Geology of Petroleum Systems

Petroleum Geology

Objectives are to be able to:

- Discuss basic elements of Petroleum Systems
- Describe plate tectonics and sedimentary basins
- Recognize names of major sedimentary rock types
- Describe importance of sedimentary environments to petroleum industry
- Describe the origin of petroleum
- Identify hydrocarbon trap types
- Define and describe the important geologic controls on reservoir properties, porosity and permeability

Outline

- Petroleum Systems approach
- Geologic Principles and geologic time
- Rock and minerals, rock cycle, reservoir properties
- Hydrocarbon origin, migration and accumulation
- Sedimentary environments and facies; stratigraphic traps
- Plate tectonics, basin development, structural geology

Petroleum System - A Definition

- A Petroleum System is a dynamic hydrocarbon system that functions in a restricted geologic space and time scale.

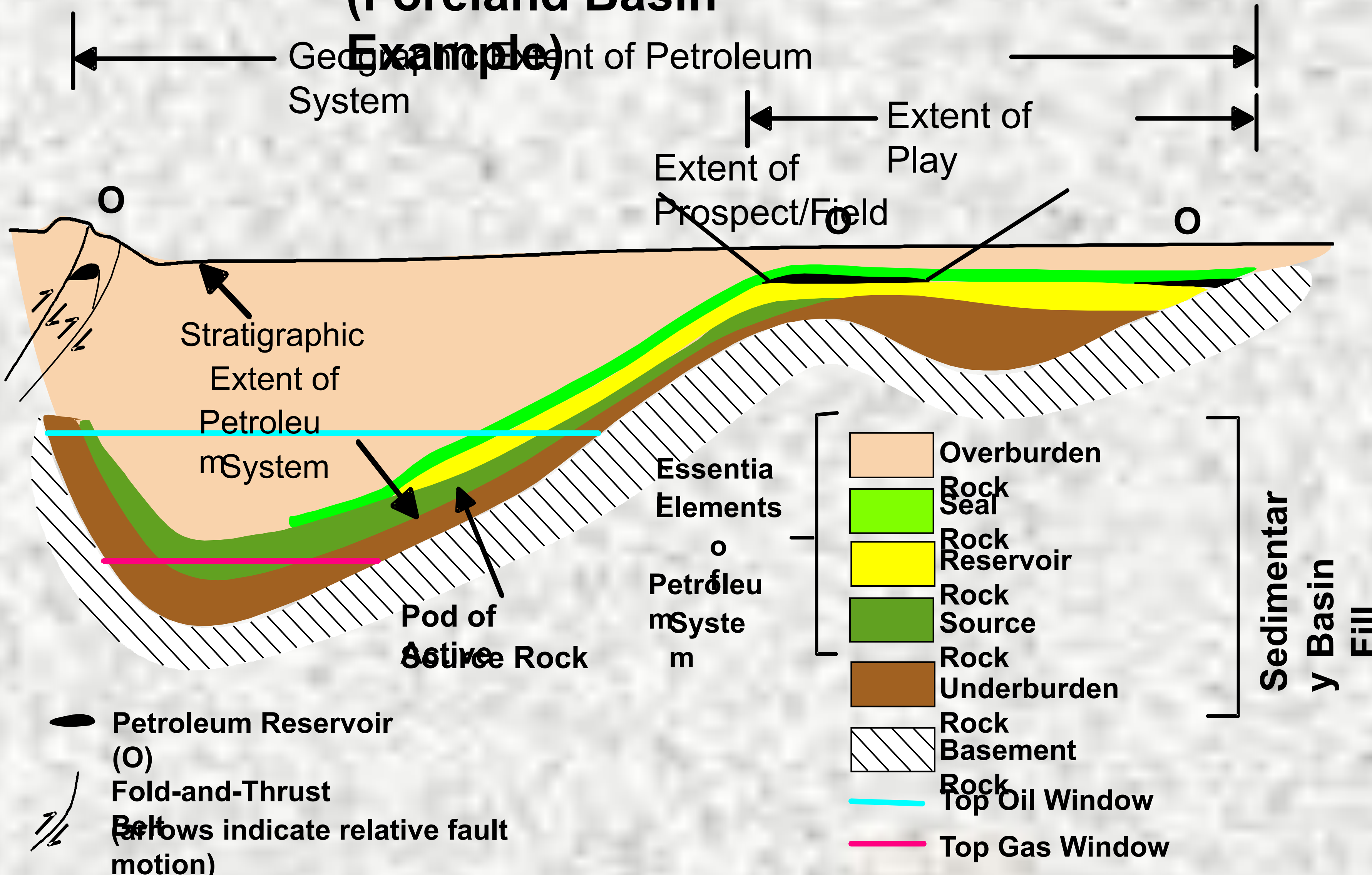
- A Petroleum System requires timely convergence of geologic events essential to the formation of petroleum deposits.

These Include:

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

(modified from Demaison and Huizinga, 1994)

Cross Section Of A Petroleum System (Foreland Basin Example)

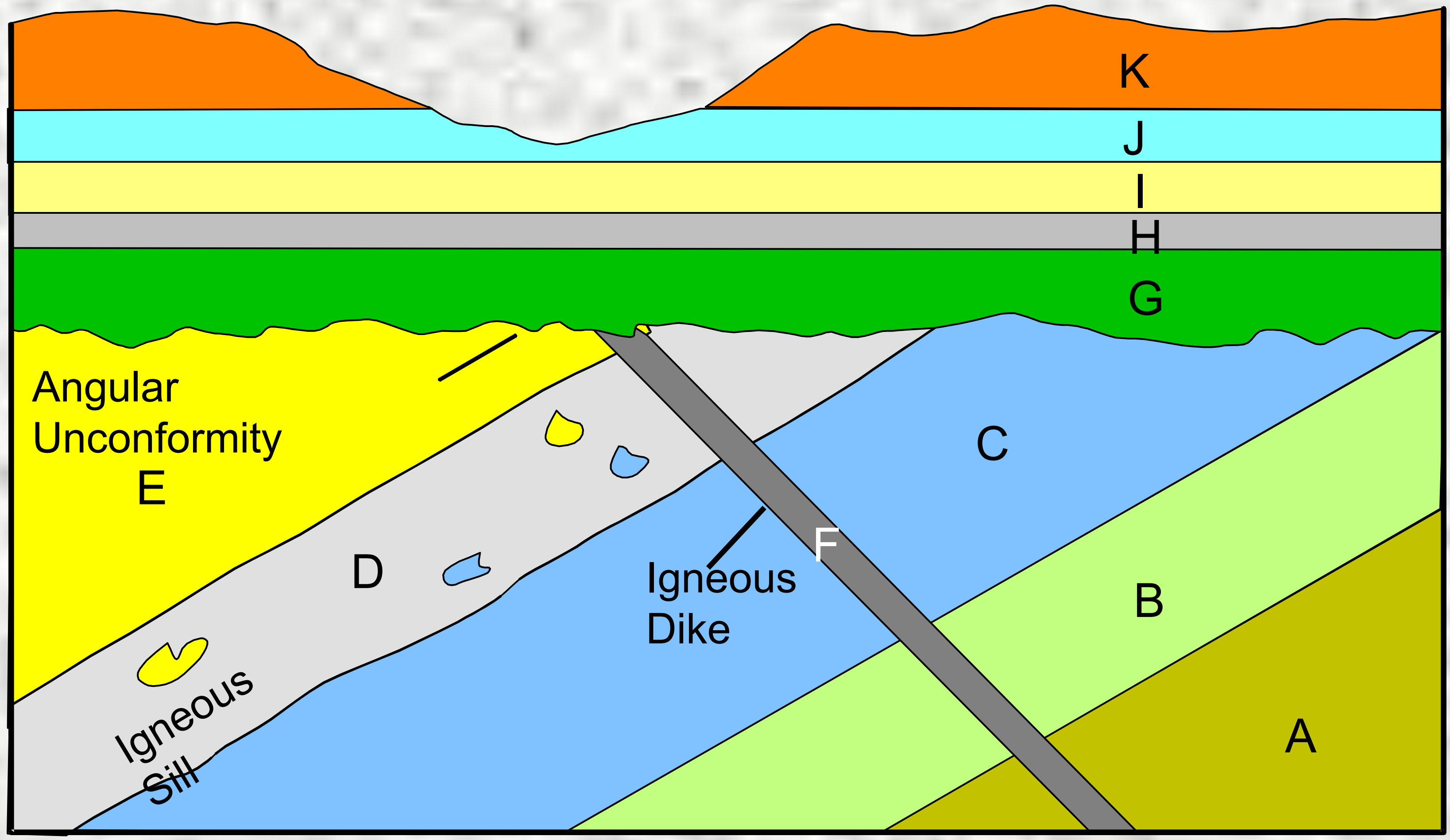


(modified from Magoon and Dow, 1994)

Basic Geologic Principles

- Uniformitarianism
- Original Horizontality
- Superposition
- Cross-Cutting Relationships

Cross-Cutting Relationships



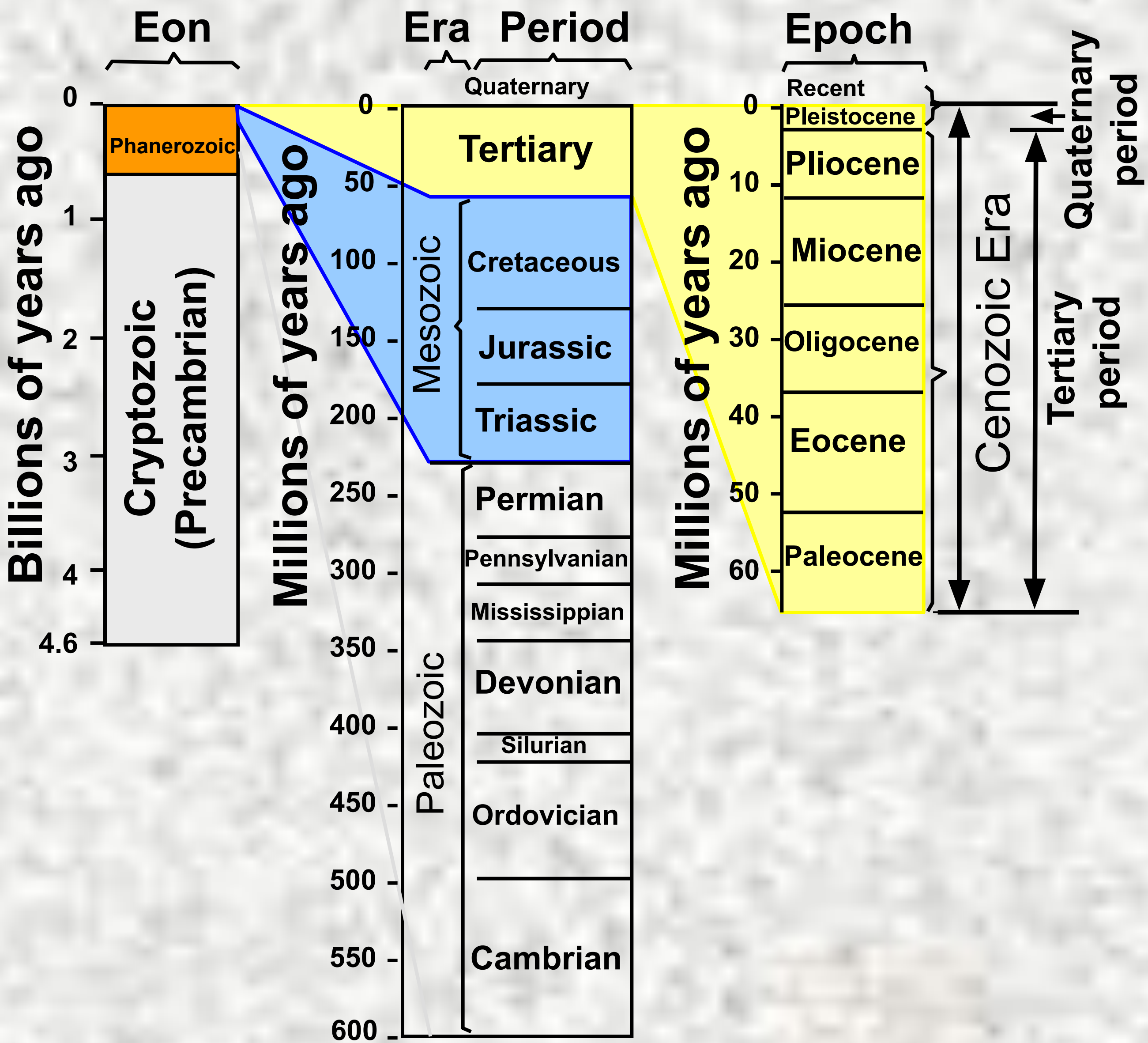
Types of Unconformities

- Disconformity
  - An unconformity in which the beds above and below are parallel
- Angular Unconformity
  - An unconformity in which the older bed intersect the younger beds at an angle
- Nonconformity
  - An unconformity in which younger sedimentary rocks overlie older metamorphic or intrusive igneous rocks

Correlation

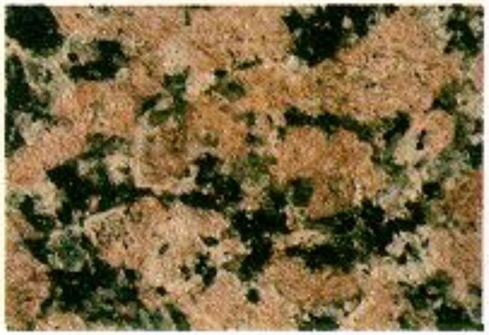
- Establishes the age equivalence of rock layers in different areas
- Methods:
  - Similar lithology
  - Similar stratigraphic section
  - Index fossils
  - Fossil assemblages
  - Radioactive age dating

