

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.**

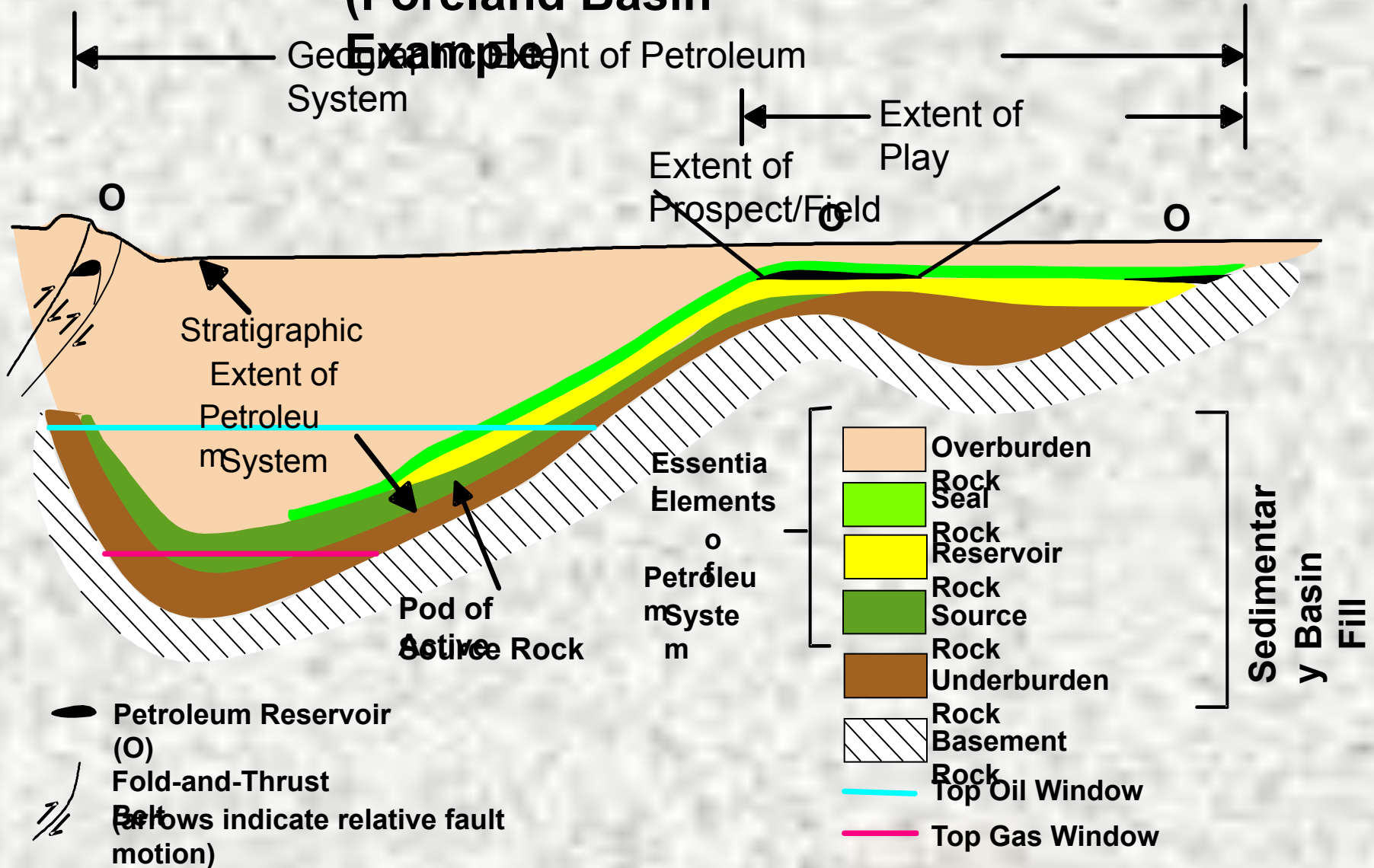
These Include:

- **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)

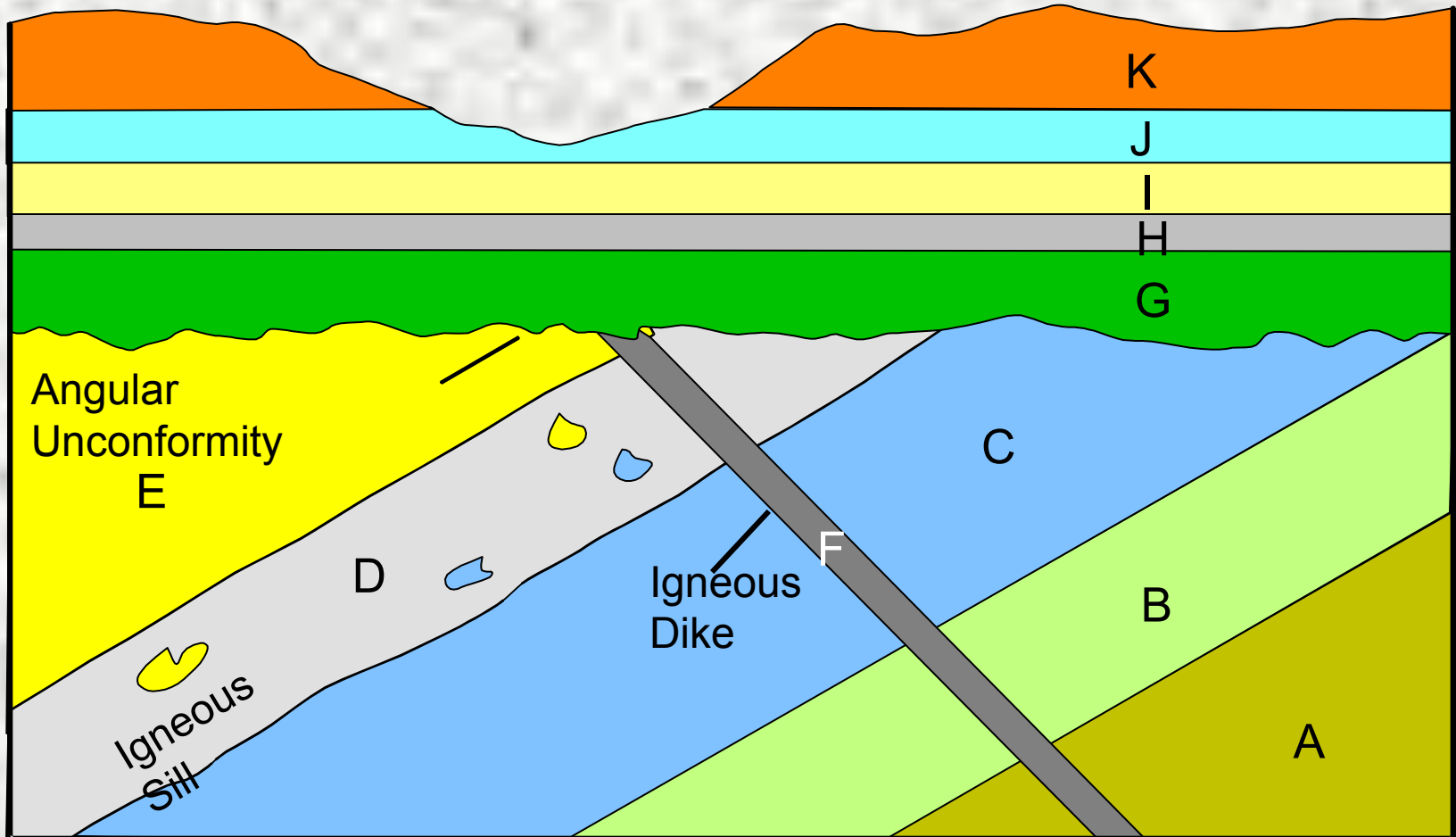


(modified from Magoon and Dow, 1994)

