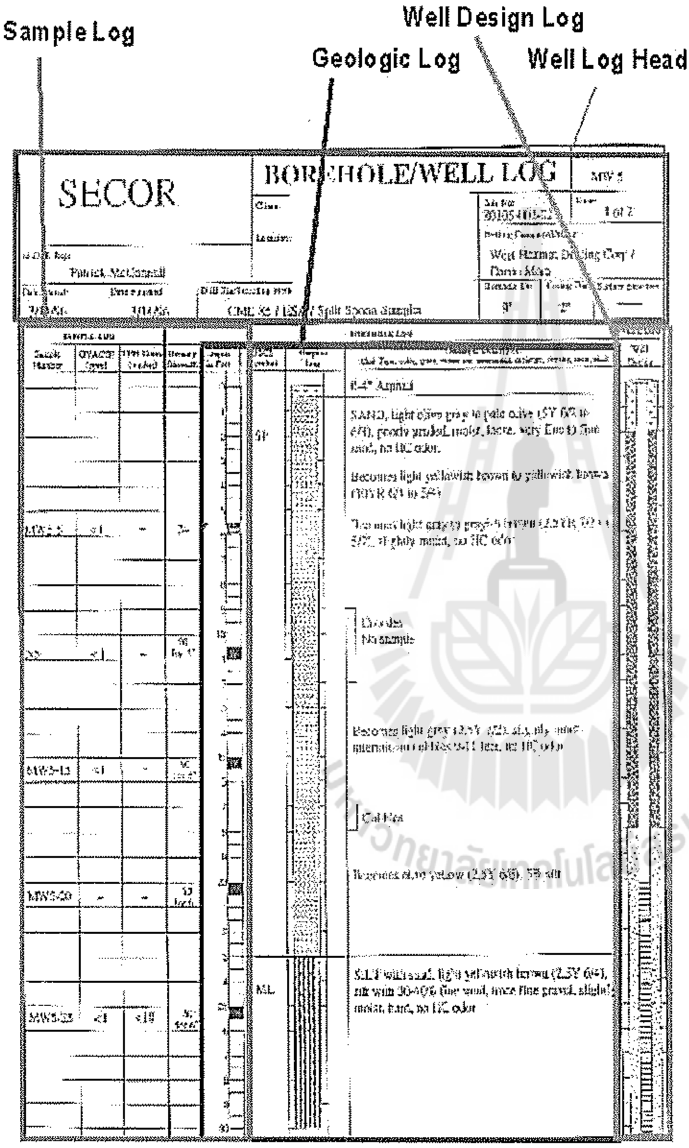




Drill cuttings are usually removed by circulating the drilling fluid over shale shakers

Cutting Log Type

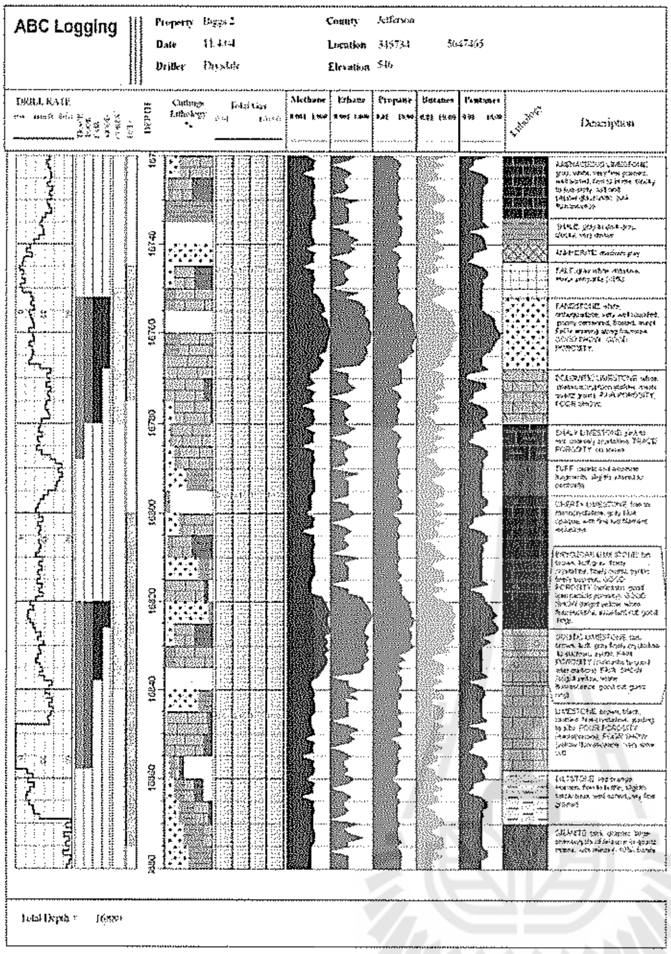
1. **Sample log:** show formation boundary & lithology (Description+symbols)
2. **Mud log:** a graphical representation of the **ROP** (**R**ate **O**f **P**enetration), **lithology, hydrocarbons** and other drilling parameters generated while drilling a petroleum well.



Sample Log

- Formation boundary
- Lithology

(Description+symbols)



Mud Log

Rate Of Penetration (ROP): Drill Rate

Lithology (Description+ Symbol)

Hydrocarbon: Gas & Oil show

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CORING METHODS

The rock samples are obtained by cutting a piece of rock from the well bore; the process is called ***Coring***.

Important elements in a reservoir description

- Porosity
- Permeability
- Grain density
- Mineralogy

: By estimate of these properties from **Well logs or Rock samples** can be done in the **laboratory.**

Core Type

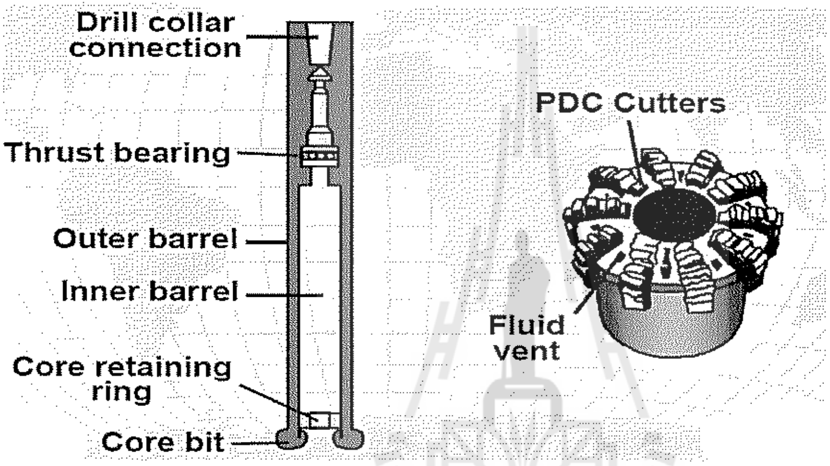
1. Conventional Cores are cut using a specialized subassembly at the bottom of the drill string.

: This consists of a **coring drill bit** (usually a diamond bit), **a core barrel** to hold the recovered core

2. Sidewall Cores used to cut samples measuring 15/16 in x 1 ¾ in. from the formation.

: Sidewall **core gun** or a sidewall **rotary coring** tool. The sidewall core gun uses black powder explosives to fire a steel bullet into the rock adjacent to the tool.

1. Conventional Cores



Coring assembly on bottom of drill string and coring bit

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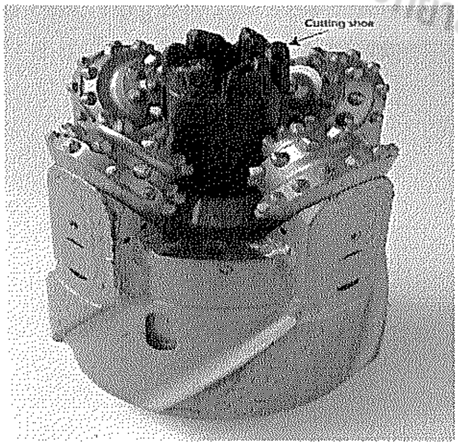
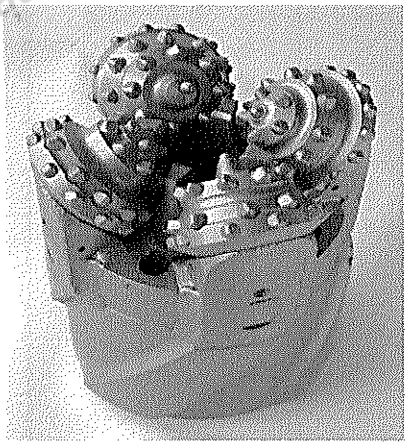
Drilling Core Barrels



Extended Core Barrel

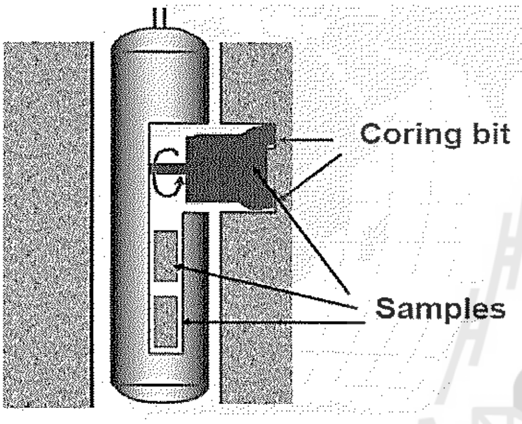


RCB Roller Cone Barrel

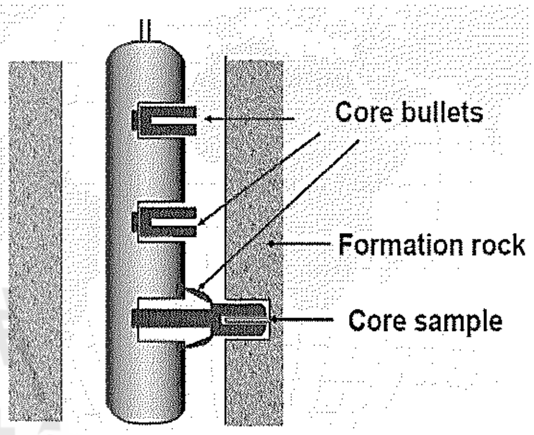
How it is physically accomplished

1. Coring assembly is run on the bottom of the drilling assembly.
2. Weight is applied to the core bit and the drillstring is rotated.
3. Doughnut is cut by the core bit
4. Core is swallowed by the core barrel.

2. Sidewall Cores



1. Rotary core drill on wireline



2. Sidewall core gun with steel bullets

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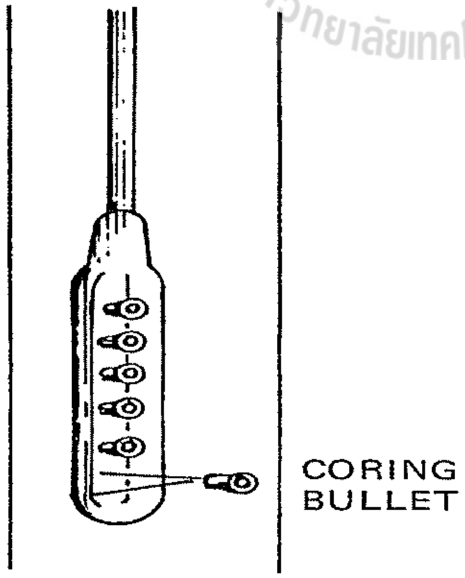
Sidewall Core gun



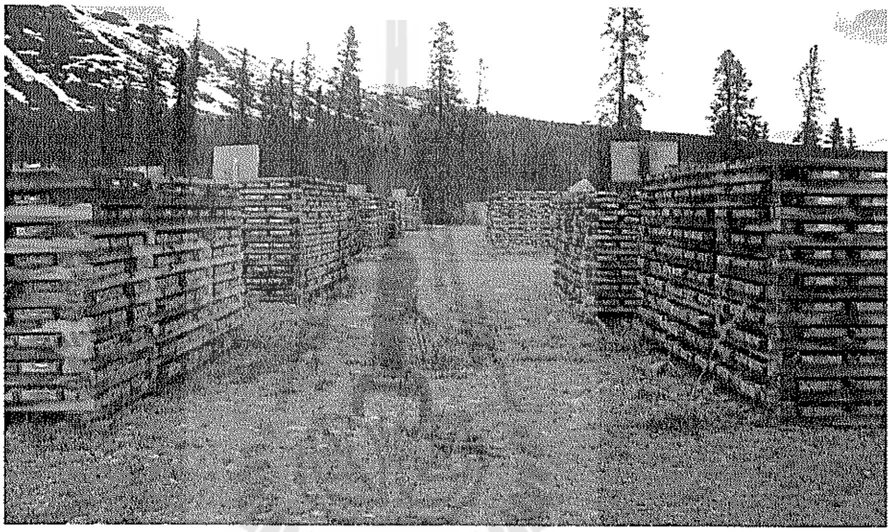
The sidewall core gun uses black powder explosives to fire a steel bullet into the rock.

Why sidewall cores?

1. Much **cheaper** than conventional cores
2. Core after drilling through the formations and have run electric logs
3. You do not core in zones where core data is not needed.
4. You can selectively retrieve formation samples.

Storage and transport

- Most cores are analyzed on the rig, then the cores are transported to land.
- Cores are then available for additional study by personnel or by other interested parties.



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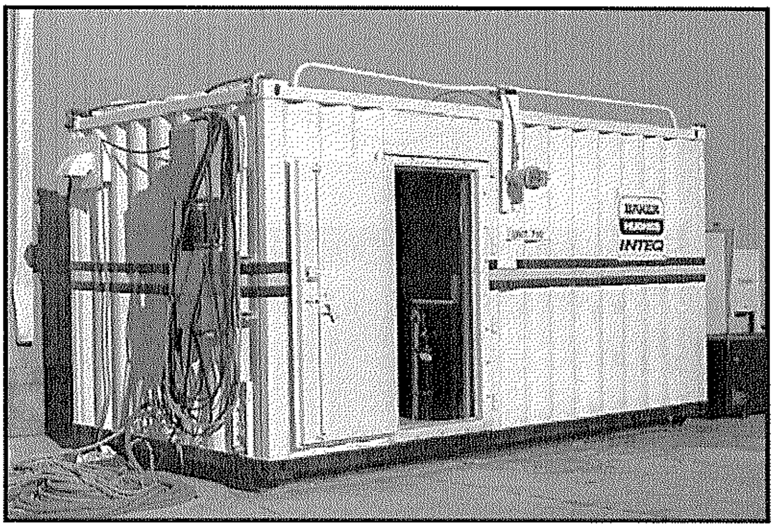
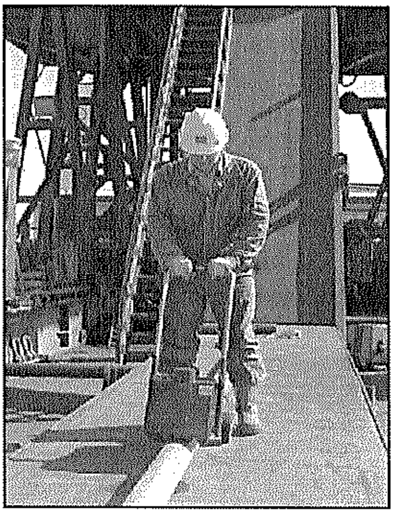
Wellsite Core Evaluation

- Furnish quick preliminary evaluation of core samples
- Cut and preserve core samples for detailed laboratory analysis.





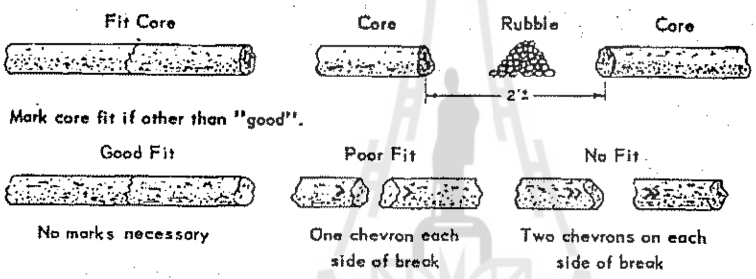
The GammaTrak system logs the recovered core on the laydown table

Why protect the cores

- Altered permeability
- Altered porosity
- Altered fluid content and saturations

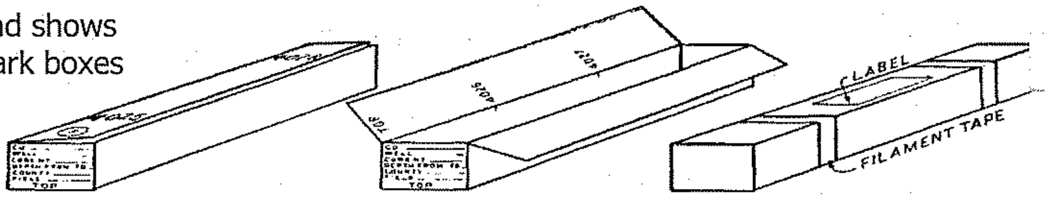
Core Handling Procedures

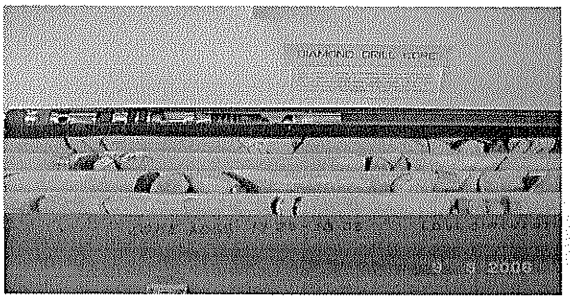
1. Prepare adequate number of boxes. Have rags
2. Set up joints of drill pipe, as required to lay out core
3. Supervise core lay-out to insure correct orientation and order
4. Wipe core clean, with clean dry rags. DO NOT WASH.
5. Fit core. Space rubble between ends of core. Then record depth.

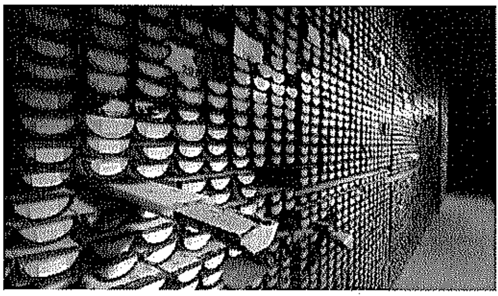


6. Strap core. The unrecovered interval
7. Scribe core with reference lines and depth, using marker pens and straight edge: Black line always to the right; Red line always to the left

8. Describe core and shows
9. Box core and mark boxes







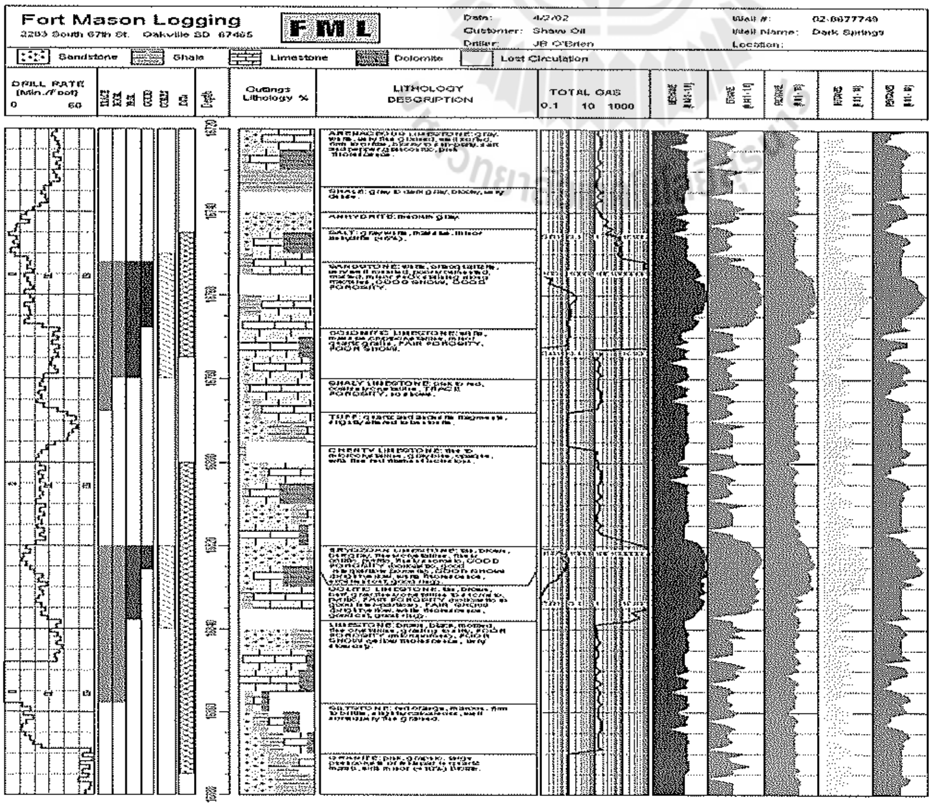
Basic logging form (refer handout)

Logging requirements apply generally to logging of rock

- Dates of drilling
- Drilling method
- Drilling machine make & model
- Drilling fluid type & amount
- Depth and type of casing
- Zones of severe core loss
- Problems that necessitated casing
- Fluid losses
- Bad drilling zones
- Zones of severe bit wear
- Groundwater levels & dates measured

Rock Core Logs

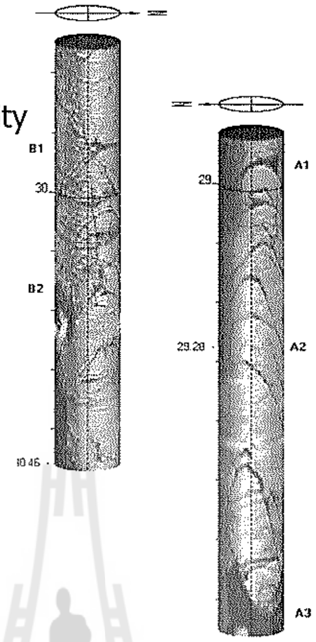
- To record all relevant information about the core and to make a field description
- Contains:
  - Percent core recovery
  - Amount and location of core loss
  - Depth of the beginning and ending of each core run

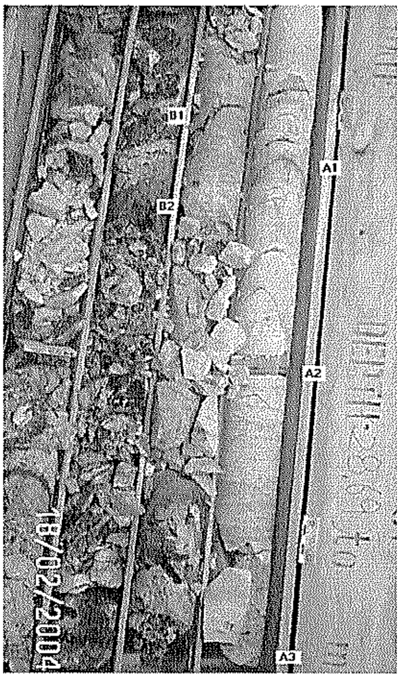


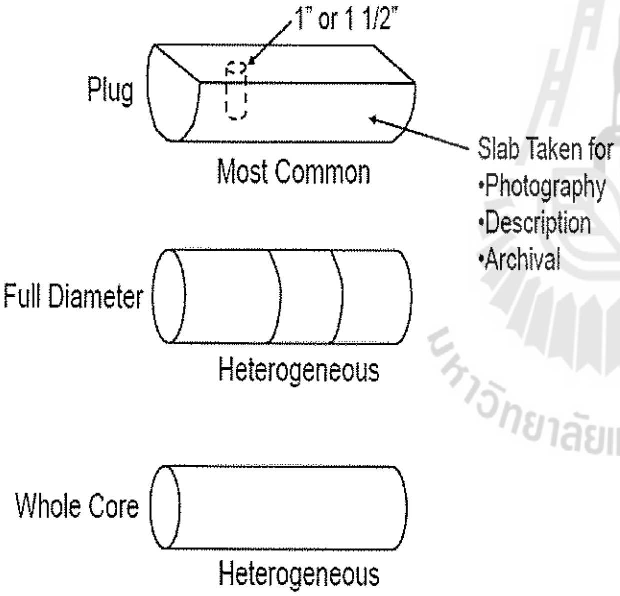
SAMPLE CORE ANALYSIS REPORT

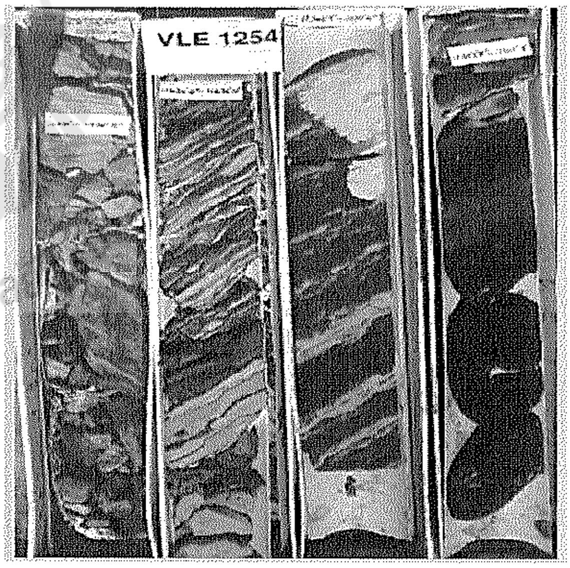
Laboratory Core Analysis

- Porosity
- Fluid content and saturation
- Permeability, relative permeability
- Chemical composition
- Particle size distribution
- Rock strength









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Core slab, core plug, full diameter,

Core photo of slabbed core

and whole core definition

Sample Description
From Cutting & Cores

Order of written Description

Required a standardized order of description:

1) Reduces the chance of not recording all important properties
2) Increase the uniformity of description among geologists
3) Saves time in obtaining specific information from description

Handling Procedures

The following order is used:

1. Rock type or lithology-underlined and followed by classification
2. Color
3. Texture-including grain size, roundness, and sorting
4. Cement and matrix material
5. Fossil and accessories
6. Sedimentary structure
7. Porosity and permeability
8. Hydrocarbon show

1. Rock Type or Lithology

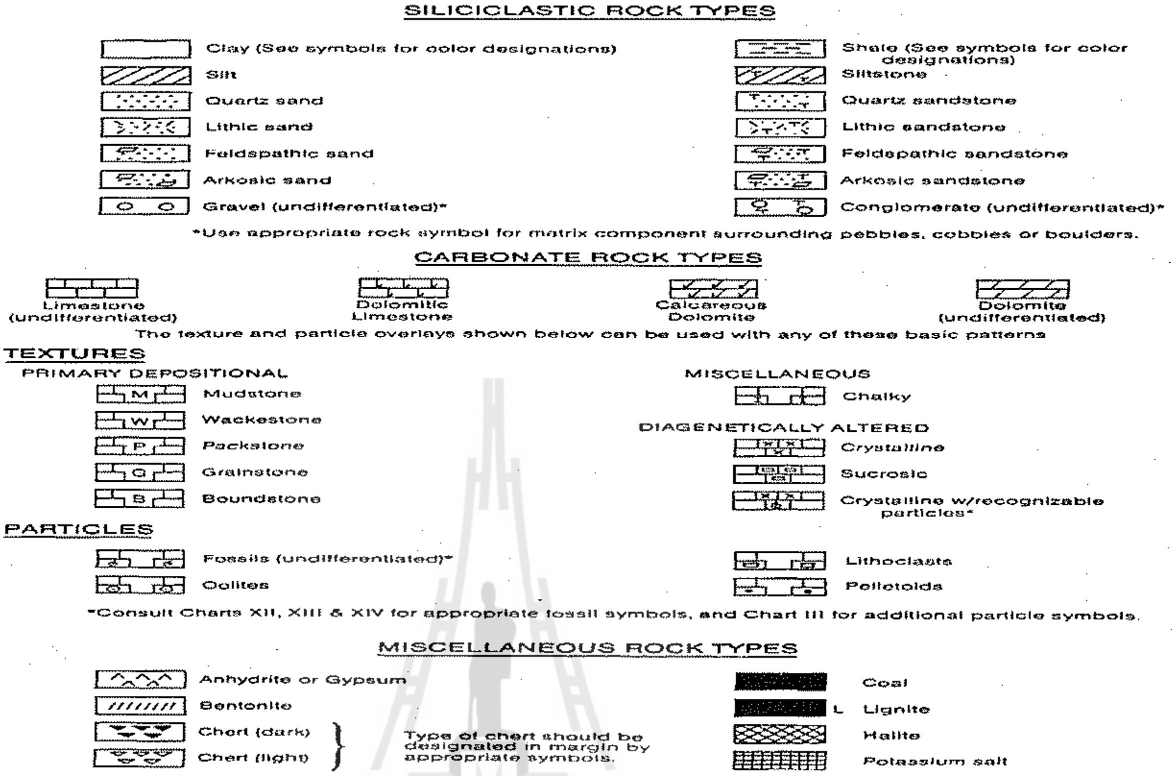
Rock type can be classify into two types:

1. **The basic rock name:** rock name that has underline, such as Sandstone, Dolomite, Limestone, Shale, Conlomerate,etc.

2. **The proper composition:** describe to textural of rock, such as Lithic, Oolitic, Grainstone, Calcareouse, Sandy, Silty, Coaly, Dolomite etc.

Chart XIX: Black and White Lithologic Symbols

To be used for Stratigraphic Columnar and Cross Sections



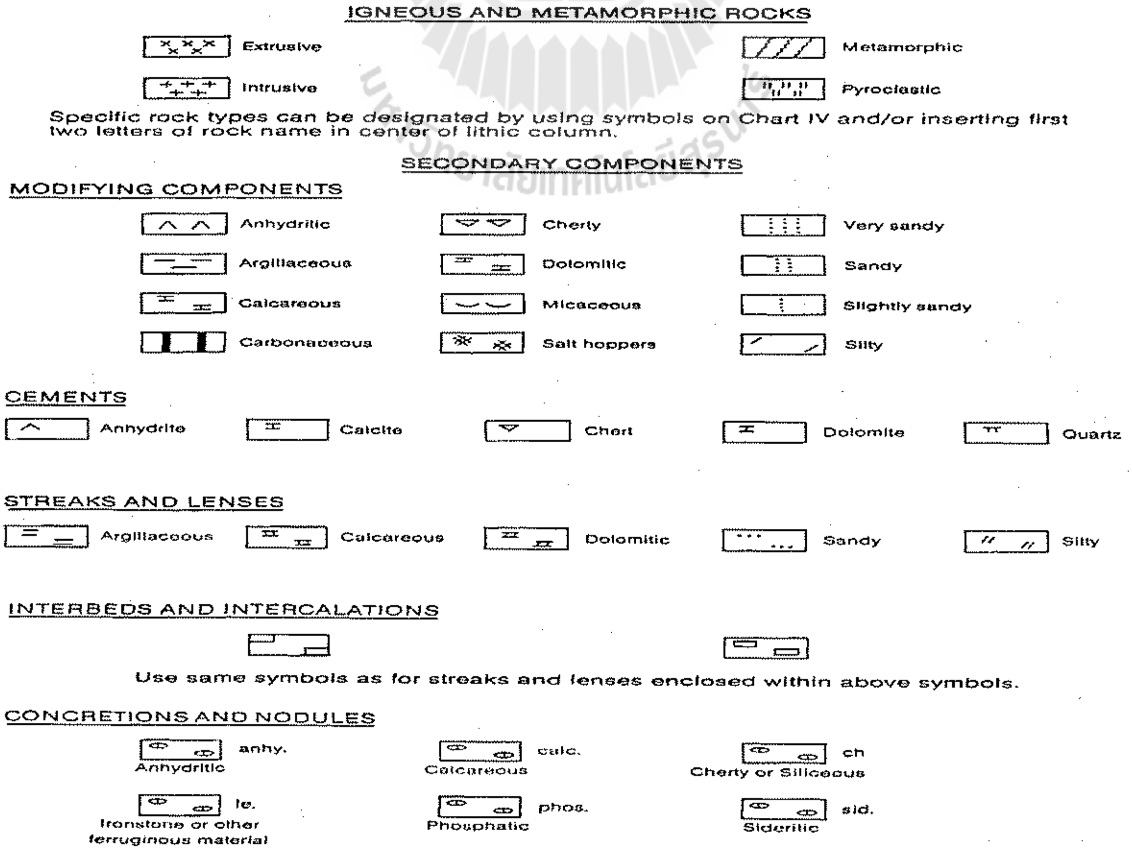
*Use appropriate rock symbol for matrix component surrounding pebbles, cobbles or boulders.

The texture and particle overlays shown below can be used with any of these basic patterns

*Consult Charts XII, XIII & XIV for appropriate fossil symbols, and Chart III for additional particle symbols.

Type of chert should be designated in margin by appropriate symbols.

Chart XX: Black and White Lithologic Symbols



Specific rock types can be designated by using symbols on Chart IV and/or inserting first two letters of rock name in center of lithic column.

Use same symbols as for streaks and lenses enclosed within above symbols.

2. Color

- **Red, Brown colors:** Ferric iron indicate to an oxidizing environment
- **Green blueyish gray:** Ferric iron indicate to a reducing environment
- **Dark brown, Black colors:** organic matter indicate to a potential petroleum source
- **Black color** of sulfides indicate to anaerobic environment conductive to the production of hydrocarbon

Common use of Color

Color	
Buff (สีเนื้อ, เหลืองอ่อน)	Olive
Black	Pink
Blue	Purple
Brown	Red
Grey	Tan

Extension of color

- Dark
- Light
- Moderate, Medium
- Mottled (รอยแต้มสี)
- Variegated (สลับสีสลับลาย)

3. Texture

3.1 Grain or crystal size: size grades and sorting
3.2 Shape: used to decipher the history of deposit
3.3 Sorting
3.4 Composition
3.5 Hardness
3.5 Luster

3.1 Grain or Crystal Size

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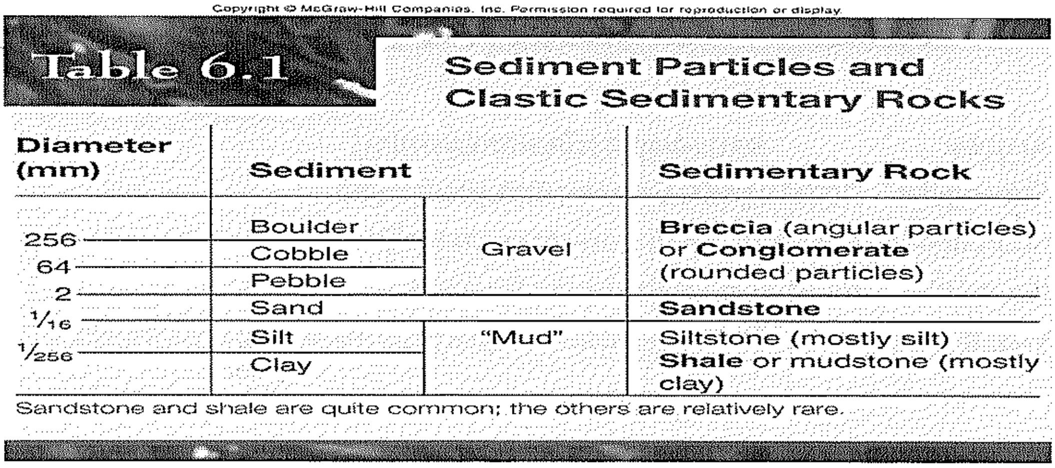

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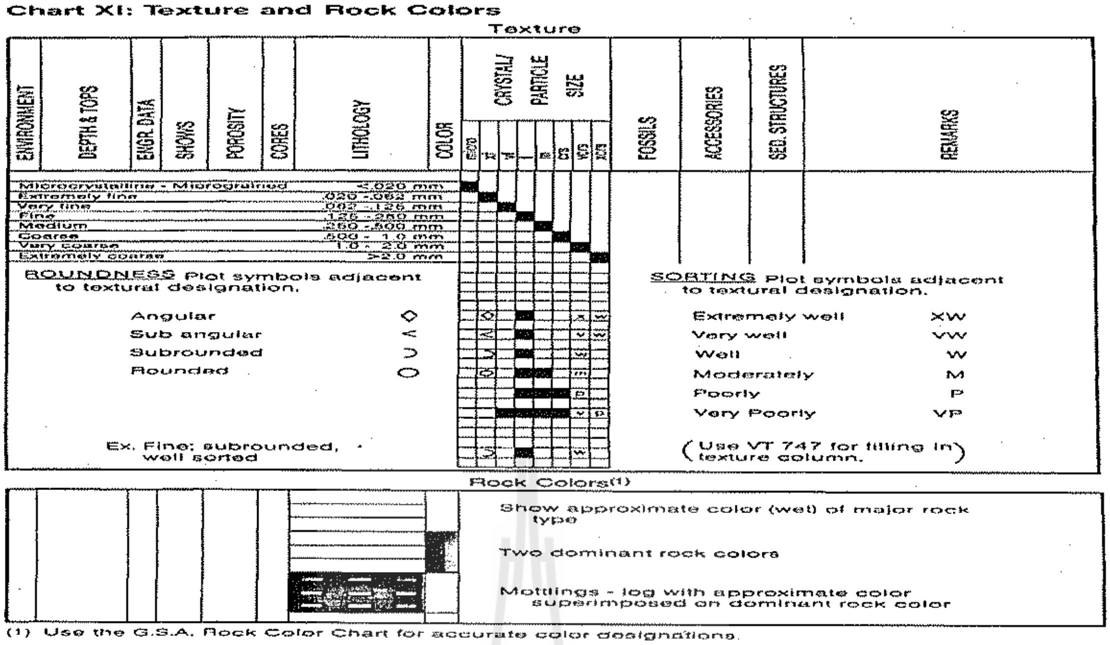
Table 6.1 Sediment Particles and Clastic Sedimentary Rocks

Diameter (mm)	Sediment		Sedimentary Rock
256	Boulder	Gravel	**Breccia** (angular particles) or **Conglomerate** (rounded particles)
64	Cobble		
2	Pebble		
1/16	Sand		**Sandstone**
1/256	Silt	"Mud"	Siltstone (mostly silt)
	Clay		**Shale** or mudstone (mostly clay)

Sandstone and shale are quite common; the others are relatively rare.

Chart XI: Texture and Rock Colors



Microcrystalline - Micrograined	<.020 mm
Extremely fine	.020 - .062 mm
Very fine	.062 - .125 mm
Fine	.125 - .250 mm
Medium	.250 - .500 mm
Coarse	.500 - 1.0 mm
Very coarse	1.0 - 2.0 mm
Extremely coarse	>2.0 mm

ROUNDNESS Plot symbols adjacent to textural designation.

Angular	◇
Sub angular	<
Subrounded	⊃
Rounded	○

Ex. Fine; subrounded, well sorted

SORTING Plot symbols adjacent to textural designation.

Extremely well	XW
Very well	VW
Well	W
Moderately	M
Poorly	P
Very Poorly	VP

(Use VT 747 for filling in texture column.)

Rock Colors(1)

Show approximate color (wet) of major rock type

Two dominant rock colors

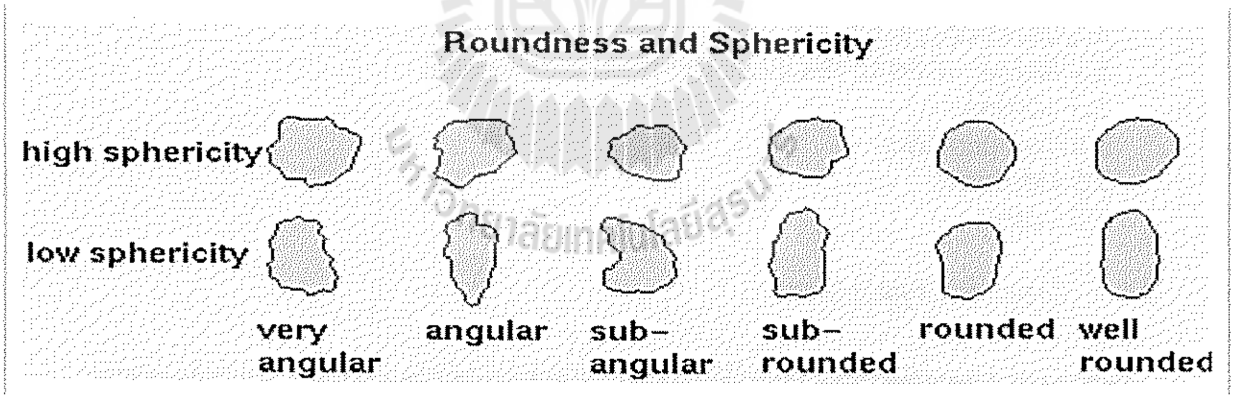
Mottlings - log with approximate color superimposed on dominant rock color

(1) Use the G.S.A. Rock Color Chart for accurate color designations.

3.2 Shape

Sphericity: refers to shape of grain.

Roundness: refers to the roughness of surface



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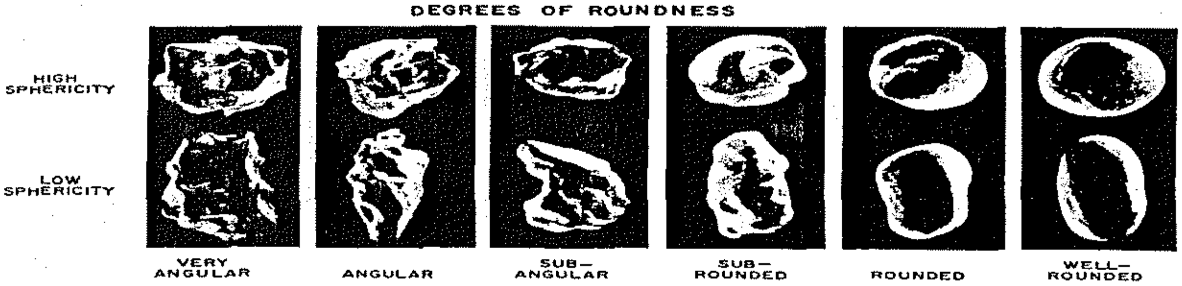
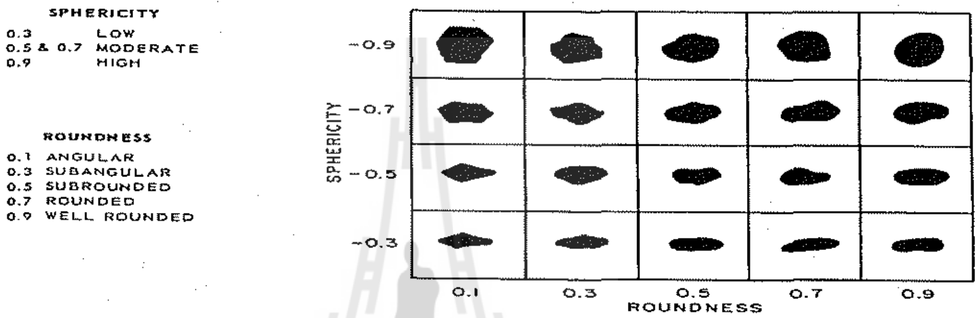
- Angular ขอบและมุมยังเป็นหยักและคมอยู่
- Subangular ผิวยังไม่ถูกขัด ขอบและมุมมนเข้ามาหน่อย
- Subrounded ผิวถูกขัดบางส่วน ขอบและมุมมนและโค้ง
- Rounded ผิวเดิมถูกขัดเกือบหมดยกเว้นบางส่วน
- Well Rounded ไม่มีผิวเดิมเหลืออยู่เลยเพราะถูกขัดจนมนและกลมหมดแล้ว

12.7 Roundness and Spericity:

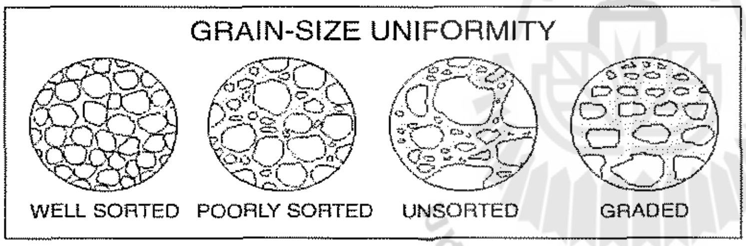
Roundness refers to the roughness of the surface; Sphericity refers to the shape of the grain. These parameters can be expressed by words or by numerical values as shown in the two charts below.

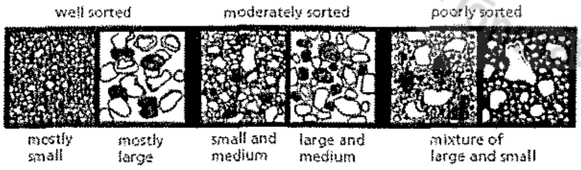


(from Powers, 1953)

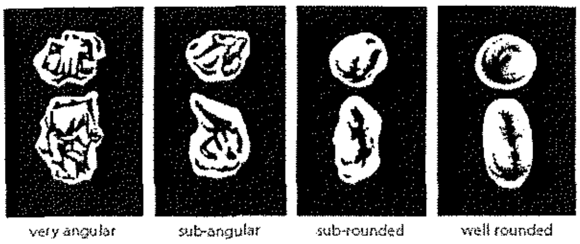


3.2 Sorting

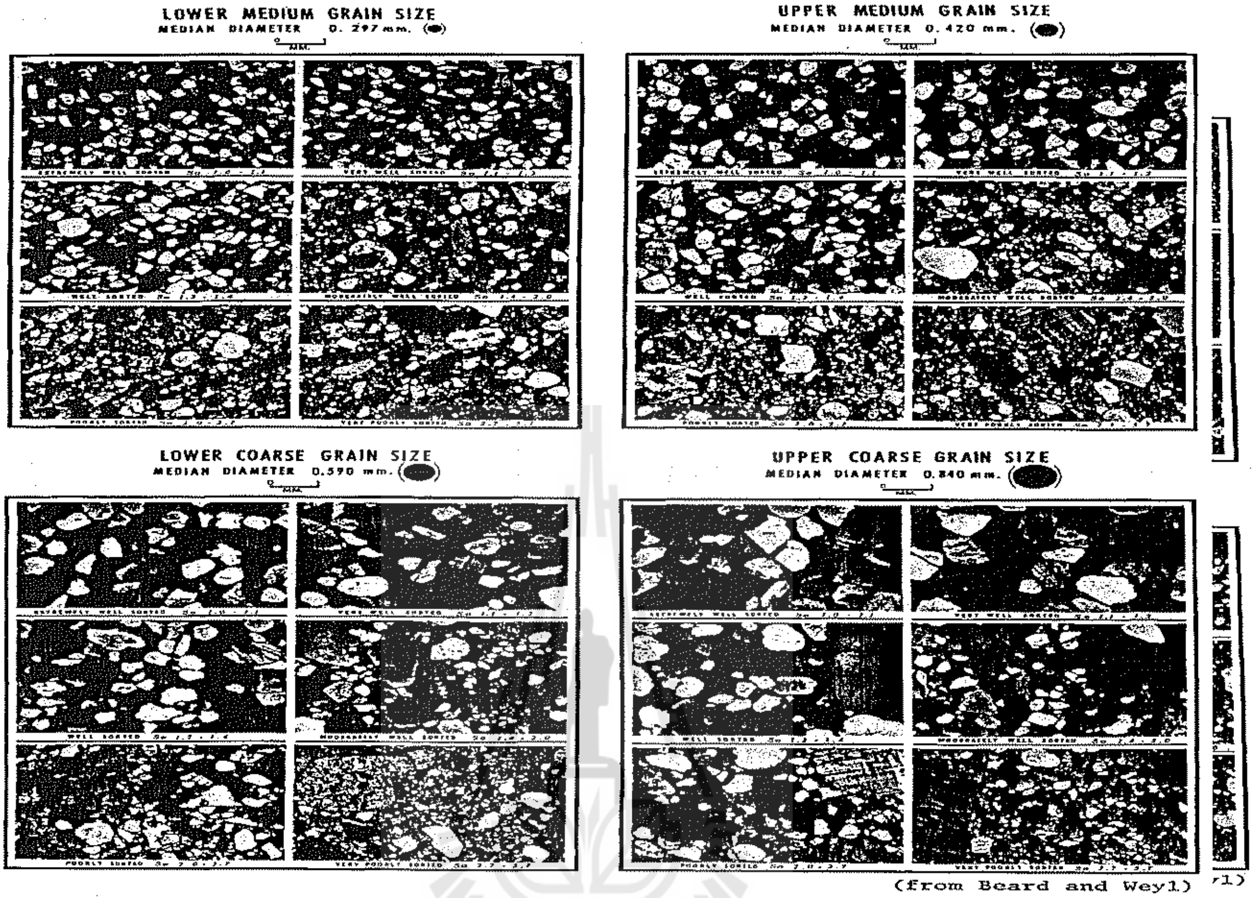




- Good: 90% in 1 or 2 size classes
- Fair: 90% in 3 or 4 size classes
- Poor: 90% in 5 or more size classes



12.51 GRAIN SIZE AND SORTING COMPARATORS (Photomicrographs of Thin Sections)



(From Beard and Weyl)

rd. Red algae gn. Green algae

5. Fossils and Accessories

- **Fossil:** Foraminifera, Ostracod, Bryozoa, Gastropods, Coral, Algae, Crinoid, Braciopod.
  - Abandant: fossils > 25%
  - Common: fossils >10-25%
  - Rare: fossils > 0-10%
- **Accessories:** glauconite, pyrite, mica, feldspar, chert, calcite, siderite, heavy minerals and sand-size rock fragments
  - Anhedral รูปผลึกไม่มีให้เห็นเลย
  - Subhedral รูปผลึกมีให้เห็นบ้าง
  - Euhedral รูปผลึกค่อนข้างสมบูรณ์

XIV & XV except:

Ash or Tuff Chlorite Quartz crystals Siderite grains

CHERTS

Transparent

bl gy Use appropriate chert symbol followed by abbreviation of color.

mica indicated by abbreviation of mineral

cal.

TEXTURES — Same as on Chart X & XI.

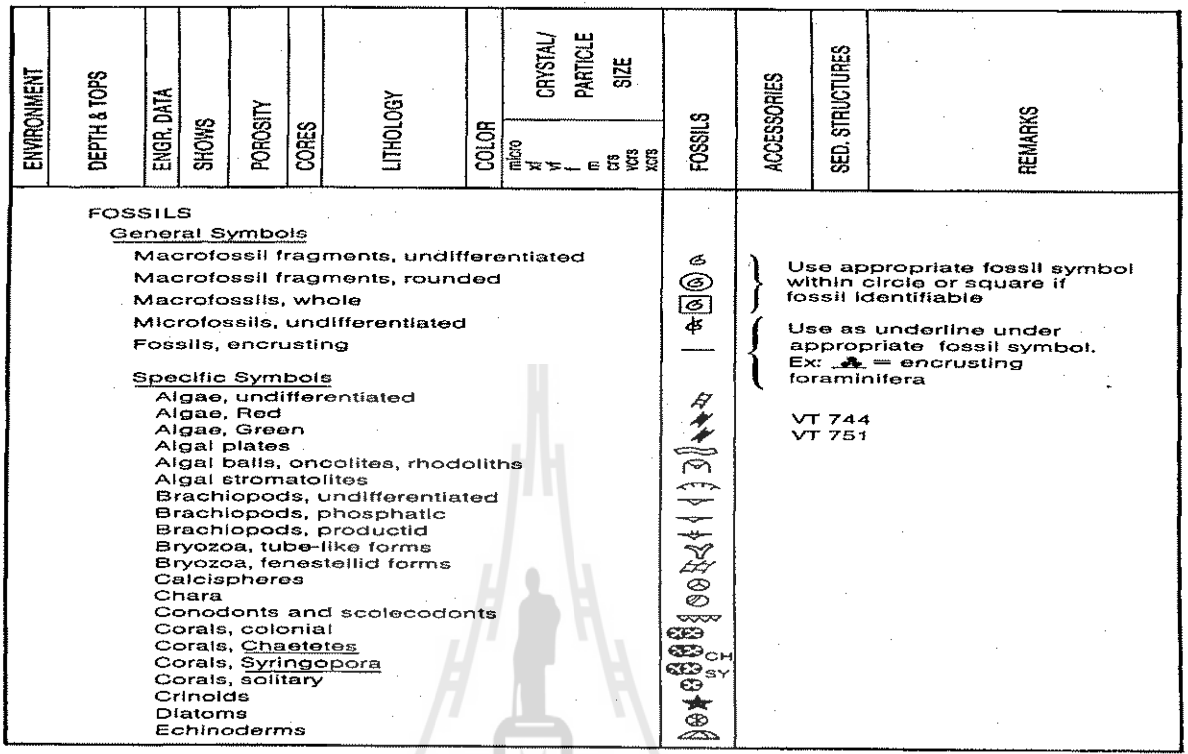
STRUCTURES — Same as on Chart XVI, XVII & XVIII

OIL SHOWS — Same as on Chart VIII except all symbols in black.

Poor oil stain Good to excellent oil stain Dead oil stain

ENGINEER — Same as on symbols in black.