Geologic Time Chart

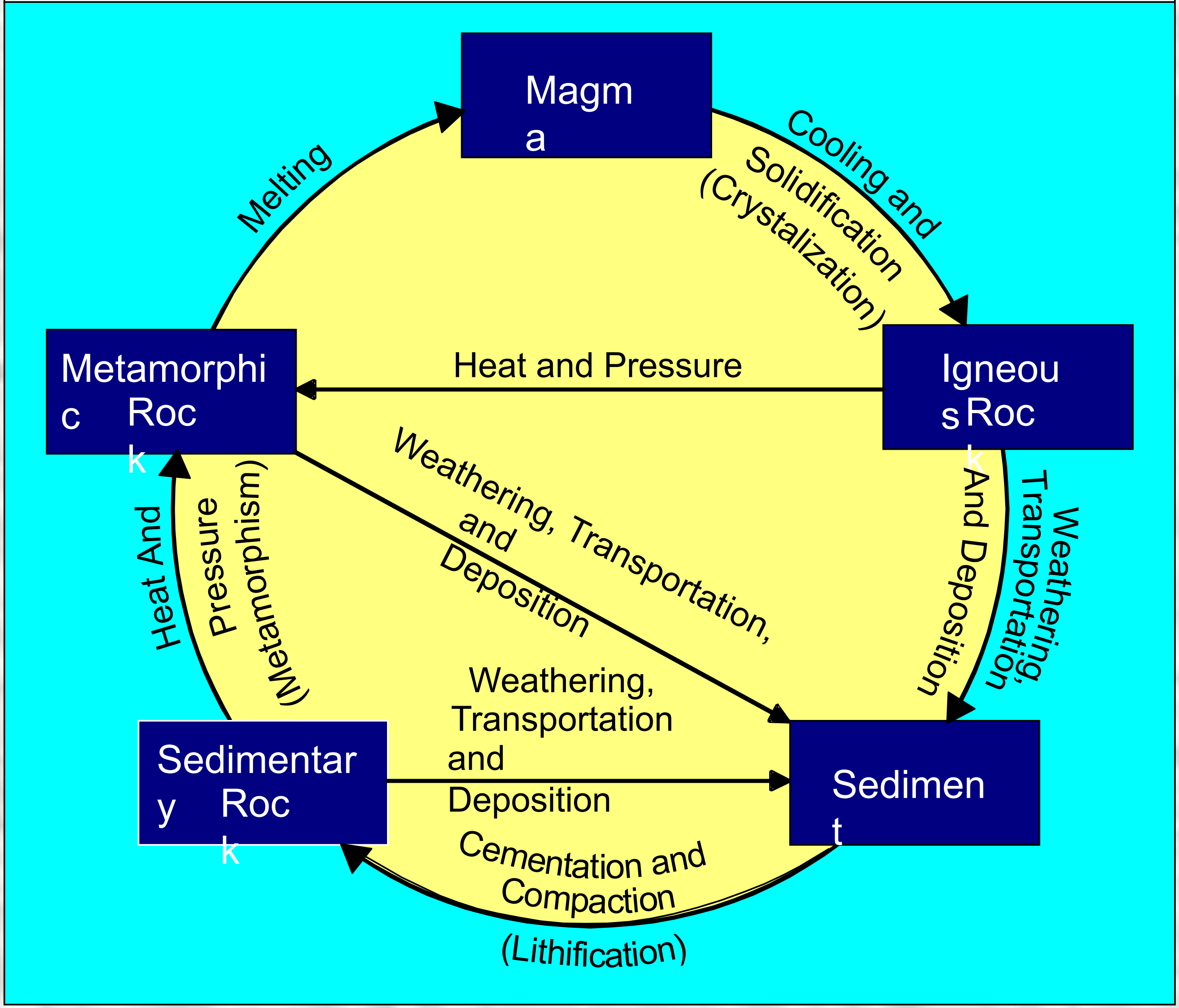


Rocks

Classification of Rocks

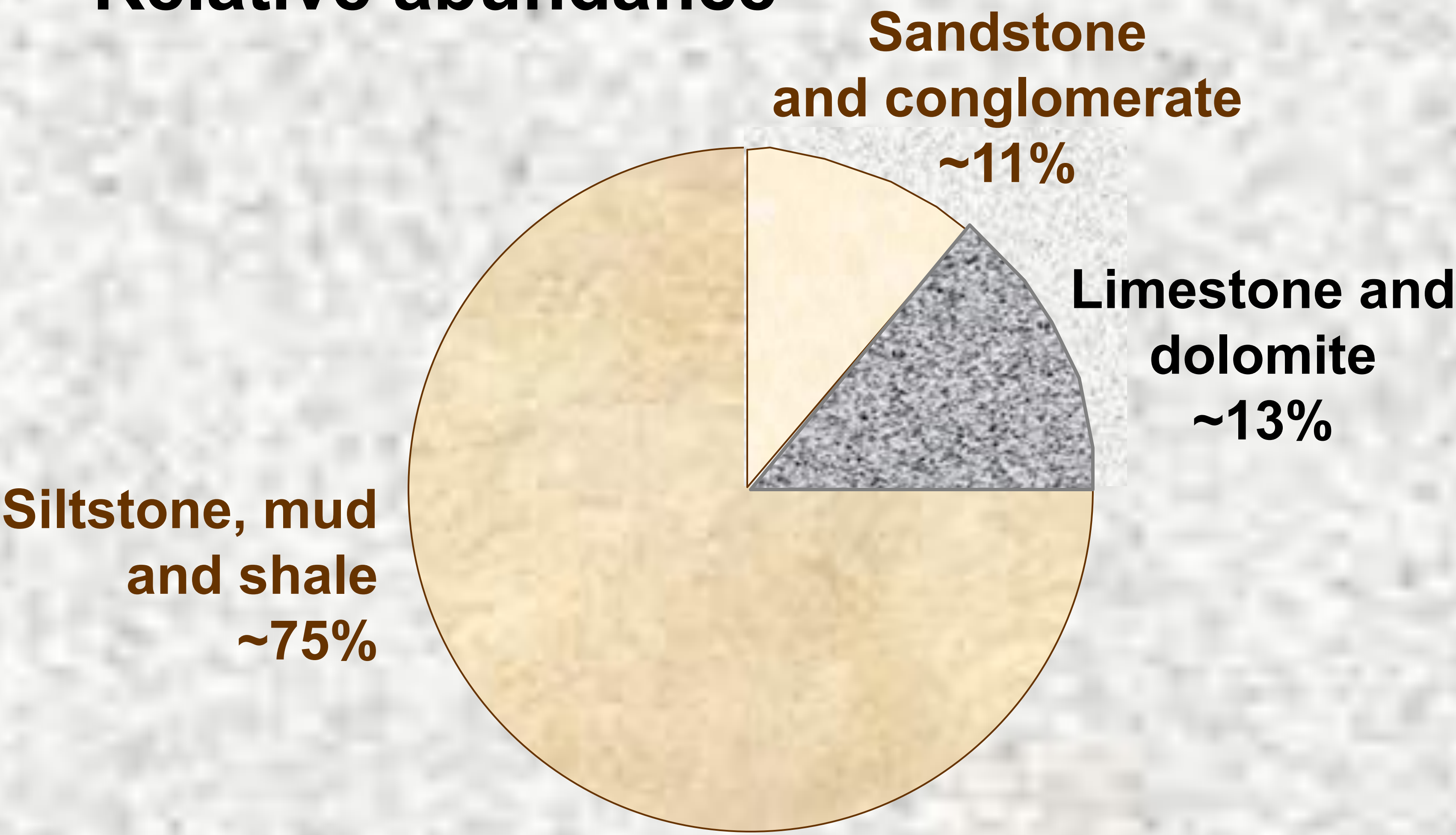
	IGNEOUS	SEDIMENTARY	METAMORPHIC
			
Source of material	**Molten materials in deep crust and upper mantle**	**Weathering and erosion of rocks exposed at surface**	**Rocks under high temperatures and pressures in deep crust**
Rock-forming process	**Crystallization (Solidification of melt)**	**Sedimentation, burial and lithification**	**Recrystallization due to heat, pressure, or chemically active fluids**

The Rock Cycle



Sedimentary Rock Types

- Relative abundance



Minerals - Definition

Quartz Crystals

- Naturally Occurring Solid
- Generally Formed by Inorganic Processes
- Ordered Internal Arrangement of Atoms (Crystal Structure)
- Chemical Composition and Physical Properties Fixed or Vary Within A Definite Range

Average Detrital Mineral Composition of Shale and Sandstone

Mineral Composition	Shale (%)	Sandstone (%)
Clay Minerals	60	5
Quartz	30	65
Feldspar	4	10-15
Rock Fragments	<5	15
Carbonate	3	<1
Organic Matter, Hematite, and Other Minerals	<3	<1

(modified from Blatt, 1982)

The Physical and Chemical Characteristics of Minerals Strongly Influence the Composition of Sedimentary Rocks

Quartz	• Mechanically and Chemically Stable • Can Survive Transport and Burial
Feldspar	• Nearly as Hard as Quartz, but Cleavage Lessens Mechanical Stability • May be Chemically Unstable in Some Climates and During Burial
Calcite	• Mechanically Unstable During Transport • Chemically Unstable in Humid Climates Because of Low Hardness, Cleavage, and Reactivity With Weak Acid

Some Common Minerals

Oxides	Sulfides	Carbonates	Sulfates	Halides
Hematite *Magnetite*	*Pyrite* *Galena* *Sphalerite*	*Aragonite* *Calcite* *Dolomite* *Fe-Dolomite* *Ankerite*	*Anhydrite* *Gypsum*	*Halite* *Sylvite*

Silicates

Non-Ferromagnesian
(Common in Sedimentary Rocks)

- Quartz
- Muscovite (mica)
- Feldspars
  - Potassium feldspar (K-spar)
    - *Orthoclase*
    - *Microcline, etc.*
  - Plagioclase
    - *Albite (Na-rich - common) through*
    - *Anorthite (Ca-rich - not common)*

Ferromagnesian
(not common in sedimentary rocks)

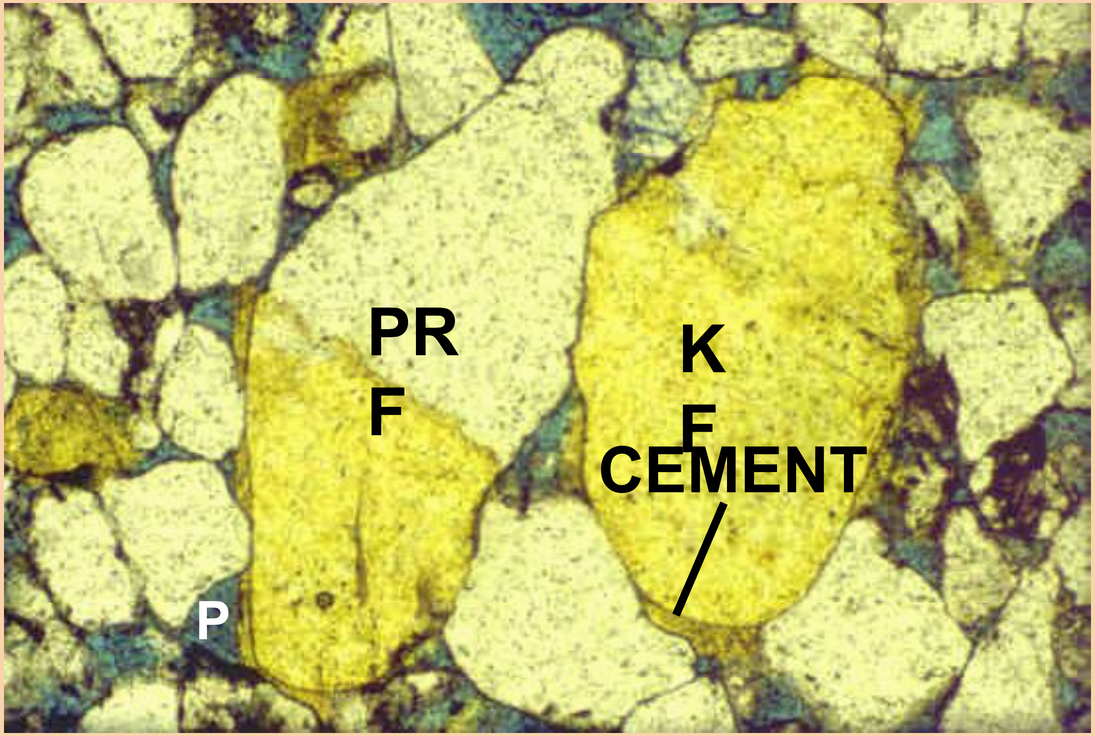
- Olivine
- Pyroxene
  - Augite
- Amphibole
  - Hornblende
- Biotite (mica)

Red = Sedimentary Rock-Forming Minerals

The Four Major Components

- Framework
  - Sand (and Silt) Size Detrital Grains
- Matrix
  - Clay Size Detrital Material
- Cement
  - Material precipitated post-depositionally, during burial. Cements fill pores and replace framework grains
- Pores
  - Voids between above components

