

เอกสารประกอบการสอน

รายวิชา 534204 ธรณีวิทยาปิโตรเลียม (Petroleum Geology)

โดย

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สาขาวิชาเทคโนโลยีธรณี

สำนักวิชาวิศวกรรมศาสตร์

มหาวิทยาลัยเทคโนโลยีสุรนารี

ธรณีวิทยาปิโตรเลียม (Petroleum Geology)

วิชาบังคับก่อน: 534200 ธรณีวิทยาทั่วไป

• Petroleum Geology เป็นวิชาที่ใช้หลักการทาง ธรณีวิทยาเพื่อศึกษาถึงการกำเนิด การกระจายตัวและ การสะสมตัวของน้ำมันและก๊าซธรรมชาติ ผลการศึกษา สามารถนำมาประยุกต์ใช้เพื่อการสำรวจและผลิต ปิโตรเลียม

Course Content

Chapter I: Earth Structure

Chapter II: The Nature and Origin of Petroleum

Chapter III: Petroleum Charge System

Course Content

Chapter I: Earth Structure

Purpose: Earth structure is fundamental to an understanding of the study of earth processes and earth history. The driving mechanisms of the earth's surface subsidence are ultimately related to sedimentary basin, which are very important in exploring and producing for hydrocarbon

Outline of Earth Structure

- 1. Introduction
- 2. Internal structure of the earth
 - 2.1 Based on chemical properties
 - 2.2 Based on physical properties
- 3. Plate tectonics
- 4. Plate tectonic and basin setting
 - 4.1 Divergent relate basin
 - 4.2 Convergent related basin
 - 4.3 Strike-slip related basin
- 5. Pre-, Syn-, and Post-

Chapter II: The Nature and Origin of Petroleum

Purpose: The elemental compositions of petroleum are combined abundantly in nature. This chapter are explain about the interrelations between the elemental composition and the routes how they come to be formed.

Outline of The Nature and Origin of Petroleum

- 1. Petroleum system
 - 1.1 Source
 - 1.2 Migration
 - 1.3 Reservoir
 - 1.4 Trap
 - 1.5 Seal

- 2. Physical and chemical properties of hydrocarbon
 - 2.1 Hydrocarbon gases
 - 2.2 Non-hydrocarbon gases
 - 2.3 Hydrocarbon crude oil
 - 2.4 Non-hydrocarbon crude oil
 - 3. The origin of petroleum
 - 3.1 Inorganic origin
 - 3.2 Organic origin

Chapter III: Petroleum Charge System

Purpose: The petroleum charge system is explains about source rocks, which must be capable of generation, expelling and migration path way into the reservoir unit.

Outline of Petroleum Charge System

- 1. Identification of petroleum source rock
- 2. Maturation
- 3. Migration
- 4. Reservoir rocks
- 5. The mechanic of sealing
- 6. Trapping

Score

1. Quiz 25%

2. Homework or Report 5%

3. Attendance 5%

4. Mid term examination 30%

5. Final examination 35%

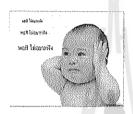


- Gerhard Einsele 1992, Sedimentary Basins.
- North, F.K., 1990, Petroleum Geology, second impression.
- Reading, H.G., 1989, Sedimentary Environments and Facies, Second edition reprinted.
- Tissot, B.P., 1984, Petroleum formation & occurrence.

Class Agreement

- 1. No Late (15 minute after class)
- 2. No Talk
- 3. No Food, Drink
- 4. No Phone, Facebook, and others









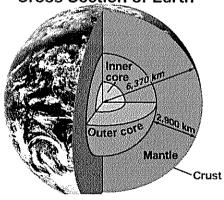
Chapter I: Earth Structure

Outline of Earth Structure

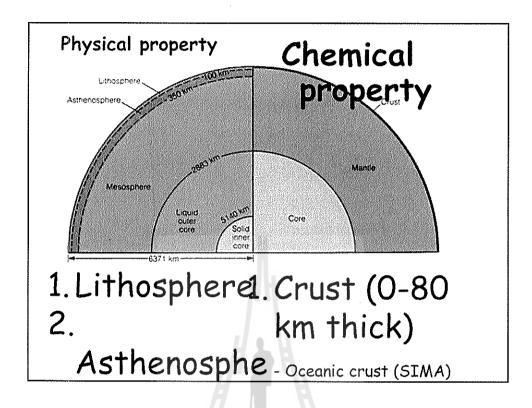
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Earth Structure

Cross Section of Earth

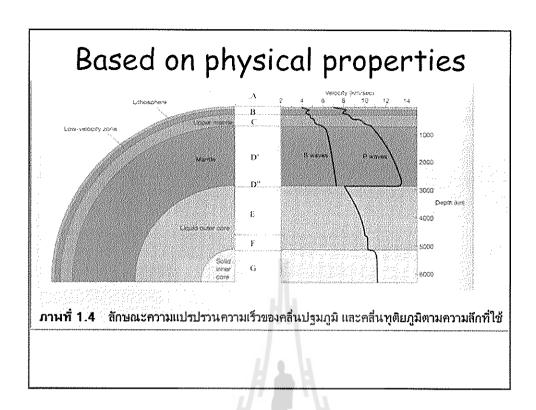


- Radius 6,300-6,400 km
- Thin crust
- Mantle extends almost halfway to the center
- The core makes up the rest

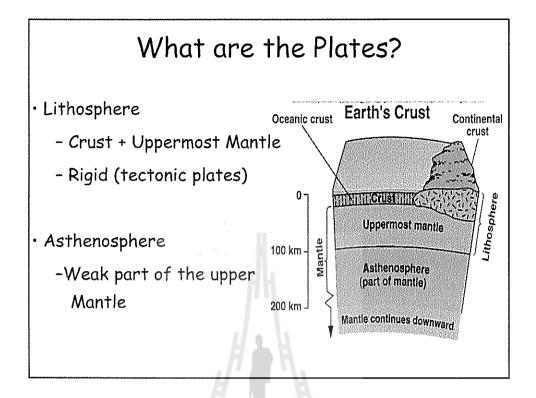


Based on chemical properties 1. Crust (0-80 km thick) - Less dense - Rich in Si and Al (continental crust) - Rich in Si and Mg (oceanic crust) แก่น โลก ชิลิกอมไทกทาไชค์ อะอุมีเนียมคอกไขก 2. Mantle (~2900 km) แกลเจียมออกไรล์ ในแกร์เรียมออกไรล์ - Dense solid rock ครร์ กออกธิหารถมาติกา - Rich in Mg and Fe อื่นๆ 3. Core (3470 km) - Metallic (Fe, Ni) Inner core - solid (1/3)

Outer core - liquid (2/3)

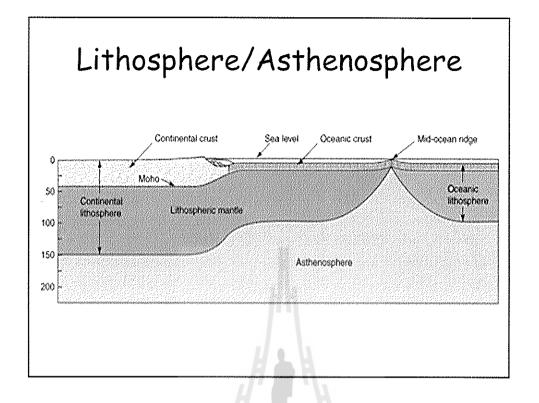


รารางที่ 1.1 โครงสร้างและองค์ประกอบของโลก						
ชันโครงสร้าง	ส่วนประกอบทางเคมี	สถานะ 🎎 🖽 💥				
บรรยากาศ (Atmcsphere)	N_2 , O_2 , H_2O , CO_2 และ ก๊าซเฉื่อย	กาช				
ชีวภาพ (Biosphere)	H ₂ O , อินทรียสาร , และ วัสดุโครงสร้าง ภระตูก	ของแข็งและของเหลว ที่มีสภาษเป็น คอสลอยด์				
ลุทกภาค (Hydrosphers)	็น้ำเค็ม น้ำจืด หิมะ และน้ำแข็ง	ของเหลว (บางส่วนเป็นของแข็ง)				
ธรณีภาค (Lithosphere) - เปลือกโลก - เนื้อโลกส่วนบนสุด	แร่ชิลิเกตทั่วไป	ของแข็ง				
ฐานฮรณีภาค (Asthenosphere) - เนื้อโลก (mantle)	แร่ชิลิเกต ประเภท โอลิวัน และ ไพรอกซีน หรือในรูปโครงสร้างอื่น ๆ ที่ความดันสูง	ชองเเชิ่ง				
- แก่นโลก (core)	โลหะผสมเหล็ก - นิกเกิล	แก่นโลกชิ้นนอกเป็นของเหลว แก่นโลกชิ้นในเป็นของแข็ง				



Asthenosphere

- · Mechanical boundary layer
- · Zone of weakness
- · Zone of partial melting (2-4% melt)
- Its depth is controlled by Temperature (1300 deg C)
- · Allows the plates to slide over it



Continental vs. Oceanic crust

Continental crust

- Light (2650 kg/m3)
- · Granite (SIAL)
- High elevation
- · Not so strong
- · Can be very old
- · Lasts for ever
- · Complex
- Moves passively

Oceanic crust

- •Dense (2850 kg/m3)
- Basalt (SIMA)
- · Low elevation
- Strong
- Young
- · Gets recycled
- · Simple
- · Drives plate motions

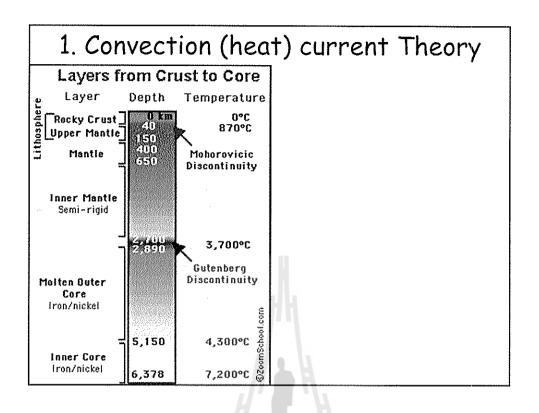
สารประกอบ ออกไซต์	องค์ประกอบ รวม (Clark and Washington, 1924)	เปลือก สมุทร (Poldery	เปลือก ทวีป aart , 19	ราม * 55)	Yaro	เปลือก ทวีป enov and shevskly 1976)		เปลือก ทวีป (Taylor 1964)	เปลือกทวีป (Goldschmidt, 1954)
SiO ₂	59.1	46.6	59.4	55.2	49.4	59.3	57.1	60.3	59.2
TiO ₂	1.0	2.9	1.2	1.6	1.4	0.7	0.9	1.0	0.3
Al ₂ O ₃	15.2	15.0	15.6	15.3	15.4	15.0	15.0	15.6	15.8
Fe ₂ O ₃	3,1	3.8	2.3	2.8	2.7	2.4	2.5		3.4
FeO	3.7	8.0	5.0	5.8	7.6	5.6	6.0	7.2 (ເກຄົດ	3.6
MnO	0.1	0.2	0.1	0.2	0.3	0.1	0.2	รวม) 0.1	0.1
MgO	3.4	7.8	4.2	52	7.6	4.9	5.5	3.9	3.3
CaO Na,O	51 37	11.9 2.5	6.6 3.1	8.8 2.9	12.5 2.6	7.2 2.5	8.4 2.5	5.8 3.2	3.1 2.1
κ ₂ ο	3.1	10	2.3	1.9	0.3	2.1	1.7	2.5	3.4
H ₂ O	1.3	-	•	1	-	-	-	-	3.0
P ₂ O ₅	0.3	0.3	02	0.3	0.2	0.2	0.2	0.2	02

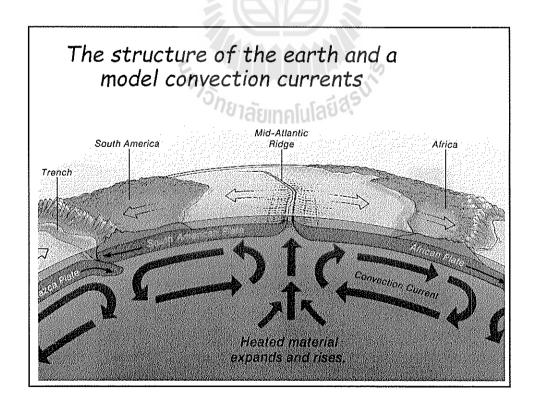
องค์ประกอบทั้งเปลือกโลก (Entre Crust)

Plate Tectonic

The Dynamic Earth Theory

- 1. Convection Current Theory
- 2. Continental Drift Theory
- 3. Seafloor Spreading Theory
- 4. Plate Tectonic Theory





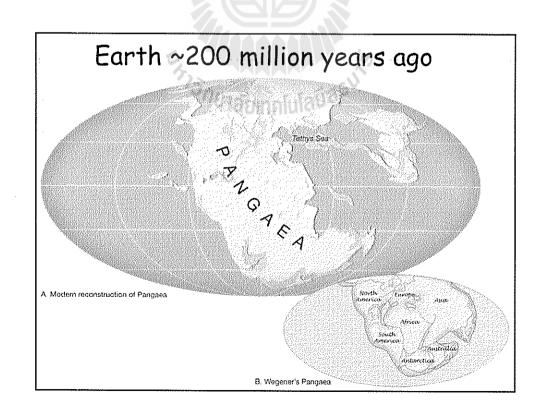
2. Continental Drift Theory

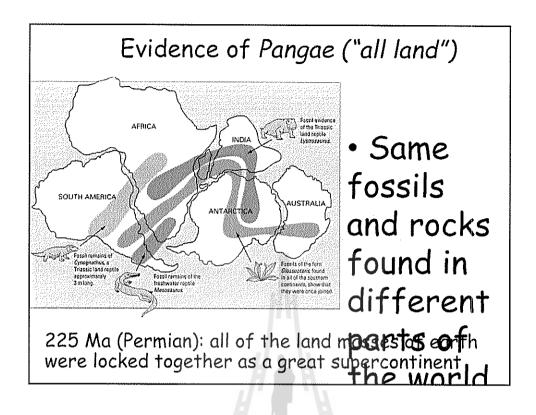
Alfred Wegener

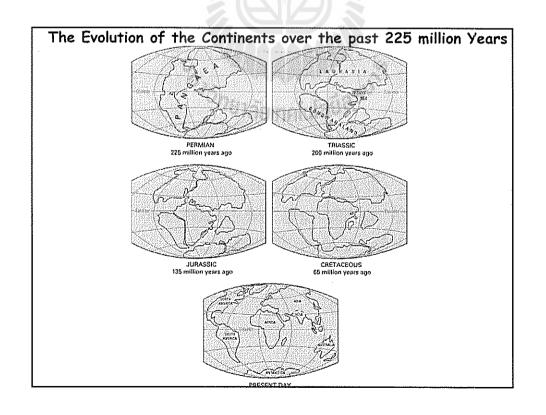
- ▶ Some people thought the Earth was shrinking and cracking
- Wegener thought whole sections of the crust moved (plate tectonics)
- Some people did not understand and thought the continents floated around in the oceans (continental drift)
- He died before people accepted his ideas



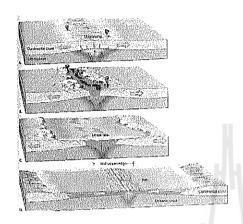








3. Sea floor spreading



- Large continents begin to crack and split apart
- The gaps fill with water
- Small seas become oceans
- The mid ocean ridge continues to produce new crust

Seafloor Spreading 1

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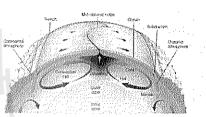
- · Mantle convects at about 1-10 cm/yr
- Rising convection at mid-ocean ridges
- Sinking at the trenches
- Oceanic basins are impermanent, continents are permanent
- The earth is a dynamic body, its surface always changing.

Why spread?

Why is the Atlantic still getting wider

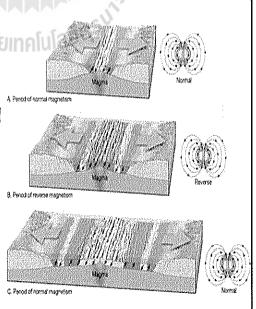
- 1. The plates are pulled apart by convection currents in the mantle below
- 2. Caused by heat released from natural radioactive processes
- 3. At the mid Atlantic ridge molten rock from below rises up to fill the gap with new basaltic





More evidence

- More evidence has been found for Wegeners theory
- The Earths North and South pole have flipped many times
- ▶ These leaves magnetic 'stripes' in rock containing iron minerals
- The ocean floor is a



The Dynamic Earth: Plate Tectonic

Plat Tectonics refers to the process of plate formation, movement, and destruction.

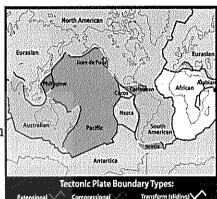
List of 14 Plates

Major

- 1. Africa
- 2. Antarctic
- 3. Australian
- 4. Eurasian
- 5. N. America
- 6. S. America
- 7. Pacific

Minor

- 1. Indian
- 2. Arabian
- 3. Carribbean
- 4. Juan de Fuca
- 5. Nazca
- 6. Phillipine
- 7. Scotia



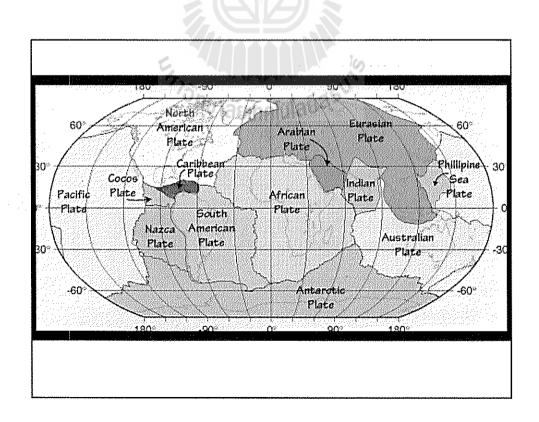
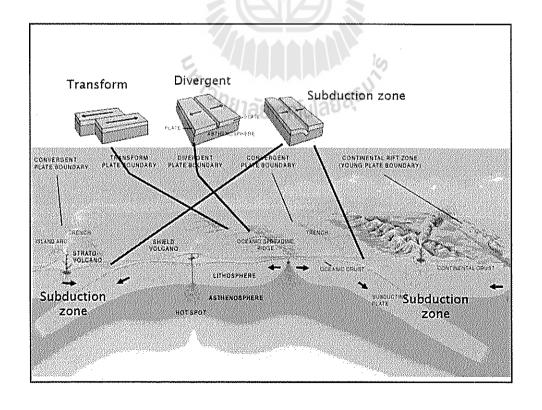
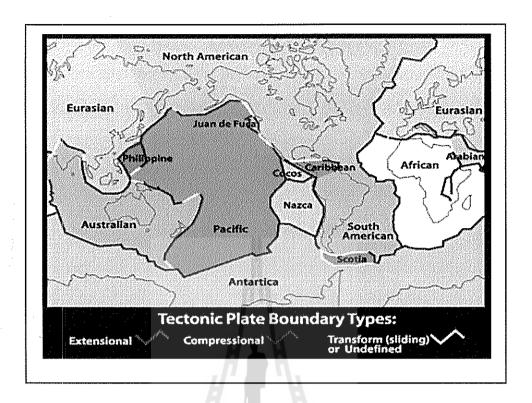
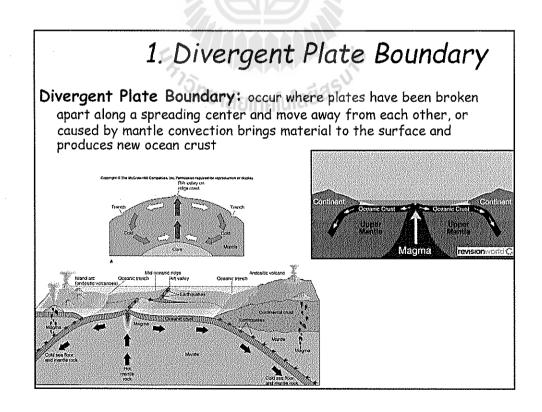
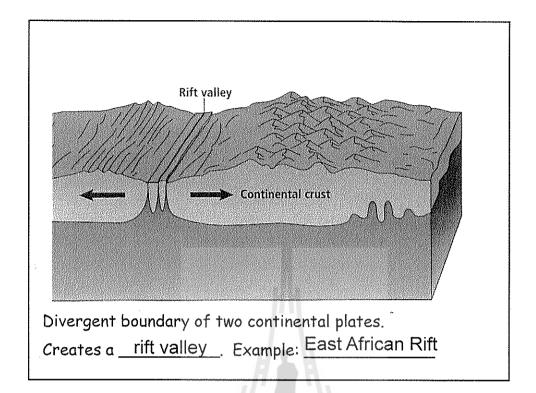


Plate Boundary 3 Plate Boundaries: according to the type of motions and related deformation that affect them. 1 3 Type of Margin Divergent Convergent Transform Motion Spreading Subduction Lateral sliding Effect Constructive (oceanic lithosphere created) (oceanic lithosphere destroyed) (lithosphere neither created or destroyed) Ridge/Rift Trench No major effect Topography Volcanic activity? Ridge Earthquakes within crust Lithosphere Asthenosphere Earthquakes (c)





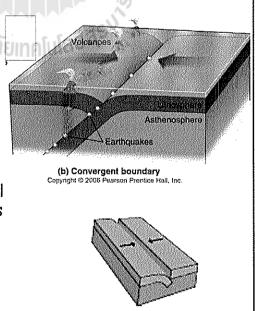


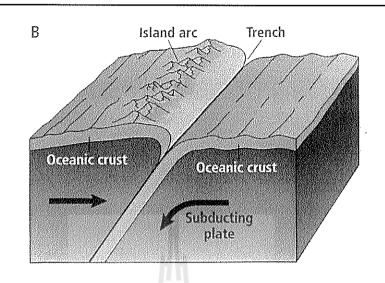


2. Convergent Plate Boundary

Convergent Plate Boundary: are developed where two continental plates or one continental and one oceanic plates collide.

Oceanic crust (more dense) subsides beneath continental plate (less dense) and causes mountains to form on the continental crust along the contact between the two plates



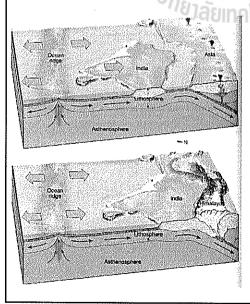


Convergent boundary of two oceanic plates.

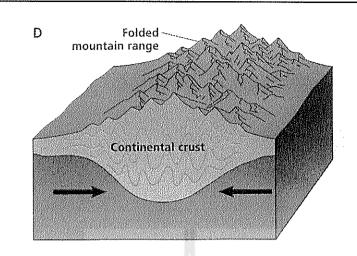
Creates an island arc and a trench.

Example: Japan

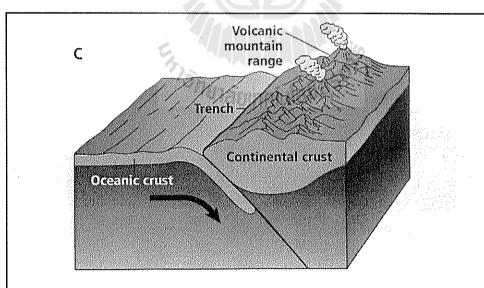
Continents Collide



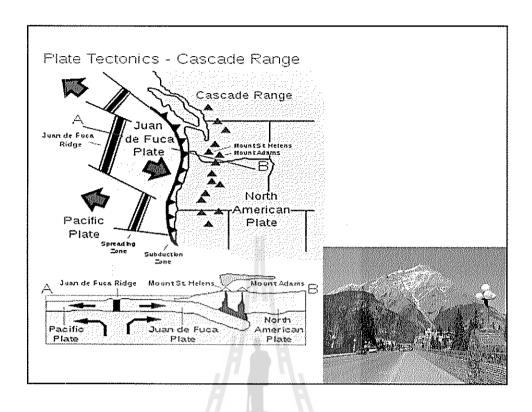
- Eventually when plates move together the continental crust collides
- The heat and pressure make metamorphic rock
- It also pushes and folds the rocks into high mountains
- The Himalayas rise to 8848m and are still growing today



Convergent boundary of two continental plates. Forms a <u>folded</u> mountain range. Examples: Himalayas ___, Alps, __Appalachians

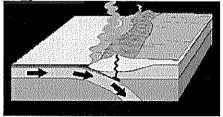


Convergent boundary of an oceanic plate and a continental plate. Forms a <u>volcanic</u> mountain range and a <u>trench</u>. Examples: <u>Cascades</u>or <u>Andes</u> Mts

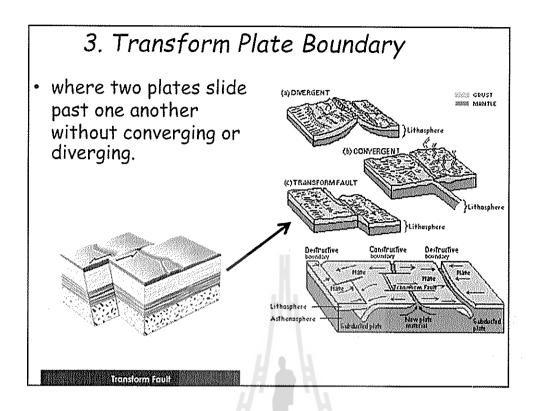


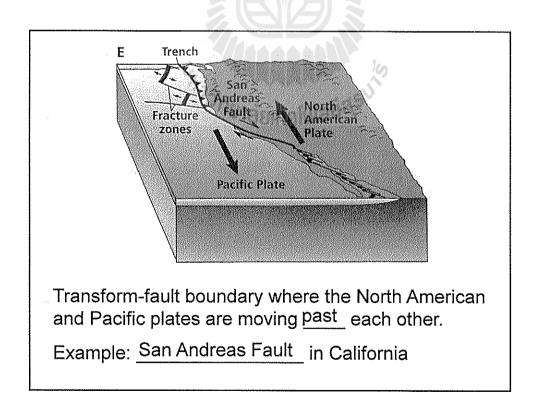
So the Earth must be growing?