Chart XII: Fossils(1) & (2)



ENVIRONMENT | DEPTH & TOPS | ENGR. DATA | SHOWS | POROSITY | CORES | LITHOLOGY | COLOR | CRYSTAL/ PARTICLE SIZE (micro, xf, vf, f, m, crs, vcrs, xcrs) | FOSSILS | ACCESSORIES | SED. STRUCTURES | REMARKS

FOSSILS

General Symbols

- Macrofossil fragments, undifferentiated
- Macrofossil fragments, rounded
- Macrofossils, whole
- Microfossils, undifferentiated
- Fossils, encrusting

Use appropriate fossil symbol within circle or square if fossil identifiable

Use as underline under appropriate fossil symbol. Ex: = encrusting foraminifera

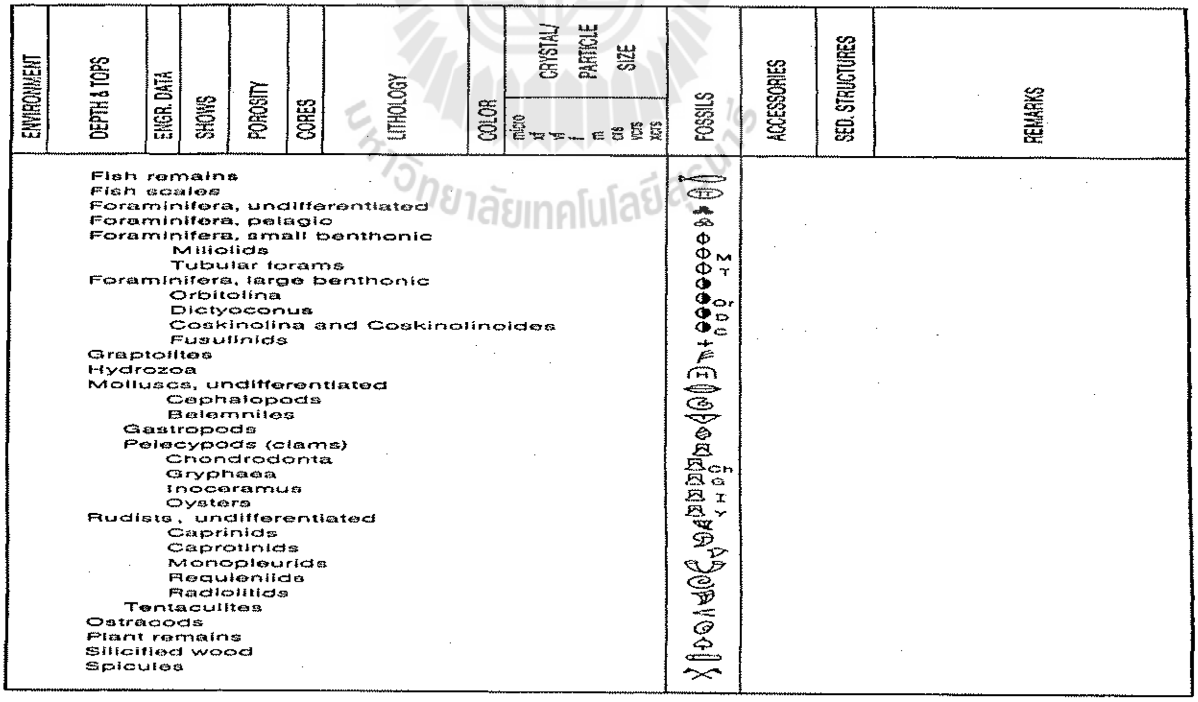
Specific Symbols

- Algae, undifferentiated
- Algae, Red
- Algae, Green
- Algal plates
- Algal balls, oncolites, rhodoliths
- Algal stromatolites
- Brachiopods, undifferentiated
- Brachiopods, phosphatic
- Brachiopods, productid
- Bryozoa, tube-like forms
- Bryozoa, fenestellid forms
- Calcispheres
- Chara
- Conodonts and scolecodonts
- Corals, colonial
- Corals, Chaetetes
- Corals, Syringopora
- Corals, solitary
- Crinoids
- Diatoms
- Echinoderms

VT 744
VT 751

(1) Relative abundance is indicated by dots over symbols
No dot — 0-10% To be used over fossil symbols

Chart XIII: Fossils, continued



ENVIRONMENT | DEPTH & TOPS | ENGR. DATA | SHOWS | POROSITY | CORES | LITHOLOGY | COLOR | CRYSTAL/ PARTICLE SIZE (micro, xf, vf, f, m, crs, vcrs, xcrs) | FOSSILS | ACCESSORIES | SED. STRUCTURES | REMARKS

- Fish remains
- Fish scales
- Foraminifera, undifferentiated
- Foraminifera, pelagic
- Foraminifera, small benthonic
  - Miliolids
  - Tubular forams
- Foraminifera, large benthonic
  - Orbitolina
  - Dictyoconus
  - Coskinolina and Coskinolinoides
  - Fusulinids
- Graptolites
- Hydrozoa
- Molluscs, undifferentiated
  - Cephalopods
  - Belemnites
  - Gastropods
  - Pelecypods (clams)
    - Chondrodonta
    - Gryphaea
    - Inoceramus
    - Oysters
- Rudists , undifferentiated
  - Caprinids
  - Caprotinids
  - Monopleurids
  - Requienids
  - Radiolitids
  - Tentaculites
- Ostracods
- Plant remains
- Silicified wood
- Spicules

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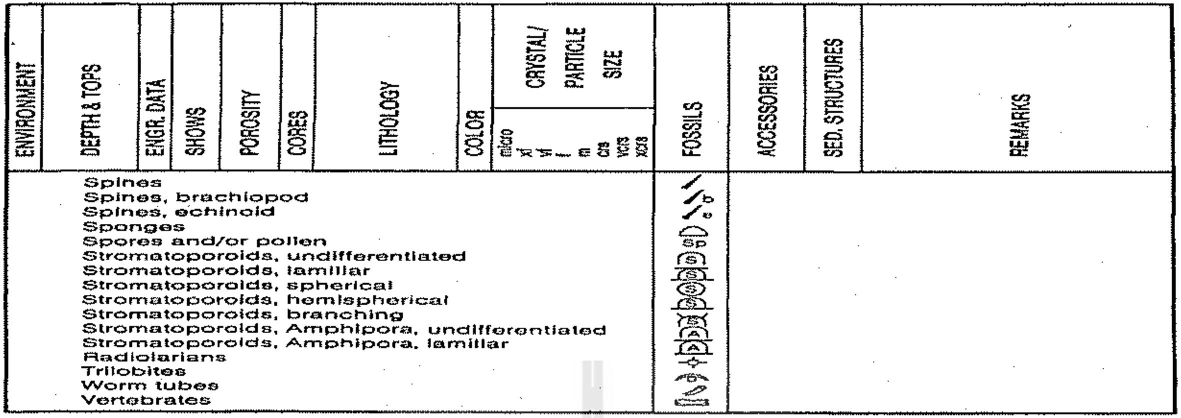
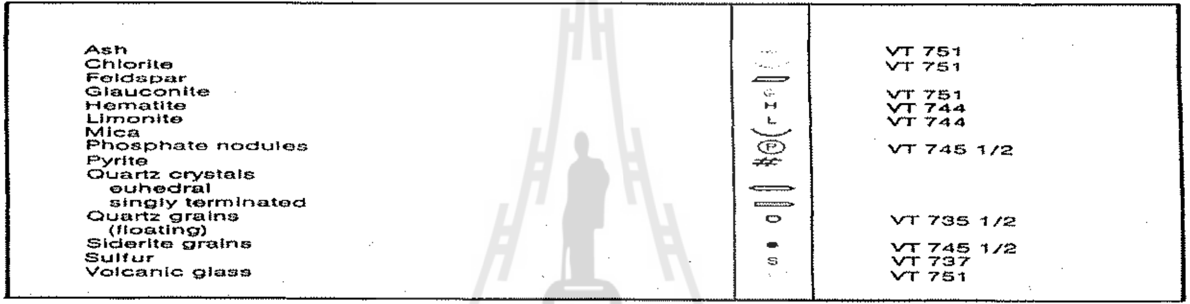
Chart XIV: Fossils, continued; and Accessories

Fossils



- Spines
- Spines, brachiopod
- Spines, echinoid
- Sponges
- Spores and/or pollen
- Stromatoporoids, undifferentiated
- Stromatoporoids, lamillar
- Stromatoporoids, spherical
- Stromatoporoids, hemispherical
- Stromatoporoids, branching
- Stromatoporoids, Amphipora, undifferentiated
- Stromatoporoids, Amphipora, lamillar
- Radiolarians
- Trilobites
- Worm tubes
- Vertebrates

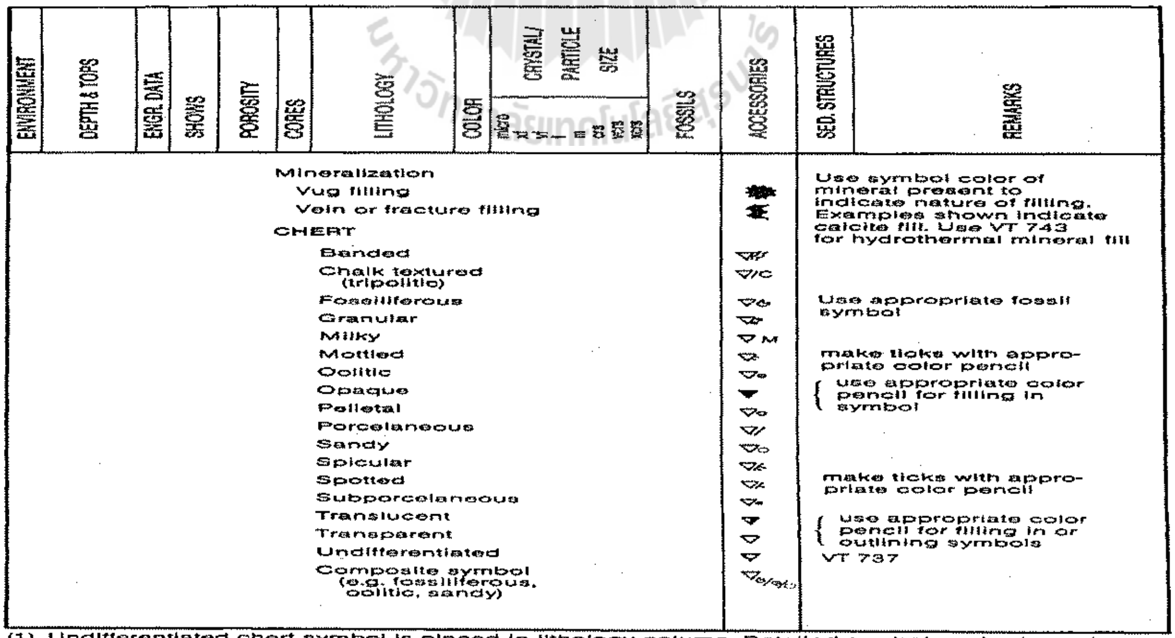
Accessories(1) & (2)



Ash	VT 751
Chlorite	VT 751
Feldspar	
Glauconite	VT 751
Hematite	VT 744
Limonite	VT 744
Mica	
Phosphate nodules	VT 745 1/2
Pyrite	
Quartz crystals	
euhedral	
singly terminated	
Quartz grains (floating)	VT 735 1/2
Siderite grains	VT 745 1/2
Sulfur	VT 737
Volcanic glass	VT 751

(1) Relative abundance is indicated by dots over symbols (see Chart XII)
(2) Any of these symbols can be used as overlays in the lithic column if they represent a major rock constituent.

Chart XV: (Accessories) Chert(1), (2) & (3)



Mineralization	
Vug filling	Use symbol color of mineral present to indicate nature of filling. Examples shown indicate calcite fill. Use VT 743 for hydrothermal mineral fill
Vein or fracture filling	
CHERT	
Banded	
Chalk textured (tripolitic)	
Fossiliferous	Use appropriate fossil symbol
Granular	
Milky	
Mottled	make ticks with appropriate color pencil
Oolitic	
Opaque	{ use appropriate color pencil for filling in symbol
Pelletal	
Porcelaneous	
Sandy	
Spicular	
Spotted	make ticks with appropriate color pencil
Subporcelaneous	
Translucent	{ use appropriate color pencil for filling in or outlining symbols
Transparent	
Undifferentiated	VT 737
Composite symbol (e.g. fossiliferous, oolitic, sandy)	

(1) Undifferentiated chert symbol is placed in lithology column. Detailed symbology is shown in accessory column.
(2) Chert symbols should be made with colored pencil approximating the color of the chert. White chert symbol should be colored light blue (VT 741 1/2).
(3) Relative abundance is indicated by dots over symbols (see Chart XII).

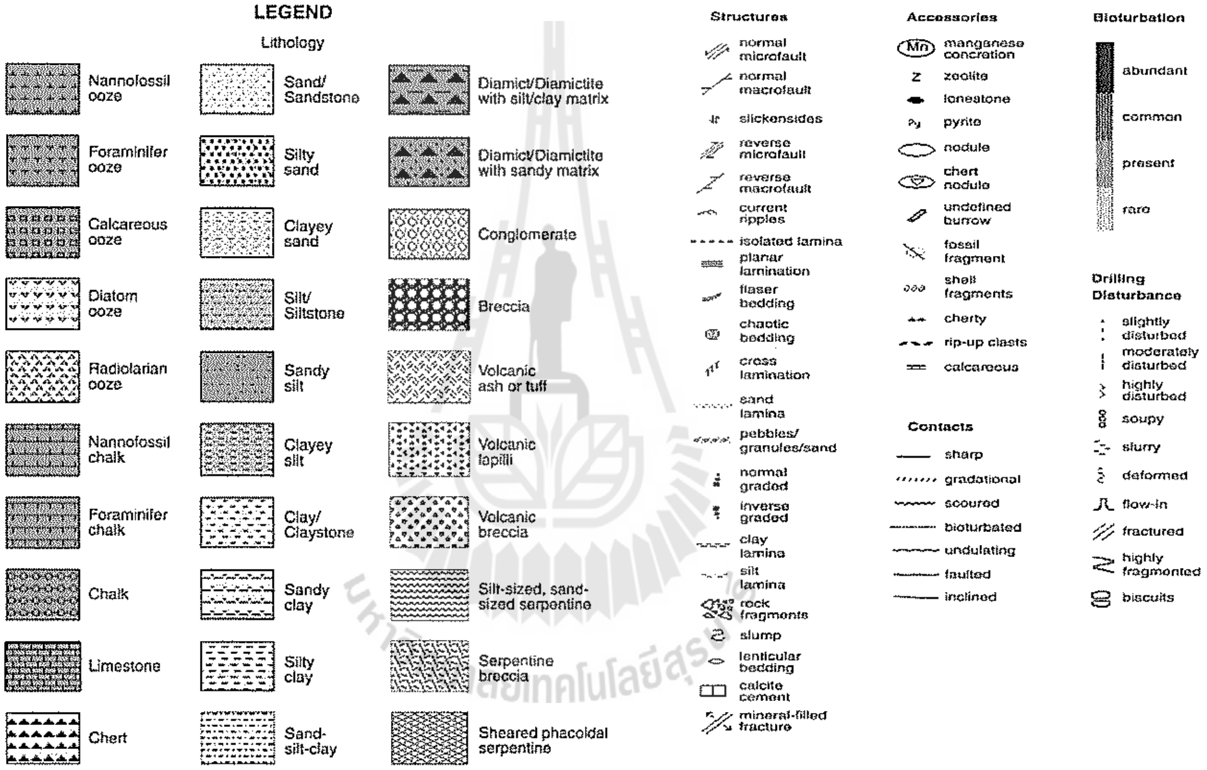
6. Sedimentary structure

- Structure can not found in cutting but it can found in any core
- Structures related to statification
- The origin can be divide into 2 deposition:

6.1 Syngenetic (formed during with deposition): very important environmental deposition indicator

6.2 Epigenetic (formed after deposition and burial)

Common symbols



7. Porosity and Permeability

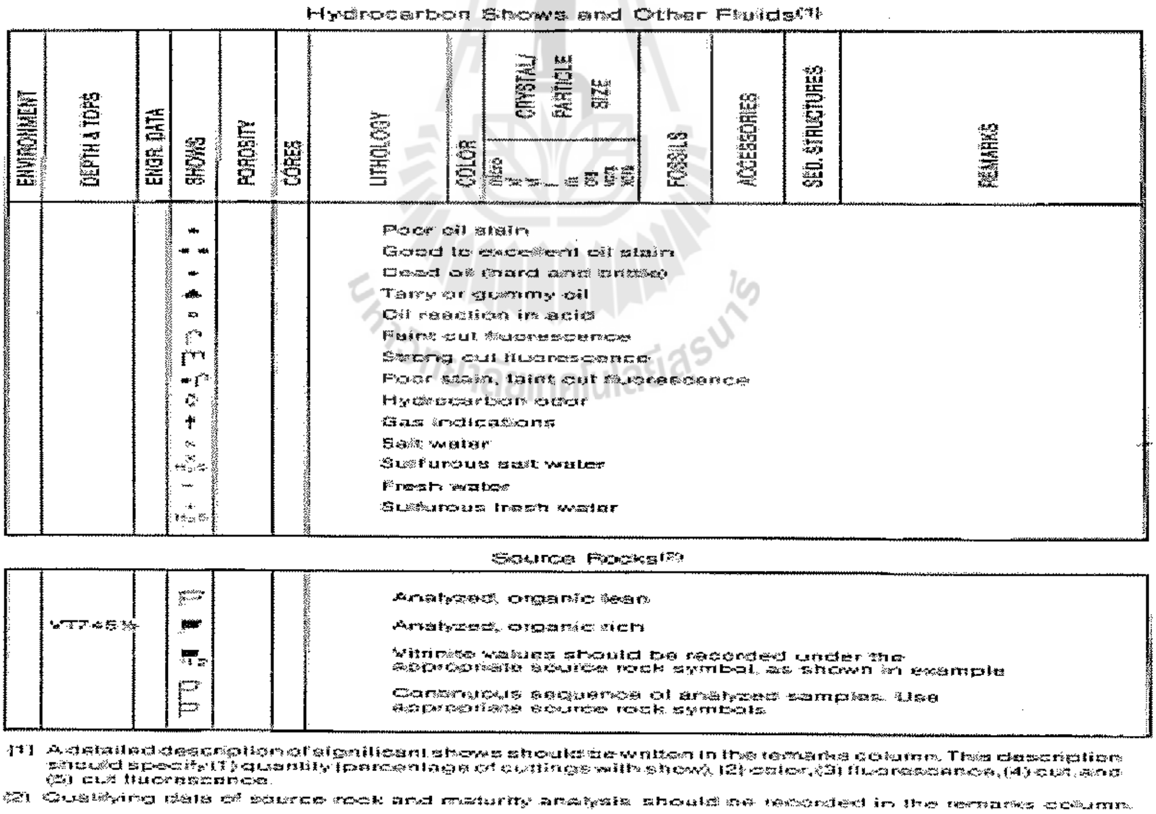
- **Porosity (f)** = measures the fraction of the total rock volume that is void space.
- **Permeability (k)**=The ability of rocks to store and transmit
- **Cementation** tends to reduce pore volume (porosity) and pore interconnection (permeability).
  - Calcite, silica and iron oxides are the common cements in sediments.
- **Clean sands** free from fines (silt and clay) make the best aquifers and reservoir rocks.

- **Dirty sands** have the porosity plugged by fine particles.

8. Hydrocarbon Show

8.1 Charecteristic of fluorescent samples (fresh, wet, dry)
8.2 Distribution
8.3 Colors
8.4 Concentration
8.5 Acetone color of cut
8.6 Chlorothene color of cut
8.7 Fluoresence Chlorothene cut
8.8 Fluorescence acetone cut

Chart VIII: Hydrocarbon Shows and Other Fluids, and Source Rocks



Hydrocarbon Shows and Other Fluids(1)

ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL/ PARTICLE SIZE	FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS

Poor oil stain
Good to excellent oil stain
Dead oil (hard and brittle)
Tarry or gummy oil
Oil reaction in acid
Faint cut fluorescence
Strong cut fluorescence
Poor stain, faint cut fluorescence
Hydrocarbon odor
Gas indications
Salt water
Sulfurous salt water
Fresh water
Sulfurous fresh water

Source Rocks(2)

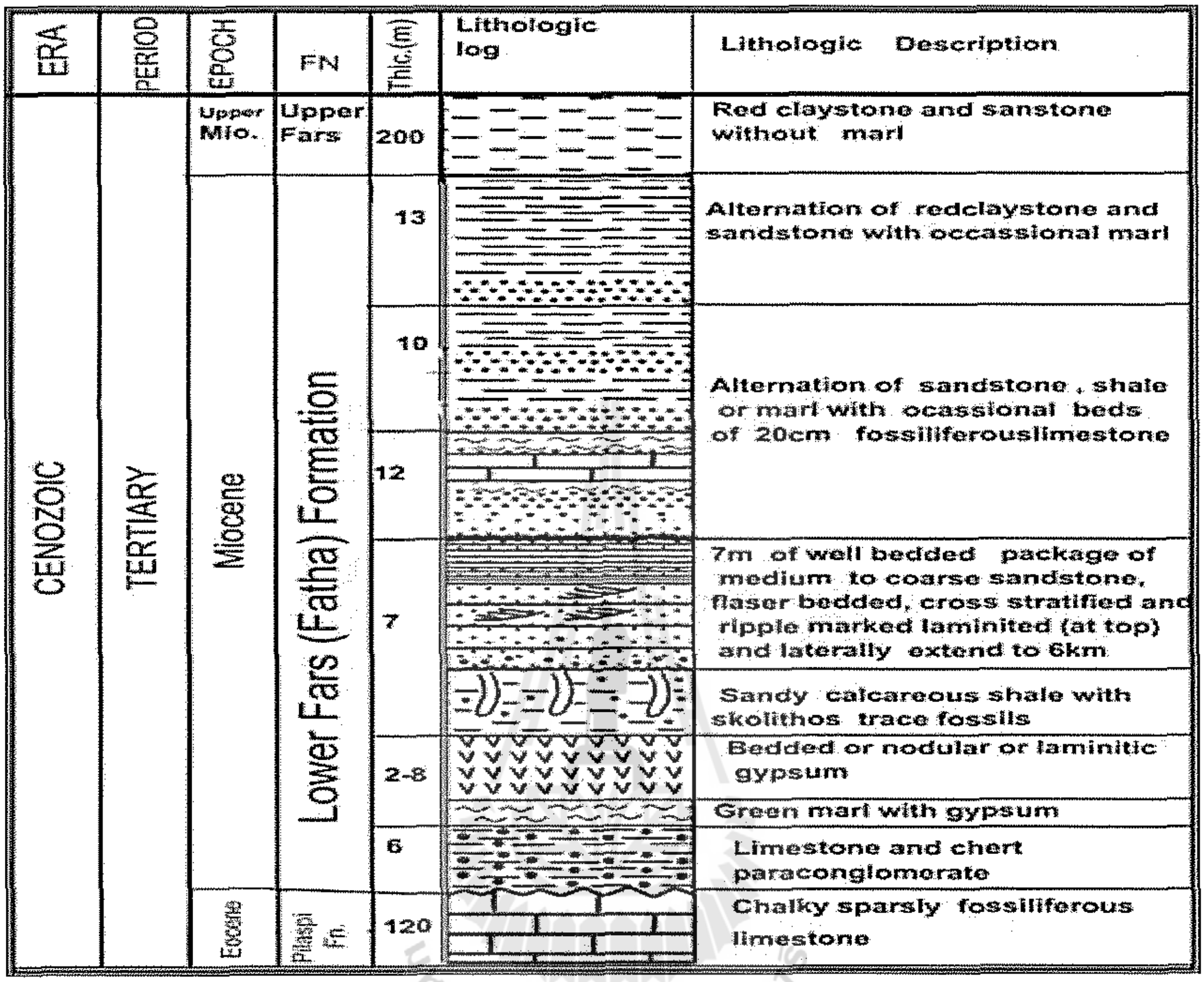
VT7-45%

Analyzed, organic lean
Analyzed, organic rich
Vitrinite values should be recorded under the appropriate source rock symbol, as shown in example
Continuous sequence of analyzed samples. Use appropriate source rock symbols

(1) A detailed description of significant shows should be written in the remarks column. This description should specify (1) quantity (percentage of cuttings with show), (2) color, (3) fluorescence, (4) cut, and (5) cut fluorescence.

(2) Qualifying data of source rock and maturity analysis should be recorded in the remarks column.

Example of Lithologic Logs



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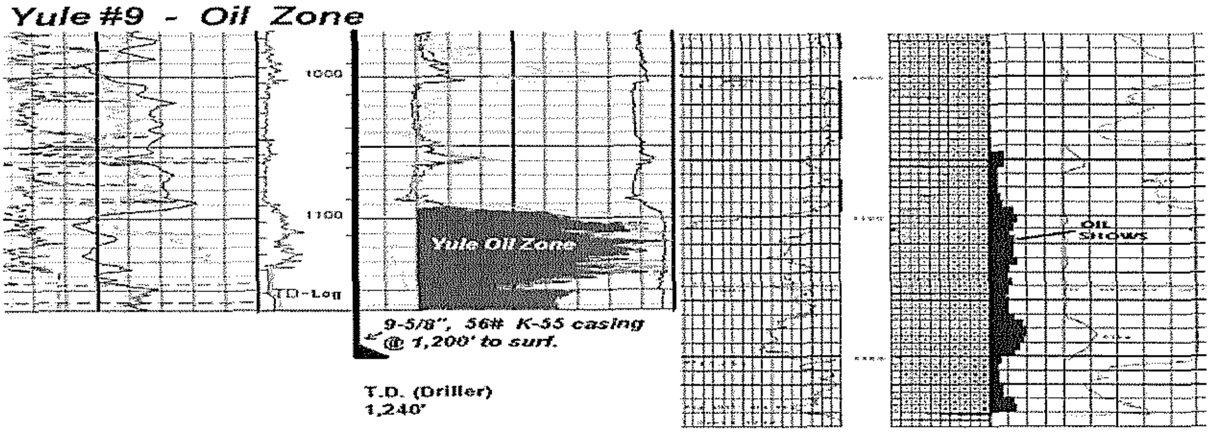
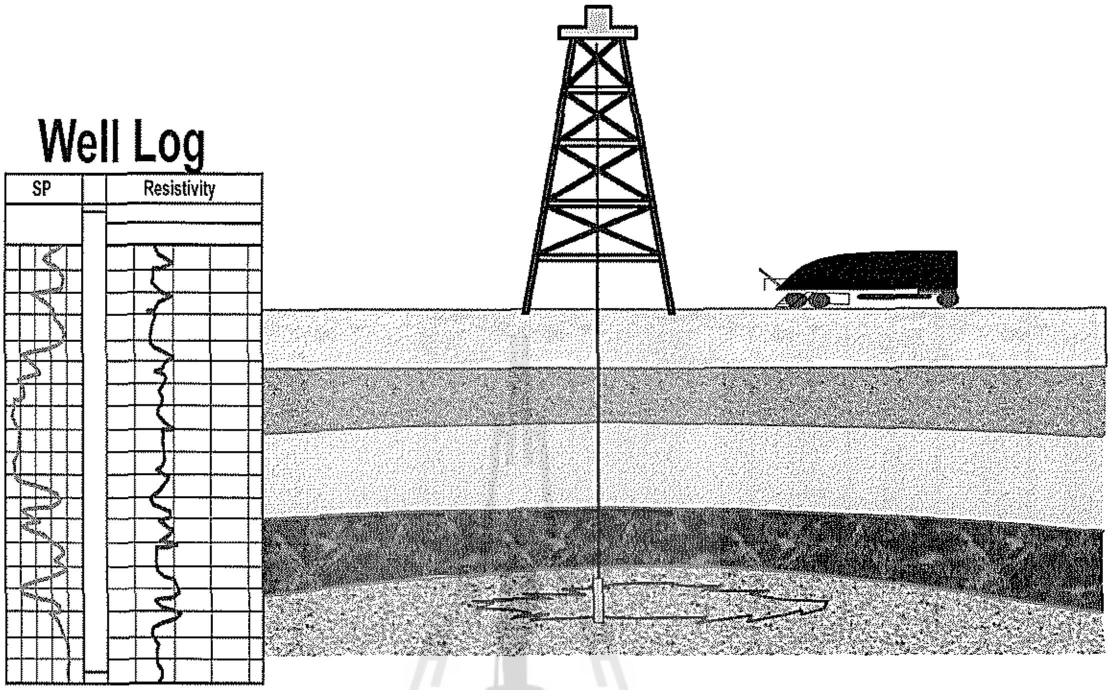
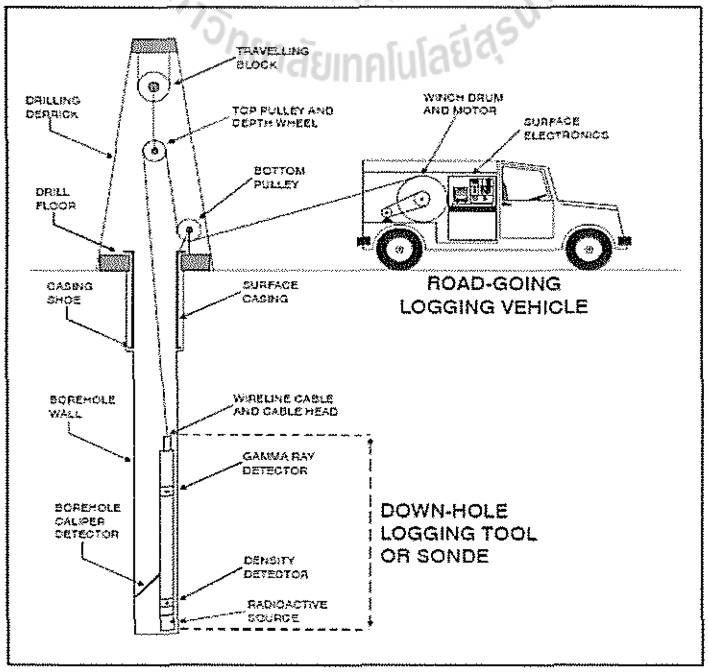


2. Well logging methods and interpretation



Wireline logs

- Wireline logs, Well log, logs หรือ การหยั่งธรณีในหลุมเจาะ
- เป็นการเก็บข้อมูลสมบัติของชั้นหินหรือการตรวจสอบของไหลที่ถูกกักเก็บในชั้นหิน



What do we need to find out?

- **Rock type?**
    - Sandstone? Shale?
      Limestone?
- **Rock Properties**
    - Porosity
    - Permeability
    - Bedding Orientation
    - Fractures
    - Fault
    - Temperature
- **Fluids**
    - Type (water, oil, gas)
    - Saturation
    - Salinity
    - Pressure
- **Engineering**
    - Well trajectory (coord)
    - Shape of hole
    - Casing Joints
    - Quality of cement

What for? (Log applications)

- Lithology type
- Stratigraphic correlation
- Formation Tops
- Quantitative Oil, Gas , Water saturations
- Porosity & Permeability
- Correlation with seismic data
- Sedimentological studies
- Reservoir modeling
- Structural studies etc.

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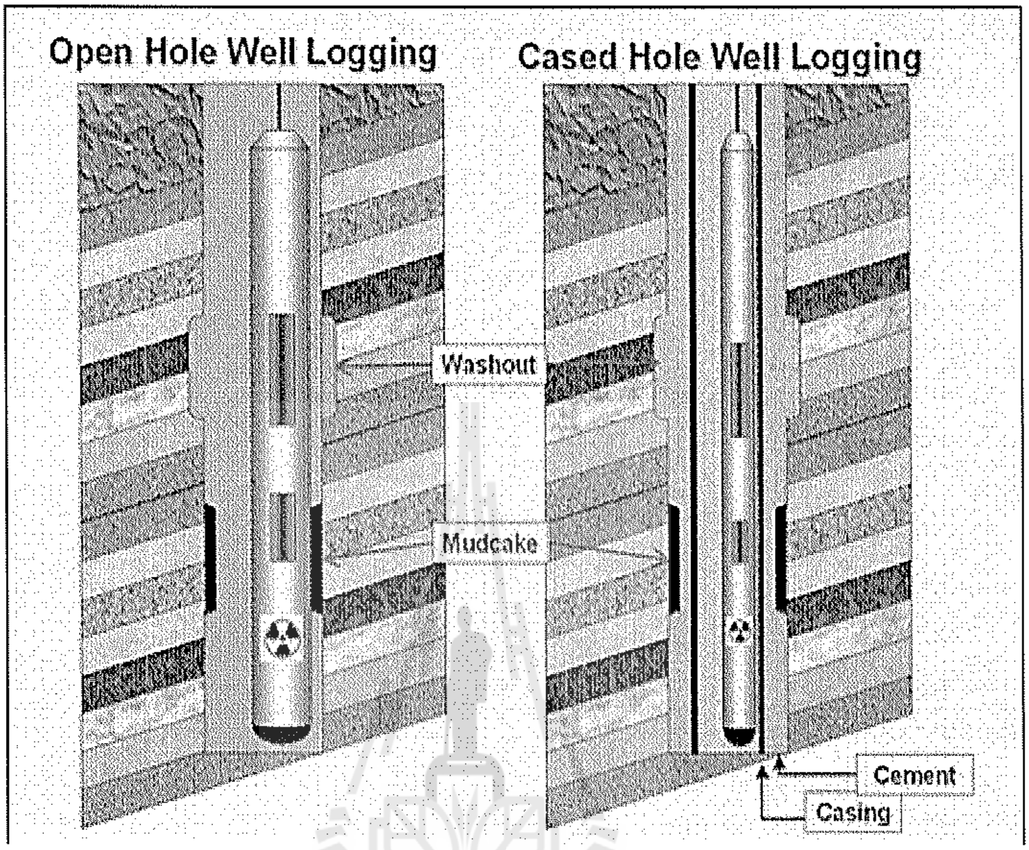
Wireline Log Type



Log Types

- Lithologic Logs
  - Spontaneous Potential (SP)
  - Gamma Ray (GR)
- Porosity Logs
  - Neutron
  - Density
  - Sonic
- Resistivity Logs (Fluid Type)
  - Resistivity

- Other
  - Dipmeter
  - Caliper
  - Temperature
  - Acoustic
  - FMI
  - Many more ...

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Log	Properties measured	Units	Geologic uses
Spontaneous potential (SP)	Natural electric potential	millivolts	Lithology (in some cases), Correlation, Curve shape analysis, Identify porous zones
Resistivity	Resistance to electric current flow	ohm.meters	Identification of coals, Bentonitess, Fluid evaluation
Gamma-Ray	Natural radioactivity related to K, Th, U	API units	Lithology (shaliness), Correlation, Curve shape analysis
Sonic	Velocity of compressional wave	msec/meter	Identification of porous zones, Coal. Tightly cemented zones
Caliper	Size of hole	centimeters	Evaluation hole condition, Reliability of other logs
Neutron	Concentration of hydrogen in pores	% porosity	Identification of porous zones, Crossplots with sonic, density logs for empirical separation of lithology
Density	Bulk density includes pore fluid in measurement	g/cc	Identification of some lithologies, such as anhydrite, halite, nonporous carbonates
Dipmeter	Orientation of dipping surface by resistivity changes		Structure analysis, stratigraphic analysis

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Borehole environment

สภาวะความดันระหว่างการเจาะและการหยั่งธรณีในหลุมเจาะ เกิดจากปัจจัยสองส่วนคือ

1. **ความดันในชั้นหิน** (Formation pressure): pressure occur from fluid & gas in formation under pressure condition
2. **ความดันของคอลัมน์ของน้ำโคลน**

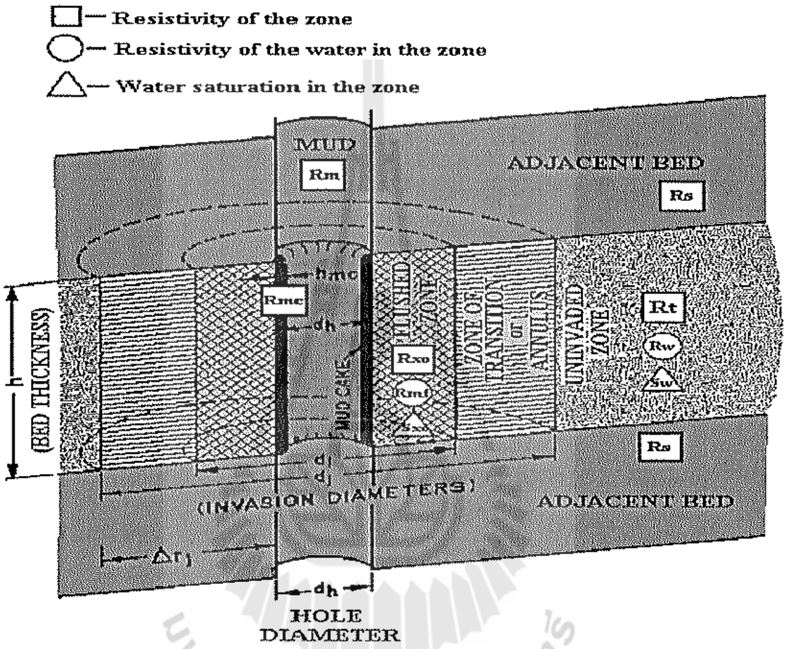
   ความดันของคอลัมน์ของน้ำโคลนขึ้นอยู่กับความลึกและความหนาแน่นของน้ำโคลน P_{mud} > $P_{formation}$==เพื่อใช้ป้องกันแรงดันภายในชั้นหินน้ำซึมผ่านได้ที่จะดันให้หัวเจาะและเครื่องมือที่ปากหลุมเจาะเกิดการเสียหาย ส่วนผสมในน้ำโคลนซึ่งเป็นของแข็งจะเกิดการสะสมตัวเกาะอยู่ ที่ผนังหลุมเจาะบริเวณที่เป็นชั้นหินน้ำซึมผ่านได้ซึ่งเรียกว่า ***Mud cake*** ส่วนที่เป็นของเหลวซึ่งเรียกว่า ***Mud filtrate*** จะไหลเข้าไปในชั้นหินน้ำซึมผ่านได้ดันให้ของไหลที่เคยอยู่ในชั้นหินกักเก็บเดิมไหลลึกเข้าไปในชั้นหิน

บริเวณที่เกิดการแทรกตัวของน้ำโคลน (Invasion zone)

สามารถแบ่งออกได้เป็น 2 ส่วนใหญ่ๆคือ

1. **Flushed zone** เป็นส่วนที่ของไหลเดิมที่เคยอยู่ในชั้นหินน้ำซึมผ่านได้ทั้งหมดถูกแทนที่ด้วย mud filtrate
2. **Transition zone** เป็นส่วนที่ของไหลเดิมที่เคยอยู่ ในชั้นหินน้ำซึมผ่านได้บางส่วนถูกแทนที่ด้วย mud filtrate

   : ***virgin or uninvaded zone*** คือ บริเวณที่ mud filtrate ไม่สามารถแทรกผ่านเข้าไปได้



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Borehole Condition for Wireline logging

- Avg. Depth= **6,000** ft (may be 1,000 ถึง 20,000 ft)
- Borehole diameter **9"** (may be 15")
- Borehore dip **0-5^{o} (onshore) and 20-40^{o} (offshore)**
- Bottom Temperature avg. = 150^{O}F (may be between 350^{O}F)
- Mud salinity avg. = 10,000 ppm (may be 3,000-200,000 ppm)
- Wt. of mud avg. 11 lb/gal (may be 9 -16 lb/gal)
- Bottom pressure avg. = 3,000 psi (may be 3,000 -15,000 psi)
- Thickness of Mud cake avg. 0.5" (may be 0.1-1")

Formation parameters

ในการแปลความหมายข้อมูลที่ได้จากการหยั่งธรณีในหลุมเจาะ สิ่งสำคัญที่ต้องเกี่ยวข้องมีอยู่ 2 ส่วนคือ

1. **ส่วนประกอบของหิน** (constitutes of rock) ได้แก่ **เนื้อหิน (matrix) หินดินดาน (shale) ของไหล (fluids)**
2. **ธรรมชาติของชั้นหิน** (nature of formation) ได้แก่ ความพรุน (porosity) สัมประสิทธิ์ความซึมได้ (permeability) ความต้านทานไฟฟ้า (resistivity)

Matrix **เนื้อหิน**	**• ส่วนประกอบของหินที่เป็นของแข็ง ยกเว้นส่วนที่เป็นหินดินดานหรือชั้นดินเหนียว** **• ประกอบไปด้วยแร่หลักชนิดต่างๆ (grains) และ ตัวเชื่อมประสาน (cements)**	**• Clean formation หมายถึงชั้นหินที่ไม่มีดินเหนียวหรือหินดินดานปะปนหรือแทรกสลับอยู่** **• Shaly formation หรือ Dirty formation ชั้นหินที่มีดินเหนียวหรือหินดินดานปะปนหรือแทรกสลับอยู่**
Shale หินดินดาน	**• ประกอบด้วยตะกอน clay และ silt** **• เกิดการสะสมตัวเมื่อกระแสน้ำที่พัดพาเอาตะกอน เหล่านี้มามีความเร็วลดลง**	**• High Ø, Low K** **• Clay ประกอบด้วยแร่ดิน (clay minerals) ได้แก่ montmorillonite, illite, chlorite, kaolinite**
Fluid	**น้ำ อากาศ ก๊าซ น้ำมัน**	**• อากาศ ก๊าซ น้ำมัน มีสมบัติที่ตัวนำไฟฟ้าที่ไม่ดี** **• น้ำ ซึ่งมักละลายเอาแร่ธาตุต่างๆไว้ จะเป็นตัวนำไฟฟ้าที่ดี**

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Structure of Shale

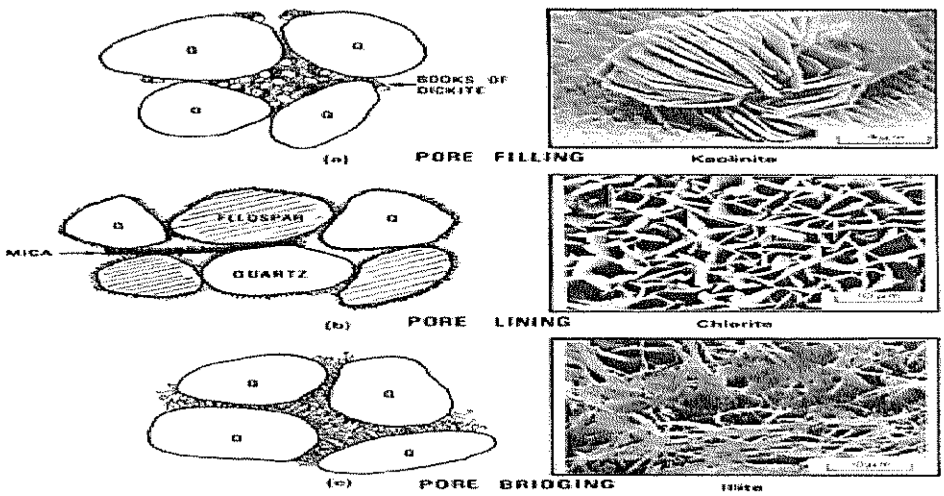

Fig. 3.14. The three types and distributions of dispersed authigenic clay minerals in pore space (From Neasham, 1977)

Logging techniques

การหยั่งธรณีหลุมเจาะ เพื่อวัดค่าสมบัติต่างๆ ของชั้นหินในหลุมเจาะนั้น สามารถแบ่งออกได้เป็น 2 ลักษณะคือ

1. **การวัดค่าที่เกิดขึ้นเองตามธรรมชาติ (Natural phenomena)**

- Natural gamma radioactivity (Gamma)
- Spontaneous potential (SP)
- Resistivity (R)
- Formation temperature
- Borehole diameter (Caliper)
- Inclination of borehole and formation(Dipmeter)

2. การวัดค่าที่ได้จากการเหนี่ยวนำ (Induced phenomena)

- Electrical measurement: Induction log
- Nuclear measurement: Density, Neutron
- Acoustic measurement: Sonic

1. Spontaneous potential or Self potential log (SP Log)

- One of the oldest logging measurements
    - ❖ Used commercially in 1931
- Discovered as Noise in Resistivity
- Found to be Related to Presence of sandstone

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SP Log Properties

- Measures natural electrical potentials that occur in boreholes
- "Battery" mechanism caused by drilling with fluid that has a different salinity from formation waters
- Ions diffuse from more concentrated solution (generally formation water) to more dilute
- Ion flow an electrical current
- Potential measured in millivolts

The earth well works like a battery

$E = -K \log (a_w/a_{mf})$

When: E is in millivolts, a_w= water salinity, a_{mf}= mud salinity

Principle of SP

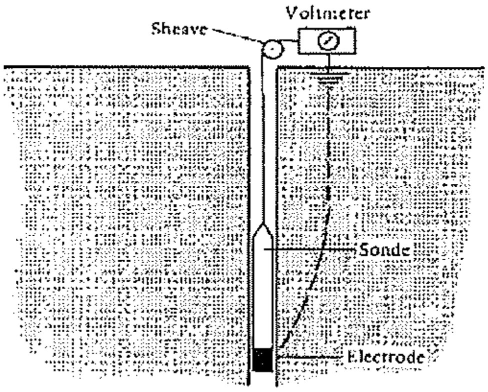
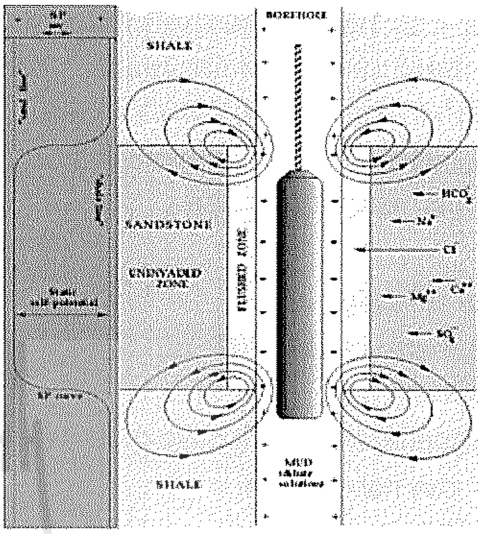


FIGURE 3.18 Basic arrangement for the S.P. log.



Ion flow is easier in permeable sandstones

การไหลเวียนของกระแสไฟฟ้า

การไหลเวียนของกระแสไฟฟ้ามีสาเหตุมาจากแรงกระตุ้นทางไฟฟ้า(electromotive forces, emf) ในชั้นหินที่ได้จาก

1. **ความต่างศักย์ไฟฟ้าเคมี (Electrochemical potential, E_c)** เกิดได้ใน 2 ลักษณะ คือ *liquid junction potential* **(E_{lj})**และ *membrain potential* **(E_m)**

$$E_c = E_{lj} + E_m$$

2. ความต่างศักย์ไฟฟ้าเชิงกล (Electrokinetic potential, E_k) อาจเรียกว่า *streaming potential* **(E_{mc})**หรือ *electrofiltration potential* **(E_{sb})**

$$E_k = E_{mc} + E_{sb}$$

$$E_{total} = E_c + E_k$$

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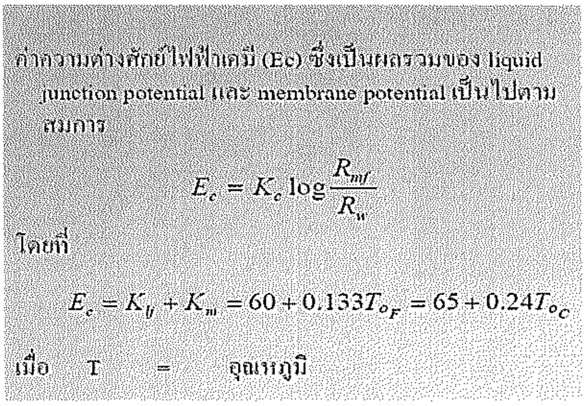
Total Electrochemical potential, E_c



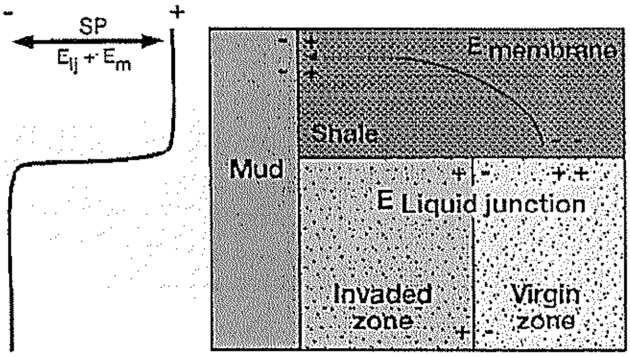
ค่าความต่างศักย์ไฟฟ้าเคมี (Ec) ซึ่งเป็นผลรวมของ liquid junction potential และ membrane potential เป็นไปตามสมการ

$$E_c = K_c \log \frac{R_{mf}}{R_w}$$

โดยที่

$$E_c = K_{lj} + K_m = 60 + 0.133T_{^oF} = 65 + 0.24T_{^oC}$$

เมื่อ T = อุณหภูมิ



Total SP Picture

Total potential

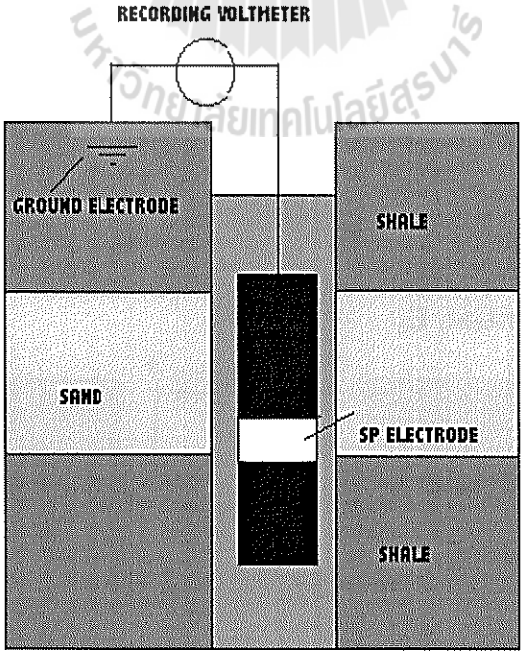
- ***ความต่างศักย์รวม (Total potential)***

  $$E_{total} = E_c + E_k$$

- ถ้าค่า $E_k < E_c$ ในบริเวณที่น้ำในชั้นหินมีค่าความเค็มสูง (ค่าความต้านทานไฟฟ้าน้อยกว่า 0.1 โอห์ม -เมตร) และความแตกต่างของความดันมีค่าไม่มาก (ประมาณ 200-300 psi หรือน้อยกว่า) สามารถที่จะไม่นำ ค่า E_k มารวมคำนวณได้
- ถ้าค่า E_k จะเริ่มมีผลกับค่าความต่างศักย์รวม เมื่อมีความผิดปกติของค่าความแตกต่างของความดัน หรือ K (permeability) ต่ำมาก

Condition for SP Log

- **SP log** measure **the difference of the natural electric potential** that occur in borehole
- Mud properties==Conductive mud: water base mud
- SP log can not work in
  - oil-base mud,
  - Air or foam drilling,
  - empty holes
  - cased holes
- The SP electrode is built into different logging tools for example:
  - Induction log, Laterolog, Sonic log. , Sidewall core gun etc.



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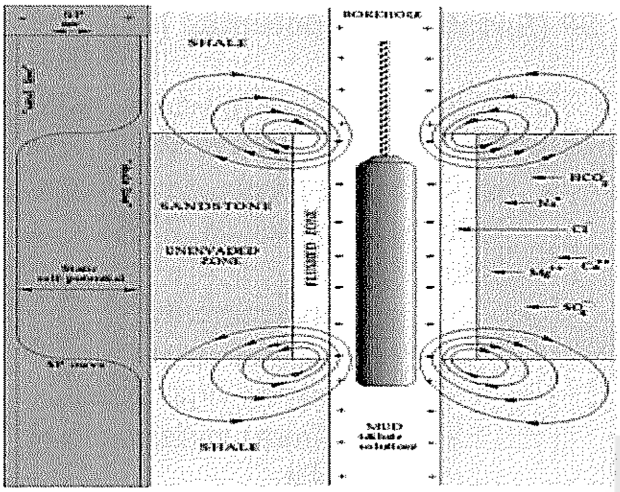
Properties of Mud for SP Log



1. Conductivity mud; water base mud
2. Salinity: Water salinity > Mud salinity==electrical current flow

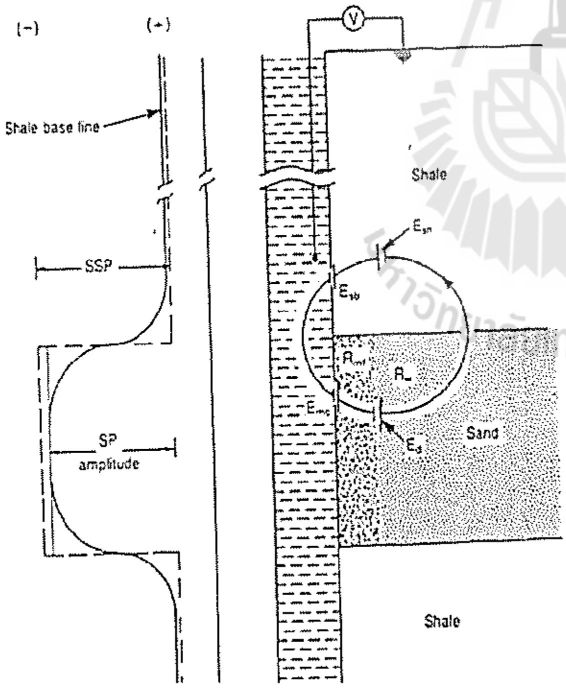
ประโยชน์ของ SP Logs

1. หาความสัมพันธ์ระหว่างชั้นหิน (correlation)
2. กำหนดลักษณะชนิดของหิน (lithology indicator)
3. ใช้ประมาณค่าความพรุนและค่าความซึมได้ (porosity and permeability indicators)
4. วัดค่าความต้านทานไฟฟ้าและค่าความเค็มของน้ำในชั้นหินกักเก็บ (formation water resistivity (Rw) and formation water salinity)
5. ใช้กำหนดตำแหน่งของชั้นหินดินดาน ชั้นถ่าน หรือประมาณ สัดส่วนของหินดินดาน (lithologic indicator: shale, coal-seam, shale fraction estimation)
6. ใช้วิเคราะห์หา Facies จากรูปร่างลักษณะของกราฟ (facies analysis)
7. ใช้กำหนดความเป็นไปได้ในการเป็นแหล่งกักเก็บสารไฮโดรคาร์บอนในชั้นหิน รวมถึงการกำหนดตำแหน่งความลึกของรอยสัมผัสของก๊าซและน้ำมัน

SSP versus SP

SSP (Static Spontaneous potential)	**SP (Spontaneous potential)**

• การวัดกระแสไฟฟ้าในน้ำโคลนเมื่อมีการไหลของกระแส เป็น สภาวะในอุดมคติ (idealized condition)
• การวัดค่าความต่างศักย์ไฟฟ้าสูงสุดเทียบกับความต่างศักย์ไฟฟ้าที่เกิดขึ้นในชั้นหินดินดาน
• ค่า SSP ในชั้นหินดินดาน = 0 เรียก ความต่างศักย์ไฟฟ้าในชั้น หินดินดานว่า Shale base line
$SSP = -K_c \bullet \log\left[\frac{R_{mfeq}}{R_{weq}}\right]$
	• การวัดกระแสไฟฟ้าในน้ำโคลนเมื่อมีการไหลของกระแส ในสภาวะจริง
	• ค่า SP ที่ peak มีค่าน้อยกว่า SSP เรียกว่า Pseudostatic potential (PSP) ขึ้นอยู่กับ
	  • ความหนาของชั้นหิน
	  • ค่าความต้านทานไฟฟ้าของ invaded และ virgin zones
	  • ความลึกของ invasion ปริมาณของแร่ดิน
	$SP = -(.133\ T°F + 61)\ \log \frac{Rmf}{Rwe}$



$$SSP = -K_c \bullet \log\left[\frac{R_{mfeq}}{R_{weq}}\right]$$

$$SP = -(.133\ T°F + 61)\ \log \frac{Rmf}{Rwe}$$

SSP : potential in mud when SP currents are prevented from flowing (idealized condition)

SP: potential in mud when SP currents are flowing

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Static SP (SSP)

ในสภาวะโดยทั่วไป ผลรวมของความต่างศักย์ที่ เรียกว่า **Static SP (SSP)** สามารถคำนวณจากสมการ

$$SSP = -K_c \bullet \log \left[\frac{R_{mfeq}}{R_{weq}} \right]$$

$$K_c = 65 + .24 \bullet T(°C)$$

$$K_c = 61 + .133 \bullet T(°F)$$

SSP	is Static SP (mv) measured from a shale baseline,
R_{mfeq}	is equivalent resistivity (activity) of mud filtrate at formation temperature,
R_{weq}	is equivalent resistivity (activity) of formation water,

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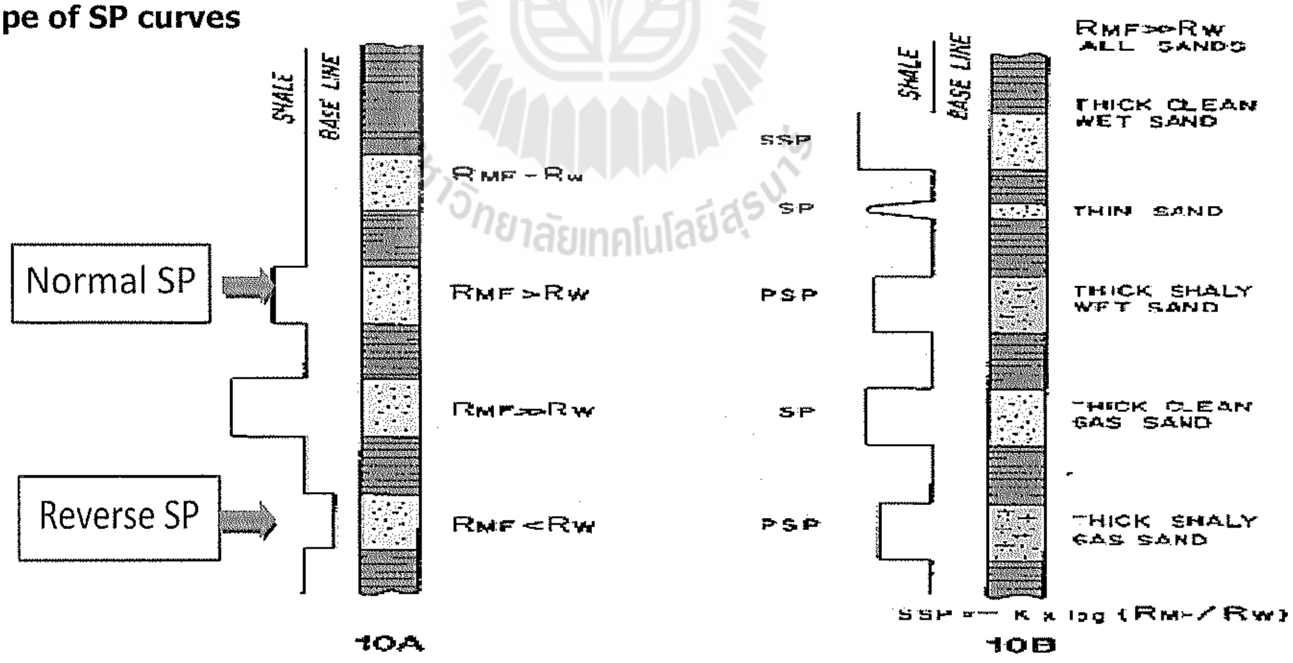
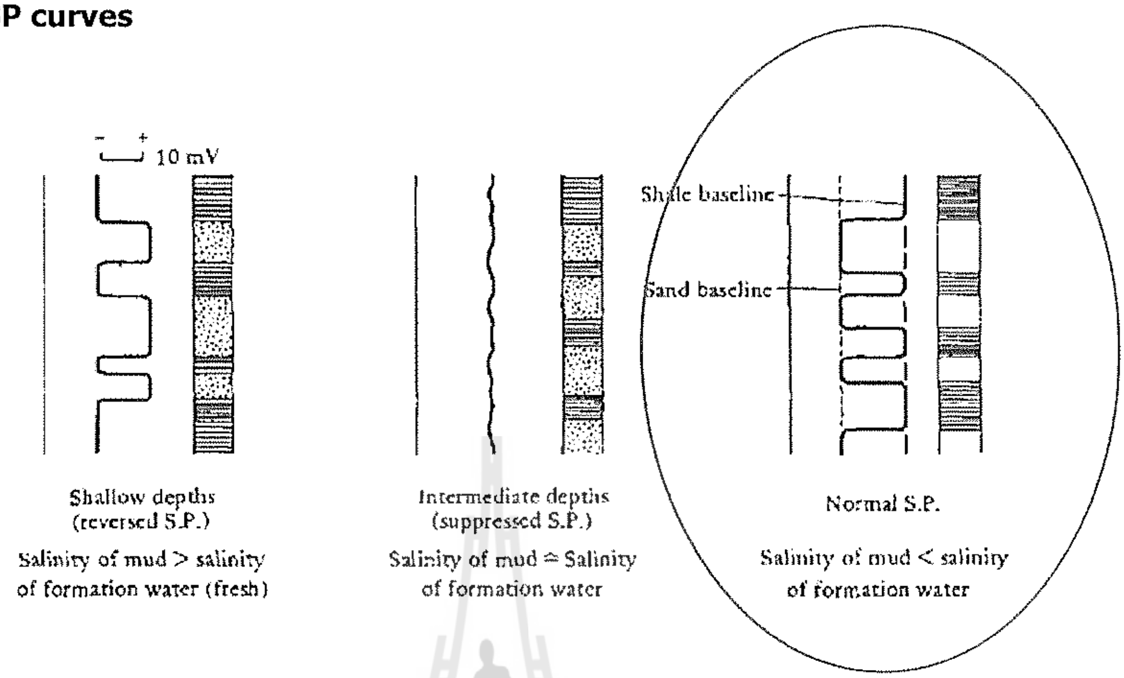
Shape of SP curves