Sandstone Composition
Framework Grains

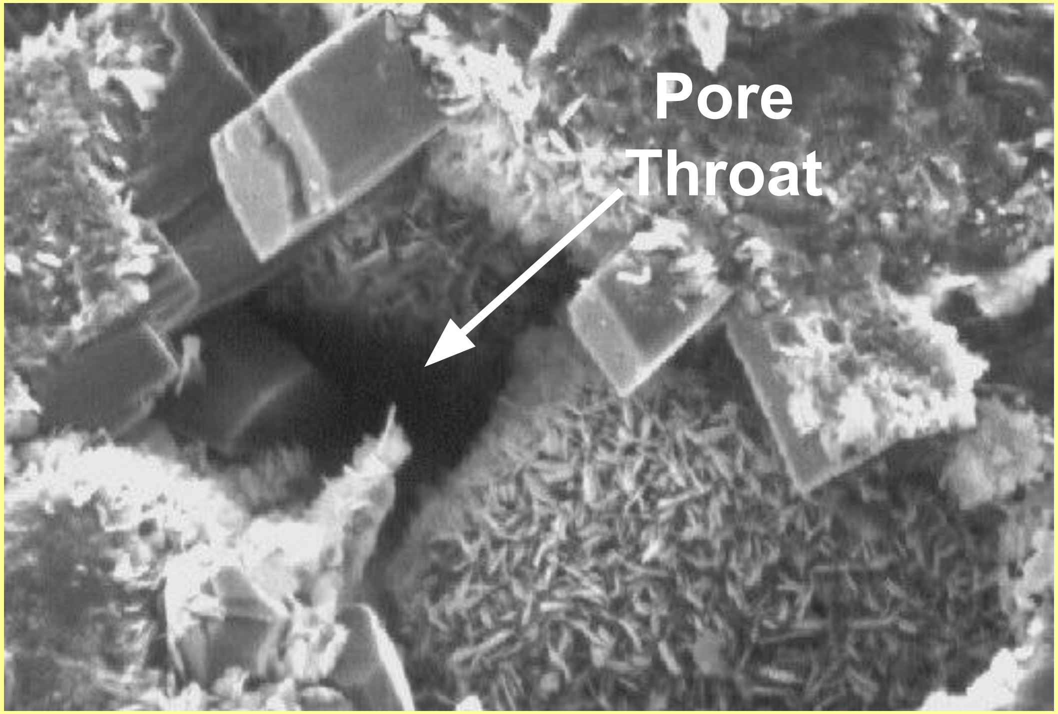


Norphlet Sandstone, Offshore Alabama, USA
Grains are About =< 0.25 mm in Diameter/Length

KF = Potassium Feldspar
PRF = Plutonic Rock Fragment
P = Pore

Potassium Feldspar is Stained Yellow With a Chemical Dye
Pores are Impregnated With Blue-Dyed Epoxy

Porosity in Sandstone



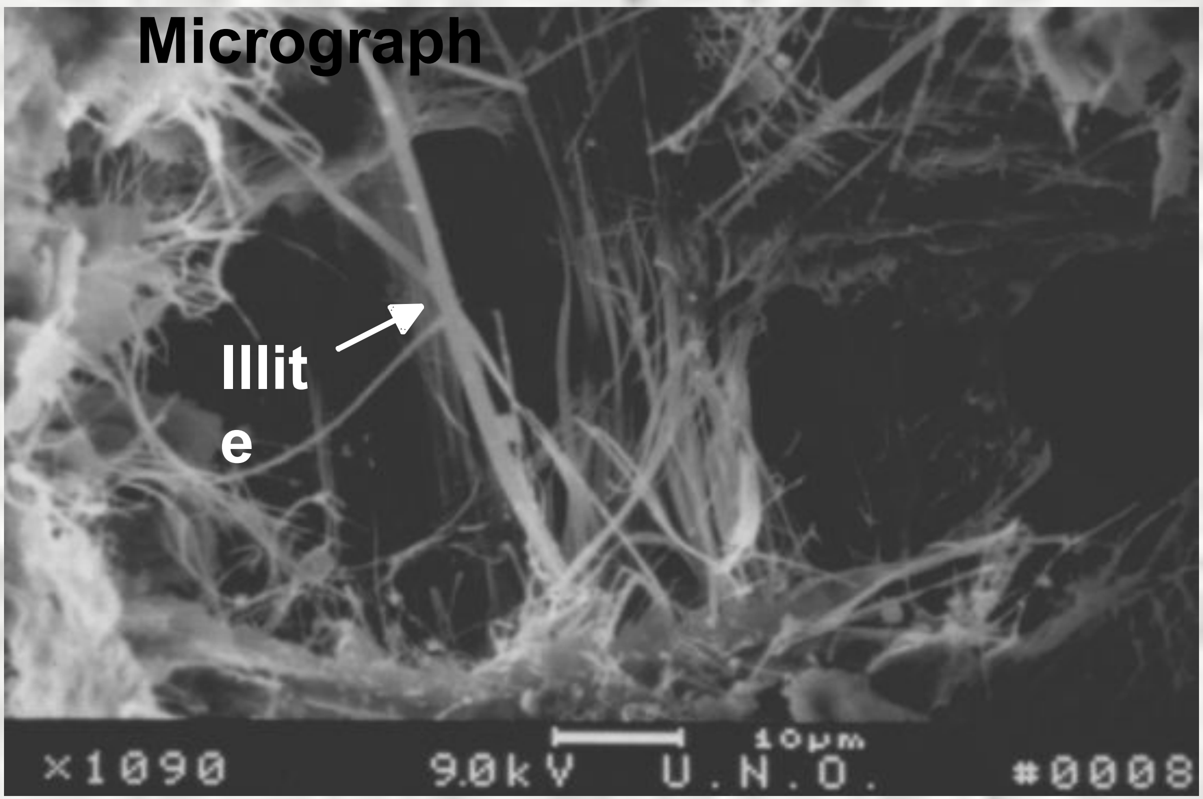
Scanning Electron Micrograph
Norphlet Formation, Offshore Alabama, USA

Pores Provide the Volume to Contain Hydrocarbon Fluids

Pore Throats Restrict Fluid Flow

Clay Minerals in Sandstone Reservoirs
Fibrous Authigenic Illite

Secondary Electron Micrograph



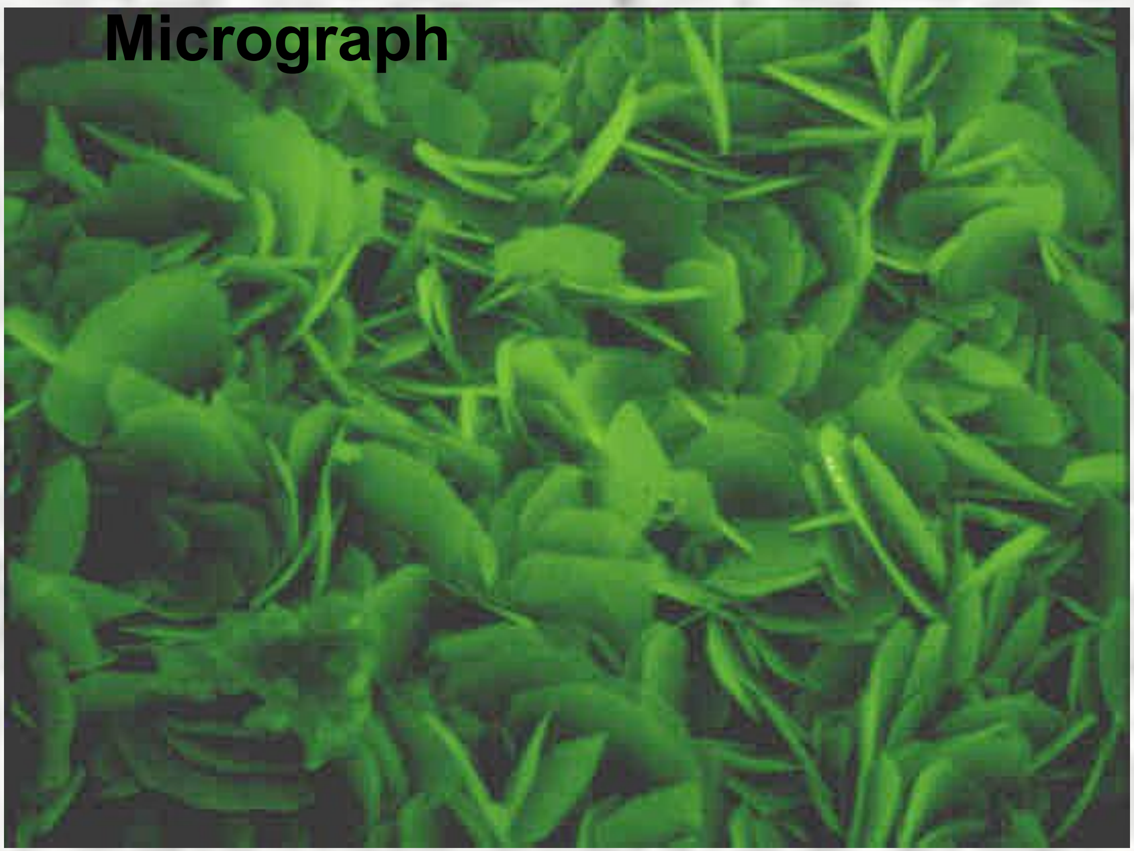
Jurassic Norphlet Sandstone
Hatters Pond Field, Alabama, USA

- Significant Permeability Reduction
- Negligible Porosity Reduction
- High Irreducible Water Saturation
- Migration of Fines Problem

(Photograph by R.L. Kugler)

Clay Minerals in Sandstone Reservoirs
Authigenic Chlorite

Secondary Electron Micrograph



Jurassic Norphlet Sandstone
Offshore Alabama, USA

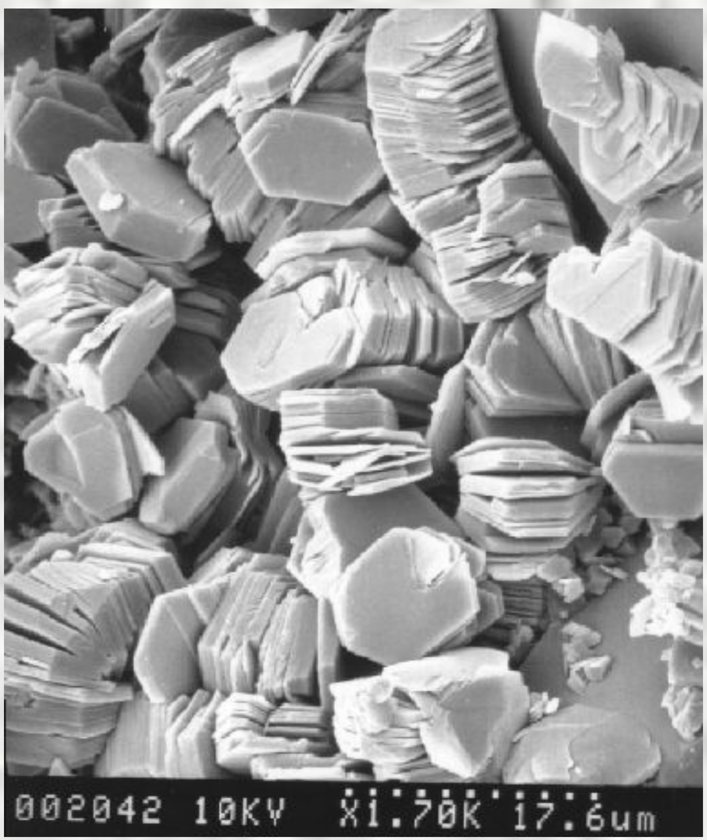
~ 10 µm

- Iron-Rich Varieties React With Acid
- Occurs in Several Deeply Buried Sandstones With High Reservoir Quality
- Occurs as Thin Coats on Detrital Grain Surfaces

(Photograph by R.L. Kugler)