- Dense heavy oceanic crust can be subducted below less denser continental crust.
- The friction melts rock
- This magma rises through the crust to form new volcanoes
- This is happening in South America (The Andes)

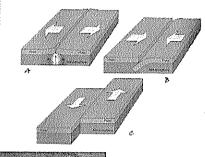


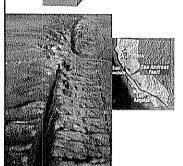






Earthquakes





- Plates moving in any direction causes earthquakes
- The worst are caused by plates rubbing past each other as in C
- This happens along the Californian coast

The plates: Distribution of Earthquakes Active Volcanoes, Plate Tectonics, and the "Ring of Fire" North American Plate Plate North American Plate P

Outline of Earth Structure

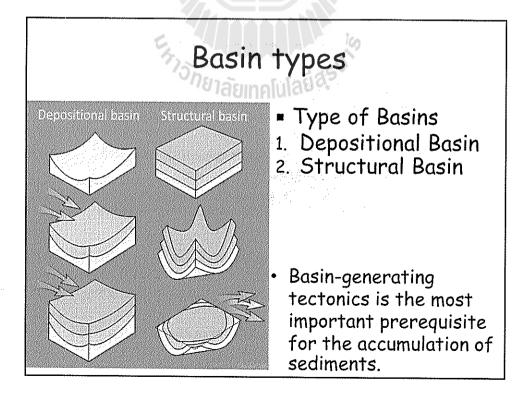
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- 5. Pre-, Syn-, and Post- Depositional Basins
- 6. Depositional Environment
- 7. Sedimentation and Plate Tectonic

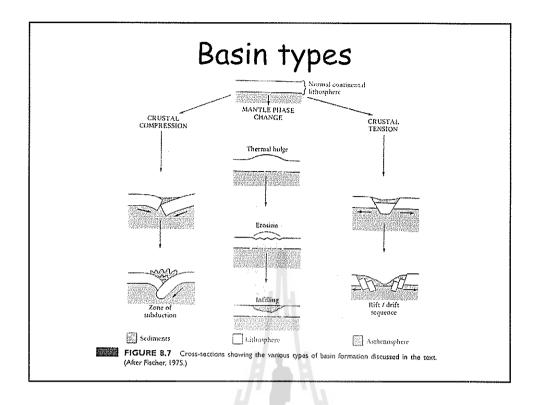
Basins & basin types

<u>Basin</u>: a region of depressed crust, typically with greater thicknesses of sediment accumulation than surrounding regions.

- Basins form by tectonic processes that cause the crust to subside, and so to create large amounts of accommodation space. Rapid A-space growth translates into abundant and well-preserved organic matter within the sediment.
- The abundance of organic matter combined with the low grade burial metamorphism that sediments in thick accumulation experience translate into major oil and gas accumulations.
- Basins provide the most complete successions of the geological record.

Basins are containers for sediment Earth's basins contain sedimentary rocks, air, or water continental shelf continental she



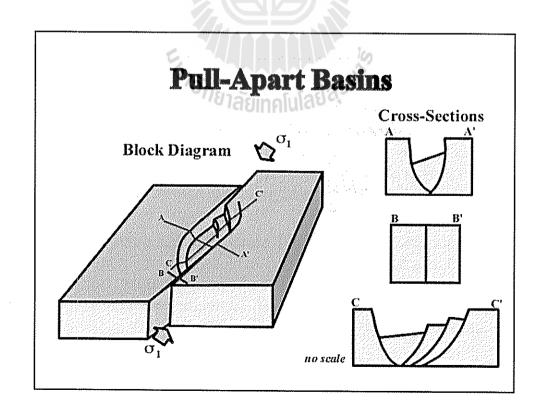


Tectonic setting for the majority of basins

- 1. Constructive (spreading) margins: This setting produces a genetic series of basins from localized rift-related basins through narrow oceans (Red Sea phase) to voluminous passive margin basins.
- 2. Destructive (convergent) margins: This setting produces basins associated with subduction zones (foredeep basins), intra-arc spreading basins, backarc spreading basins (Sea of Japan, Great Basin), and back-arc thrust (foreland) basins.

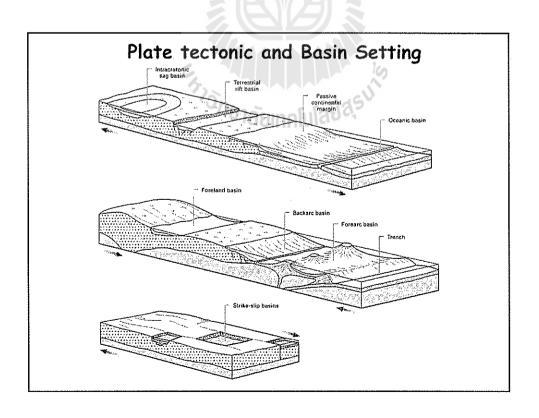
Tectonic setting for the majority of basins (cont.)

- 3. Transform (strike-slip) margins: mostly localized pull-apart basins such as the Gulf of California and Dead Sea. Grades into rift-type and thrust-type tectonics where relative plate motion is not fully strike-slip (i.e., transtensional and transpressional regimes).
- 4. Intra-cratonic basins. Fairly mysterious, concentrically subsiding basins formed on continental crust well away from plate boundaries. The cause of subsidence is unknown, but is generally considered to involve some combination of density-driven stress and in-place stress.



Relationship between plate tectonic setting and structural style:

Tectonic Setting	Stress State	Types of Structures	Examples
Divergent plates	extension	normal faults, roll over anticlines, tilted blocks	North Sea, Red Sea Basin and Range
Convergent plates	compression	thrust faults, folds, faulted folds	Andes, Zagros Mts (Iran), Canadian Rockies
Transform plate	strike-slip	strike-slip faults, compressional and extensional flower structures	San Andreas fault, Alpine Fault (New Zealand).



Concept of a Basin

- Three dimensional architecture of basin fill.
- Affected by spatial and temporal pattern of tectonic subsidence:
 - Lithospheric deformation process.
 - Three basic causes of subsidence:
 - · Loading and flexure (like an elastic plate).
 - Thermal and density changes isostasy.
 - Faulting isostasy.
- · Sea level changes.
- Sediment supply rates and source position (drainage basin outlets).

Basin Analysis

- Basins
 - Topographically low places where sedimentary
 - materials accumulate.
 - Basins are characterized by accomudation space.
 - Accomudation is created by...
 - · Eustatic sea-level rise
 - Subsidence

Basin Analysis

Basin analysis is the detailed investigation of the processes that

- Form basins
- Fill basins
- Alter basins
- Uplift (invert) basins
- Destroy basins
- Requires sedimentology, stratigraphy,
 hydrogeology, petroleum geology, seismology,
 geophysics, geochemistry, paleontology, etc.

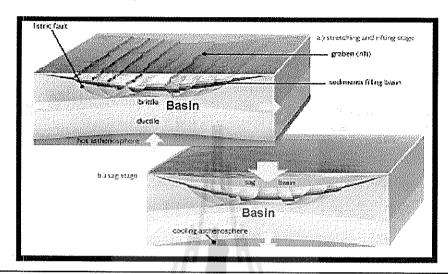
Tectonic Basin Classification

1. Divergence or extensional related basin

- Sag basin: e.g. Chad Basin, Africa.
- Rift basin: Half graben/graben: e.g. Basin and Range, U.S.A.
- Failed rift or aulacogen basin
- Passive margin basin: Atlantic margin

Basins: Forces that shape the earth's crust

Basins form in response to subsidence of the crust and grow due "loading" of sediment deposited in them

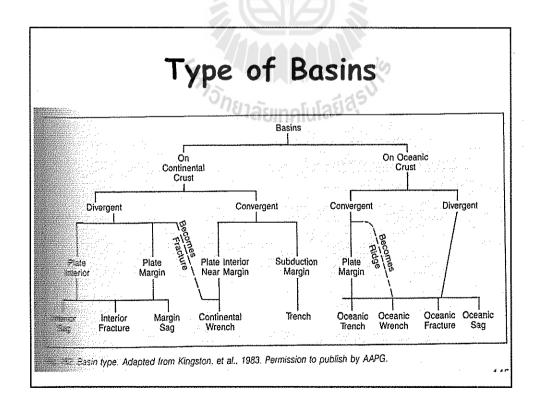


Tectonic Basin Classification (cont.)

2. Convergence or compressional related basin

- 2.1 Subduction related basin
- Oceanic trenches basin: e.g. Marianas Trench.
- Accretionary basin
- Fore-arc basin: Taiwan or Median Valley in Scotland.
- Back-arc basin: Sea of Japan.
- Intra-arc basin
- 2.2 Collision related basin
- Foreland basin: flexural loading of the Earth's lithosphere-e.g. Himalaya.
- 3. Strike-slip related basin
- Strike-slip basin: e.g. Dead Sea, Israel.

	Basin category	Special basin type or synomym(s)	Underlying crust	Style of tectonics	Basin characteristics
J.	Continental or interior sag basins	Epicontinental basins, infra- cratonic basins	Continental	Divergence	Large areas, slow subsidence
ester Rit	Continental or interior fracture basins	Graben structures, rift valleys and rift zones, aulacogens	Continental	Divergence	Relatively narrow basins, fault-bounded rapid subsidence dur- ing early rifting
Divergence Reave Rij	Basins on pas- sive continen- tal margins, margins sag basins	Tensional-rifled basina, tension-sheared basina, sunk margin basina	Transitional	Divergence + shear	Asymmetrio basins partly outbuilding of sediment, moderat to low subsidence du- ing later stages
تر.	Oceanic sug	Nascent ocean basin (growing oceanic basin)	Occanie	Divergence	Large, asymmetrie, slow subsidence
2.5	Basins related to subduction	Deep-sea trenches	Octanie	Convergence	Partly asymmetric,
ي مي لا فر	Marie Communication of the Com	Foreare basins, backare basins, interare basins	Transitional, oceanic	Dominantly divergence	greatly varying depth and subsidence
Comvexgence	Basins related to collision	Remnant basins	Oceanic	Convergence	Activated subsidence due to rapid sedi- mentary loading
Com		Foreland basins (peripheral), retreare basins (intramontane), broken fereland basins,	Continental ,	Crustal flexuring, focal con- vergence or transform motions	Asymmetric basins, trend to increasing subsidence, uplift and subsidence subsidence
& U		Terrane-related basins	Oceanic		Similar to backare basins
Teans from	Strike-alip/ wrench basins	Pull-upart basins (transtensional) and transpres- sional basins	Continental and/or occanic	Transform motion, ± di- vergence or convergence	Relatively small, clongate, rapid subsidence

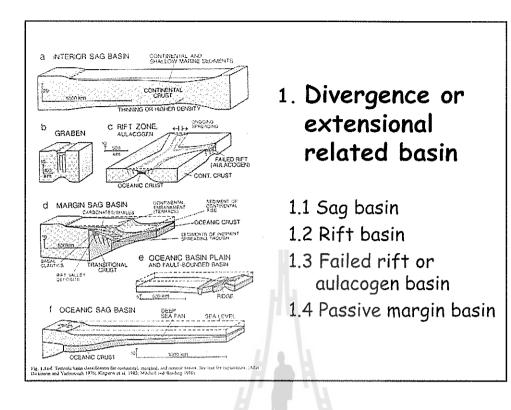


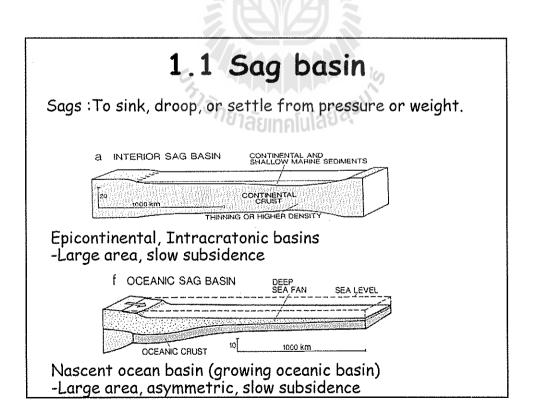
Continental margin sedimentation

- > Siliciclastic systems
 - Regionally extensive, tabular units
 - Moderately mature sands quartz dominant grade to fine-grained pelagic sediments
 - Generally well developed bedding
- > Carbonate systems
 - Confined to low latitude, warm clear seas with little terrigenous input
 - Patterns affected by organisms, such as those that form reefs, not just sedimentation processes

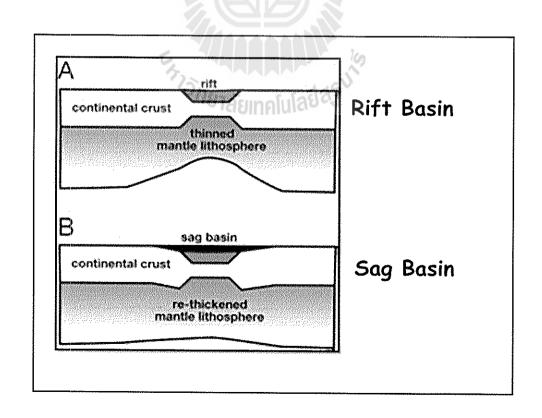
Ocean basins

 Dominated by pelagic deposition (biogenic material and clays) in the central parts and turbidites along the margins





- Sag basins occur along the San Andreas and other transcurrent (strike-slip) faults.
 They're the counterpart of pressure ridges. (more below)
- The two sag ponds lie in a larger rift, a linear valley. Sag basins can be quite large; e.g San Francisco Bay
- Sag basins can also form along faults with part normal and part strike-slip motion, where the blended stress called transtension operates. They may be called pull-apart basins.

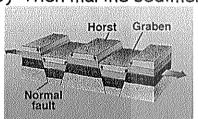


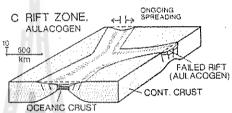
1.2 Rift basin

• Rifts - Divergent plate boundaries that eventually develop into spreading centers.

Sedimentation

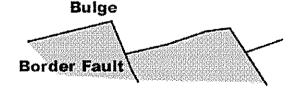
- 1) Initial rift sediments are arkosic sandstones interbedded with basalts.
- 2) Basin rifts then flood and deposit a thick sequence of evaporites.
- 3) Then marine sedimentation takes over

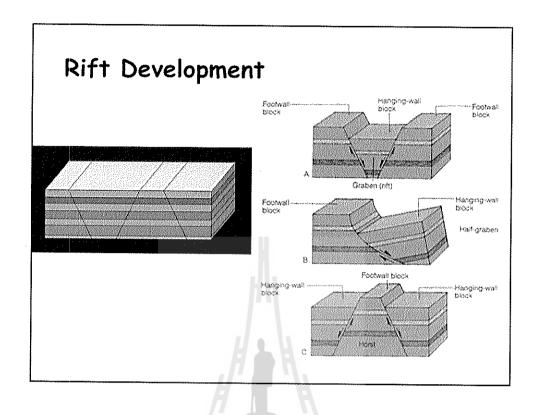


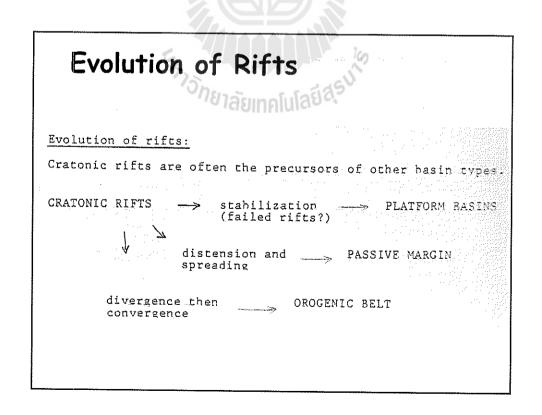


Rift Development

- 1. Crustal thinning produces depocenters
- 2. Half-graben geometry results in asymmetric patterns of deposition
- 3. Sediments are typically immature, intercalated with volcanic rocks
- 4. Distribution of sediment types over time records tectonic activity
- 5. Older sedimentary layers have higher dips than younger layers







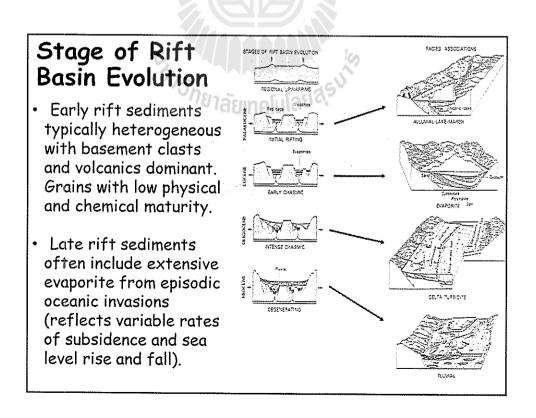
Characteristic of Rift Basins

- Smallish volumes of sediment (100-1000 m of accommodation space) in localized, fault-bounded basins.
- Dominantly terrestrial (subaerial and lacustrine) and arid as result of uplifted margins that cast rain-shadows into the basins
- Examples: Viking Graben (North Sea), Gulf of Suez (Egypt), African rift valley

Characteristic of Rift Basins

- Rifts are point of great interest for petroleum geologists.
- Early marine rift sediments are often restricted, organic-rich sediments with are preserved by rapid burial and yield hydrocarbons because of high heat flows.

Two stages of an opening rift Sea level Sea level



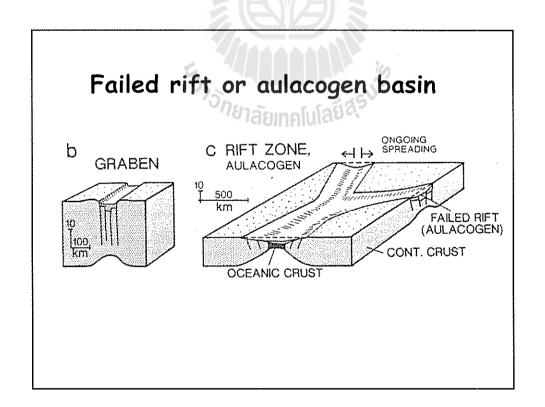
1.3 Failed rift and aulacogen

Failed rift

 Cause: divergent plate motion comes to an end before the moving blocks are separated by accretion of new oceanic crust, the rift zone is referred to as "failed".

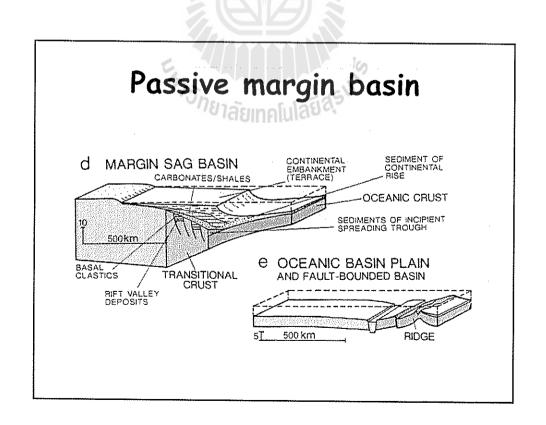
Aulacogens

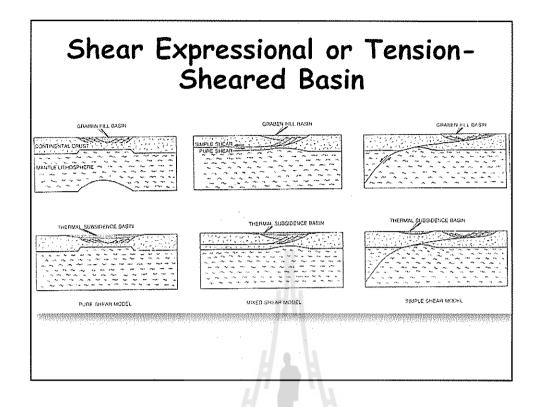
 Aulacogens represent the failed arms continue their development to form an oceanic basin.
 Aulacogen floors consist of oceanic or transitional crust and allow the deposition of thick sedimentary sequences



1.4 Passive margin basin

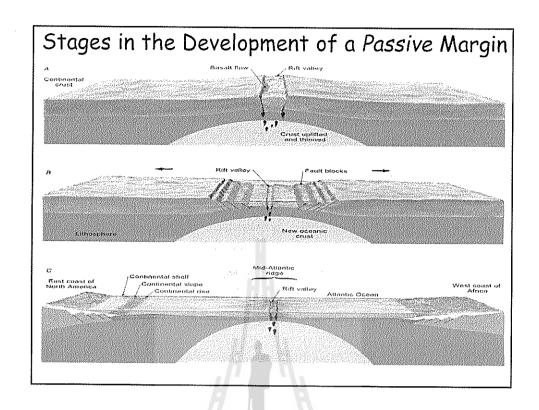
- Passive margin: occur where plates are in contact but are not undergoing active differential movement, plateform type sedimentation prevails.
- > Basins on passive continental margins, margin sag basins (Transitional crust)
- > Tensional-rifted basins, tension-sheared basins, sunk margin basin (Divergence+shear)
- > Passive margins represent rifts which formed and continued to widen until the two sides of the rift became completely separated.

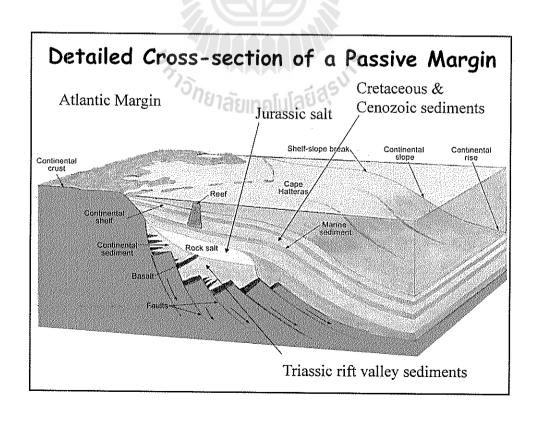




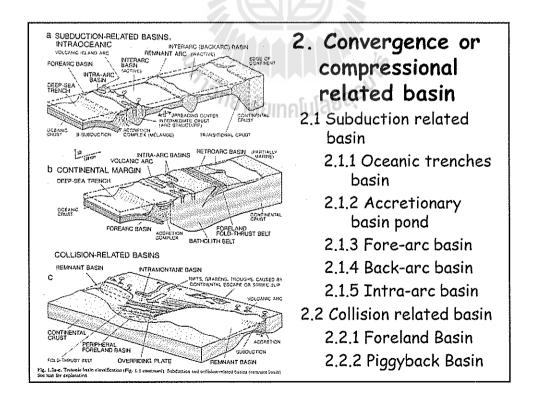
Characteristic of Passive margin basins

- Lots of accommodation space (10,000 to 15,000 m or more) from combination of thermal and sediment loaddriven subsidence.
- Two distinct sedimentary profiles corresponding to the rift and post-rift stages.
 - Early rift: Evaporites, black shales and organic rich marls. (Marine sediments)
 - Post rift: marine trough and deep water sedimentsmarginal deltas and turbidite fans if sedimentation rate remain high.
- Example: Atlantic coast of North America, South America, Africa, and Europe.
- The eastern margin of North America was dominated in the Cambrian and Ordovician entirely by carbonates. Both are major source of petroleum.



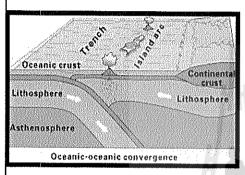


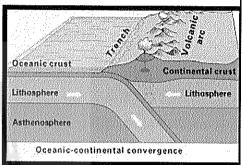
Conversion of a passive margin to a convergent margin A classic passive A. Passive margin margin (A) can be converted into an active convergent margin by collision with an arc (B). Thrust loading and B. Active margin erosion of mountains produce a foreland basin (FB). Cessation of tectonic activity and deep erosion can produce a new passive margin (C).



2.1 Subduction related basin

Subduction is the process of the oceanic lithoshpere colliding with and descending beneath the continental or oceanic lithosphere.



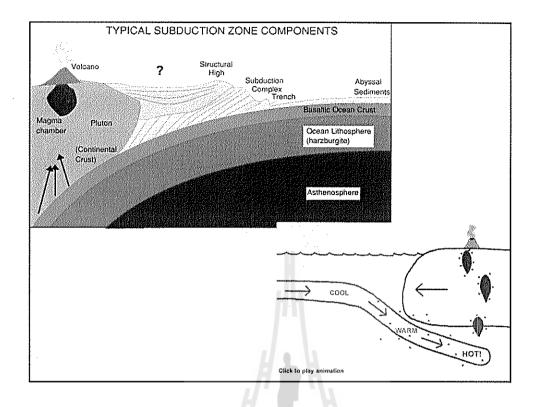


Subduction zones

also termed convergent or consuming plate margins

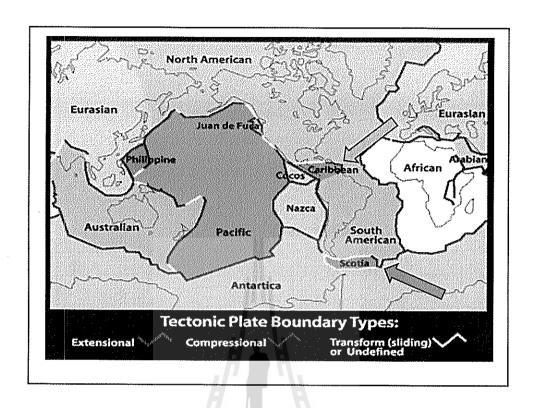
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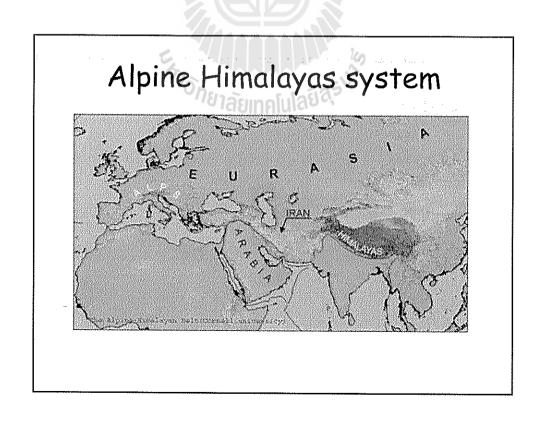
- occur where adjacent plates move toward each other and relative motion is accommodated by one plate over-riding the other.
- These zones are classified as either oceanic or subcontinental, depending on the overriding plate.
- If the "subducting" plate is continental, subduction will cease and a mountain belt will form within a collision zone.