$R_{mf} > R_w$:SP deflects to the left (- SP)

$R_{mf} < R_w$:SP deflects to the right (+ SP)

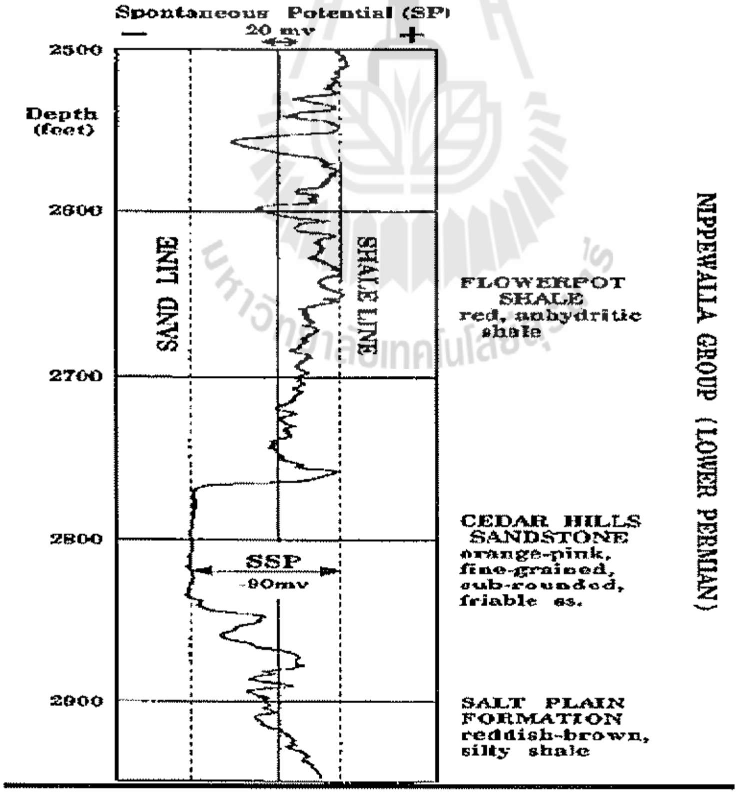
Shape of SP curves



Shallow depths
(reversed S.P.)
Salinity of mud > salinity
of formation water (fresh)

Intermediate depths
(suppressed S.P.)
Salinity of mud ≃ Salinity
of formation water

Normal S.P.
Salinity of mud < salinity
of formation water



Factors influencing the SP curve

ลักษณะกราฟของ SP และค่าผิดปกติที่เกิดขึ้น ขึ้นอยู่กับหลายปัจจัย การนำเอาค่า SP ไปใช้จึงต้องมีความระมัดระวังปัจจัยต่างๆได้แก่

1. **ความหนาของชั้นหินซึมน้ำได้:**
2. **ความต้านทานไฟฟ้าของชั้นหินซึมน้ำได้ และความต้านทานไฟฟ้าของ mud filtrate: SP**
   ,R_t/R_m ↑ (in virgin zone)
   SP ↑ ,R_{xo}/R_m ↑ (in invaded zone)

3.ความลึกของชั้น invasion: SP ↓ ,Depth ↑

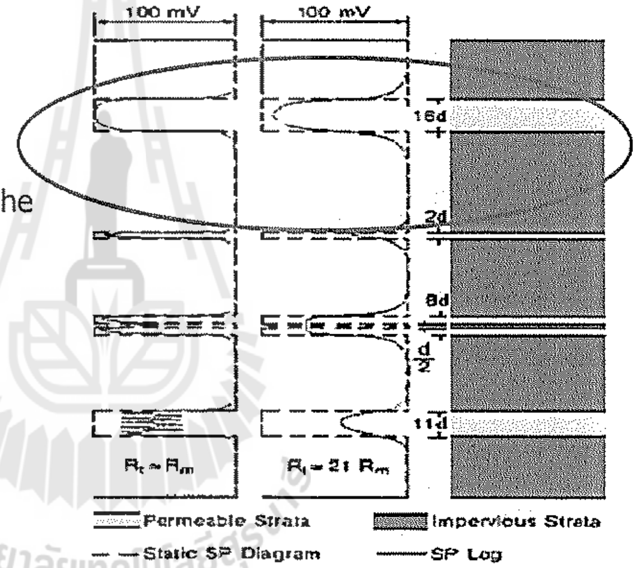
4. เส้นผ่าศูนย์กลางของหลุมเจาะ: SP ↓, diameter ↑

5. ความต้านทานไฟฟ้าของชั้นหินดินดาน: SP ↓, Rsh ↑

6. สารประกอบไฮโดรคาร์บอน: SP ↓ @ HC zone

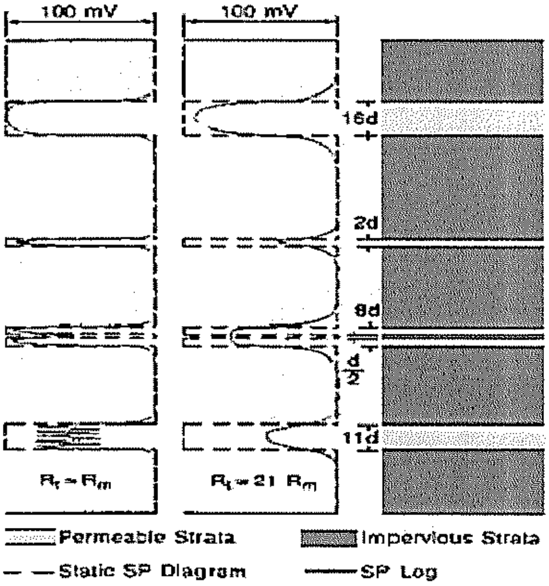
ความหนาของชั้นหินซึมน้ำได้

- SP ↑ ,voltage in mud ↓
- SP=SSP: Rt<<Rm when thick formation
- In thin formation can not occurs the completed current
- Thus SP ↓, Formation thickness ↓



ความต้านทานไฟฟ้าของชั้นหินซึมน้ำได้และความต้านทานไฟฟ้าของ mud filtrate

- In virgin zone: R_t/R_m ↑ ,SP ↓
  (cause can not indentified the boundary)
- SP ↓ at HC zone
- SP in shale ↑ , R_{sh}/R_m ↑
- In Invaded zone: SP ↑ ,R_{xo}/R_m ↑



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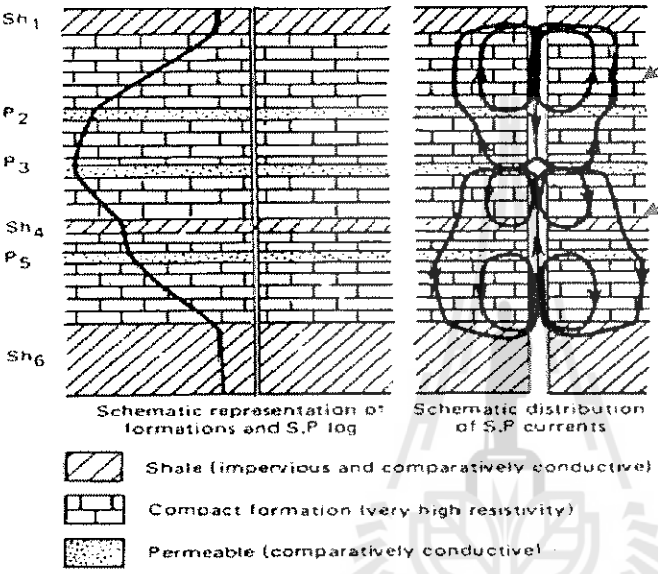
$R_t = R_m = R_s$; SP curve clear & SP =SSP

: $R_t = R_s = 21\ R_m$; SP curve not clear & SP< SSP

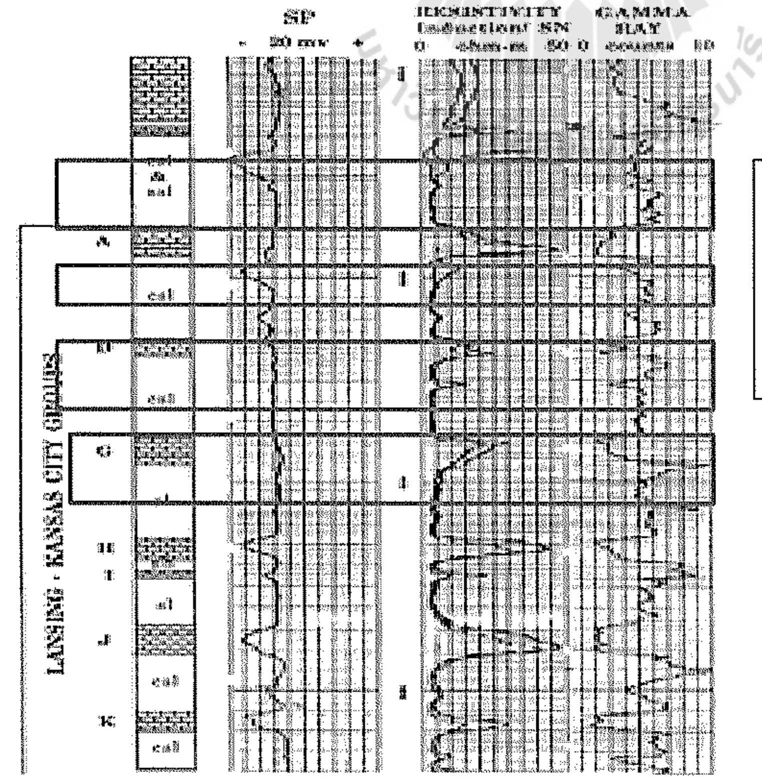
Irregular anomaly of SP curves

1. Highly resistivity formations or tight formation



ในชั้นหินน้ำซึมผ่านได้กราฟของ SP สูงขึ้น

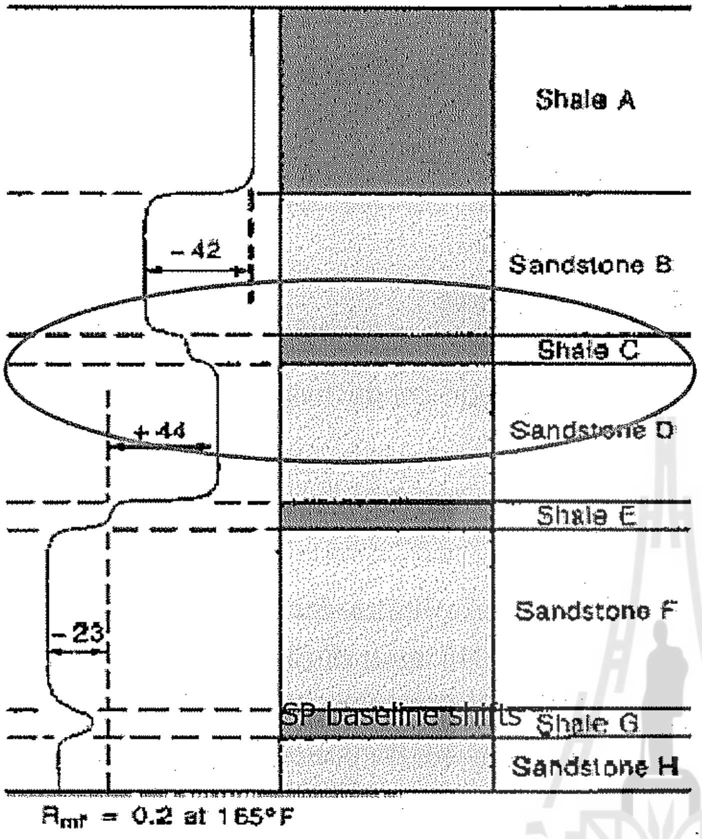
ในชั้นหินเนื้อแน่นกราฟของ SP ต่ำลง

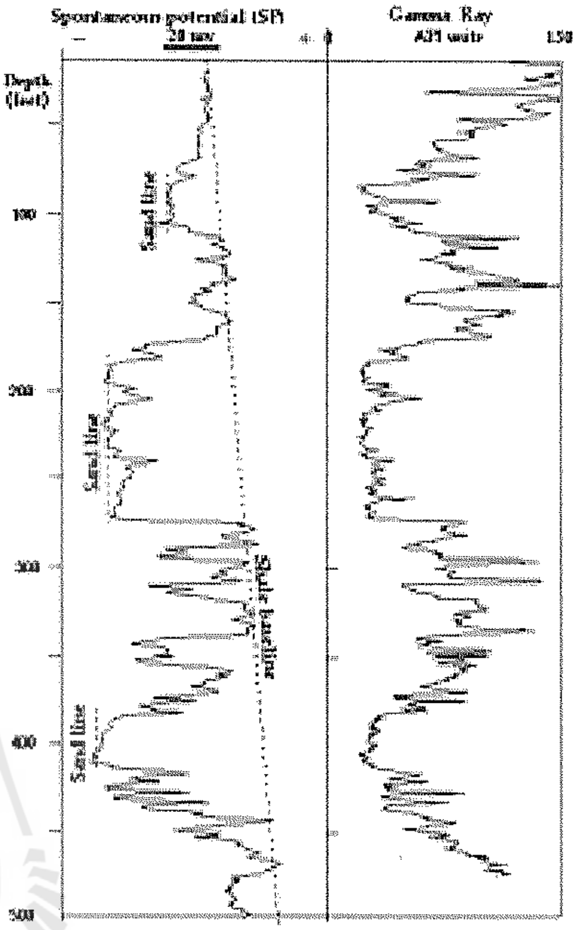


Key: sl = siltstone ; cal = calcareous siltstone ; ssl = sandy siltstone ; sh = shale

- SP log has Poor Limestone Response
- GR and Resistivity logs can be detect

2. Shale baseline shifts





ปัญหาและข้อจำกัดของ SP log

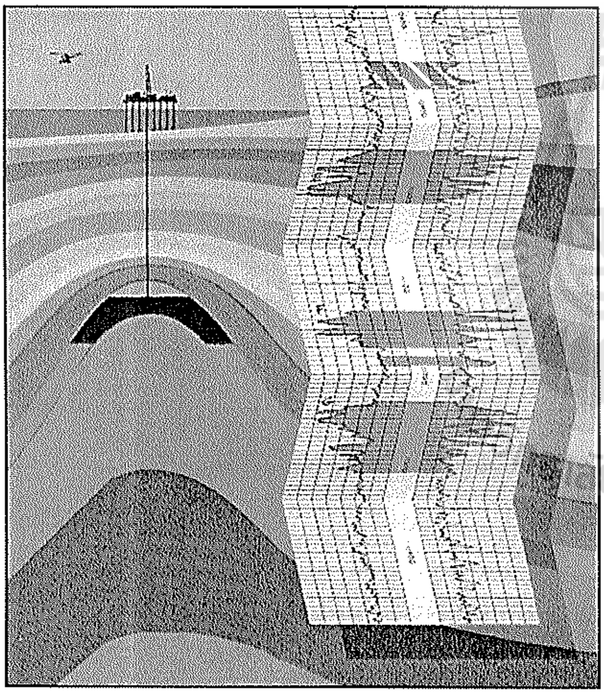
ปัญหาต่างๆที่พบได้ในการประยุกต์ใช้ กราฟของ SP ใน การศึกษาสภาพแวดล้อมของการเกิด เช่น

1. ถ้ามีการเปลี่ยนแปลงค่าความเค็มของน้ำในชั้นหินทราย จนกระทั่งทำให้เกิดลักษณะที่ชั้นหินทรายที่มีน้ำไม่เค็ม แสดงลักษณะเหมือนชั้นหินดินดาน
2. การใช้น้ำโคลนที่แตกต่างกันในในการเจาะหลุมหนึ่งๆ จะมีผลให้เกิดการเปลี่ยนแปลงกราฟของ SP โดยเฉพาะเมื่อ mud filtrate และ น้ำในชั้นหิน มีค่าความต้านทานไฟฟ้า เท่ากัน ทำให้แปลผลว่าเป็นชั้นหินดินดาน
3. ในบางกรณีอุณหภูมิมีผลต่อกราฟของ SP
4. หินทรายที่มีก๊าซหรือน้ำมัน ค่า SP จะลดลง
5. การใช้กราฟของ SP ร่วมกับกราฟของความต้านทานไฟฟ้า จะเหมาะสมเฉพาะกับบริเวณที่เป็นชั้นหินทราย -หินดินดาน เนื้อแน่น แต่จะใช้ไม่ได้ ผลดีกับบริเวณที่ชั้นหินเนื้อไม่แน่นที่ มีค่าความพรุนมากและมีความเค็มของน้ำในชั้นหินสูง
6. SP log ไม่สามารถทำในหลุมเจาะที่แห้ง (ไม่มีน้ำโคลน) หรือหลุมที่ใช้ Oil base mud หรือหลุมที่ลง Casing แล้ว

2. **Gamma Ray Log**

- Lithology log
- Measures natural radioactivity
- Uses a scintilometer (Gaiger counter)
- Potassium (K), Uranium, Thorium, Phosphorous
- K → abundant in clay → shales
- Unaffected by fluids
- Gamma ray log can work both open hole and cased hole
- GR log can be use for replacement SP log
- GR logs can work in salt mud, air or oil-based mud (non-conductivity mud)

Objective of gamma ray log



1. หาความสัมพันธ์ของชั้นหิน (correlation)
2. ประเมินปริมาณของชั้นหินดินดานในชั้นหิน
3. วิเคราะห์ชนิดของแร่
4. บอกชนิดและปริมาณของธาตุที่ปลดปล่อย
5. รังสีแกมมาที่มีอยู่ในชั้นหินดินดาน

Principles of Gamma rays

- **Three naturally radioactive isotopes abundant in nature:**
  - **Uranium series (U-235, U-238)** – fixed by fine-grained organic material
  - **Thorium series (Th-232)**– absorbed by clay minerals
  - **Potassium-40 (K-40)** – part of clay mineral composition (particularly illite)

Where are these radioactive element found?

- In zones containing potassium feldspars (i.e. granites, feldspathic sands)
- Volcanic and igneous rocks
- Sands containing volcanic ash
- Clays
    - Shales tend to be more radioactive than "clean" sandstones, limestones
    - Exceptions: feldspathic sandstone (k-spar),

  uranium mineralization in carbonates, etc.

Gamma ray tool

- Scintillation detector (originally Geiger counters): present use **sodium iodide crystal**
- Measured in American Petroleum Institute (API) units
    - Arbitrary scale
    - Calibration in API test pit at U. of Houston – 200 API = 2x average "midcontinent shale"

Gamma ray tool

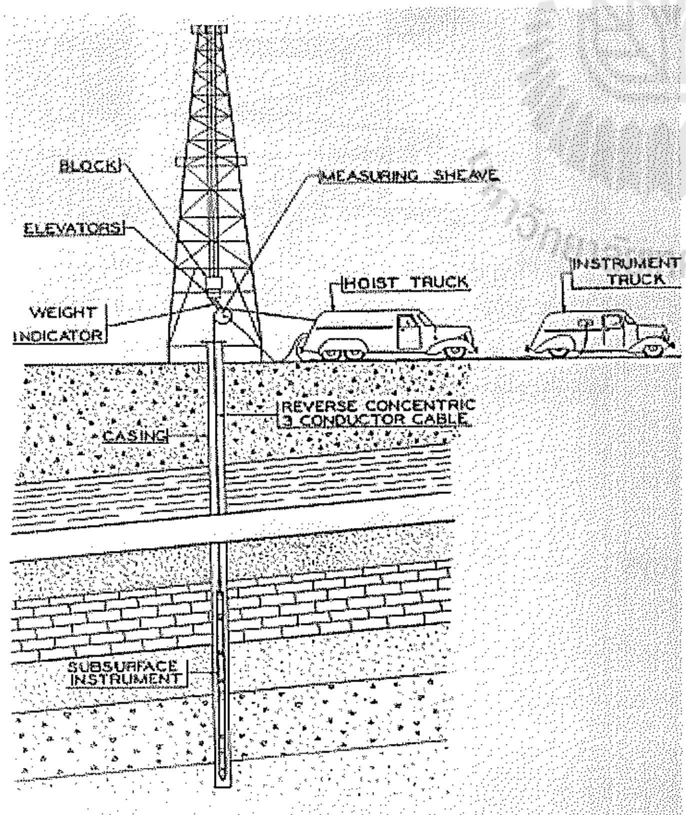
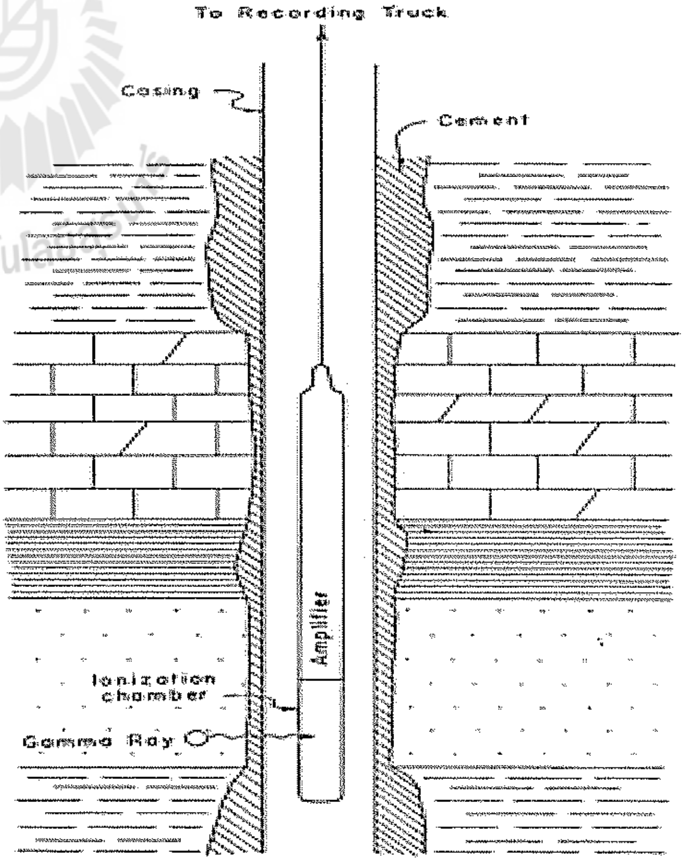


FIGURE 15-1. Radioactivity logging set-up.



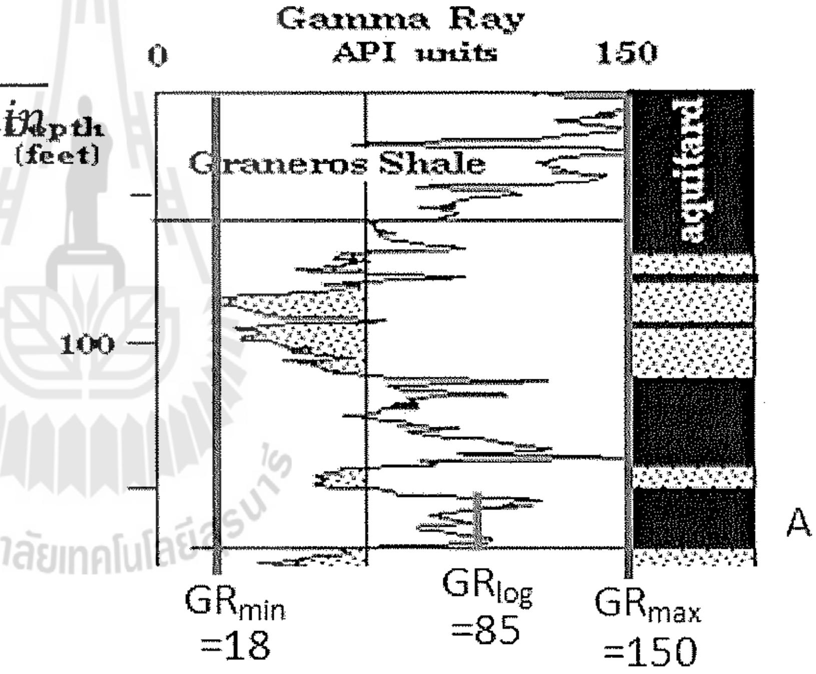
Gamma ray Application

1. Broad-scale lithology: "clean" versus shaly units
2. Quantification of shale content
3. Stratigraphic correlation
4. Depositional environment identification
5. Quantification of radioactive element content

Estimating shale content

- เนื่องจากธาตุกัมมันตรังสีมักมีความสัมพันธ์กับแร่ดินซึ่งเป็นส่วนประกอบหลักของชั้นหินดินดาน ดังนั้นจึงสามารถใช้รังสีแกมมาที่วัดได้มาประเมินปริมาตรของ shale-volume indicator

$$Vshale = \frac{\mathrm{GR} - \mathrm{GRmin}}{GRmax - GRmin}$$



Vshale=(85-18)/(150-18) =51%

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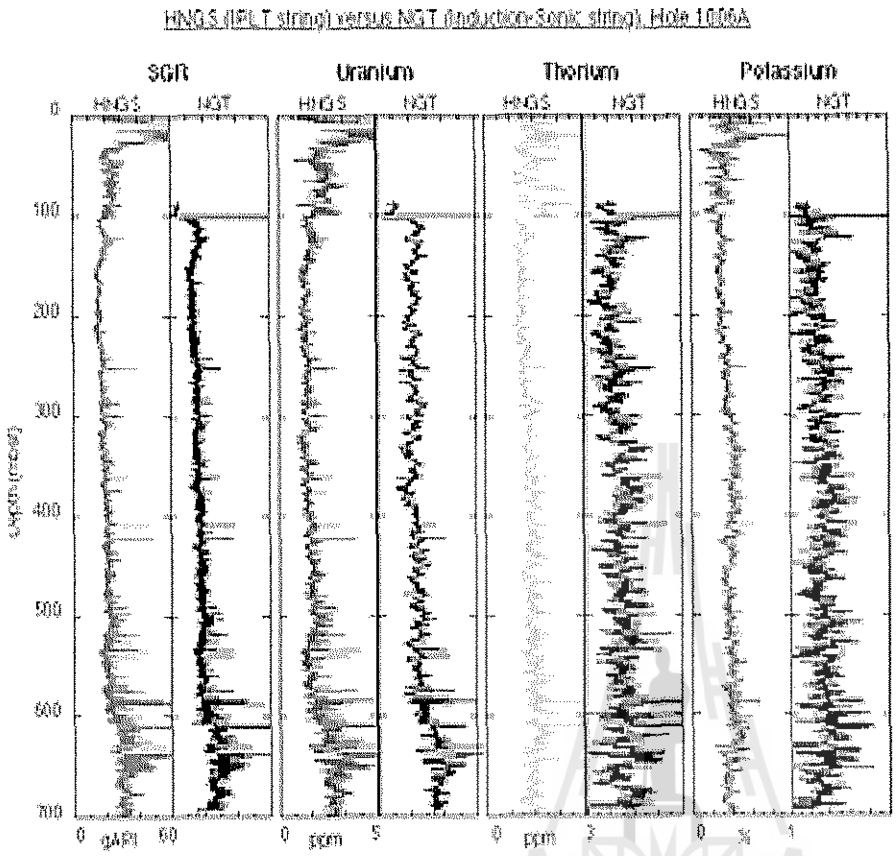
Spectral Gamma Ray (SGR)

Differentiates the different sources of gamma rays

: Type and quantity of radioactive element



Units

- **Th & U= ppm**
- **K= %**

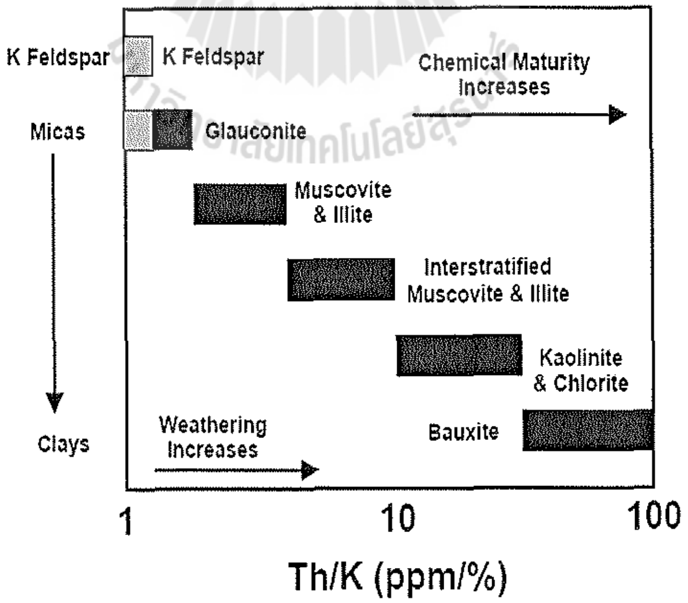


Figure 12.5 Thorium/potassium ratio plot for mineral identification using spectral gamma ray

Table 12.3 Sedimentological inferences from spectral gamma ray data.

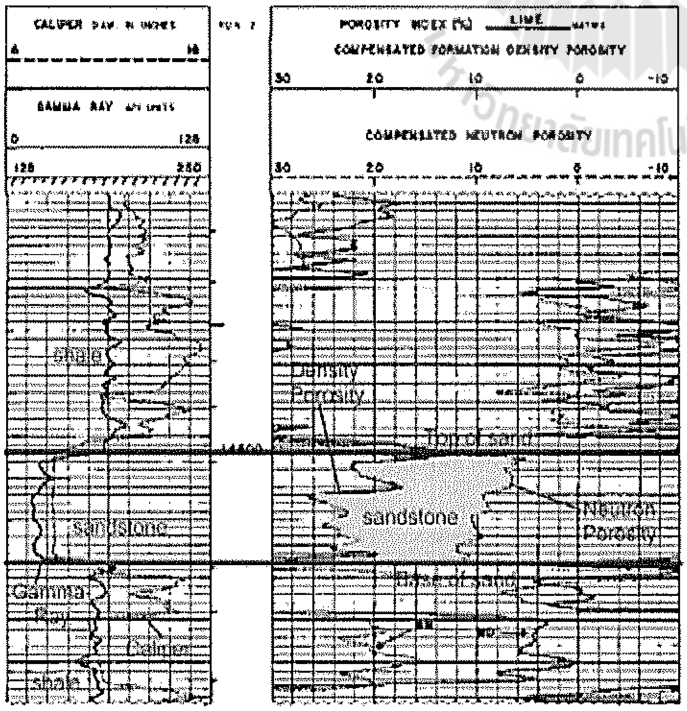
SGR Observation	**Sedimentological Inference**
Presence of glauconite	Marine, mainly continental shelf origin.
Phosphatic deposits	Marine, mainly continental shelf origin, with warm water in a reducing environment.
Uranium	Low energy, reducing conditions
Clay type	Analysis of depositional environment.
Bauxite	Warm, humid, continental environment with good drainage.
Feldspars	Indicator of the degree of evolution of sand facies, only found in abundance close to the igneous source.

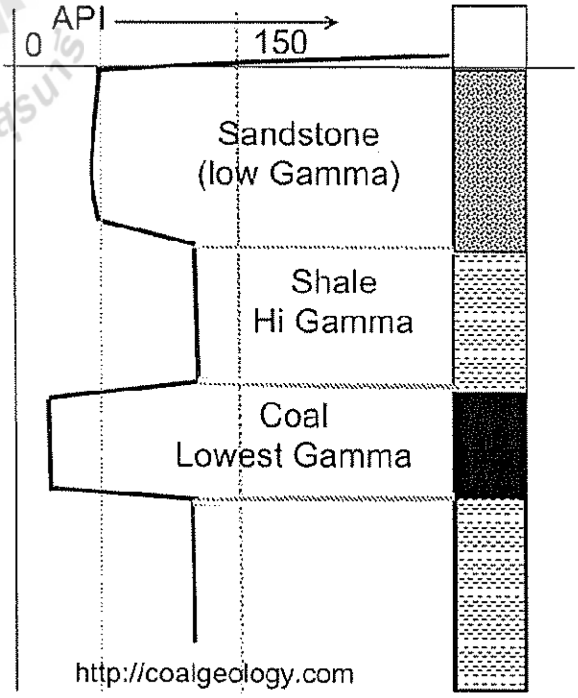
Table 12.1 Interpretation of spectral gamma ray data in carbonates.

K	Th	U	Explanation
Low	Low	Low	Pure carbonate, no organic matter or oxidizing environment.
Low	Low	High	Pure carbonate, organic matter, reducing environment.
Low	High	Low	Not a carbonate, or shaly carbonate with rarer low K high Th clay minerals, no organic matter or oxidizing environment.
Low	High	High	Not a carbonate or shaly carbonate with rarer low K high Th clay minerals, organic matter, reducing environment.
High	Low	Low	Glauconite carbonate, no organic matter or oxidizing environment. Also consider K-bearing evaporites.
High	Low	High	Algal carbonate, or glauconite present, organic matter, reducing environment.
High	High	Low	Shaly carbonate, no organic matter or oxidizing environment.
High	High	High	Shaly carbonate, organic matter, reducing environment.
Note: Stylolites can locally concentrate U, clays and organic matter.			

CHARACTERISTICS OF GAMMA RAY

1. เป็นการวัดรังสีแกมมา Gamma ray ที่มีอยู่ในหินตามธรรมชาติ ไม่มีการวัดคุณสมบัติทางกระแสไฟฟ้าใด ๆ เลย
2. ลักษณะของ GR curve ที่ปรากฏคล้ายกับ SP curve ซึ่งเป็นจริงในหินทรายและหินดินดาน แต่ใช้ไม่ได้เสมอไปในหินปูน
3. ชั้นหินแต่ละชนิดจะมีคุณลักษณะของ Curve เฉพาะหิน
4. สามารถใช้เฉพาะ GR curve อย่างเดียวแปลความหมายของชั้นหินในหลุมเจาะได้
5. สามารถใช้ GR curve ตรวจสอบความถูกต้อง (Shale) ของชั้นหิน และเปรียบเทียบกับข้อมูลอื่น ๆ ได้ เช่น SP Curve
6. หินดินดาน (Shale) ปกติจะให้ค่า GR สูง
7. ช่วงกลางของ Slope ของ GR curve จะเป็นตัวบอกระยะ Top และ bottom ของชั้นหิน
8. GR curve จะไม่มีค่าศูนย์และ base line ทุกค่าที่อ่านได้เป็นบวก (+)
9. GR curve คือการตรวจวัดกัมมันตรังสีที่มีหรือไม่มีในชั้นหินโดยตรง
10. GR curve ไม่ขึ้นกับขนาดของหลุมเจาะ หรือแม้แต่ว่าจะมีการขยายหลุมเจาะ (Enlarged bore well)
11. GR curve จะไม่มีผลกระทบต่อจำนวนท่อกรุท่อกรอง ที่ติดตั้งไว้แล้วในบ่อบาดาล
12. GR curve จะไม่มีผลกระทบกับ Formation fluid และ Bore hole fluid
13. GR curve จะไม่บอกคุณสมบัติของชนิด Formation fluid ใด ๆ เพราะค่า Gamma ไม่ได้ขึ้นอยู่กับสารละลายใด ๆ ทั้งที่อยู่ในหลุมเจาะและในชั้นหินนั้น ๆ
14. GR curve ไม่ใช่ตัวบอก Porosity และ Permeability เพราะเป็นการวัดค่ากัมมันตรังสีของชั้นหิน ไม่สามารถนำมาใช้ได้กับการตรวจวัด Porosity และ Permeability





http://coalgeology.com

Log Shape – Depositional Environments

- Gamma ray and SP curves sensitive to "shaliness"
- Different types of depositional environments produce stratigraphic columns that show characteristic changes in lithology/shaliness
- Use vertical GR or SP profiles to identify depositional environment

Log Shape – Depositional Environments

- Caution: Similar curve shapes may be produced in a variety of depositional environments
  E.g., "cylindrical" – braided fluvial channels, submarine channels, sharp-based shorefaces, carbonate shelves, etc.
- Use in conjunction with other lines of evidence (core, lateral correlations, seismic data, etc.)

Recognition of sandstone depositional environments

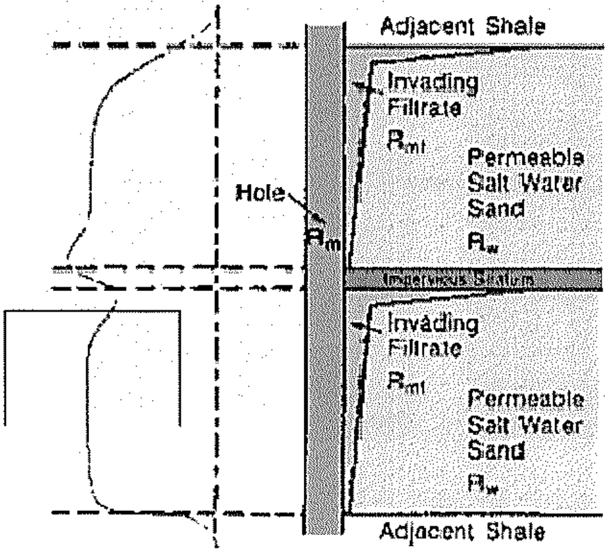
กราฟของ SP ที่วัดจากชั้นหินทรายจะให้ลักษณะที่สามารถบ่งบอกถึง

- Boundary: แสดงลักษณะการเปลี่ยนแปลงค่าความต่างศักย์ไฟฟ้าอย่างชัดเจนด้วยการแทรกสลับของชั้น หินดินดาน ชั้นหินดินดานปนทราย
- Interbedded: ลักษณะการแทรกสลับของชั้นหิน และ Grain distribution: การกระจายตัวของขนาดของเม็ดตะกอน

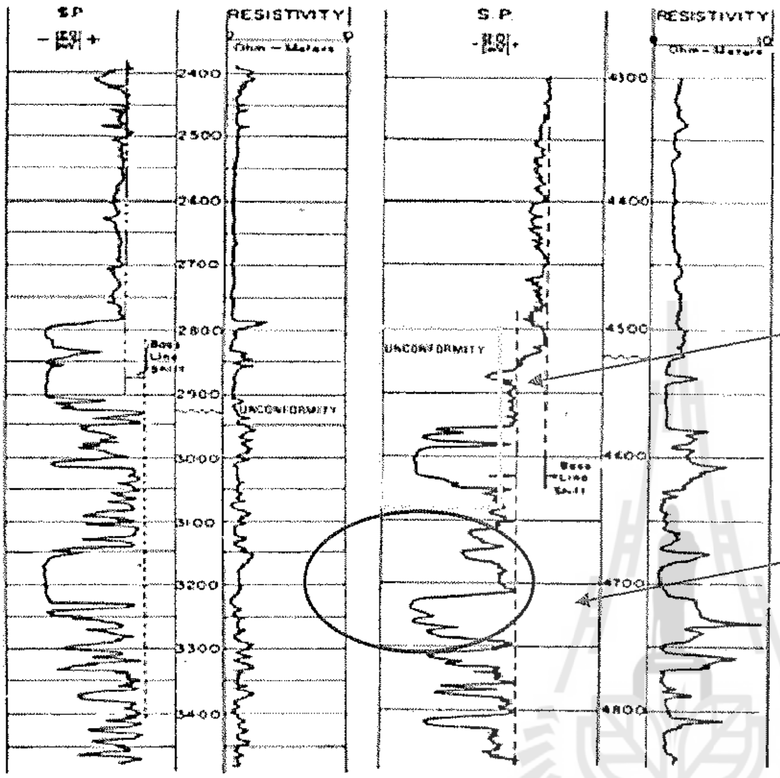
ในชั้นหินทราย (Sandstone)

- ลักษณะของกราฟแบบฟันปลา (serrated) เนื่องจากค่า SP ได้รับผลกระทบอย่างมากจากการเปลี่ยนแปลงปริมาณหินดินดานในชั้นหิน ทำให้ การบอกถึงลักษณะการกระจายตัวของเม็ดตะกอนทำได้ยากขึ้น
- กราฟของ SP ที่วัดจากบริเวณที่เป็นหินทราย อาจสามารถแปลความหมายในลักษณะของการลดขนาดของตะกอนขึ้นด้านบน (Fining upward) หรือ การเพิ่มขนาดขึ้นด้านบน (Coarsening upward)

- Sandstone with thin shale interbeded result the saw-tooth pattern (ลักษณะฟันเลื่อย)
- Upper= abnormal of SP > SSP



- Under= abnormal of SP< SSP
- This abnormal result from mud filtrate deposit under shale bed



coarsening upward

แบบฟันปลา
(serrated)

Fig. 4-21. Field examples of SP base line shift and unconformity (from Doll, 1948).

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Shape of SP graph

รูปร่างพื้นฐาน 4 แบบของกราฟของ SP ที่วัดได้จากชั้นหินทราย ได้แก่

1. ***รูประฆัง (Bell)***
2. ***รูปทรงกระบอก (Cylinder)***
3. ***รูปกรวย (Funnel)***
4. ***รูปไข่ (Egg)***
    - ***รูปฟันปลา (Serrated)***
    - ***รูปทรงเรียบ (Smooth)***
    - ทำให้สามารถแปลความหมายถึง รูปร่างภายนอก ลักษณะเนื้อหิน และสภาพแวดล้อมการเกิด
    - การใช้เพียงกราฟของ SP ในการแปลความหมายอาจมีความผิดพลาดได้ง่ายจึงควรที่จะใช้ประกอบกับข้อมูลอื่นๆ เช่น หินโผล่ แท่งหินจากหลุมเจาะ เป็นต้น

Shape of SP graph

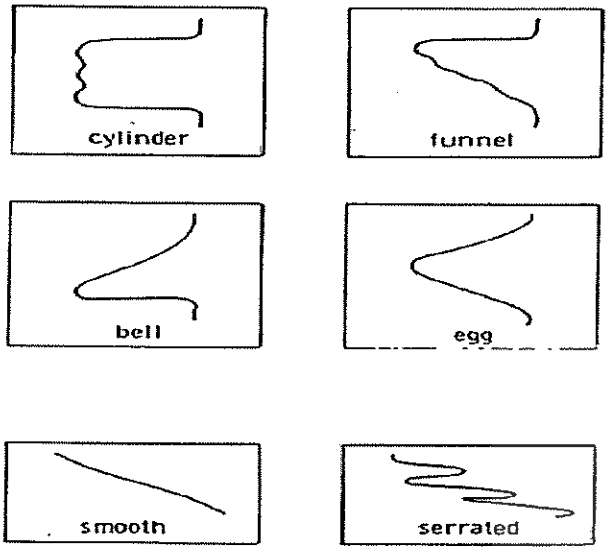

FIGURE 4. Basic descriptive shapes of SP profiles.

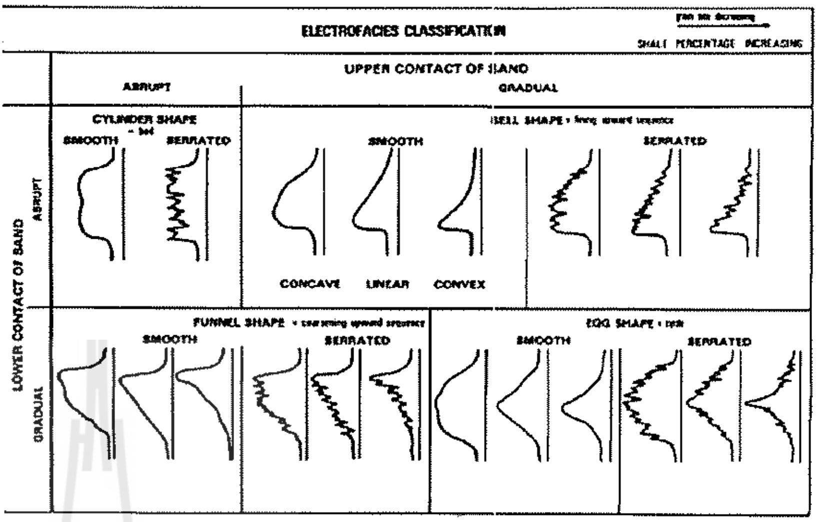

Fig. 5-1. - Classification of electrofacies by shapes of log responses.

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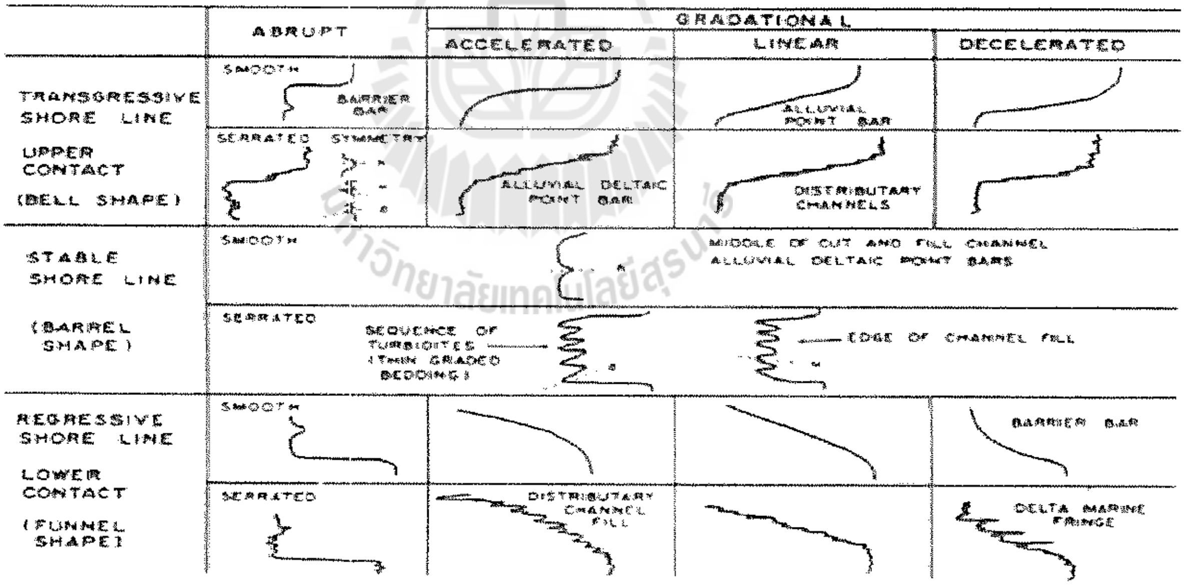
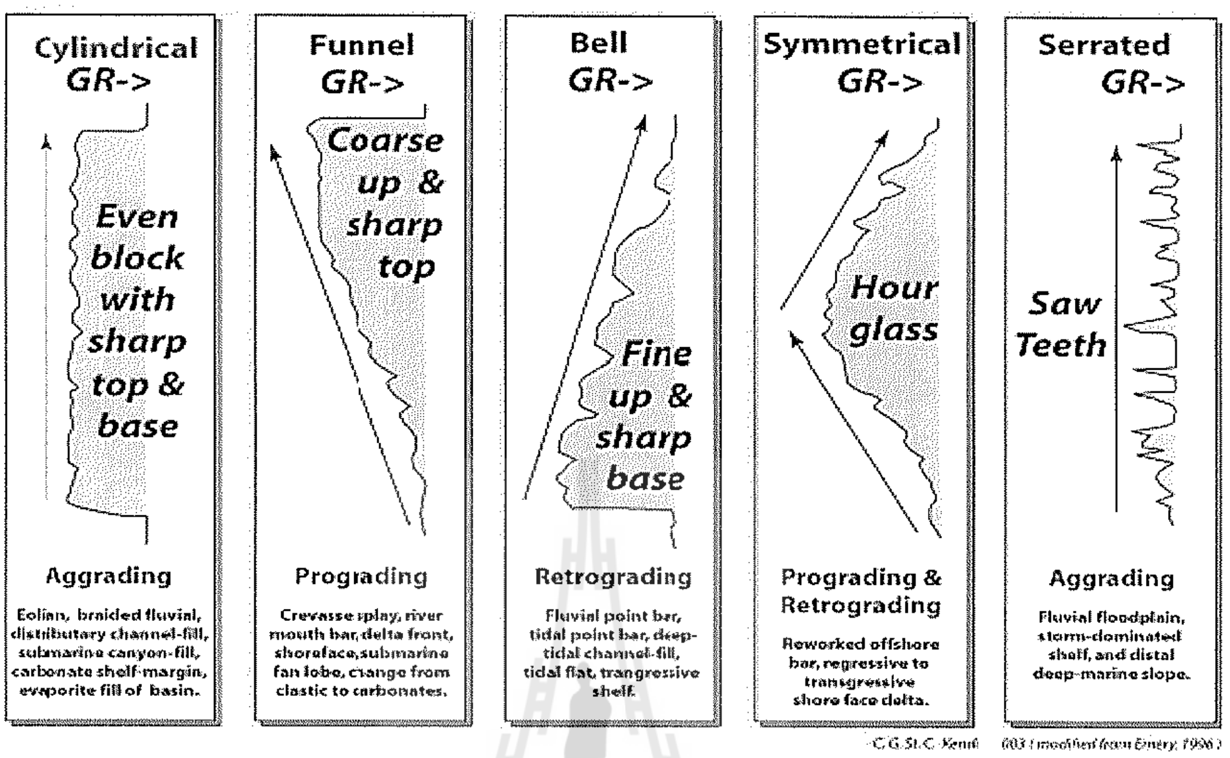


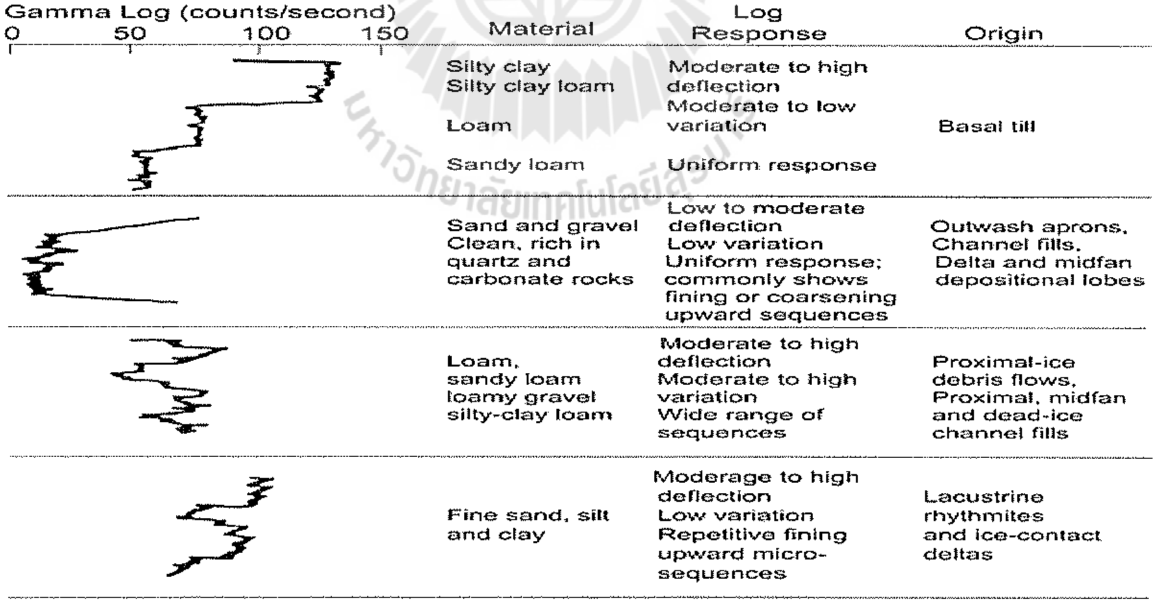
Fig. 5-2. - Classification of SP curve shapes in terms of sedimentary patterns (courtesy of Pirson, 1970, and Gulf Publishing Co., fig. 2-1).