Clay Minerals in Sandstone Reservoirs
Authigenic Kaolinite

Secondary Electron Micrograph

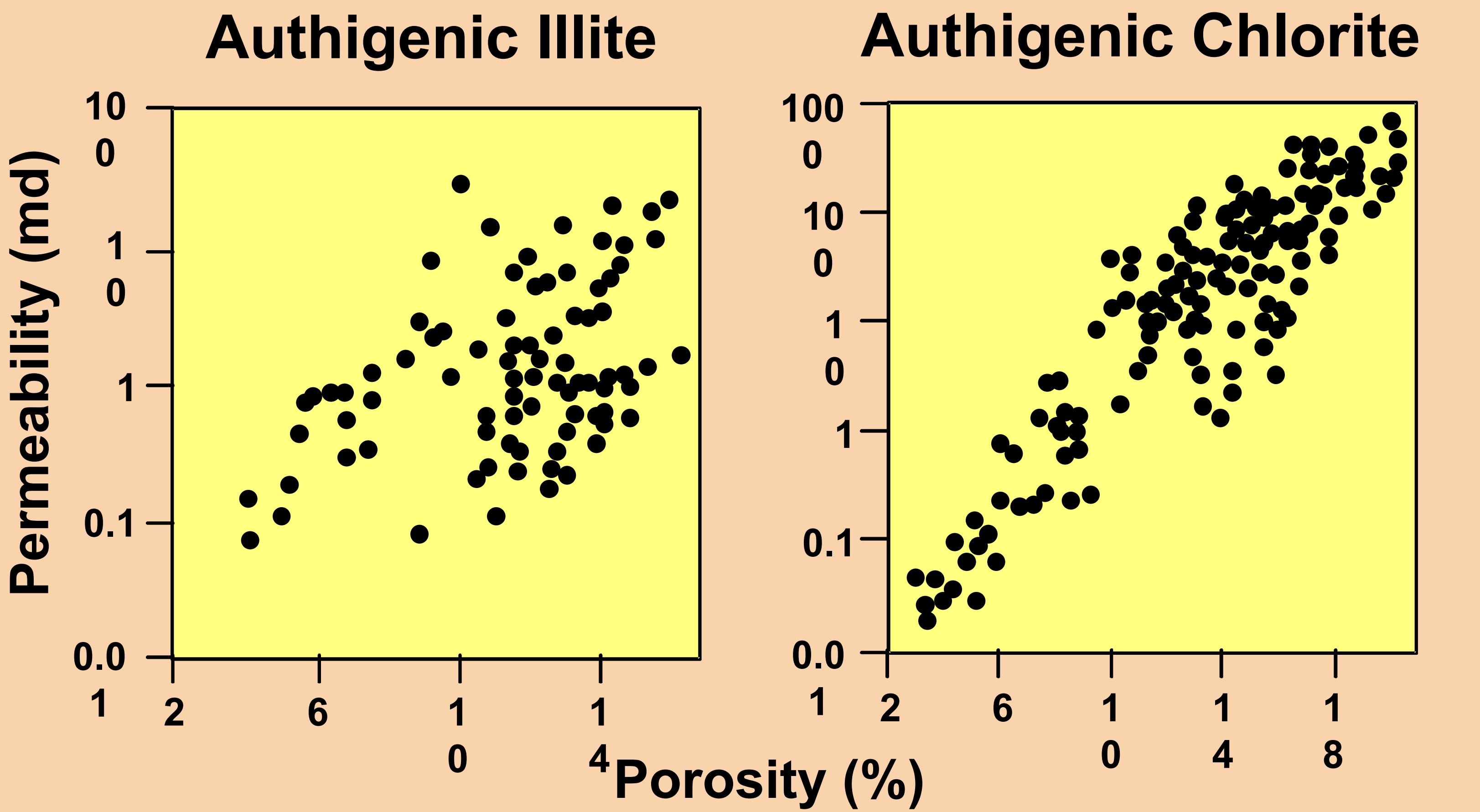


Carter Sandstone
North Blowhorn Creek Oil Unit
Black Warrior Basin, Alabama, USA

- **Significant Permeability Reduction**
- **High Irreducible Water Saturation**
- **Migration of Fines Problem**

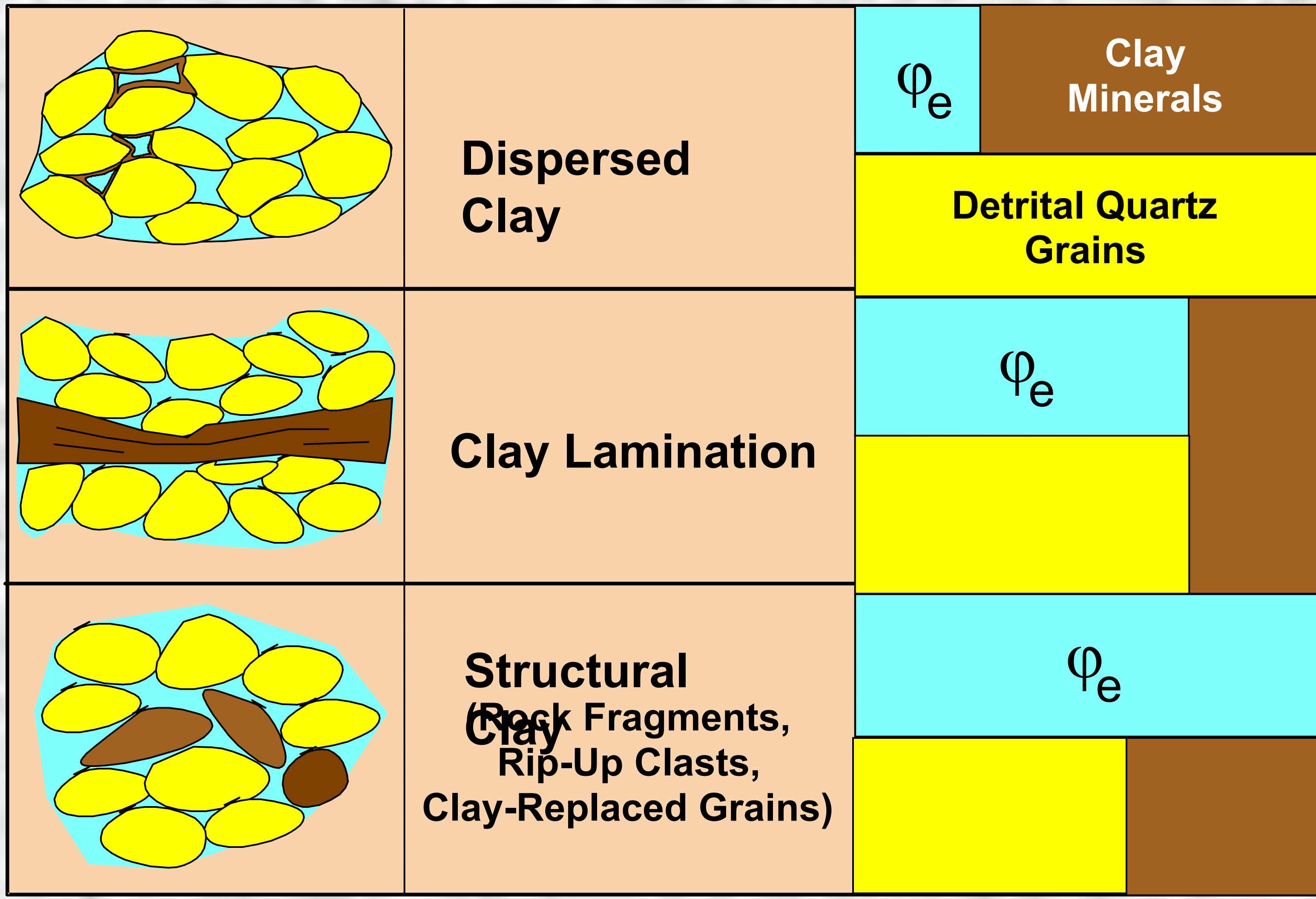
(Photograph by R.L. Kugler)

Effects of Clays on Reservoir Quality

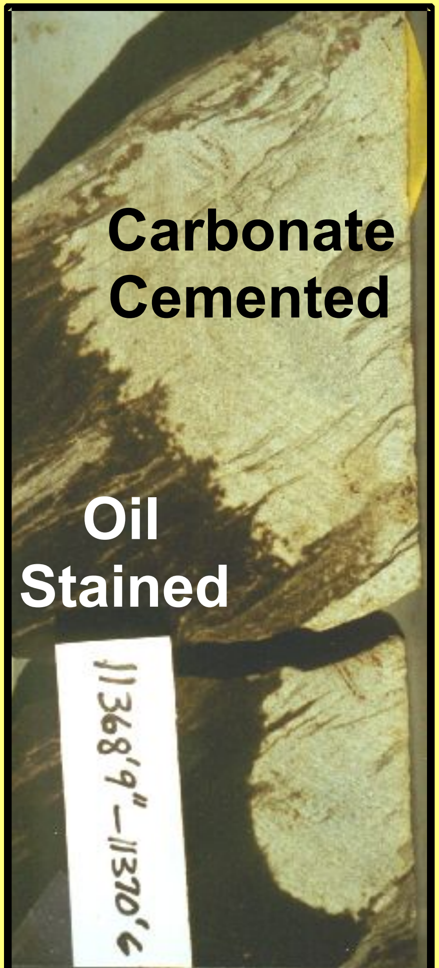


(modified from Kugler and McHugh, 1990)

Influence of Clay-Mineral Distribution on Effective Porosity



Diagenesis

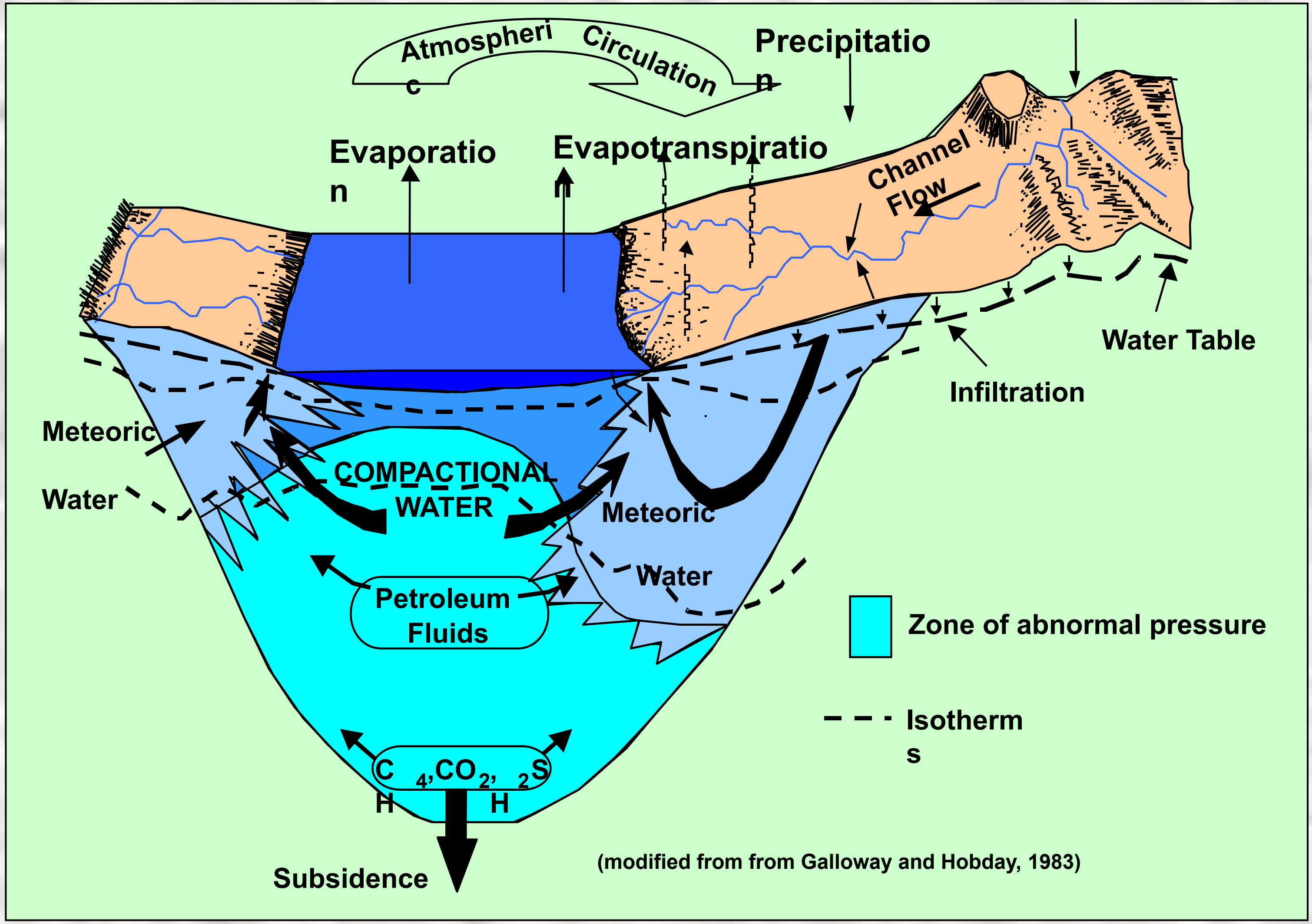


Whole Core

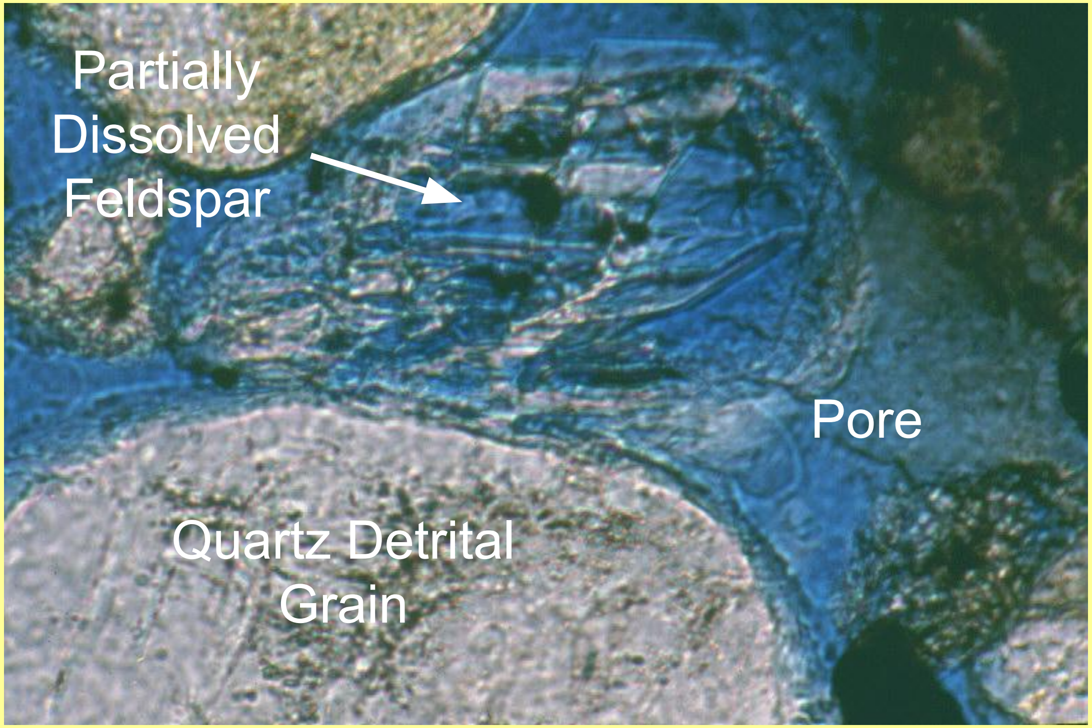
Misoa Formation, Venezuela

- Diagenesis is the Post-Depositional Chemical and Mechanical Changes that Occur in Sedimentary Rocks
- Some Diagenetic Effects Include
  - Compaction
  - Precipitation of Cement
  - Dissolution of Framework Grains and Cement
- The Effects of Diagenesis May Enhance or Degrade Reservoir Qualit y