Where do subduction zones occur?

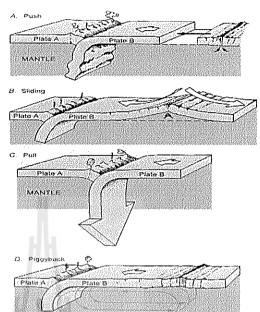
- · Along the "Ring of Fire" around the Pacific Ocean.
- · Two short subduction zones occur at
 - the Lesser Antilles, at the eastern side of the Carribean plate
 - the South Sandwich Island plate.
- · Three short segments of
 - the Alpine Himalayan system involve subduction of oceanic lithosphere.
 - the Calibrian and Aegean boundaries in the Mediterranean Sea
 - Makran boundary along the SW boundary of the Iran plate.





Possible Driving Mechanisms for Plate Tectonics & See

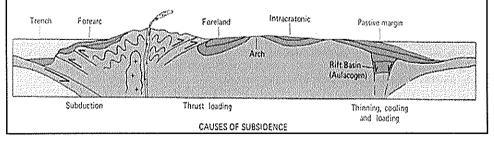
- A. Ocean ridge push
- B. Gravity sliding (down slope of an ocean ridge)
- C. Gravitational pull on a cold plate (down a subduction zone)
- D. Carried on convection cell.

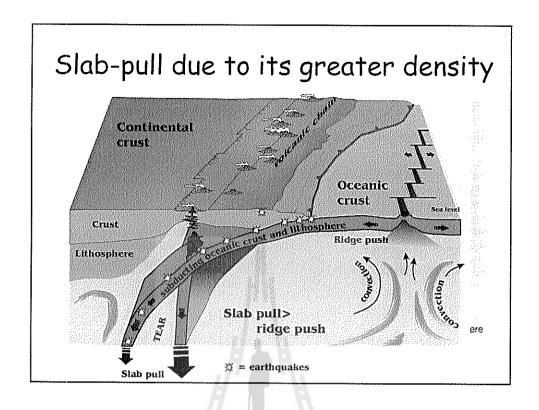


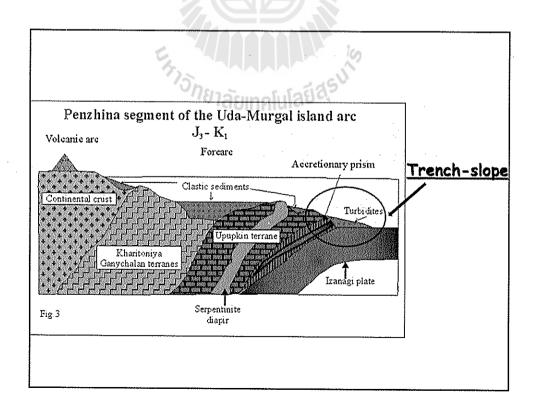
2.1.1 Oceanic trenches basin

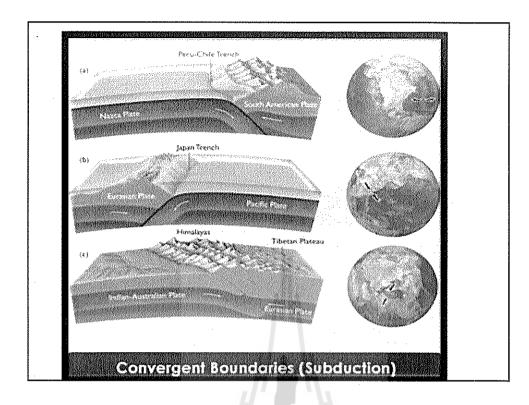
Elongate trends of thick sedimentary sequences associated with subduction zones

- <u>Trench</u>: Trench basins can be very deep, and the sedimentary fill depends primarily on whether they are intra-oceanic or proximal to a continent.
 - Accretionary prism includes material carried to trench on downgoing slab; wedge-shaped, faulted and folded
- Trench-slope: (intra-slope basins)
 - Hemipelagic sediments, turbidites, slumps









Chemical Differentiation

Mid-Ocean Ridge:

Partial melting of Mantle basalt magma

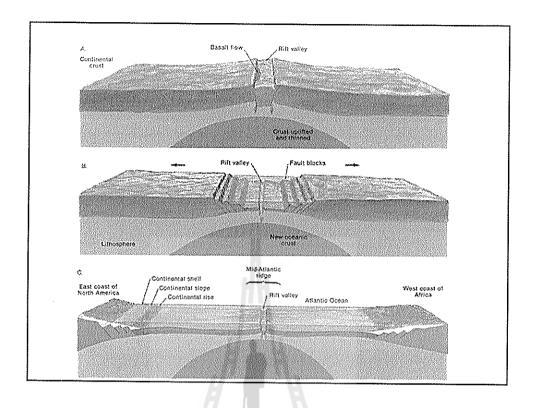
Subduction Zone:

Partial melting of Basalt crust, Andesite magma

Mature Arcs:

Partial melting of Andesite crust, rhyolite magma

- All of this is an irreversible chemical differentiation of the mantle in several stages
- Continental crust grows by accumulation of increasingly silica-rich rocks

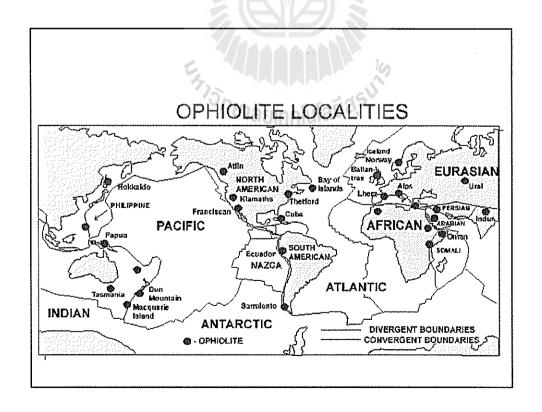


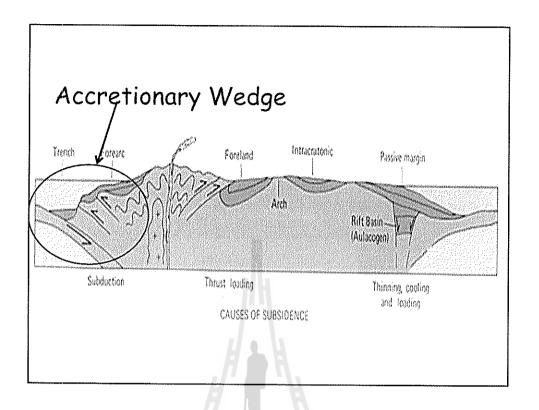
Metamorphic Rocks and Subduction ^กยาลัยเทคโนโลย*ต*

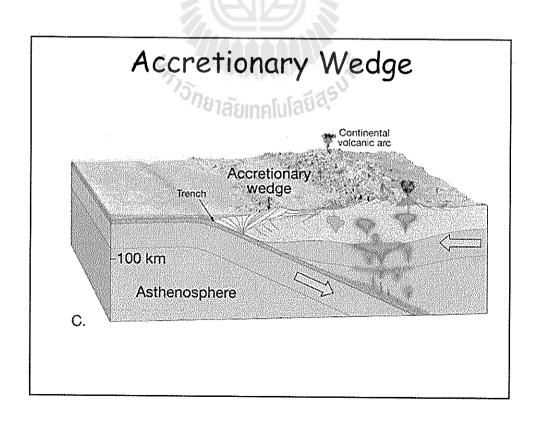
- High Temp Low Pressure
 Metamorphism
 occurs in the core of volcanic arcs
- - Abnormal heating of the crust
 - thermal effects of subduction-related magmatism
- High Pressure-Low Temp.
 Metamorphism
- - occurs in the accretionary wedge
 - Old rocks are dragged to great depths and then upthrust again Granites

2.1.2 Accretionary basin pond

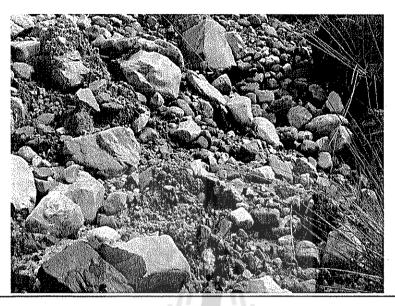
- Unconsolidated sediment from the ocean floor is scraped off the descending plate at the trench
- Slices of the oceanic crust may be included as ophiolite belts
- These rocks form a complex rock mass called an Accretionary Wedge
- The Accretionary Wedge is buckled upwards as new material is pushed beneath its base
- The chaotic jumble of rocks in the Accretionary wedge is called a Tectonic Mélange Accretionary Wedge
- The accretionary prism underlies the inner trench wall, the outer ridge and part of the fore-arc basin.





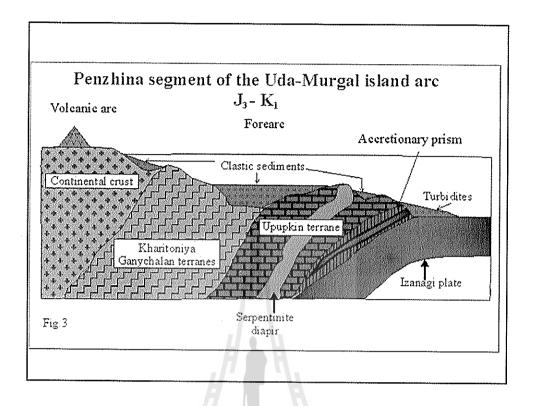


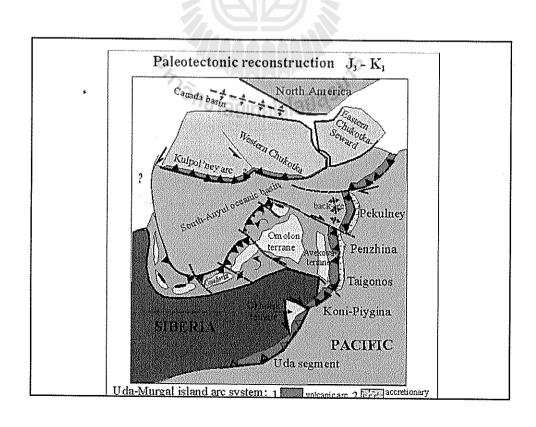
Chaotic jumble of rocks and gravel called Tectonic Mélange Accretionary Wedge



Accretionary Prism

- · Wedge of deformed sedimentary rocks
- · The main locus of crustal deformation
- Rocks are typically cut by numerous imbricate thrust faults that dip in the same direction as the subduction zone.
- As more material is added to the toe of the wedge, the thrusts are moved upwards and rotate arcwards.
- Rocks within the accretionary prism are derived from the downgoing and/or overriding plates.





Accretionary Prism

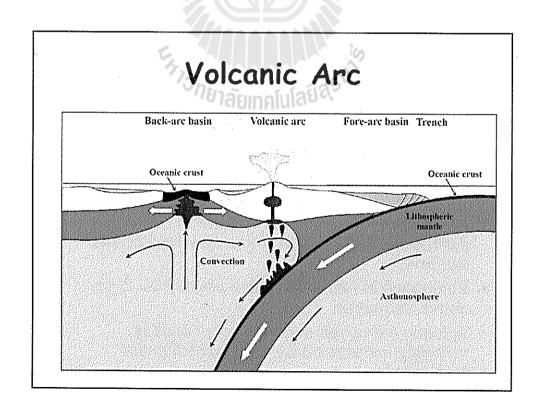
- At the toe of the wedge, sediments are added thru offscraping
- propagation of the basal thrust into undeformed sediments on the subducting plate.
- This process results in progressive widening of the wedge, and eventually a decrease in dip on the subduction zone.

Volcanic Arc

- Active arc built on a topographically high region of older rocks,
- In oceanic arc, the basement may be a shallow marine platform or an emergent region of older rocks.
- In continental arcs, the basement is continental crust standing a few kms above sea level.
- Volcanoes in island arcs are usually 1 2 km above sea level.
- Volcano elevation in continental arcs is strongly influenced by continental crust thickness.

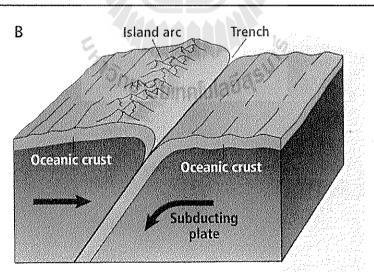
Basins related to volcanic arcs

- 1. Fore-arc
- 2. Back-arc
- 3. Intra-arc
- All may be either submarine or subaerial, or may have marine & subaerial parts
- Much sediment is supplied from active arc.



Volcanic arcs may develop...

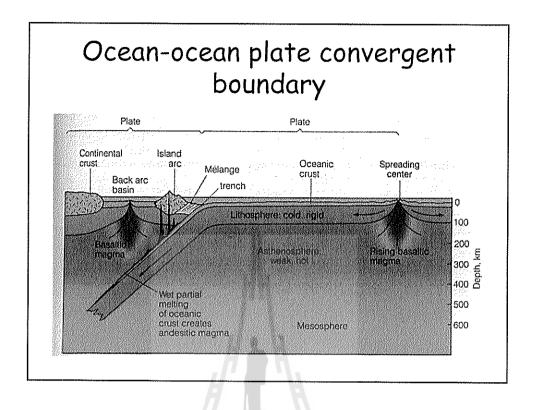
- 1. Within oceanic lithosphere, where ocean floor subducts beneath ocean floor, and an island arc results, e.g. Japan
- 2. At the edge of a continent, where oceanic lithosphere subducts beneath continental lithosphere, and a continental margin magmatic arc forms, e.g. Andes

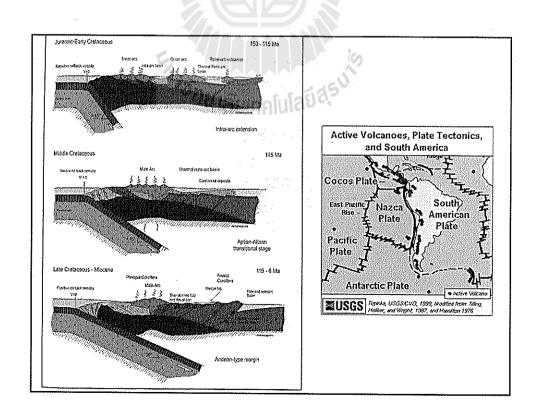


Convergent boundary of two oceanic plates.

Creates an island arc and a trench.

Example: <u>Japan</u>





Characteristic of Arcs

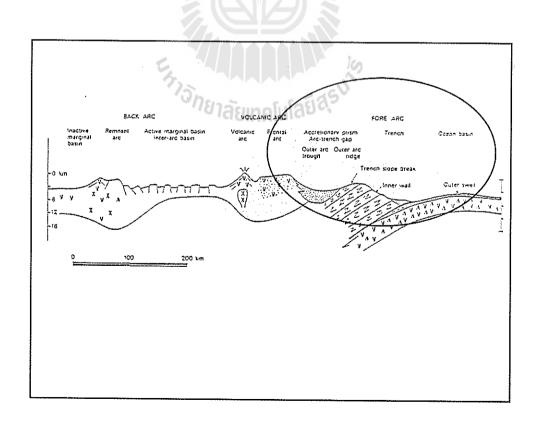
- Arc basement
 - older more deformed and metamorphosed rocks in platform on which the modern arc is built.
 - Oceanic rocks
 - on the continents, complex continental basement.
- Volcanic arc
 - a chain of largely andesitic stratovolcanoes spaced at fairly regular intervals of 70 km.
 - The structural environment of these arcs is commonly extensional (numerous normal faults)
 - volcanoes in grabens termed volcanic depressions.
 - underlain by large plutonic bodies (e. g. the Sierra Nevada).

Characteristic of Arcs

- Metamorphism
 - common and suggest a high geothermal gradient.
 - Much of the lower crust may be at the melting temperature of granite.
- Sediments
 - debris from active volcanoes.
 - deposited as turbidites.
 - In tropics, settings these volcanogenic sediments may interfinger with carbonate reefs.
 - In continental arcs, sediments are often deposited subaerially.

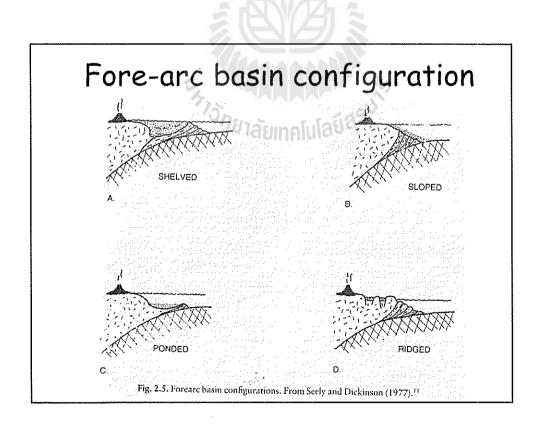
2.1.3 Fore-arc basins

- Fore-ach basin: the shelf basin formed on the trench side of an active volcanic arc
- Lie in the arc-trench gap, between volcanic arc and submarine trench
- range from small basins on trench slope to large basins (50 to 100 km wide, and > 500 km long) with thick fills (several km)
- Basins tend to become wider and shallower with time, partly because of accretion at trenches



Fore-arc (Arc-Trench Gap)

- Consists of region between trench and the arc.
 - steep inner trench wall (lower trench slope)
 -dips of 10 degree
 - flattens into a gentle slope termed the forearc basin (upper trench slope).
 - The inner trench wall is usually separated from the forearc by the outer ridge.
 - The accretionary prism underlies the inner trench wall, the outer ridge and part of the forearc basin.



Fore-arc basins

Sediment sources:

- volcanic arc
- outer arc
- longitudinally from a continent

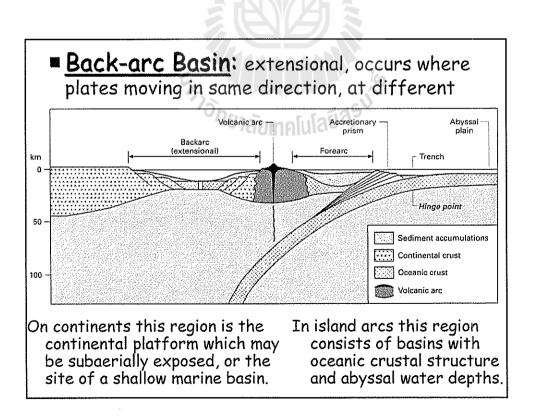
Tectonic style varies:

- compressional
- extensional
- strike-slip

Example of Forearc basin in South America (Andes) 15-15-15-15 PRINT CANADATA DESCRIPTION DES

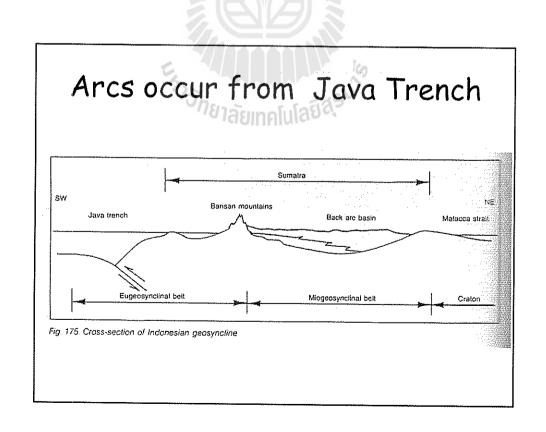
2.1.4 Back-arc basins

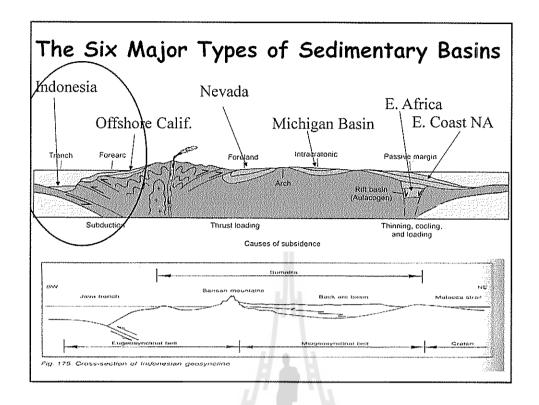
- Structural/depositional basin in the convex area
- · Area behind the volcanic arc.
- · Lie behind the magmatic arc
- Often the site of extension & thinning of crust
- May overlie either ocean or continental crust



Back-arc sediments

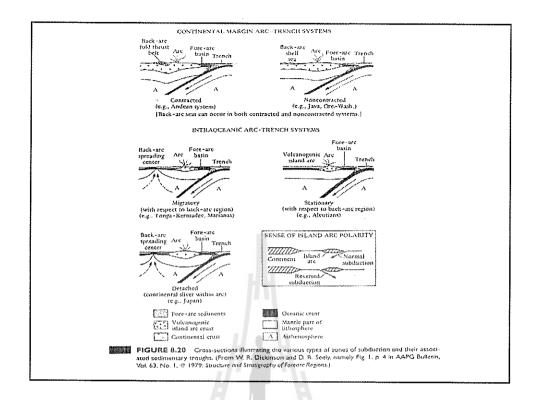
- extensional tectonics and subsidence.
- In oceans arc-derived sediments are deposited in an ocean basin behind the arc termed the back-arc basin.
- In continents, sediments are deposited into basins on the continental platform and are termed foreland basins or retro-arc basins.

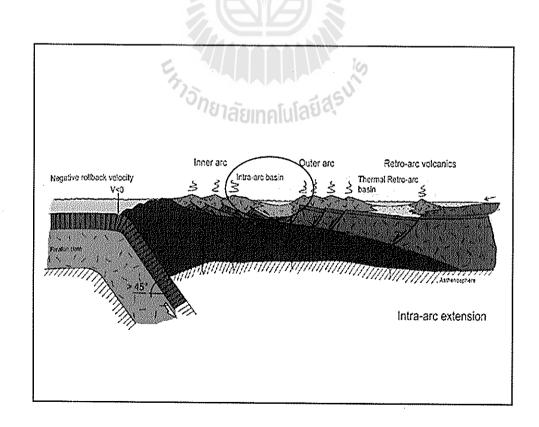


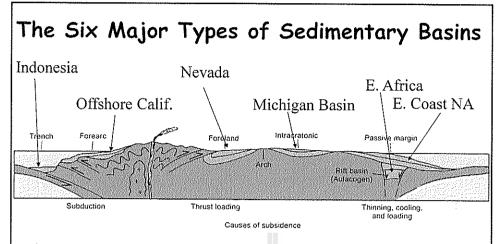


2.1.5 Intra-arc basins

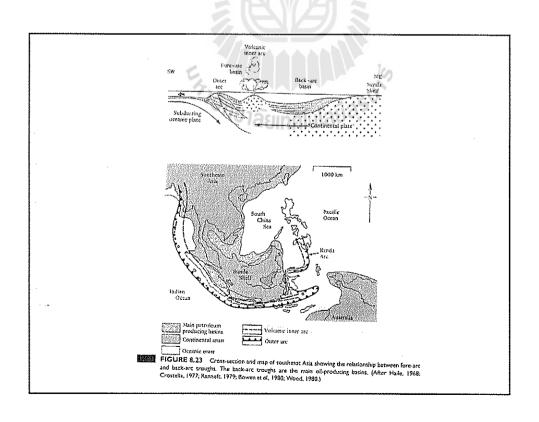
- > Sedimentary basins within magmatic arcs, between volcanoes, or between older and younger belts of the arc
- > Some are fault-bounded and subside rapidly. Faulting due to extension within arc, or flexure of lithosphere due to weight of volcano.
- > With time, position of the arc migrates, and basins may change between intra-arc, back-arc and fore-arc.

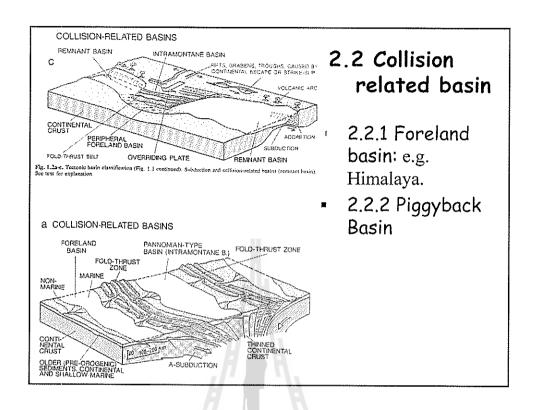


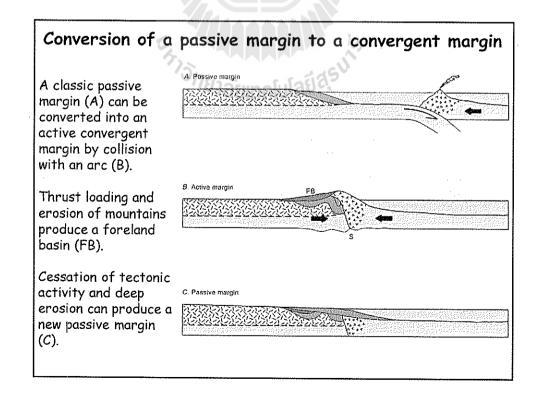


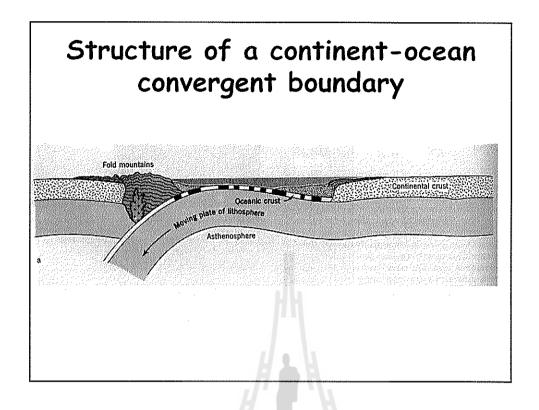


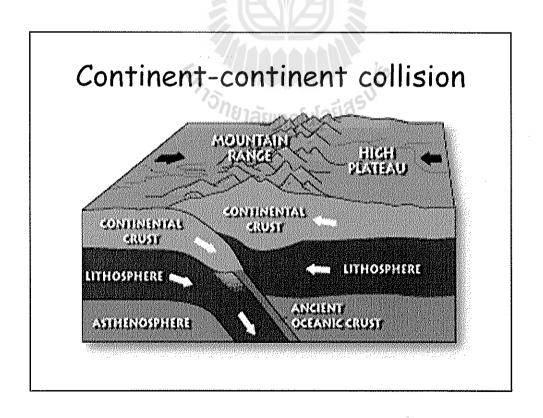
The six major types of sedimentary basins are shown in their plate-tectonic settings. The major physical cause or causes of subsidence for each case are shown below the diagram. Some examples are indicated in top.