General Gamma Ray Response to Variations in Grain Size

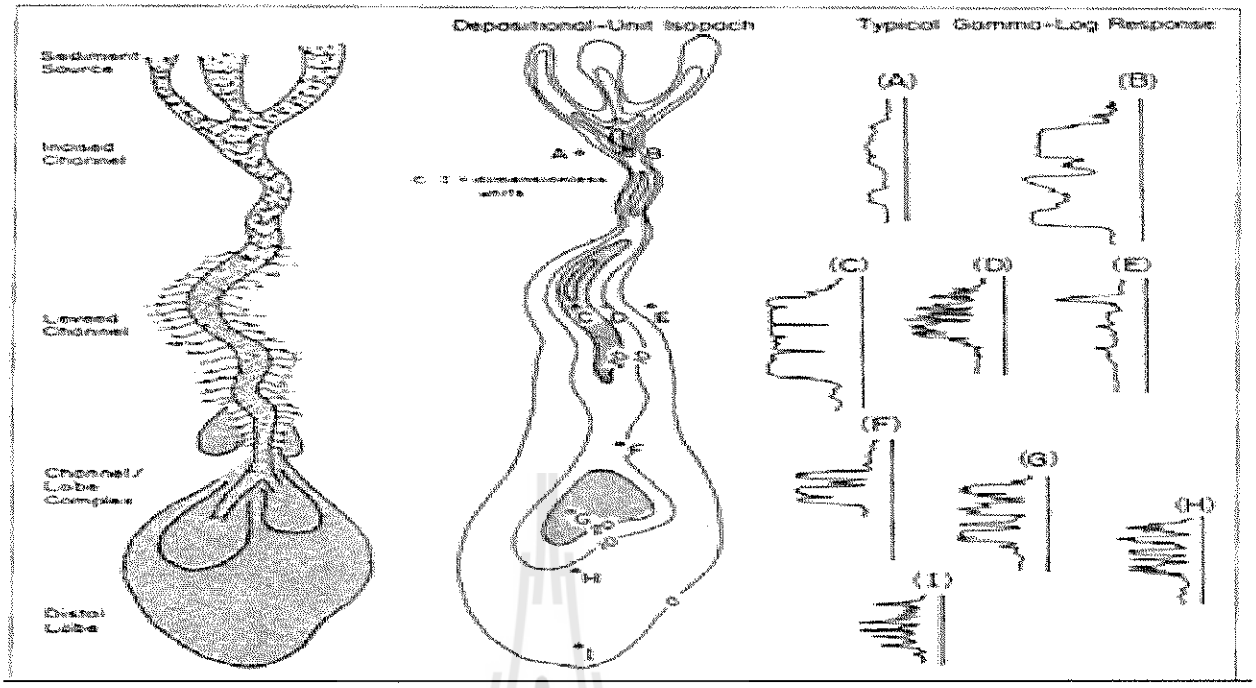


C.G.St.C. Kend 003 (modified from Emery, 1996)

Gamma-Ray Log Responses of Some Glacigenic Materials in Northeast Indiana



Gamma Log (counts/second) 0 50 100 150	Material	Log Response	Origin
	Silty clay Silty clay loam Loam Sandy loam	Moderate to high deflection Moderate to low variation Uniform response	Basal till
	Sand and gravel Clean, rich in quartz and carbonate rocks	Low to moderate deflection Low variation Uniform response; commonly shows fining or coarsening upward sequences	Outwash aprons, Channel fills, Delta and midfan depositional lobes
	Loam, sandy loam loamy gravel silty-clay loam	Moderate to high deflection Moderate to high variation Wide range of sequences	Proximal-ice debris flows, Proximal, midfan and dead-ice channel fills
	Fine sand, silt and clay	Moderage to high deflection Low variation Repetitive fining upward micro-sequences	Lacustrine rhythmites and ice-contact deltas



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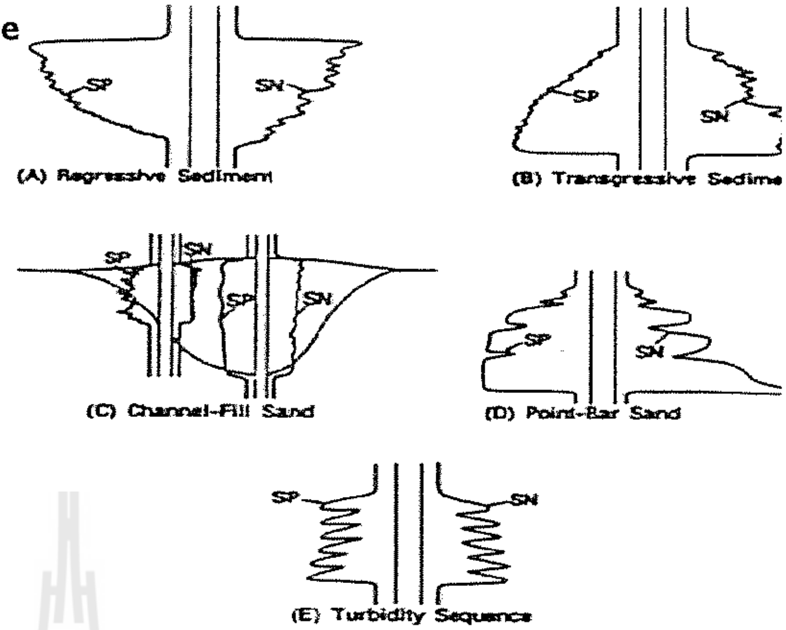
GR and SP curve shape vs. Environment

- Depositional environment: Use GR and SP vs. resistivity curve
- Resistivity curve is opposite from SP curve
- Resistivity log can identify **coal** and **dense limestone** but SP can not identify

- **GR & SP curve:**
  - Bell or cylinder pattern in Closed bay
  - Funnel pattern in Barrier island and marine bars
  - SP curve show close to shale base line in Pro-delta
  - Serrated pattern in Regressive sands in delta front

SP vs. short-normal device curve shape

1. **Regressive sand**
2. **Transgressive sand**
3. **Channel-fill sand bar**



(A) Regressive Sediment

(B) Transgressive Sedime

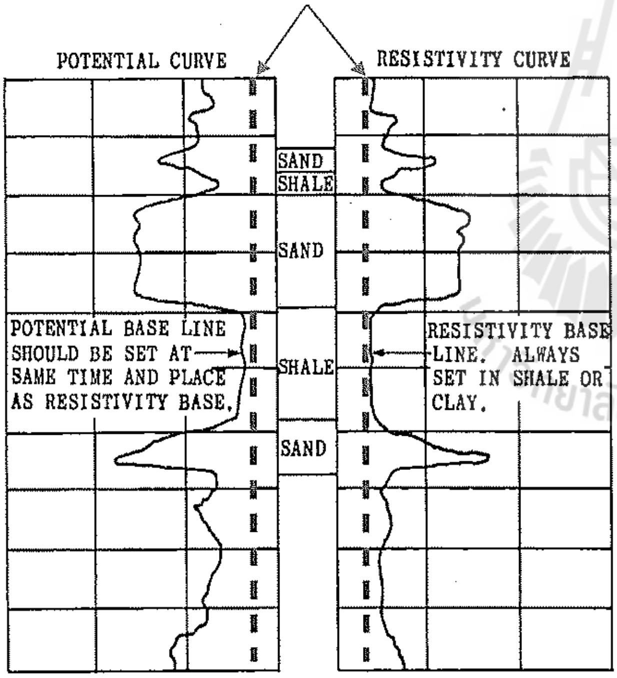
(C) Channel-Fill Sand

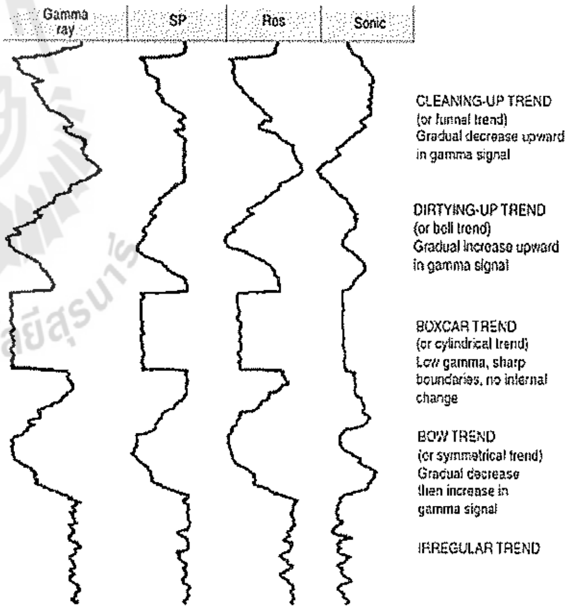
(D) Point-Bar Sand

(E) Turbidity Sequence

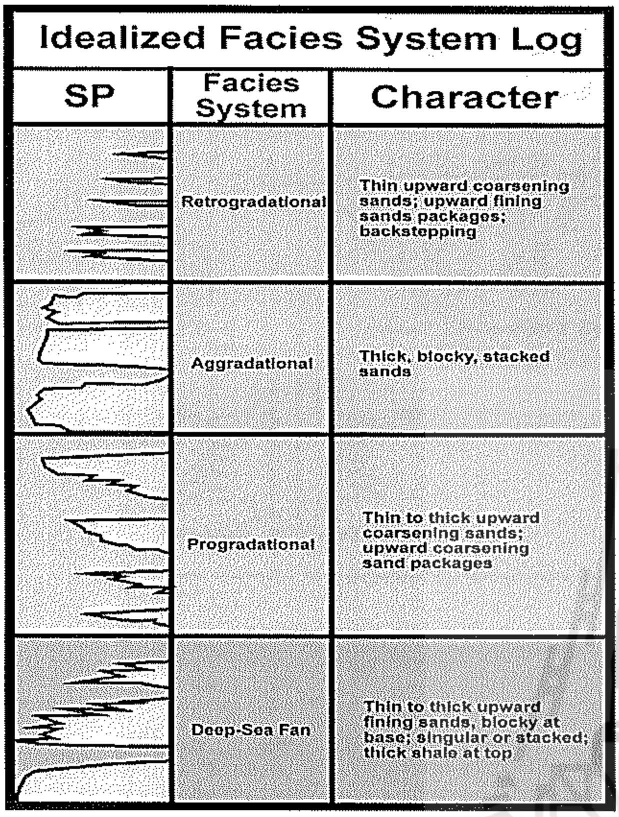
Figure 1-2. Sedimentation patterns and SP-short normal curves.

Shale base line



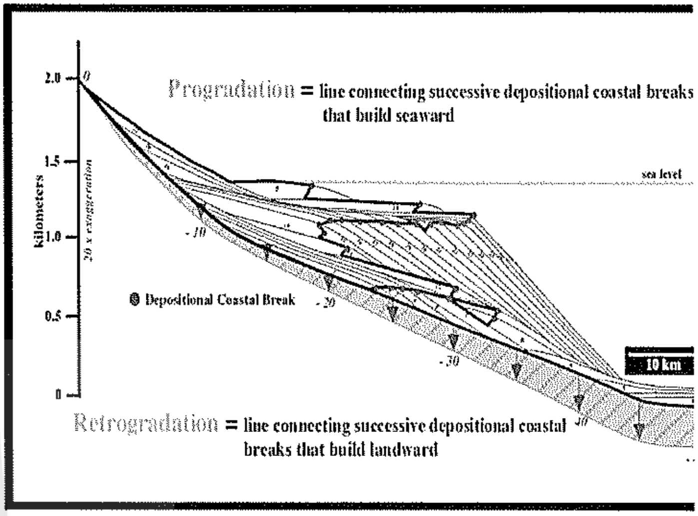


4. Turbidite



Idealized Facies System Log		
SP	Facies System	Character
	Retrogradational	Thin upward coarsening sands; upward fining sands packages; backstepping
	Aggradational	Thick, blocky, stacked sands
	Progradational	Thin to thick upward coarsening sands; upward coarsening sand packages
	Deep-Sea Fan	Thin to thick upward fining sands, blocky at base; singular or stacked; thick shale at top

Progradation



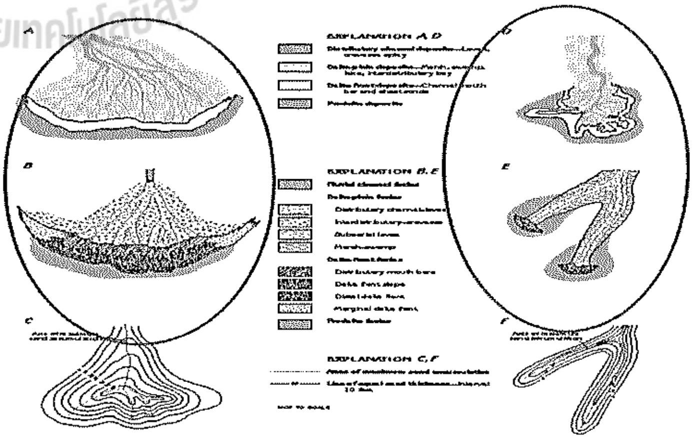
Progradation = line connecting successive depositional coastal breaks that build seaward

Retrogradation = line connecting successive depositional coastal breaks that build landward

5. Constructive delta

Lobate

Elongate



Modified from Fisher, W.L., 1969, Facies characterization of Gulf Coast basin delta systems, with some Holocene analogues: Gulf Coast Association of Geological Societies Transactions, v. 19, p. 239-261.

Figure 82. Constructional deltas are characterized by lobate (A) and elongate (D) shapes. The different delta sedimentary facies are arranged in a fan shape in the lobate delta (B) but are fingerlike in the elongate delta (E). Sand thickness distribution patterns (C, F) are different for the two delta types, but sands are thickest in the distributary channels of both types.

Deltas

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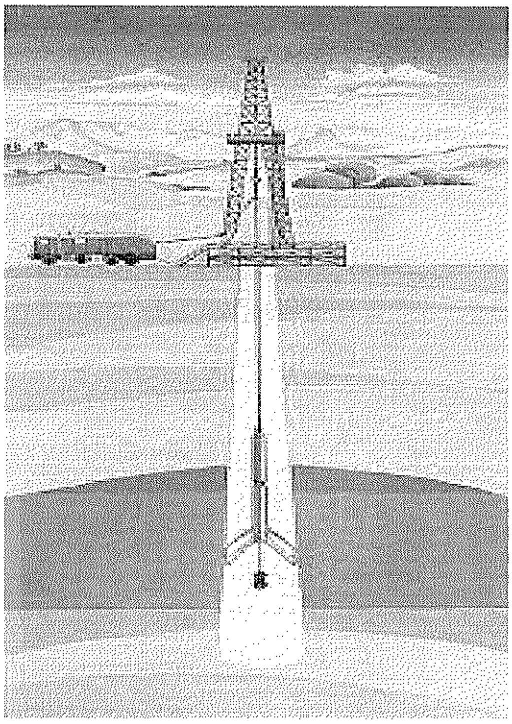
3. Resistivity Logs



Wireline logging

- Several tools are run on each logging trip into the hole.
- **First run** will usually be a "**resistivity run**" using a combined tool "string" (several tools attached together) consisting of a gamma-ray tool, a caliper tool, and three different types of resistivity tools.
- The log generated from this run is called a "Gamma-Ray & Resistivity Log".

Resistivity Log

- Resistivity measures the electric properties of the formation,
- Resistivity is measured as, R (Ohm-m unit)
- Resistivity is the inverse of conductivity,

Related to:

- Fluid content (hydrocarbons/water)
- Porosity
- Mineralogy
- Temperature
- Measured in several ways

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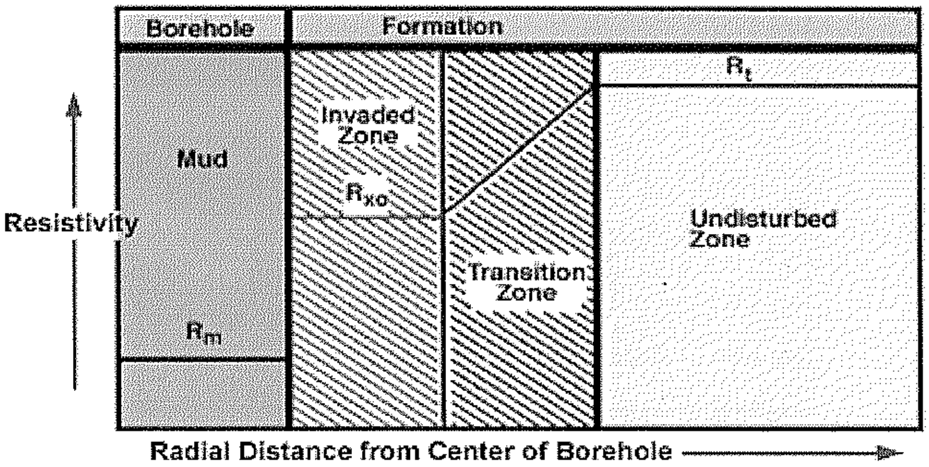
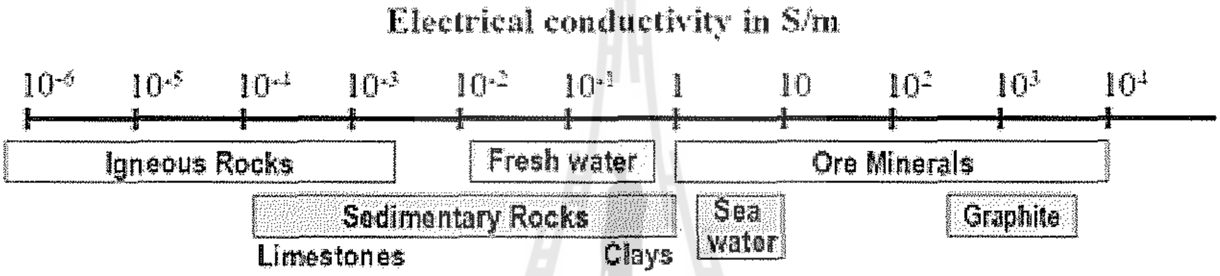
Resistivity Log in borehole



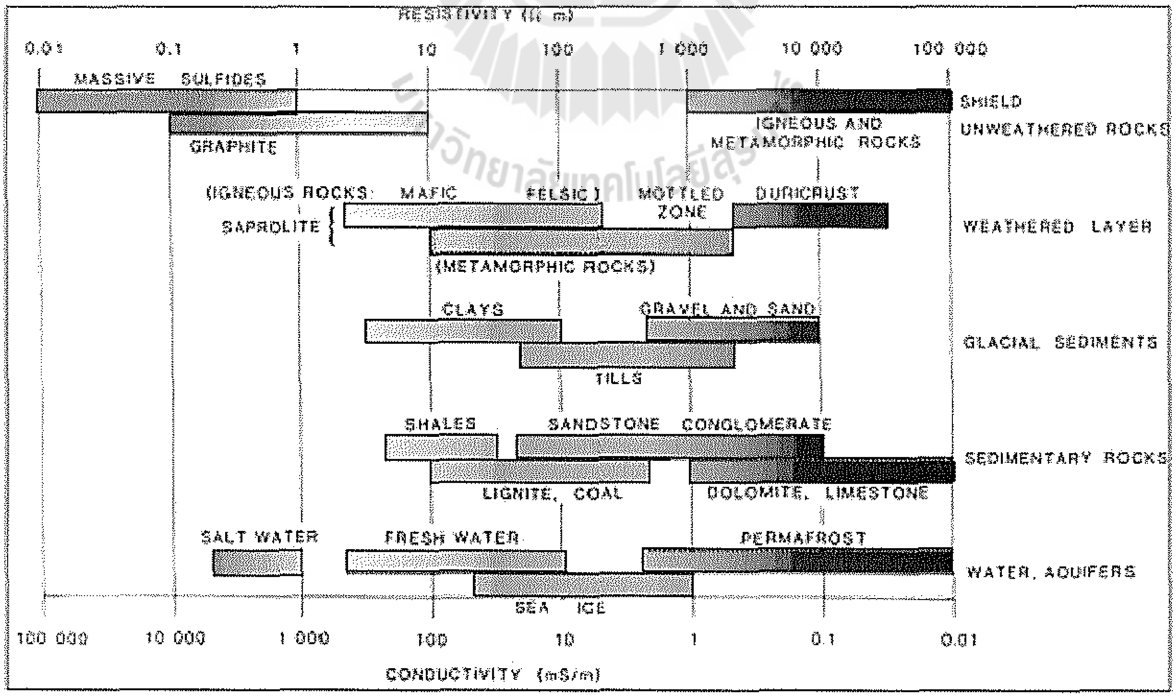
R_m is mud resistivity
R_{xo} is shallow resistivity
R_i is medium resistivity
R_t is virgin resistivity

Resistivity and Conductivity

- **ความต้านทานไฟฟ้า (resistivity)** ของวัตถุใดๆ เป็นการวัดค่าการต่อต้านการไหลของกระแสไฟฟ้าที่ไหลผ่านวัตถุนั้นๆ มี หน่วยเป็น ohm.m
  - Water: low resistivity
  - Oil and gas: high resistivity
- **การนำไฟฟ้า (conductivity)** ของวัตถุใดๆ เป็นการวัดความสามารถในการยอมให้กระแสไฟฟ้าผ่านวัตถุนั้นๆ หรือ ความสามารถในการนำไฟฟ้าซึ่งเป็นส่วนกลับกับความต้านทานไฟฟ้า มีหน่วยเป็น (s/m)
  - Water: high conductivity
  - Oil and gas: low conductivity



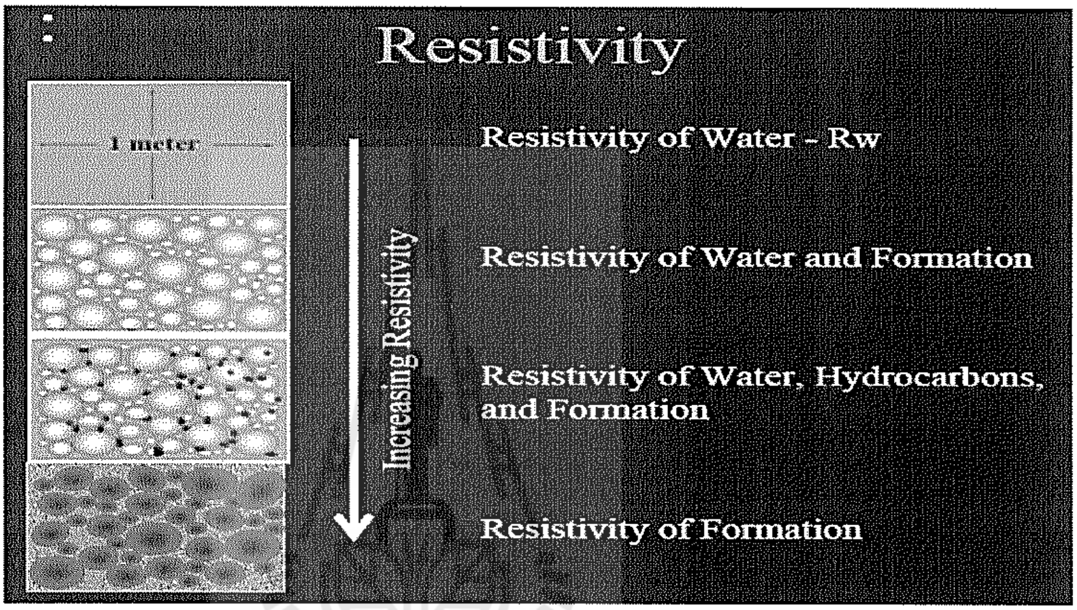
Specific resistivity and conductivity in rocks



ความต้านทานไฟฟ้าของชั้นหิน ขึ้นอยู่กับ

ความต้านทานไฟฟ้าของน้ำในช่องว่างจะขึ้นอยู่กับ

- ธรรมชาติ และปริมาณของสารที่ละลายอยู่ในน้ำ
- ชนิดของหิน ธรรมชาติและปริมาณของแร่ดิน และ แร่ที่นำไฟฟ้า
- เนื้อหิน การกระจายตัวของช่องว่างการกระจายตัวของแร่ดิน และแร่ที่นำไฟฟ้า
- อุณหภูมิ



Resistivity

Resistivity of Water - Rw

Resistivity of Water and Formation

Resistivity of Water, Hydrocarbons, and Formation

Resistivity of Formation

ความสัมพันธ์ระหว่างความต้านทานไฟฟ้ากับความเค็ม resistivity & salinity

- เนื่องจากความต้านทานไฟฟ้าขึ้นอยู่กับความเข้มข้น และชนิดของสารละลายในน้ำ ความต้านทานไฟฟ้าจะมีค่าลดลงเมื่อ ความเข้มข้นของสารมีค่าเพิ่มขึ้น (นำไฟฟ้าได้ดี)
- ความเค็ม (salinity) เป็นการวัดค่าความเข้มข้นของสารละลาย มี หน่วยเป็น ppm หรือ g/l
- Reservoir Rock ไม่สามารถนำไฟฟ้าได้ เนื่องจากทั้งHydrocarbon and sediment ไม่นำไฟฟ้า กระแสไฟฟ้าจะไหลผ่านชั้นหินได้ก็ต่อเมื่อมีน้ำที่มีสารละลายอยู่ในช่องว่างของเนื้อหิน
- ความเข้มข้นของสารละลาย (salinity) เป็นตัวกำหนดความสามารถในการต้านทานการไหลของกระแสไฟฟ้า โดยที่สารละลายที่มีความเข้มข้นมาก จะมีค่าความต้านทานไฟฟ้าต่ำหรือนำไฟฟ้าได้ดี
- ในชั้นหินที่มีความพรุนสูงที่อิ่มตัวด้วยน้ำจะมีค่าความต้านทานไฟฟ้าต่ำ ดังนั้นการวัดค่าความต้านทานไฟฟ้าจึง เป็นวิธีการหนึ่งในการศึกษาถึงค่าความอิ่มตัวด้วยน้ำของชั้นหิน (Sw)

Resistivity of clays

- Clay mineral ซึ่งเป็นส่วนประกอบหลักของหินดินดาน และยังอาจแทรก อยู่ตามช่องว่างระหว่างเม็ดตะกอน ทำให้ค่าความต้านทานไฟฟ้า ของชั้นหินเปลี่ยนแปลงได้

- ค่าความต้านทานไฟฟ้าต่ำ ในชั้นหินดินดาน เนื่องจากว่าแร่ดินสามารถนำไฟฟ้าได้ (SP สูง)
- การนำไฟฟ้าของแร่ดินเกิดได้ 2 ลักษณะ คือ การนำไฟฟ้าเนื่องจากน้ำที่อยู่ในโครงสร้างของแร่ดิน และโครงสร้างของแร่ดินเอง
- โครงสร้างของแร่ดินเป็นชั้นของ silicate ซึ่งมีผิวเป็นประจุลบ ทำให้ประจุบวกของอิออนต่างๆมาล้อมรอบและจับตัวกับ โมเลกุลของน้ำที่ล้อมรอบ Na^+ อีกชั้นหนึ่ง น้ำที่ล้อมรอบแร่ดินเหล่านี้เรียกว่า Bound water

Resistivity devices เครื่องมือวัดค่าความต้านทานไฟฟ้า

หลักการทำงาน

- การส่งกระแสไฟฟ้าเข้าไปในชั้นหิน และวัดการตอบสนองของชั้นหิน ที่มีต่อกระแสไฟฟ้าที่ส่งเข้าไป โดยใช้ตัวรับสัญญาณไฟฟ้าซึ่งมี ค่าระยะห่างระหว่างตัวส่งกระแสไฟฟ้ากับตัวรับสัญญาณไฟฟ้าที่คงที่ค่าหนึ่ง ค่าระยะห่างระหว่างตัวส่งกระแสไฟฟ้ากับตัวรับสัญญาณไฟฟ้าจะเป็นตัวกำหนดความลึกที่เครื่องมือจะสามารถวัดเข้าไปในชั้นหินได้

Type of Resistivity Device

1. Resistivity devices or Conventional resistivity tools
   - 1.1 Non-focus long-spacing tools
     - 1.1.1 Normal configuration
     - 1.1.2 Lateral and inverse configuration
   - 1.2 Focus long-spacing tools
     - 1.2.1 Laterologs: which are used with salt mud.
     - 1.2.2 Spherically focused log (SFL)
2. Induction devices; which are used with fresh water base mud
3. Non-focused Microtools: Microlog (ML), Microlaterolog (MLL), Microproximity log (PL), Microspherically focused log (MSFL)

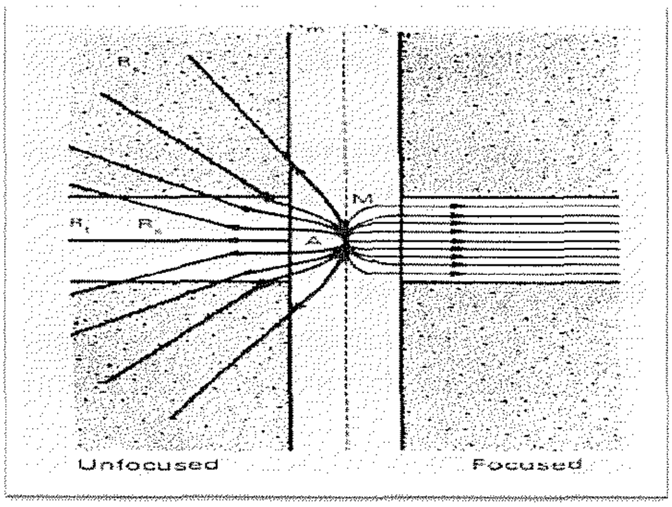
Resistivity or Conventional resistivity tools

It consist of

1.1 Non-focus long-spacing tools

1.2 Focus long-spacing tools:

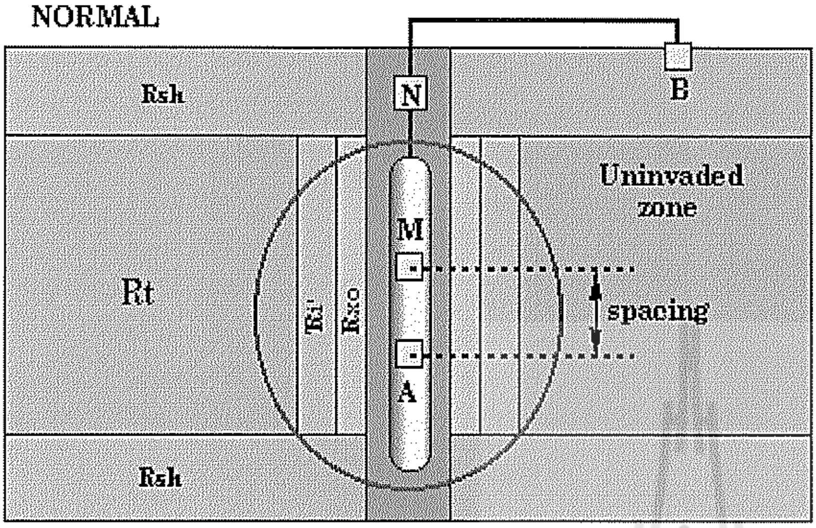
- Laterologs



1.1 Non-focus long-spacing tools

1.1.1 Normal Resistivity Tool

Spacing of electrodes determines penetration



Short normal

- Spacing A and M = 16 in

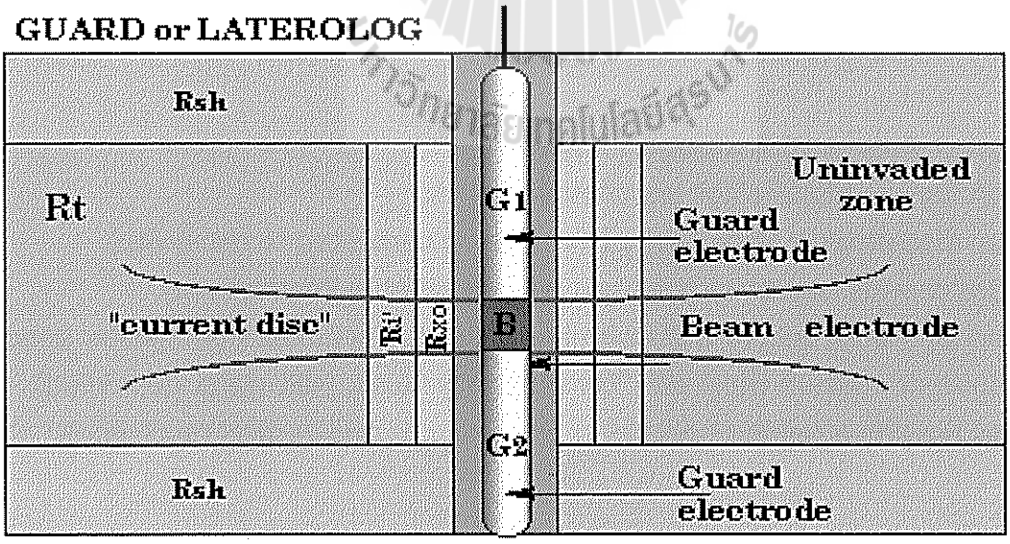
Long Normal

- Spacing A and M = 64 in

Normal devices: 2 current electrode (A, B) and 2 potential electrode (M, N)

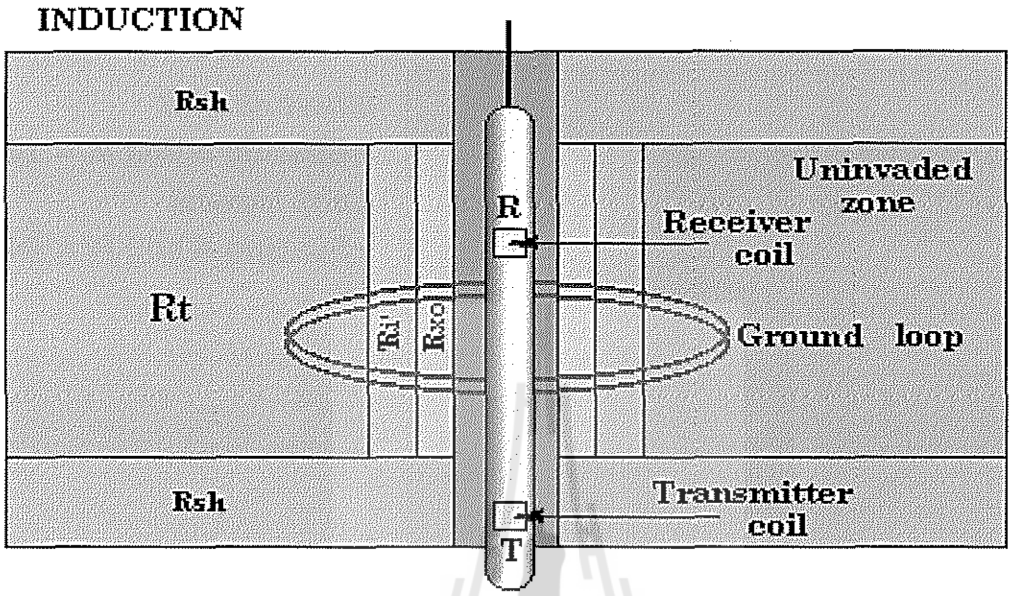
1.1.2 Guard or Laterolog Tool

The guard electrodes focus the current in a narrow disk



1.1.3 Induction (Conductivity) Tool

- Receiver coil measures the induced electrical



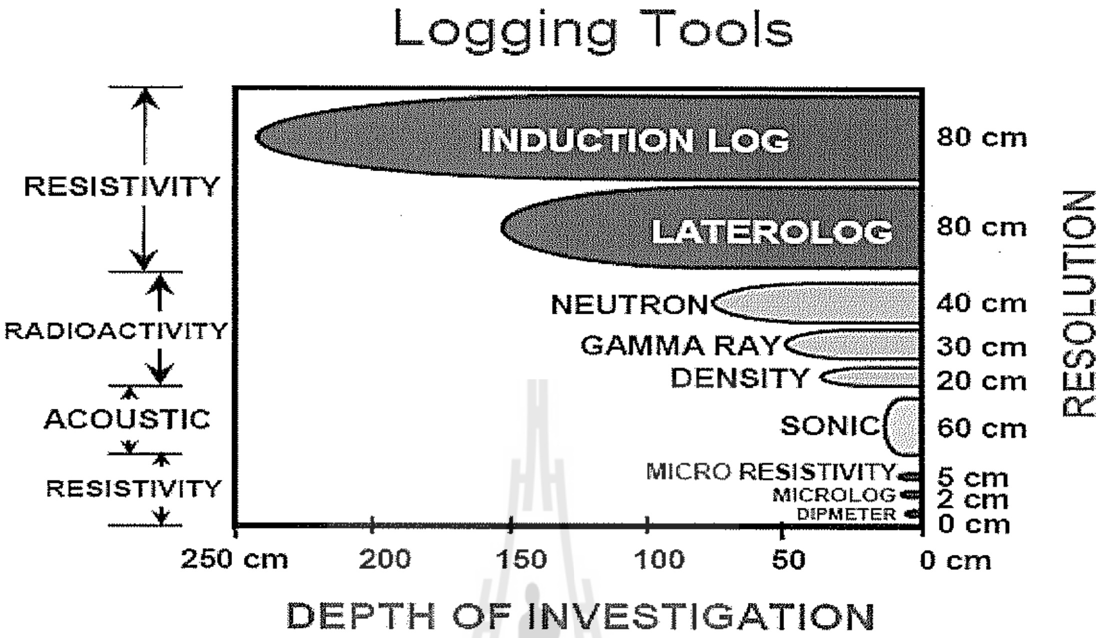
Resistivity logs and Induction logs

- Resistivity logs: ความต้านทานไฟฟ้า (electrical resistivity) ของวัตถุเป็นความสามารถในการต้านทานการไหลของกระแสไฟฟ้าผ่านวัตถุนั้นๆ
- ค่าความต้านทานไฟฟ้าของชั้นหิน สามารถวัดได้จากการ เปลี่ยนแปลงค่ากระแสไฟฟ้า (current variations) โดยใช้ เครื่องมือ electrical devices
- Induction logs: การวัดจากค่าการเปลี่ยนแปลงค่ากระแสไฟฟ้าเหนี่ยวนำ (induced current variation) โดยใช้ เครื่องมือ induction devices

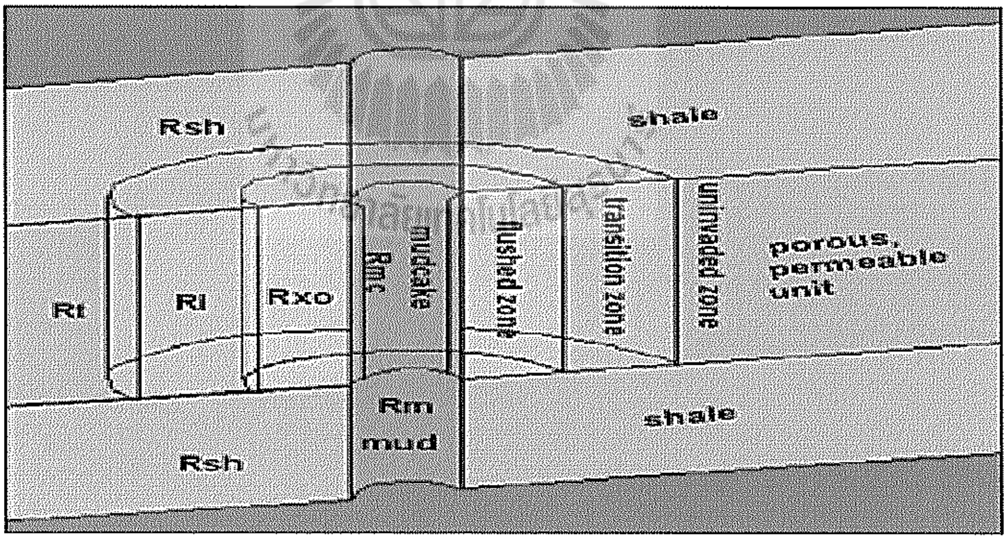
Comparing Laterologs and Induction Logs

- Induction logs and Laterologs are complimentary,
- Induction logs provide conductivity (that can be converted to resistivity).
- Laterologs provide resistivity (that can be converted to conductivity).
- Induction logs work best in wells with low conductivity fluids. (fresh water base mud)
- Laterologs work best in wells with low resistivity fluids. (salt water base mud)
- Both logs provide a range of depths of penetrations and vertical resolutions.

Depth of Investigation of Logging Tools



The Borehole Environment



Resistivity log depth of investigation:

Flushed zone Rxo	Invaded zone Ri	Uninvaded zone Rt
Micro Log (ML)	Short normal (SN)	Long normal
Microlateor log (MLL)	Laterolog-8 (LL-8)	Latero log (LL)
Proximity log (PL)	Spherically focused log (SFL)	Deep induction Log (ILD)
Microspherical focused log (MSFL)	Induction log medium (ILM)	Deep latero log (LLD)
	Shallow latero log (LLS)	Laterolog-3 (LL-3)
		Laterolog-7 (LL-7)

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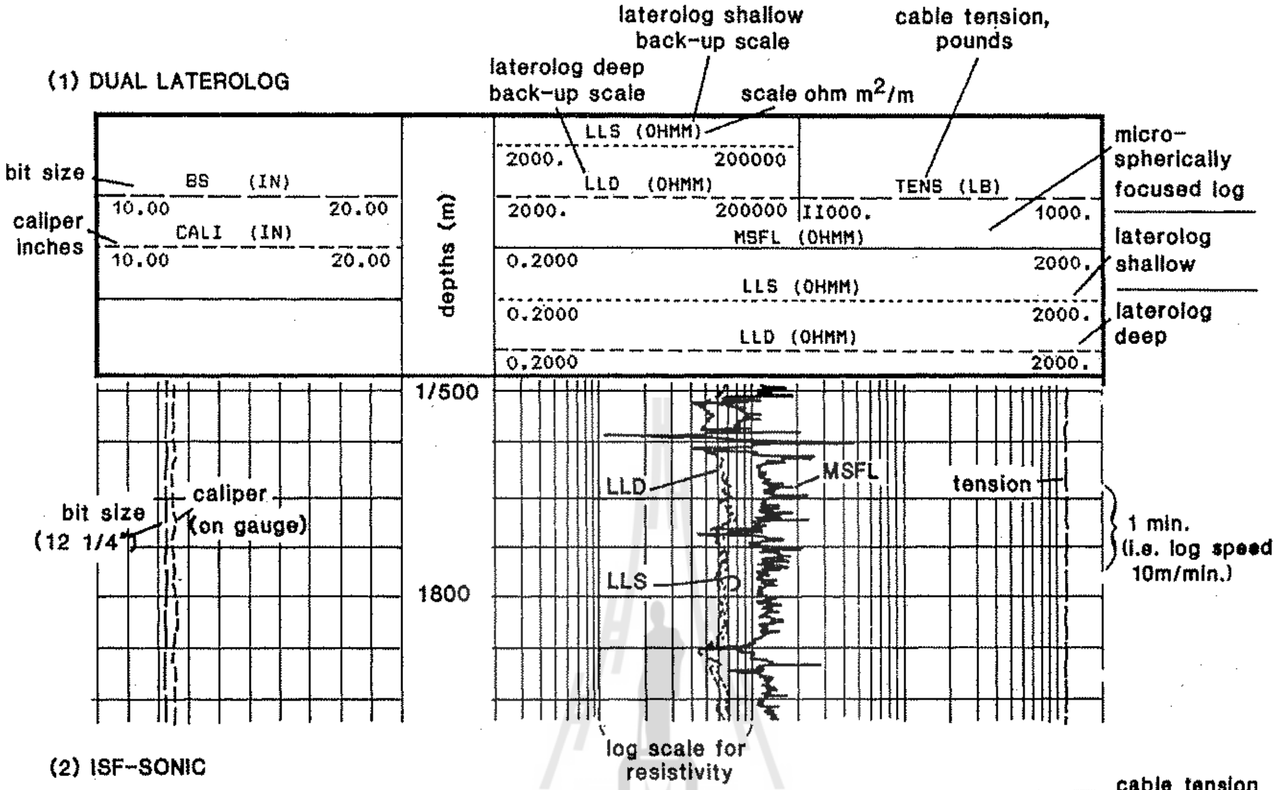
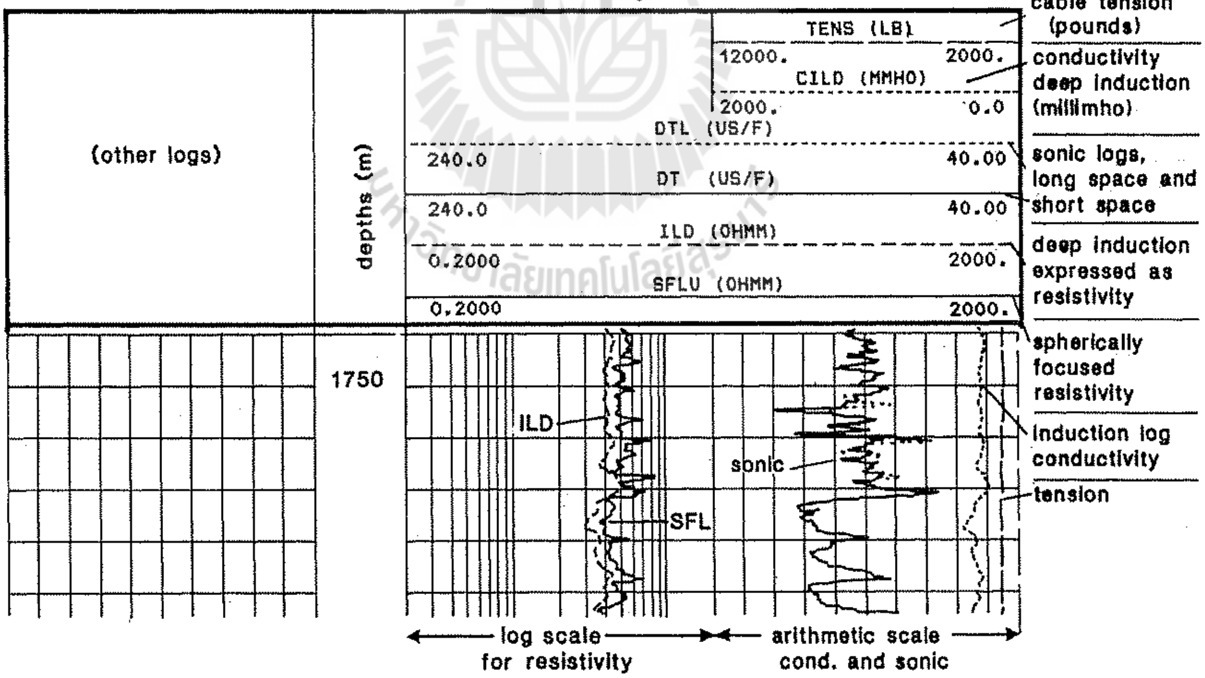
Log Presentation

(1) DUAL LATEROLOG



(2) ISF-SONIC



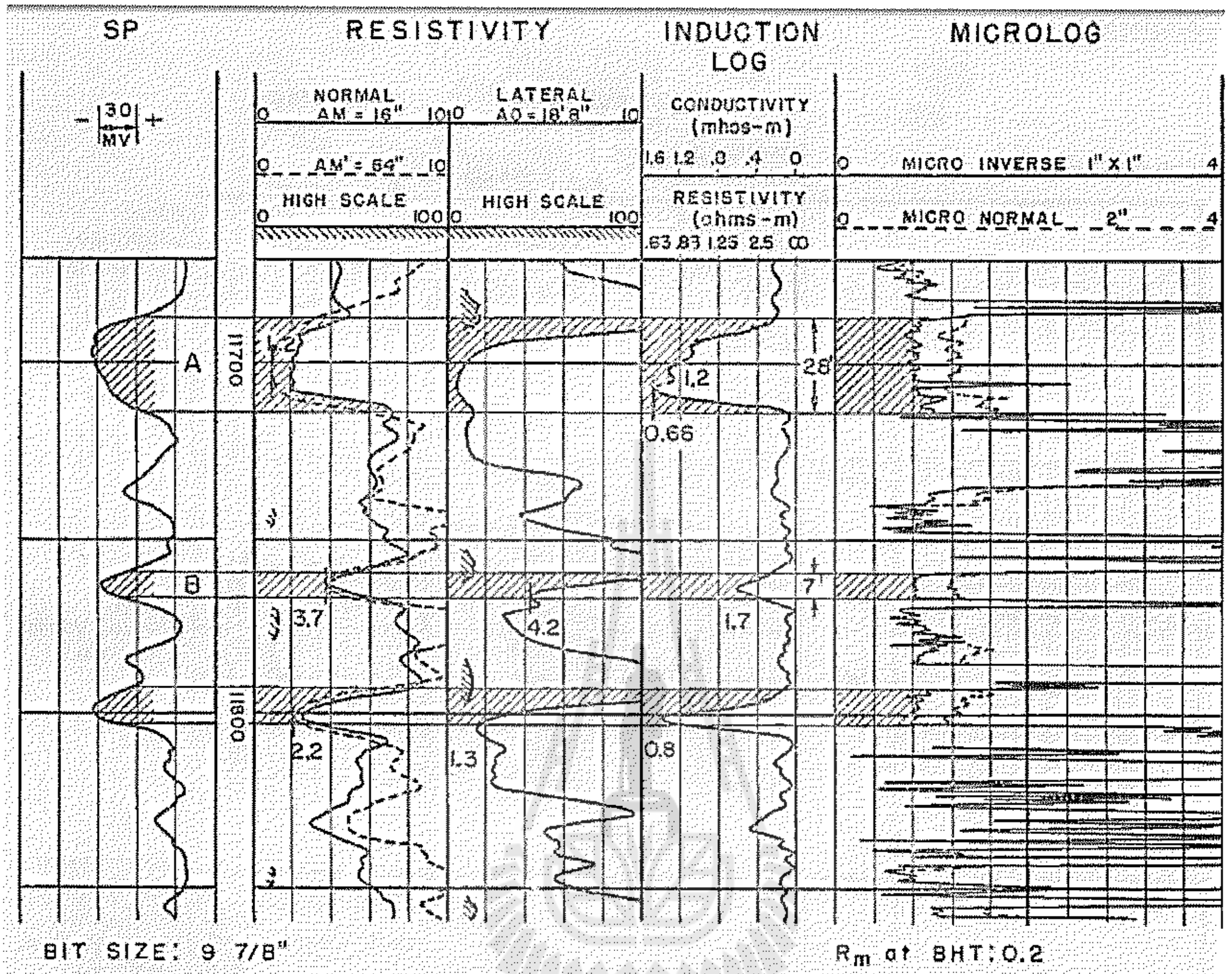


FIGURE 14-16. Example of induction log.

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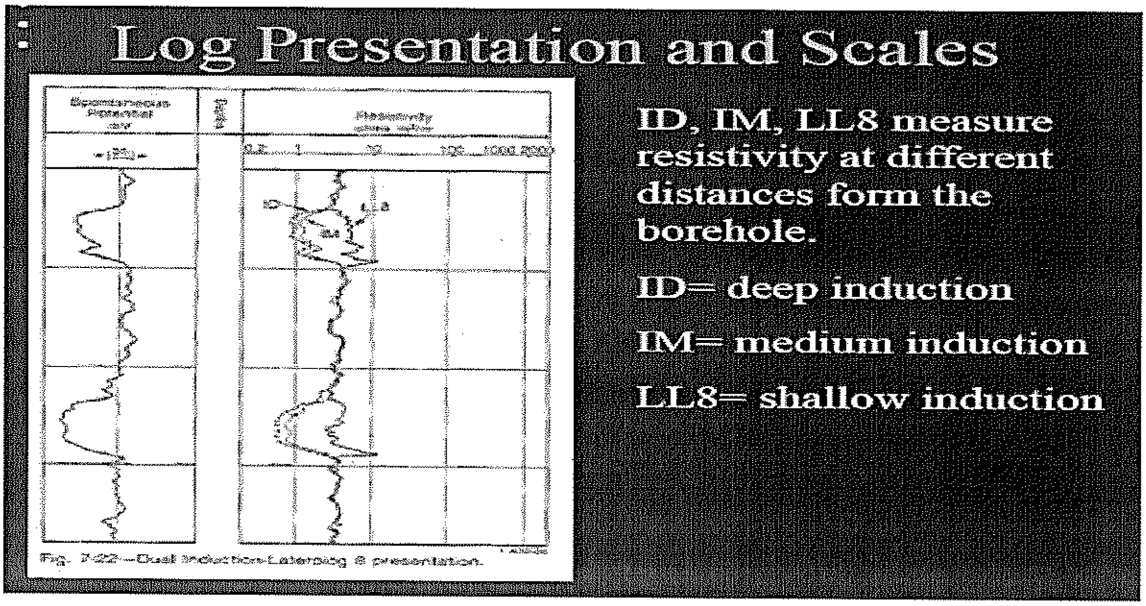


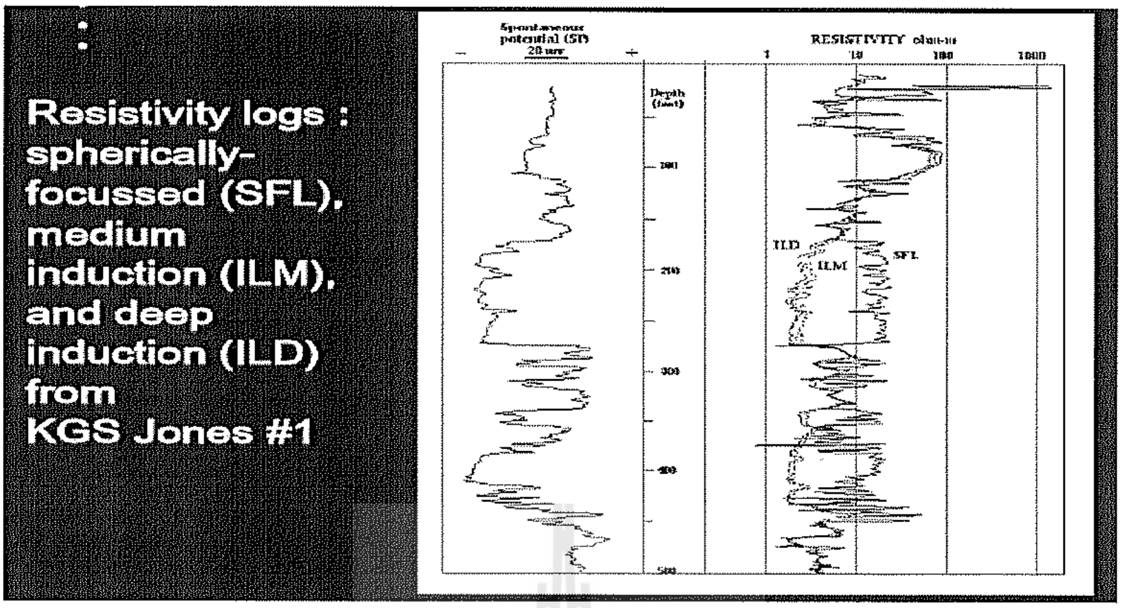
Log Presentation and Scales

ID, IM, LL8 measure resistivity at different distances form the borehole.

ID= deep induction

IM= medium induction

LL8= shallow induction



Resistivity logs : spherically-focussed (SFL), medium induction (ILM), and deep induction (ILD) from KGS Jones #1

Resistivity Log Applications

1. "True" Rt Formation Resistivity
2. Fluid Saturation Sw from Archie's Equation
3. Determination of Hydrocarbon-Bearing vs. Water-Bearing Zones
4. Geopressure Detection
5. Diameter of Invasion
6. Porosity & Permeability
7. Source rock identification and it is maturity.
8. Stratigraphic correlation and facies depositional environment.

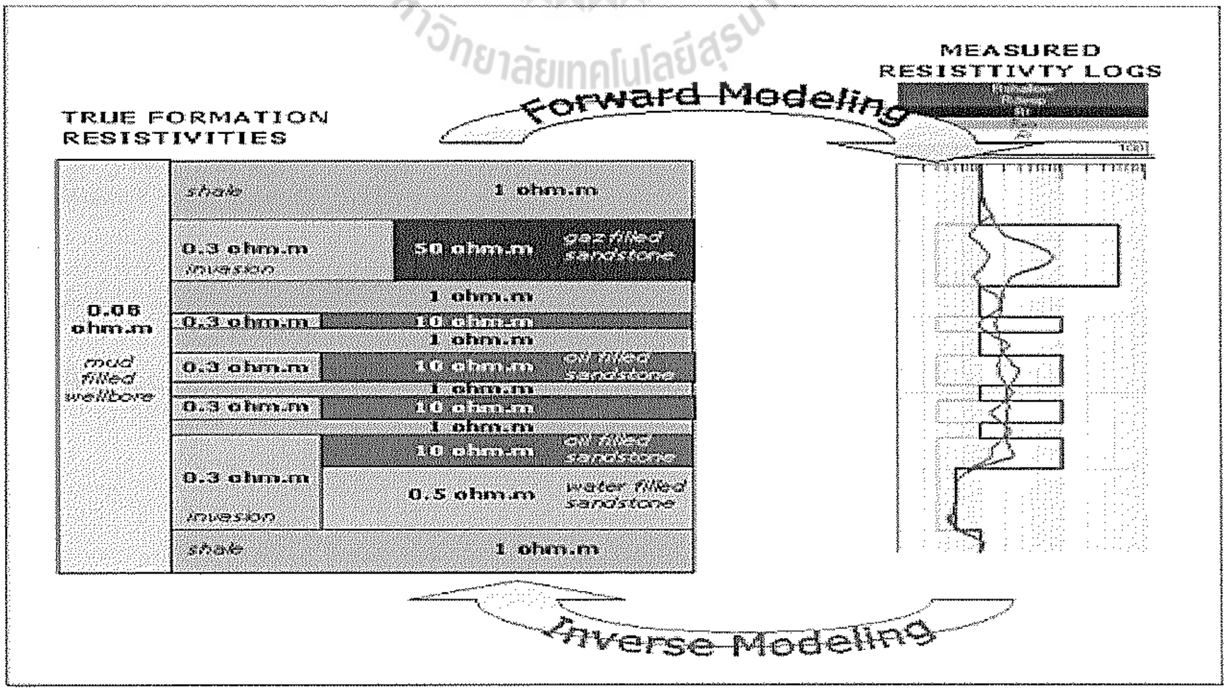


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Figure 19.25 shows the characteristics that are being looked for schematically.

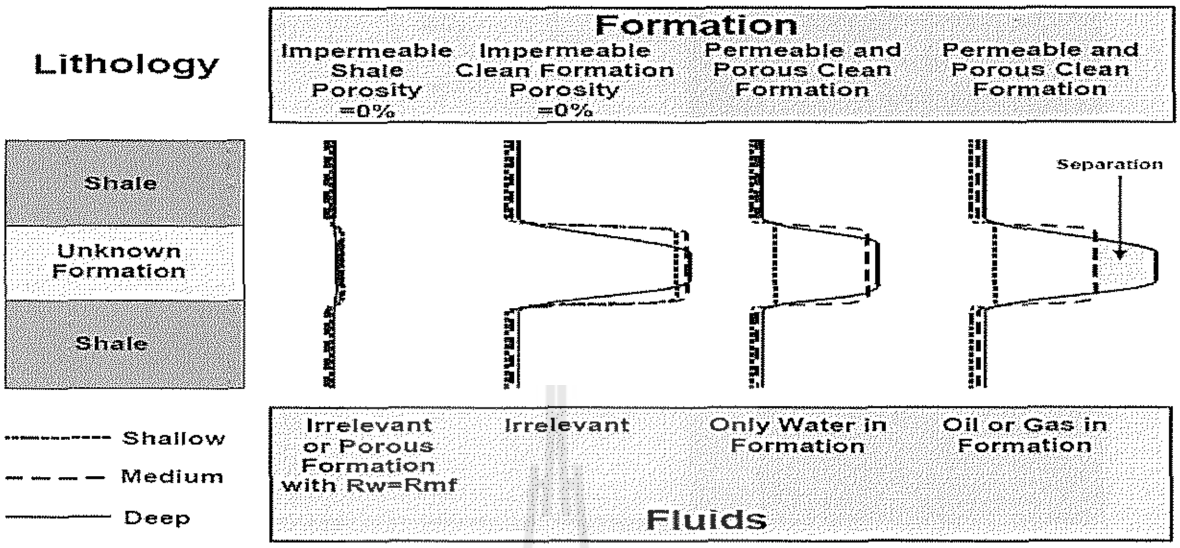


Figure shows the response of resistivity logs in formations with various fluids (recognition of hydrocarbon zones).