Fluids Affecting Diagenesis



Dissolution Porosity



Thin Section Micrograph - Plane Polarized Light
Avile Sandstone, Neuquen Basin, Argentina

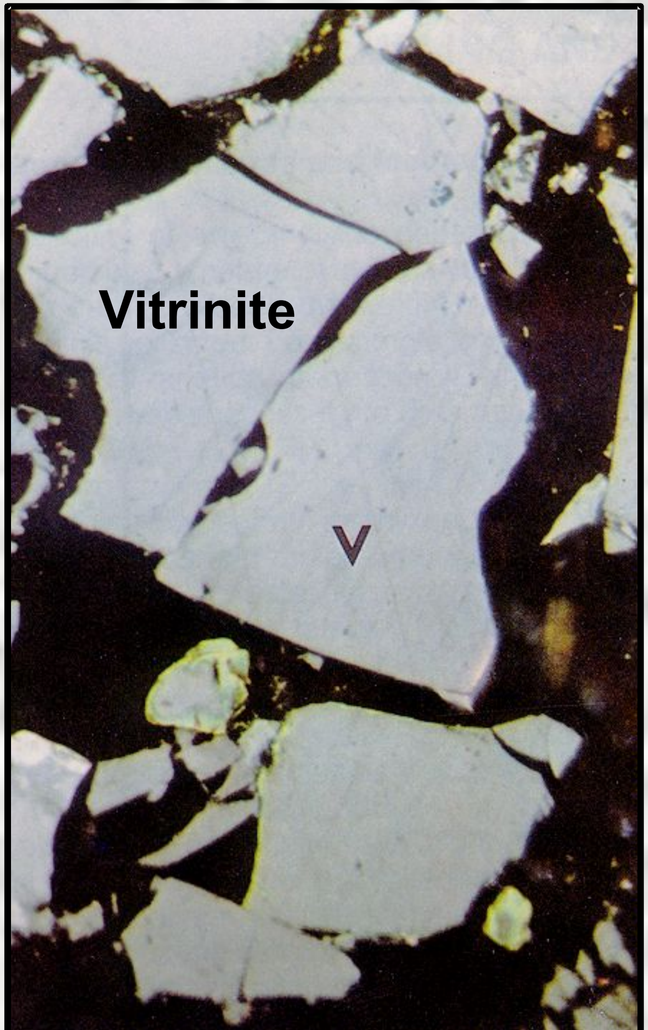
Dissolution of Framework Grains (Feldspar, for Example) and Cement may Enhance the Interconnected Pore System

This is Called Secondary Porosity

(Photomicrograph by R.L. Kugler)

Hydrocarbon Generation, Migration, and Accumulation

Organic Matter in Sedimentary Rocks



Reflected-Light Micrograph of Coal

Kerogen

Disseminated Organic Matter in Sedimentary Rocks That is Insoluble Oxidizing Acids, Bases, and Organic Solvents.

Vitrinite

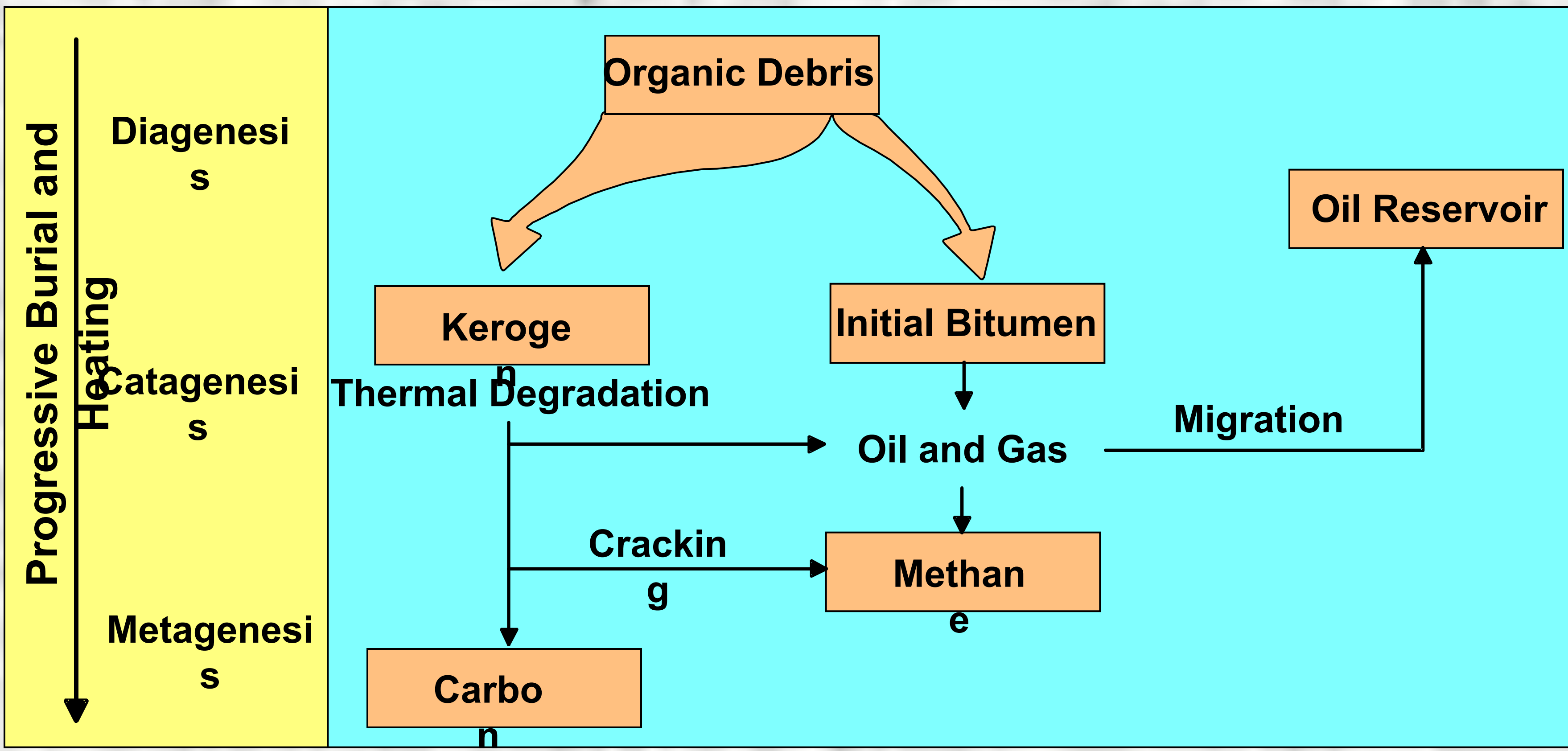
A nonfluorescent type of organic material in petroleum source rocks derived primarily from woody material.

The reflectivity of vitrinite is one of the best indicators of coal rank and thermal maturity of petroleum source rock.

Interpretation of Total Organic Carbon (TOC) (based on early oil window maturity)

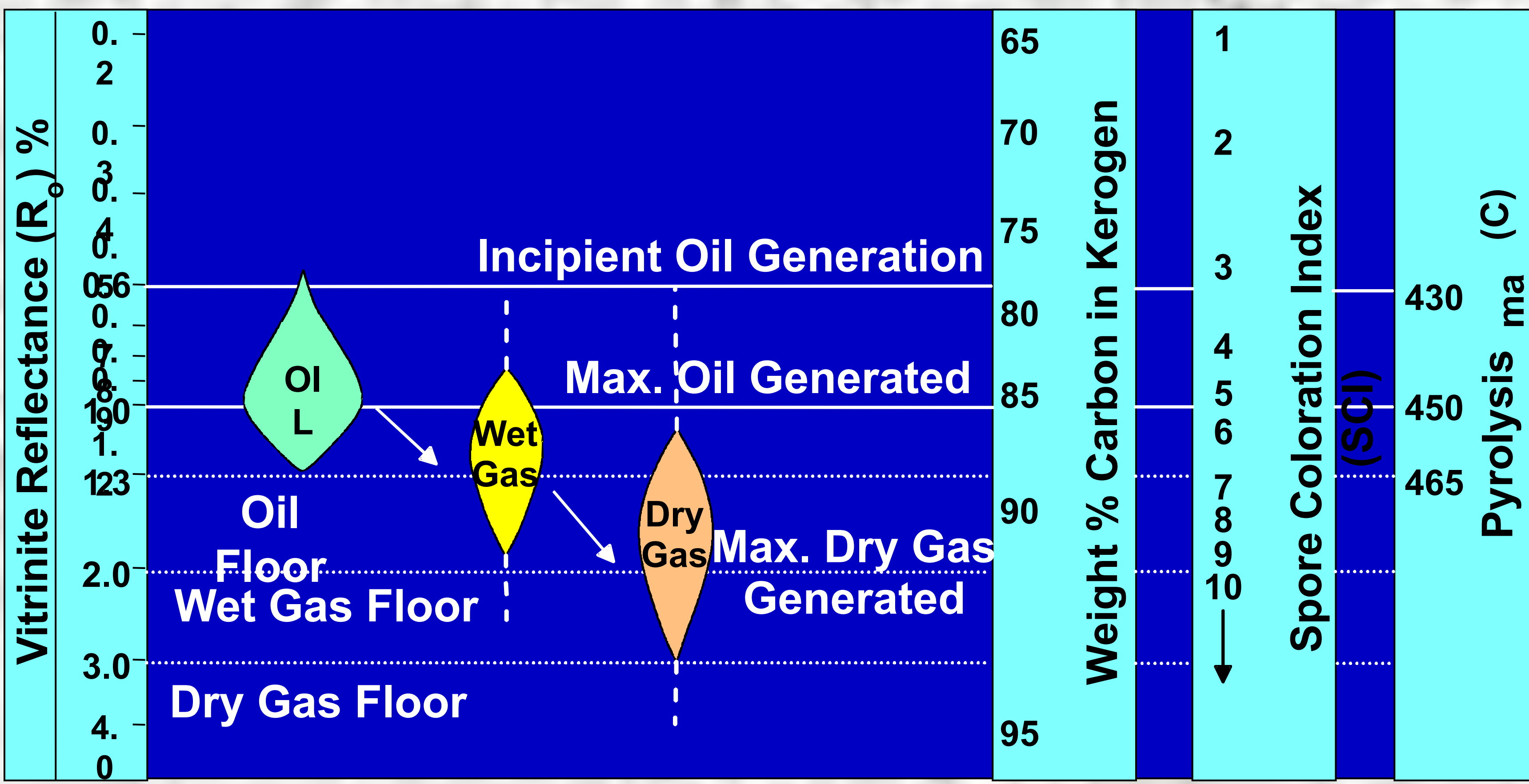
Hydrocarbon Generation Potential	TOC in Shale (wt. %)	TOC in Carbonates (wt. %)
Poor	0.0-0.5	0.0-0.2
Fair	0.5-1.0	0.2-0.5
Good	1.0-2.0	0.5-1.0
Very Good	2.0-5.0	1.0-2.0
Excellent	>5.0	>2.0

Schematic Representation of the Mechanism of Petroleum Generation and Destruction