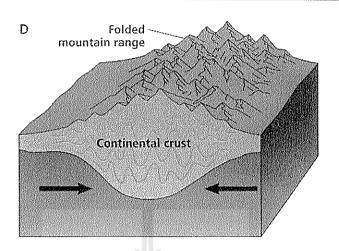












Convergent boundary of two continental plates. Forms a <u>folded</u> mountain range. Examples: Himalayas , Alps, Appalachians

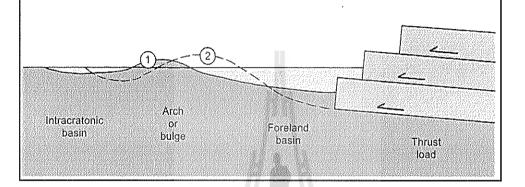
2.2 Collision related basin

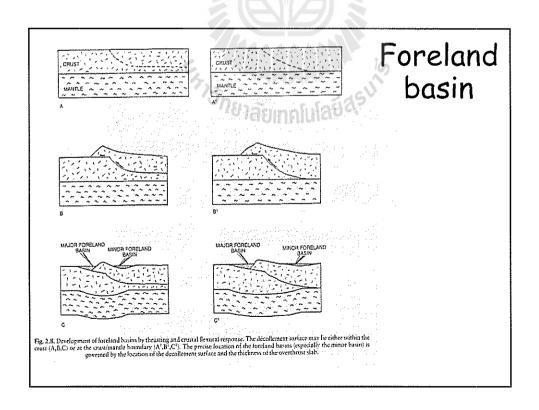
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- Foreland basin: elongate regions of potential sediment accumulation that form on continental crust between constructional orogenic (fold and thrust) belt and craton (produced by thrust loading)
- Arch or bulge separates foreland from cratonic basin

Formation of an intercratonic basin and a foreland basin

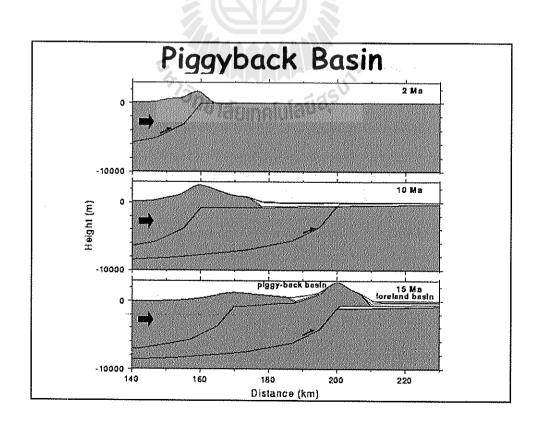
Formation of an intercratonic basin and a foreland basin and an intervening arch by "thrust loading" e.g thrust faulting a package of rock onto a continental margin.





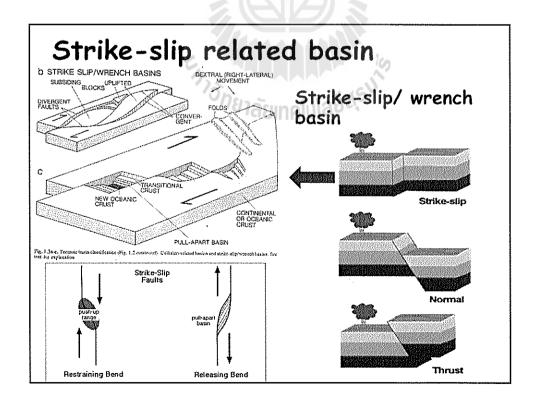
Piggyback Basin (thrust sheet top basin)

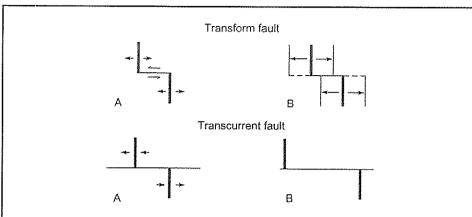
- Thrust belt typically propagates into foreland basin, moving depocenter in the direction of thrust motion
- Piggyback Basin: basins that are on the hanging wall of a thrust fault and move with the hanging wall.
- Sediments evolve from fine-grained turbidites to shallow water continental seds over time



3. Transform or Strike-slip related basin

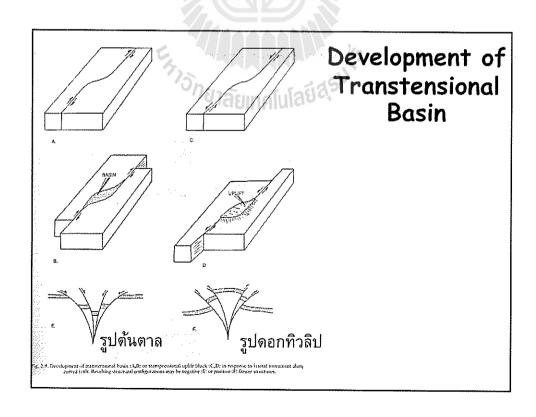
- Strike-slip basin: basin associated with convergent and divergent plate boundaries.
 Some plate margins are transcurrent and develop a particular type of rift basin.
- Transcurrent plate margins are defined by major wrench faults.
- One type of rift basin, very deep, subside rapidly and have rates of high heat flow such as Dead Sea rift

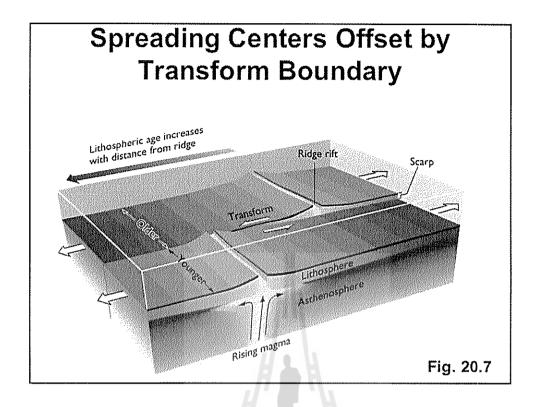


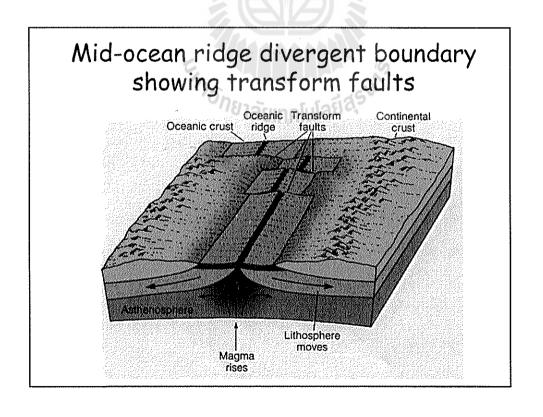


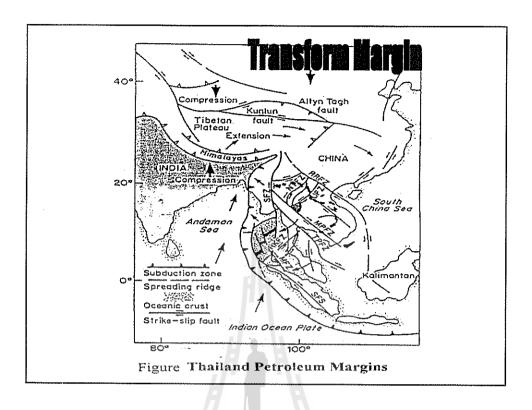
Upper: Plates are spreading away from ridge axis and the transform fault connects two offset segments of that axis. Segments of adjacent moving oceanic crust slide past one another along the transform while spreading occurs.

Lower: Sea-floor spreading ceased before A and then a transcurrent fault cut the ridge. Between times A and B the dead ridge was offset in the direction shown by the arrows in the opposite sense of displacement from that of the transform fault.

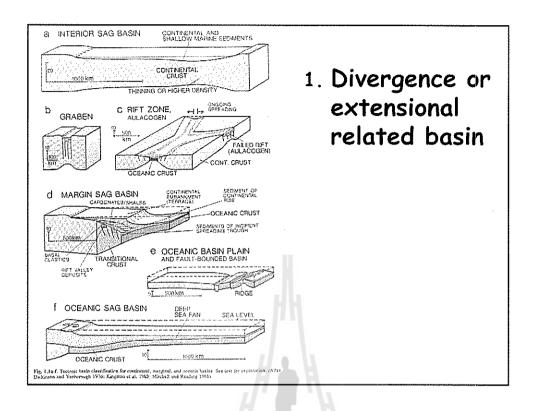


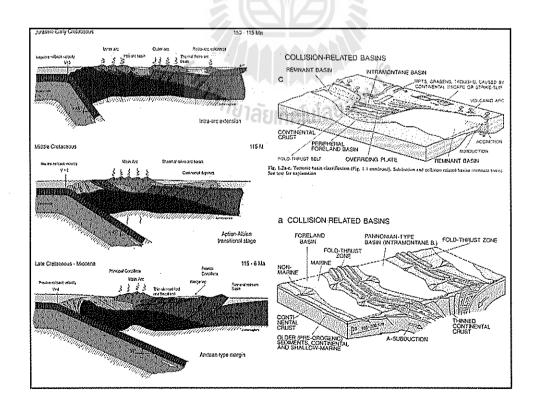


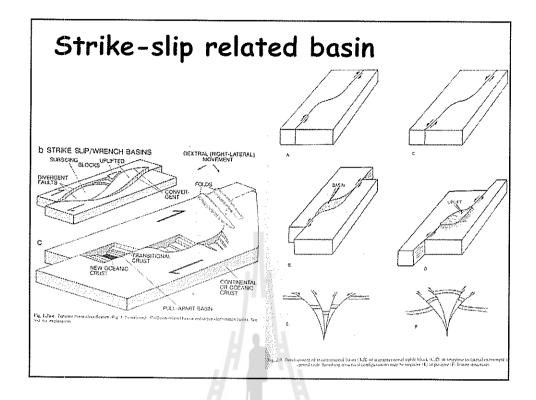




	Basin category	Special basin type or synomym(s)	Underlying crust	Style of tectonics	Basin characteristics
Ĵ	Continental or interior sag basins	Epicontinental basins, infra- cratonic basins	Continental	Divergence	Largo areas, slow subsidence
erce Rit	Continental or interior fracture basins	Graben structures, rist valleys and rist zones, aulacogens	Continental	Divergence	Relatively narrow basins, fault-bounde rapid subsidence du- ing early rifting
Divergence Rane RIF	Basins on pas- sive continen- tal margins, margin sag basins	Tensional-rifted basins, tension-sheared basins, sunk margin basins	Transitional	Divergence + shear	Asymmetrie basins partly outbuilding of sediment, moders to low subsidence du ing later stages
تز	Oceanie sag basurs	Nascent ocean basin (growing oceanio basin)	Oceanic	Divergence	Large, asymmetric, slow subsidence
,	Basins related to subduction	Deep-sea trenches	Oceanic	Convergence	Partly asymmetric,
<u>ن</u> 4	The Park of the Community of the Communi	Foreure basins, backare busins, interare basins	Transitional, oceanie	Dominantly divergence	greatly varying depth and subsidence
Comvesgeence	Basins related to collision	Remnant basins	Oceanic	Convergence	Activated subsidence due to rapid sedi- mentary loading
-		Foreland basins (peripheral), retroare basins (intramostane), broken foreland hasins,	Continental .	Crustal flexuring, local con- vergence or transform motions	Asymmetric basins, trend to increasing subsidence, subsidence, sidence of the sid
930	•	Terrane-related basins	Oceanic		Similar to backare basins
Franspoon	Strike-alip/ wrench basins	Pull-apart basins (transtensional) and transpres- sional basins	Continental and/or oceanic	Transform motion, ± di- vergence or convergence	Relatively small, clongate, rapid subsidence







Pre-, Syn-, and Post-Depositional Basins

Tectonic movements and sedimentary processes can interact in 3 different ways.

- 1. Pre-depositional basin—Before dep.
- 2. Syn-depositional basin—During dep.
- 3. Post-depositional basin—After dep.

1. Pre-depositional basin

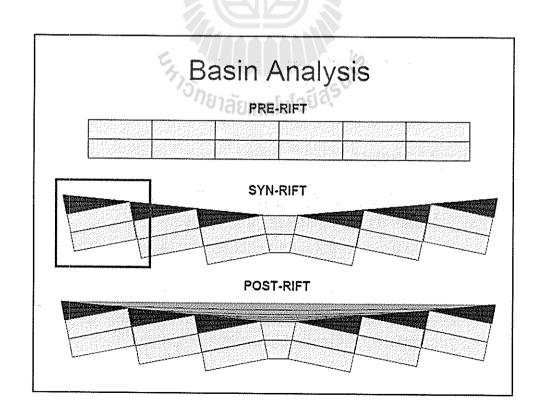
- Occur before the basin development
- Rapid tectonic movement predate significant sediment accumulation and create a morphology basin
- The water depth in the basin decreases with time
- Sediment transport as well as vertical and lateral facies development

2. Syn-depositional basin

- Occur during the basin development
- Sediment accumulation is affected by syndepositional tectonic movement
- The distribution and facies of sediments will be affect by morphology of basin
 - High sedimentation=subsidence: sedimentary transport, distribution and facies remain unchanged
 - Low sedimentation
 subsidence: sedimentary
 transport, distribution and facies are
 changed

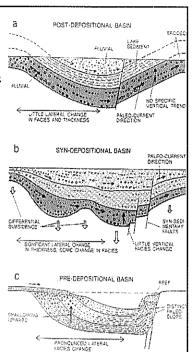
3. Post-depositional basin

- · Occur after the basin development
- No or little relationship between the transport, distribution, and facies of the sediments and the later evolved basin structure.



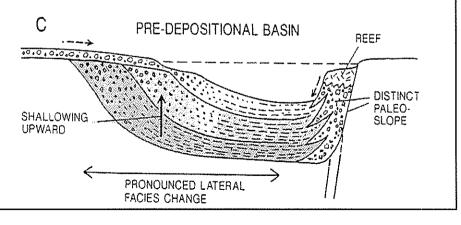
Basin Morphology

- A. Post deposition basin created by tectonic movements after the deposition of sheet-like fluivial and lake sediments; younger syntectonic basin fill is removed by subsequent erosion.
- B. Syn-depositional tectonic movement control varying thicknesses of fluvial and shallow-marine sediments and generate a basin-fill structure, although a morphological basin barely existed.
- C. Rapid, pre depositional tectonics creates a deep morphological basin which later filled up by post-tectonic sediments. The geometry of the former basin can be derived from transport directions and facies distribution



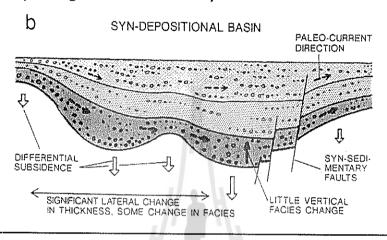
Basin Morphology: Pre-Dep.

Rapid, pre depositional tectonics creates a deep morphological basin which later filled up by posttectonic sediments. The geometry of the former basin can be derived from transport directions and facies distribution



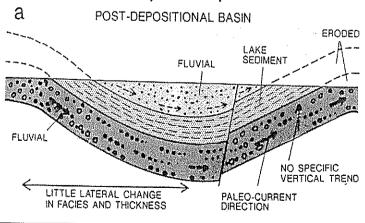
Basin Morphology-Syn-dep.

Syn-depositional tectonic movement control varying thicknesses of fluvial and shallow-marine sediments and generate a basin-fill structure, although a morphological basin barely existed.



Basin Morphology: Post-Dep.

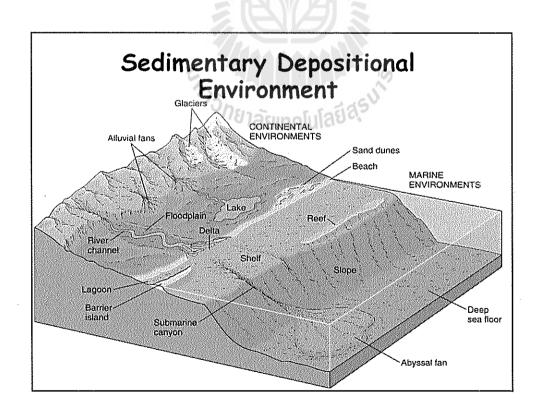
Post deposition basin created by tectonic movements after the deposition of sheet-like fluivial and lake sediments; younger syn-tectonic basin fill is removed by subsequent erosion.



Depositional Environments

Depositional Environments can be divided into 3 major of sedimentary basins:

- 1. Continental: fluvial, glacial, eolian, lucustrine (lake),
- 2. Adjacent sea basins and epicontinental seas of varying salinity (Transition=between continental and marine)
- 3. Marine depositional areas of normal salinity



Base level of erosion in different Environment

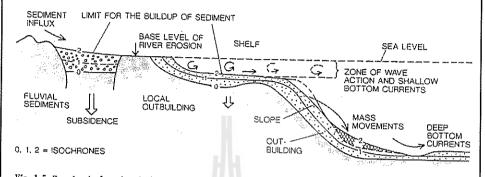
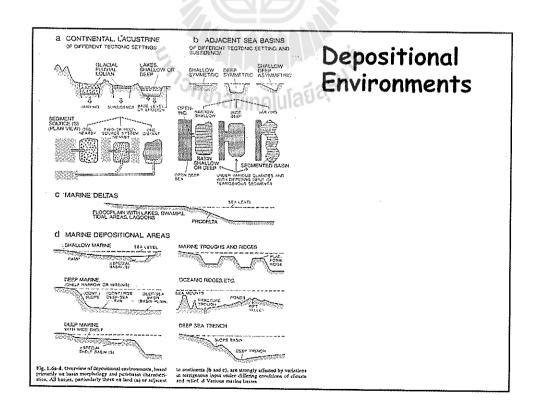
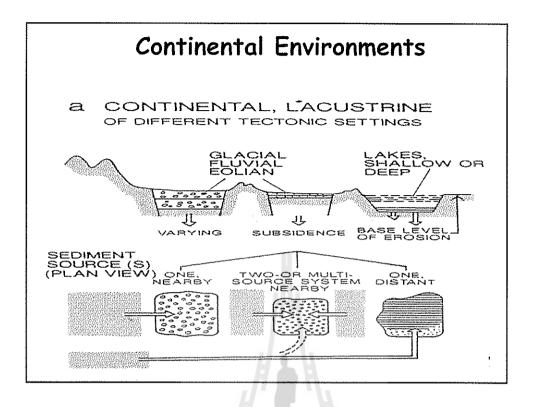
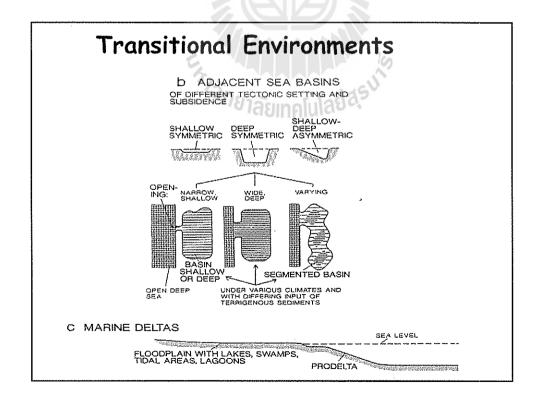
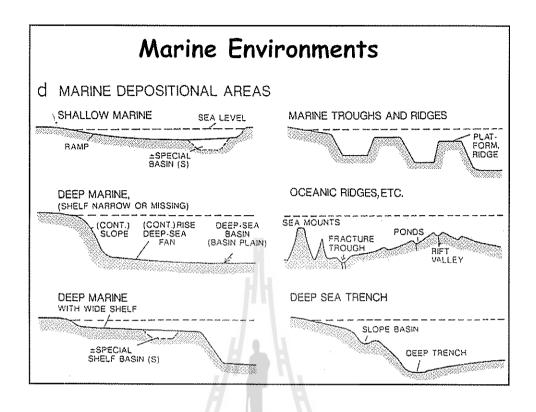


Fig. 1.5. Base level of erosion, hydrodynamic regime in the sea, and gravity mass movements as limiting factors controlling upbuilding and outbuilding of sediments. Note that the model may be modified by sea level changes





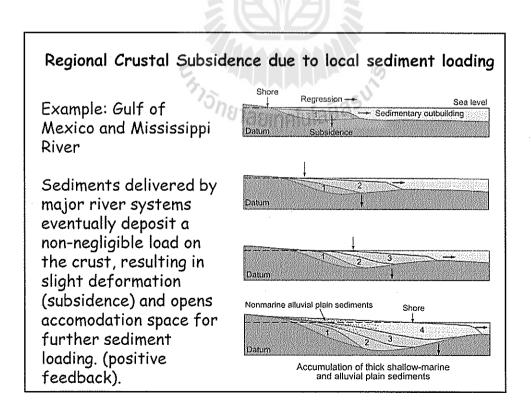




		Sedi	imentary Depo:	sitional Env	vironments	ĺ
	Depositional Environment	Environmental Characteristics	Organisms	Sediment	Sedimentary Structures	Sedimentary Rocks
non-marine	river channel	variable stream current (high-to lave-E), water may dry-up, oxidation	Skritters Skritters	graves, sand, mud; variable sorting & rounding	crossbeds, reple thinks, maded beds, maknocks, plant 3 annial toess trayperts	conglomerate eandstene mudstone
	flood plain	fisoda (low-E), dryzng, oxidation, sod termation	land-freshyvater planso 3 critters	mud, cond; well-sorted	bedding, ripple marks, graded tieds, mulicracks, abundant tassis	mudatone (red beda) sandatone
	riyer delta	streom current, ticles love-E	and-trechwater plants & critters	sand, mud; well-sorted	bedding, cross beds, rapsie marks, gravied beds, attunded tossas	sandstone mudstone
	alluvial fan	periodic flash floods, mustlows high-E	land plants & centers	gravel > const poorly-sorted & prepare	plant & animal fossil tragments	sedimentary brecsia erkose
		veriable wind current (high- to low-E), dry, wintzing	smež insects š reptūrs; sparse plants	sand, well-sorted & well-conded	cross bads, ripple marks, trace fossis	#Andstone
	playa	low-5, high eveporation, floods periodically, dry	emai insects, repties, faw plants	evaporêes mud	mud crecks, rigste marks, trace fossis	eveporke mudstone
	lake	iowe, stadowniego starofra water	and-Keshwater parts A criters	nud, cand, carbonale sedineri	becking, rapie marks, graded beds, abundard (oscis	mudstone sandatone timestone
	glacier	ice, bare rock, cost	sporae planic & Critiers	gravet orgalar & poorly sorted	lew	tifl
nsitions	heach	waves (ligh- to low-E), tides, currents, wed	derre & non-derrie Criticia	grayet, sand, mud, corbonale sections well-sorted & well-rounded	tippie marką, crossbeds, obundant rozass & fossi frogments	conglomerate samdatone imudatone imeatone & coguina
	lagoos	low-E, lides, not very oxidized	morine à non-marine plants à criters	HAIG	hodány, rppie marks, abundaní tassis	mudstone (green-black, not red)
ASSESSED OF		waves (high- to low-E), Intes, ctrong ocean currents, what	markes places & critices	sand, mud, carbonale sediment well-sorted & well-rounded	bedång crossbeds, ripple mæls, disurdad mælee fossis	sandstone medatone limestend
T S	reel	wanes (high- to low-E), lides, strong ocean currents, wind	marine placks & critica	gravel, sækl, mud, dæbonsfe sedineri variable serling	abundari marine fossis	limestand bracele sendstane mudstane
ALCOHOL:	deep marine	kin-č, variskie cureras	weird market plants & Criffers	nui, catonale & sicecus coze	abundaré marini foccis	mudstone Briestone chort

Subsidence Mechanisms

- 1. Subsidence related to cooling
 - Passive continental margin
- 2. Subsidence related to crustal thinning
- 3. Subductional subsidence (trench)
- 4. Loading
 - Glaciers
 - Sediments
 - Thrust loading
- 5. Local basin formation in transcurrent settings



Sediment supply and transport

Sediment supply

- Sediment supply varies according to volcano behaviour, governed by magma viscosity and gas content.
- In deep water, explosive activity is suppressed by hydrostatic pressure.
- More silicic magmas in more evolved arcs therefore greater explosive activity, more supply of pyroclastic sediment.