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

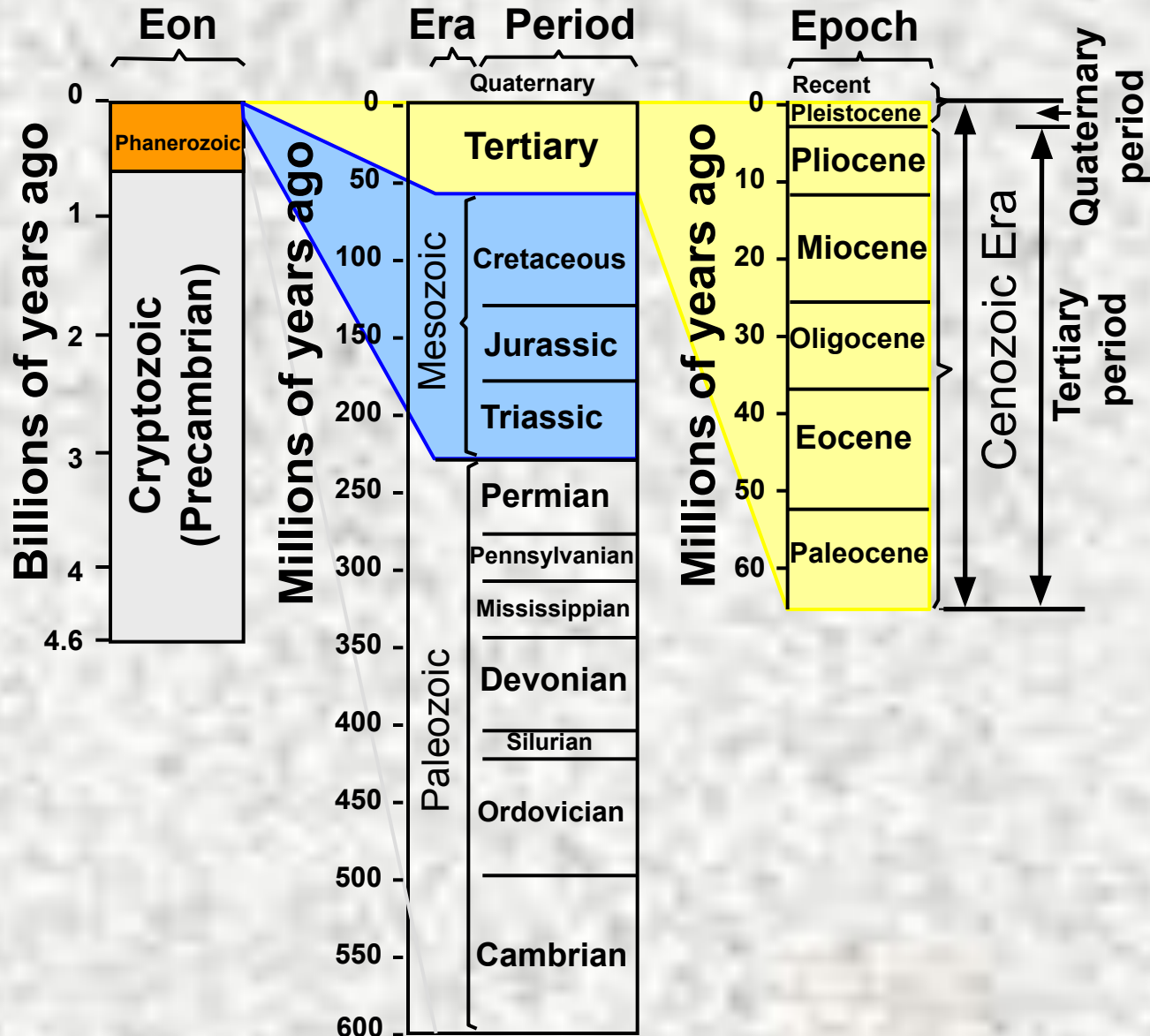
- **Nonconformity**

- 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**

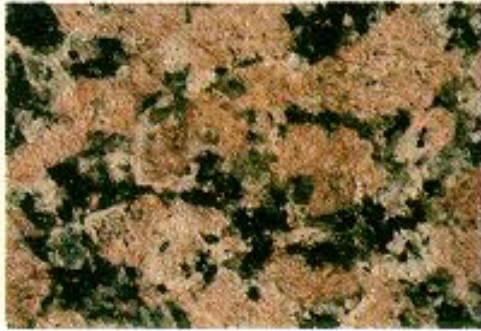
Geologic Time Chart



Rocks

Classification of Rocks

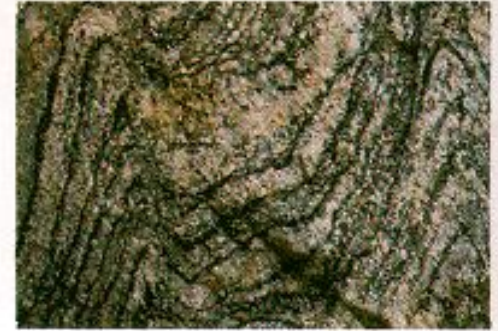
IGNEOUS



SEDIMENTARY



METAMORPHIC



Source of material
Rock-forming process

Molten materials in deep crust and upper mantle

Crystallization (Solidification of melt)

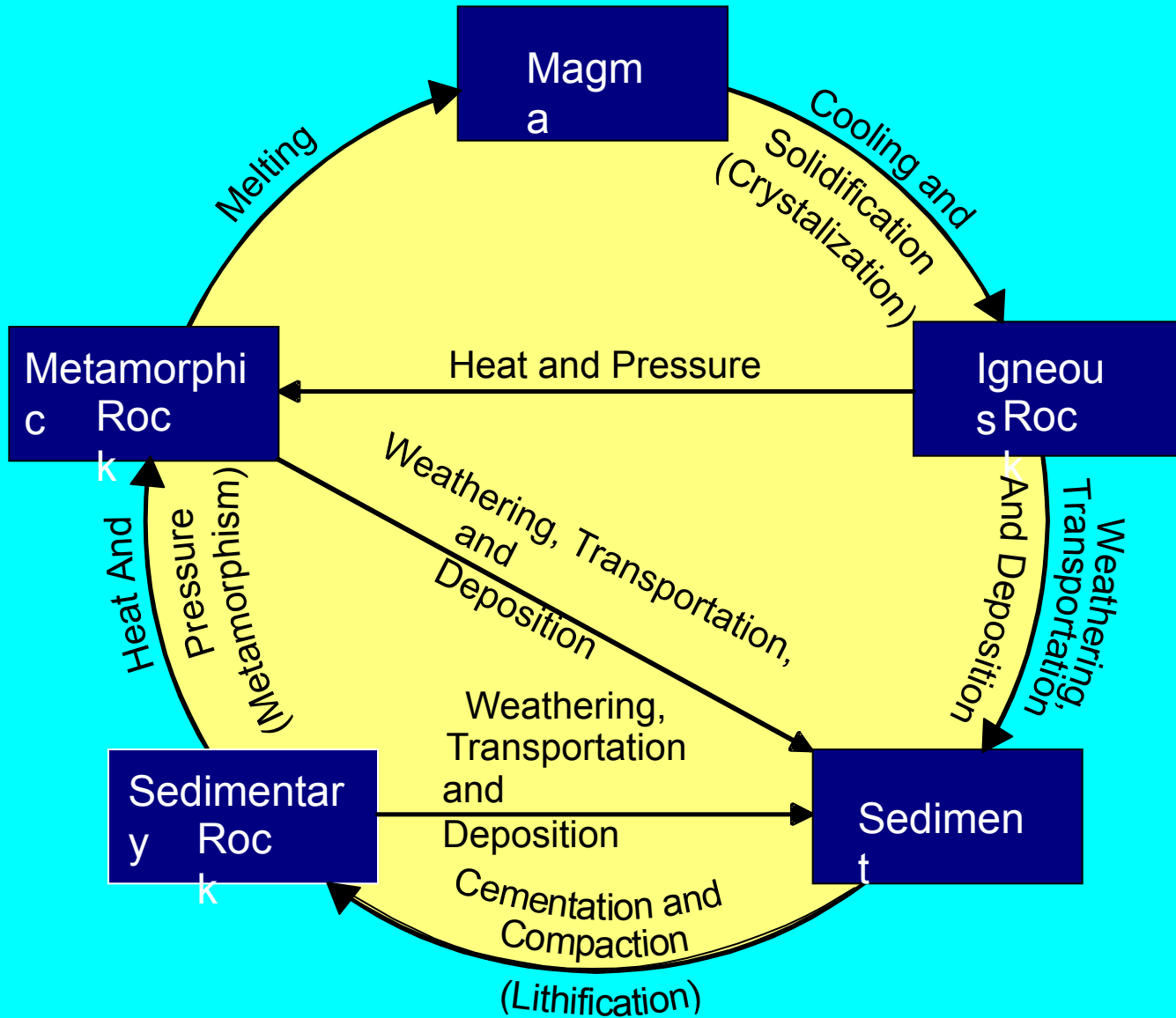
Weathering and erosion of rocks exposed at surface

Sedimentation, burial and lithification

Rocks under high temperatures and pressures in deep crust

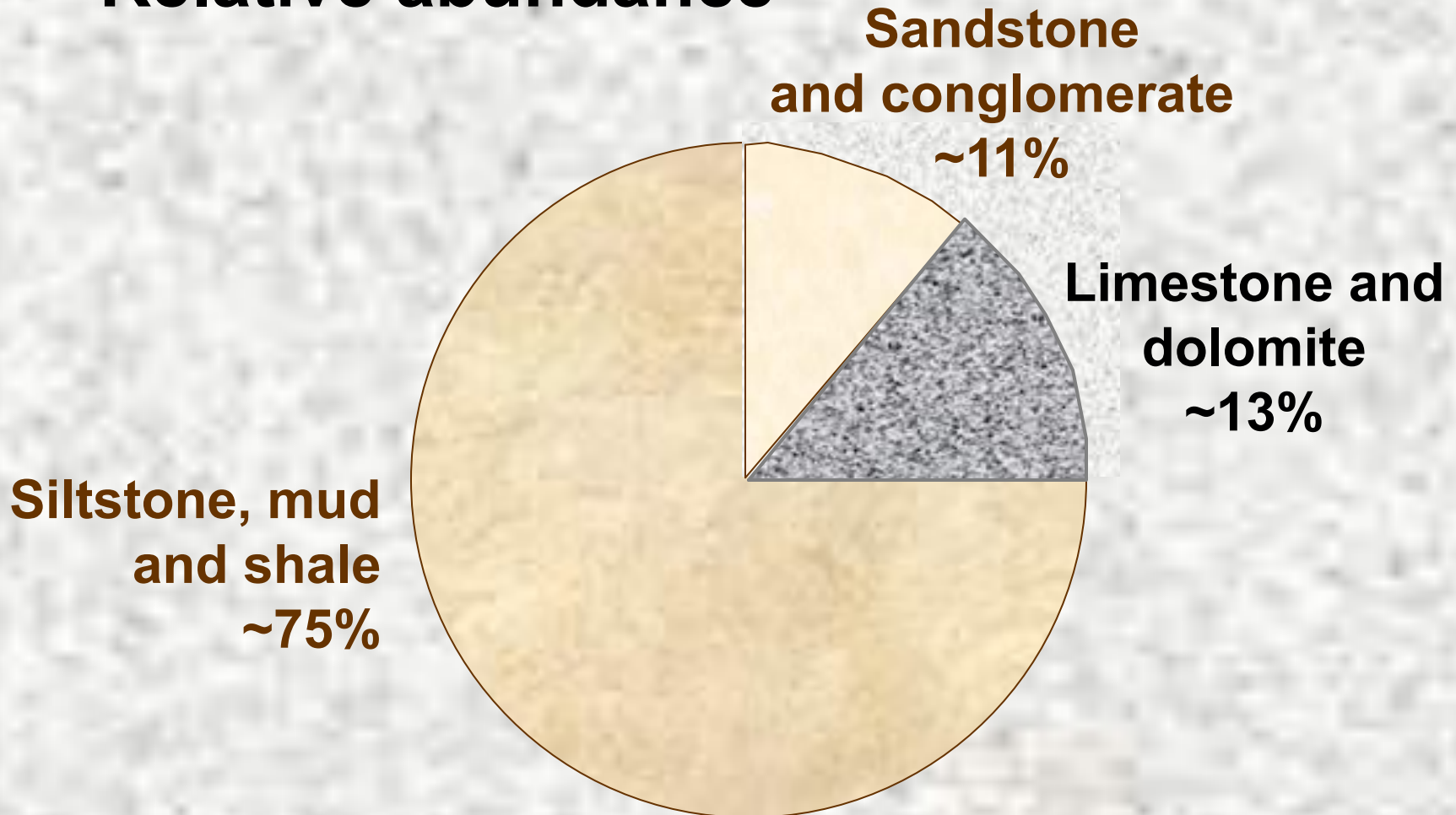
Recrystallization due to heat, pressure, or chemically active fluids