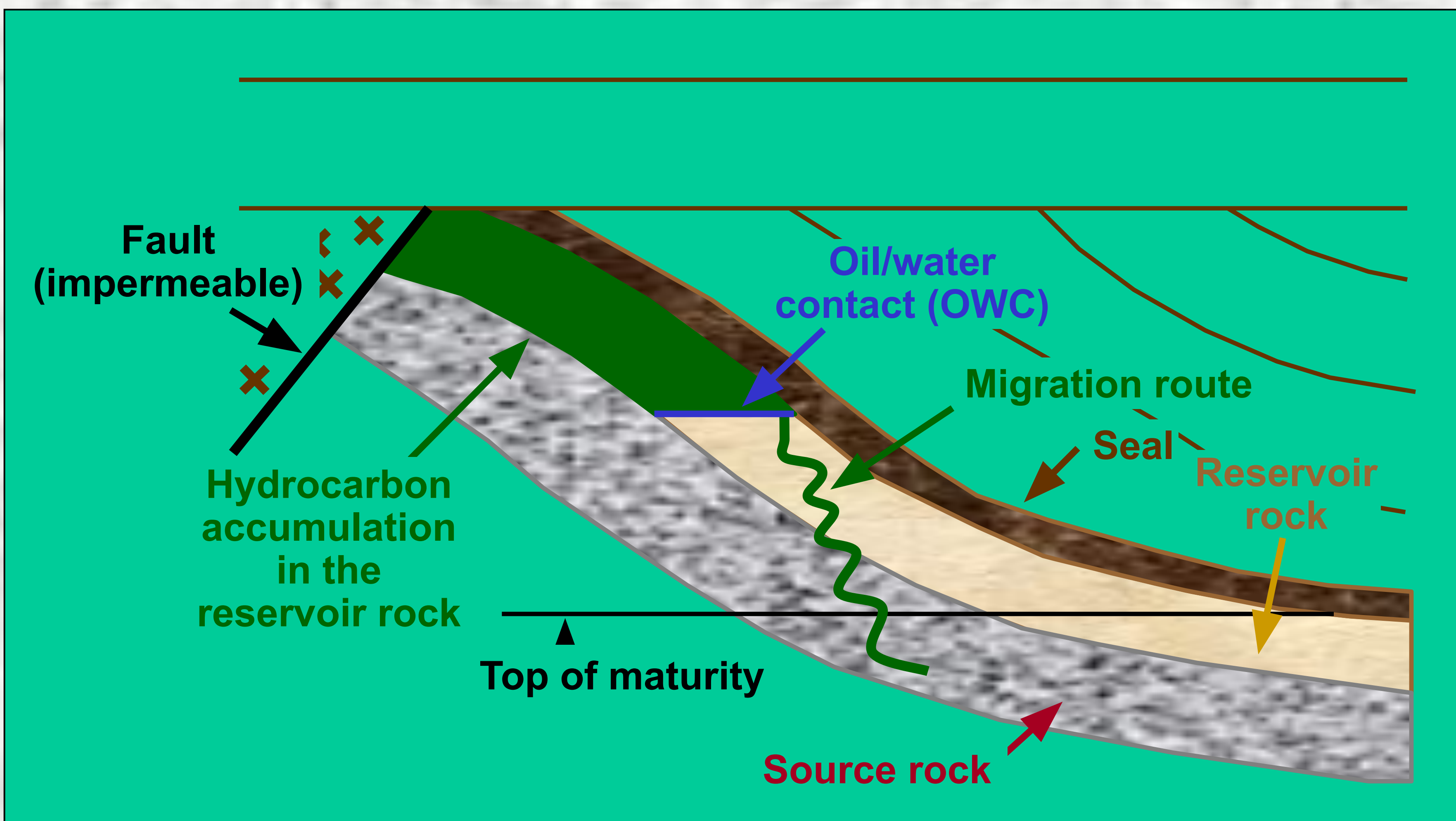
(modified from Tissot and Welte, 1984)

Comparison of Several Commonly Used Maturity Techniques and Their Correlation to Oil and Gas Generation Limits

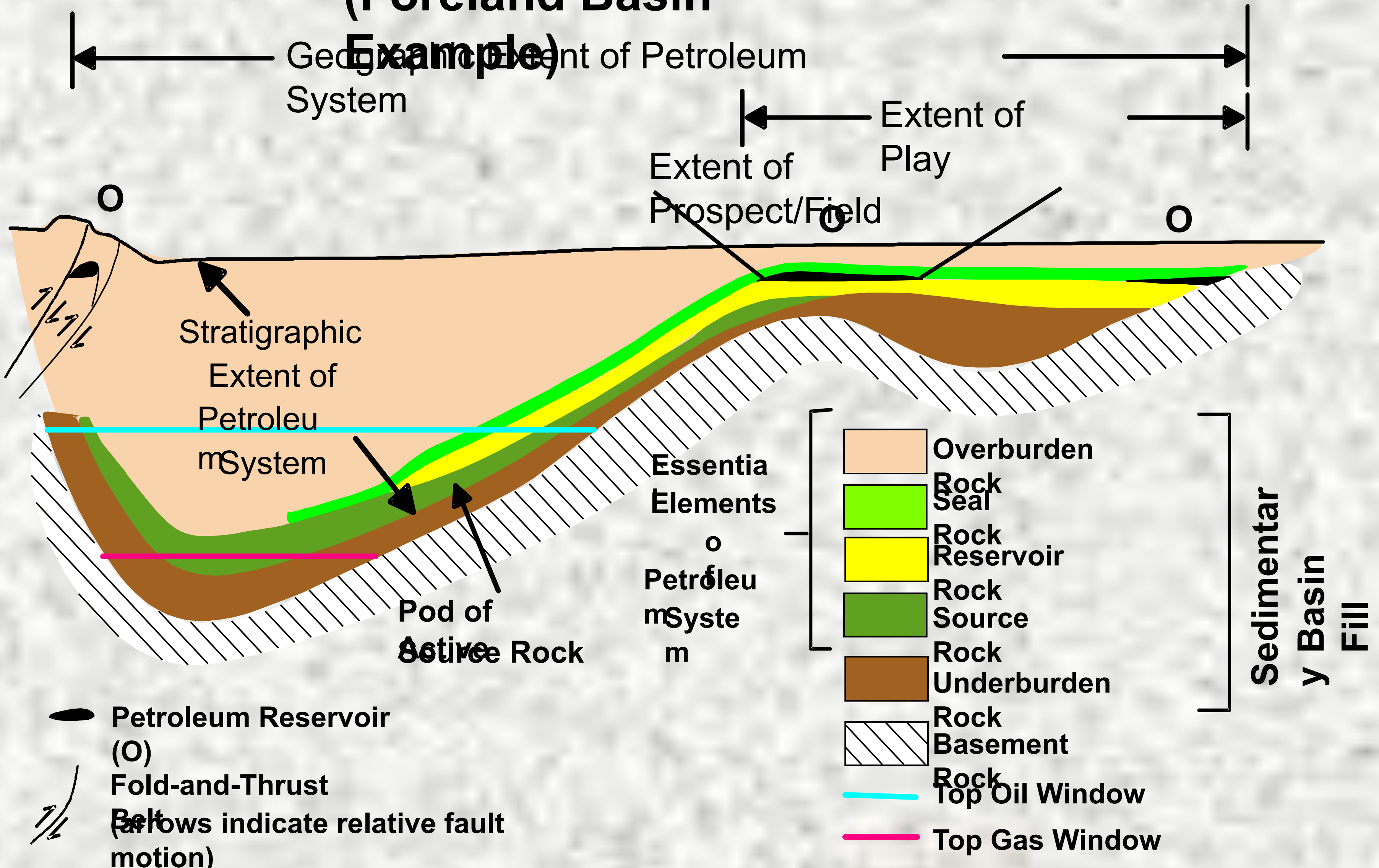


(modified from Foster and Beaumont, 1991, after Dow and O’Conner, 1982)

Generation, Migration, and Trapping of Hydrocarbons



Cross Section Of A Petroleum System
(Foreland Basin Example)

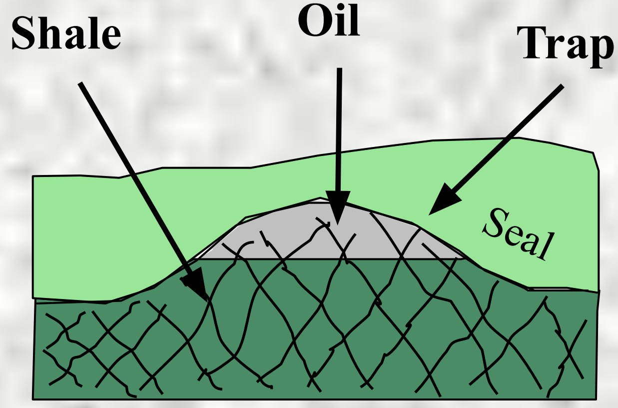


(modified from Magoon and Dow, 1994)