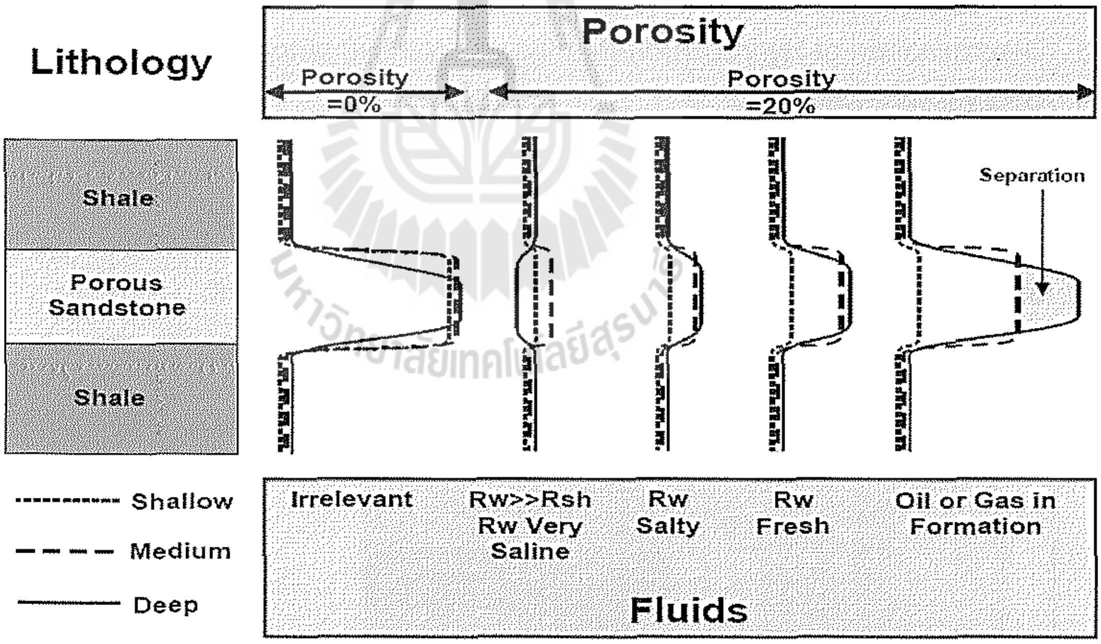


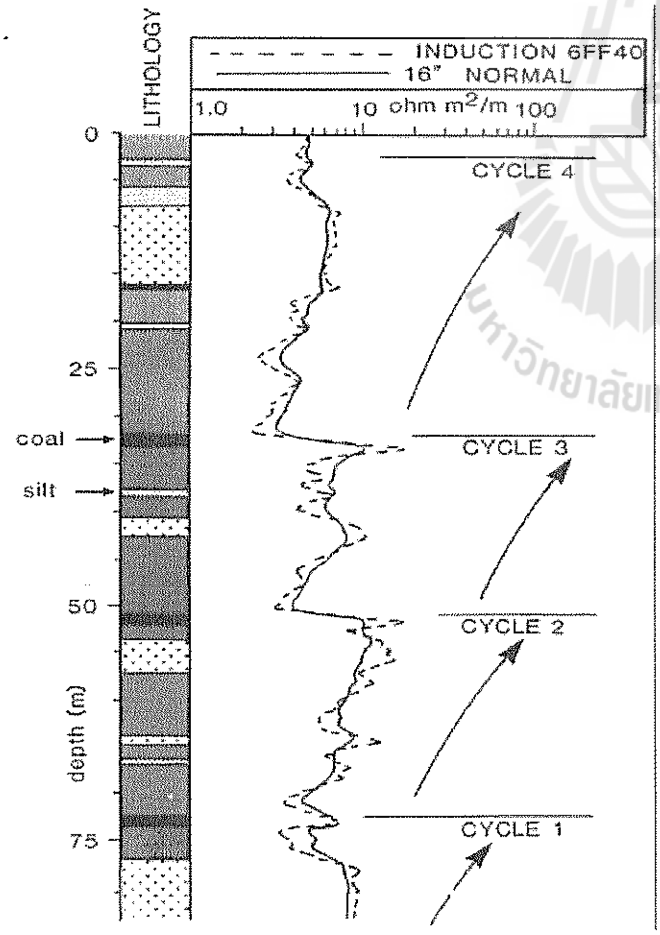
Fig. 19.26 The behaviour of the resistivity log responses for different formation water salinities.

การจำแนก Hydrocarbon Zones

Recognition of oil and gas in reservoir rocks is carried out by:

- Oil shows in the mud log. Noting a difference in the shallow, medium and deep resistivity tool responses.
- If all three curves are low resistivity, and overlie each other, the formation is an impermeable shale, or, rarely, the formation is permeable and water-bearing but the mud filtrate has the same resistivity as the formation water.
- If all three curves are higher resistivity than the surrounding shales, and overlie each other, the formation is an impermeable cleaner formation (sandstone, limestone).
- If the shallow curve has low resistivity, but the medium and deep penetrating tools have a higher resistivity that is the same (they overlie each other), the formation is permeable and contains only formation water.
- If the shallow curve has low resistivity, the medium as a higher resistivity, and the deep one has an even higher resistivity (i.e., there is separation of HC formation)

Textures and Facies Recognition



Use of resistivity logs to track changes of lithofacies.

In this case the log shows small scale deltaic cycles

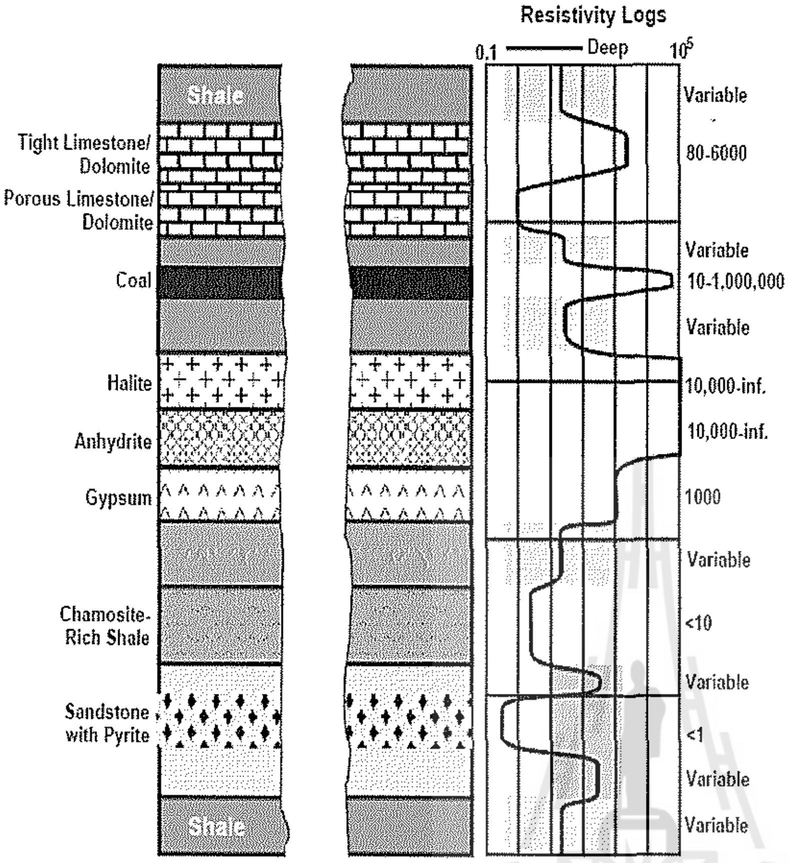
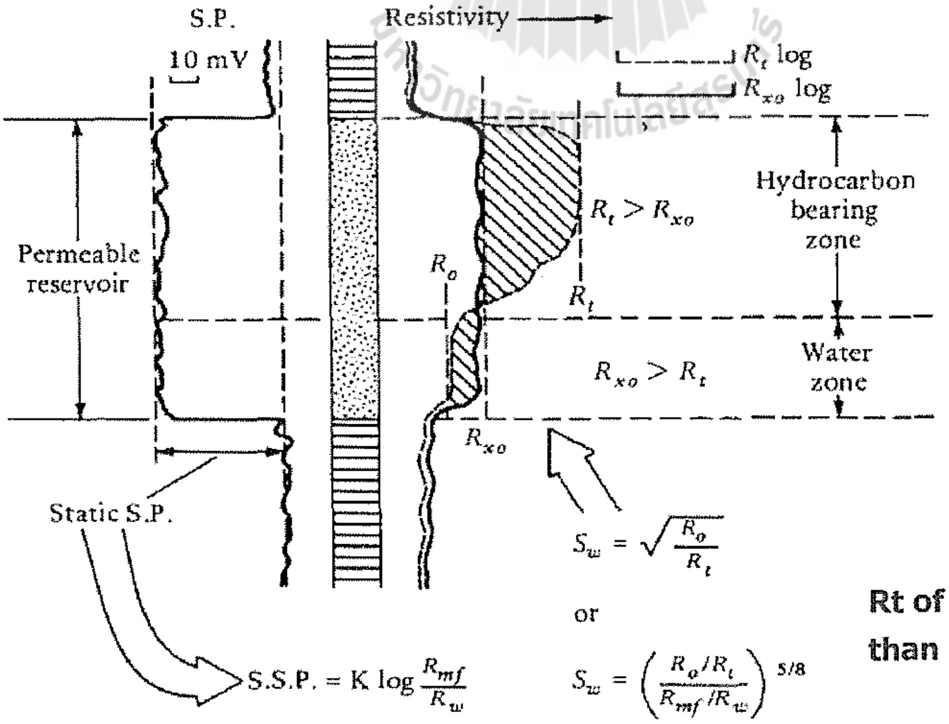


Fig. 19.28 Characteristic resistivities from various lithologies recorded by resistivity logs.

Lithology Recognition

- Gypsum 1000 Ωm.
- Anhydrite 10,000 - α Ωm.
- Halite 10,000 - α Ωm.
- Coals 10 –106 Ωm.
- Tight limestones and dolomites 80 – 6000 Ωm.
- Disseminated pyrite < 1 Ωm (pyrite has a resistivity of 0.0001 – 0.1 Ωm.
- Chamosite <10 Ωm.



Rt of HC zone is higher than Rt in water zone.

Fluid Saturation

Calculating Fluid Saturation

$$S_w = \varphi(R_w/R_t)^{0.5} \quad \text{or} \quad S_w = \frac{(R_{xo}/R_t)^{5/8}}{(R_{mf}/R_w)}$$

Where

R_{xo}= Resistivity of flushed zone

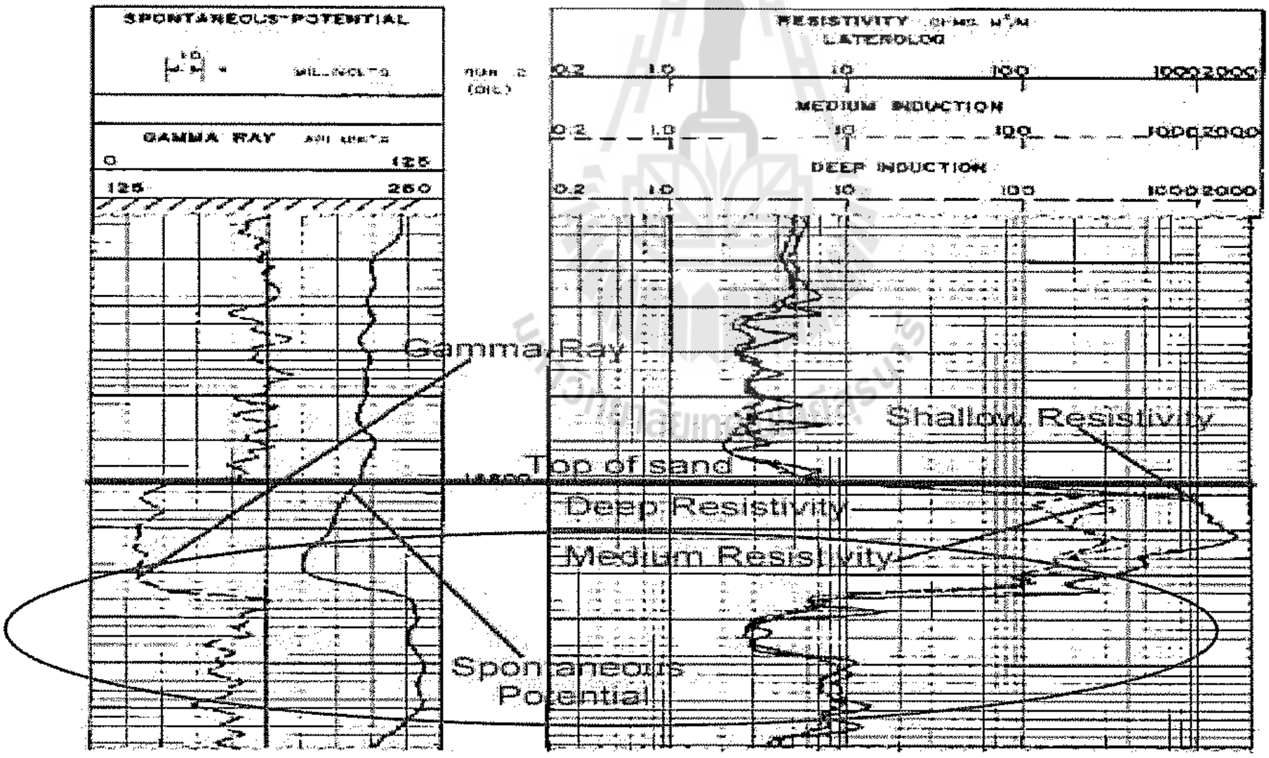
R_w= Resistivity of formation water

R_{mf}= Resistivity of mud filtrate

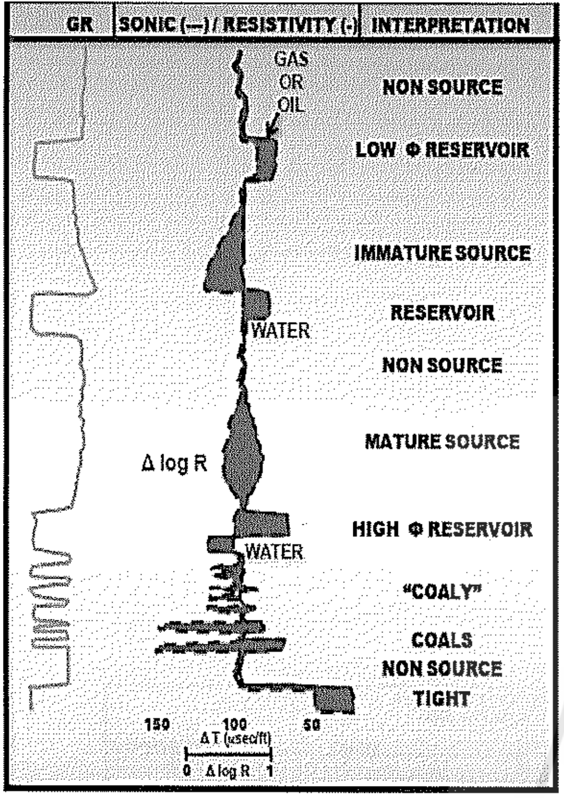
R_t= Resistivity of uninvaded zone

Φ = Porosity of formation

Gamma ray, Sp and Resistivity logs correlation



หลักการแปลความหมายจากกราฟ SP, Gamma ray และ Resistivity



- ***Basic* Rule "A":** เมื่อ GR (or SP) ย้ายไปทางซ้ายแสดงถึง clean และอาจเป็น reservoir.

เมื่อ GR ไปทางขวา ปกติเป็น Shale zone (not a reservoir quality rock).

- **Basic Rule "B":** Porosity logs (sonic log) แสดงค่า higher porosity ไปทางด้านซ้าย แสดงค่า lower porosity ไปทางด้านขวา ซึ่งบ่งบอกว่าเป็นชั้น clean formation and porous reservoir, ดังนั้น การเปรียบเทียบ GR กับ Porosity log จะบอก clean+porous zones.

- **Basic Rule "C":** Resistivity logs ค่าresistivity สูงไปทางด้านขวา

ค่า resistivity สูงๆ บ่งบอกว่าเป็นชั้น hydrocarbons or low porosity.

ค่า resistivity ต่ำ บ่งบอกชั้น shale or water zones.

ดังนั้น clean+porous+high resistivity เป็น formation ที่น่าจะเป็น reservoir ที่ดี.

4. Dipmeter Log

Dipmeter tool:

Records the attitude (dip angle and dip direction) of rock layers in the borehole

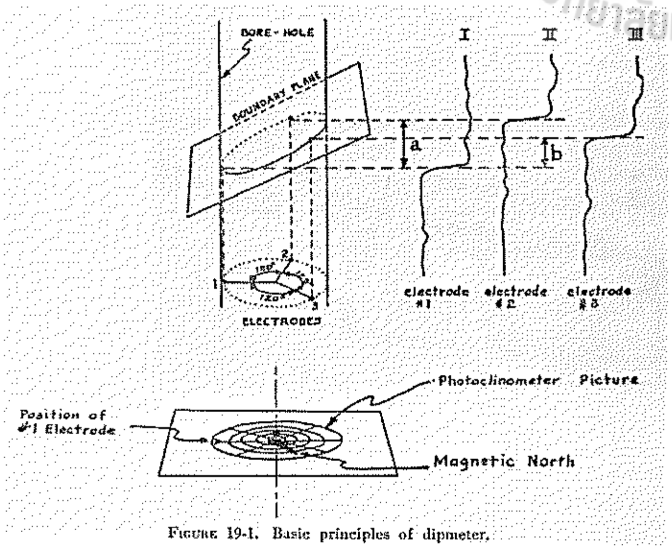
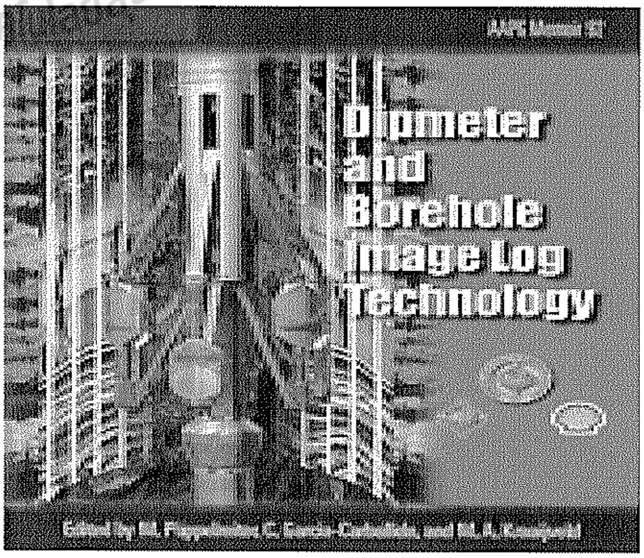


FIGURE 19-1. Basic principles of dipmeter.



AAPG Memoir 92

Dipmeter and Borehole Image Log Technology

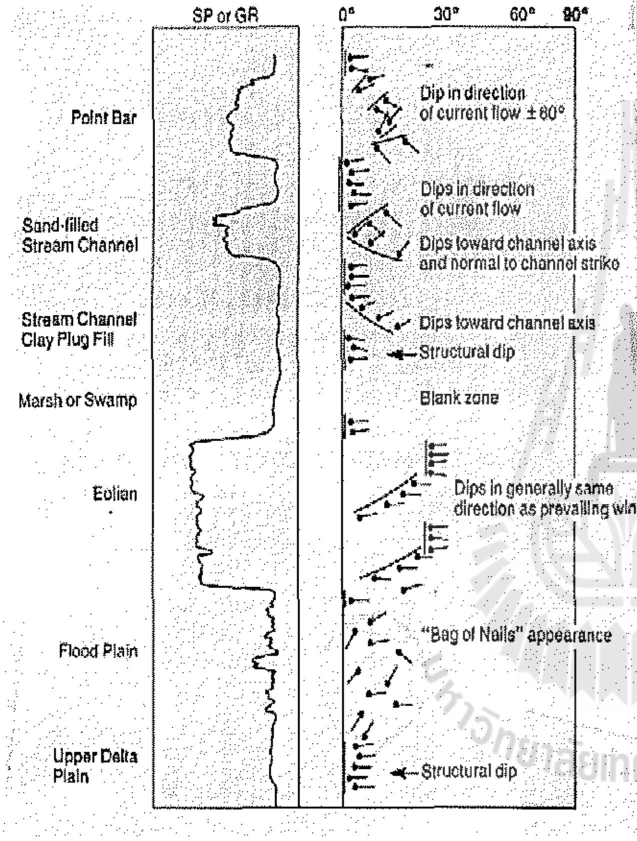
Edited by M. Pöppelreiter, C. García-Carballido, and M. A. Kraaijveld

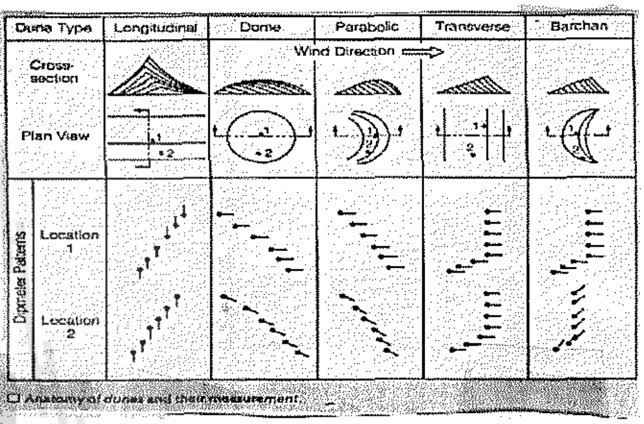
มหาวิทยาลัยเทคโนโลยีสุรนารี

Dipmeter survey

การหาค่ามุมเอียงเทของชั้นหินที่อยู่ใต้ผิวดิน จำเป็นอย่างยิ่งที่ จะต้องได้ข้อมูลการวางตัวของชั้นหินจากหลุมเจาะอย่างน้อย 3 หลุมที่ไม่อยู่ในแนวเส้นตรงเดียวกัน ซึ่งทำได้ยากเนื่องจาก จะต้องมีหลุมเจาะถึง 3 หลุมเป็นอย่างน้อย และชั้นหินที่ต้องการ ศึกษาต้องผ่านหลุมเจาะทั้ง 3 หลุมด้วย ทำให้สิ้นเปลืองทั้งเวลา และค่าใช้จ่ายในการเจาะมาก

Log Presentation





☐ Anatomy of dunes and their measurement.

Logs are presented at tadpole plots with the tail indicating the bearing and the position the dip.

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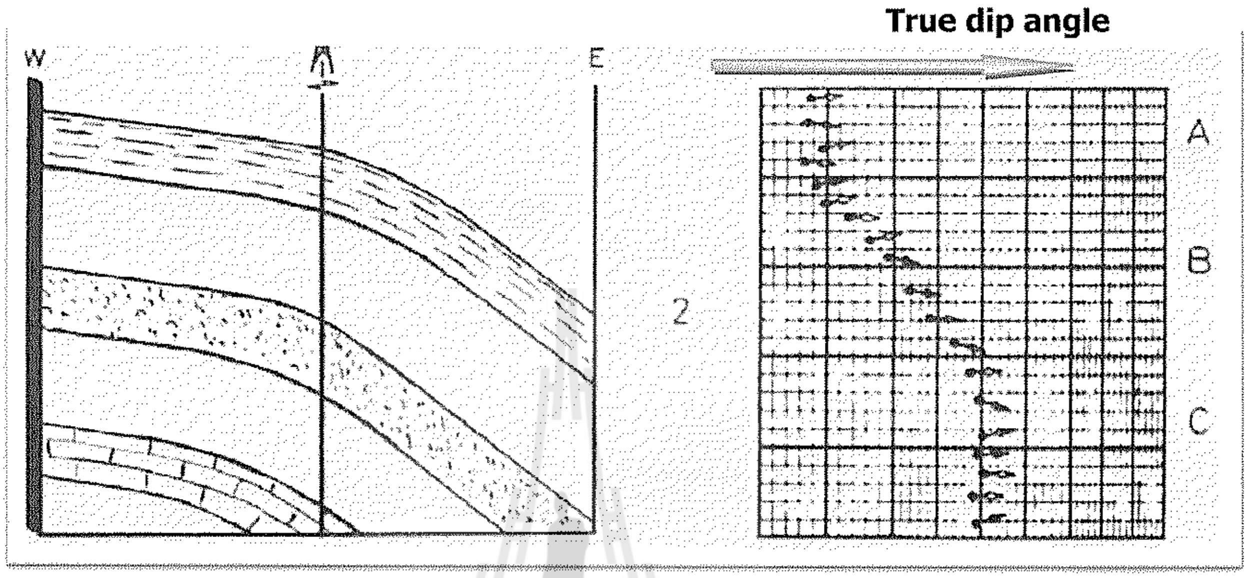
ประโยชน์ของ Dipmeter log

1. Tectonic or structural application

- ค่ามุมเอียงเทที่ได้จากเครื่องมือถูกใช้เป็นข้อมูลพื้นฐานในการกำหนดค่ามุมเอียงเทของโครงสร้างโดยทั่วไปในบริเวณนั้น
- ค่ามุมเอียงเทที่ผิดปกติไปจากค่ามุมเอียงเทปกติในบริเวณนั้นทั้ง ขนาดและทิศทาง อาจเกิดเนื่องจากการแปรสภาพของโครงสร้าง เช่น รอยเลื่อน รอยสัมผัสไม่ต่อเนื่อง การคดโค้งโครงสร้างที่เกิดเป็นบริเวณแคบๆ เช่น โดมเกลือหิน

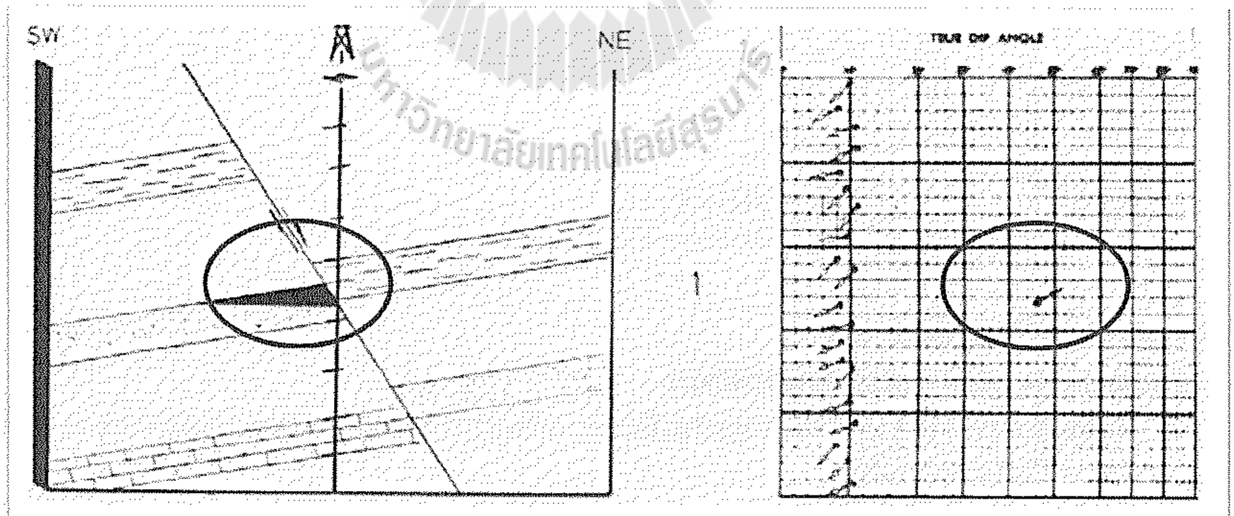
1.1 Salt dome

- บริเวณใกล้โดมเกลือหินค่ามุมเอียงเทจะมีค่ามากและน้อยลงเมื่อห่างจากโดมเกลือหิน



1.2 Fault

รอยเลื่อนสามารถสังเกตเห็นได้จากการเปลี่ยนแปลงค่ามุมเอียงเท อย่างฉับพลันจากหินด้านหนึ่งของรอยเลื่อนไปยังอีกหินอีกด้านหนึ่งของรอยเลื่อน



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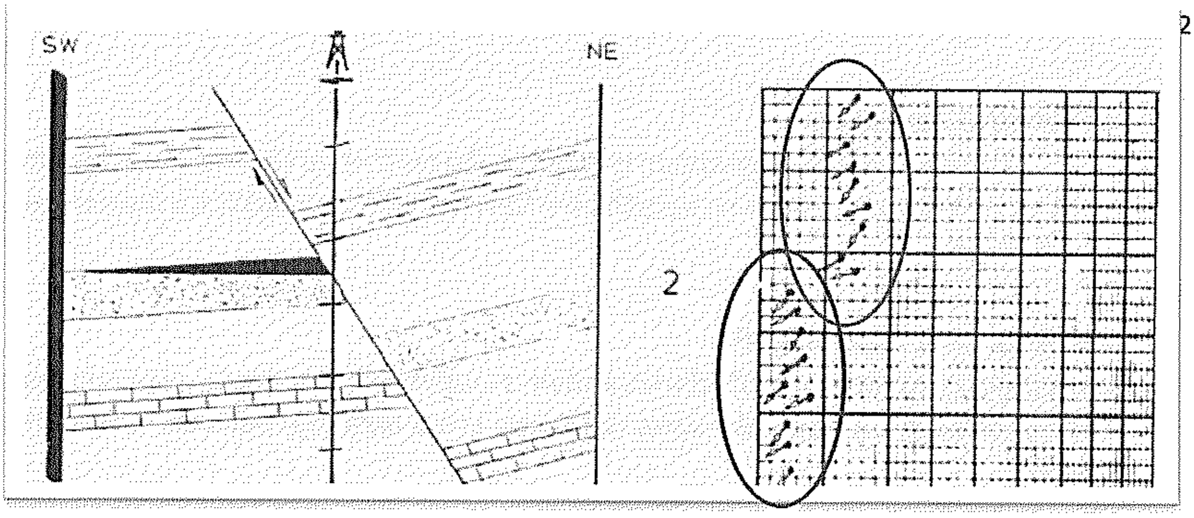

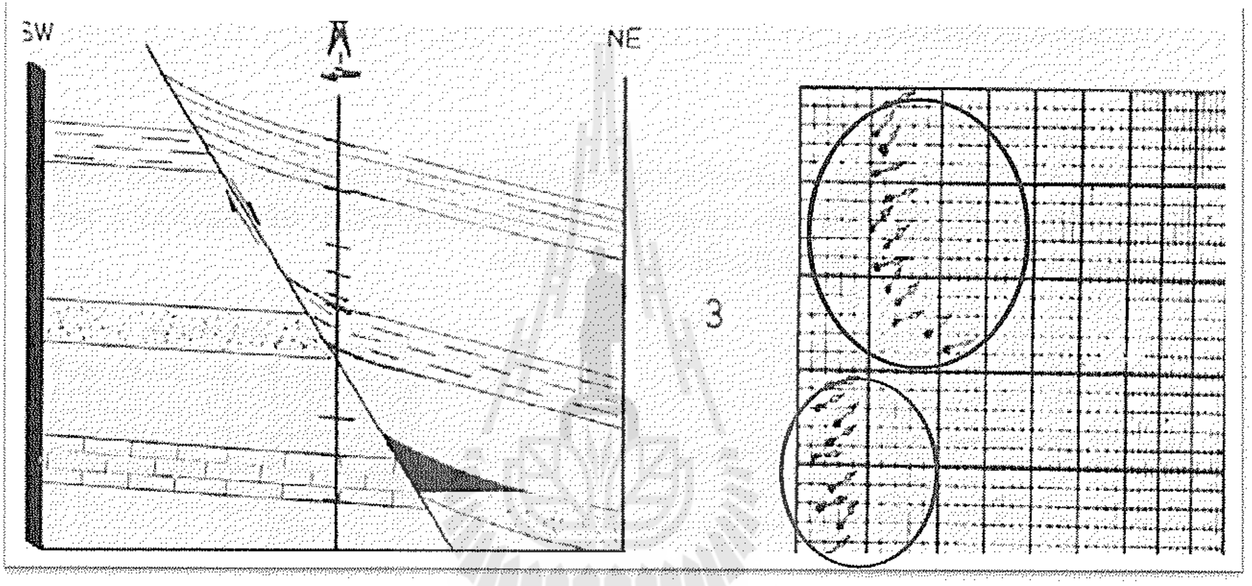

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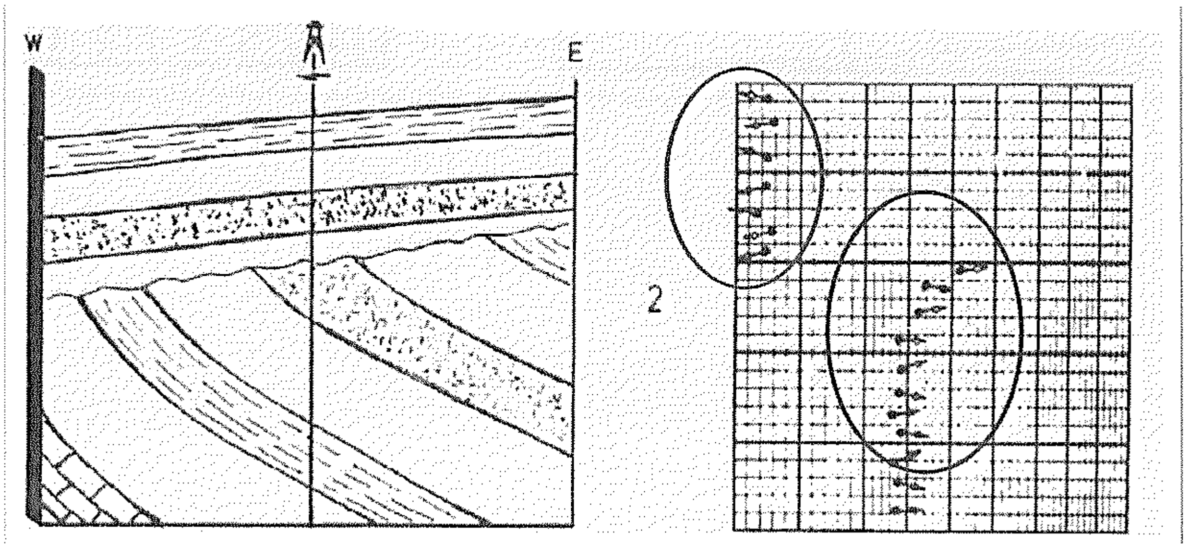
1.3 Unconformity

รอยสัมผัสไม่ต่อเนื่องสังเกตจากการเปลี่ยนแปลงทั้งทิศทางและค่ามุมเอียงเทจากหินชุดหนึ่งไปยังหินอีกชุดหนึ่ง



2. Structural mapping

จากค่ามุมเอียงเทและทิศทางการวางตัวของโครงสร้างต่างๆที่วัดได้จากเครื่องมือสามารถนำมาสร้างเป็นแผนที่โครงสร้างทางธรณีวิทยาหรือภาพตัดขวางทางธรณีวิทยาแสดงลักษณะโครงสร้างได้

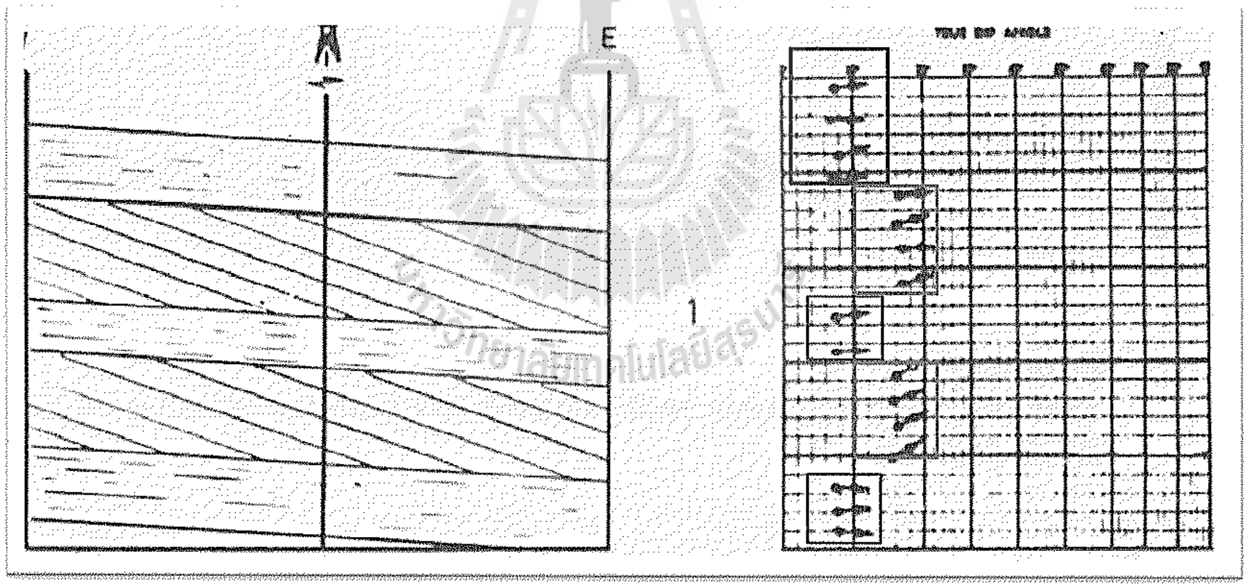
3. Sedimentary applications

- ค่ามุมเอียงเทและทิศทางการวางตัวบ่งบอกถึงการวางตัวของชั้นหิน กักเก็บ ซึ่งอาจอาศัยข้อมูลของการวางตัวของโครงสร้างทางหิน ตะกอนต่างๆ เช่น cross bedding, paleocurrent, slumps และ drapes
- ลักษณะที่สำคัญของหินตะกอนของชั้นกักเก็บในแต่ละช่วงสามารถนำไปสู่การแปลความหมายถึงขบวนการสะสมตัวได้

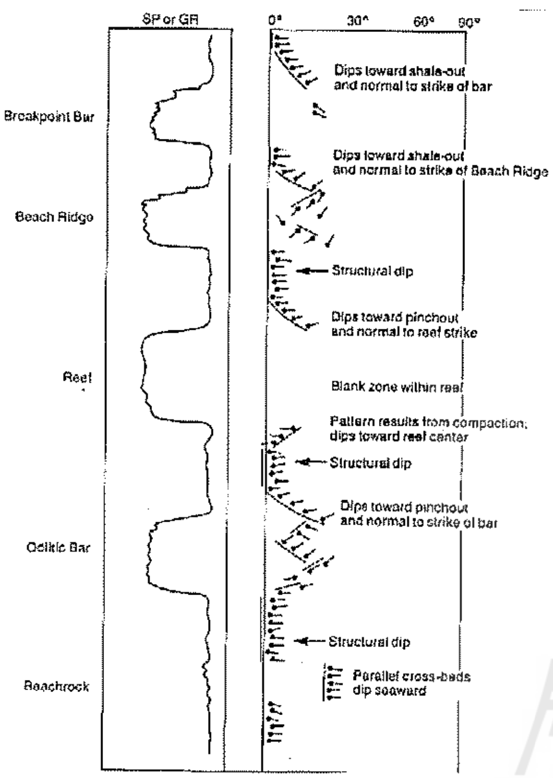
4. Formation Thickness

- ค่าความต้านทานและมุมเอียงเทจะมีความสัมพันธ์กับความหนาของชั้นหิน ปรากฏการณ์ที่เกิดซ้ำๆ กัน การพัฒนาของหินในแนวดิ่ง ขนาดของเม็ดตะกอน ส่วนประกอบ ชนิดของชั้นหิน จุดกำเนิดของรอยต่อของชั้นหิน หรือ ความเป็นเนื้อเดียวของชั้นหิน

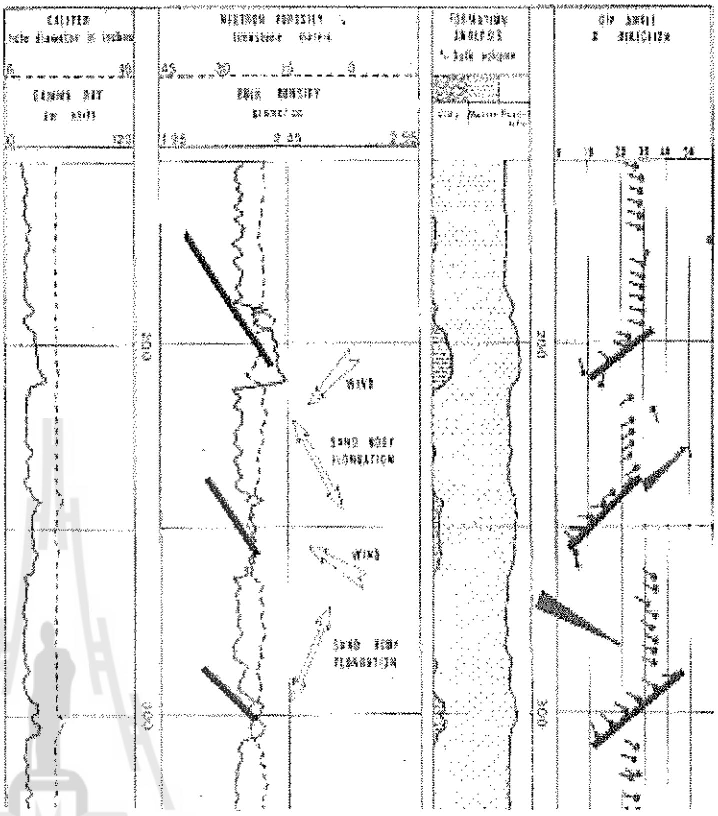
วิทยาลัยเทคโนโลยีสุร



5. Stratigraphic application



Calipper and Dipmeter in sand dune



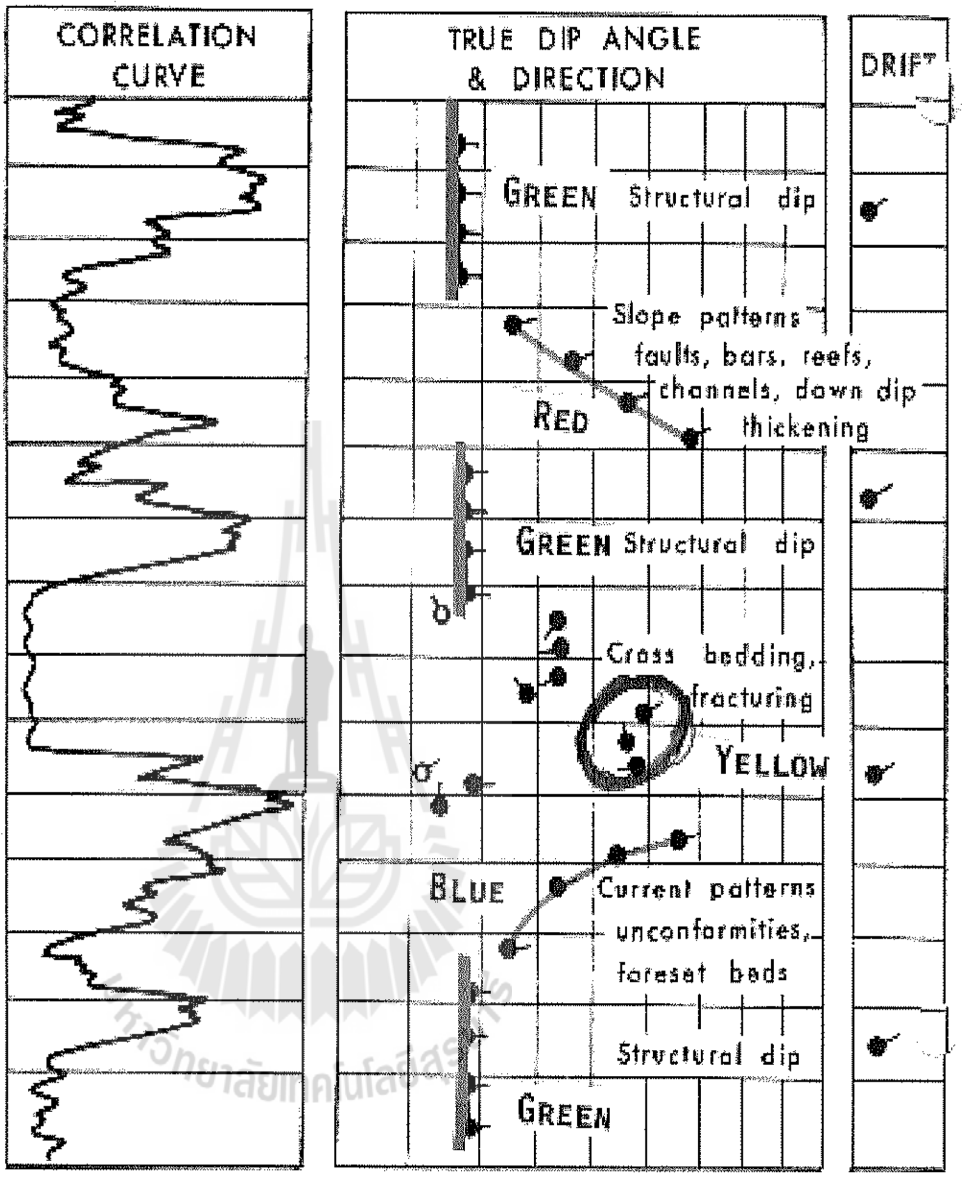
Dipmeter in reef environment

Dip Pattern

Structural analysis begins with a review of the arrow plot. It defined by the color of the pencil used to mark them:

1. GREEN PATTERNS (GP): nearly constant dip and direction, representing regional dip, sometimes called structural dip.
2. RED PATTERNS (RP): increasing dip with depth, representing drape, down dip thickening, differential compaction, drag on faults, or folding.
3. BLUE PATTERNS (BP): decreasing dip with depth, representing drag on faults or folding.
4. BLACK PATTERNS: abrupt change in dip and/or direction, representing unconformities, fault planes, or erosional boundaries between stratigraphic units.
5. CIRCLED PATTERNS or YELLOW PATTERNS: random dip angles or directions indicates bad hole conditions, contorted bedding, fractures, slumping, or breccia, sometimes associated with fault planes.

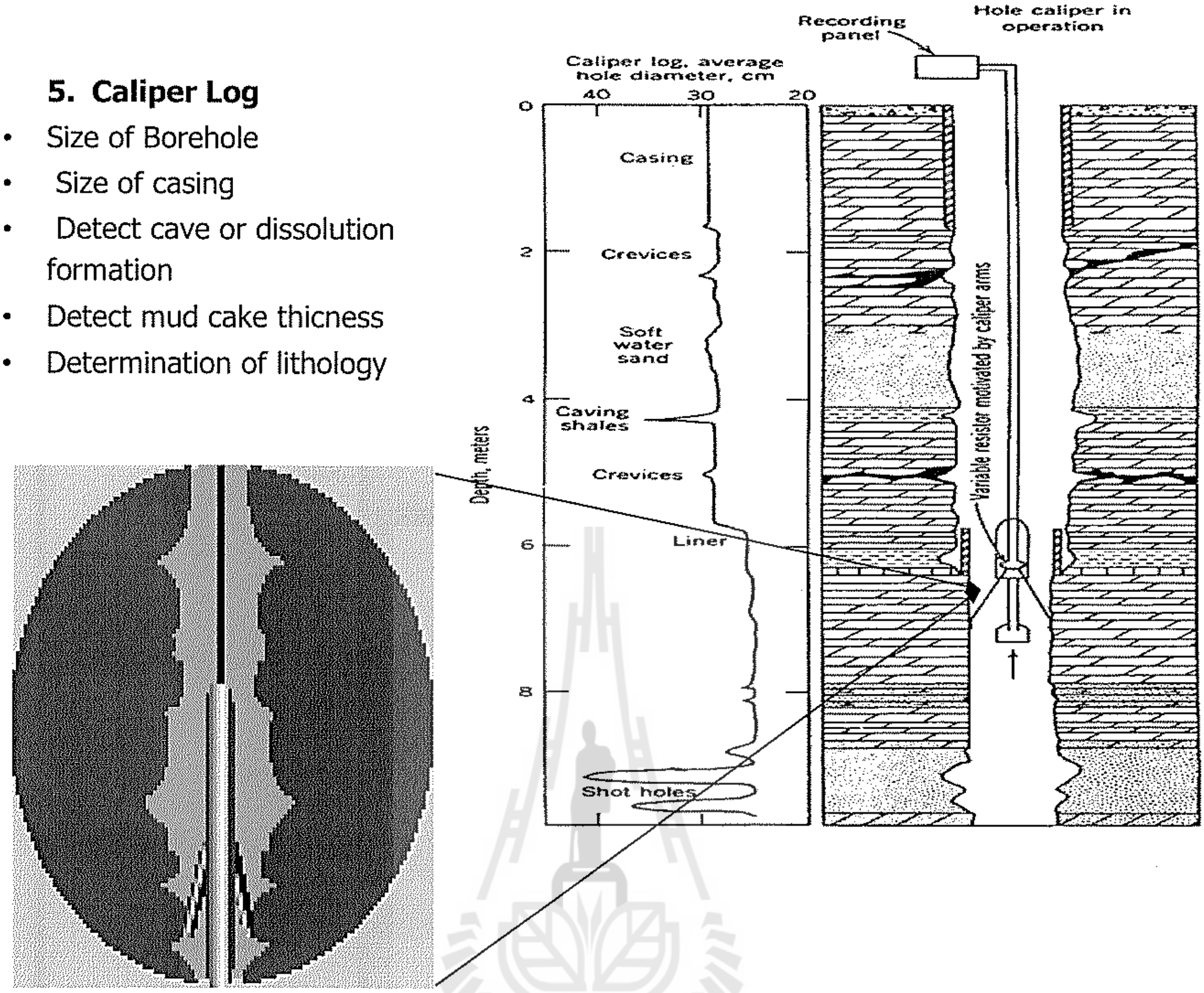
Dip Pattern



มหาวิทยาลัยเทคโนโลยีสุรนารี

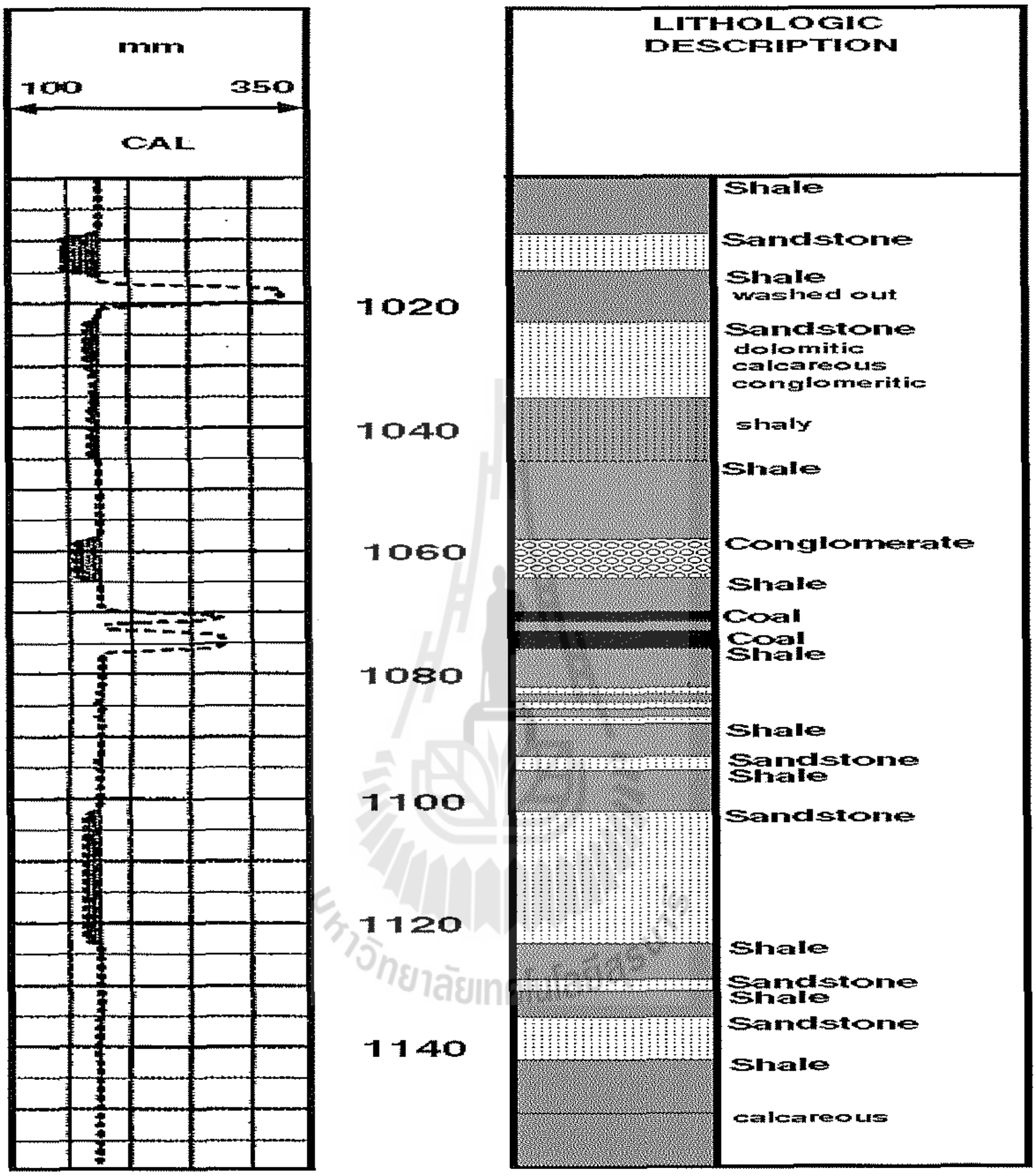
5. Caliper Log

- Size of Borehole
- Size of casing
- Detect cave or dissolution formation
- Detect mud cake thicness
- Determination of lithology



Caliper Log

- To assist in the quantitative interpretation of many other logs that are sensitive to borehole diameter and wall roughness (rugosity).
- Normally run with GR or SP log.
- The deflections Mud cake (smaller radius) and Caving (oversize excursions)
  - Shales , coals and LS are lithologies that tend to cave.
  - The absence of mud cake adjacent to a porous bed may indicate a tight sand or possible overpressure.