The Rock Cycle



Sedimentary Rock Types

- **Relative abundance**



Minerals - Definition



Quartz
Crystals

- Naturally Occurring Solid
- Generally Formed by Inorganic Processes
- Ordered Arrangement of Atoms (Crystal Structure)
- Chemical Composition and Physical Properties 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

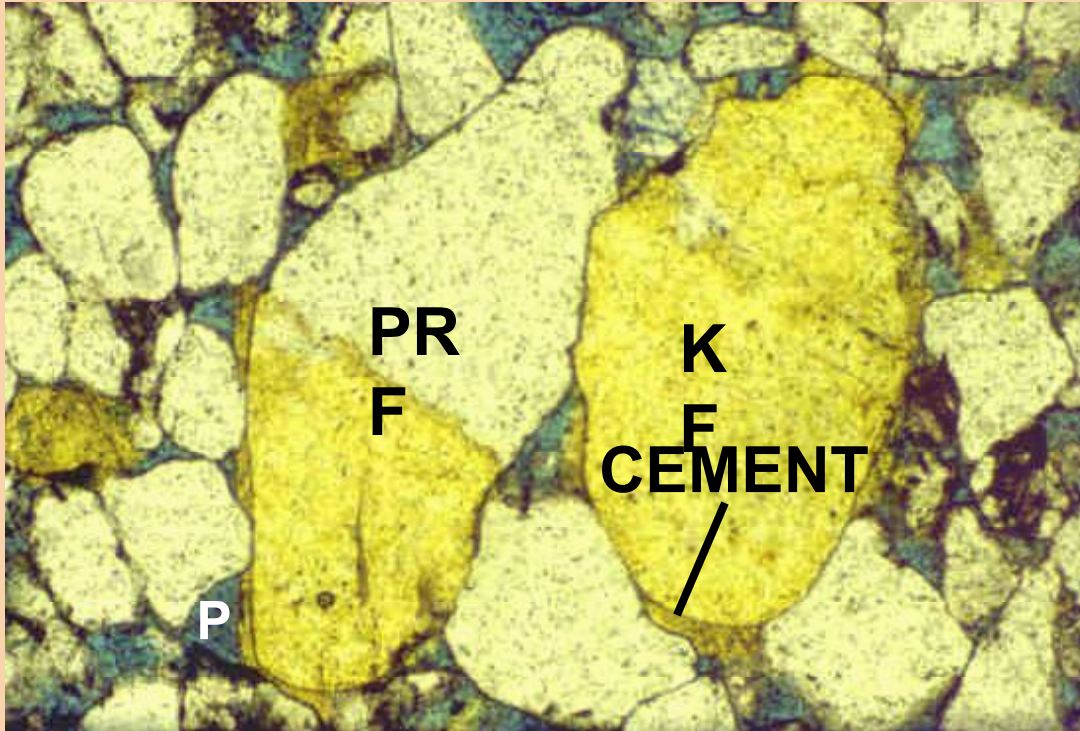
Oxides	Sulfides	Carbonates	Sulfates	Halides
Hematite Magnetite	Pyrite Galena Sphalerite	Aragonite Calcite Dolomite Fe-Dolomite Ankerite	Anhydrite Gypsum	Halite Sylvite
e Silicates				
Non-Ferromagnesia (Common in Sedimentary Rocks)		Ferromagnesia (not common in sedimentary rocks)		
Quartz Muscovite (mica) Feldspars Potassium feldspar (K-spar) <i>Orthoclase</i> <i>Microcline, etc.</i> Plagioclase <i>Albite (Na-rich - common) through Anorthite (Ca-rich - not common)</i>		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



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

Norphlet Sandstone, Offshore Alabama, USA
Grains are About \leq 0.25 mm in Diameter/Length

Porosity in Sandstone



**Scanning Electron Micrograph
Norphlet Formation, Offshore Alabama, USA**

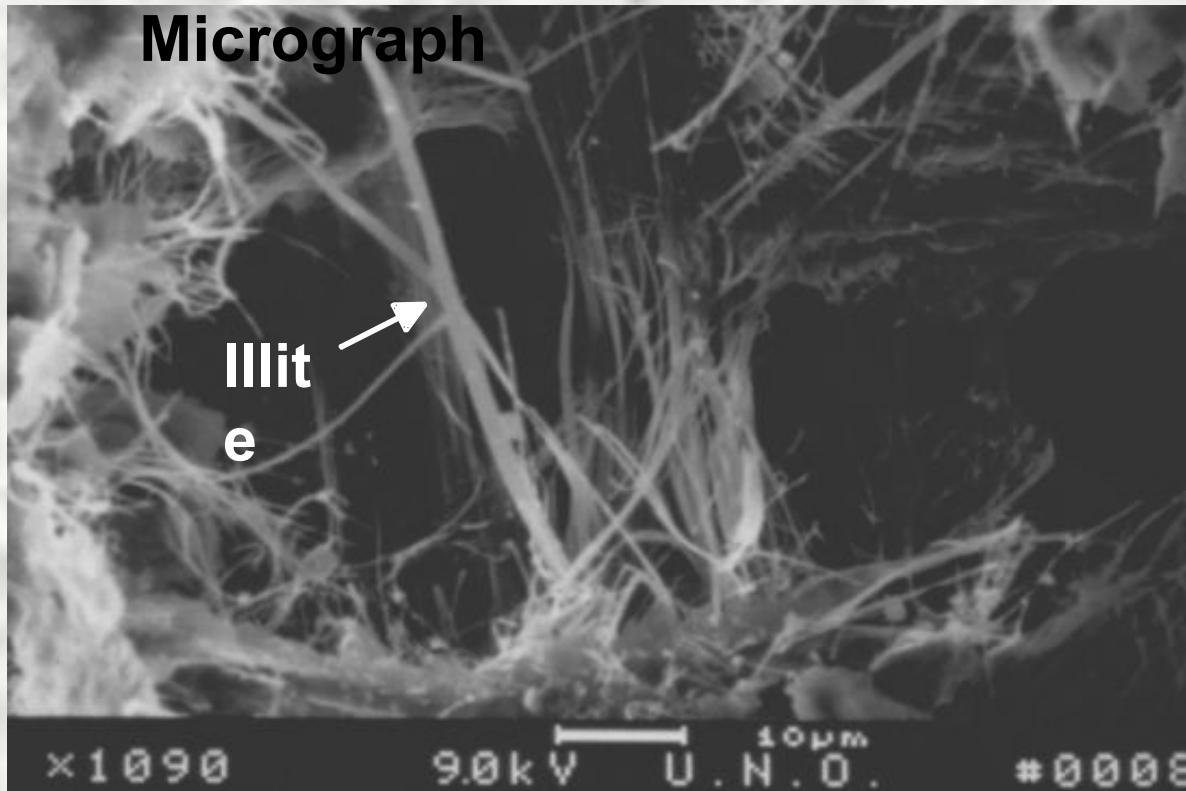
**Pores Provide the
Volume to Contain
Hydrocarbon Fluids**

**Pore Throats Restrict
Fluid Flow**

Clay Minerals in Sandstone Reservoirs

Fibrous Authigenic Illite

Secondary Electron Micrograph



Jurassic Norphlet Sandstone
Hatters Pond Field, Alabama, USA

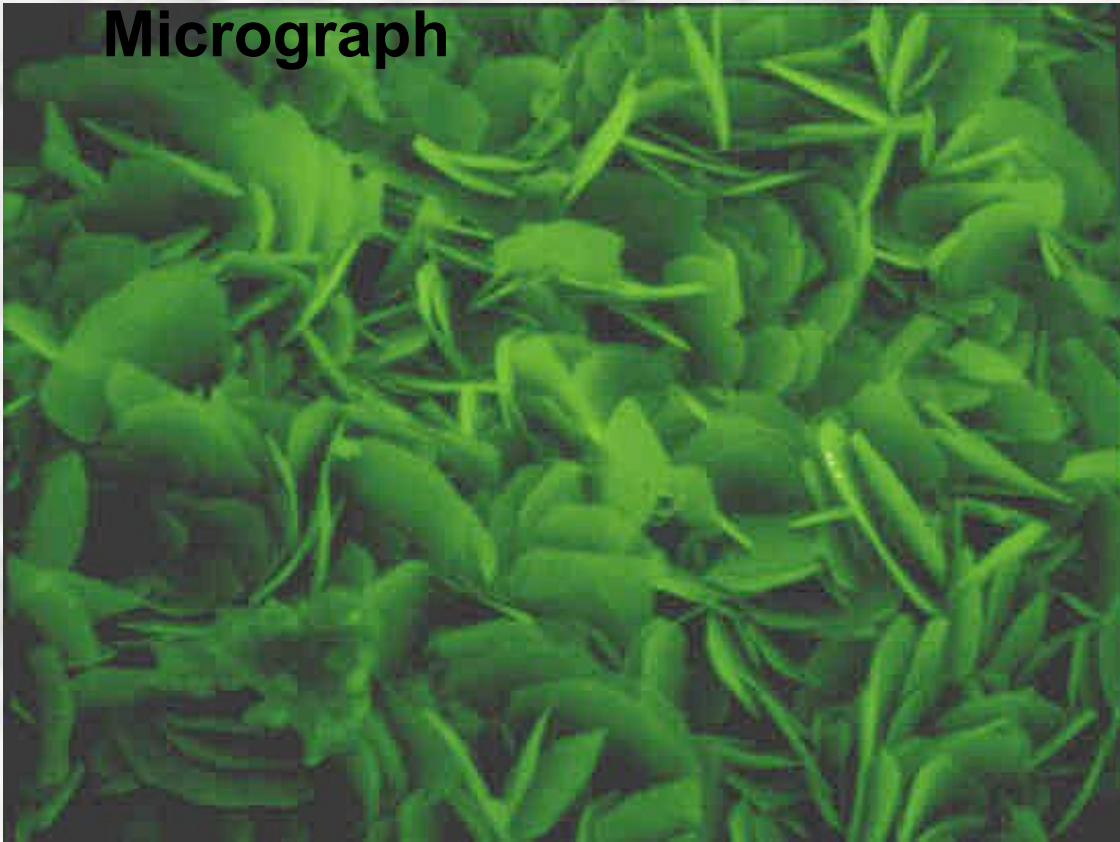
- Significant Permeability Reduction
- Negligible Porosity Reduction
- High Water Saturation
- Migration fines Problem