Sediment transport and deposition is controlled by:

- 1. Topography both subaerial and submarine
- 2. Volcanic processes, especially eruption column height, direction of pyroclastic flows
- 3. Sediment transport systems e.g. rivers, prevailing winds

Sedimentation and Rate of Subsidence

1. Rapid subsidence and Rapid deposition

Subsidence = Deposition

- thick sediments
- · source area: sediments strongly uplift
- · Strong tectonism
- · Rapid dep. make no destroy sediments
- Poorly sorted sedimentary rock
- Unstable mineral
- No carbonate and non-clastic rocks
- Eugeosyncline

Sedimentation and Rate of Subsidence

- 2. Rapid subsidence and Slow deposition Subsidence > Deposition
 - Deep basin==may reach bathyal or absyssal
 - Fine sediments and non-clastic rock
 - Less deposition due to less sediments weakly uplift, subsidence is near Island arc until sea level
 - Eugeosyncline: Restricted condition

Sedimentation and Rate of Subsidence

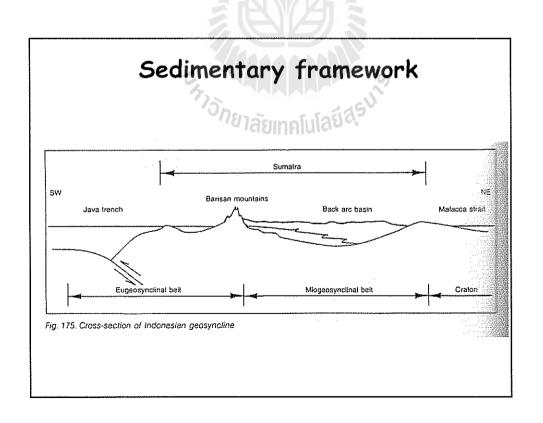
- 3. Slow subsidence and Rapid deposition Subsidence < Deposition
 - Sediments be higher than base level
- e.g. Delta: Deposition faster than wave or current
 - Clastic rock
 - Shallow marine brackish or continental deposits
 - Shelf area

Sedimentation and Rate of Subsidence

- 4. Slow subsidence and Slow deposition Subsidence = Deposition
 - Slow transportation
 - No Unstable minerals
 - Rounded sand and well sorted
 - Slow subsidence and deposition are the slow erosion of source area
 - Stable shelf area on craton

Sedimentation and Plate Tectonic

- Sedimentation and Plate Tectonic or Sedimentary tectonics refer to the sedimentation and tectonism
- There are 2 components:
 - Sedimentary framework
 - Degree of tectonism



1. Geosycline

- 1) Eugeosyncline: more active, (outer belt) near marine
 - Graywacke sandstone
 - Dark siliceous shale
 - Minor siliceous limestone or bedded chert
 - May show quartzose sandstone or conglomerate in the section
 - Volcanic rock
- · Sediments derived from Island arc
- 2) Miogeosyncline: less active, near Eugeosyncline
 - Have sedimentary rocks
 - No volcanic rock
 - Have carbonate rock more than Eugeosyncline

2. Craton Stable Part

^{7ย}าลัยเทคโนโลยี^ส

 Craton stable part or central part of the continent between Orthogeosyncline

It consist of

- 2.1 Intracratonic basin
- 2.2 Cratonic shelf area
 - 2.2.1 Stable shelf
 - 2.2.2 Unstable shelf

Lithologic Association

- Group of sedimentary rock that occurs in same tectonic condition
- Depend on type of sandstone be with shale or limestone
- Each group of sedimentary rock relate to tectonic intensity

Classification of Lithologic Association

- 1. Geosynclinal Associations
 - 1.1 Eugeosyncline
 - 1.2 Miogeosyncline
- 2. Craton Stable part
 - 2.1 Cratonic Shelf Area
 - 2.1.1 Stable Shelf
 - 2.2.2 Unstable Shelf
 - 2.2 Intracratonic Basin
- 3. Other Lithologic Association
 - 3.1 Red Beds
 - 3.2 Black Shales
 - 3.3 Cyclothem

1. Geosynclinal Associations

1.1 Eugeosyncline association

<u>Sandstone</u> - Graywacke (commonly with interbedded greenstones (ophiolite)) salt-and pepper sandstone, commonly tuffaceous

<u>Shales</u> - chiefly siltstones, chloritic gray, green, red, black siliceous, micaceous, pyritic carbonaceous

- Large variety of minerals in silt

<u>Limestone</u> - Dense, dark, silicoues

- Bedded chert

1. Geosynclinal Associations

1.2 Miogeosyncline association

Sandstone - Graywacke to subgraywacke saltand pepper sandstone, Abnormally

thickened shelf sandstone

<u>Shales</u> - Chiefly siltstones, some clay shales, gray, green, red, black siliceous,

micaceous, carbonaceous and calcareous

Limestone - Dense, dark, silicoues

- Abnormally thickened shelf types normal marine, fossiliferous fragmental-foraminiferal limestone

2. Craton Stable Parts

2.1 Cratonic Shelf Areas Associations

2.1.1 Stable Shelf

Sandstone

- Pure quartz type
- Quartz-glauconite
- Quartz-iron oxide
- -Quartz-muscovite

Shales - Chiefly clay shales

- Gray, green, red, brown, black
- Calcareous, glauconitic, carbonaceous
- Quartz common in silt

Limestone

- Normal marine type
- Fossiliferous-fragmental
- Foraminiferal
- Biothermal
 - -2nd chert and dolomite common
 - Random reef distribution

2. Craton Stable Parts

2.1 Cratonic Shelf Areas Associations

2.1.1 Ustable Shelf: subsidence more than stable shelf

Sandstone

- Feldspatic
- "Blanket" arkose
- -Quartz-muscovite, subgraywacke

Shales

- Cheifty silty shales
- Gray, green, red, brown, black
- Micaceous, aalcareous, carbonaceous
- feldspar may be common in silt

Limestone

- Nodular types
- Dense, argillaceous
- Thickened, stable shelf types

2. Craton Stable Parts

2.2 Intracratonic Basin Association

Basin occurs in subsidence of the middle craton

1) Normal "Open Basin" Association

Sandstone - Subgraywacke

Shales

- Chiefly siltstone

- Gray, red, brown, black, chiefly dark,
- Calcareous, siliceous, micaceous
- Variety of minerals in silt

- Limestone Thickened shelf types
 - Dense, often argillaceous

2) "Wedge" Arkose Association: occur in granite rock with near basin

Sandstone - Arkose

Shales

- Silty, micaceous, kaolinitic red and chocolate colors
- Abondant feldspar in silt

Non-clastics- Nodular limestone types

-Special evaporite sequence

2. Craton Stable Parts

2.2 Intracratonic Basin Association

3) Arid "Restricted Basin" Association

Sandstone

- Subgraywacke

Shales

- Chiefly siltstone
- Gray, red, brown, black, chiefly dark,
- Calcareous, siliceous, micaceous
- Variety of minerals in silt

Limestone

- Fine-textured, calcitic types
- Dense "primary" dolomites
- marginal reef belts of biothermal

limestone

Evapolites

- Sulphates (gypsum and anhydrite)
- Chlorides (halite)
- "Primary" dolomite

2. Craton Stable Parts

- 2.2 Intracratonic Basin Association
 - 4) Black shale "Restricted Basin" Association

Sandstone

- Subgraywacke

- Thin quartzose types

Shales

- Chiefly black, pyritic

carbonaceous

Limestone

- Thin shelf types

- Dense, dark with much organic matter

3. Other Lithologic Association

- 3.1 Red Beds can be define into 4 types:
- 1. <u>Primary Red Beds:</u> red color derived from source area and in situ deposition e.g Piedmont and alluvial plain
- 2. <u>Post depositional Red Beds</u>: oxidation of sediments e.g delta
- 3. <u>Secondary Red Beds</u>: red color of rock occur from exist sediment color by transportation
- 4. <u>Chemical Red Beds</u>: red color occur while deposition

Chapter II: The Nature and Origin of Petroleum

Purpose: The elemental compositions of petroleum are combined abundantly in nature. This chapter are explain about the interrelations between the elemental composition and the routes how they come to be formed.

Outline of The Nature and Origin of Petroleum

- 1. Petroleum system
 - 1.1 Source
 - 1.2 Migration
 - 1.3 Reservoir
 - 1.4 Trap
 - 1.5 Seal
- 2. Physical and chemical properties of hydrocarbon
 - 2.1 Hydrocarbon gases
 - 2.2 Non-hydrocarbon gases
 - 2.3 Hydrocarbon crude oil
 - 2.4 Non-hydrocarbon crude oil
- 3. The origin of petroleum
 - 3.1 Inorganic origin
 - 3.2 Organic origin

History of Petroleum

First Use:

- · Egyptians: oil to preserve mummies
- · Chinese: natural gas for fuel
- · Babylonians: oil to seal walls and pave streets
- · Americans: tar to seal canoes

First Drilling:

- · Chinese using bamboo: to 800' in 347 AD
- · Americans using cable tool: to 70' in 1859 AD

First Product:

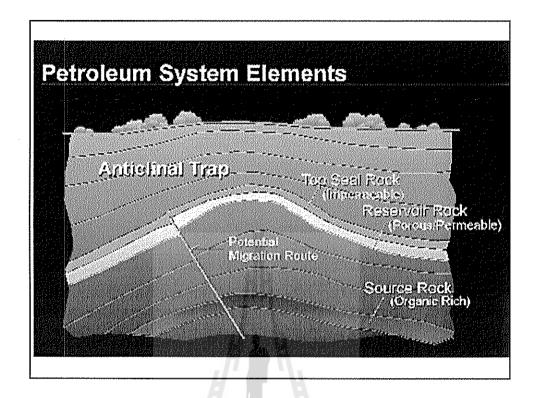
- Kerosene for lamps
- · Gasoline was unwanted by-product

Demand Increase: Industrial Revolution

- -Internal Combustion Engine (1885)
- -Global Economic Growth

Petroleum System Elements

- 1. Source Rock A rock with abundant hydrocarbon, hydrocarbon-prone organic matter
- 2. Reservoir Rock A rock in which oil and gas accumulates:
 - Porosity space between rock grains in which oil accumulates
 - Permeability passage passage-ways between pores through which oil and gas moves
- Seal Rock A rock through which oil and gas can't move effectively (such as mudstone and claystone)
- 4. Migration Route Avenues in rock through which oil and gas moves from source rock to trap
- 5. Trap The structural and stratigraphic configuration that focuses oil and gas into an accumulation



Petroleum System - A Definition

- •A Petroleum System is a dynamic hydrocarbon system that functions in a restricted geologic space and time scale.
- •A Petroleum System requires timely convergence of geologic events essential to the formation of petroleum deposits.

These Include:

- Mature source rock
- Hydrocarbon expulsion
- Hydrocarbon migration
- Hydrocarbon accumulation
- Hydrocarbon retention

(modified from Demaison and Huizinga, 1994)

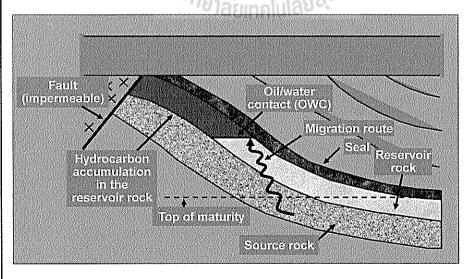
Petroleum Systems

Elements

- **➢Source Rock**
- ➤ Migration Route
- ➤ Reservoir Rock
- ➤ Seal Rock
- ➤Trap

- Generation
- •Migration
- Accumulation
- Preservation

Generation, Migration, and Trapping of Hydrocarbons

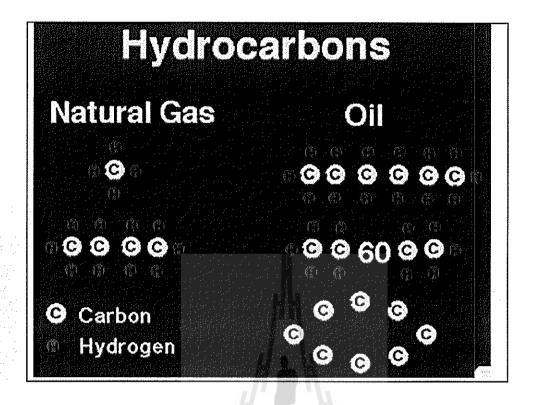


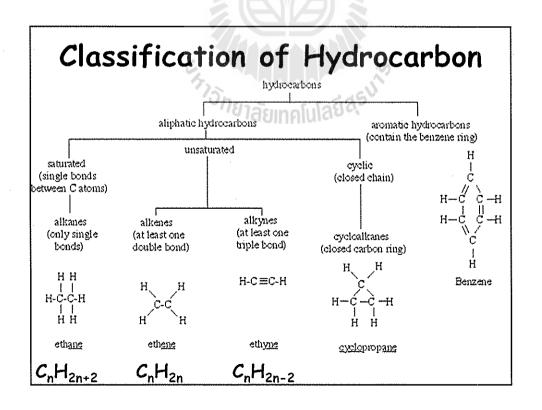
What is Petroleum?

- Petroleum: a natural yellow to-black flammable liquid hydrocarbon found beneath the earth's surface
 - -H (11-15 %wt),
 - -C (82-87 %wt),
 - -bits of S, N, 0
- Hydrocarbon: an organic compound made up of carbon and hydrogen atoms

Hydrocarbon

- 1. Gas
 - Natural Gas: wet and dry gas
 - Condensate
- 2. Liquids
 - Oil, Crude oil
- 3. Plastic
 - Asphalt, Tar
- 4. Solids
 - Cool
 - Kerogen- Insoluble in organic solvents
 - Bitumen-Soluble





Physical and chemical properties of hydrocarbon

- 1. Hydrocarbon gases
- 2. Non-hydrocarbon gases
- 3. Hydrocarbon crude oil
- 4. Non-hydrocarbon crude oil

1. Physical and chemical properties of HC gas

- > Various descriptive terms for natural gas:
 - Dissolved gas- That portion of natural gas that is dissolved in liquid phase in the subsurface. It can be (and usually is) physically separated from the liquid when the fluids are produced.
 - Associated gas- Also known as the "gas cap" is free gas (not dissolved) that sits on top of, and in contact with crude oil in the reservoir.
 - Non-associated gas- Free gas that is trapped without a significant amount of crude oil.
 - Natural gas liquids The liquids that can be, and are liquified, in the field and at gas processing plants. Include the wet gases, natural gasoline, and condensate.
 - Sweet Gas (and Oil)- Contains no H2S
 - Sour Gas (and Oil)- Contains H₂S.

Hydrocarbon Gas Type

The common gasses in reservoirs can be divided based on their origins:

- (1) Inorganic-Helium, Argon, Krypton, Radon
- (2) Mixed inorganic and organic- CO2, H2S
- (3) Organic- Hydrogen (???), Methane, Ethane, Propane, Butane

In summary: there are two major type of hydrocarbon gas is

- 1. Hydrocarbon gas
- 2. Non-hydrocarbon gas

1. Hydrocarbon gases

Hydrocarbon gases are largely composed of the paraffin series (C1-C4)

- straight and branched
- single bonded changes of hydrocarbons

The gases decrease in abundance up through pentane (C5).

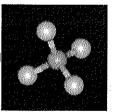
Hydrocarbon Gas consist of:

- 1. Methane
- 2. Heavier hydrocarbon

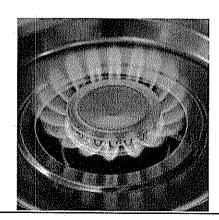
- 1. Methane is the largest constituent of natural gas. It can form in three ways:
- <u>a) Mantle methane:</u> Derived from the mantle (presumably primordial methane).
- <u>b) Microbial methane:</u> As a reaction product of the bacterial decay of organic matter. Large caused by the reduction of CO_2 during oxidation of the organic matter.
- c) Thermogenic methane: Thermal breakdown of heavier hydrocarbons. Appears that the thermal degradation has to be catalyzed for it to occur in nature.
- Microbial methane can be distinguished from thermogenic methane on the basis of its isotopic composition.
- Microbial is lighter in ^{13}C (range from -80 to -60 ‰) than thermogenic methane (range -40 to -30‰)

Hydrocarbon Gas

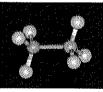
Methan



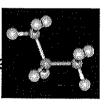
- Paraffins (Alkanes)
- · Saturated Chains







Propane



Natural Gas

- Chains of 1 to 4 Carbons
 - CH₄ Methane
 - C2H6 Ethane
 - C₃H₈ Propane
 - $-C_4H_{10}$ Butane
- Plus He, Argon, Krypton, Radon, N₂, O₂, CO₂, H₂, H₂S
 - >Dry gas: C1 > 90%
 - ➤ Wet gas: C1 < 90%</p>
 - Condensate: gas phase at reservoir and liquid phase at
 - surface
 - \triangleright Gas hydrates- Solids composed of water molecules surrounding gas molecules, usually methane, but also H_2S , CO_2 , and other less common gases.

2. Heavier hydrocarbons:

Rarely (perhaps never) formed by bacterial processes. Thus the presence of heavier hydrocarbons in natural gas probably reflects proximity to liquid hydrocarbon reservoir.

Gases are important during drilling of wells-

- (1) commonly overpressured, can cause blowouts
- (2) Useful way to identify producing (or hydrocarbon bearing) horizons.
- Extract gas from drilling mud, run through chromatograph, identify the amount and type of gases entering the well bore.

2. Non-hydrocarbon gas

1) Noble Gases- Helium, Argon, and Radon

These gases are inert- do not take part in **chemical** reactions.

They originate from decay of radioactive isotopes of various elements, predominately the U series elements.

They can be quite concentrated in natural gas (>1% of the gas present)

2. Nitrogen

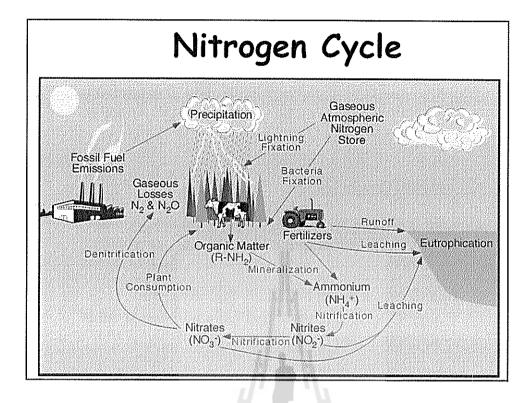
Three potential origins of nitrogen:

(1) Oxidation of NH₄, which is derived from thermal breakdown of organic matter. The oxidation-reduction reaction includes Ferric Fe redbeds- Nitrogen-bearing deposits are commonly associated with redbeds.

^{าย}าลัยเทคโนโลยี

- (2) Atmospheric origin (atmosphere is 70% nitrogen)-How does it get into the subsurface?
- (3) <u>Mantle outgassing-</u> continuation of the outgassing that started soon after the formation or the earth.

There is no economic significance to the nitrogen (other than is reduces the concentrations of economic hydrocarbons).



3. Hydrogen

Hydrogen is so mobile and reactive, it cannot be permenantly retained in the subsurface. It must be actively produced with in reservoir, adjacent source beds, or diffusing upward from depth.

Nonetheless, it can be concentrated- 35% of the gas in the Mid-continent rift system is hydrogen.

Possible origins include:

- 1) from reactions in the crust that involve Ferrous iron reduction
- 2) during thermal maturation of organic matter.

4. Carbon dioxide

 CO_2 has erratic distribution in the subsurface because of numerous sources and variations in solubility

a) Solubility of CO2

- @ STP, about 1/1 in water (volume ratio)
- @ 7,000 psi (~15,000 ft depth), about 30/1 in water
- @ 7,000 psi, about 170/1 in 40° API oil
- @ $T > 31^{\circ}C$, any undissolved CO_2 will exist as a gas regardless of the pressure

b) Inorganic clay reactions- largely from reaction between carbonates and kaolinite to form chlorite group:

 $5FeCO_3 + SiO_2 + Al_2Si_2O_5(OH)_4 + 2H_2 <---> Fe_5Al_2Si_3O_{10}(OH)_8 + 5CO_2$

Occurs between temperature of 100 and 160°C

c) Volcanic activity - Decomposition of carbonate rocks during injection of high temperature magmas and by acidic water.

 CO_2 now used for enhanced oil recovery so it can be economic.

3. Physical properties of HC Crude Oil

- 1) Appearance- color- yellow, green, brown to black.
- 2) Texture-Oily
- 3) Viscosity- generally decreases with temperature, so that oil at surface is less viscous than oil in subsurface.
- 4) Density- most commonly expressed according to a formula that uses the specific gravity of the oil, given units of °API (API stands for American Petroleum Institute)

American Petroleum Institute (API)

° API = (141.5/specific gravity @60/60 ° F) - 131.5

- Light oils : > 40 °API (5G=0.83)
- Heavy oils: < 10 °API (with SG=1).
- Most oil: > 10 °API, and thus will float on water.

Increasing API gravity = decreasing density

- Low API = High Density, high viscosity
- High API = Low Density, low viscosity

Hydrocarbon Crude Oil

- Mix of hydrocarbons of different types
 - >30% Paraffins- Chains
 - >50 % Naphtenes- Single bond rings
 - >15 % Aromatics Double bond rings
 - >5 % Asphaltics- Include impurities (N, S, O)

Paraffins

- · C1 to C80 chains
- · Millions of possible branched chains
- · C1-C4 Gases
- C5-C14 Liquids
- · >C15 Solid
- Waxy
- C5-C8 in gasoline

Naphetenes (Cycloparaffins)

- Rings with single bonds
- Most common HC in crude oil (~50%)
- C5 Cyclopentane
- · C6 Cyclohexane

Aromatics

- Unsaturated rings
- Based on benzene
- High octane rating
- · Concentrate in heavy fraction
- Carcinogenic

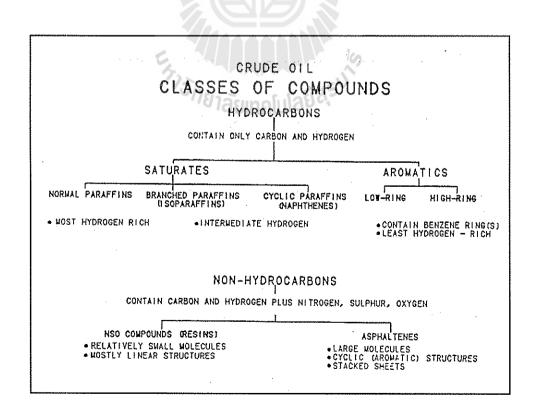
$$H$$
 H
 H
 CH_3

Toluene

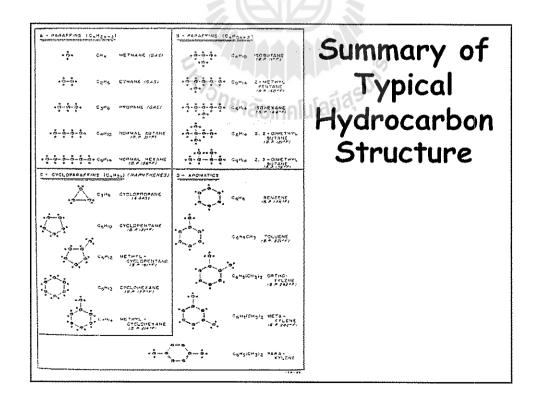
Benzene

4. Non-hydrocarbon Crude Oil

- They main "other" elements in crude oil include Nitrogen, Oxygen, Sulfur
 - Oxygen: 0.06 and 0.4 wt. %,
 - Nitrogen: 0.01 and 0.9 wt %,
 - Sulfur: 0.1 and 7 wt%.
- These elements are not other compounds (e.g. H_2S or free N) or contaminants
- There are also some metals, but only Nickel and Vanadium have been shown to be part of the compounds and not contaminants.



	Chemical Composition of Typical Petroleum				
Element	Crude Oil Asp ament % Weight % W		Natural Gas % Weight		
Corbon	82.2-87.1	80-85	65-80		
Hydrogen	11.7-14.7	8.5-11	1-25		
Sulfur	0.1- 5.5	2- 8	trace=0.2		
1/50 Nitrogen	0.1- 1.5	0- 2	1-15		
(Oxygen	0.1- 4.5				
MOLECUL	***************************************		<u> ΨΤ.</u>		
MOLECUL GA KER GA: LUB RES	AR SIZE SOLINE (C, OSENE (C, S OIL (C, RICATING (IDUUM()C	-C ₁₀) -C ₁₂) C ₂₀) OIL (C ₂₀ C ₄₀	<u>WT.</u> 31 10 15		
MOLECUL GA KER GA: LUB RES	AR SIZE SOLINE (C. OSENE (C.) S OIL (C.) RICATING (IDUUM (>C.) AR TYPE	-C ₁₀) -C ₁₂) C ₂₀) OIL (C ₂₀ C ₄₀	WT. 31 10 15 20 24		
MOLECUL GA KER GA: LUB RES MOLECUL	AR SIZE SOLINE (C. OSENE (C.) S OIL (C.) RICATING (IDUUM(>C.) AR TYPE AFFINS	-C ₁₀) -C ₁₂) C ₂₀) OIL (C ₂₀ C ₄₀	WT. 31 10 15 0 20 24 100		
MOLECUL GA KER GA: LUB RES MOLECUL PAR	AR SIZE SOLINE (C. OSENE (C.) S OIL (C.) RICATING (IDUUM(AC. AR TYPE AFFINS PHTHENES	-C ₁₀) -C ₁₂) C ₂₀) OIL (C ₂₀ C ₄₀	WT. 31 10 15 20 24 100 30 49		
MOLECUL GA KER GA: LUB RES MOLECUL PAR NAF	AR SIZE SOLINE (C. OSENE (C.) S OIL (C.) RICATING (IDUUM(>C.) AR TYPE AFFINS	-C ₁₀) -C ₁₂) C ₂₀) OIL (C ₂₀ C ₄₀	WT. 31 10 15 0 20 24 100		



HYDROCARBON E	FORMULA	MOL WT	BOILING POINT
K METHANE C	CH ₄	16-0	-161 °C (-259 °F)
K ETHANE C-	c CzHz	30.1	-89 °C (-128 °F)
* PROPANE C-C	-c C3H8	44.1	-42°C (-44°F)
	: 	58·1	- 12 °C (11 °F) 0 °C (31 °F)
NEOPENTANE WISOPENTANE N-PENTANE	Cs Hrs Cs Hrs Cs Hrs	72-1 72-1 72-1	9 °C (49 °F) 18 °C (82 °F) 36 °C (97 °F)
n-HEPTANE .	C7 H16		98°C (208°F)
CYCLOPENTANE	Cs Hip	70-1	49°C (121°F)
, BENZENE 1995	Calle	78-1	80°C (176°F)
ETHYLENE	- 10 mg	2\$.0	- 104°C (-155°F)

Properties	idigh APA Gravity	Gravity	· Remarks
Viscosity	low	high	Temperature sunsitive. Inverse measure of sinisty to flow flot pressure-seasitive.
Calcr	light	dork	Yellow, red brown to black by trunsmitted light (usually geen by reflected light).
Fluorescence	yellaws	prosens	White-yellow through yellow and brown. Described an color, intensity and hue.
Refractive index	1.39	1.55	Determined with Abe refractometer
Flash and burn points	lo#	high	>50 ⁰ F
Cloud and pour points	low	high	~70°F to + 110°F
Coefficient of Expension	high	low	Noncompressible as far as logging is concerned.
Density	API Nor SG	gravity = 1 mai Range water = 1 =	composition. 415 (1660 ⁻ p) - 131.5 = 18 to ^{50°} API gravity. 110° API at 50°°F.
Odor) Ara	eilin and a maties – ur y unoleusan	sphinens crudes small like crewate. pleasant. Sulfur compounds it.
Optioni activity	C,	H.OH).	t. Due to cholesterol (an alcohol Medaly in intermediate distillation point 200 ⁴ to 300 ⁹ C)
Wax content	to o	15% main!; affins. No n found bu des (NB ce	ir points and viscosity range 0.5% y 7% and consists mainly of normal law wax peraffin crudes have t there are some high wax - nophthene resin). Wax content apparently in fresh water/brackish source.