Caliper log graph and lithology

6. Porosity logs

- เครื่องมือที่นิยมใช้ในการหาความพรุนในหิน ได้แก่
    - Density log
    - Neutron log
    - Sonic log
- เครื่องมือเหล่านี้ได้รับอิทธิพลจาก ความพรุนของเหลวในช่องว่าง และส่วนประกอบทางแร่ในหิน (matrix mineral)
- ค่าความพรุนที่หาได้จากเครื่องมือแต่ละชนิดอาจให้ค่าที่ไม่เท่ากันได้ ดังนั้นในการสำรวจจึงยังมีความจำเป็นที่จะต้องใช้เครื่องมือทั้ง 3 ชนิดในการหาค่าความพรุนที่เหมาะสมของชั้นหิน

6.1 Density log

- ความหนาแน่นเป็นสมบัติของชั้นหินอันหนึ่งที่สำคัญสำหรับการ ประเมินศักยภาพของชั้นหิน ซึ่งใช้เป็นดัชนีเบื้องต้นที่บ่งบอกถึงความพรุนของชั้นหิน

Density log ถูกใช้เป็นเครื่องมือวัด

- ค่าความหนาแน่นของชั้นหิน (bulk density)
- ความพรุนของชั้นหิน
- จำแนกชนิดของแร่ประกอบหิน
- ตรวจสอบการสะสมตัวของก๊าซในชั้นกักเก็บ
- หาค่าความหนาแน่นของไฮโดรคาร์บอน
- ประเมินคุณสมบัติของ ชั้นทรายที่มี shale ปนอยู่ (shaly sands)
- เนื้อหินที่ซับซ้อน (complex lithology)
- คำนวณค่าความดันที่เกิดจากตะกอนที่ปิดทับอยู่ด้านบน (overburden pressure)
- ประเมินค่าของ oil-shale
- ตรวจสอบสมบัติทางกลของหิน

  ความหนาแน่นของชั้นหินที่วัดได้เป็นความหนาแน่นรวมของเนื้อหิน (matrix) หรือแร่ที่ประกอบหิน (rock-forming minerals) และของเหลว (fluid) ที่อยู่ในช่องว่าง == Bulk density

Principle of Density Log

- เมื่อธาตุกัมมันตรังสี (Cs-137 หรือ Co-60) ปลดปล่อยรังสีแกมมาพลังงานปานกลางเข้าไปในชั้นหิน รังสีแกมมาเหล่านี้เมื่อชนกับอิเล็คตรอนจะสูญเสียพลังงาน บางส่วนให้กับอิเล็คตรอนและถูกดูดกลืนอยู่ในชั้นหิน
- ชั้นหินที่มีความหนาแน่นมาก ปริมาณการชนของรังสีแกมมาขึ้นกับจำนวนอิเล็คตรอนก็จะมากขึ้นด้วย
- การดูดกลืนรังสีแกมมาในชั้นหินที่มีความหนาแน่นมาก จะดีกว่าในชั้นหินที่มีความหนาแน่นน้อย

มหาวิทยาลัยเทคโนโลยีสุรนารี

- รังสีแกมมาที่เหลืออยู่จะเดินทางกลับมายังตัวตรวจจับรังสีแกมมา ทราบระยะห่างระหว่างแหล่งกำเนิดรังสีและตัวตรวจจับรังสีแกมมาก็สามารถคำนวณความหนาแน่นของชั้นหินได้

เนื่องจากความหนาแน่นของ Formation สามารถวัดได้จาก Density log สรุปได้ว่า

หินเนื้อแน่น (Dense formation) สามารถดูดกลืนรังสีแกมมาได้ดี แสดงถึง high-density formations

หินที่มีความพรุน (Porous formation) สามารถดูดกลืนรังสีแกมมาได้น้อย แสดงถึง low-density formations

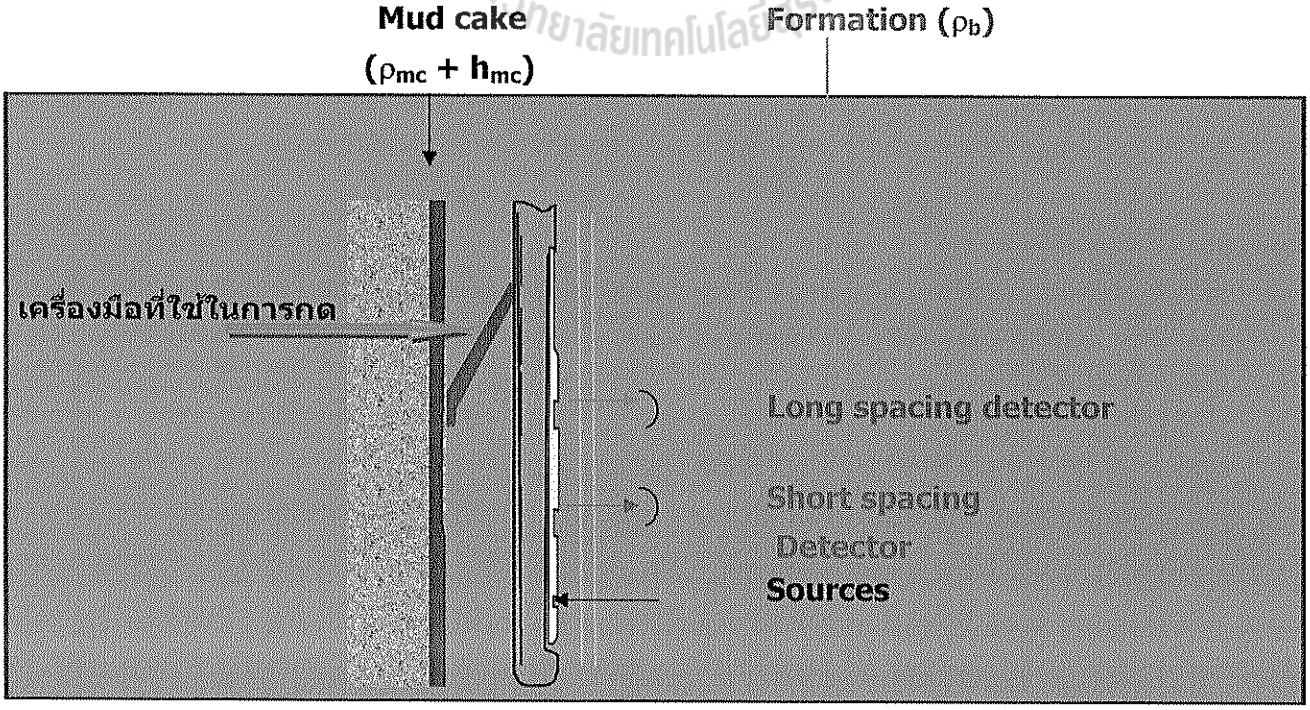
ดังนั้น ค่าความพรุนของชั้นหิน พิจารณาจากปริมาณการชนของรังสีแกมมากับอิเล็คตรอน ความหนาแน่นของอิเล็คตรอน สัมพันธ์กับความหนาแน่นรวมของชั้นหิน (true bulk density, ρ_b) ซึ่งขึ้นอยู่กับความหนาแน่นของส่วนประกอบทางแร่ของหิน ความพรุน และ ความหนาแน่นของของเหลวที่อยู่ในช่องว่าง

Type of Density Logs

1) Compensated formation density tool (FDC)

- เครื่องมือประกอบด้วยตัวปลดปล่อยรังสีแกมมา (source) ที่ติดอยู่ ด้านล่าง 1 ตัว และตัวตรวจจับรังสีแกมมา (scintillation detector) 2 ตัว
- ตัวที่อยู่ใกล้ตัวปลดปล่อยรังสีแกมมาเรียกว่า ตัวตรวจจับรังสีแกมมาตัวใกล้ (short-spacing detector) และ ตัวตรวจจับรังสีแกมมาตัวไกล (long-spacing detector)
- มีเครื่องมือที่ใช้ในการกดให้เครื่องมือติดกับผนังของหลุมเจาะ เพื่อให้รังสีแกมมาที่ ปลดปล่อยออกมาเดินทางเข้าไปในชั้นหินโดยไม่ผ่านชั้นที่เป็น mud cake

Source of **Compensated formation density tool (FDC)**



มหาวิทยาลัยเทคโนโลยีสุรนารี

Density porosity determination

ในกรณีของ clean formation ที่มีของเหลวอยู่ในช่องว่าง ค่าความพรุนที่ได้จาก density log และ φ_D คำนวณได้ตามสมการ

$$\rho_{log} = \rho_{ma}(1 - \varphi_D) + \rho_f \varphi_D$$

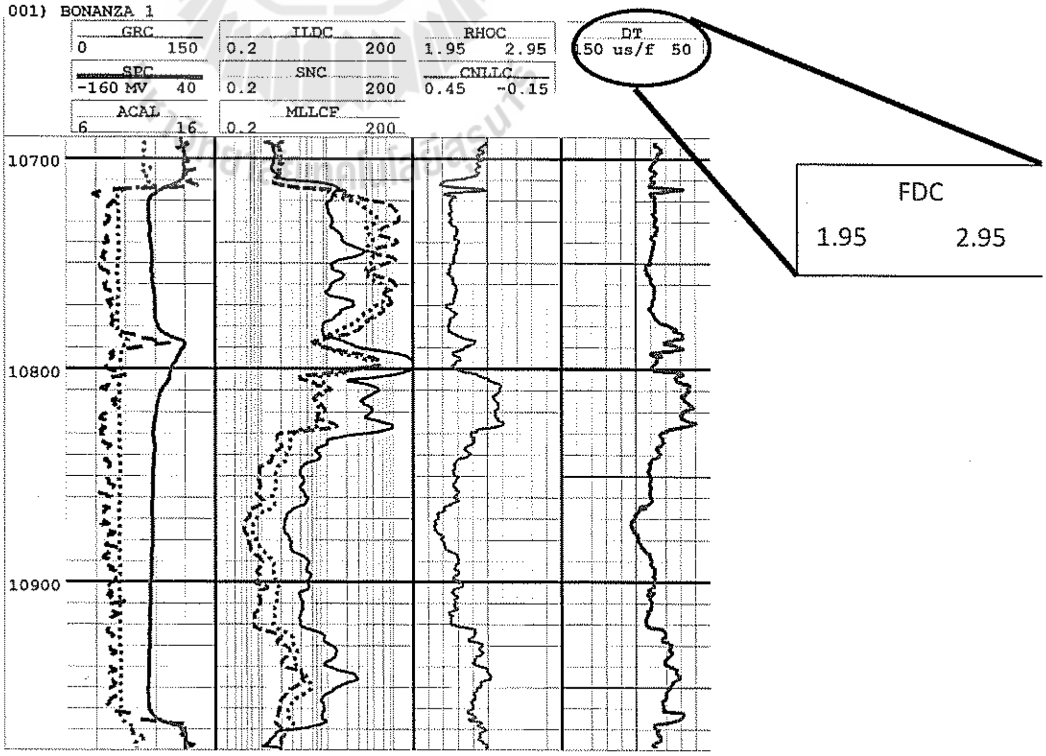
หรือ

$$\varphi_D = \frac{\rho_{ma} - \rho_{log}}{\rho_{ma} - \rho_f}$$

เมื่อ ρ_{ma} = ความหนาแน่นของ matrix
ρ_{log} = ความหนาแน่นที่อ่านได้จาก log
ρ_f = ความหนาแน่นของของเหลว

- Bulk density, ρ_b, is dependent upon:
  - Lithology
  - Porosity
  - Density and saturation of fluids in pores
    - Saturation is fraction of pore volume occupied by a particular fluid (intensive)

BULK DENSITY LOG



Some effects on density log

1. Borehole effect

เนื่องจาก density tool ถูกกดให้ติดกับผนังหลุมเจาะ ดังนั้นใน บริเวณที่ผนังหลุมเจาะขรุขระหรือมี washout จะมีผลกับค่าที่อ่านได้ ดังนั้นค่า caliper ที่อ่านได้ จะถูกนำไปใช้ในการแก้ไขค่า

2. Hydrocarbon effect

ชั้นหินที่เป็น oil-bearing formation เนื่องจากความหนาแน่นของน้ำมันและน้ำมีค่าใกล้เคียงกันมาก จึงไม่สามารถแยกให้เห็น ความแตกต่างได้จาก density log

แต่ใน gas bearing formation ค่าความหนาแน่นมีค่าน้อยกว่าน้ำ ดังนั้น density log ที่อ่านได้จึงมีค่าน้อยกว่าปกติ

3. Effect of shale

ในชั้นหินที่มี shale หรือ clay อยู่ ถึงแม้ว่าสมบัติของ shale อาจเปลี่ยนแปลงไปบ้างในแต่ละชั้นหิน แต่ความหนาแน่นของ shale จะอยู่ในช่วง 2.2 ถึง 2.65 g/cm^3 แนวโน้มค่าของความหนาแน่นของ shale เพิ่มขึ้นตามความลึกและ compaction

ดังนั้นในชั้นหินที่ shale ที่ไม่ compaction หรือ เป็นชั้นหินที่มี clay อยู่ในช่องว่าง ค่าความหนาแน่นของชั้นหินที่อ่านได้จะมีค่าน้อยกว่าปกติ

4. Effect of pressure

โดยปกติแนวโน้มของความหนาแน่นของ shale เพิ่มขึ้นตามความลึกและการอัดตัว (compaction) แต่ในบริเวณ overpressure ความหนาแน่นของ shale ลดลง เมื่อความลึกเพิ่มขึ้น มักพบได้ มากในบริเวณที่อยู่ใกล้ high-pressure permeable sands

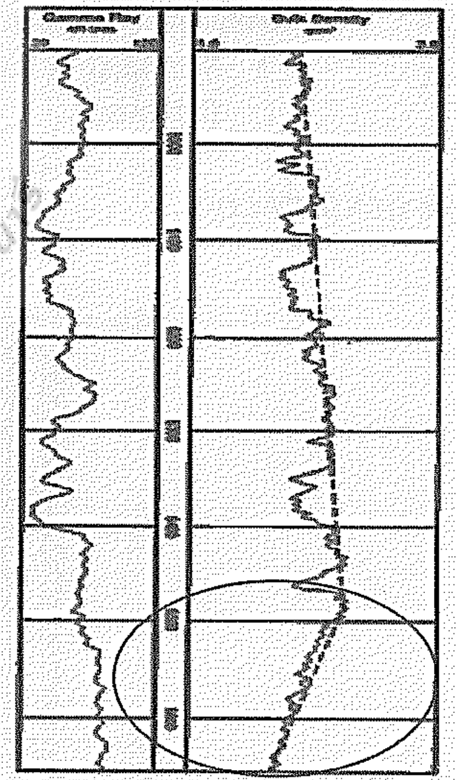


Fig. 5-18—Density log in overpressured shales.

ประโยชน์ของ Density Logs

1. การวัดค่าความหนาแน่นสามารถนำไปช่วยในการแปลความหมาย การสำรวจด้านแรงโน้มถ่วงและการสำรวจด้านคลื่นไหวสะเทือนได้
2. เมื่อใช้ร่วมกับ neutron, sonic log และ log ชนิดอื่นๆ สามารถ บอกถึง lithology ได้
3. ใช้ร่วมกับ neutron และ resistivity log ในการกำหนด gas-oil, gas-water, oil-water contact

6.2 Neutron log

- Neutron log เป็นเครื่องมือที่ถูกนำมาใช้ในการหาชั้นหินที่มีความพรุน (porous rock) และค่าความพรุนของชั้นหินนั้นโดยตรง
- เครื่องมือจะตรวจสอบปริมาณของไฮโดรเจนในชั้นหิน โดยสมมุติฐานว่าช่องว่างในเนื้อหินมีของเหลวอยู่ ซึ่งของเหลวนี้อาจ เป็นน้ำหรือน้ำมัน
- ในการตรวจสอบชั้นหินที่มีก๊าซสะสมตัวอยู่ neutron log จะต้องใช้ควบคู่กับเครื่องมือชนิดอื่น เช่น GR, resistivity log หรือ core

Neutron log

: เป็นการตรวจวัดจำนวนอนุภาค neutron ที่ถูกปล่อยออกจากแหล่งกำเนิด (source) ที่เป็นธาตุ Americium-241 และ Beryllium-226

โดยเมื่ออนุภาคของ Amercium-241 ถูกปล่อยออกมาและชนกับ Beryllium ก็จะทำให้เกิดการปล่อยนิวตรอนออกมา แต่บางครั้งอาจใช้คู่ของธาตุ Plutonium-239/Beryllium-226 หรือ Radium-226/Beryllium-226 เป็นตัวกำเนิดอนุภาคของนิวตรอนก็ได้

: จากนั้นอนุภาคของนิวตรอนที่ถูกปล่อยออกมาจะเดินทางเข้าไปในชั้นหิน และบางส่วนจะมีการชนกันกับอนุภาคของชั้นหินทำให้สูญเสียพลังงานไปหรืออาจอนุภาคบางส่วนถูกกักเก็บไว้ในชั้นหินก่อนที่ส่วนที่เหลือจะเดินทางกลับเข้ามาที่เครื่องมือตรวจวัด (detector)

:โดยพลังงานส่วนมากที่หายไปเกิดจากการที่อนุภาคของนิวตรอนไปชนกับ hydrogen ion ซึ่งเป็นส่วนประกอบหลักของน้ำ (H_2O) ดังนั้นพลังงานที่สูญเสียไปนี้จึงมีความสัมพันธ์โดยตรงกับปริมาณน้ำในช่องว่างของหิน ถ้าปริมาณอนุภาคนิวตรอนหายไปมาก แสดงว่าในช่องว่างของหินเหล่านั้นมีปริมาณน้ำอยู่มาก

หลักการทำงานของ Neutron Logging Tool

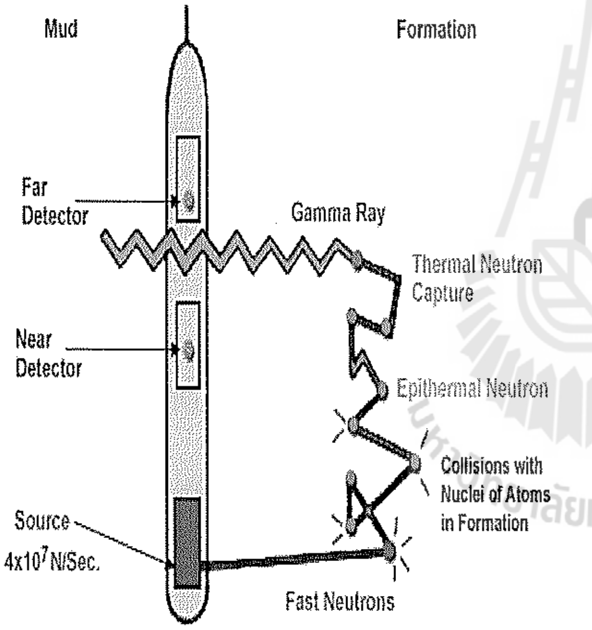
1) Logging tool emits high energy neutrons into formation
2) Neutrons collide with nuclei of formation's atoms
3) Neutrons lose energy (velocity) with each collision
4) The most energy is lost when colliding with a hydrogen atom nucleus
5) Neutrons are slowed sufficiently to be captured by nuclei
6) Capturing nuclei become excited and emit gamma ray

Equipment

เครื่องมือสำหรับนิวตรอนได้รับการพัฒนาขึ้นเป็นลำดับ จาก

1. Gamma ray/Neutron Tool (GNT) ซึ่งประกอบด้วย แหล่งกำเนิด อนุภาคนิวตรอน 1 ตัว และตัวรับรังสีแกมมา (Scintillation หรือ Geiger-Mueller detector) 1 ตัว เนื่องจากอิทธิพลจากหลุมเจาะมีมากทำให้ค่าความพรุนที่วัดได้ผิดพลาดได้มาก เครื่องมือชนิดนี้ จึงไม่มีการใช้แล้วในปัจจุบัน
2. Sidewall neutron porosity tool (SNP) or Neutron-epithermal neutron log (CNT-G) ซึ่งในปัจจุบันมีใช้น้อยแล้วเช่นกัน
3. เครื่องมือที่ยังใช้ในปัจจุบันเป็น Compensated neutron logging (CNL) และ Dual-energy neutron logging (DNL)

Compensated neutron logging (CNL)



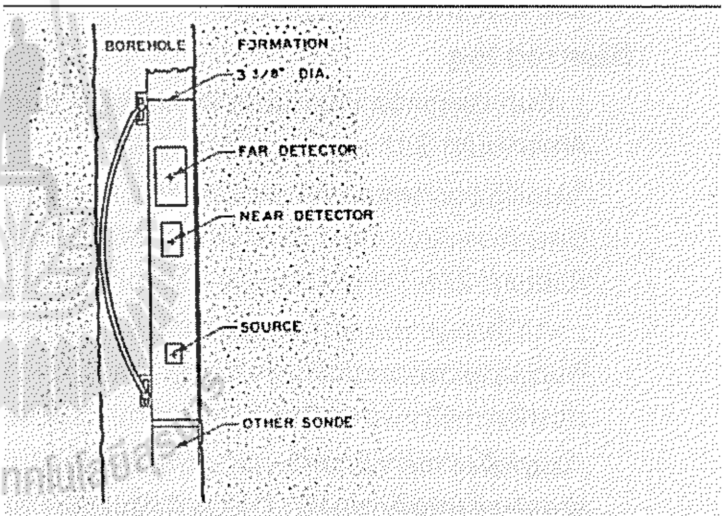


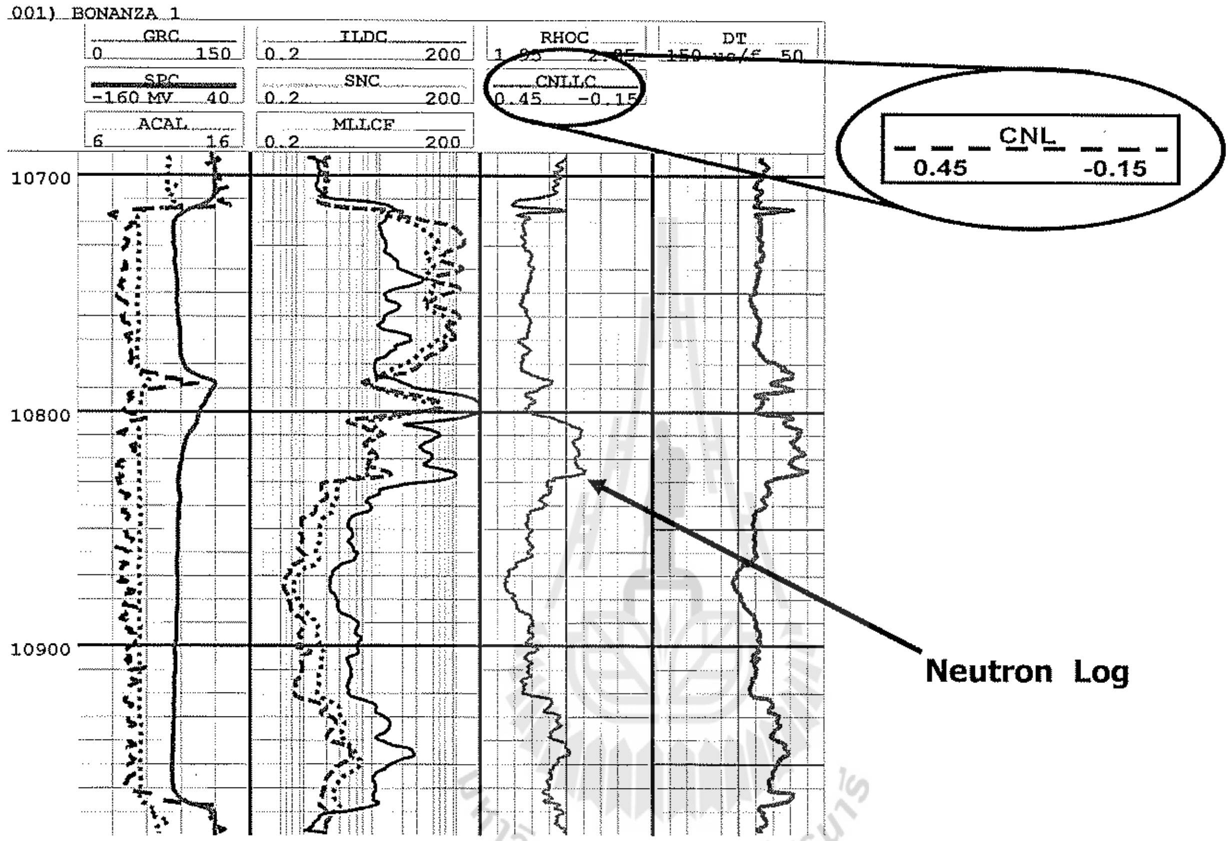
FIGURE 18.3 *Detail of a Compensated Neutron Tool. Reprinted by permission of the SPE-AIME from Alger et al. 1971, fig. 2. © 1971 SPE-AIME.*

Log presentation

- ค่าความพรุนที่ได้จาก SNP logging จะถูกบันทึกและเขียนออกมา ใน scale เชิงเส้น trace ที่ 2 และ 3 ได้โดยตรง ค่าที่อ่านได้จาก log อาจต้องมีการแก้ค่าผิดพลาด เนื่องจากน้ำหนักของน้ำโคลน ความเค็ม อุณหภูมิและขนาดของบ่อ
- CNL tool และ DNL tool จะแสดงค่าความพรุนโดยอ้างอิงกับชนิดของหินที่กำหนดไว้ ซึ่งอาจเป็นหินปูน หรือ หินทราย เมื่อชนิดของหินเปลี่ยนไปจากที่กำหนดไว้ จะต้องมีการคำนวณแก้ค่าในกรณีที่ใช้ CNL log ทำการวัดข้อมูลร่วมกับ porosity log ตัวอื่น เช่น Compensated density (FCD)

- ค่าความพรุนที่อ่านจาก neutron tool และความหนาแน่นที่อ่านได้ จาก density tool อาจเขียนลงใน trace เดียวกันได้ เพื่อให้ง่ายต่อการแปลความหมายถึงค่าความพรุนและชนิดของหิน โดยเฉพาะอย่างยิ่งในบริเวณที่เป็นแหล่งสะสมตัวของก๊าซ

POROSITY FROM NEUTRON LOG



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Environmental effect

1. Response to hydrocarbon

- Oil มีผลการตอบสนองของ neutron log ใกล้เคียงกับน้ำ
- Gas (มีปริมาณไฮโดรเจนน้อยกว่า) ซึ่งขึ้นอยู่กับอุณหภูมิและความดัน ดังนั้น ถ้ามีก๊าซอยู่ใกล้กับขอบของชั้นหินทำให้ปริมาณความหนาแน่นของไฮโดรเจนลดลง ค่าความพรุนที่อ่านได้ จะมีค่าน้อยกว่าปกติ ซึ่งจากการใช้ neutron log ร่วมกับ log อื่นๆ สามารถตรวจสอบบริเวณที่มีการสะสมตัวของ ก๊าซหรือเป็นบริเวณรอยสัมผัสระหว่างก๊าซและของเหลวได้ (Gas-Oil Contact: GOC)

2. Shale, bound water

เนื่องจาก neutron log ตรวจสอบปริมาณไฮโดรเจนในชั้นหิน ซึ่งใน บางครั้งไฮโดรเจนอาจไม่เกี่ยวข้องกับของเหลวที่กักเก็บอยู่ในช่องว่างของชั้นหินก็ได้ เช่น น้ำที่อยู่ระหว่างโครงสร้างแต่ละชั้นของ shale ทำให้ค่าความพรุนที่อ่านได้ มีค่ามากกว่าความเป็นจริง

3. Effect of lithology

เนื่องจากค่าความพรุนที่อ่านได้จาก neutron log ถูกกำหนดให้ เปรียบเทียบกับหินชนิดหนึ่งๆ ซึ่งโดยทั่วไปใช้อาจหินปูน หรือ หินทราย ดังนั้น ถ้าเป็นการวัดค่าความพรุนในหินอื่น จึงจำเป็นต้องมีการคำนวณค่าความพรุนใหม่

ประโยชน์ของ Neutron Log

- SNP tool ถูกออกแบบให้ทำงานในหลุมเปิด และให้ค่าความพรุนที่ไม่มีผลเนื่องจากหลุมเจาะ ทั้งยังสามารถใช้ได้ดีกับหลุมเจาะที่ใช้อากาศเจาะ (air mud)
- Neutron tool เมื่อใช้ร่วมกับ resistivity tool, sonic tool หรือ density tool สามารถบอกถึงบริเวณที่มีการสะสมตัวของก๊าซ หรือไฮโดรคาร์บอนน้ำหนักเบาได้ หรือ ใช้ในการจำแนกชนิดของหินได้
- Neutron tool ใช้ในการตรวจสอบ gravel pack

Responses of porosity logs

- The three porosity logs:
  - Respond differently to different matrix composition
  - Respond differently to presence of gas or light oils
- Combinations of logs can:
  - Imply composition of matrix
  - Indicate the type of hydrocarbon in pores

6.3 Sonic or Acoustic log

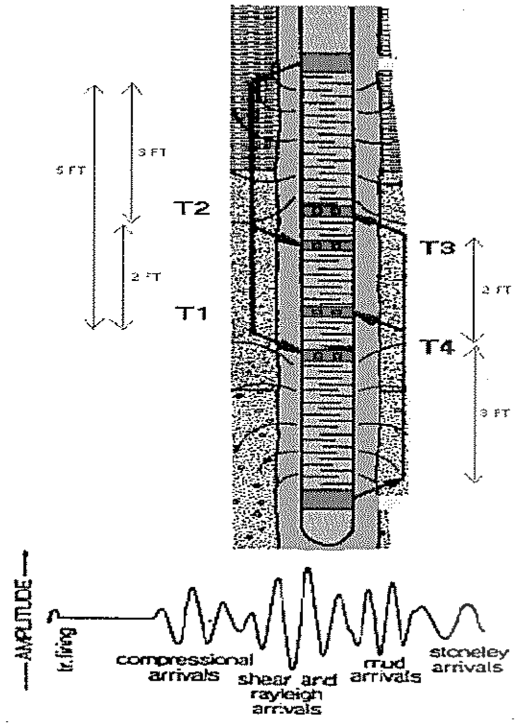
Sonic tool เป็นเครื่องมือที่ออกแบบเพื่อ

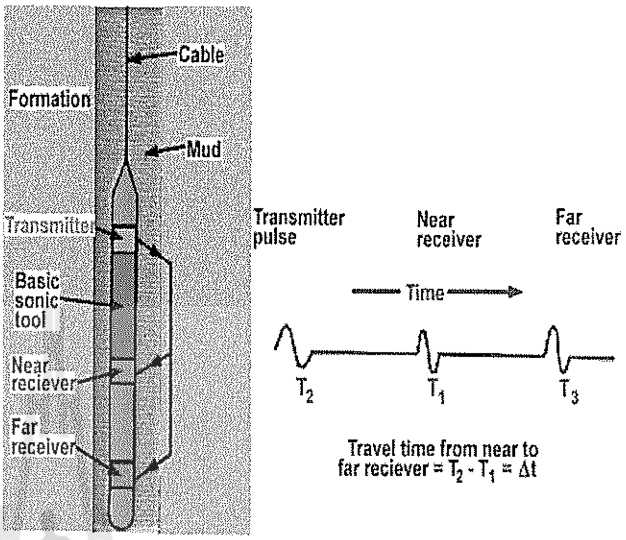
  - การวัดค่าความพรุนของชั้นหิน ในหลุมเจาะที่มีของเหลวอยู่ โดยอาศัยความเร็วของคลื่นเสียงที่เดินทางผ่านเข้าไปในชั้นหิน
  - ข้อมูลที่ได้จาก sonic tool ยัง ถูกนำไปใช้ประกอบกับการแปลความหมายข้อมูลการสำรวจด้านคลื่นไหวสะเทือน
  - การกำหนดความเร็วคลื่นของชั้นหิน
  - การทำ synthetic seismogram
- Sonic tool ประกอบด้วย ตัวส่งคลื่น (transmitter) ซึ่งเป็นตัวปลดปล่อยคลื่นเสียง (sonic pulse) และ ตัวรับสัญญาณ (receiver) ซึ่งเป็น piezoelectric ทำจาก lead zirconate titanate (PZT) เป็นตัวรับคลื่นเสียงที่เดินทางผ่านชั้นหินกลับมาถึงในรูปของความดัน ทำการเปลี่ยนสัญญาณที่เป็นความดันไปเป็นสัญญาณไฟฟ้า และส่งสัญญาณไปตามสายไฟฟ้าเพื่อการบันทึกข้อมูล

Principle of Neutron Log

- Tool usually consists of one sound transmitter (above) and two receivers (below)

- Sound is generated, travels through formation
- Elapsed time between sound wave at receiver 1 vs receiver 2 is dependent upon density of medium through which the sound traveled





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Type of sonic log tool

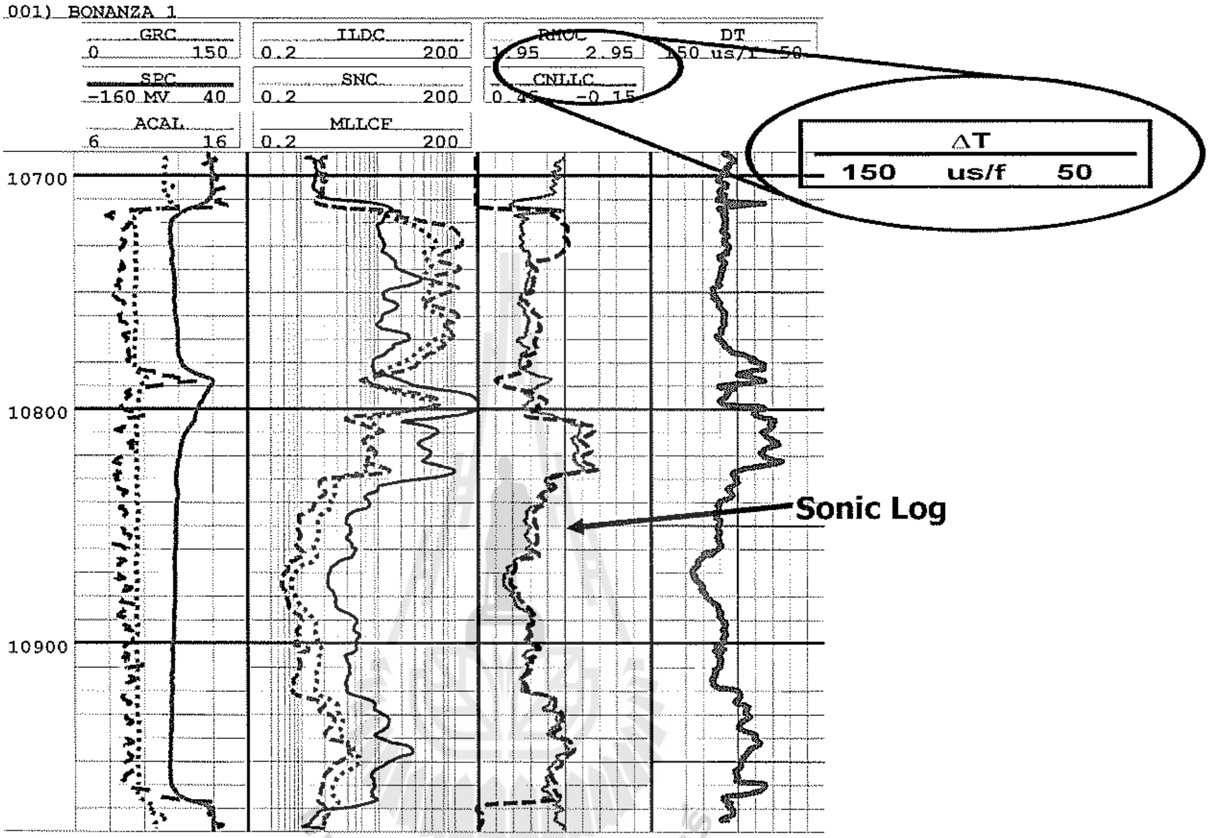
1. Conventional sonic tool
2. Borehole compensated sonic tool (BHC)
3. Long-spaced sonic tool (LLS) หรือ depth- derived borehole compensated
4. Array-sonic tool สามารถวัดได้ทั้งแบบ BHC log และ LSS log ใน open hole และ cement bond log (CBL) และ variable density log (VDL) ใน cased hole

Log presentation

- ค่า interval transit time ของ sonic log มักแสดงไว้ที่ trace 2 และ 3
- เป็น scale แบบเชิงเส้น (linear scale) ในหน่วยของ µs/ft โดยที่ค่า interval transit time (t) ที่เพิ่มขึ้นอยู่ทางด้านซ้ายของ trace ซึ่งหมายความถึง การเพิ่มขึ้นของค่าความพรุนด้วย ค่า t โดยปกติอยู่ในช่วงระหว่าง 40 ถึง 140 µs
- นอกจากผลที่ได้จาก sonic tool แล้วยังมีข้อมูลอีกชุดหนึ่ง แสดงเป็นชุดของขีดเล็กๆ (series of pips) อยู่ในบริเวณด้านซ้าย ของ trace 2 ซึ่งแต่ละขีดเล็กแสดง 1 millisec ของ integrated travel time (TTI) ขีดใหญ่แสดง 10 msec ซึ่งแสดงถึงเวลาที่ ได้จากค่าเฉลี่ยของความเร็วของ

ชั้นหินพล็อตเปรียบเทียบกับความลึกในแนวดิ่ง มีประโยชนสำหรับหาความสัมพันธ์ ระหว่างเวลาและความลึกในภาพตัดขวางทางคลื่นไหวสะเทือน (seismic section)

SONIC LOG GRAPH



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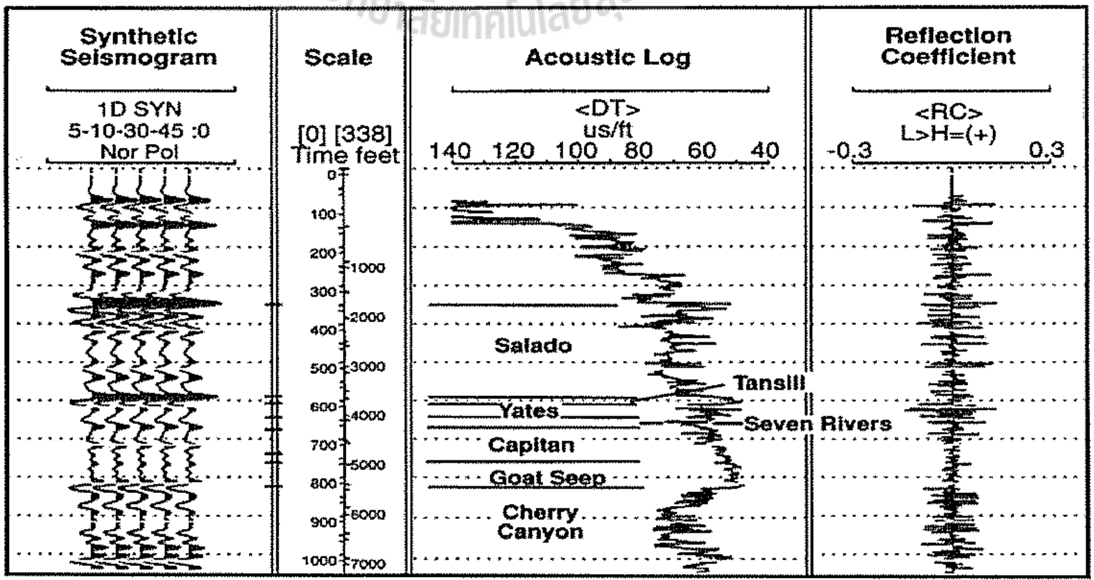
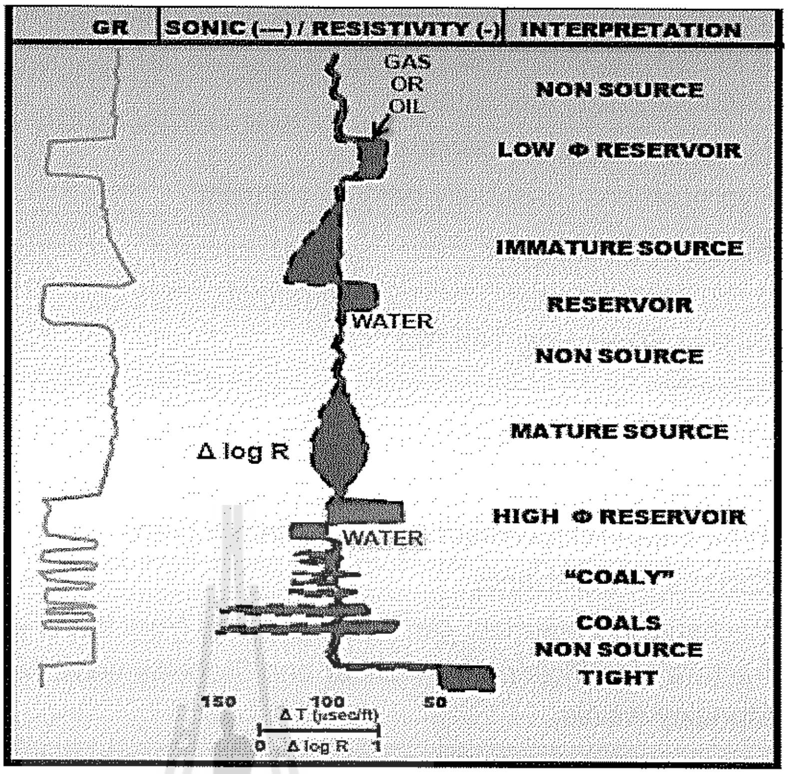
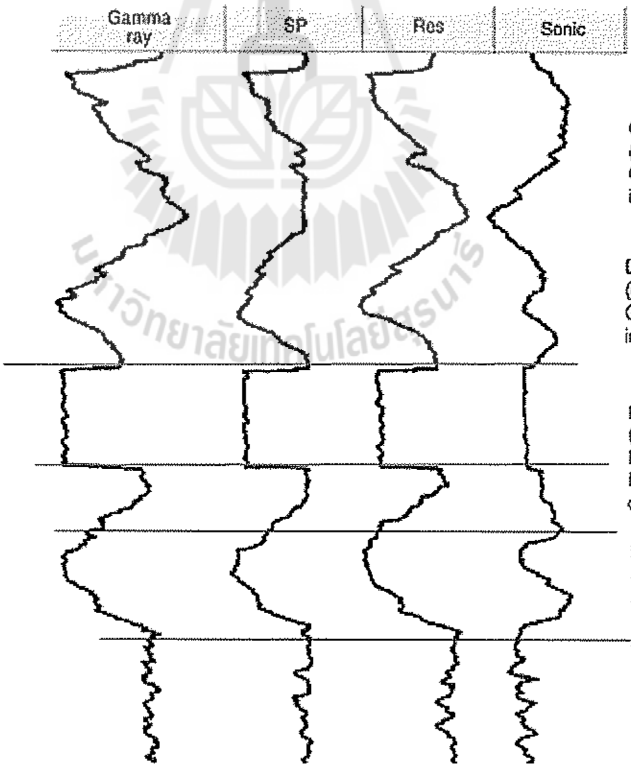


After Saller & Harris, 1999

Sonic vs. Resistivity



Sonic and other logs



CLEANING-UP TREND
(or funnel trend)
Gradual decrease upward in gamma signal

DIRTYING-UP TREND
(or bell trend)
Gradual increase upward in gamma signal

BOXCAR TREND
(or cylindrical trend)
Low gamma, sharp boundaries, no internal change

BOW TREND
(or symmetrical trend)
Gradual decrease then increase in gamma signal

IRREGULAR TREND

Factors affecting sonic log response

1. Unconsolidated formation
2. Naturally fractured formations
3. Hydrocarbons (especially gas) ค่า t มากขึ้น
4. Rugose salt section

ประโยชน์ของ Sonic Log ได้ข้อมูล

1. Porosity
2. Volume of clay (V_S)
3. Lithology
4. Time-depth relationship: Synthetic seismogram
5. Reflection coefficients
6. Mechanical properties: can be determined from the shear and compressional waves, fracture identification from shear and Stoneley waves and permeability indication from Stoneley waves.

- ในกรณีของ gas-bearing zone จะสามารถสังเกตเห็นได้จากการลดลงของความเร็วของ compressional waves ทำให้เวลาที่คลื่นใช้ในการเดินทางเพิ่มขึ้น ค่า interval transit time (t) มากขึ้น
- ในชั้นหินที่ทราบสมบัติความยืดหยุ่น sonic log สามารถนำไปใช้ทำนายถึงบริเวณที่เหมาะสมสำหรับทำ hydrofracturing

Porosity determination by logging

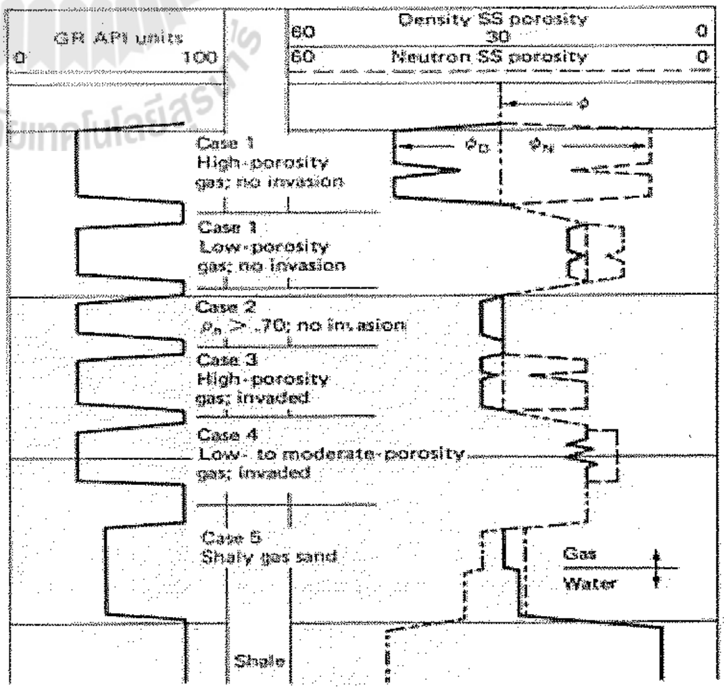


FIGURE 10-2 Schematic overlay of neutron (CNL) and density logs that shows the effect of gas and shale. (Truman et al., 1972.)

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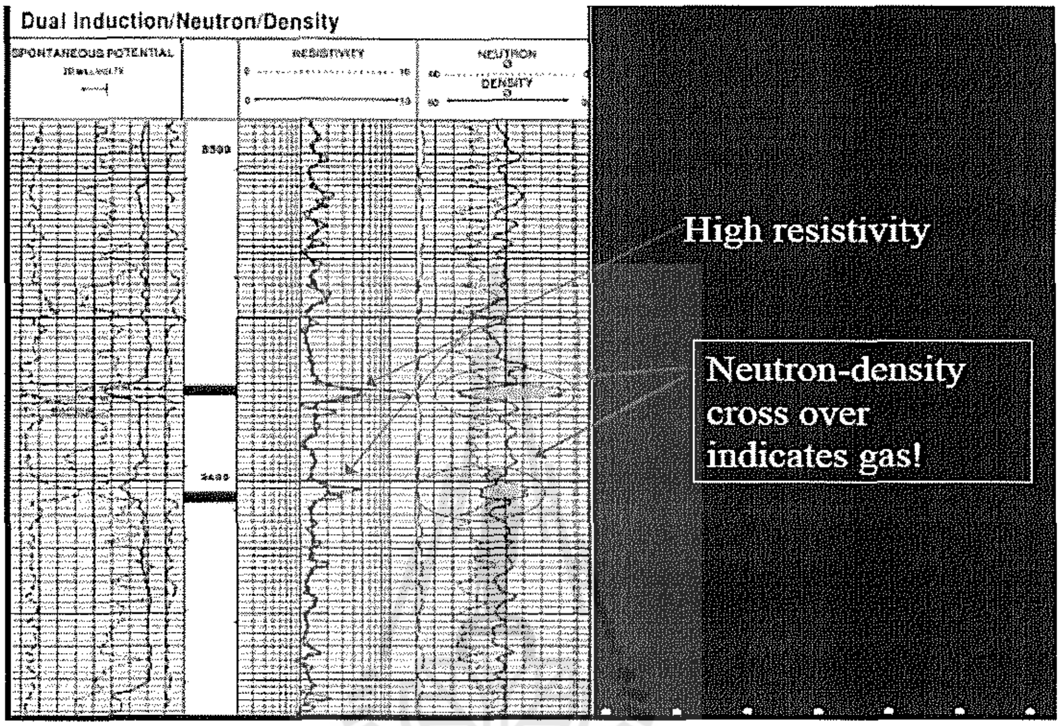
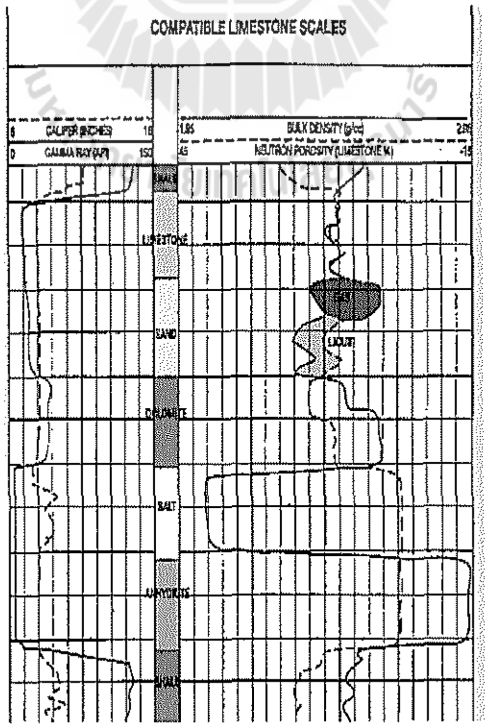
Gas Effect

- Density – Porosity is too high
- Neutron- porosity is too low
- Sonic- porosity is not significantly affected by gas





Summary of Combination of Wireline Logging

1) **Bed boundary:** Drilling rate may be compared with Sonic/GR logs and gave a good interpretative of bed boundary.
2) **Horizontal variation:** The same lithology interpretation of Mud log/Cores/Wireline logs may be used for Horizontal analysis
3) **Vertical variation:** Base line/Color/Curve separation of Mud log/Cores/Wireline logs may be used for vertical analysis
4) **Completion log:** Mud log+Cores+Wireline logs can be corroborated and compared for Completion/Final/Composite log
5) **Lithology:** GR, SP, Density & Neutron logs combination may indicates matrix type
6) **Fracture, Overpressure zone and Unconformity:** Density & Sonic logs combination, Dipmeter log may indicate those feature
7) **Source rock potential:** Density+Neutron+Resistivity+GR combination may indicates source rocks

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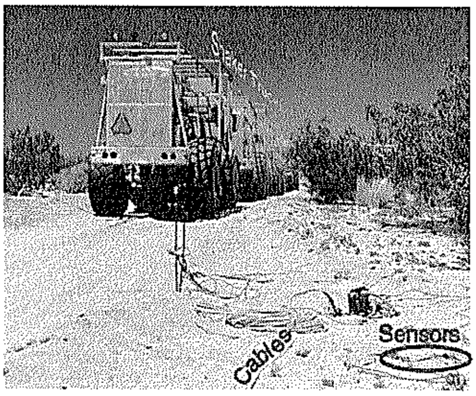
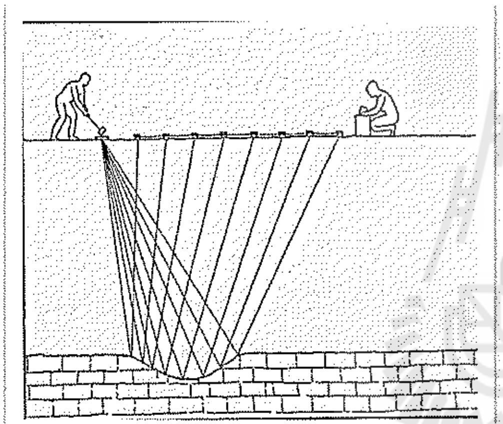
Seismic Interpretation

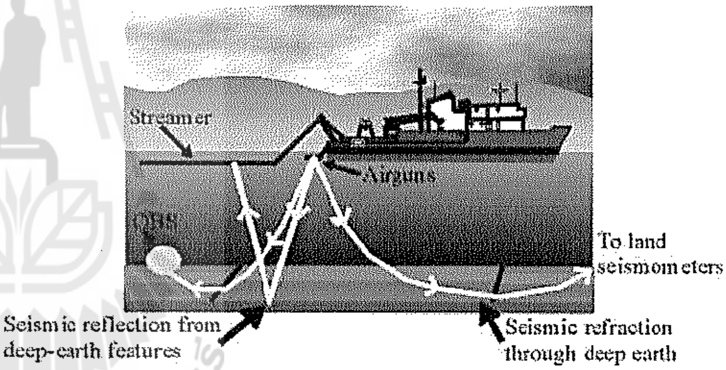
- Seismic stratigraphphy is technique for interpreting stratigraphic information from seismic data
- The resolution of the seismic reflection follow gross bedding and as such they approximate time line

Seismic Reflection

- The seismic reflection method works by bouncing sound waves off boundaries between different types of rock.
- The reflections recorded are plotted as dark lines on a seismic section.







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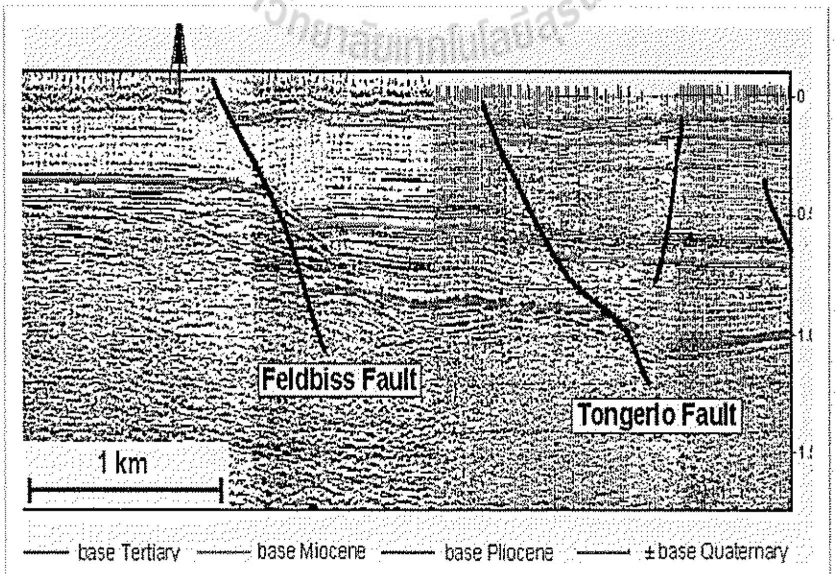
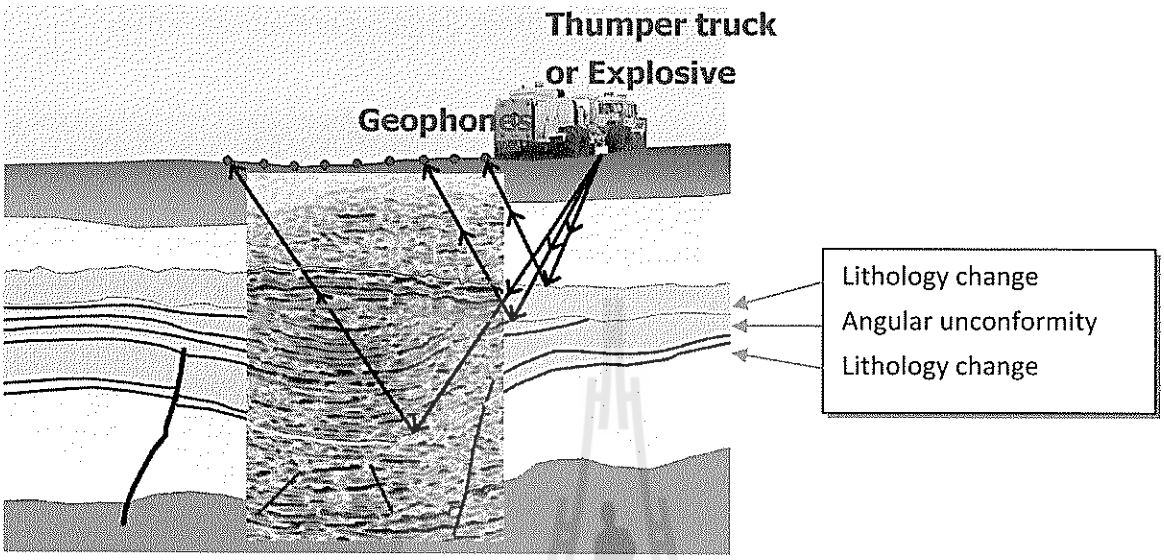
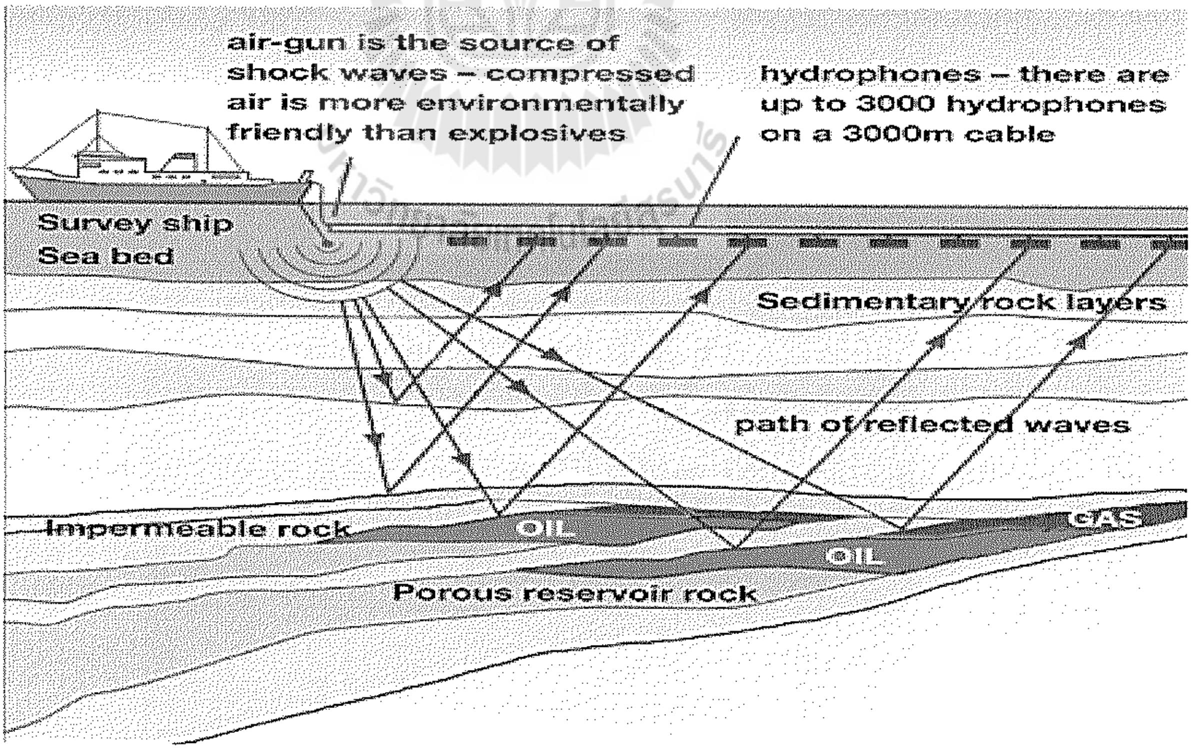


Seismic acquisition onshore

- Seismic horizons represent changes in density and allow the subsurface geology to be interpreted.



Seismic acquisition offshore



Application of Seismic reflection

1. Seismic Facies Analysis
2. Seismic Stratigraphic Analysis
3. Seismic Sequence Analysis

1. Seismic Facies Analysis

3-D units of reflection indicating:

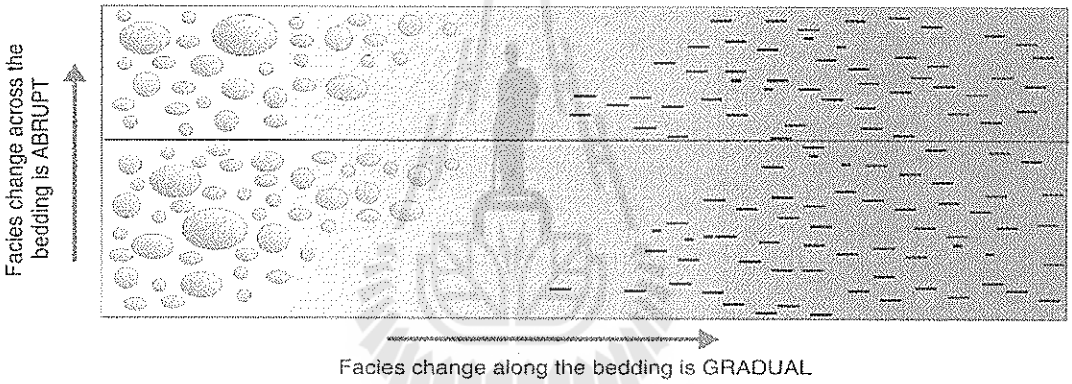
1.1 Configuration and Continuity

1.2 Amplitude

1.3 Geometry of the reflection package

All are resulting from the depositional environment

Seismic Reflection vs. Facies change



- The key is that the contrast represented by seismic lines come from bedding surface and not lateral variations (facies changes).