(Photograph by R.L. Kugler)

Clay Minerals in Sandstone Reservoirs

Authigenic Chlorite

Secondary Electron Micrograph



Jurassic Norphlet Sandstone
Offshore Alabama, USA

~ 10 μm

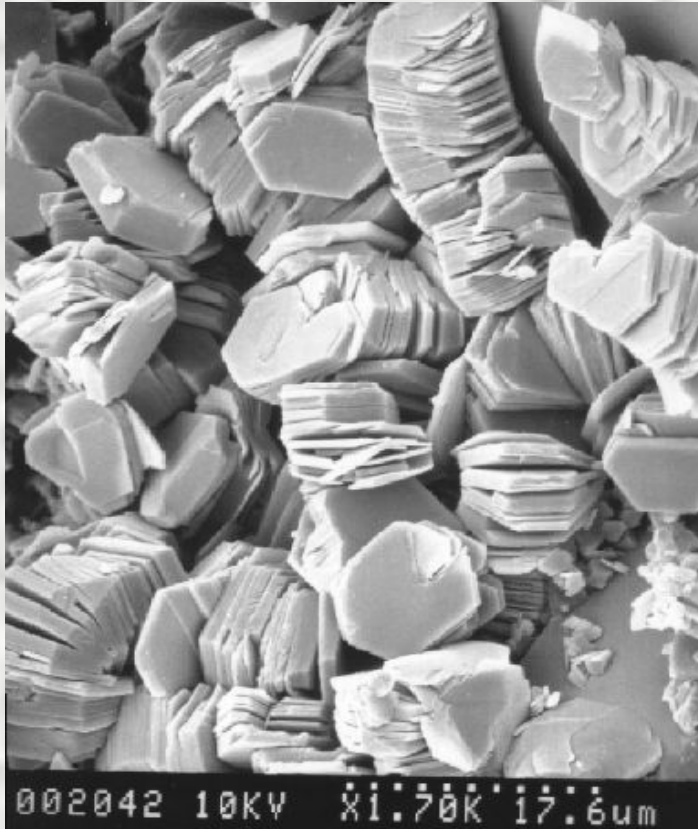
- Iron-Rich Varieties React With Acid
- Occurs in ~~Deeply~~ Buried Sandstones With High Reservoir Quality
- Occurs as ~~Clots~~ on ~~Grain~~ Surfaces

(Photograph by R.L. Kugler)

Clay Minerals in Sandstone Reservoirs

Authigenic Kaolinite

Secondary Electron Micrograph



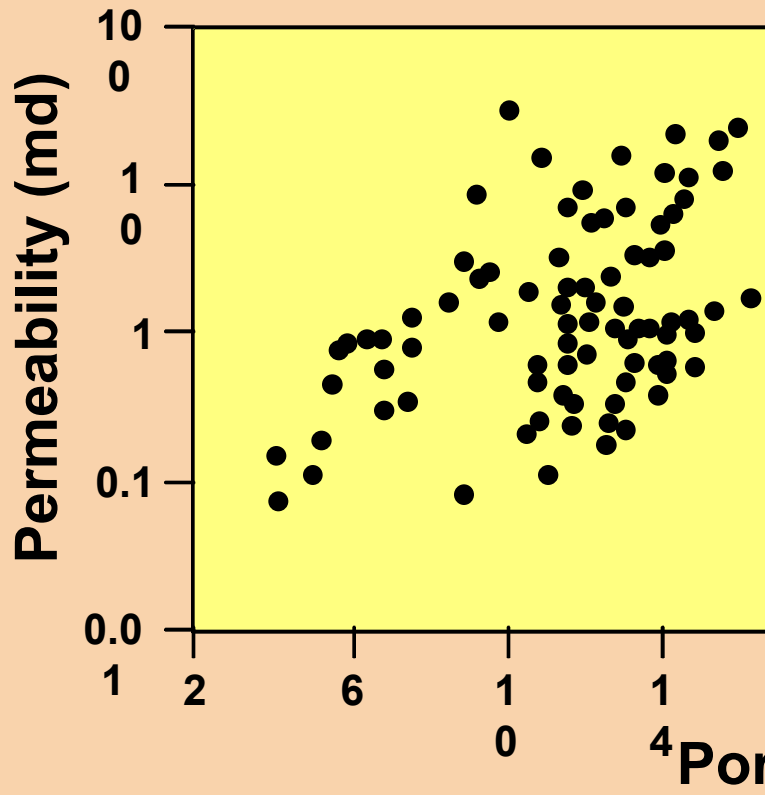
- Significant Permeability Reduction
- High Irreducible Water Saturation
- Migration of Fines Problem

Carter
North Blount
Whorn Creek Oil Unit
Black Warrior Basin, Alabama, USA

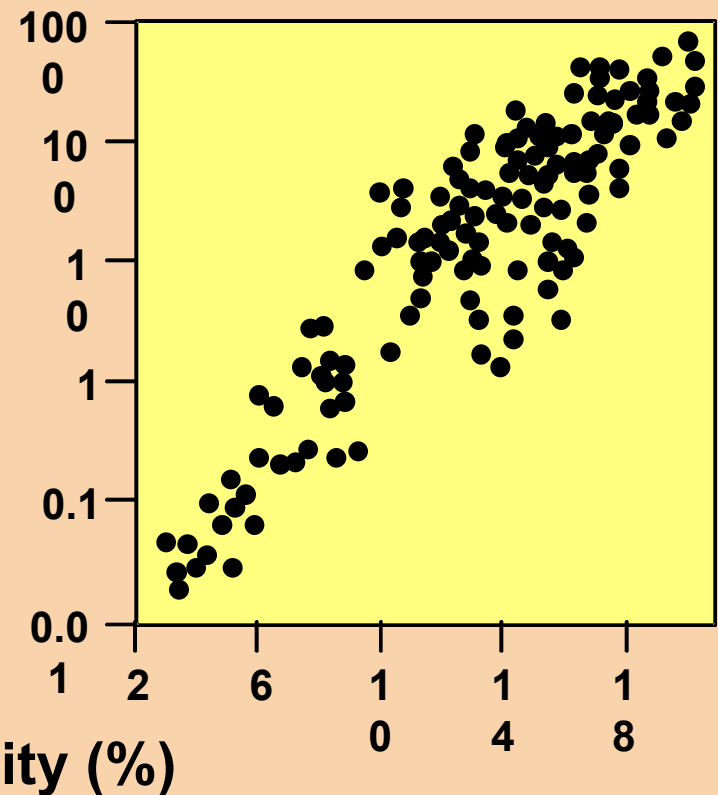
(Photograph by R.L. Kugler)