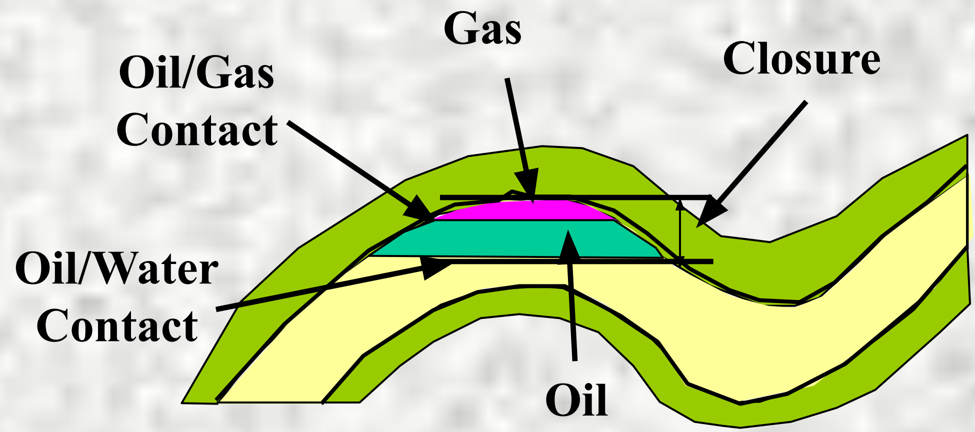
Hydrocarbon Traps

- Structural traps
- Stratigraphic traps
- Combination traps

Structural Hydrocarbon Traps

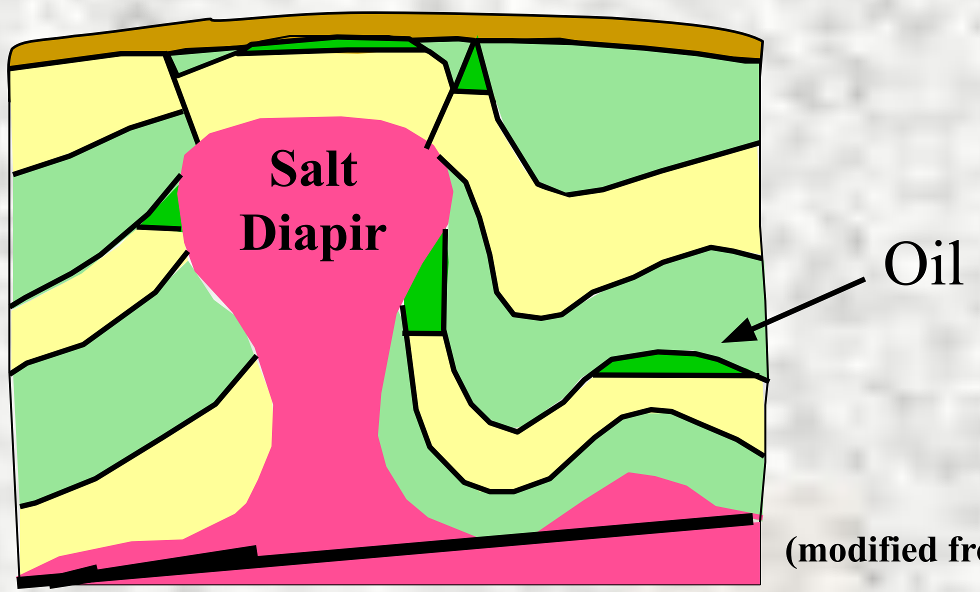


Fracture Basement



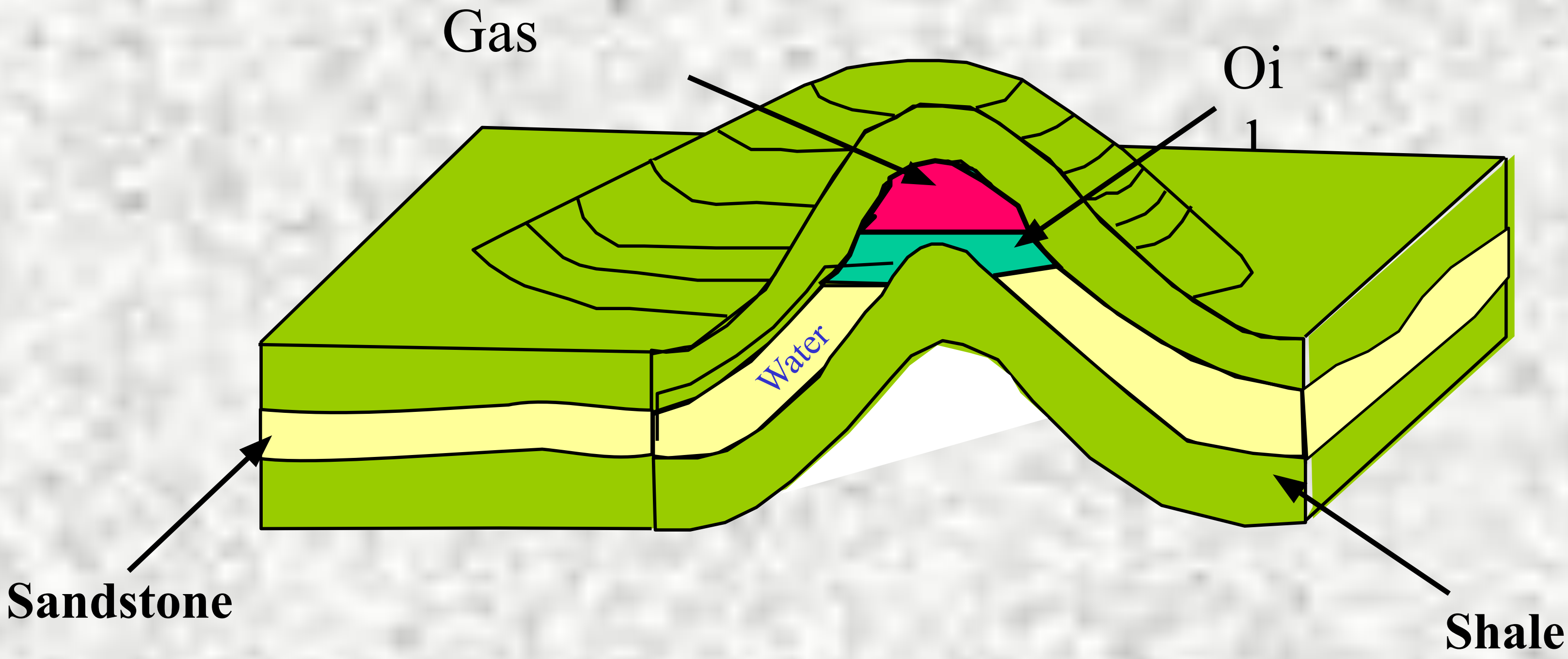
Fold Trap

Salt Dome

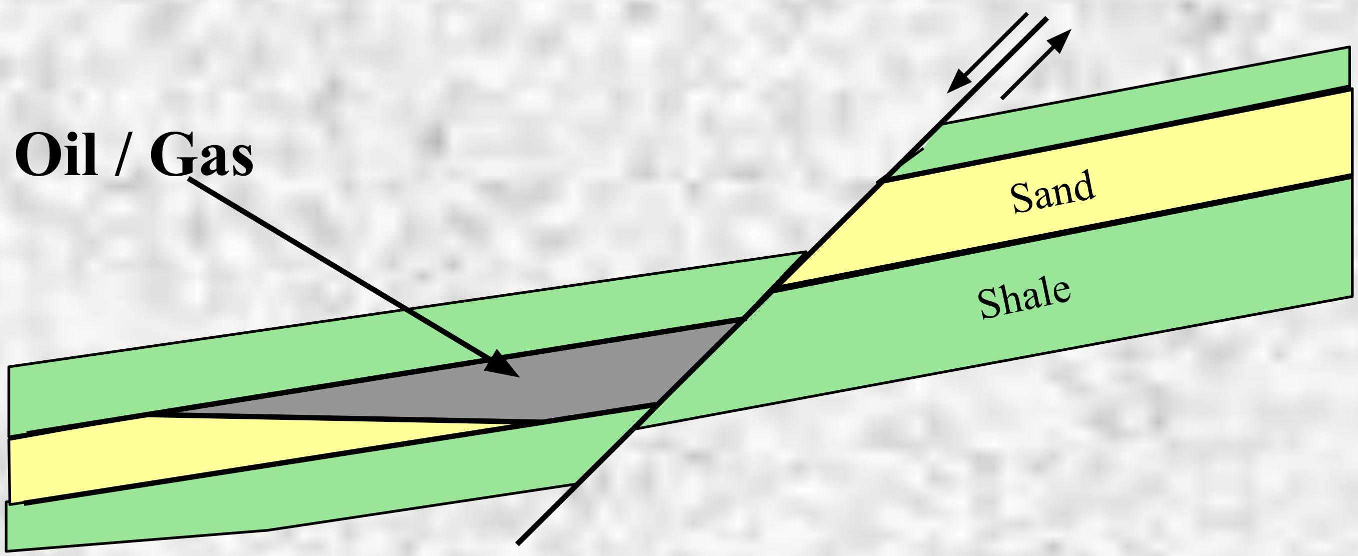


(modified from Bjorlykke, 1989)

Hydrocarbon Traps - Dome

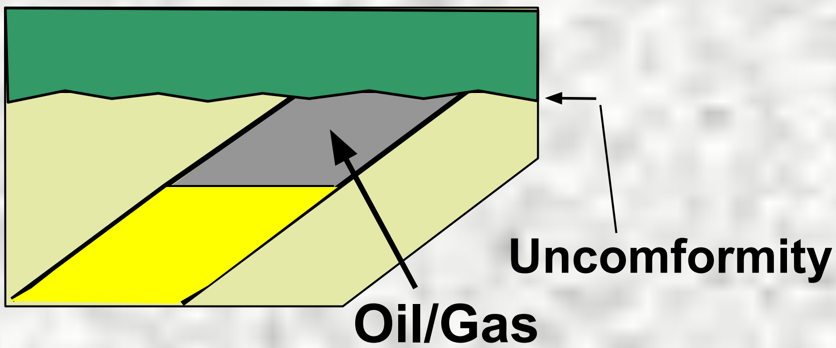


Fault Trap

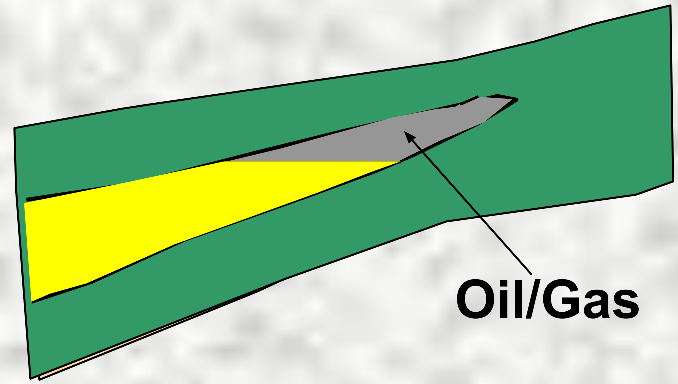


Stratigraphic Hydrocarbon Traps

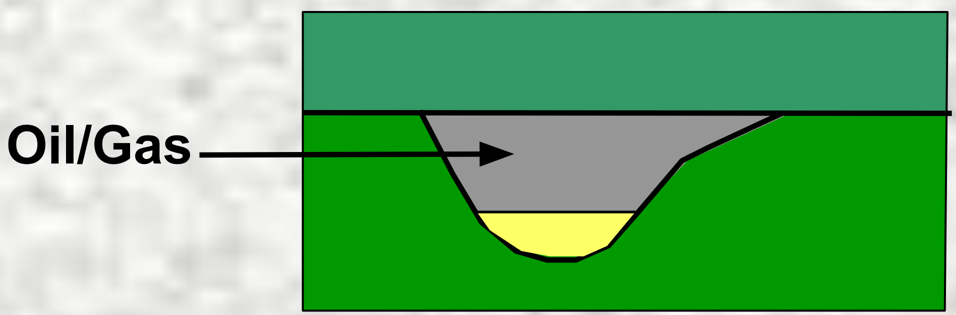
Unconformity



Pinch out



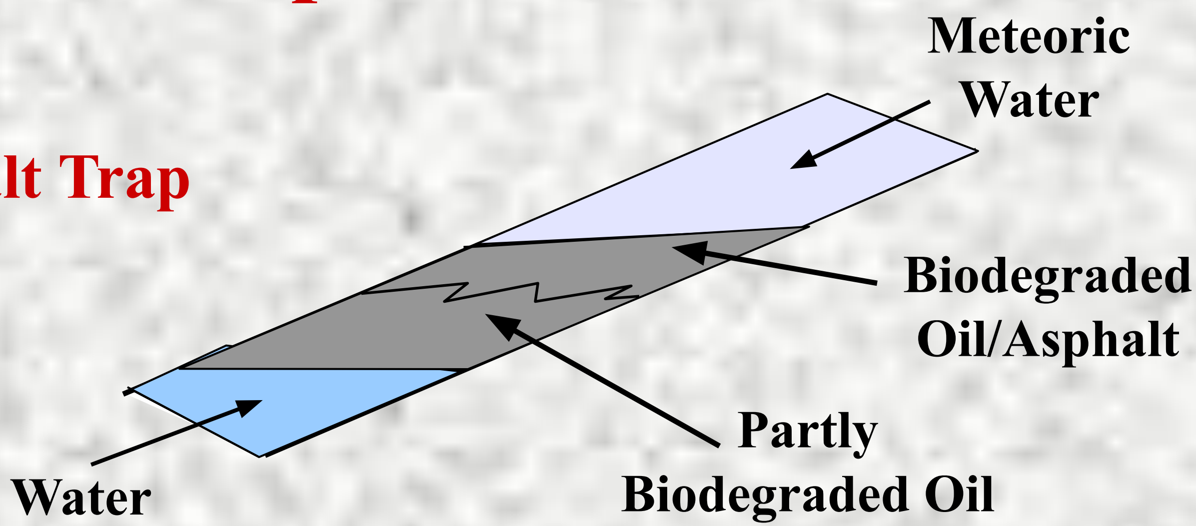
Channel Pinch Out



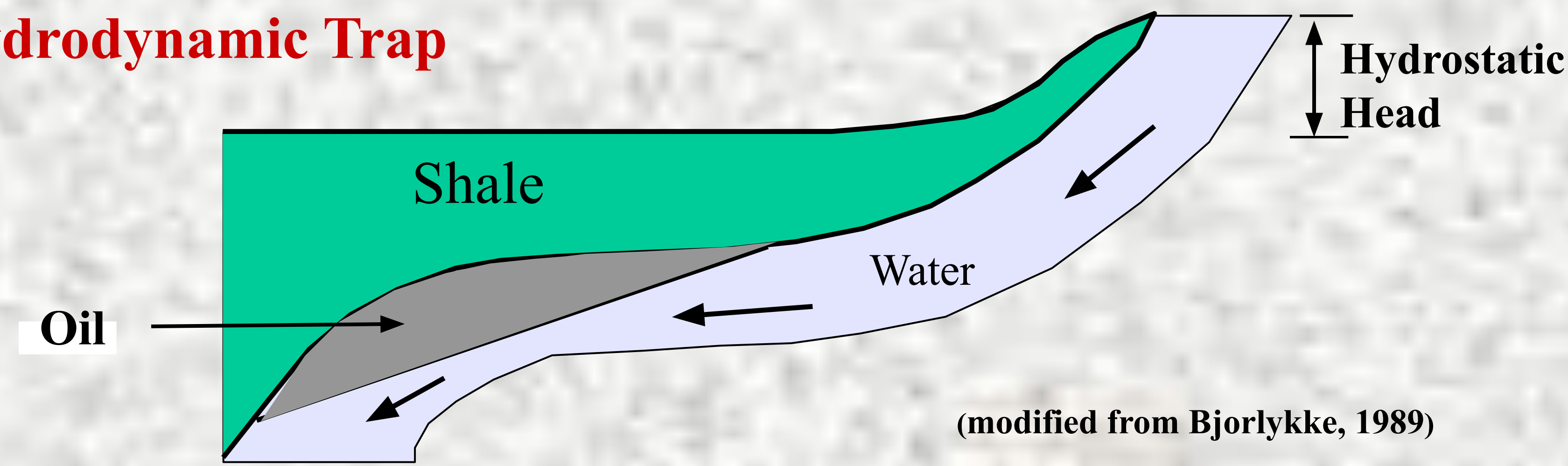
(modified from Bjorlykke, 1989)

Other Traps

Asphalt Trap



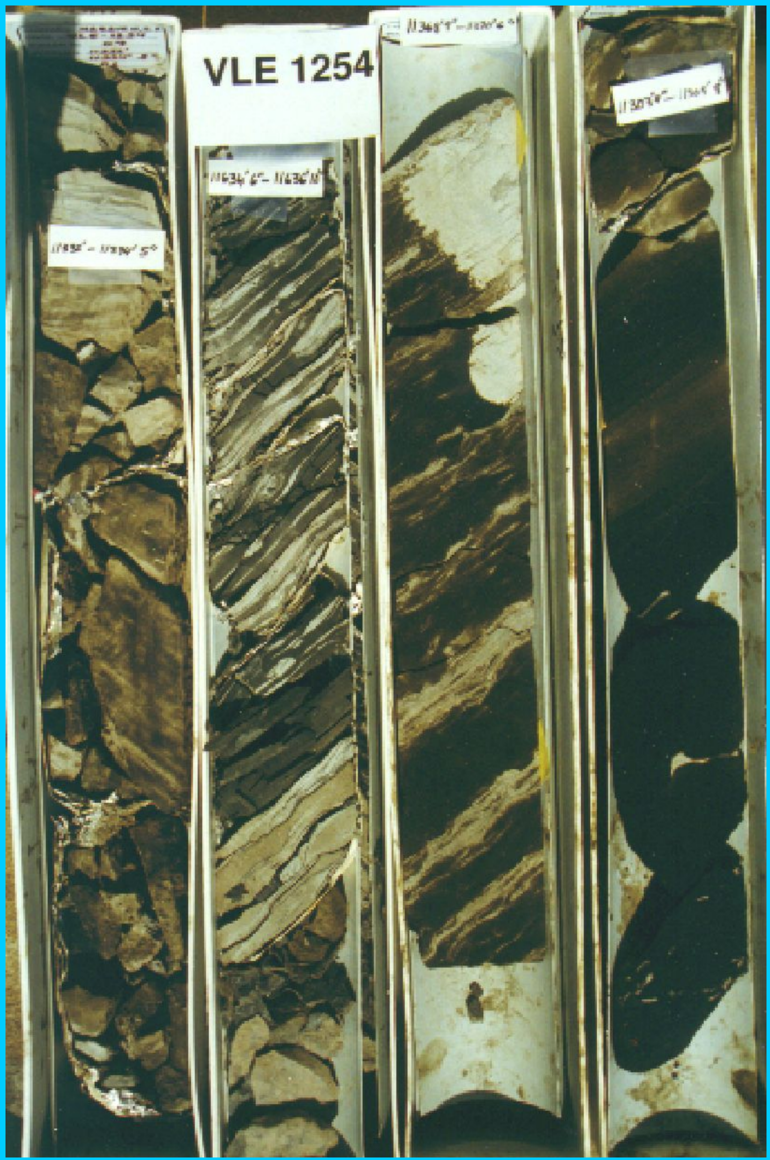
Hydrodynamic Trap



(modified from Bjorlykke, 1989)