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1.1 Seismic reflection configuration & continuity

Configuration:

1) Parallel/Sub-parallel Configuration

(Uniform rate of deposition or subsidence)

2) Divergent Configuration

(Differential rate of deposition or subsidence)

3) Clinoform Configuration

–**Oblique unit:** Shallow water with high energy deposit

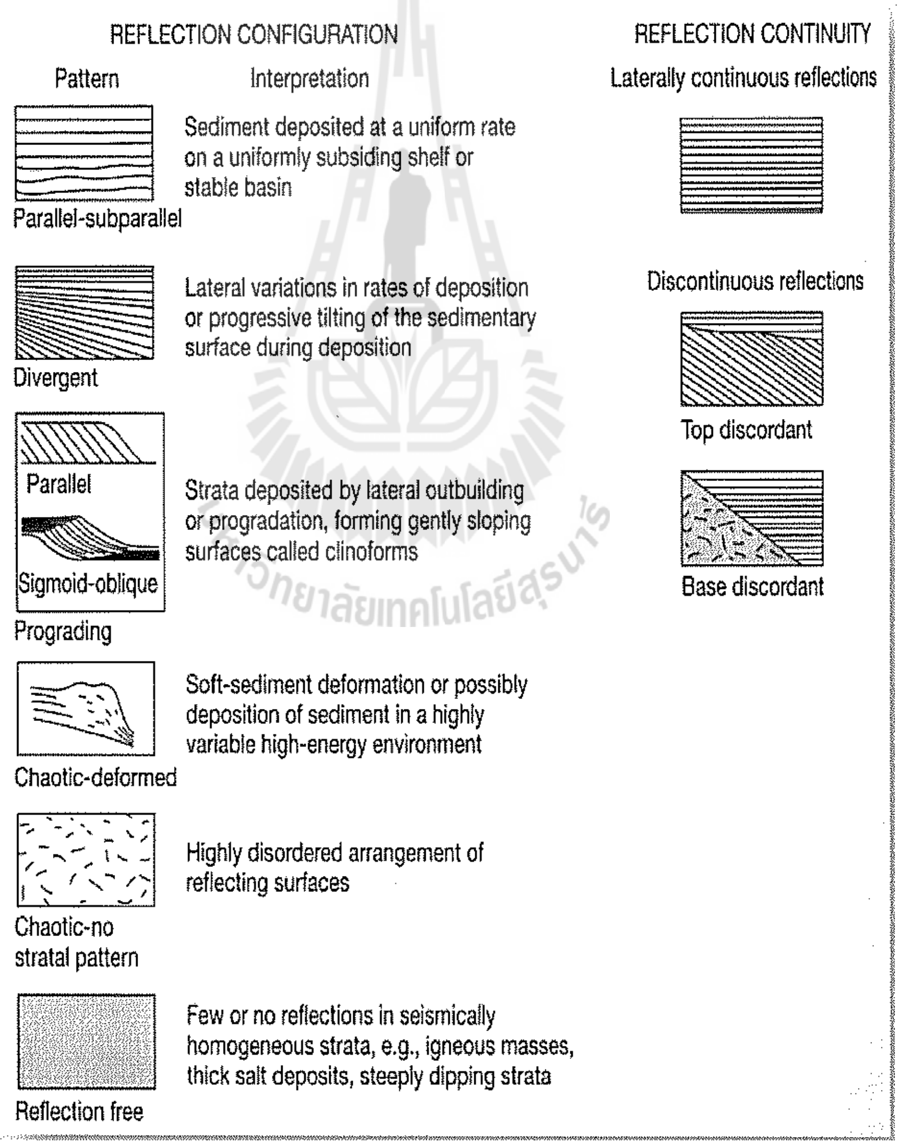
–**Sigmoid unit:** Deeper water with low energy deposit

–**Hummocky unit:** Shallow water with storm deposit
–**Shingled unit (Off-lap):** Continental shelf
–**Lenticular unit:** Submarine fan, Reef

Continuity:

- Good Continuity: Large area with low energy deposit
- Poor Continuity: Small area with high energy deposit

Primary depositional conditions
– Parallel, divergent, prograding



Parallel-subparallel: Sediment deposited at a uniform rate on a uniformly subsiding shelf or stable basin

Divergent: Lateral variations in rates of deposition or progressive tilting of the sedimentary surface during deposition

Prograding: Strata deposited by lateral outbuilding or progradation, forming gently sloping surfaces called clinoforms

Chaotic-deformed: Soft-sediment deformation or possibly deposition of sediment in a highly variable high-energy environment

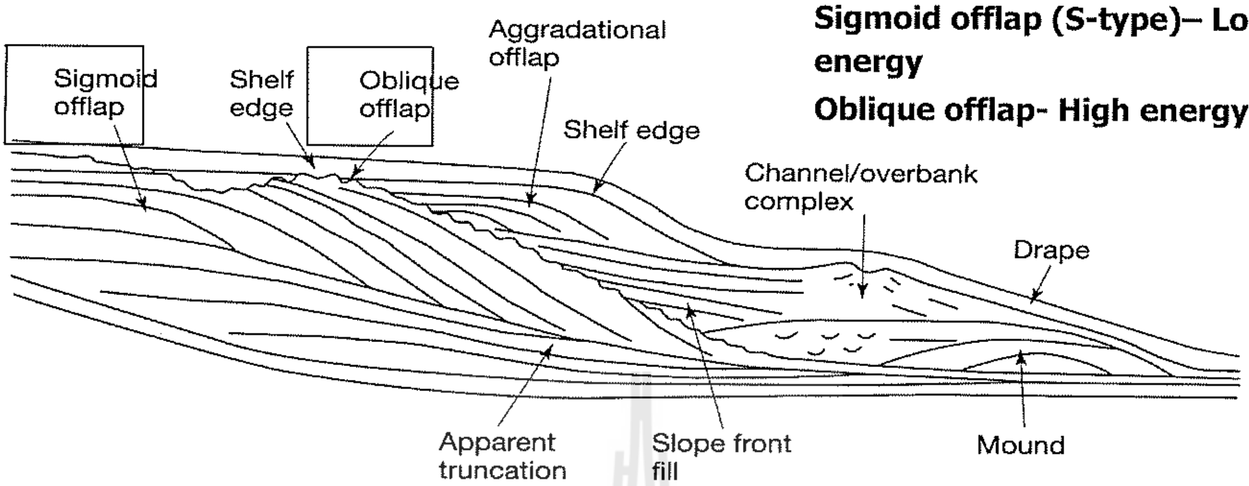
Chaotic-no stratal pattern: Highly disordered arrangement of reflecting surfaces

Reflection free: Few or no reflections in seismically homogeneous strata, e.g., igneous masses, thick salt deposits, steeply dipping strata

Common Seismic facies patterns

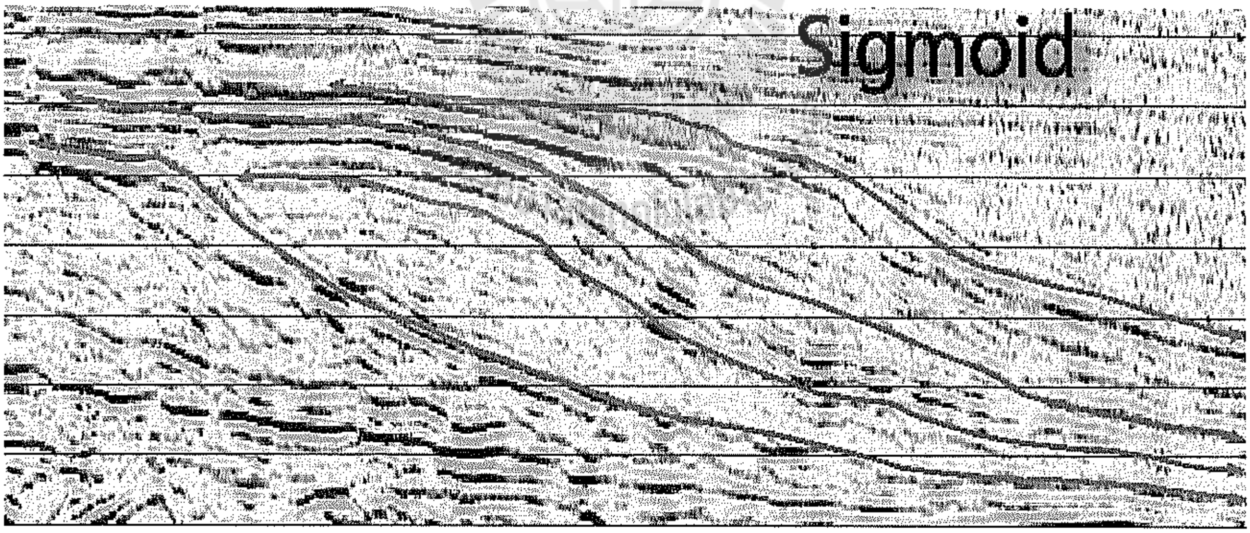
Sigmoid offlap (S-type)– Low energy

Oblique offlap- High energy



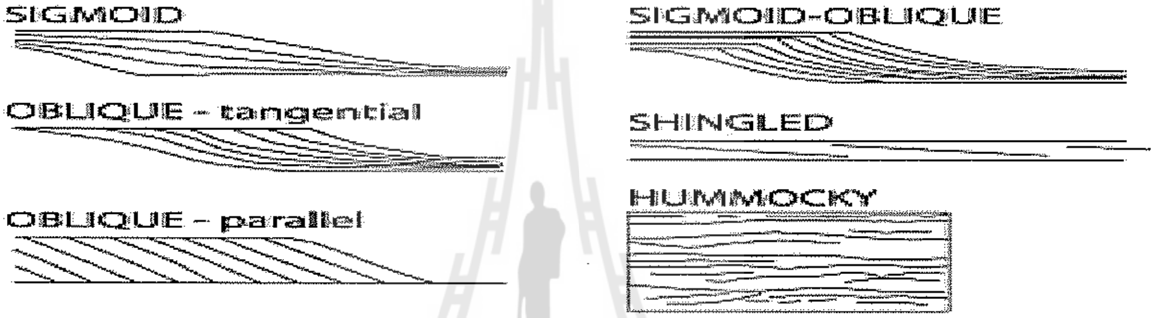
Seismic facies unit – mappable, aerially definable, 3-D unit composed of seismic reflections, differ from adjacent units

A prograding clinoform pattern formed by a number of superposed sigmoid (s-shaped) reflections interpreted as strata with thin, gently dipping upper and lower segments, and thicker



Sigmoid offlap (S-type) – Low energy
Oblique offlap- High energy

Clinoform pattern



Clinoform Profiles *(from Mitchum, 1977)*

1.2 Amplitude

- **Amplitude** – indicates bed thickness, and spacing
  - Fluid and gas in formation affect amplitude
  - Bright spots – dark bands

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Depend on

1. **Reflection frequency**

– number of oscillations of seismic waves per second, hertz (Hz) or kilohertz (KHz)

– Frequency of seismic waves induced by energy source used to create the waves

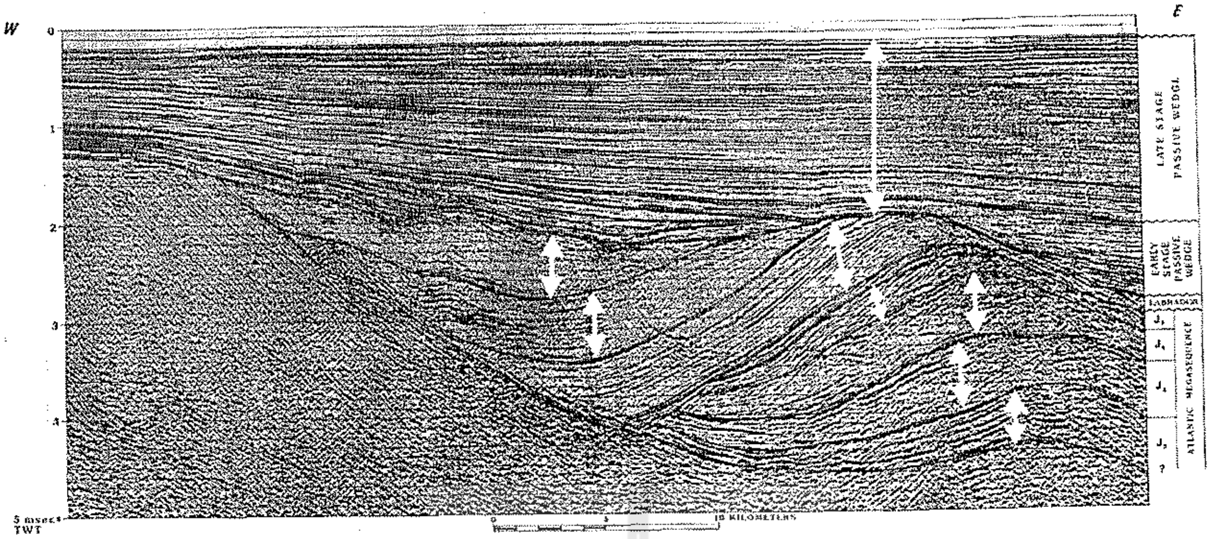
2. **Interval velocity**

– average velocity of seismic wave between reflectors.

– Porosity, density, external pressure and pore pressure affect this.

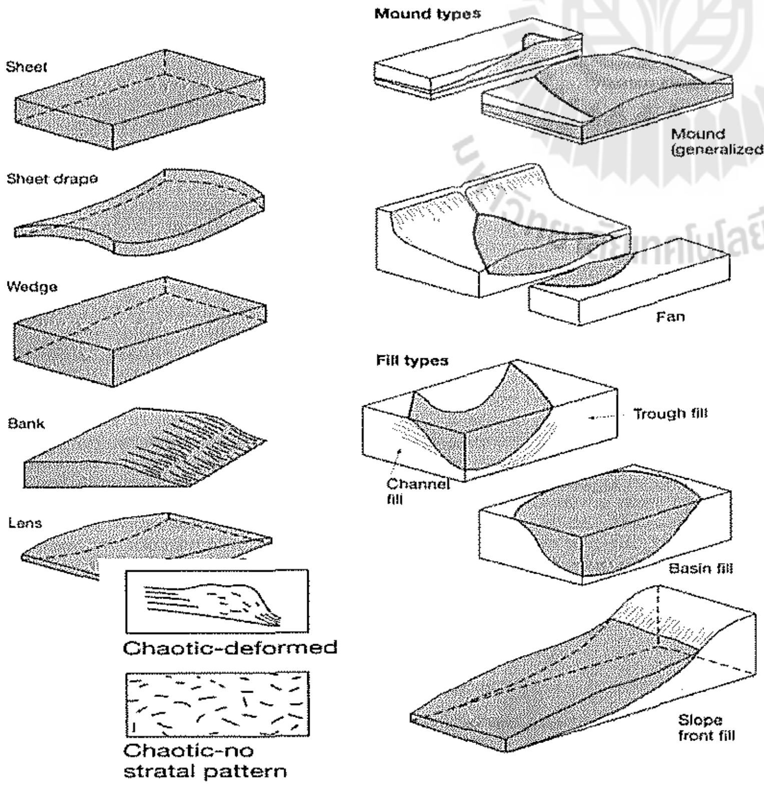
3. **External form**

– geometry of the stratigraphic body, seismic facies



Variable-Density Mode, waves of certain amplitude shaded black, other light colored

- ➢ **If High Amp. & Good Continuity== Quiet water deposition (lake, lacustrine)**
- ➢ **If Low Amp. but Good Cont. ==Deep sea**



- **High Amp. & Poor Continuity== Continental deposition (Alluvial, Fluvial)**
- **High Amp. & Good Continuity== Quiet water deposition (lake, lacustrine)**
- **Low Amp. but Good Cont. ==Deep sea**
- **High Amp. & Poor Continuity== Continental deposition (Alluvial, Fluvial)**

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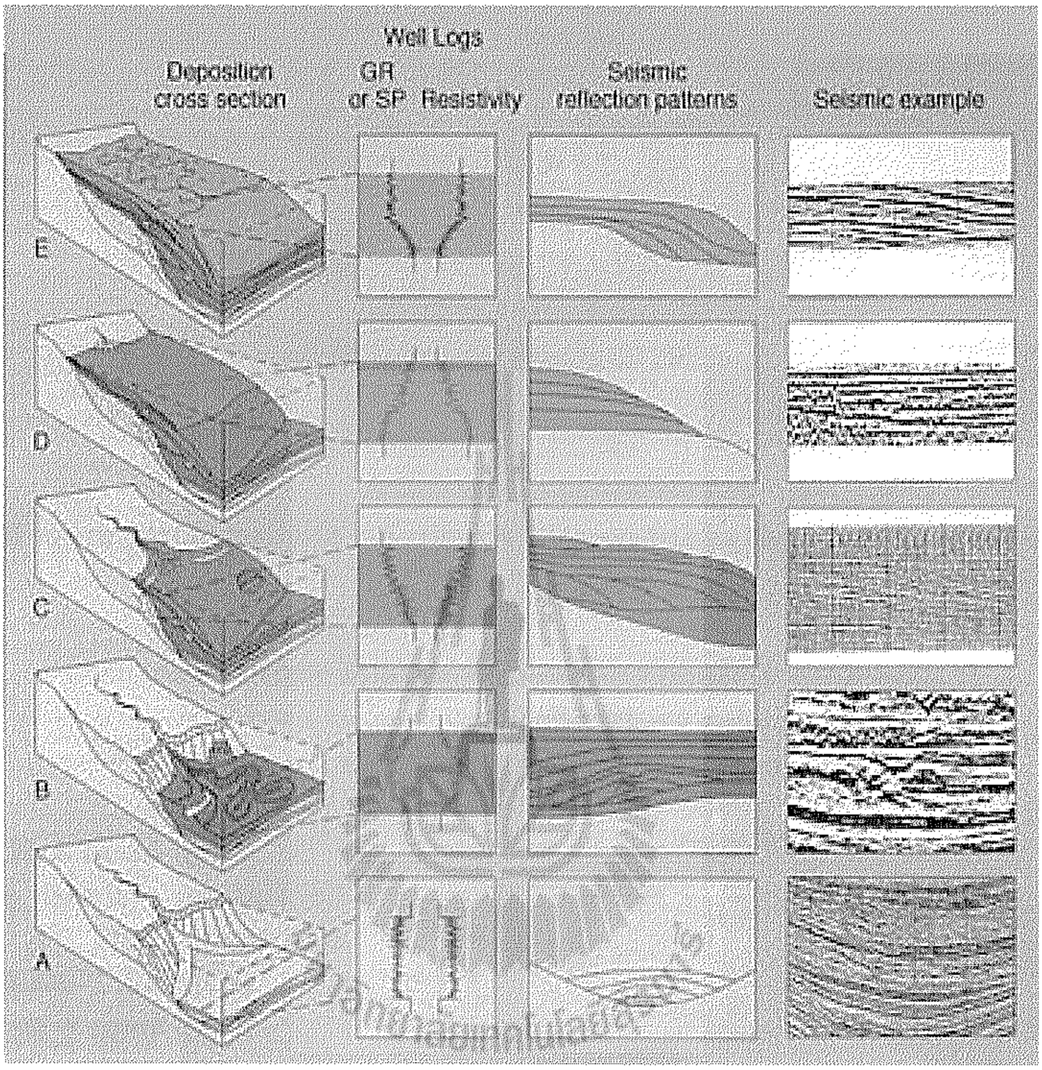
Elements of sequence stratigraphic interpretation



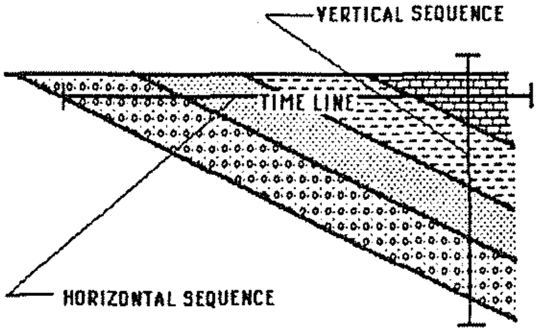
2. Seismic Stratigraphic Analysis

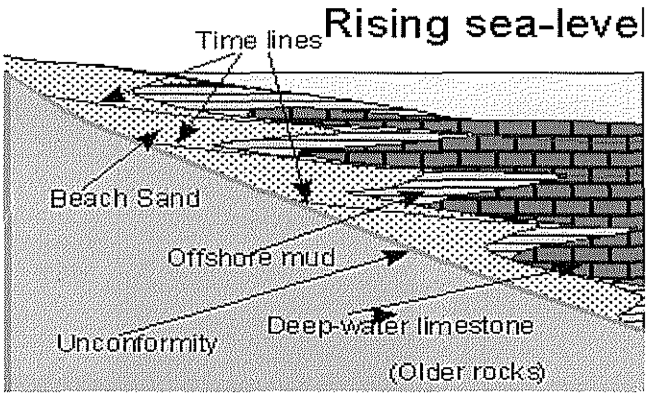
- Depositional processes interpreted from seismic profiles
- Based on analog from established stratigraphic and depositional models
- Used for: lithofacies changes, relief, topography of unconformities, paleobathymetry (depth relationships),burial history

Time line

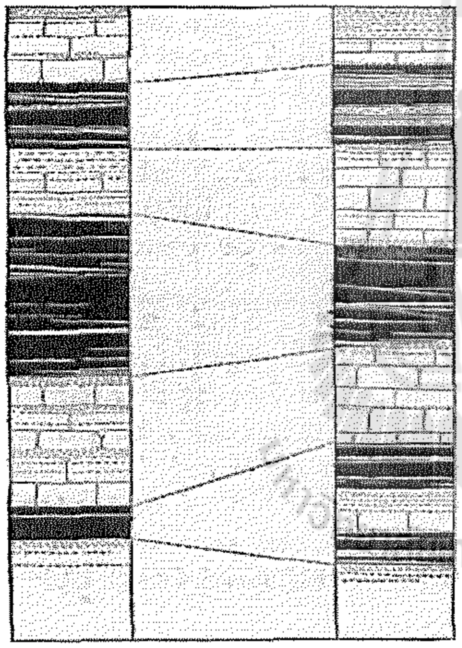
Time line can divide into 2 type:

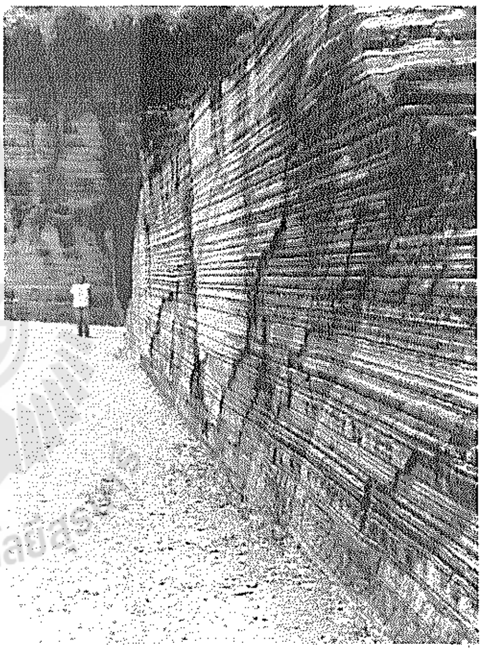
1. Chronostratigraphy : Parallel to bedding surface (เกิดในช่วงเวลาเดียวกัน)
2. Transgressive: Cross to bedding surface (ชั้นหินเกิดในเวลาที่แตกต่างกัน)



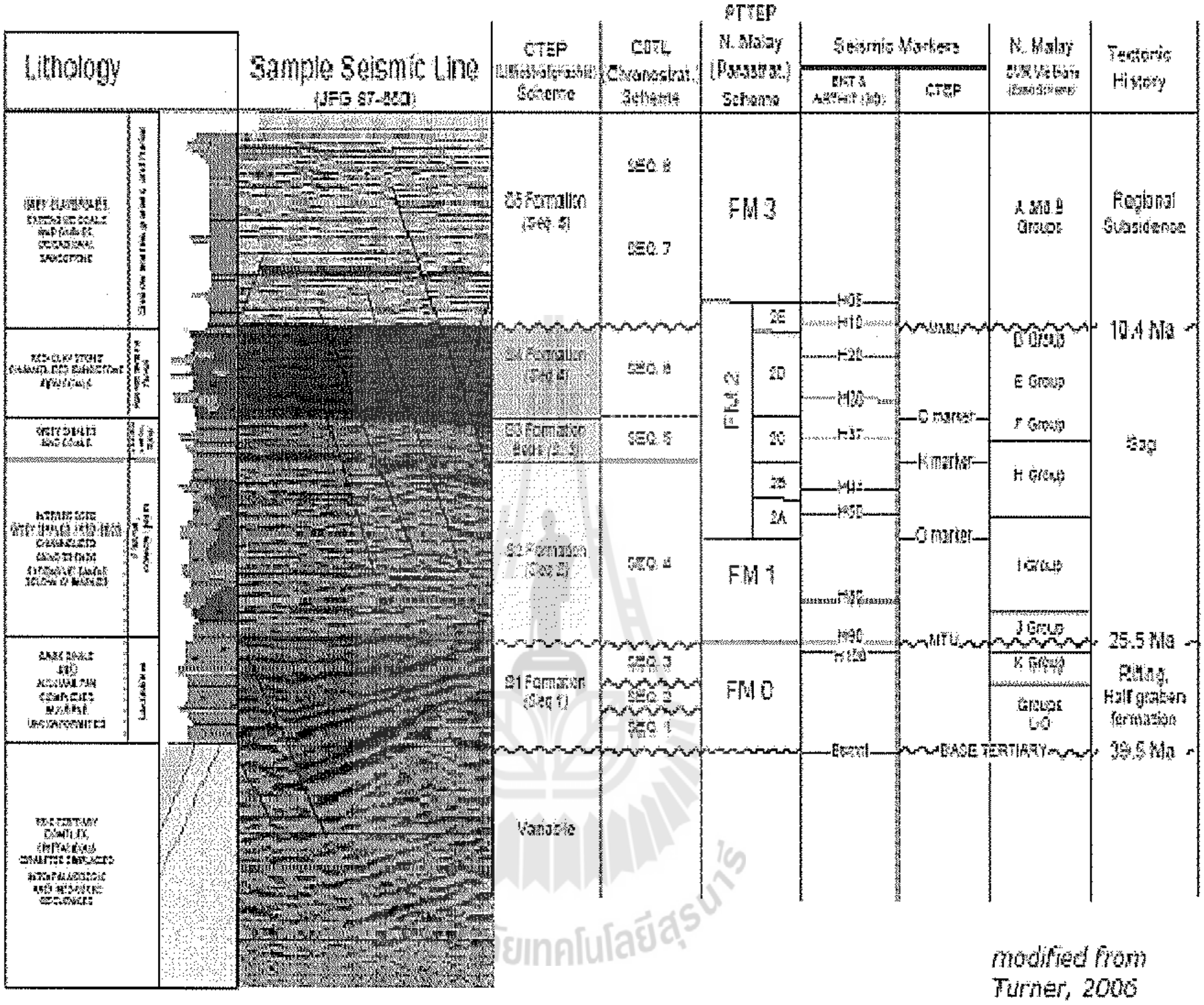


Parallel Bedding





Example of Seismic Stratigraphy Gulf of Thailand

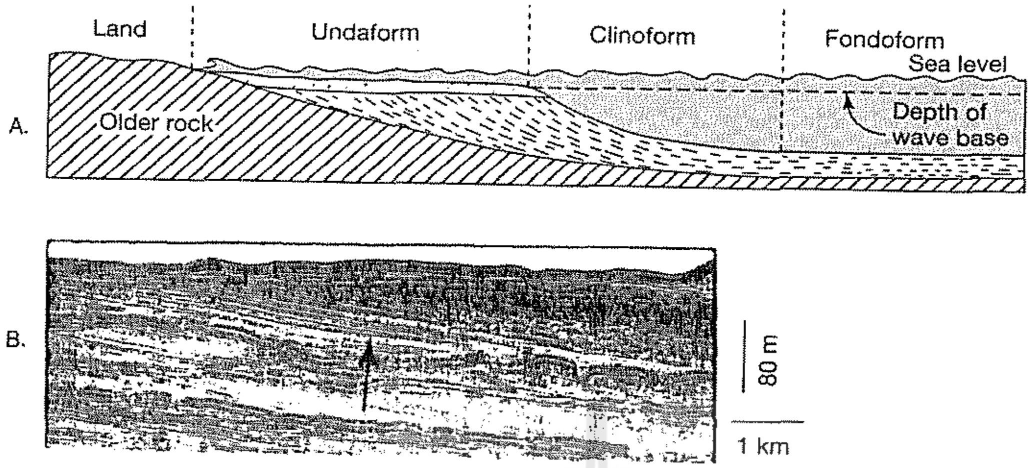


modified from Turner, 2006

3. Seismic Sequence Analysis

- **Sequence** - any grouping or succession of strata; (more restrictive) distinctive stratigraphic units
- **Depositional sequence** – stratigraphic unit composed of a relatively conformable grouping of genetically related strata and bounded at its top and base by unconformities or their correlative conformities

Undaform, Clinoform and Fondoform



Depositional Environments in relationship to wave base.

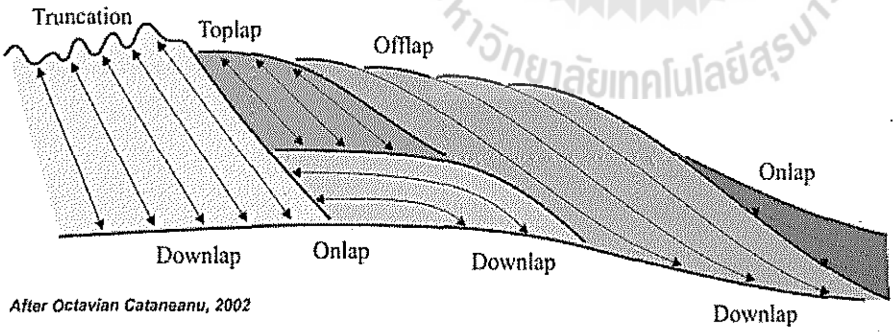
(1) Unda for shallow water overlying the shelf,

(2) Clino for the deeper water overlying the slope

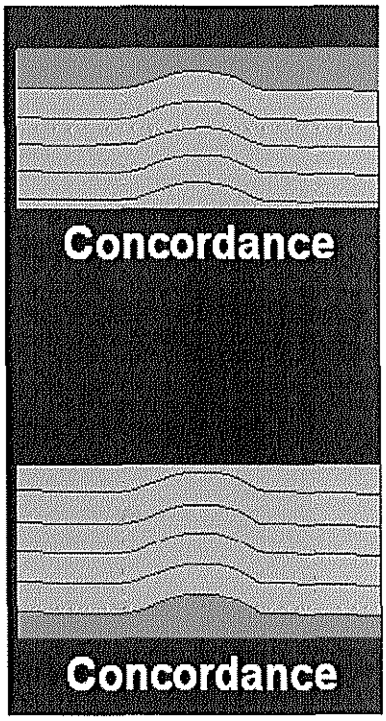
(3) Fondo for the deepest water covering the bottom of the basin

Internal Relationships

- **Concordant** – parallel to the sequence boundary
- **Discordant** – lack parallelism with sequence boundaries



After Octavian Cataneanu, 2002



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Seismic Boundaries

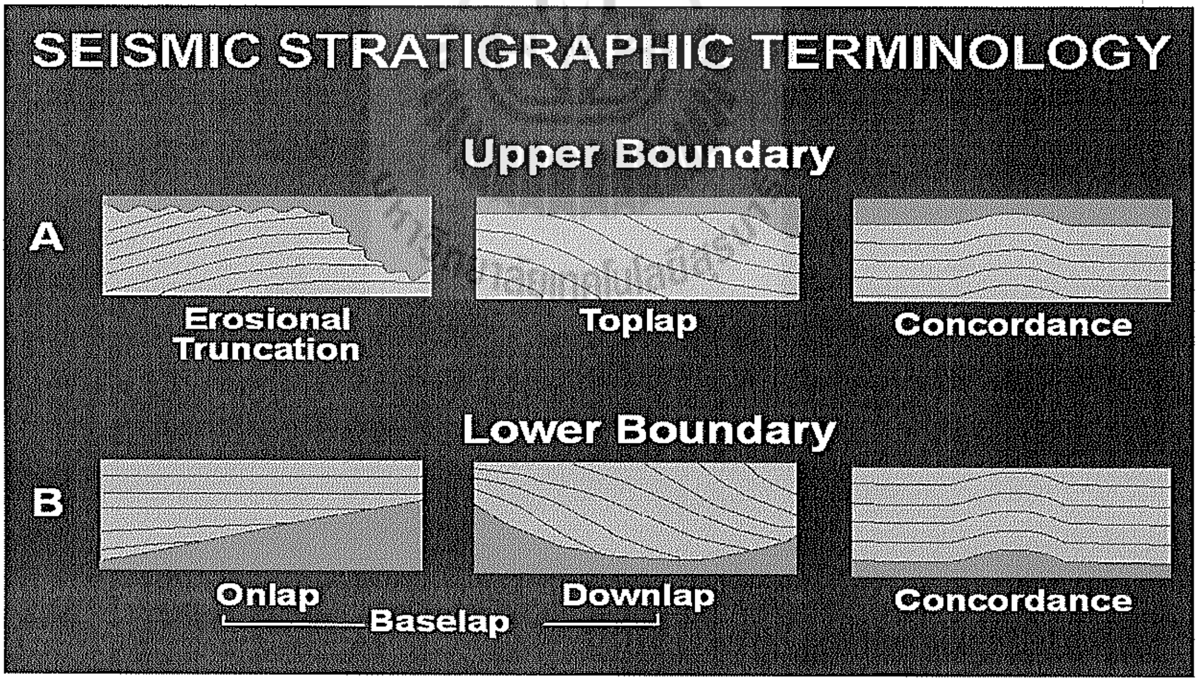
Termination below discontinuity, or upper sequence boundary :

- **Toplap:** termination of strata against an overlying surface, representing the result of non-deposition and/or minor erosion
- **Truncation** of sediment surface (same with toplap but have erosional surface)
- Often channel bottom

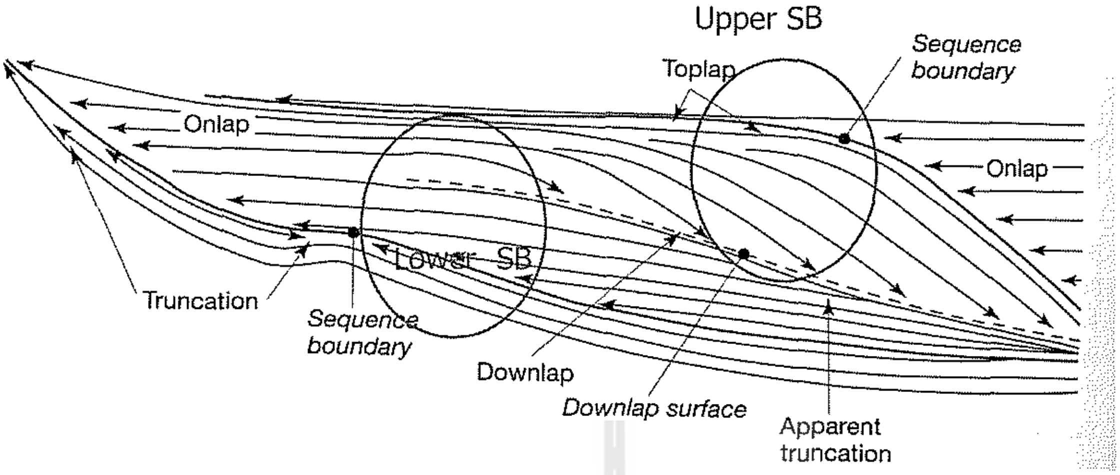
Termination above a discontinuity defining lower sequence boundary:

- **Onlap:** A base-discordant relationship in which initially horizontal strata progressively terminate against an initially inclined surface (Two Types: marine & coastal)
- **Downlap:** seismic reflections of inclined strata terminate downdip against an inclined or horizontal surface

Original Sequence Stratigraphic Approach (seismic stratigraphy) was based on recognition of unconformity-bound sequences using geometry and termination patterns of seismic reflectors.



Sequence Boundaries, Downlap, Reflection termination

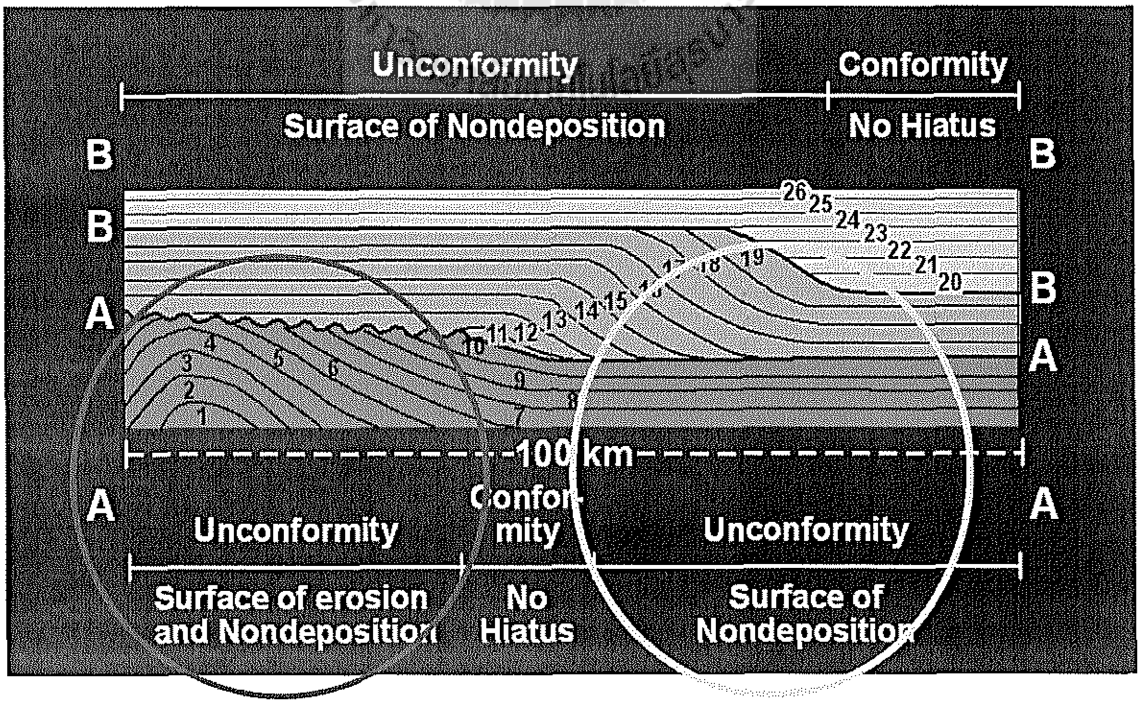


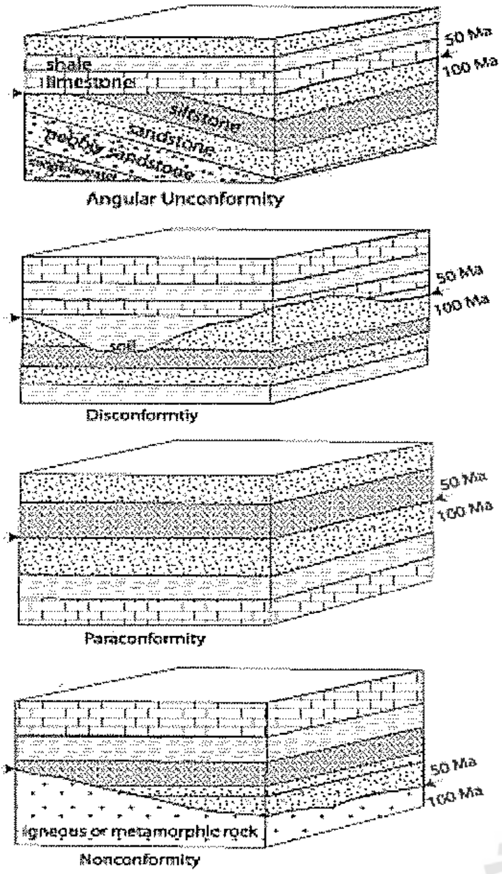
Above discontinuities (Lower boundary) – onlap, downlap

Below discontinuities (Upper boundary) – truncation, toplap, apparent truncation

Unconformities

- **Outcrop** – there are 4 kinds; Angular, Disconformity, Paraconformity and Nonconformity
- **Seismic stratigraphic** – 2 kinds of discontinuities – good reflectors
  1) **Erosional unconformity surface** – hiatus produced by subaerial or subaqueous erosional truncation
  2) **Downlap surfaces** – marine surfaces representing a hiatus without evidence of erosion.





Unconformities (redrawn from Boggs, 2001)

Unconformity (OUTCROP)

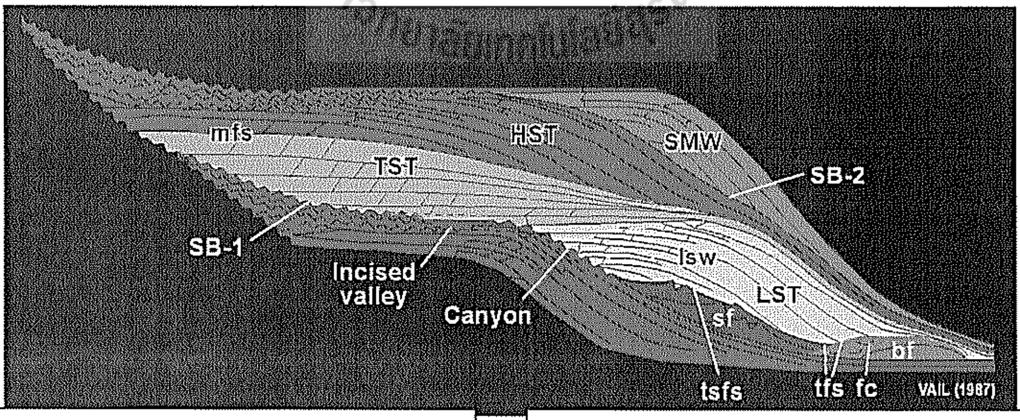
1) **Angular unconformity**: younger sediments rest upon the eroded surface of tilted or folded older rocks.

2) **Disconformity**: contact between younger and older beds is marked by a visible, irregular or uneven erosional surface.

3) **Paraconformity**: beds above and below the unconformity are parallel and no erosional surface is evident; but can be recognized based on the gap in the rock record.

4) **Nonconformity**: develops between sedimentary rock and older igneous or metamorphic rock that has been exposed to erosion.

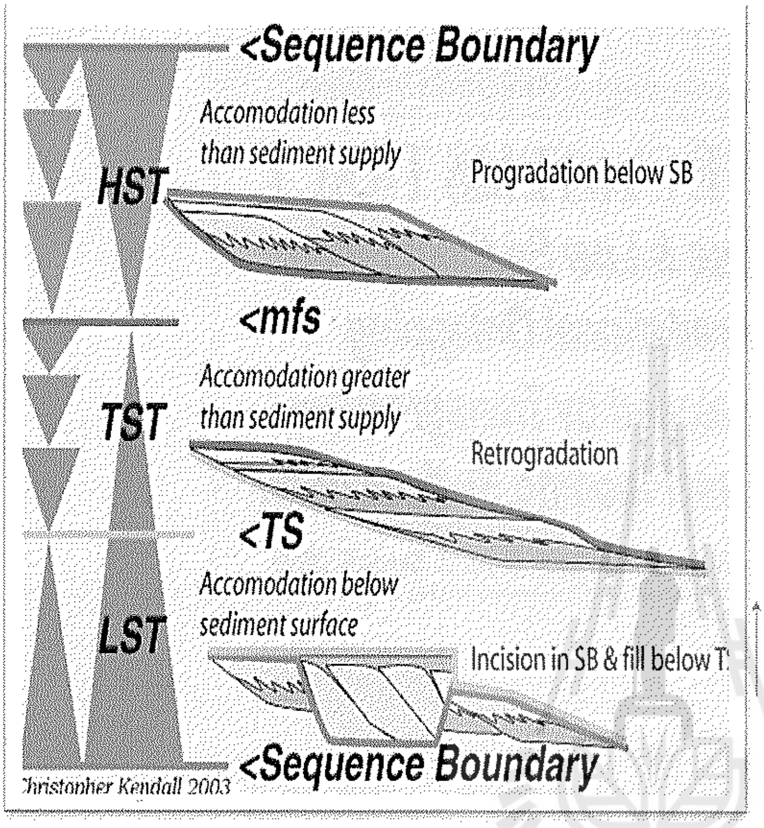
The Classic Slug Exxon Model

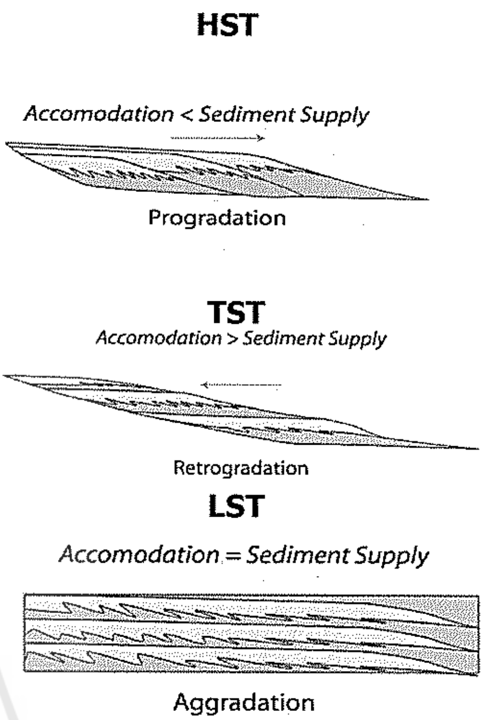


SB – sequence boundary
LST – Lowstand systems tract
TST – Transgressive systems tract
HST – Highstand systems tract
SMW – shelf-margin wedge

Mfs – maximum flooding surface
Lsw – lowstand wedge
Sf – slope fan
Bf – basin-floor fan

System Tracts





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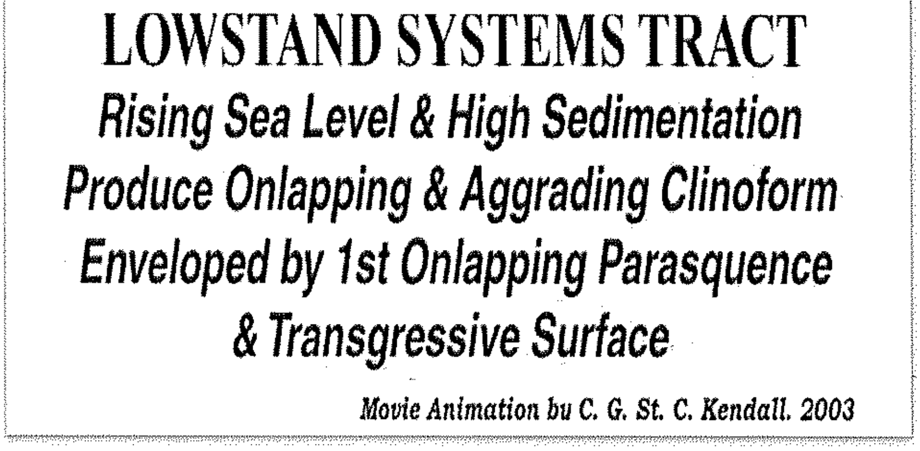
Seismic System Tracts

1. **LST – Lowstand systems tract**

bounded by the Falling Stage Systems Tract and the Transgressive Systems Tract

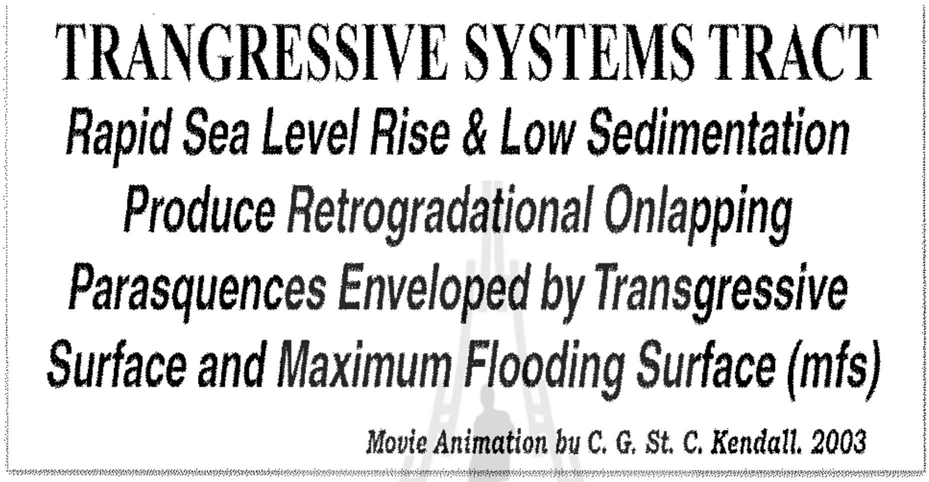

LOWSTAND SYSTEMS TRACT

Rising Sea Level & High Sedimentation
Produce Onlapping & Aggrading Clinoform
Enveloped by 1st Onlapping Parasquence
& Transgressive Surface

Movie Animation bu C. G. St. C. Kendall. 2003

2. TST – Transgressive systems tract

- below by underlying SB and above by mfs
- mounded geometry
- less grainstone prone, more diverse skeletal assemblages



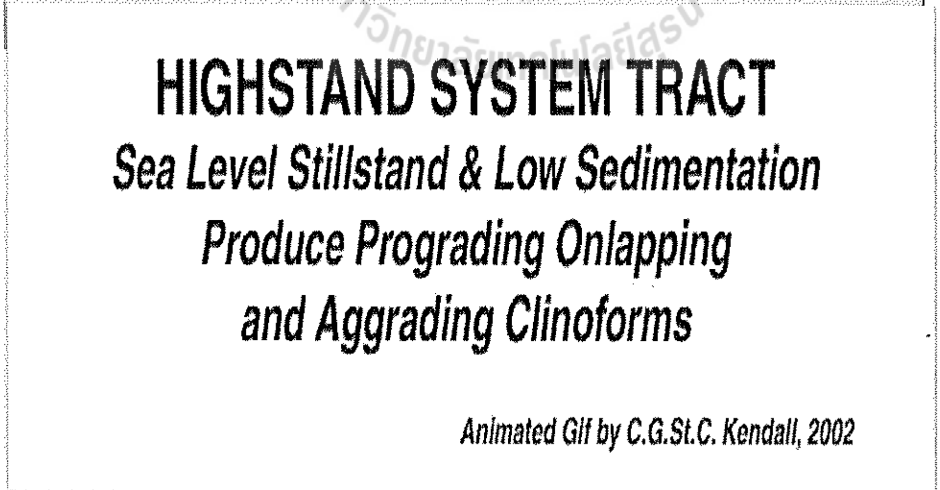
TRANGRESSIVE SYSTEMS TRACT

Rapid Sea Level Rise & Low Sedimentation Produce Retrogradational Onlapping Parasquences Enveloped by Transgressive Surface and Maximum Flooding Surface (mfs)

Movie Animation bu C. G. St. C. Kendall. 2003

3. HST – Highstand systems tract

- below by mfs and above by SB
- shingled or offlapping (clinoformal) stratal geometry



HIGHSTAND SYSTEM TRACT

Sea Level Stillstand & Low Sedimentation Produce Prograding Onlapping and Aggrading Clinoforms

Animated Gif by C.G.St.C. Kendall, 2002

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Principle of Seismic interpretation

1. Check line scale and orientation
2. Work from the top of the section, where clarity is usually best, towards the bottom.
3. Distinguish the major reflectors and geometries of seismic sequence

Recommended procedures for performing seismic sequence analysis include:

1. Identifying the unconformities in the area of interest. Unconformities are recognized as surfaces onto which reflectors converge.
2. Mark these terminations with arrows.
3. Draw the unconformity surface between the onlapping and downlapping reflections above; and the truncating and toplapping reflections below.
4. Extend the unconformity surface over the complete section. If the boundary becomes conformable, trace its position across the section by visually correlating the reflections.
5. Continue identifying the unconformities on all the remaining seismic sections for the basin.
6. Make sure the interpretation ties correctly among all the lines.
7. Identify the type of unconformity:
    a. Sequence boundary: this is characterized by regional onlap above and truncation below.
    b. Downlap surface: this is characterized by regional downlap.