Effects of Clays on Reservoir Quality

Authigenic Illite

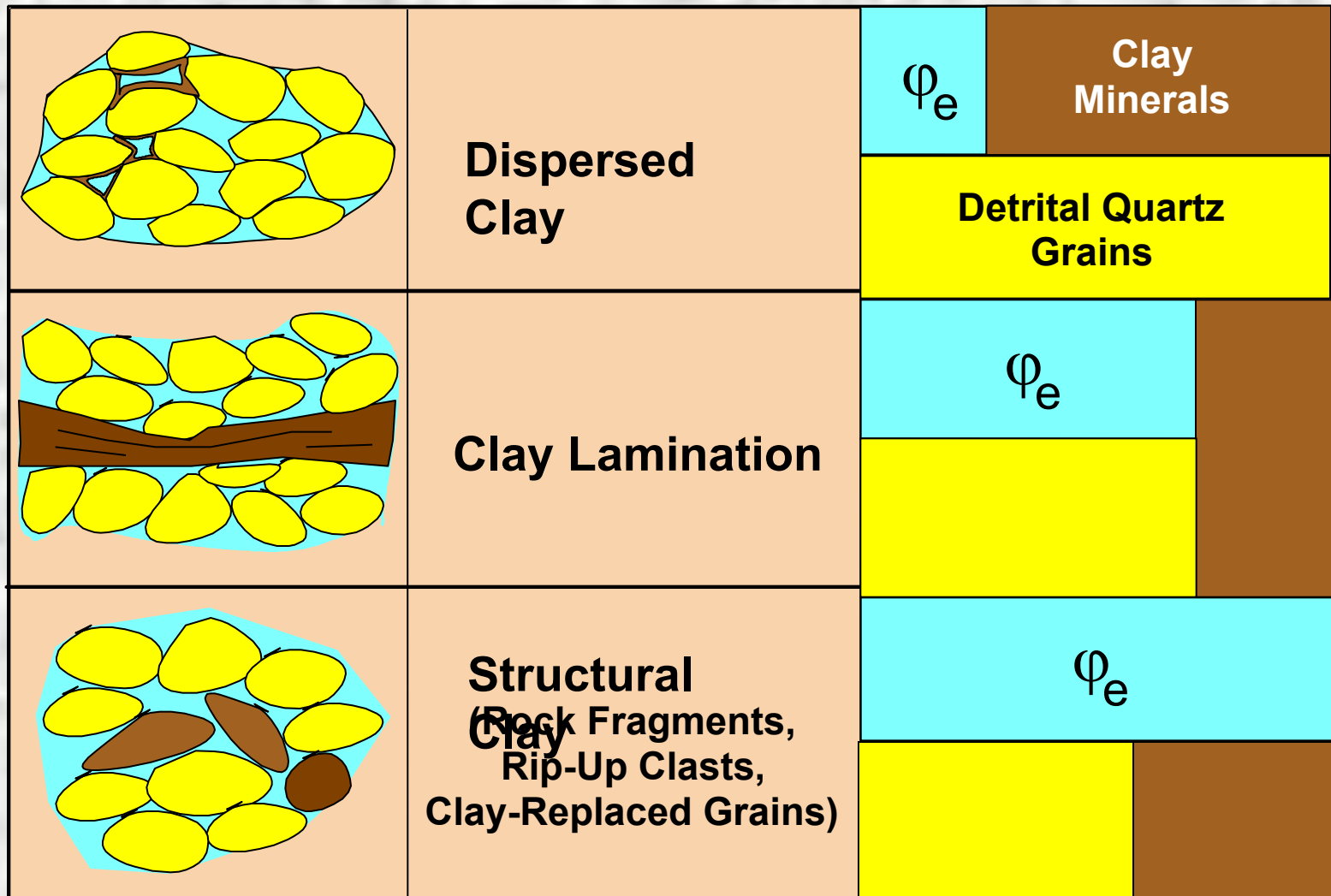


Authigenic Chlorite

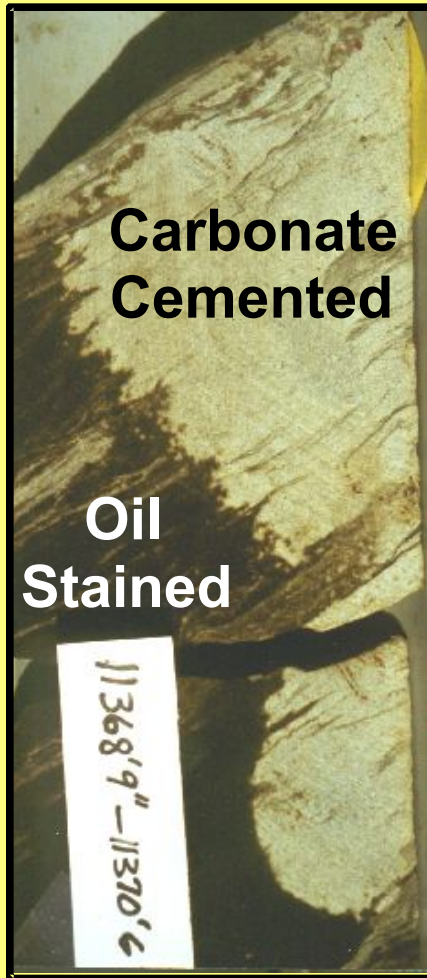


(modified from Kugler and McHugh, 1990)

Influence of Clay-Mineral Distribution on Effective Porosity



Diagenesis



Carbonate
Cemented

Oil
Stained

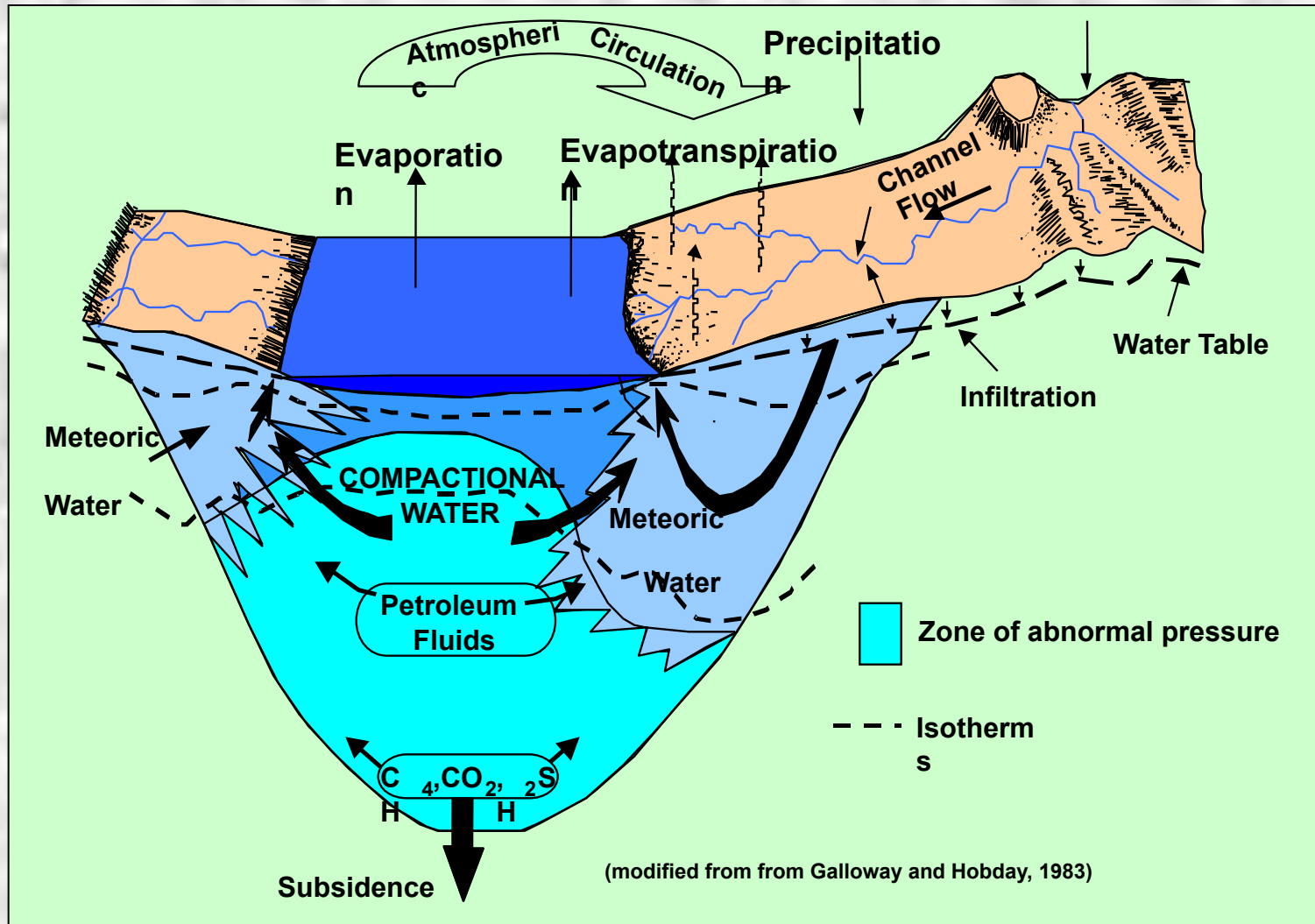
11368'9"
-11370'6"

Whole

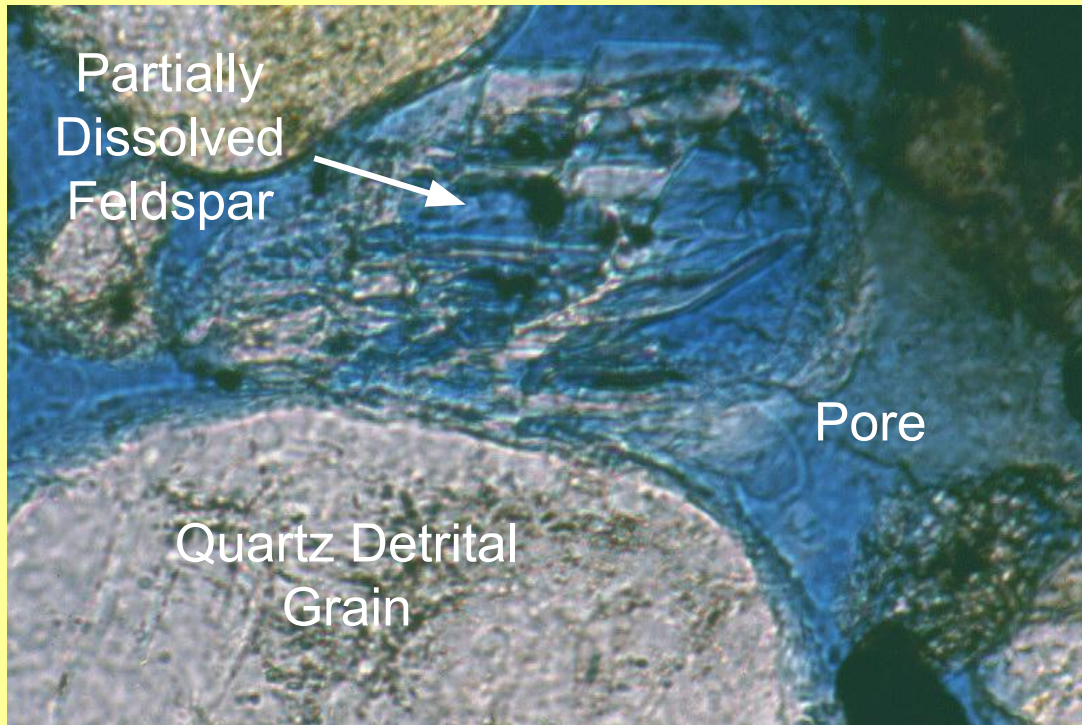
Misoa Formation,
Venezuela

- Diagenesis is the 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 Quality

Fluids Affecting Diagenesis



Dissolution Porosity



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

This is Called Secondary Porosity

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

Hydrocarbon Generation, Migration, and Accumulation

Organic Matter in Sedimentary

Rocks

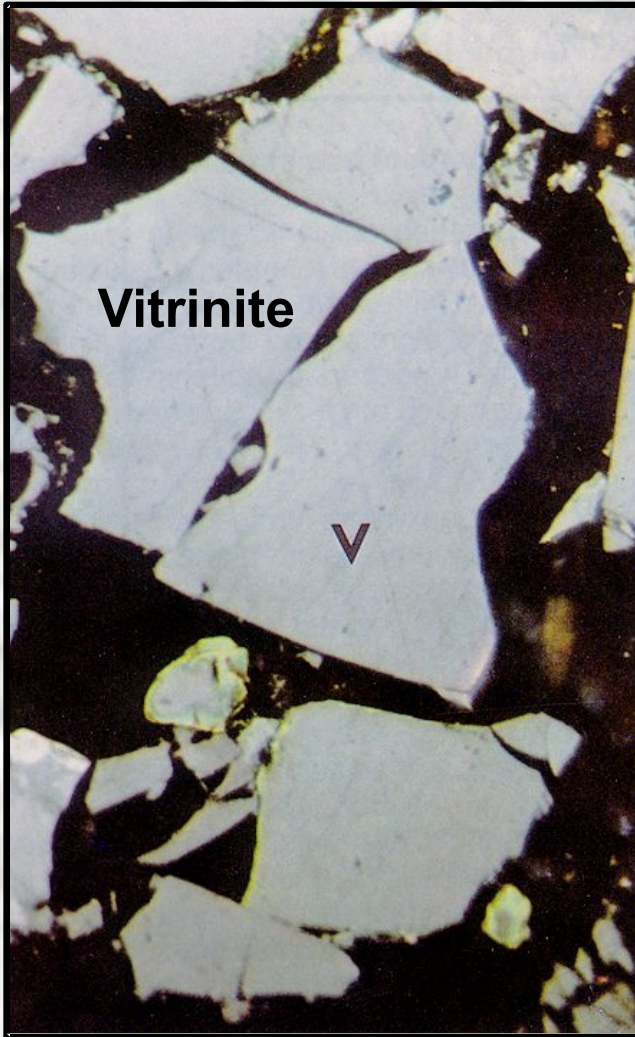
Kerogen

Disseminated Organic Matter
in Sedimentary Rocks That is
Insoluble in 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
the maturity of petroleum source
rock.