Impurity	Equipment Available to Measure Impurity
Sulfur	H ₂ S Detector
Nitrogen	All Gas/Nitrogen Detector
CO ₂	TC Chromatograph
Helium	TC Chromatograph
Oxygen	All Gas Detector
Water	Salinity Check
Salt	(AgNO3 Titration)
Ash	

Figure 2-43. Impurities Associated with Hydrocarbons

Crude	Product 🦠	Gas Range	Distillate Type	API Gravity
Gas A	Natural Gas LNG (Liquid Natural Gas)	С ₁ , С ₂	โนโลซ์ส ^{ุรุง}	>110°
	Natural Gasoline	IC4, C5, C6, C7	Condensate:	74° to 110°
	Gasoline	C ₅ +	Light Distillates BP* < 160°C	50° to 95°
	Kerosine Diesel		Middle Distillates; BP 160° to 350° ©	30° to 50°
	Fuel Oil Lube Oil		Heavy Distillates: BP 350° to 520°C	18 ⁰ to 30 ⁰
† Эіі	Wax/Asphalts		Residuum: BP > 520°C	

Figure 2-44. Crude Oil Products

Origin Of Hydrocarbon Theory

There are Two theory:

- 1. <u>Inorganic</u> (Igneous and metamorphic rocks)
- 2. Organic matter (sedimentary rock)

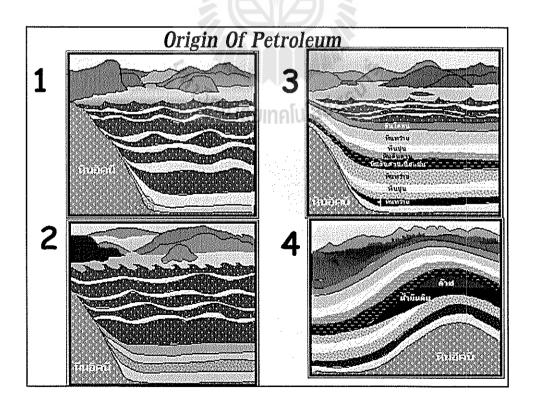
The Origin of Petroleum Hydrocarbon Hydrocarbons Organic? Anorganic? Deep origin: carbide + water = acetylene Geological association: Associated witth unaltered aquatic (marine, lacustrine) (C2H2), subsequent condensation sediments Variation: Association with hydrothermal Inferences: Similar to known biotic oils: Whale oil, fish oil Knowledge from mining: Gas and coal Cosmic origin: Hadean "petroleum rain" closely associated Analysis: Chemically similar to known components of life: proteins, fats, fatty

Isotopes: Always very light C13

Which Theory does most accept?

Most exploration today is based on the **Organic Theory**.

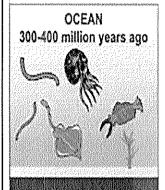
- 99.9% of oil in sedimentary basins (not in igneous or metamorphic rocks)
- 99% in rocks younger than 400 million yrs
- Bituminous shales can be heated up to produce oil
- Analogous to coal (which contains plant fossils)
- Crude oil contains many biomarkers
- ${}^{13}C/{}^{12}C$ is typical of biological activity (enriched in ${}^{12}C$)



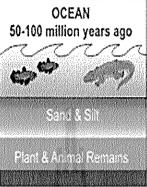


Development of the oil and natural gas shown in three steps

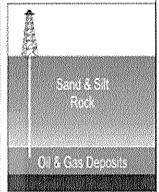
PETROLEUM & NATURAL GAS FORMATION



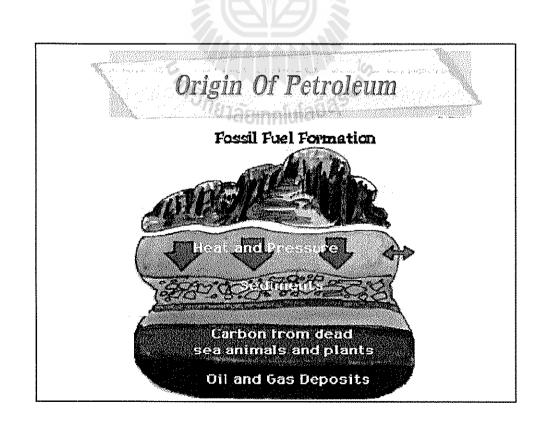
Tiny sea plants and animals died and were buried on the ocean floor. Over time, they were covered by layers of silt and sand.



Over millions of years, the remain: were buried deeper and deeper. The enormous heat and pressure turned them into oil and gas.



Today, we drift down through layers of sand, silt, and rock to reach the rock formations that contain oil and gas deposits.



Chapter III: Petroleum Charge System

Purpose: The petroleum charge system is explains about source rocks, which must be capable of generation, expelling and migration path way into the reservoir unit.

Outline of Petroleum Charge System

- 1. Identification of petroleum source rock
- 2. Maturation
- 3. Migration
- 4. Reservoir rocks
- 5. The mechanic of sealing
- 6. Trapping

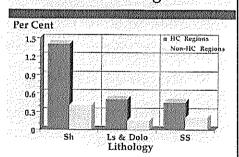
Source Rock

- Petroleum/Oil: complex mixture of naturally occurring organic compounds.
- · Organic rich sediments are buried in a basin.
- Through time, under pressure and temperature associated with deep burial, organics undergo physical and chemical changes, eventually forming oil.
- A good source rock is a black organic rich shale (mud), claystone (OM > 1%==Good source rock)
- Once the generation of oil has begun, it normally begins to move (migrate) through the rock column.

Characteristics of a Good Oil Source Rock

- High organic carbon (TOC)
- High Hydrogen Index (HI)
- Vitrinite reflectance (indication of maturity)
 between 0.5 - 1.4 R_o

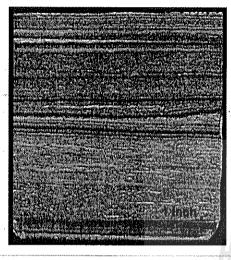
Variation of Organic C



Source Rock for Petroleum

Organic-Rich

Thin Laminae



Total Hydrogen Index
3.39 378

Table 1. Classic interpretations of TOC content in sediments (based on early oil window maturity)

(a)	· .	
Generation Potential	TOC in Shales (wt. %)	TOC in Carbonates (wt. %)
Poor	0.0-0.5	0.0-0.2
Fair	0.5-1.0	0.2-0.5
Good	1.0-2.0	0.5-1.0
Very good	2.0-5.0	1.0-2.0
Excellent	>5.0	>2.0

Organic Matter Composition

- · Proteins
- Carbohydrates (sugars, starch, cellulose)
- · Lipids (oils, fats)
- · Lignin (in plants)
- HC generation is limited by available H (reducing environment)

Types of OM in Sediments

- Structured
 - -Spores and pollen
 - -Cellular plant tissues (leaves, stems, roots)
- Amorphous
 - Algal debris
 - Decayed higher plants (marine or terrestrial)
- Charcoal (carbonized wood)
- Recycled kerogen

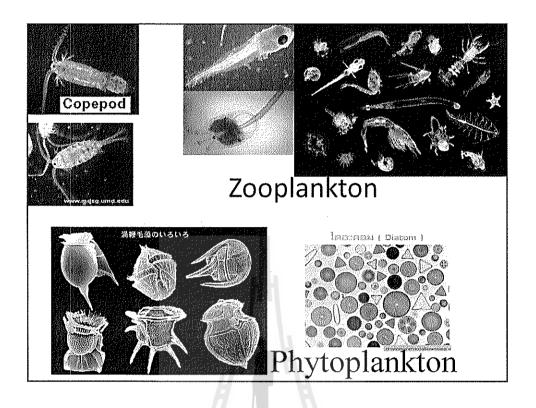
Average chemical composition of natural substances

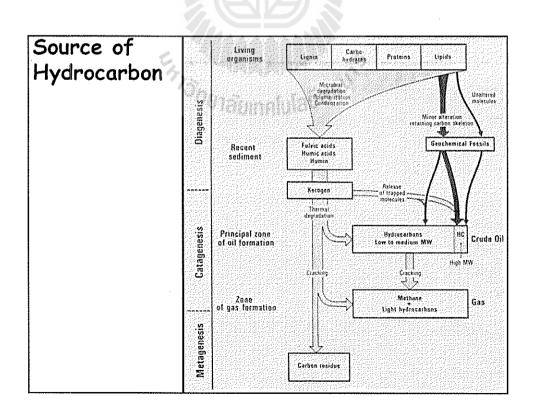
Substances		Elemental	Composit	ion in wt. ((%)
	С	Н	0	S	N
Carbohydrate	44	6	50	anna da ann a leann an lea an da ann an leann a	
Lignin	63	5	31	0.1	0.3
Proteins	53	7	32	2	16
Lipid	80	10	10		
Petroleum	82-87	12-15	0.1-2	0.1-5.0	0.2

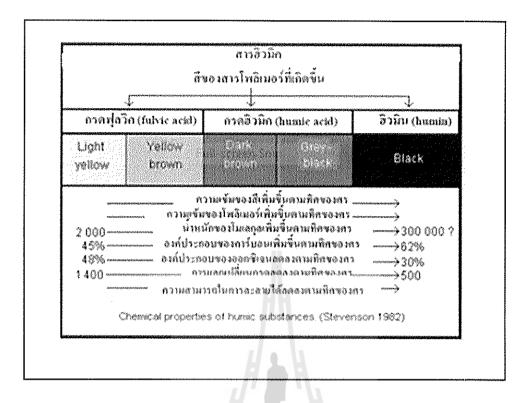
Classification of Organic Matters

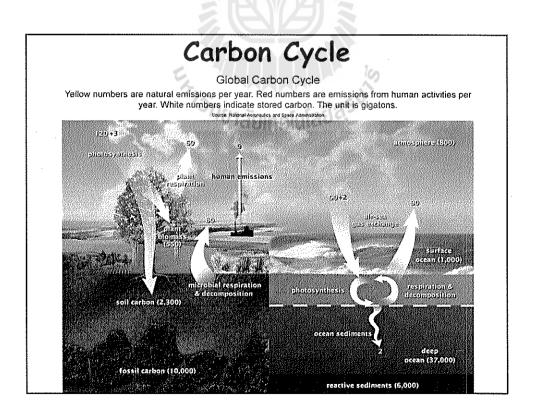
- Marine & Lacustrine Plankton;
 Protein & Carbohydrate= 50% and Lipid 25%
- Bacteria; Protein and Lipids
- Landplant; Cellulose, Lignin, Waxes, Resin and small Lipid

Composition of Living Matter						
Life Form	Wt. % of Major Constituents					
<u>Plants</u>	Proteins	Carbohydrate	Lignin	Lipids		
Oak leaves	5	44	32	4		
Phytoplankton	3 (3 15)(3 15 (3 15 (3 15 (3 15 (3 15 (3 15)(3 15 (3 15 (3 15 (3 15 (3 15 (3 15 (3 15 (3 15 (3 15 (3 15 (3 15 (3 15 (3 15 (3 15 (3 15)(3 15 (3 15)(3 15 (3 15 (3 15 (3 15 (3 15 (3 15)(3 15 (3 15 (3 15 (3 15)(3 (3 15 (3 15 (3 15)(3 15 (3 15)(3 15 (3 15)(3 15 (3 15)(3 15 (3 15)(3 15 (3 15)(3 15 (3 15)(3 15 (3 15)(3 15 (3 15)(3 15)(3 15)(3 15)(3 15)(3 15 (3 15)(66	in dangad <mark>a 2</mark> 9 da Kabupata (19 da) da			
Diatom	29	63		8		
<u>Animals</u>		n 2009 nagrusie negrotisk det nagreste Bande nagrus en generalisk skalender				
Zooplankton	53	5		15		
Copepods	65	22		8.		
Higher Invertebrates	70	20	 -	10		









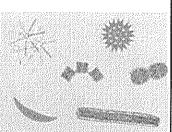
Exchange between Carbon

Reservoirs

- 24% Organic C (reduced) in sediments
- -76% Inorganic C (oxidized) in Limestones
- > 0.01% in Coal and Oil
- > 0.005% in oil reservoirs
- > 0.04% Dissolved in the Ocean
- >0.005% Atmosphere and life

Requirements for High Organic Productivity

- Light (for photosynthesis)
- Temperature
- · Nutrients
- Low turbidity
- Phytoplankton (Photosynthesizing algae)90% of Organic Matter in Oceans
- + Bacteria, zooplankton, fish, etc

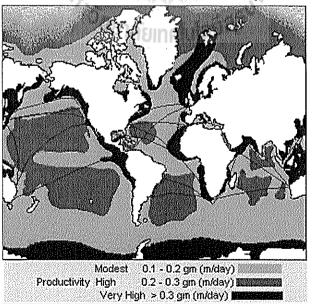


Photosynthesis

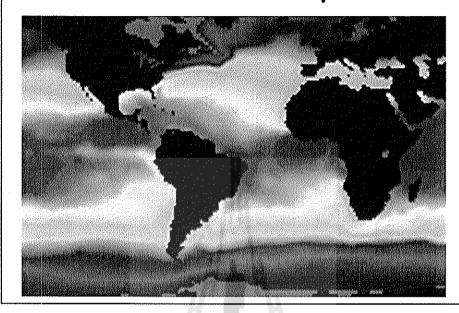
The most important reaction on the planet (for us)

chlorophyl CO2
$$\uparrow$$
 + H2O \rightarrow [CH2O] + O2 \uparrow light glucose

Plankton Productivity Map



Ocean surface Temperature



Preservation of OM

- High productivity (high nutrient supply)
- Moderate sedimentation rate
- Low oxygen supply (Anoxic conditions)
- Rapid burial

Reaction of Organic Matter

Oxic conditions

$$CH_2O + O_2 ===> CO_2 + H_2O$$

(Limiting condition: $O_2 > OM$)

Anoxic conditions

$$2CH_2O + H_2SO_4^= ===> 2CO_2 + 2H_2O + H_2S$$

(Limiting condition: OM > O₂)

Anoxic: O_2 demand $\geq O_2$ Supply

The bottom of a basin

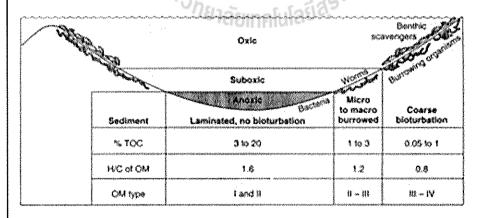
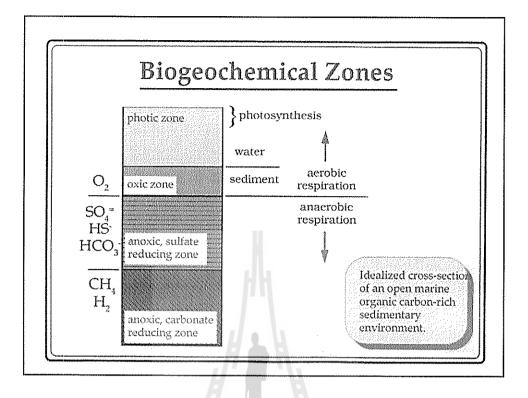


figure 5-1

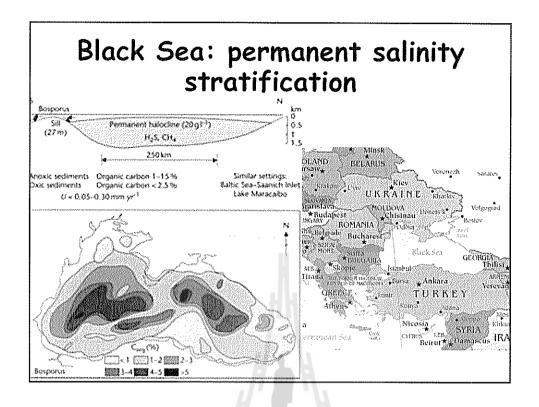
Marine and lacustrine benthic environments. Oxygen contents in mN H₂O are oxic greater than 1, suboxic 1 to 0.1, and anoxic less than 0.1 OM. Types 1 to IV are defined in Chapter 6.

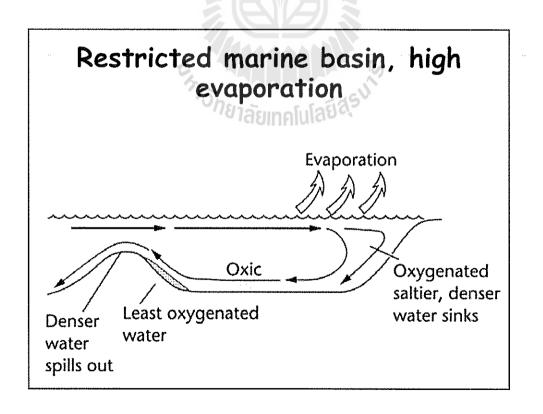


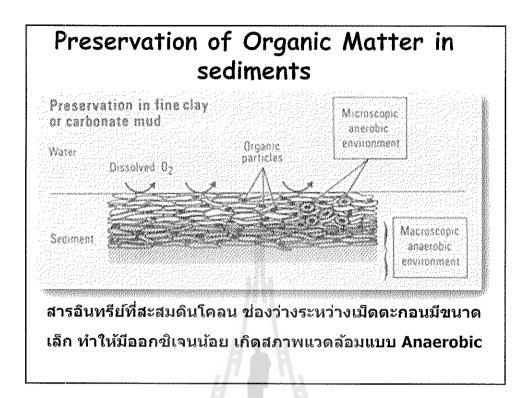
How do you get Anoxic conditions?

^กยาลัยเทคโนโลยี^ล์

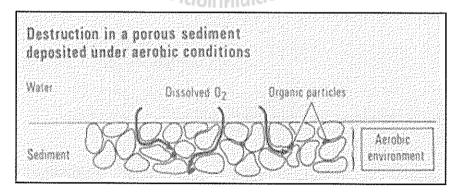
- Water Stratification
- Temperature
- Salinity
- · High organic productivity near surface



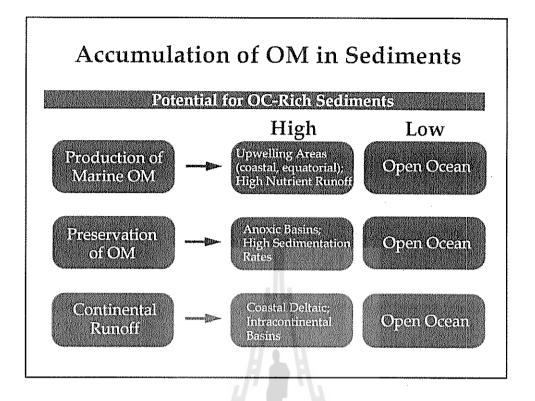


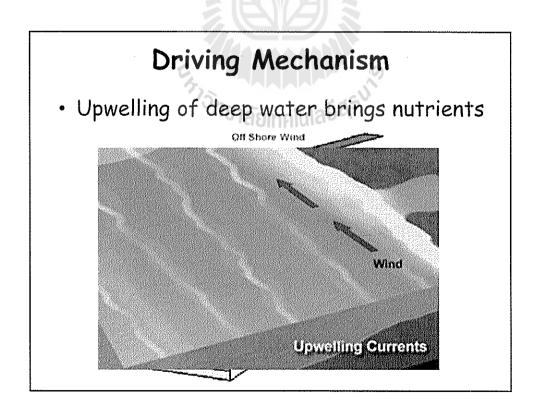


Destruction of Organic Matter in sediments



สารอินทรีย์ที่สะสมในตะกอนที่มีรูพรุนขนาดใหญ่ จะเกิดปฏิกิริยา ออกชีเดชั่น ทำให้สารอินทรีย์ถูกทำลาย





Factors Leading to Low OM

- Low productivity
- Low or high sedimentation rate
- Low OM supply from land
- High water depth

OM decreases

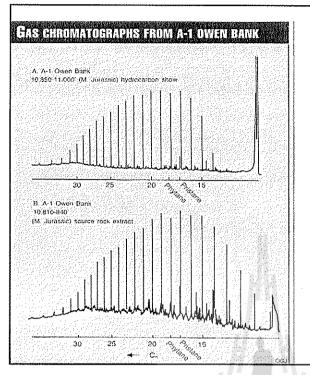
Onshore -----> Offshore

Composition of Organic Matter

Common Analytical Methods Used

- Elemental Analyses (C, H, O, N, S)
- Isotopes
- Gas Chromatography (GC)
- GC combined with Mass Spectrometry (GC/MS)
- Rock-Eval pyrolysis (Hydrogen Index and Oxygen Index)

Extractable OM Kerogen - 90% Extractable - 10

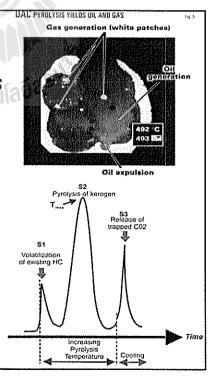


Source rock kerogen can be correlated to oil/gas found in carrier beds and reservoirs

Pyrolysis

- Pyrolysis (pyr "fire" and lysis "separating") is a thermochemical decomposition of organic material at elevated Temp. in the absence of oxygen.
- Pyrolysis typically occurs under P&Temp. > 430 °C (800 °F).

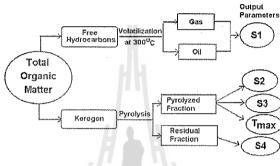
Rock Evan Pyrolysis

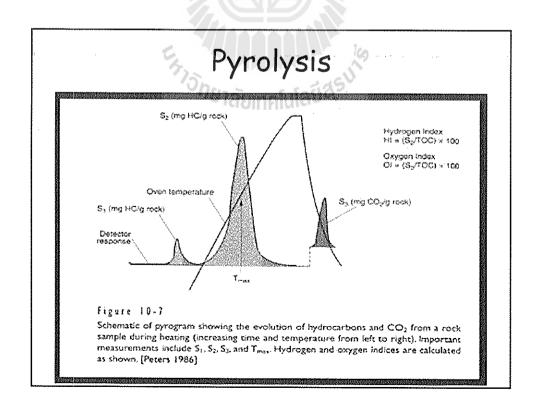


Rock Eval Pyrolysis

- Samples are heated in an inert atmosphere at $300^{\circ}C$ for 3-5 mins to distill out free hydrocarbons S_1 peak
- Heated at a fixed rate to $550-600^{\circ}C$ to pyrolyse the kerogen the S_2 peak
- The temperature at which maximum pyrolysis occurs is called Tmax

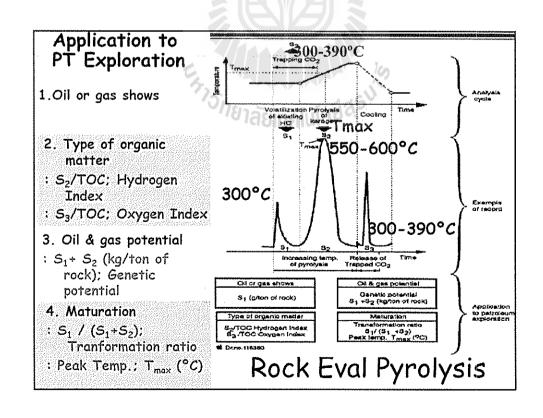
• The CO₂ released between 300-390°C is measured - S₃ peak

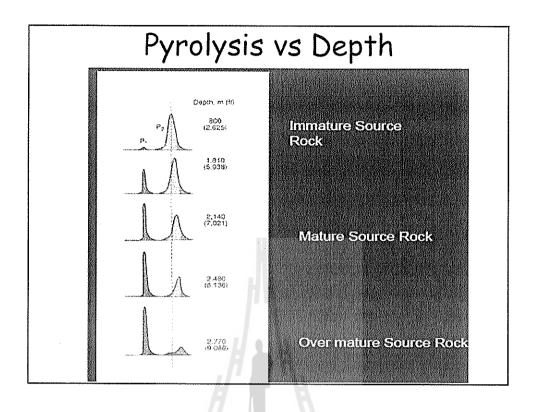




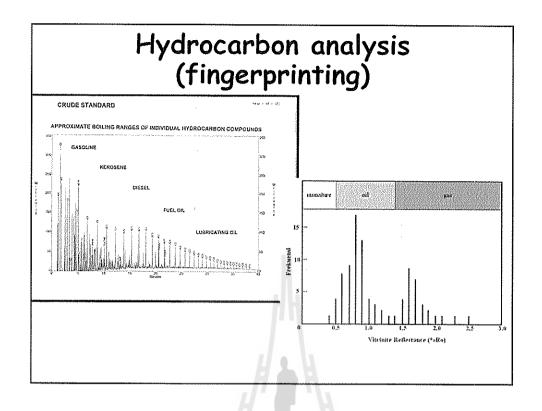
Term in PT Geochemistry

- ❖ S₃: Amount of CO₂ released during pyrolysis
- ❖ Tmax: Temperature of maximum release of hydrocarbons. Tmax indicates the stage of maturation.
- From this data the origin of the organic matter can be determined by
 - ✓ Hydrogen index (HI) measures the hydrogen richness of the sample.
 - Oxygen index (OI) measures the oxygen richness of the sample.
 - ✓ Production index (PI) is the ratio of generated hydrocarbons to potential hydrocarbons. Low ratios indicate immature or postmature organic matter.