Recommended color codes:

Red: Reflection patterns and reflection terminations.
Green: Downlap surfaces
Blue: Transgressive surfaces (TS)
Other colors: Sequence boundaries (SB)

If using only black and white:

Thin solid lines ——— : Reflection patterns
Thicker solid lines ——— : Sequence boundaries (SB)
Dashed lines – – : Downlap surfaces
Dotted lines ·······: Transgressive surfaces (TS)

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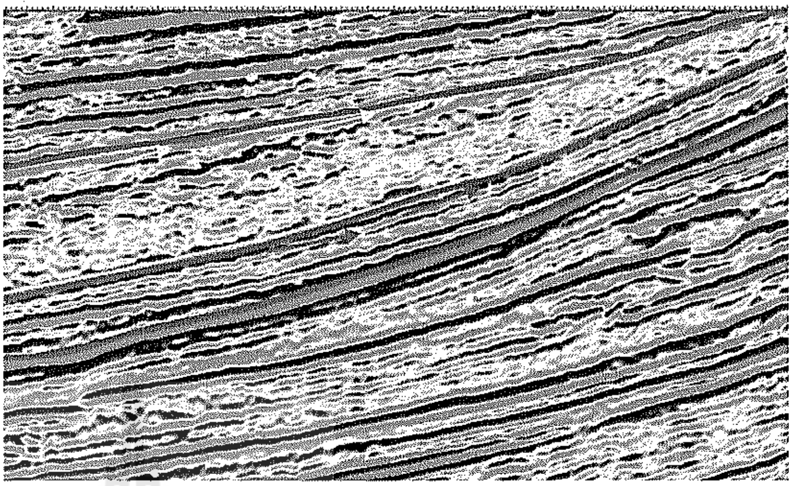
Reflector character and geometry

- Continuous reflector truncating short ones
- Next continuous reflector
- Reflectors onlapping continuous one



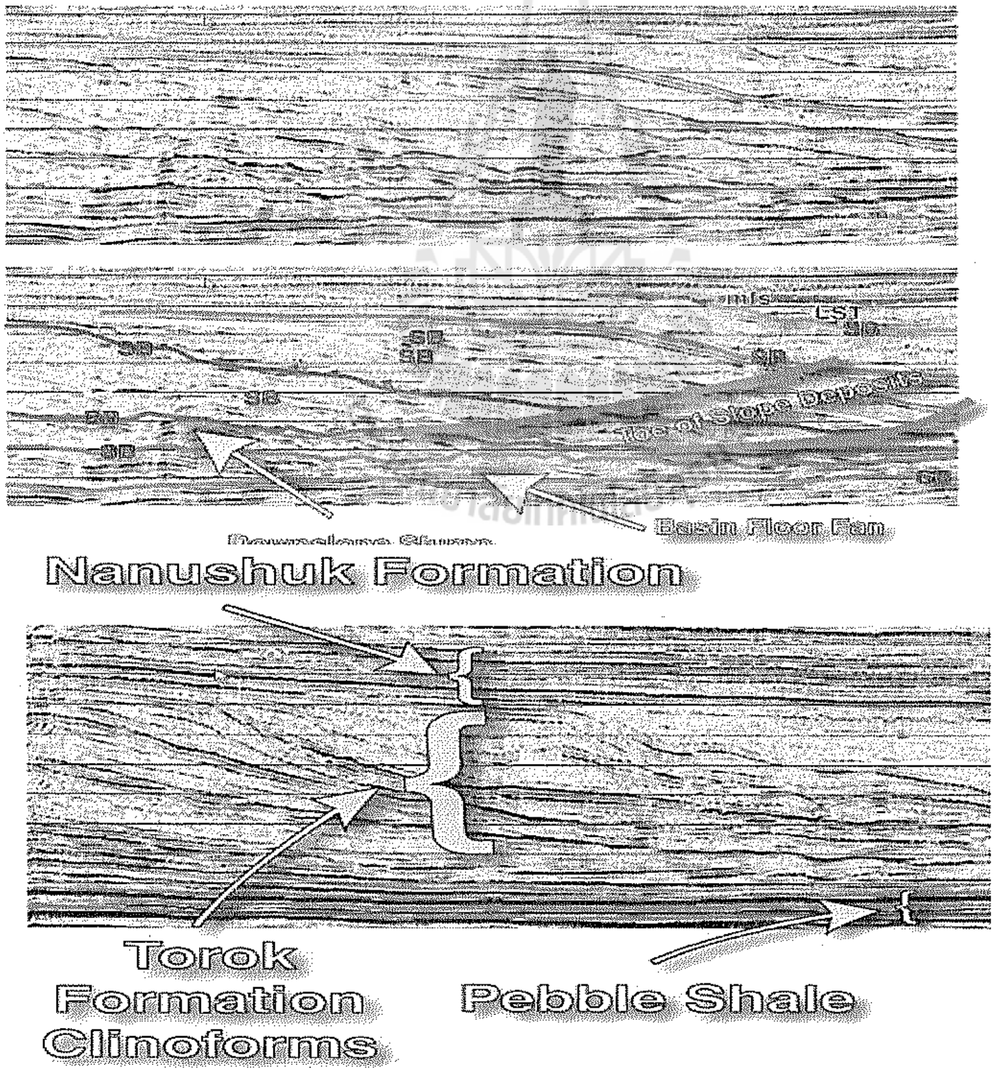
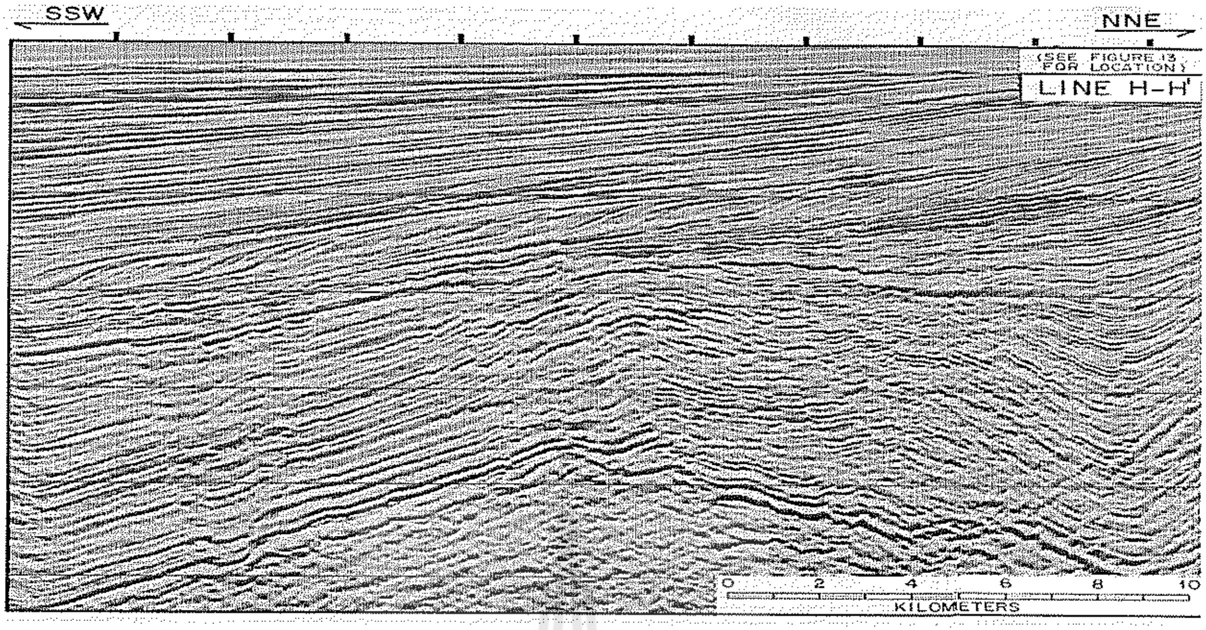
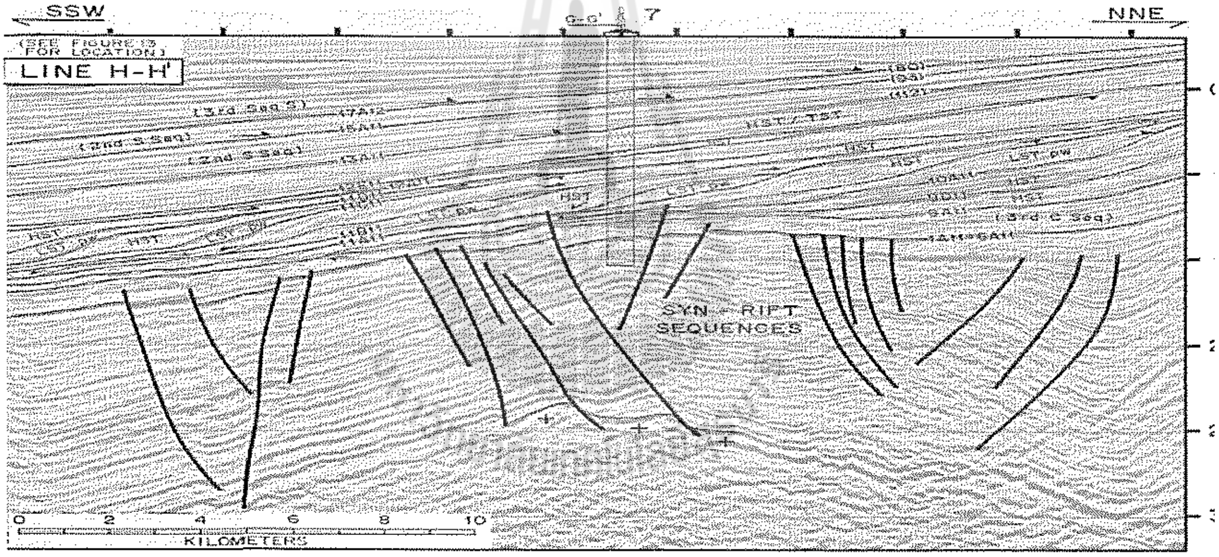


Figure 3. Regional seismic line illustrating the stratigraphic relationships among the major rock units within the NPRA.



Low-resolution seismic example (offshore South Africa)



Advantages of Seismic Data

- Good lateral resolution
- Good definition of structural features
- May be only data type present in some areas (exploration)
- Conductive to digital analyses
- Lithology prediction, etc.

Disadvantages of Seismic Data

- May be expensive to collect
- Vertical resolution is poor
  - Depends on frequency content of seismic data
  - 10s of meters common
- Difficult to collect good-quality data in places
- Non-unique answers possible

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Table show the summary of Sandstone Reservoir Facies

	Sandstone Reservoir Facies		
Sedimentary Deposition	**Cores**	**Logs**	**Seismic**
1. Alluvial	Upper fan: coarser+angular+ poor sorting Lower fan: finer+crossbedding CU seq.	High GR Shale of low dip angle (GP) Low GR Sand of 3 braided channel (BP) Fanglomerate (random dip pattern)	Poor continuity
2. Braided streams	Channel: sharp erosional base	Blocky GR: braided channel sand	Homogeneity lithology: poor internal reflection
3. Meandering streams	Channel: sharp erosional base + FU	Bell GR: point bar sand Structure dip (GP) + Accretion slopes (RP)+ high crossbedding (BP)	Erosional base: high amplitude
4. Eolian dune	Well sorting (rework)+crossbedding	Blocky GR: sand dune body Saw toothed FDC/GR: finer grain+mica (base) Low dip angle at the base then increase upward until reaching a max. of about 25-35 degree	Not detectable
5. Lacustrine	Define as fancies group and consider as small inland seas Non-marine fossil & rift graben-type		
6. Coastal barrier islands	Well sorting upward +CU Abundance & scale of cross stratification increasing upward but Bioturbation incrasing downward	Funnel GR/SP BP Dip	High amplitude (beach/dune sand overlying marine/lagoonal shale
7. Continental Shelf Sand	F-VC grain, mod-well sorting crossbedding Sst Ripple Sst intercalated with silty gy Sh/Bioturbated Sst and Sh Burrowed silty gy Sh	Funnel GR/SP (CU)	High amplitude and become transitional updip to the right
8. Deep sea sands	Dominate cut-and-fill channel in upper portion Incomplete turbidite sequence in lower portion	Blocky or bell GR/SP+random dip in upper fan Thinner bell GR/SP+RP dip in mid fan Funnel GR/SP in lower fan	Mountd-shaped with an interal hummocky/chaotic
9. Deltas	**Fluvial dominate delta** : Upper part-alluvial channel (meandering) : Lower part-distributary delta		
	Wave or tidal dominate delta : Barrier island, tidal channel, tidal flat		
	Distributary channel sands : Moderate to well sorting+FU : Crossbedding (lower)+ripple & plain lamp (upper)	Blocky to bell GR/SP RP Dip	
	Distributary mouth bar sands	Funnel GR/SP	Oblique

Chapter 5
Subsurface Mapping

Correlation points of Logged Data

Using **correlation points/data points/key beds/log markers** to define surfaces.

1. Distinctive thin configuration
2. Similar curve configuration
3. Recognizable over large area

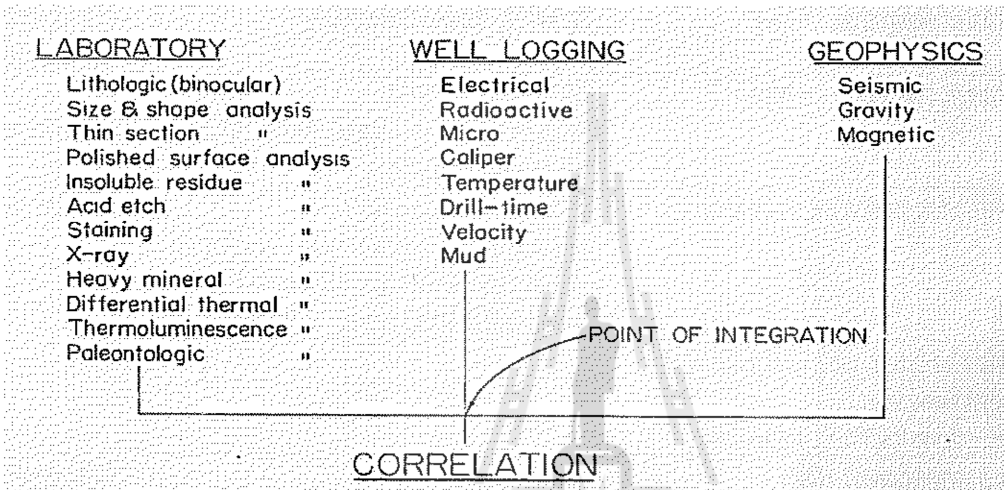

FIGURE 23-10. Procedures applied in correlation of strata. Some correlation problems require a combination of procedures; others may involve only one to obtain favorable correlation results.

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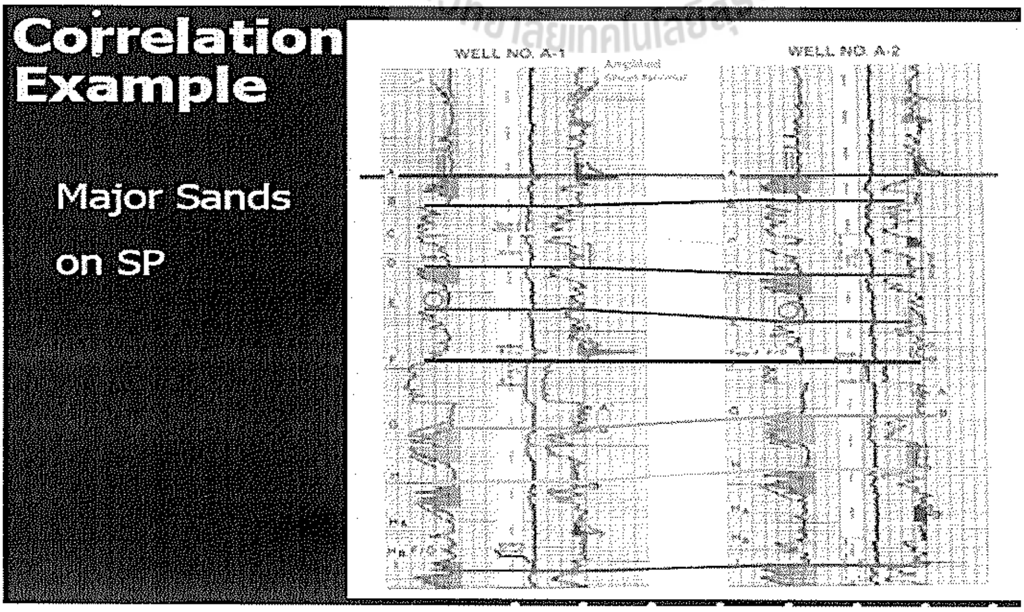
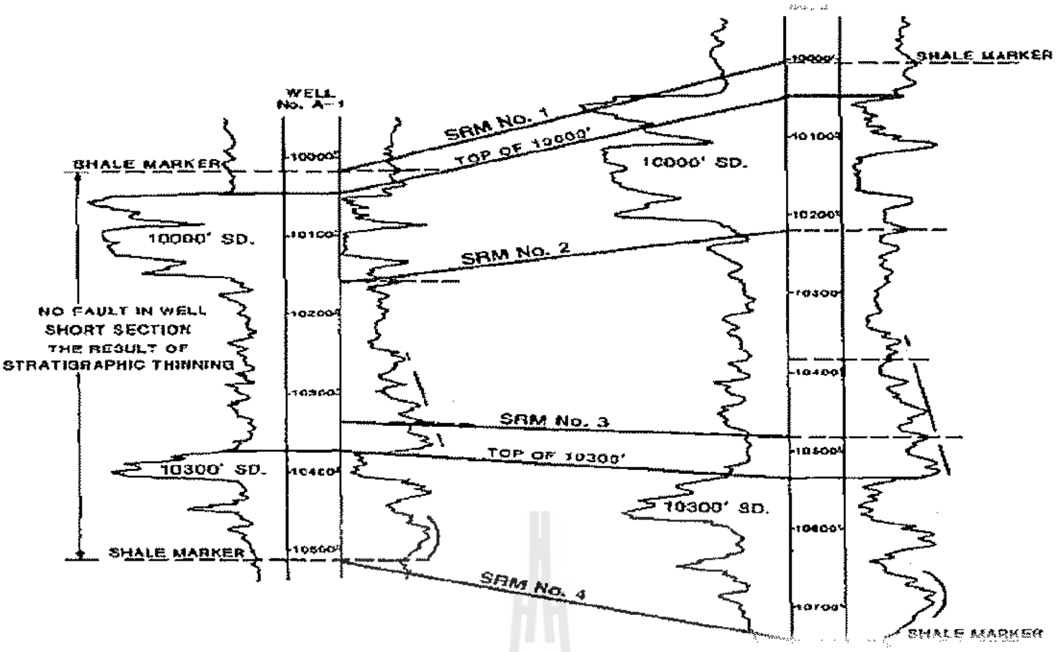
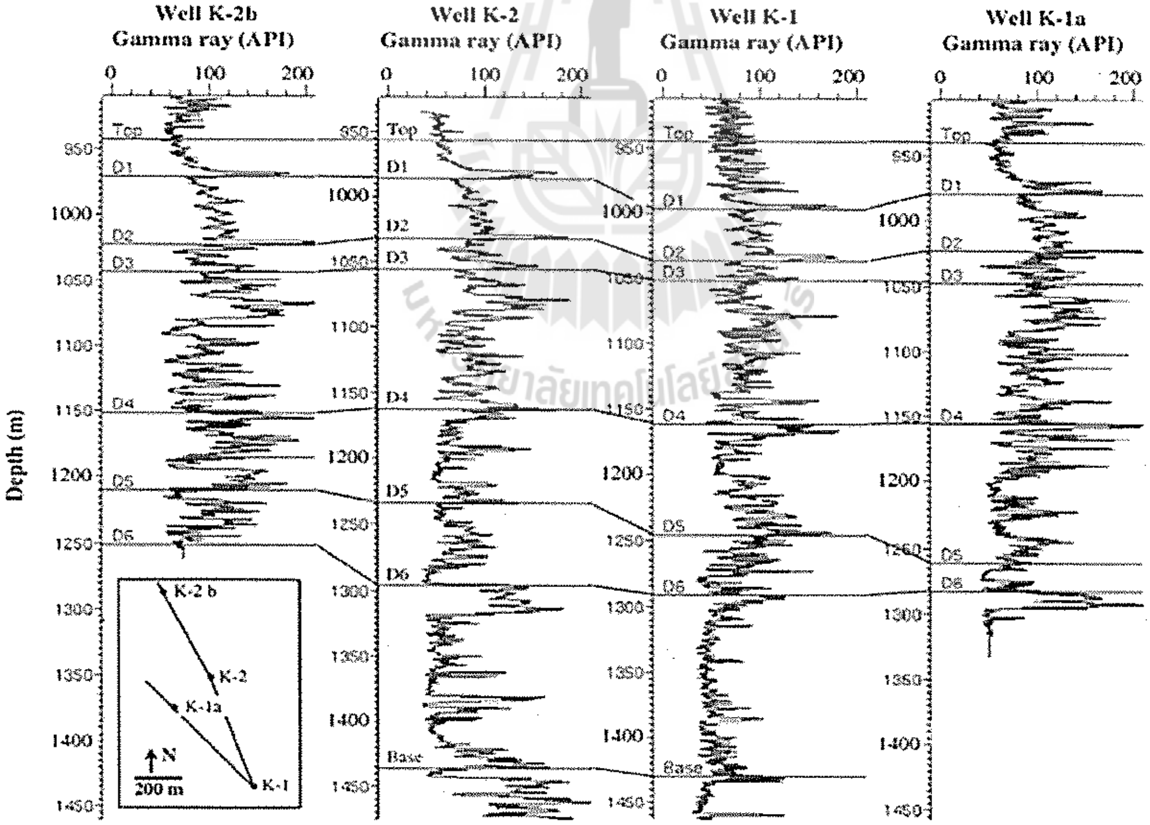
Example of Correlation


Correlation Example

Major Sands on SP


WELL No. A-1
SHALE MARKER
10000' SD.
NO FAULT IN WELL
SHORT SECTION
THE RESULT OF
STRATIGRAPHIC THINNING
10300' SD.
SHALE MARKER
SRM No. 1
TOP OF 10000'
SRM No. 2
SRM No. 3
TOP OF 10300'
SRM No. 4
10000'
10100'
10200'
10300'
10400'
10500'
10600'
10700'
SHALE MARKER
10000' SD.
10300' SD.
SHALE MARKER


Well K-2b
Gamma ray (API)
Well K-2
Gamma ray (API)
Well K-1
Gamma ray (API)
Well K-1a
Gamma ray (API)
0
100
200
Depth (m)
Top
D1
D2
D3
D4
D5
D6
Base
950
1000
1050
1100
1150
1200
1250
1300
1350
1400
1450
K-2 b
K-2
K-1a
K-1
N
200 m

Type of correlation points

1. Vertical correlation points

The correlation points is seen either as a surface of a mass of strata containing some property in common or as a tangible trace of as abstract geological event.

2. Horizontal correlation points

Lithofacies and biofacies shift laterally in space through time

Stratigraphic Law

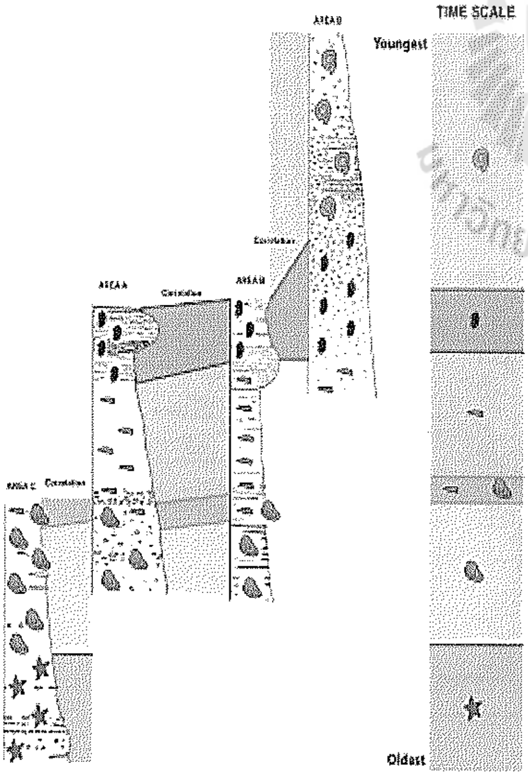
1. Superposition

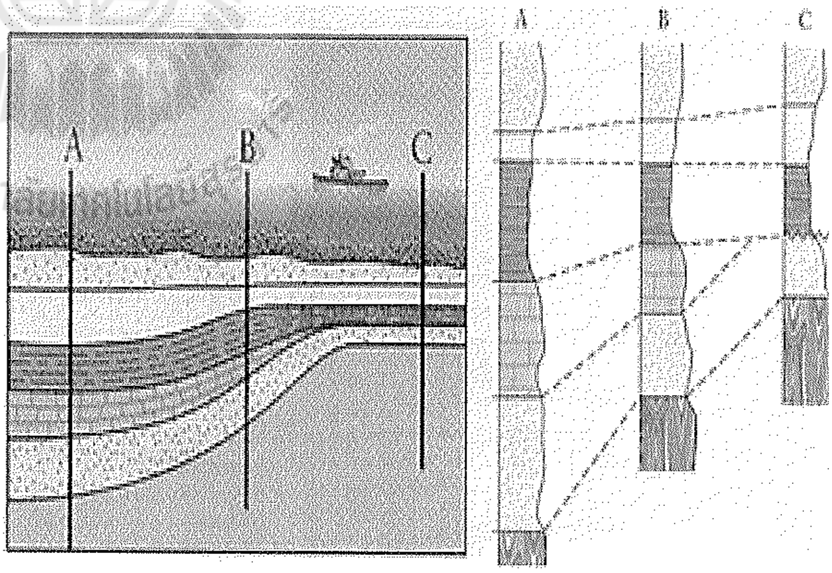
- Each sedimentary bed is younger than the bed beneath it and older than the bed above it.

2. Faunal Succession

- The relative age of rocks can be determined from their fossil content

3. Original continuity and horizontal water-laid sediments are deposited in nearly horizontal strata; each stratum initially continuous laterally in all directions until it abuts against the edge of the original depositional basin





4. Crosscutting relationship

- A younger one cuttings an older surface

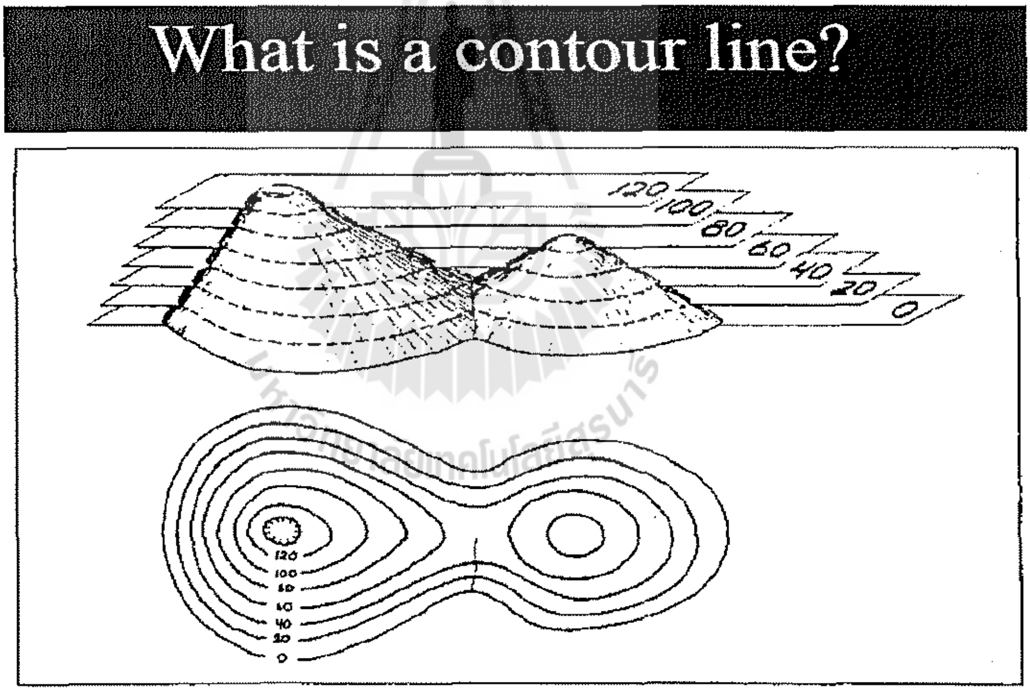
5. Correlation of facies (Walther's Law)

- Within a given sedimentary cycle, the same succession of facies that occurs laterally is also present in vertical succession

Structure contour maps

General

1. Scale & Contour should be appropriate to the data available to the map.
2. Map should not be so overloaded with data that they become confusing.
3. All the geologist's maps and sections of any one area must conform with one another.
4. The art of contouring is so critical



What is a contour line?

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Contouring Rules

1. Contour line separates points that are higher from points that are lower
2. Contour lines cannot cross
3. Contour lines cannot merge
4. Contour lines must close on themselves within the map area or extend to the edge of the map
5. Contour interval must remain constant for the entire map

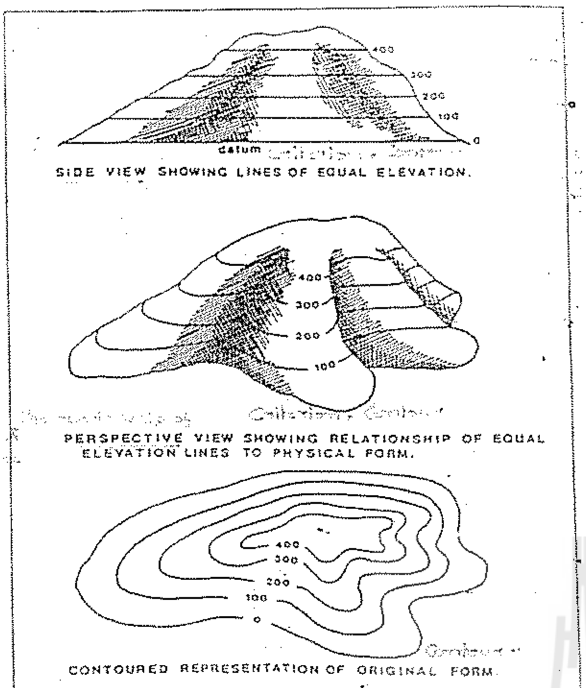


Figure 16 Relationship of contour representation and an irregular physical form.

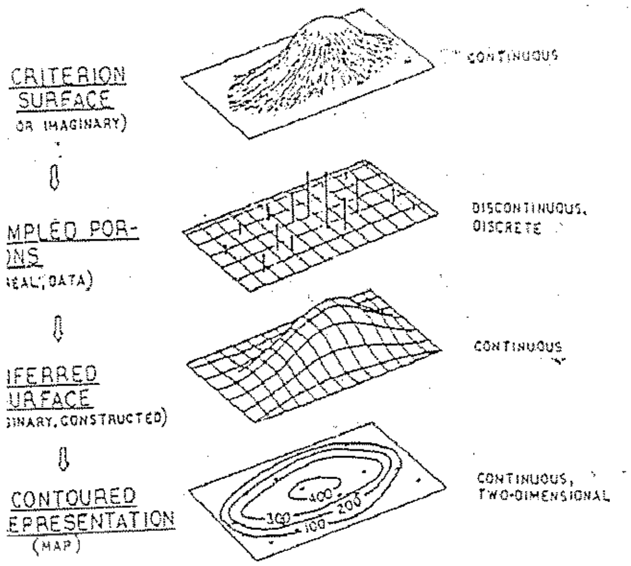
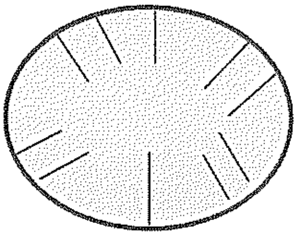


Figure 17

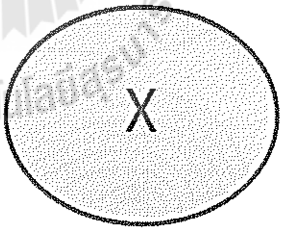
The contouring transformation from criterion to map.

Structural contour maps

1. **Datum plane (SL)**
2. **Chosen horizontal marker**
3. **Closed contours should be marked as positive (High) or negative (Low)**
4. **Faults should be shown clearly with dip direction.**



Negative (Low)



Positive (High)

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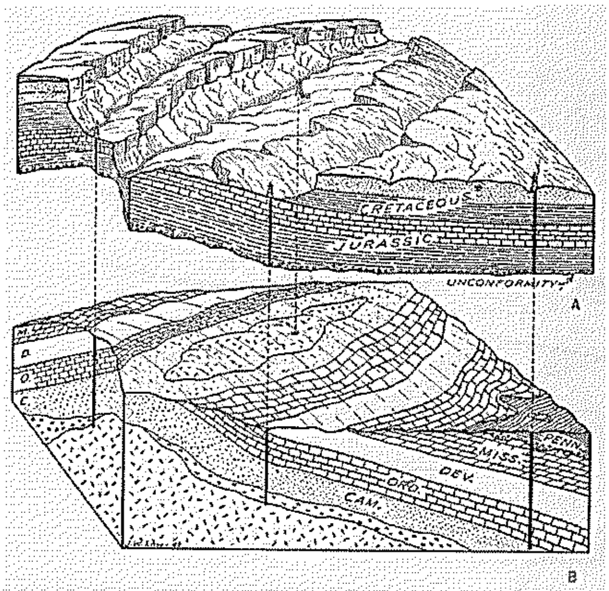
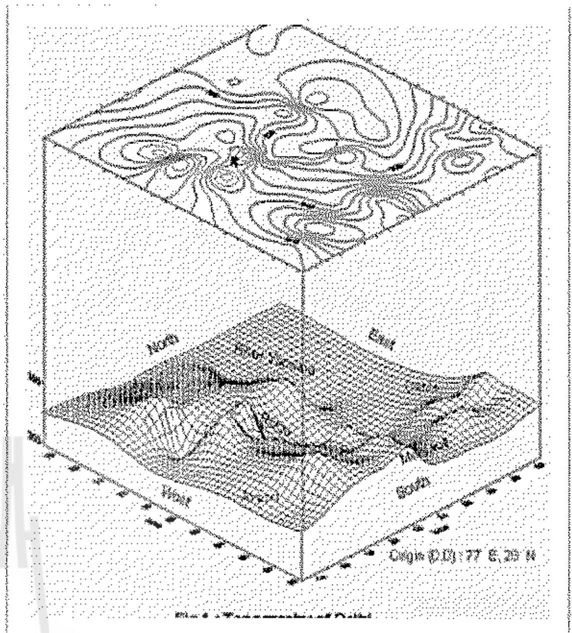


FIGURE 24-6. Typical eroded anticline involving a major unconformity in subsurface.

Ex. Subsurface Maps



Structural contour maps

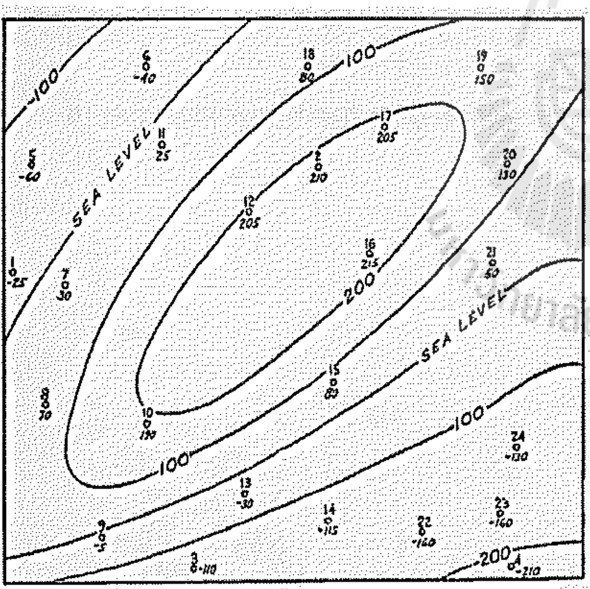


FIGURE 24-7. Structure contour map on top of Jurassic.

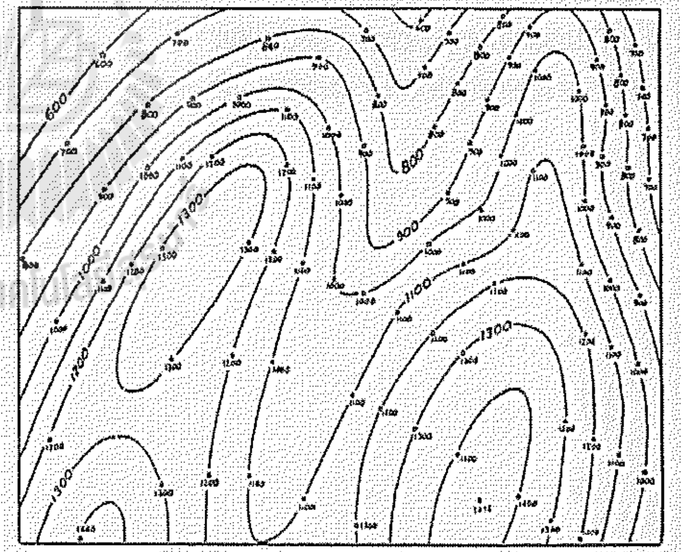


FIGURE 24-17. Subsurface structural map on top of Mississippian.

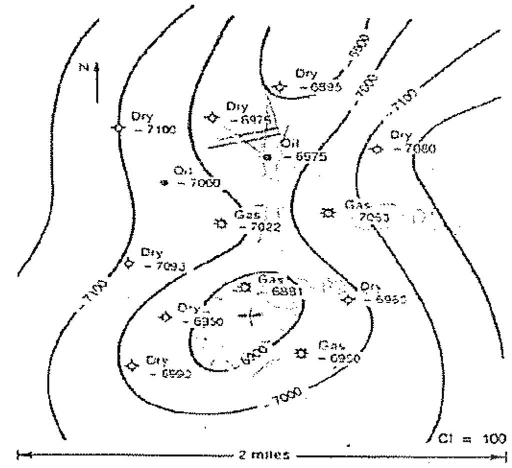


Fig. 12a Structural contour map with contours mechanically spaced, resulting in one large feature.

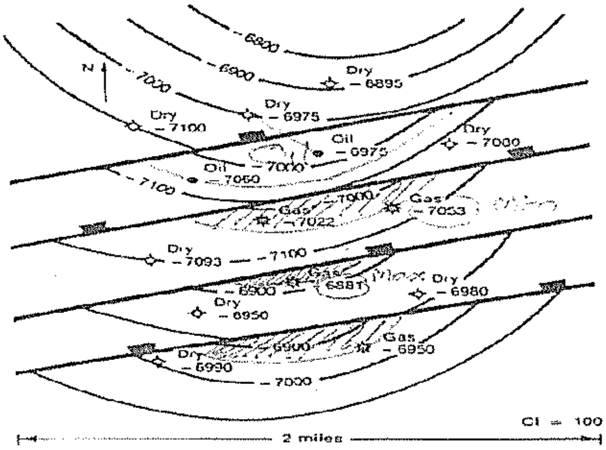


Fig. 12b Structural contour map with set of subvertical faults resulting in relatively uniform dip direction and several small fault-block reservoirs.

Cross sections

1. Correlation cross sections

First geologic structure map in the exploration drilling phase

2. Structural cross sections

Present structural attitudes of rocks in relation to sea level (SL) as the horizontal datum

3. Stratigraphic cross sections

Show correlation of strata with respect one of them selected as the horizontal datum

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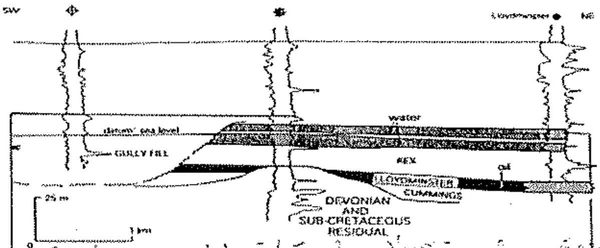


[illegible] correlate [illegible]

Figure 16.91 Correlation section through part of the South Chauvin oilfield, Lloydminster area, eastern Alberta, Canada, showing one of many paleogeomorphic traps in Lower Cretaceous sandstones. This location illustrates two trapping mechanisms, one against a pre-depositional high, the other against a post-depositional gully. (After L. W. Vigrass, *AAPG Bull.*, 1977.) (Correlation Cross Sec)

Correlation cross sections

Structural cross sections

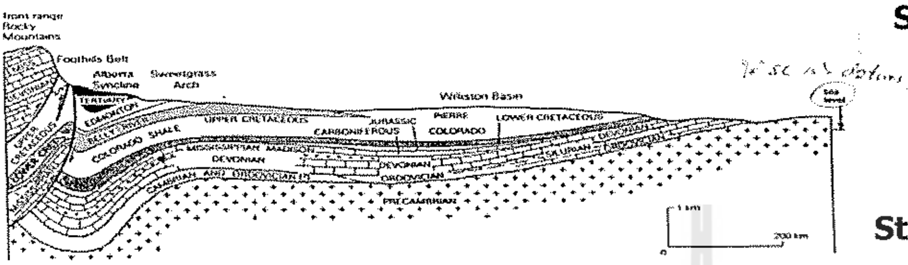


Figure 17.11 West–east profile of the Western Canadian and Williston Basins, a miogeoclinal wedge in the Paleozoic and a major compressional foredeep in the Mesozoic. (From Alberta Society of Petroleum Geologists, in *Possible future oil provinces of the United States and Canada*, Tulsa, Okla: AAPG, 1941.) (structural cross section)

Stratigraphic cross sections

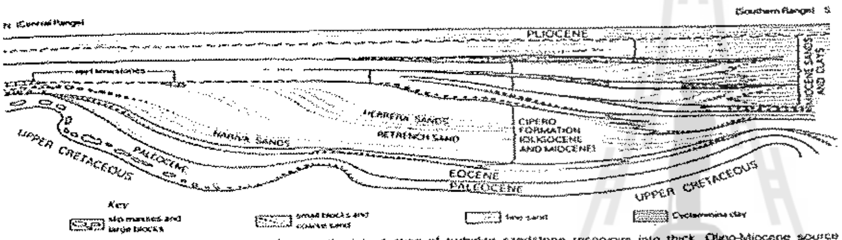


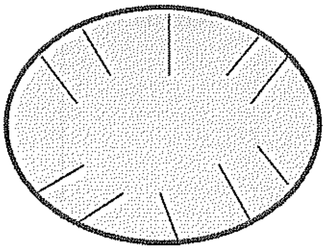
Figure 13.40 Southern basin of Trinidad, showing the introduction of turbidite sandstone reservoirs into thick, Oligo-Miocene source sediments deposited in the foredeep of the Central Range as it was progressively displaced southward. (After H. G. Kugler and J. B. Saunders, *Bol. Inf. Asoc. Venezolana Geol.*, 1957.) (stratigraphic cross section)

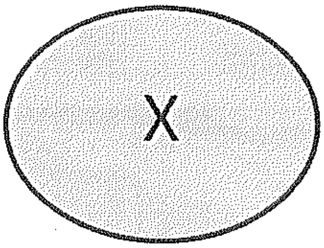
Kind of Map

1. Isopach maps

-Showing lines of equal thickness of strata contained between two reference plans.

-Uesful to determining the age and growth of stuctures both of positive structures (Uplift) and negative structures (Subsidence)





Negative structures (Subsidence) **positive structures (Uplift)**

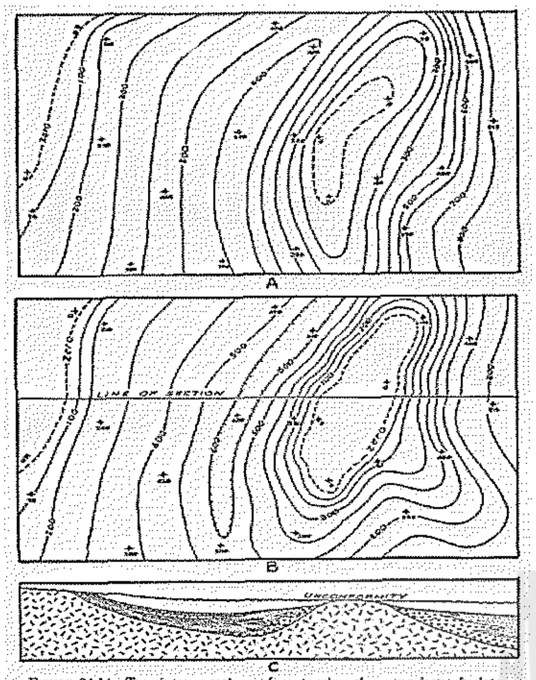


FIGURE 21-14. Two interpretations of contouring the same isopach data.

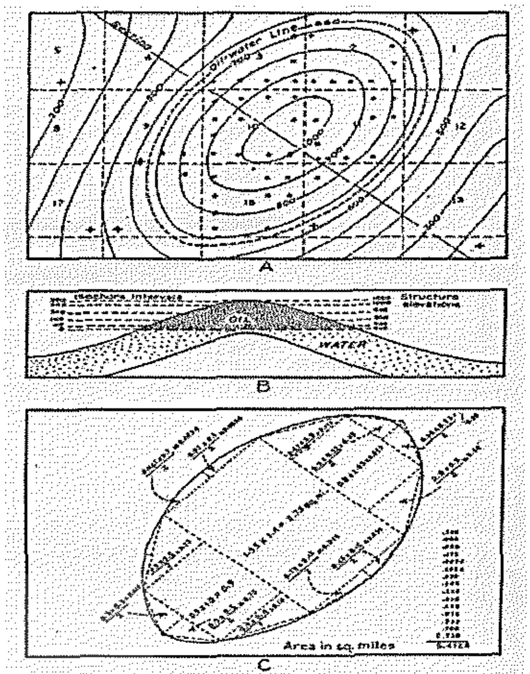


FIGURE 21-21. Method of computing oil-reservoir volume (Case I).

Isopach maps

2. Lithofacies maps

2.1 Ratio maps

Showing the ratios of thicknesses of selected components.

2.2 Isolith maps

Showing net thicknesses of single lithologic components in lithologic percentage rather than its absolute thickness.

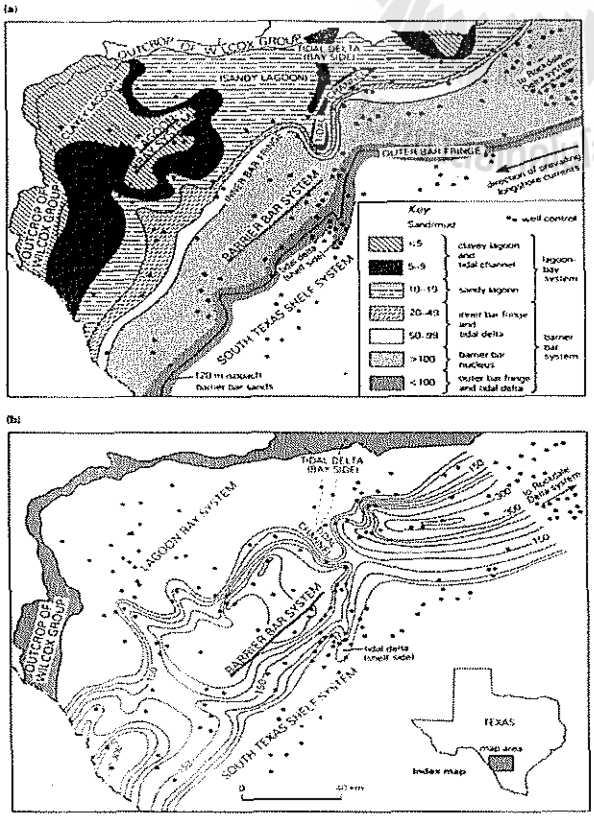


Figure 22.21 Two facies maps of a barrier-bar and bay-lagoon system in the Wilcox Group (Eocene) of the Texas Gulf Coast: (a) sandstone : shale ratio map; (b) sand isolith map – isolith interval 30 m. (From C. L. Lofton and W. M. Adams, *AAPG Memoir* 15, 1971; after W. L. Fisher and J. H. McGowen, 1967.)

Lithofacies maps

Ratio maps

Isolith maps

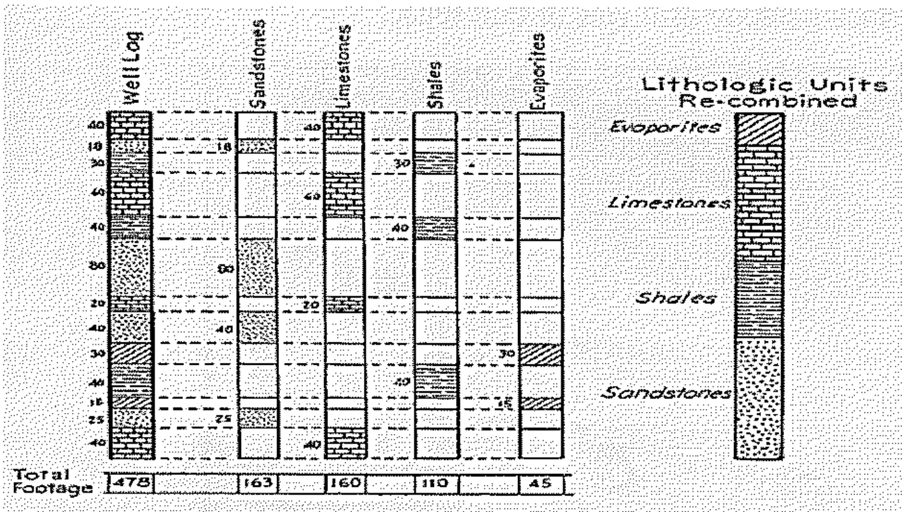


FIGURE 24-25. Lithologic breakdown of a well log into four main rock types.

Ratio value of sandstone=163/160+110+45 =0.51 ← Plot

Total thickness of the SS formation 163/478=0.34= 34%

Isolith maps

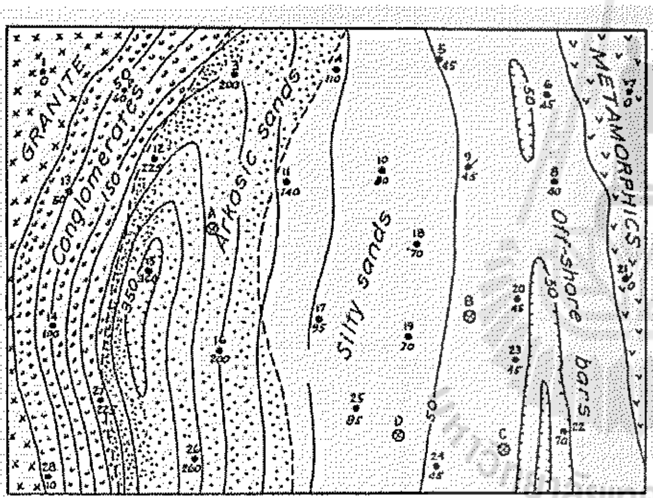


FIGURE 24-30. Sandstone isolith map of basin shown in Figure 24-29.

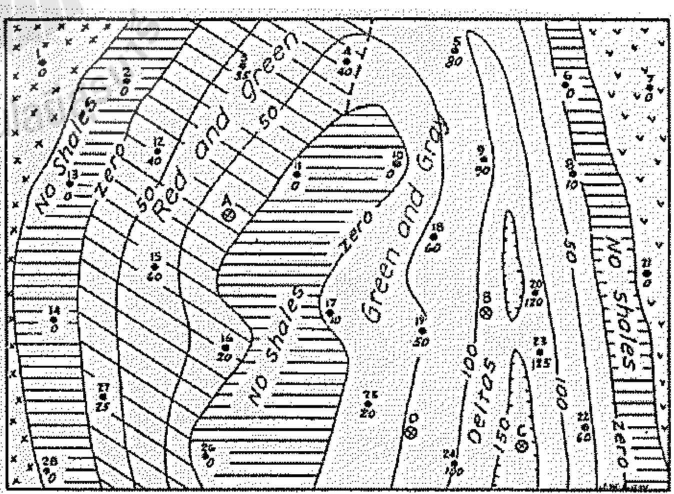
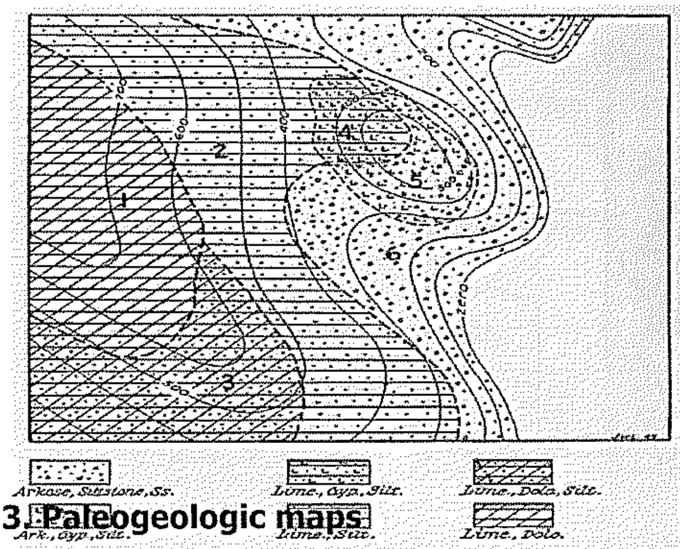


FIGURE 24-31. Shale isolith map.



3. Paleogeologic maps

FIGURE 24-28. Combination isopach and lithofacies map.

Showing the surface geology as it was at that time.

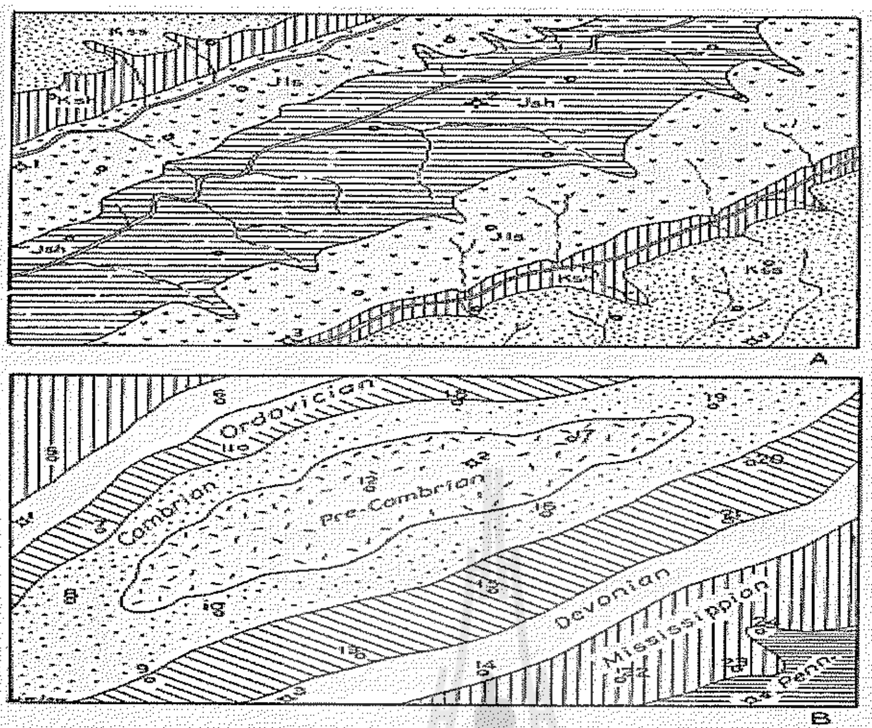
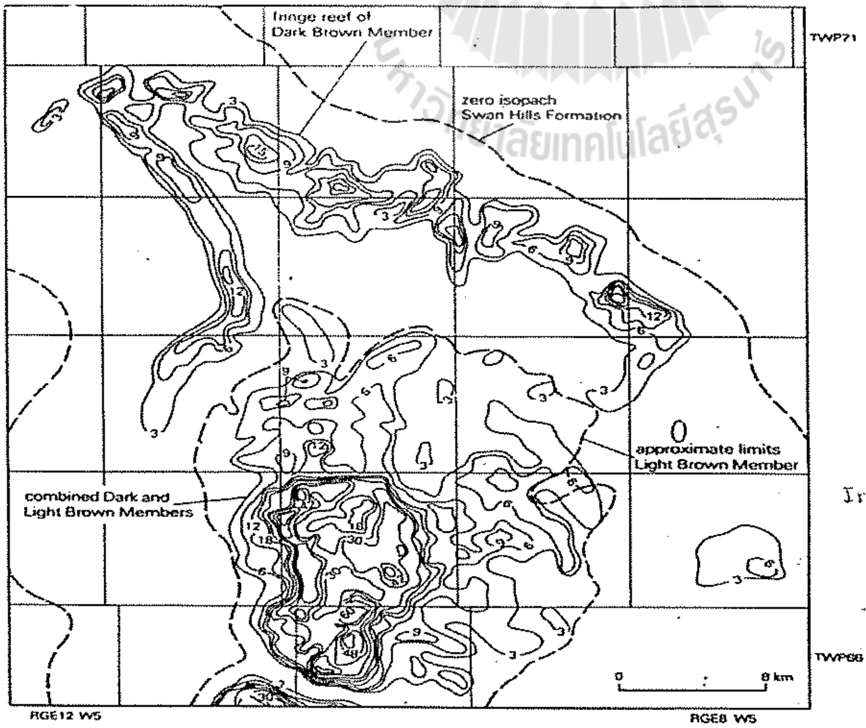


FIGURE 24-23. Paleogeologic maps. *A*—Surface areal map. *B*—pre-Jurassic areal geology.

4. Internal property maps

: Porosity – TOC – Maturity etc.



Internal property map.

Figure 22.26 Isoporosity map of Swan Hills Formation (Devonian) in Swan Hills oil-productive region of northern Alberta, Canada. Values in meters based on logs. Areas with thick porous sections are productive reefs; in interior area, loci of porosity are patch reefs and reef outwash. (From C. R. Hemphill *et al., AAPG Memoir* 14, 1970.)

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5. Hydrodynamic maps

Equipotential surfaces of Oil (U) and Water (V)

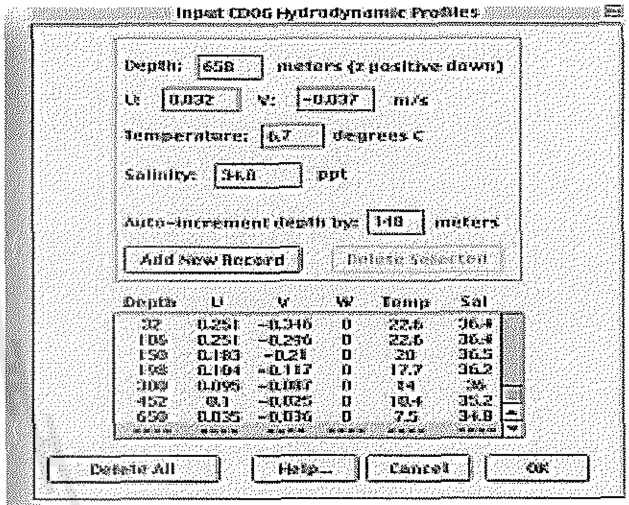
Dw=Water density Do=Oil density

Hw=Water high column Ho=Oil high column

Z =The elevation of the point of above or below datum plane.

[Do/(Dw-Do)]Ho = [Dw/(Dw-Do)]Hw-Z→ U=V-Z

FIGURE 12.12. Structure contour and facies map of the hydrodynamically tilted and displaced South Cole Creek oil pool in Wyoming. (Redrawn from Moore,


Input CDOG Hydrodynamic Profiles

Depth: 658 meters (z positive down)

U: 0.032 V: -0.037 m/s

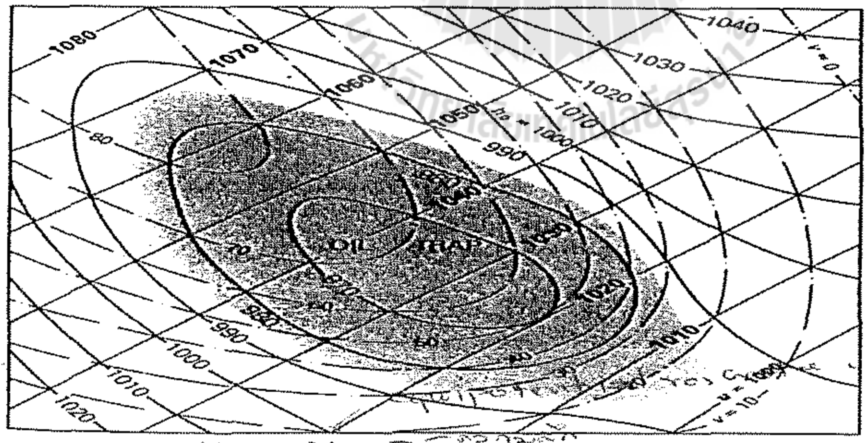
Temperature: 6.7 degrees C

Salinity: 34.8 ppt

Auto-increment depth by: 148 meters

Depth	U	V	W	Temp	Sal
32	0.251	-0.346	0	22.6	36.4
105	0.251	-0.296	0	22.6	36.4
150	0.183	-0.21	0	20	36.5
198	0.104	-0.117	0	17.7	36.2
300	0.095	-0.087	0	14	36
452	0.1	-0.025	0	10.4	35.2
650	0.035	-0.036	0	7.5	34.8

Hydrodynamic maps



U = V - Z

Figure 22.30 Map of traces of intersections of constant-value surfaces. h_o, u, and v, with upper surface of reservoir rock showing potential minimum and consequent trap for oil. (From M. K. Hubbert, *AAPG Bull.*, 1953.)

Hydrodynamic map