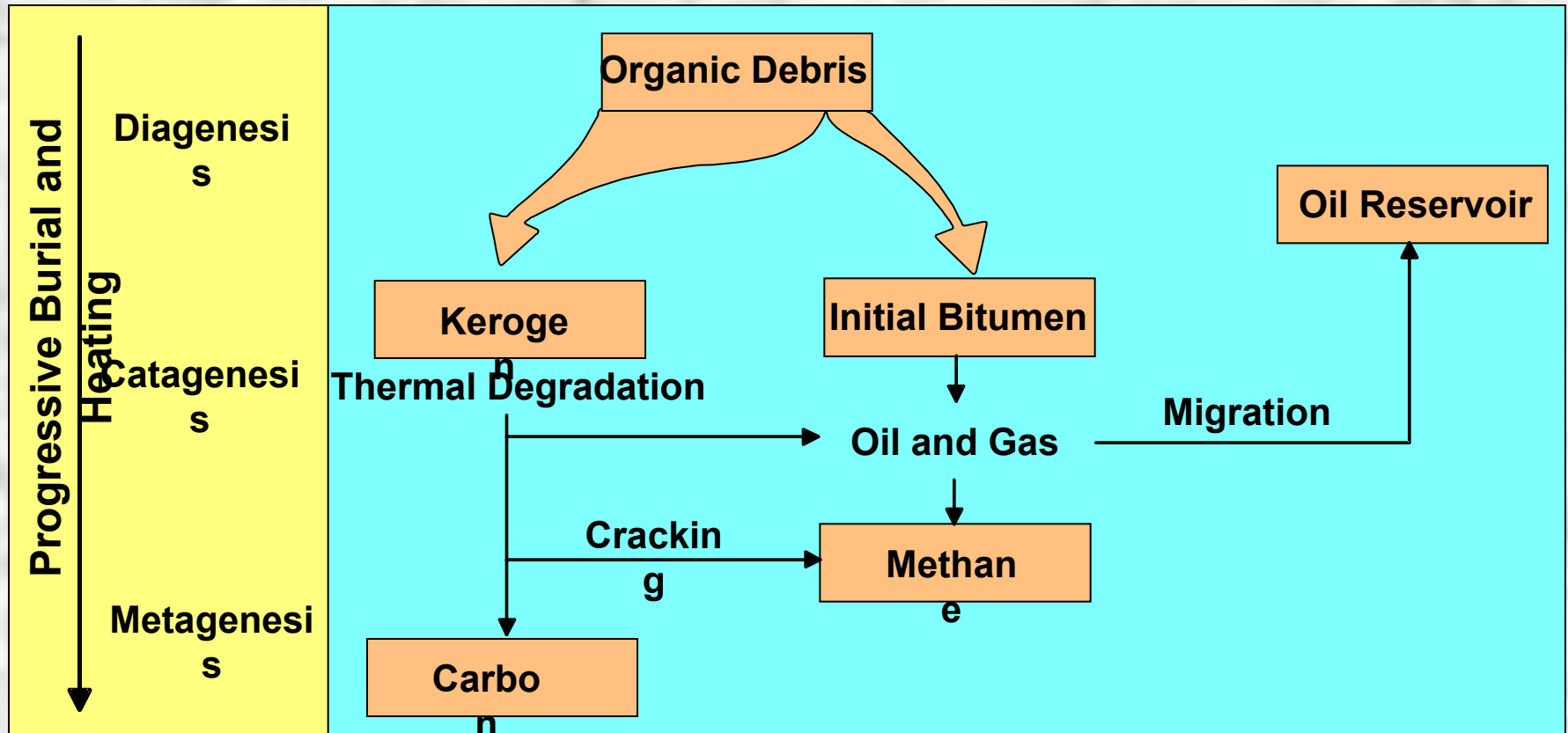


Reflected-Light
Micrograph of Coal

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

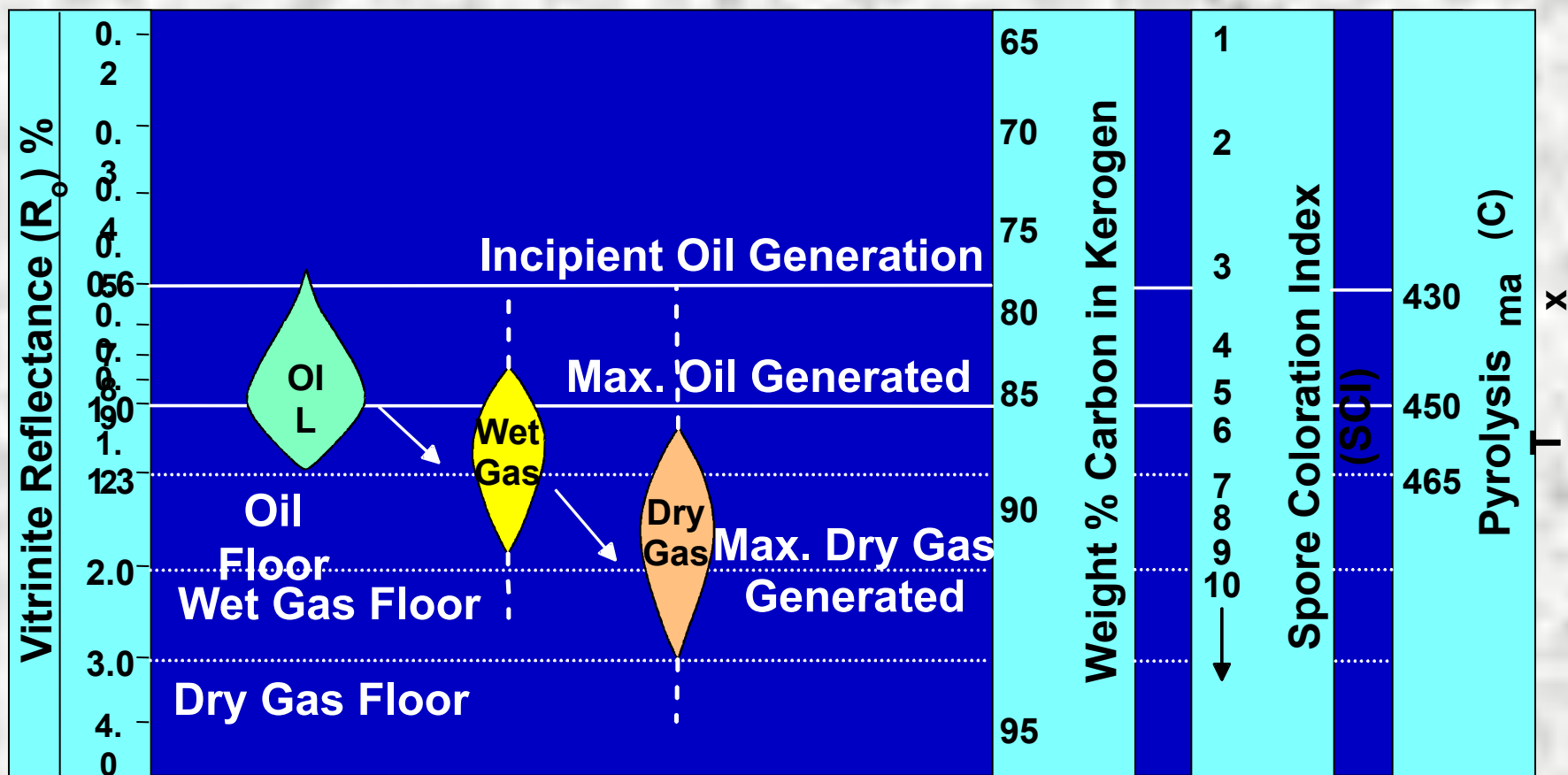
Hydrocarbon Generation Potential	TOC in Shale (wt. %)	TOC in Carbonates (wt. %)
Poor	0.0-0.5	0.0-0.2
Fair	0.5-1.0	0.2-0.5
Good	1.0-2.0	0.5-1.0
Very Good	2.0-5.0	1.0-2.0
Excellent	>5.0	>2.0

Schematic Representation of the Mechanism of Petroleum Generation and Destruction