Heterogeneity

Reservoir Heterogeneity in Sandstone



Heterogeneity

- Segments Reservoirs
- Increases Tortuosity of Fluid Flow

Heterogeneity May Result From:

- Depositional Features
- Diagenetic Features

(Whole Core Photograph, Misoa Sandstone, Venezuela)

Reservoir Heterogeneity in Sandstone

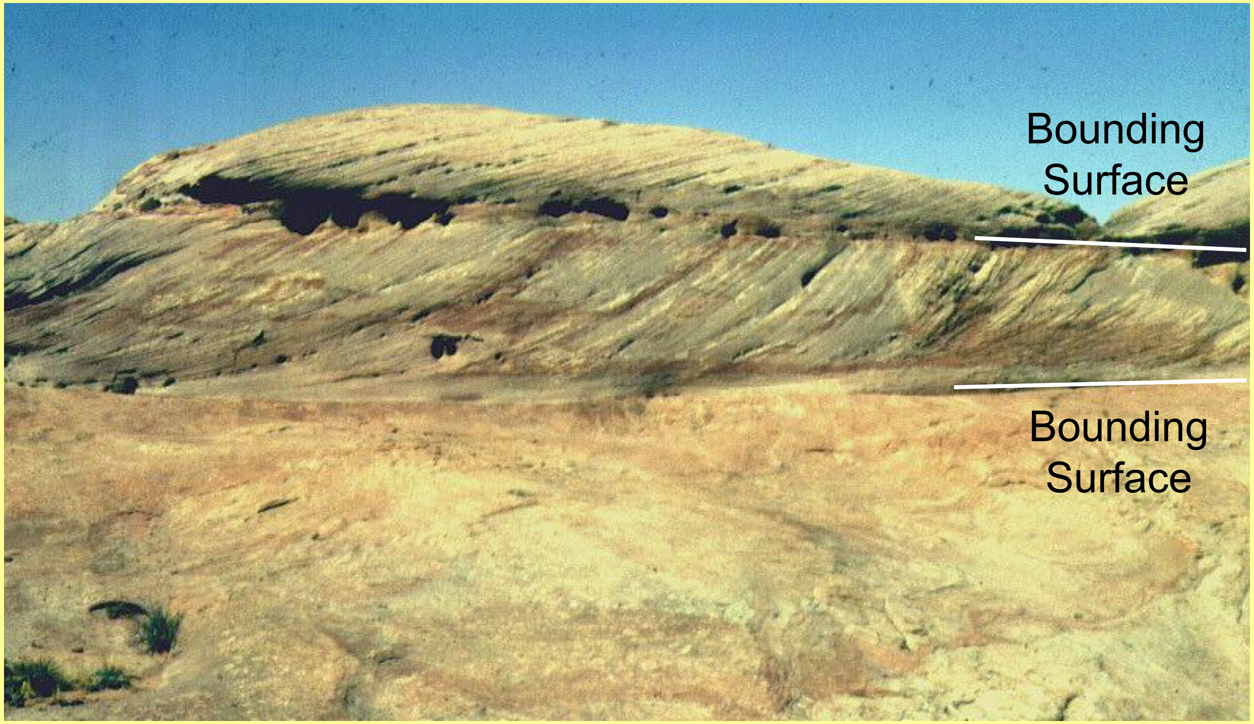
Heterogeneity Also May Result From:

- Faults
- Fractures

Faults and Fractures may be Open (Conduits) or Closed (Barriers) to Fluid Flow

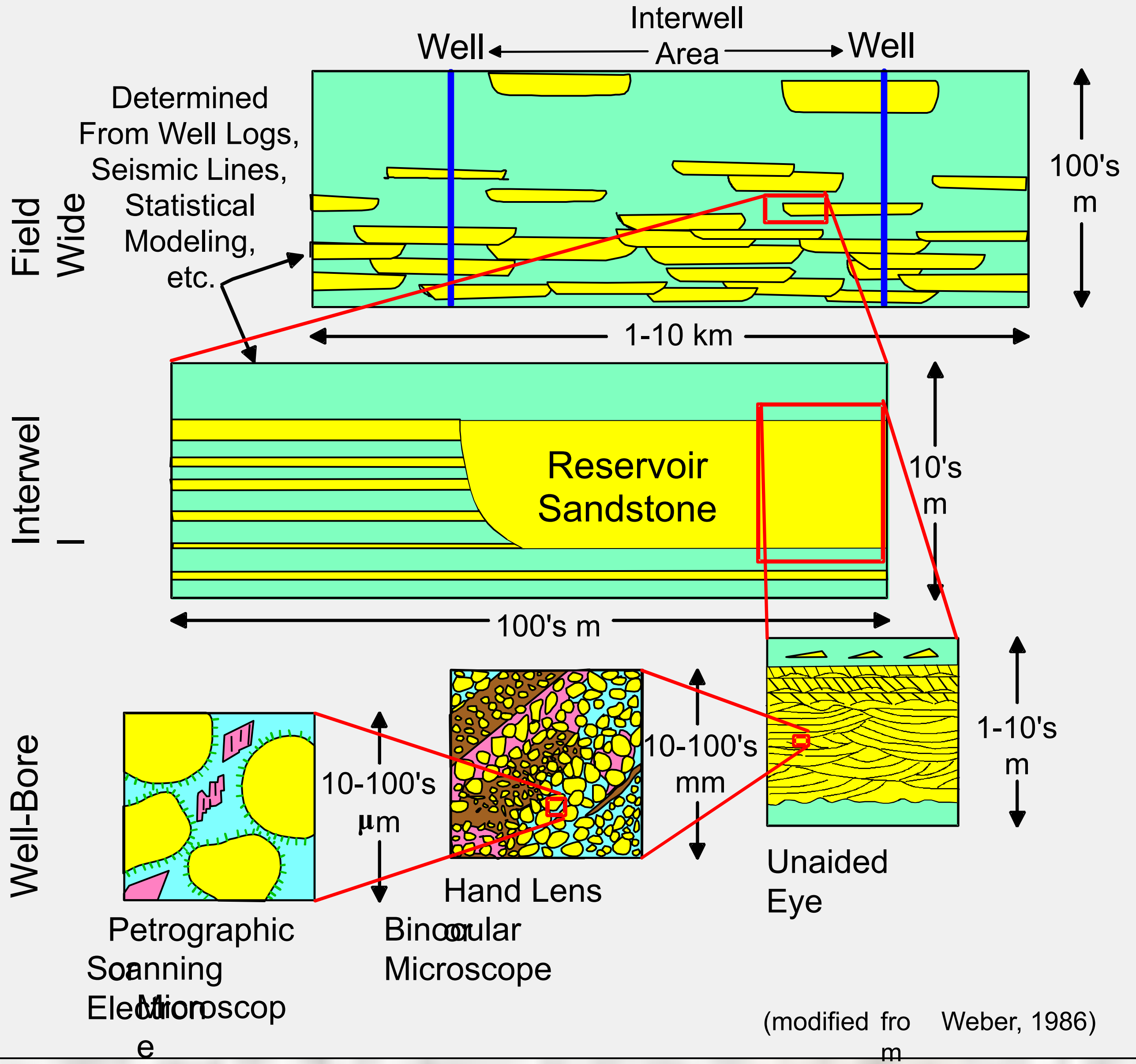
(Whole Core Photograph, Misoa Sandstone, Venezuela)

Geologic Reservoir Heterogeneity



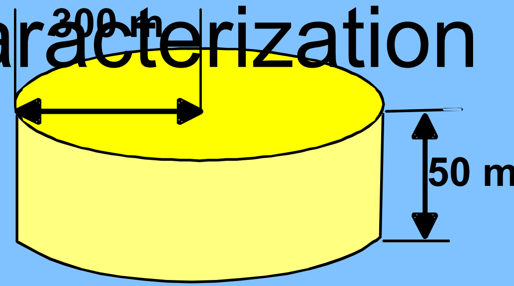
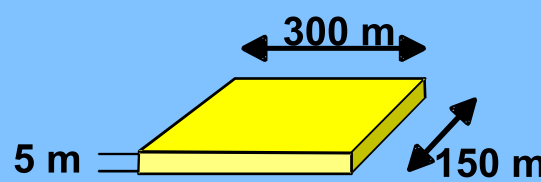
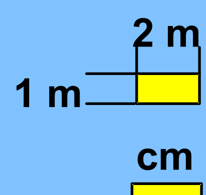
Eolian Sandstone, Entrada Formation, Utah, USA

Scales of Geological Reservoir Heterogeneity



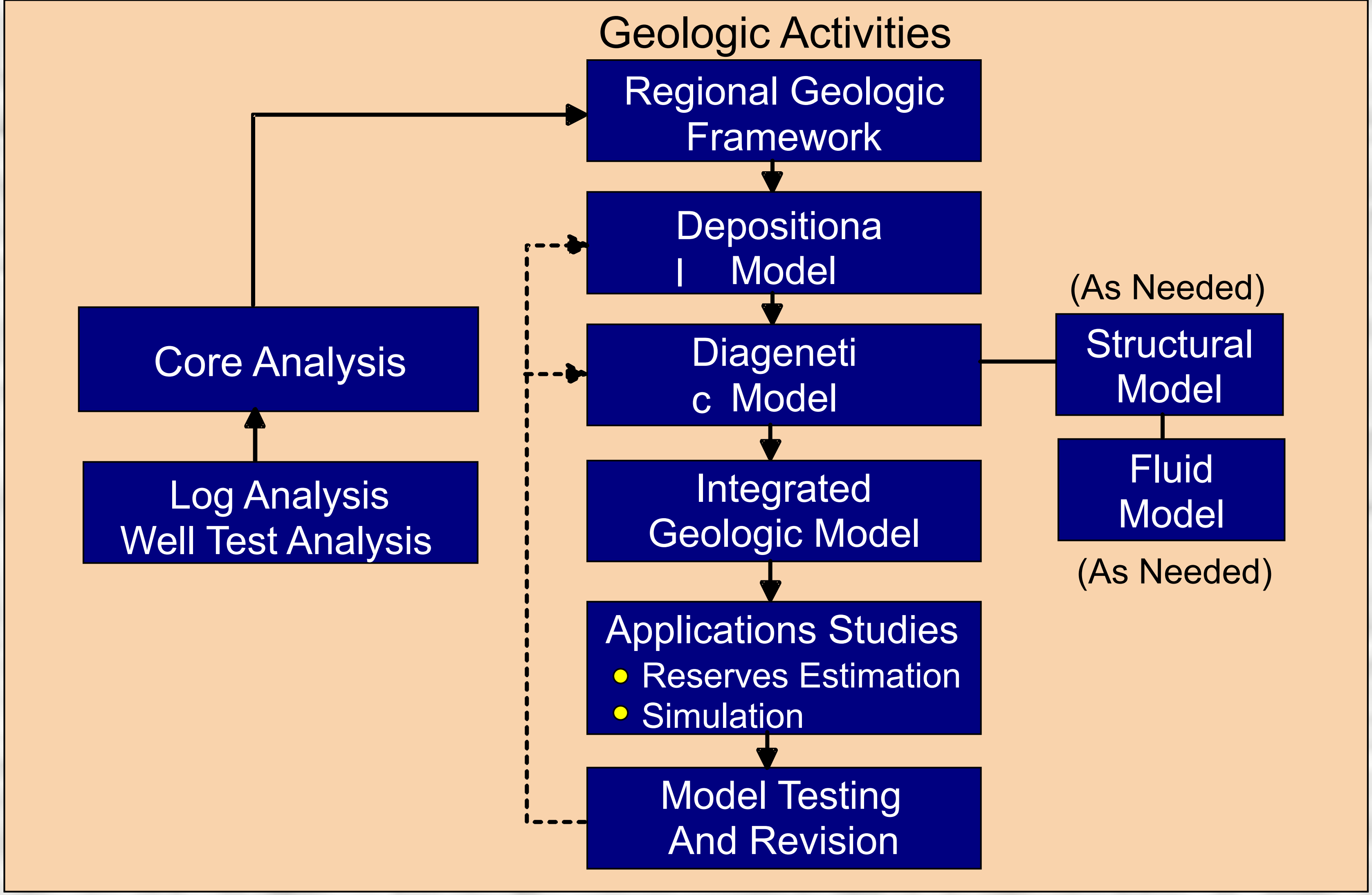
(modified from Weber, 1986)

Scales of Investigation Used in Reservoir Characterization

			Relative Volume
Gigascopic		Well Test	10^{14}
Megascopic		Reservoir Model Grid Cell	2×10^{12}
Macroscopic		Wireline Log Interva Core Plug	3×10^{7} 5×10^{2}
Microscopic		Geological Thin Section	1

(modified from Hurst, 1993)

Stages In The Generation of
An Integrated Geological Reservoir Model



Oil and Gas Formation.mp4