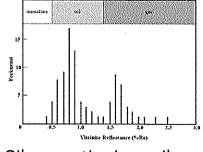
Parameter	Name (units)	Definition	Specificity	Problems	
70C Total Organic Carbon (wt. percent)		Measure of the rook's organic richness.	Organic áctiness		
3,	ig it (extestable) / towns rock	Measure of the amount of free hydroderbone diseaset in the rock.	Kercgen type. Maturity Migrated öll.		
S,	Kg fiz (keitigen pyrolysate) I tonne rock	Measure of hydrocarbons formed by cracking of kerogen, resine and asphaltanes.	Kerogen type. Maturity	High values may be obtained if oil or bitumen is present (Clementz, 1980). Lower values can arise from adsorption on the mineral matrix (Esiptase et al., 1980; Om., 1983).	
٤,	Kg CO ₂ (organic) / tonne rock	Measure of CO ₂ generated from oxygenisted sunctional groups in kerogen.	Kerogen type. Metality.	Subject to interference by CO, from decomposition of carbondle minerals (Horsfield & Douglas, 1980; Horsfield, 1984).	
S,+S,	Potential Held (Kg hc.) tonne rock)	The total hydrocarbon genetic potential. i.e., the free and knrogen-bound hydrocarbons.	Source fichness . Kerogen type.		
T.,	Position of S, pask in temperature program (*C)			Depressed values indicate migrated hydrocarbons.	
Pì	Production index (S,S,+S,)	Extent to which kerogen has been vanaformed into all and gas.	Materity. Migrated oil	Anomaious values correspond to accumulation or drainage of hydrocarbons.	
PC .,	Pyrofysable Caston The amount of TOC represented by S, Source didness, Oxidation of organic mass (wt. percent) and S, Kengen type. Maturity, values.		Oxidation of organic master lowers the values.		
н	Hydrogen Index High vidues > 150 Indicate oil prone Kerogen type, Maturity source rocks.				
CI	Oxygen Index Indicate the presence of abundant woody or oxidised organic matter. High values indicate low hydrocartion vests.		Kerogen type. Maturity	Not reliable in carbonates and organical lean sediments.	



Vitrinite reflectance

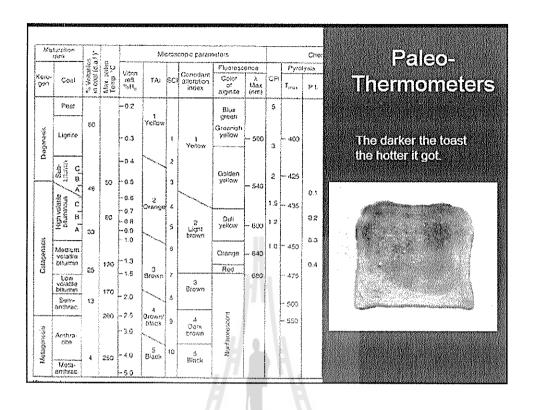
- Vitrinite reflectance (VR or Ro) is used for determining the thermal maturity of the shale and coal.
- VR is sensitive to temperatures that correlate to hydrocarbon generation (60 -120 °C).

Oil-Prone Gen	eration	Gas-Prone Generation		
Generation Stage	R ₀ (%)	Generation Stage	R ₀ (96)	
Immature	<0.6		<0.8	
Early oil	0.6-0.8	Early gas	0.8-1.2	
Peak oil	0.8-1.0	Peak gas	1.2~2.0	
Late oil	1.0-1.35	Late gas	>2.0	
Wet gas	1.35-2.0			
Dry gas	>2.0			

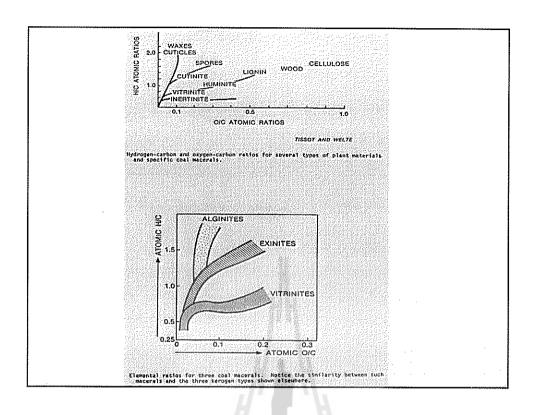


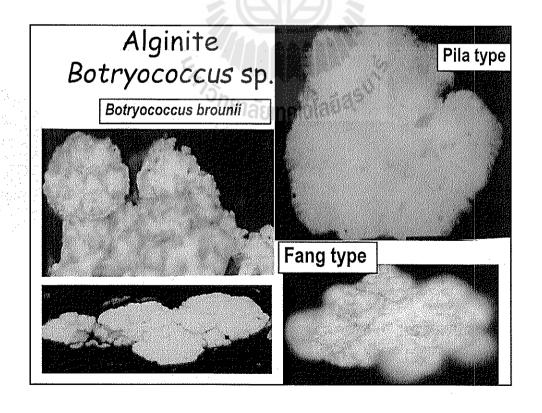
• Oil generation in an oil-prone shale is a VR of 0.6% to >1.35%

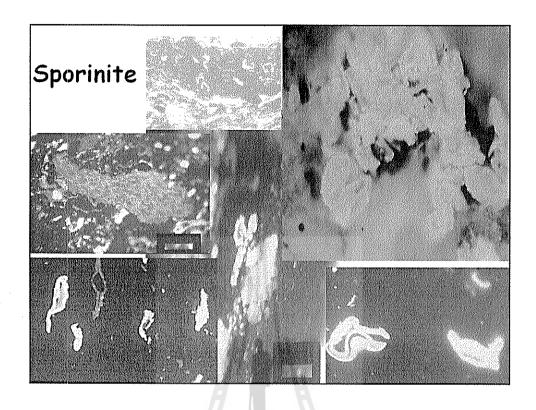
• Gas generation in a gas-prone shale is a VR of 0.8%to >2%

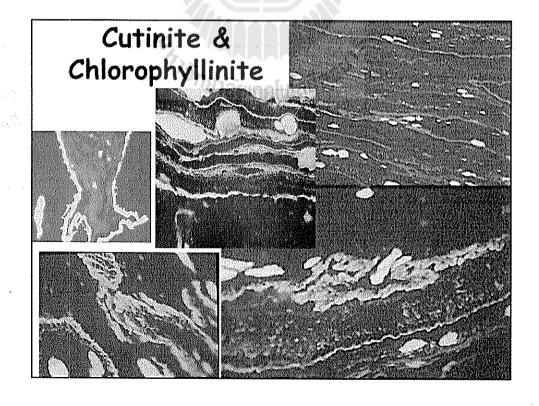


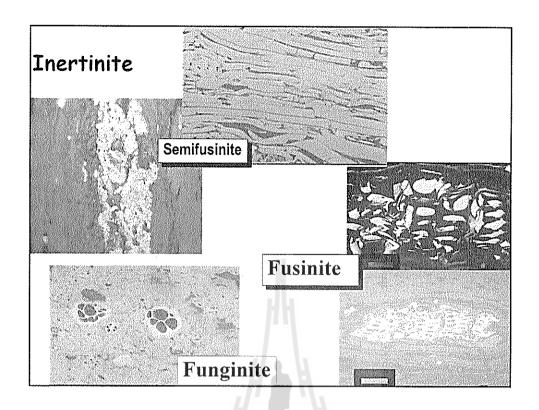
MACERAL GROUP	MACERAL SUBGROUP	MACERAL	MACERAL TYPE
		TEXTINITE	TEXTINITE A (dark) & 8 (light)
	TELOVITRINITE	(TEXTO-ULMINITE)	TELINITE
		ULMINITE	
	ACIOII IVIII	COLLOTELINITE	
VITRINITE		ATTRINITE	
	DETROVITRINITE	DENSINITE	
		VITRODETRINITE	
		COLLODETRINITE	
		CORPOHUMINITE	
	GELOVITRINITE	CORPOGELINITE	LEVIGELINITE/PORIGELINITE
	ommo viii(ii) in	GELINITE	
	Macerals with plant cell structures	FUSINITE	
		SEMIFUSINITE	
INERTINITE		FUNGINITE	
	Macerals locking plant cell structures	SECRETINITE	
		MACRINITE	
	44	MICRINITE	
	Fragmental inertinite	INERTODETRINITE	
		SPORINITE	
	**	CUTINITE	
		SUBERINITE	
		RESINITE FLUORINITE	
LIPTINITE	***		
	***	LIPTODETRINITE	
	***	ALGINITE	TELALGINITE
	**	BITUMINITE	LAMALGINITE
	Strictly a bitumen rather than a maceral		

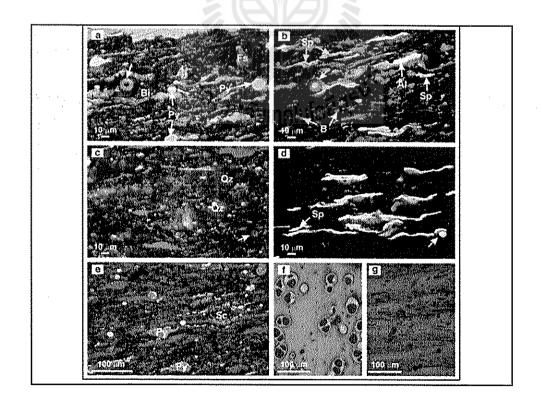












Source Material

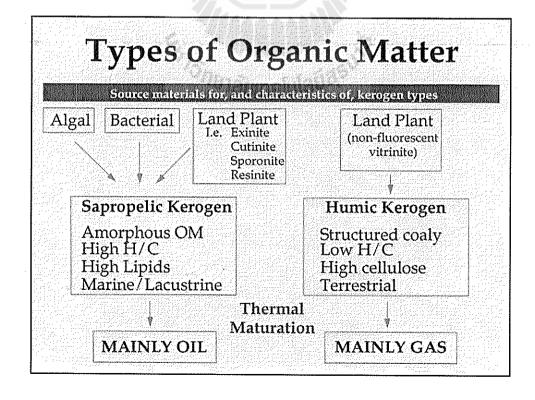
- 1. Non-Biogenic Origins
- Biogenic (Kerogen) Host rock (Shales and Coals)

Kerogen Types

Type I - Algal (oil prone) ---sapropelic

Type II - Mixed

Type III - Woody (gas prone) --- humic

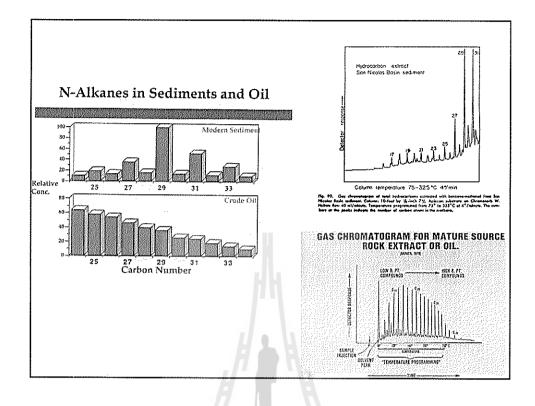


Kerogen Families

Classification	Types I and II	Type III
Descriptive Terms	Amorphous "Algal" "Sapropelic"	Structured "Coaly" "Humic"
Chemical Nature	Hydrogen-rich Oxygen-poor	Oxygen-rich Hydrogen-poor
Products of Catagenesis	Liquid and gaseous hydrocarbons	Coal, methane

Sources of n-Alkanes in Sediments

- Organisms in the water column
 - -Phytoplankton and zooplankton
- Organisms on/in the sediment
 - -Bacteria, sea grasses, invertebrates
- Terrestrial runoff
- Fossil fuel



HC Generation 1-Source Rocks

- Deposited in environments conducive to preservation of abundant sedimentary OM
- OM (kerogen) releases hydrocarbons
- Marine kerogen tends to generate oil; terrestrial kerogen tends to generate gas
- Methane forms at high (thermogenic) and low (<50 °C) temperatures (biogenic)

HC Generation 2-Temperature Effects

- Thermal alteration of kerogen requires minimum of 50-60 °C
- Oil generation is a time- AND temperature-dependent process
 - Quantity generated increases linearly with time, geometrically with temperature
 - >At high T, wet or dry gas is more stable than liquid HC
 - >Laboratory experiments at high T reproduce general aspects of HC

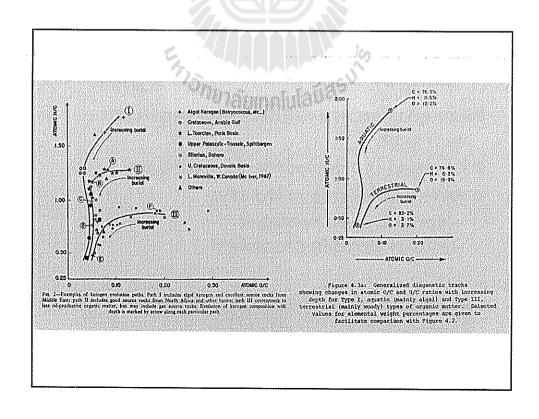
Importance of Hydrogen

- Generation of HC (alkanes) requires hydrogen
- Kerogen is the source of hydrogen
- With increasing maturity:
 - Kerogen loses hydrogen
 - H/C of kerogen decreases

Immature oil-prone kerogen will have a relatively high H/C

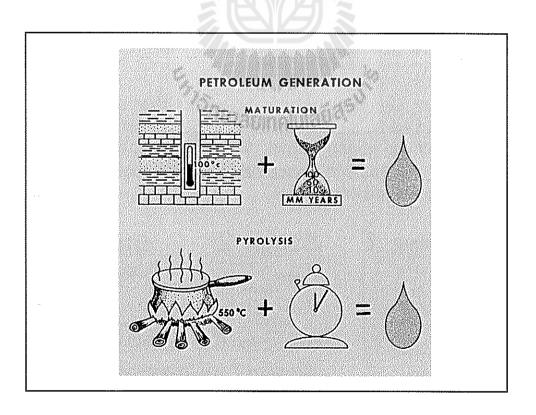
Breaking C - C Bonds

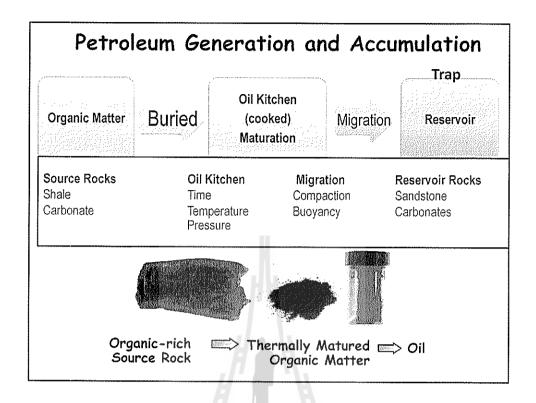
Formation of saturated hydrocarbons after breaking a C - C bond requires hydrogen.



Petroleum Generation

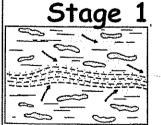
- A temperature-dependent chemical process that occurs in sedimentary basins as a natural consequence of thermal alteration of OM deposited with the sediments.
- The sedimentary OM is of biogenic origin.
- The extent of the reaction i.e., amount of oil generated is a function of the Temperature at which the reaction occurs and the duration of the reaction.

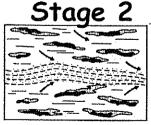


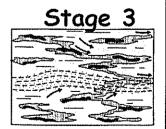


Kerogen

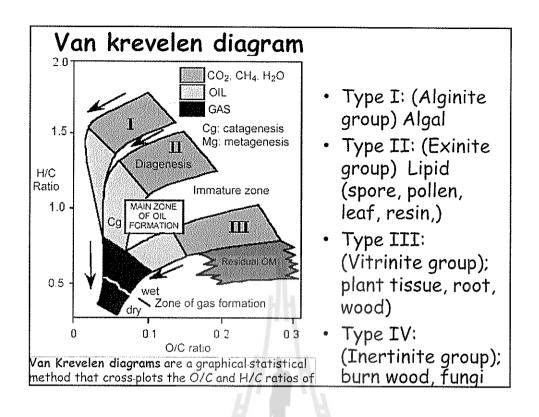
Kerogen: Complex organic molecules that are produced by modification of organic matter preserved in sediments. When heated, this solid waxy organic substance can produce coal macerals, oil and gas.

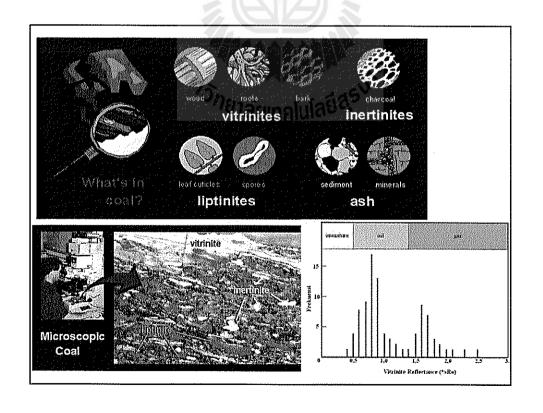






Kerogen Transformation





Kerogen Types

- Type I (Algal)--Sapropelic
 - High H:C ~1.65, Low O:C
 - Rich in lipids (mostly saturated)
 - Oil prone
- · Type II (Liptinic)
 - Intermediate H:C ~1.25, Interm O:C
 - Algal+Zooplancton
 - Oil and Gas prone

Type III (Humic)

- Low H: C ~0.84, High O:C
- Rich in aromatic compounds
- Plant material and coal
- Gas prone

Type IV (Inertinite)

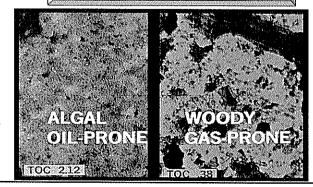
- Low H:C 0.45-0.3, High O:C
- No petroleum

Types of Petroleum

Oil and gas are formed by the thermal cracking of organic compounds buried in fine-grained rocks

Algae = Hydrogen rich = Oil-prone

Wood = Hydrogen poor = Gas-prone



TOC .38 WT.%

TOC 2.12 WT.%

Geological Control of Petroleum Types Marine versus Non-marine Organic Matters

- Marine organic matter
 - Kerogen Type II
 - Paraffinic, naphthenic or aromatic intermediate crude oils.
 - Saturated hydrocarbons 30-70%
 - Aromatics amount to 25-60%
 - High S in certain type of crude oils
- Non-marine organic matters
 - Kerogen Type III, less common Type I
 - Paraffinic: naphthenic crude oils
 - Saturated hydrocarbons 60-90%
 - Aromatics amount to 10-30%
 - Low S contents (usually <0.5%)

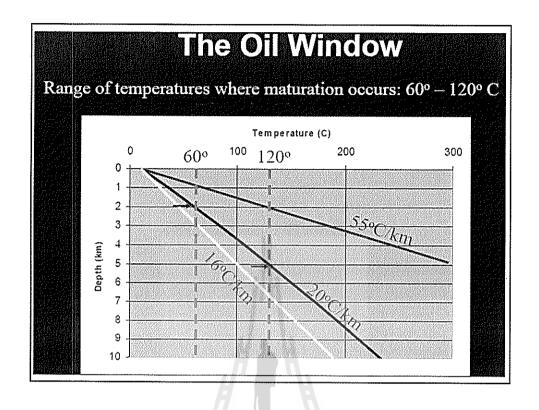
The Petroleum Kitchen (PT Maturity)

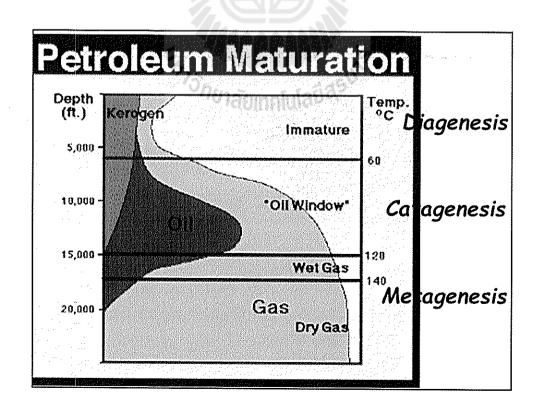
Temperature-Pressure-Time

- Geothermal Gradient: (thermogenic hydrocarbons)
 - Range: <1 to 11 °F per 100 ft
- Typical Sedimentary Basins: 1.0-1.7 ° F per 100

ft, Good average 1.2 ° F

- Oil window of \sim 60-120 $^{\circ}$ C, or depth about 5,000-20,000 ft
 - In practice,
 - Oil below 15,000 ft rare
 - Gas no practical limit to stable depth
 - Cracking of oil to gas controlled by source kerogen and temperature
 - Deep basins mostly gas



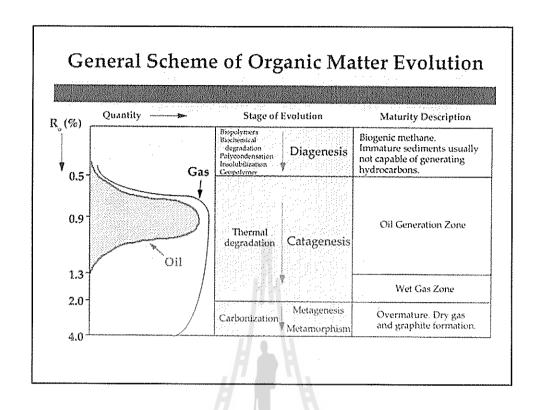


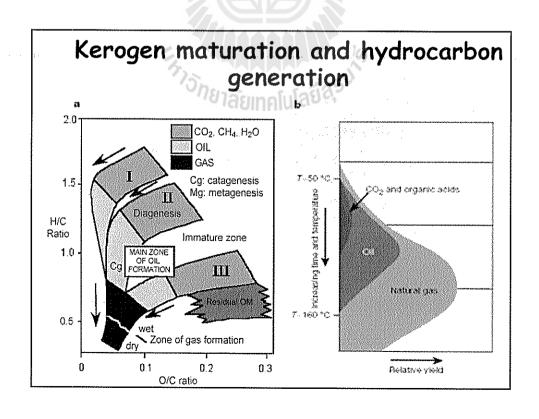
Three Stages of Genesis:

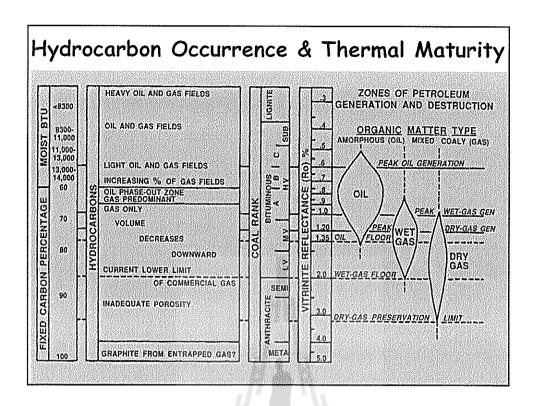
- Diagenesis. Biogenic decomposition produces biogenic methane. At slightly higher temperatures and pressures the organic matter is converted to kerogen - an amorphous material of carbon, hydrogen, and oxygen. (< 60°C, few hundred meters depth; "heavy" oil)
- 2. Catagenesis. At higher temperatures and pressures kerogen is altered and the majority of crude oil is formed. During this phase and the next, the larger molecules break down into simpler molecules (a process called cracking). (60-120°C, 120-140°C wet gas, Depth up to 15,000 ft kerogen and "light" petroleum)
- Metagenesis. In the final stage of alteration (at higher temperatures and pressures) of kerogen and crude oil, natural gas (mostly methane is formed.(>140°C dry gas, depth >15,000 ft)

Maturation of Organic Matter

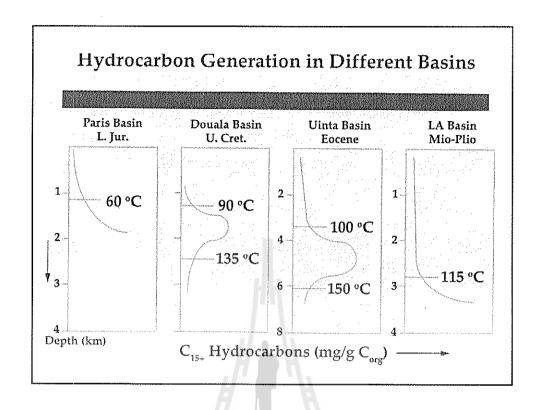
- Catagenesis 50 to 200°C
- Oil Window 60 to 120-160°C
- · Gas Window 120 to 225°C
- Thermal maturation of kerogen
- · H:C decreases

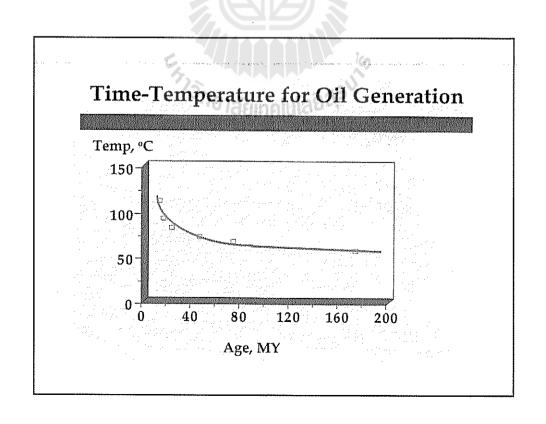






Thermal Effects on Source Rocks				
	Gas	Gasoline	Heavies	Solid
	C ₁ - C ₄	C ₄ - C ₇	C ₁₅ +	Kerogen
Immature	Mainly C ₁	Lean - Most components absent	Rich - Mainly Non-HC	Yellow
Mature	Mainly C₂ - C₄	Rich - All components present	Rich in HCs and NSOs	Yellow to brown
Overmature	Mainly C,	Lean	Lean - Mainly HC	Black





ปัจจัยที่ทำให้เกิดกระบวนการเปลี่ยนสารอินทรีย์เป็นปิโตรเลียม

Water	Organic and mineral detritus Dissolved oxygen and sulfate	
Aerobic oxidation zone	OM decomposed CO ₂ produced	
Sulfate reduction zone	OM decomposed, CO, produced Sulfate reduced to sulfide Sulfides precipitate	
Fermentation zone	OM decomposed, CH ₄ produced CO ₂ produced, carbonates precipitate	
Thermal maturation	OM altered, CO ₂ produced by decarboxylation	
zones "HC Window" {	OM altered, liquid HCs form	
	OM converted to CH, and carbon-rich residue	