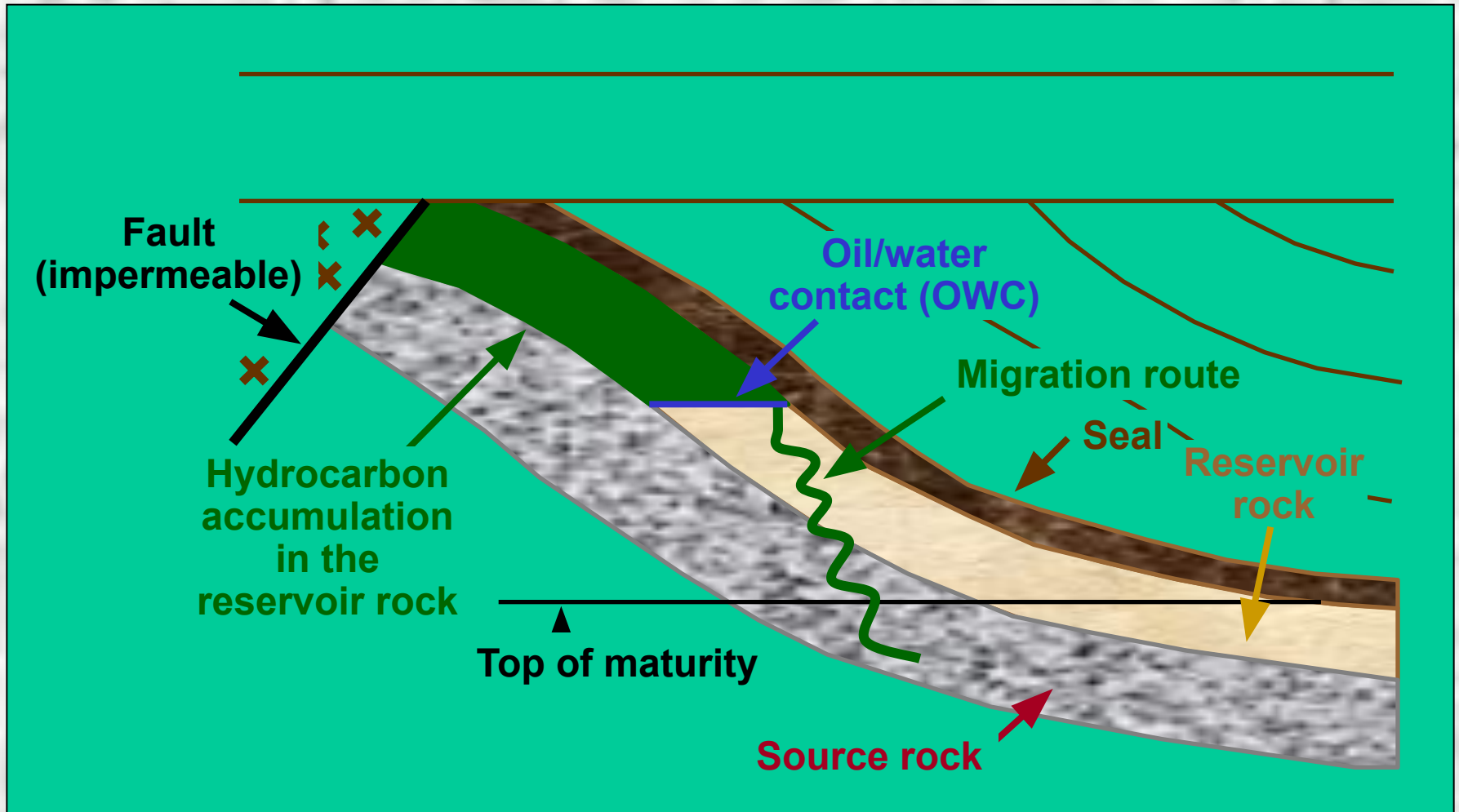
(modified from Tissot and Welte, 1984)

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



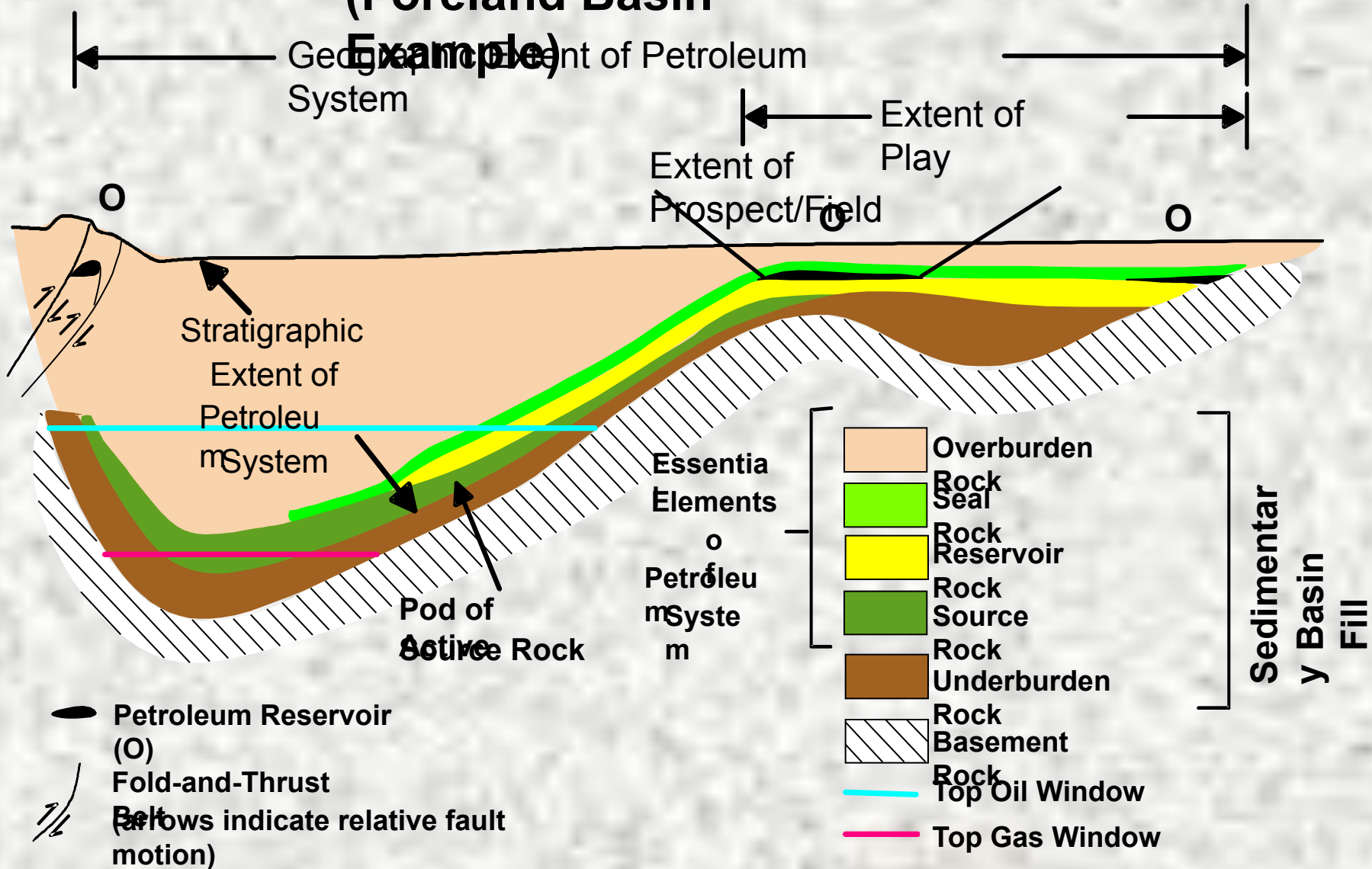
(modified from Foster and Beaumont, 1991, after Dow and O'Conner, 1982)

Generation, Migration, and Trapping of Hydrocarbons



Cross Section Of A Petroleum System

(Foreland Basin Example)

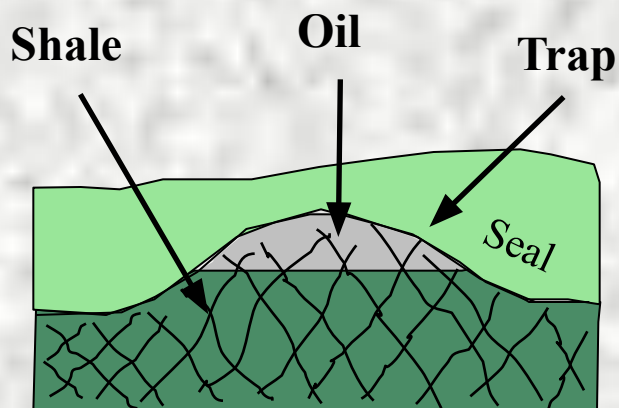


(modified from Magoon and Dow, 1994)