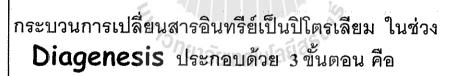
Zones of OM Degradation

ปัจจัยที่ทำให้เกิดกระบวนการเปลี่ยนสารอินทรีย์เป็นปิโตรเลียม

- การกระทำของแบคทีเรีย (Anaerobic bacteria) ซึ่ง
 เอาออกซิเจนออกไปจากซากสิ่งมีชีวิต ทำให้
 อินทรีย์สารเหล่านั้นเกิดการสลายตัวเป็น
 สารประกอบที่อุดมไปด้วยธาตุไฮโดรเจนและ
 คาร์บอน
- ความกดดันจากชั้นหินและความร้อนใต้พิภพ ทำ ให้ไฮโดรคาร์บอนซึ่งมีความหนีดสูงในระยะแรก เกิดการกลั่นตัวทางธรรมชาติกลายเป็นน้ำมันเบา (Light oil) หรือกลายเป็นก๊าซธรรมชาติไปในที่สุด

ปัจจัยที่ทำให้เกิดกระบวนการเปลี่ยนสารอินทรีย์เป็นปิโตรเลียม -

3. พวกอินทรีย์สารที่มากับตะกอนทับถมตัวแล้วจะถูก ทำลายโดยพวกจุลินทรีย์ การเปลี่ยนแปลงนี้จะ ก่อให้เกิดก๊าซ $\mathbf{CO_2}$, $\mathbf{H_2O}$, $\mathbf{CH_4}$, $\mathbf{H_2S}$ สุดท้ายจะได้ Insoluble Kerogen ซึ่งเป็น Common form ของ สารอินทรีย์ ไปเป็นคีโรเจน



- 1) Microbial Activity
- 2) Polycondendsation

3) Insolubilization

Diagenesis

1. Microbial Activity

• กระบวนการเหล่านี้เกิดเป็นขั้นตอนแรกในระดับใกล้ พื้นผิว เป็นขั้นตอนที่จุลินทรีย์ทำลาย ย่อยสลาย สารอินทรีย์เริ่มต้นในตะกอน ถ้าโดยวิธี Aerobic จะเป็นการทำลายสารอินทรีย์โดยตรง จะได้ก๊าซ CO2 และ H2O แต่ถ้าเป็น Anaerobic Method จะสลายสารอินทรีย์บางส่วนโดยวิธี Fermentation จะได้ก๊าซ CH4, Amino Acids และน้ำตาล

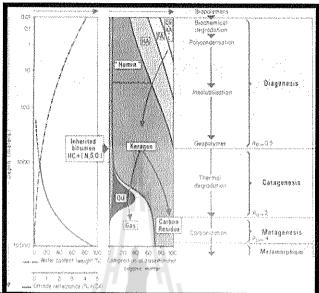
2. Polycondensation

• เมื่อเวลาผ่านไประดับลึกลงมากขึ้น กรดอะมิโนและน้ำตาล ไม่สามารถทนสภาพที่เปลี่ยนไปก็จะรวมตัวกันเป็นโมเลกุล ใหญ่ขึ้น

3. Insolubilization

• เป็นขบวนการที่ทำให้โพลีเมอร์ ที่เกิดขึ้นกลายเป็นกรดฮิวมิก และฟลูวิก และจะเปลี่ยนเป็นฮิวมิน เมื่อมีการอัดแน่นเพิ่ม มากขึ้น ขั้นตอนนี้จะเกิดที่ระดับความลึกหลายร้อยเมตร และใช้เวลาหลายล้านปี และผลสุดท้ายจะได้ ที่เรียกว่า Kerogen

รูปแบบทั่วไปของวิวัฒนาการของสารอินทรีย์ จากการสะสมตัวใน ตะกอนจากขบวนการ Diagenesis, Catagenesis จนถึง Metagenesis



Migration

General

- ^{′ีวั}กยาลัยเทคโนโลยี - Hydrocarbons are less dense than water, therefore buoyant
- Will flow up until stopped by a seal
- Horizontal migration is important alsocan be long distances.
- Vertical migration requires a break in the regional seal (faults, salt, stacked channels)

How does Oil get out of the Source rock?

After its formation, petroleum may migrate from the source rock into porous and permeable beds where it accumulates and continues its migration until finally trapped.

The forces causing this migration are:

- 1. Compaction of sediments as depth of burial increases.
- 2. Diastrophism: crustal movements causing pressure differentials and consequent subsurface fluid movements.
- 3. Capillary forces causing oil to be expelled from fine pores by the preferential entry of water.
- 4. Gravity which promotes fluid segregation according to density differences.

Why do hydrocarbons migrate?

- 1. Fluids migrate along a pressure gradient
- → pressure driven
- 2. Density contrasts between hydrocarbons and water→ buoyancy driven
- 3. <u>Diffusion</u> due to concentration differences

 → chemical gradient driven

$$u^p = u^w + (\rho^w - \rho^p) \cdot g \cdot h + p^c$$

Overpressure

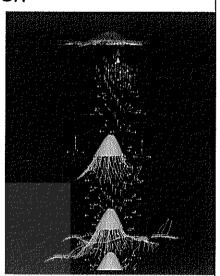
Buoyancy

Capillary Pressure

Chemical gradient driven

Hydrocarbons migrate as a separate phase from the higher potential to a lower potential on the direct way

→ topography driven



Generated HC Masses from Source

Type of Migration

Migration is the process, whereby hydrocarbons move from source rocks to traps.

Migration is divided into four categories:

Primary migration The process of loss of hydrocarbons

from the source rock (also Expulsion).

Secondary Migration from source to reservoir rock migration in trap configuration along a carrier

in trap configuration along a carrier system. Including the migration within

the reservoir rock itself.

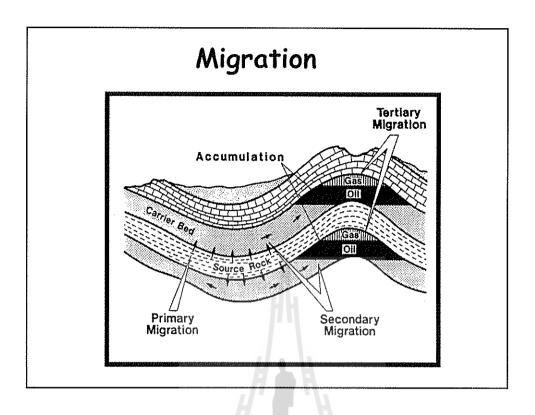
Tertiary migration Migration to the surface, either from

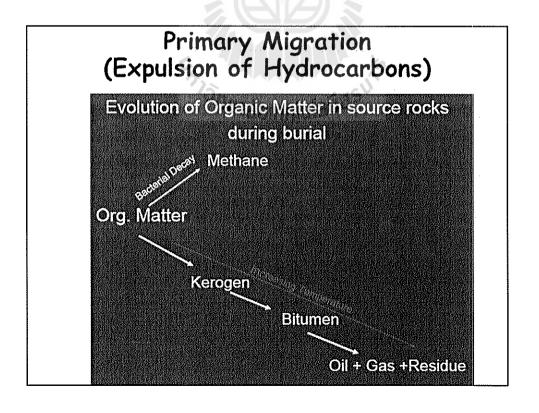
the reservoir or source rock

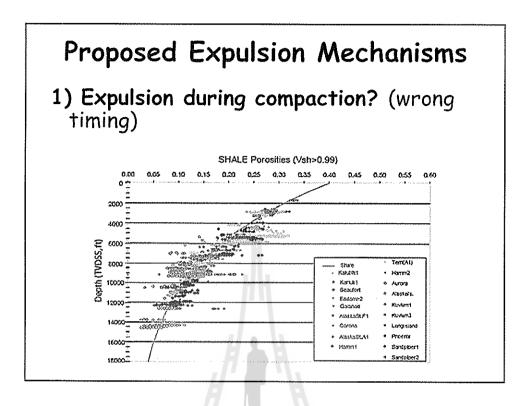
(dismigration).

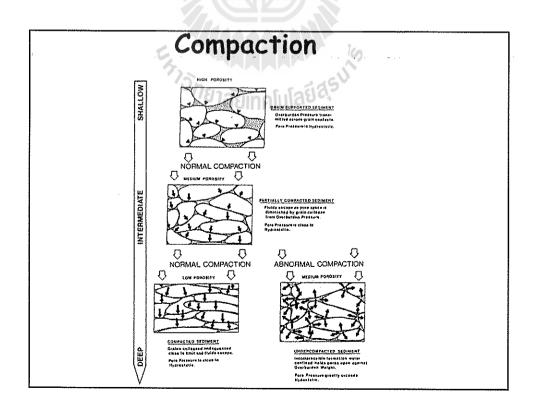
Re-migration Migration from one reservoir system

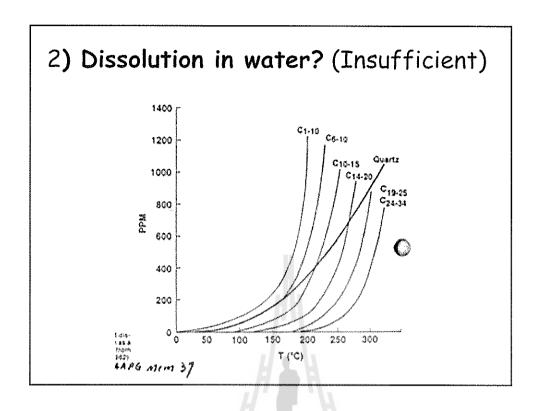
position through an intervening section into another reservoir position (trap) in the same or a different reservoir.

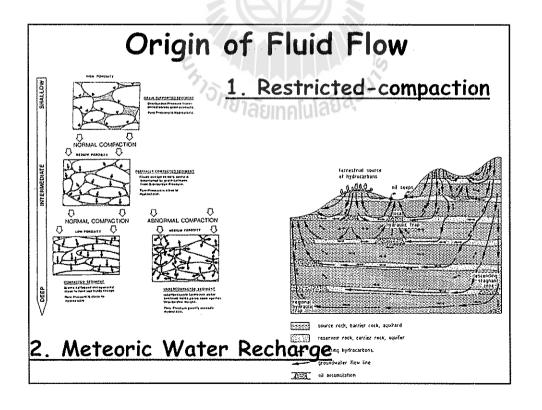




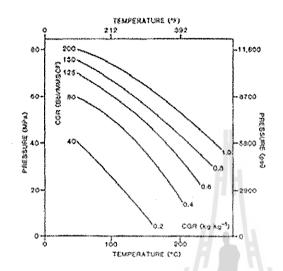








3) Dissolution in Gas Phase? (Works for light oil, but not for heavy oil)

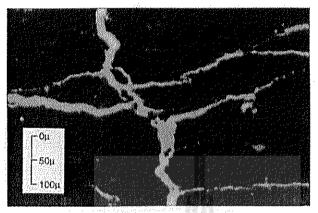


Condensate-Gas
Ratio (CGR) for oil
saturated gas.
Spindle top crude
and methane.

4) Oil Phase Migration (this is the good one)

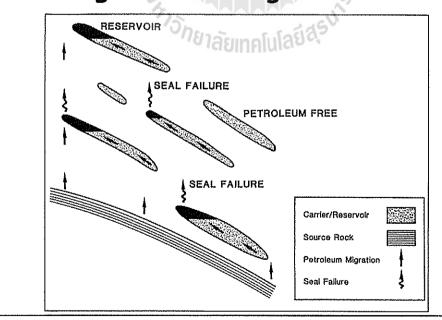
- Kerogen is 5-10% of source rocks and is load bearing
- Maturation transform kerogen to a hydrocarbon fluid.
- The fluid is also load-bearing, therefore overpressured
- Overpressure fractures the rock
- Hydorcarbons escape through microcracks
- Cracks close up until a new episode of generation takes place

Microfracture



Microfractures in organic rich shale. Hunt, 1995.

Migration through Fractures



Secondary Migration

- 1. Movement from source to trap
- 2. Along carrier bed
- As separate hydrocarbon phase (mostly)

Secondary Migration

^{ายา}ลัยเทคโนโลร์

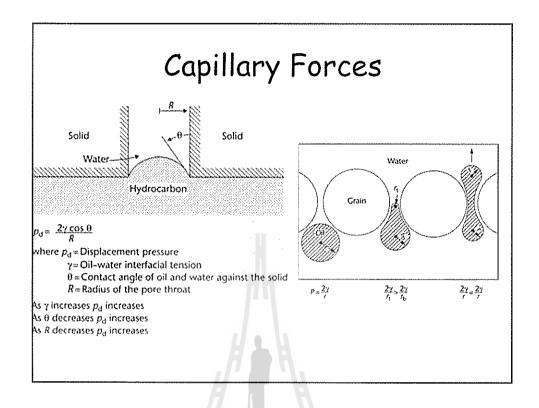
- 1. Driving Force
- 2. Resisting Forces
- 3. Phase Behavior
- 4. Rates of migration
- 5. Efficiency
- 6. Long distance migration

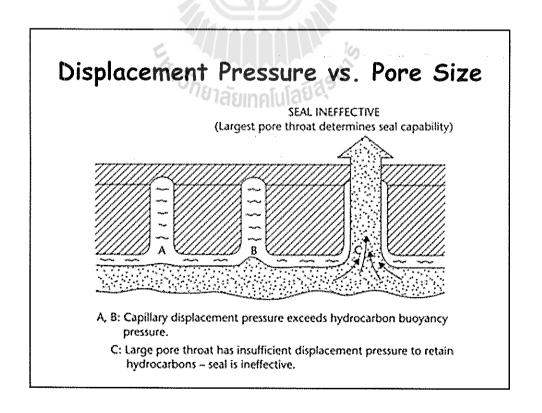
Driving forces for migration

- Buoyancy (This force acts vertically and is proportional to the density difference between water and the hydrocarbon so it is stronger for gas than heavier oil)
- Hydrodynamic flow (water potential deflect the direction of oil migration, the effect is usually minor except in overpressured zones (primary migration))

The driving mechanisms can be distinguished:

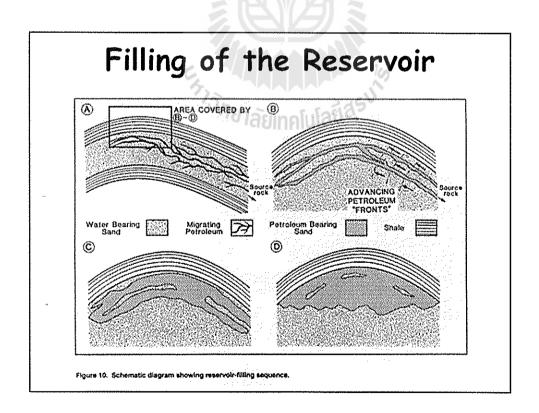
- 1. Pressure Gradient Driven
 - 1.1 Sediment Compaction → overpressure, compaction driven fluid movement, permeability
 - 1.2 Capillary inhibition \rightarrow capillary pressure differences between fine and coarse grained layers (leads to downward expulsion)
 - capillary fluid flow depends on fluid components involved, relative permeability

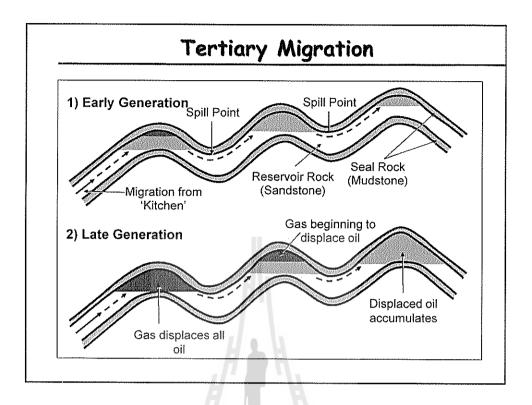


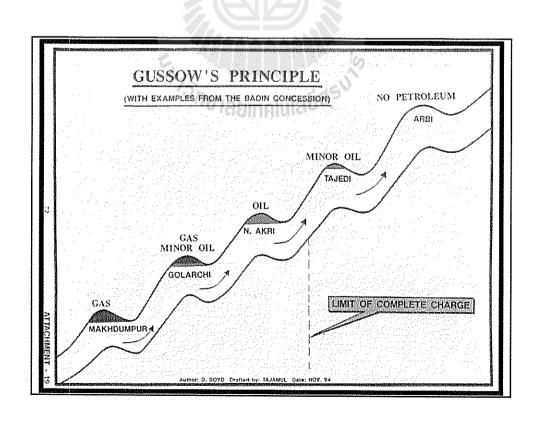


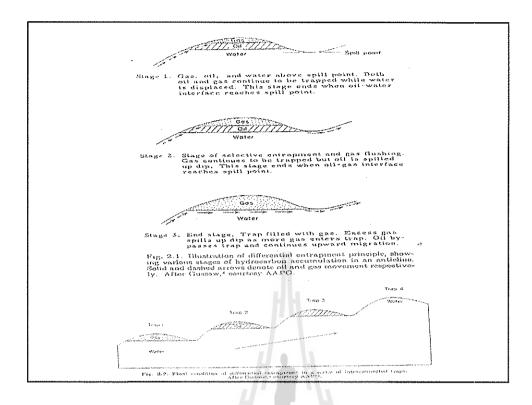
2. Buoyancy Driven

- 2.1 Fluid composition \rightarrow density contrast between hydrocarbons and water
- - primary effect the density contrast between water and HC's increase
 - secondary effect cracking to lighter HC's
- 2.3 Pressure increase leads to decreasing buoyancy
 - primary effect the density contrast between water and HC's decrease
 - secondary effect dissolving of lighter HC's into the liquid phase
- 2.4 Chemical potential → concentration differences (diffusion)







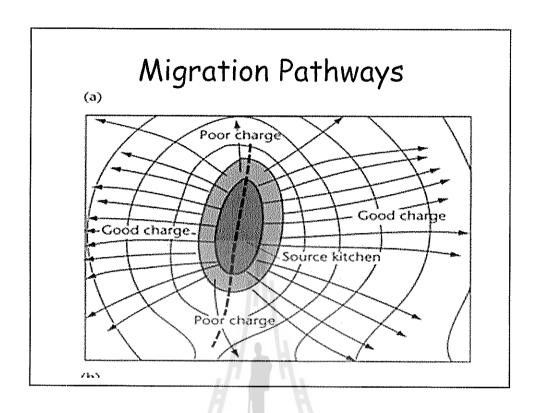


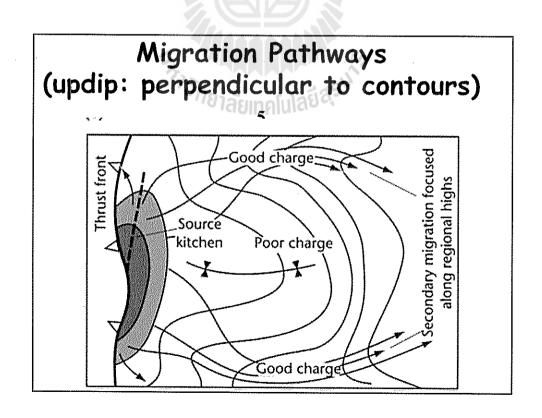
Migration Pathways

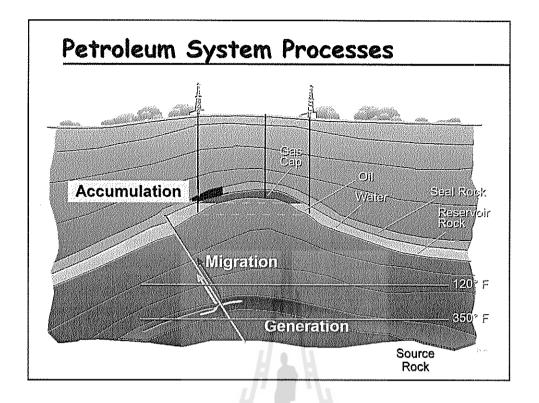
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Involved to

- 1. Hydrocarbon Expulsion
- 2. Vertical vs. Horizontal Migration
- 3. Residual Saturations



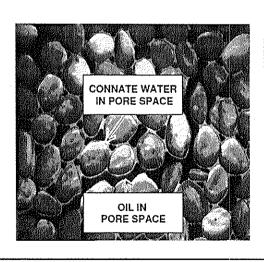




- A reservoir rock is a rock that is capable of storing a fluid or
- There are 2 requirements for a reservoir:

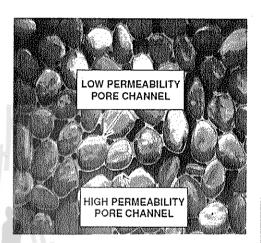
 1. Porosity

 - 2. Permeability
- A rock with pores is referred to as porous.
- It has tiny holes within which fluid (oil, water, gas) may be stored.

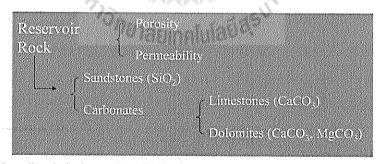


Reservoir

- A reservoir rock is also permeable. That means its pores are connected.
- If hydrocarbons are in the pores of a rock, they must be able to move out of them.
- Sandstones and carbonates (limestones) are good reservoir rock.
- A sponge is a good visual of a reservoir rock.

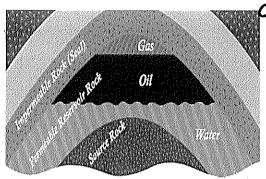


Reservoir Rock



Clastic	Chemical		Organio	o Other
Conglomer	Carbonate	Evaporite	Peat	Chert
ate		호 해양 호취 및 급기하다 4시설 기술 중요 -	Coal	
Sandstone	Limestone	Gypsum	Diatomite	
Siltstone	Dolomite	Anhydrite	Limeston	e
Shale		Salt		
		Potash		

Requirements for Good Reservoir Rocks

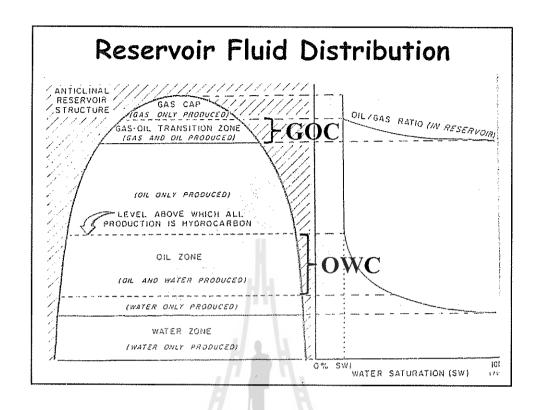


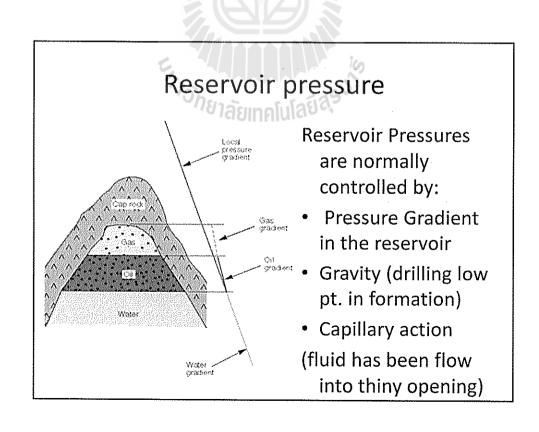
- √ High Porosity (>10%)
- √ High Permeability
- √ Great thickness (>10 ft.)
- ✓ Good lateral continuity and cover wide area

Common reservoir rocks

- 1. Sandstone (about 50%)
- High primary porosity, normally in the range of 20-40%
- Coarse grained, well sorted
- 2. Carbonate (Limestone and dolomite) (about 30%)
- Low to moderate primary porosity
- High secondary porosity

Reservoir Fluids Schematic diagrams of various gas, oil and water contacts The subterranean fluid trapped by a reservoir formation; can include: - Natural gas - Water - Oil Reservoir Fluids Gas-valer Gas-





Classify of Reservoir Drive mechanism

1. Solution gas drive (or depletion drive) depends on the associated gas of the oil. A drive mechanism where a drop in pressure releases gas from the oil that helps drive the oil towards the wellbore.

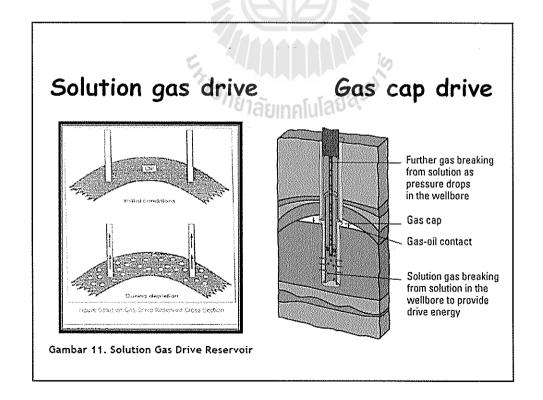
2. Gas cap drive

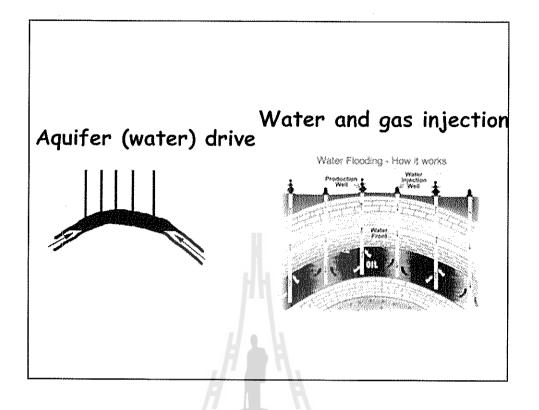
The use of the energy that raises from the expansion of compressed gas in a reservoir to move crude oil to a wellbore.

3. Aquifer (water) drive

Below the hydrocarbons may be a ground water aquifer. Water will to expand or move up as oil is produced which will push up on the hydrocarbons, maintaining pressure.

4. Water and gas injection: recovery processes





Hydrocarbon Traps Trap is the stratigraphic or structural feature that ensures the juxtaposition of reservoir and seal Classification of traps 1. Structural Traps Fold related Fault related Diapirs: Salt Dome 2. Stratigraphic traps Related to unconformities Sedimentological: Reef Pinchout

3. Hydrodynamic traps

4. Combination traps