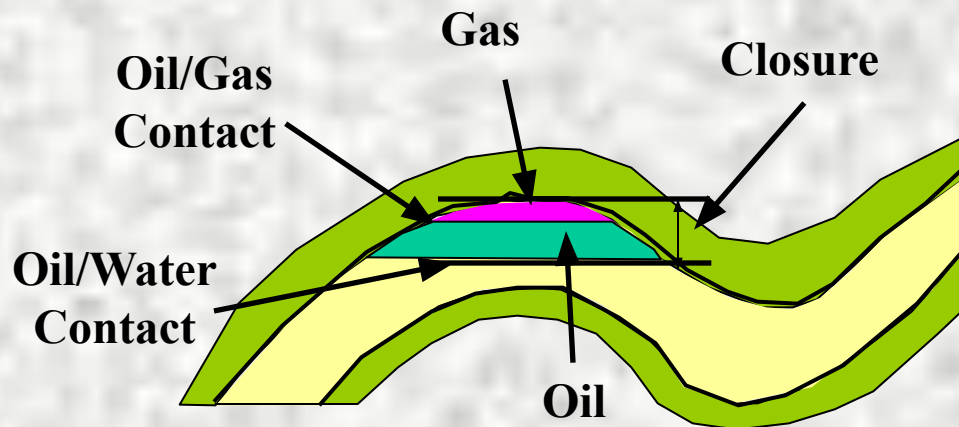
Hydrocarbon Traps

- **Structural traps**
- **Stratigraphic traps**
- **Combination traps**

Structural Hydrocarbon Traps

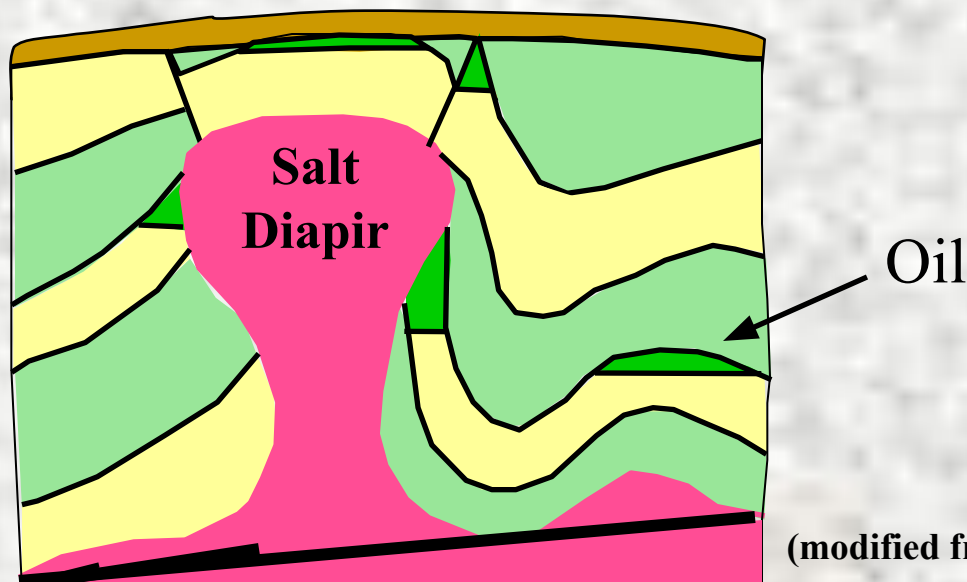


Fracture Basement



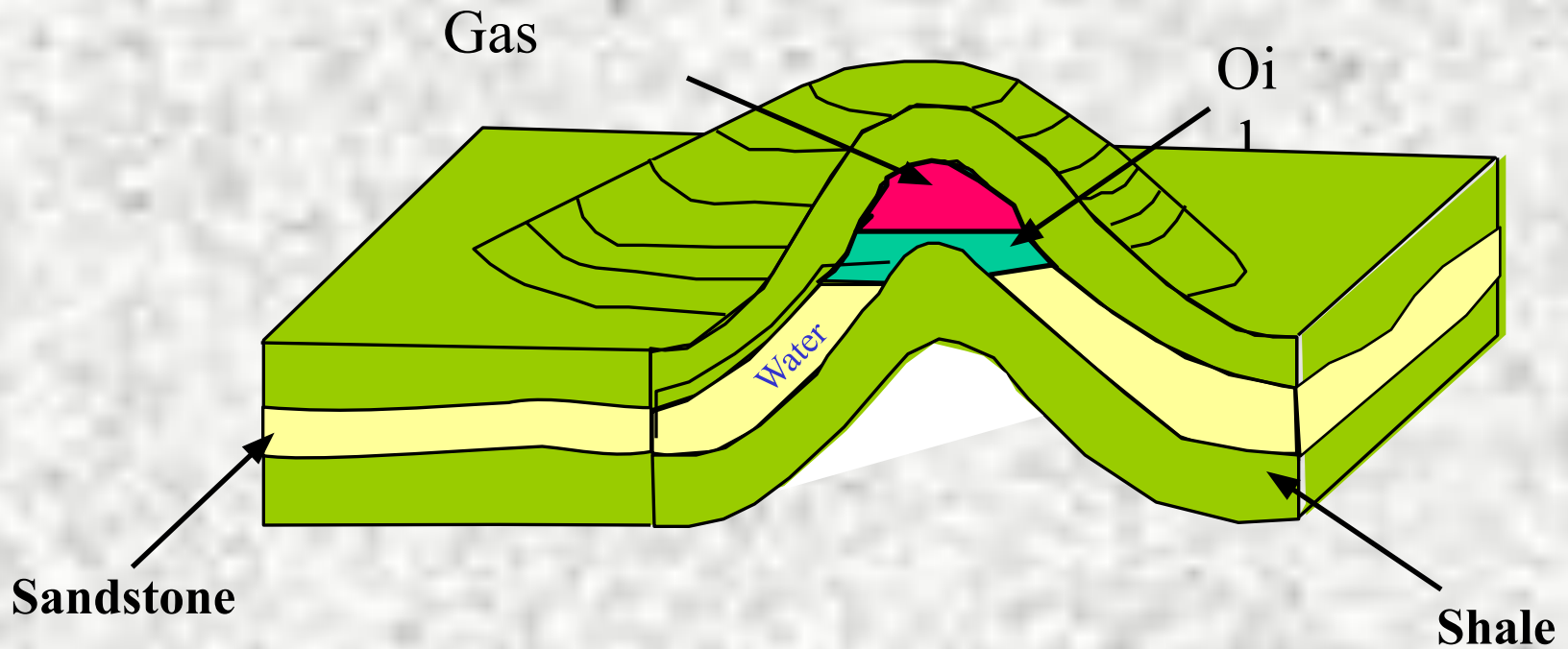
Fold Trap

**Salt
Dome**

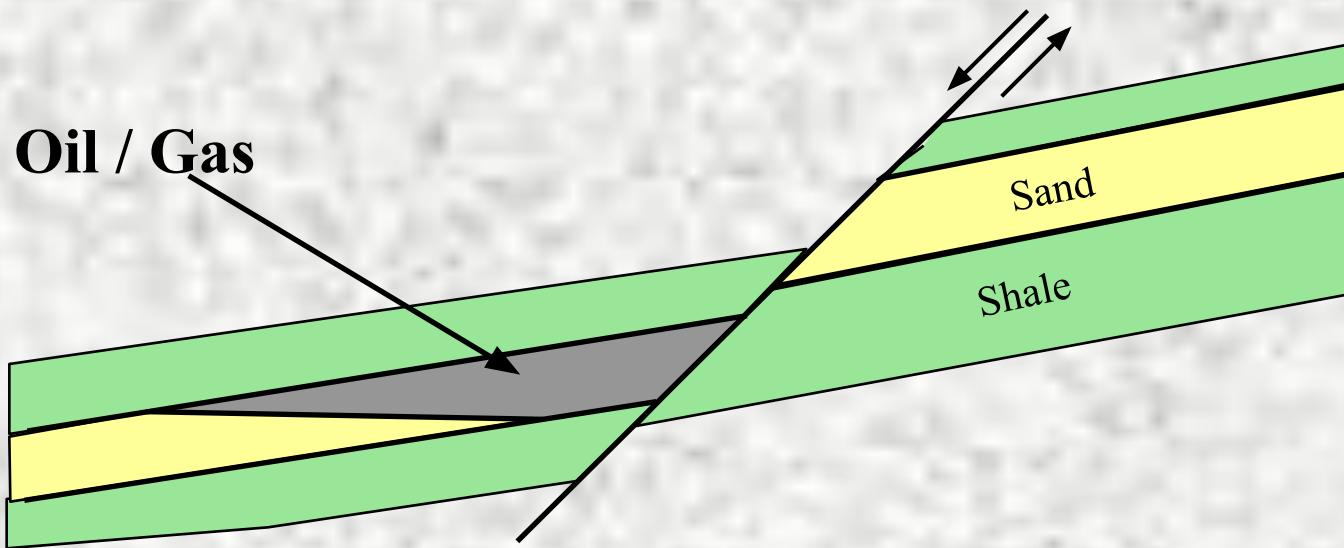


(modified from Bjorlykke, 1989)

Hydrocarbon Traps - Dome

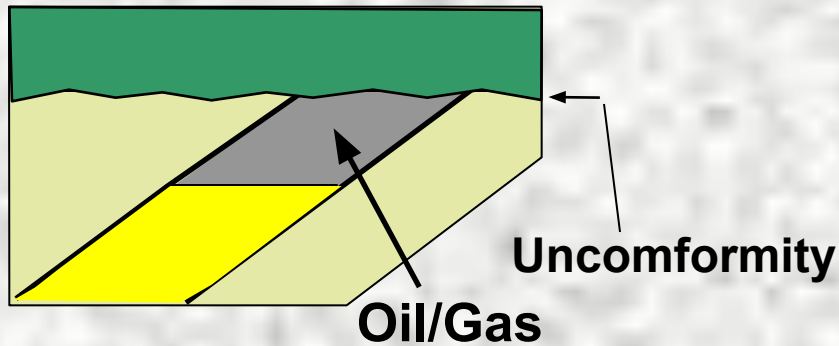


Fault Trap

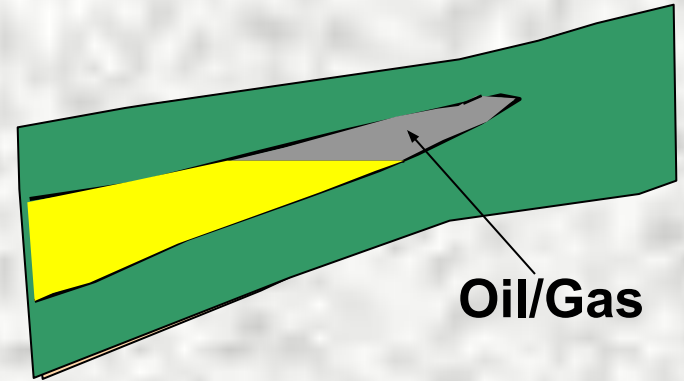


Stratigraphic Hydrocarbon Traps

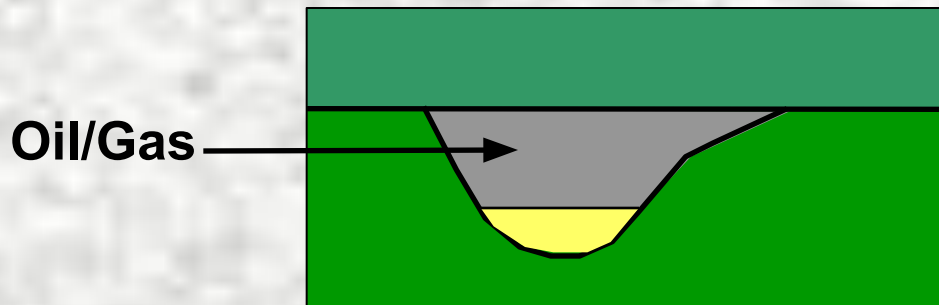
Unconformity



Pinch out

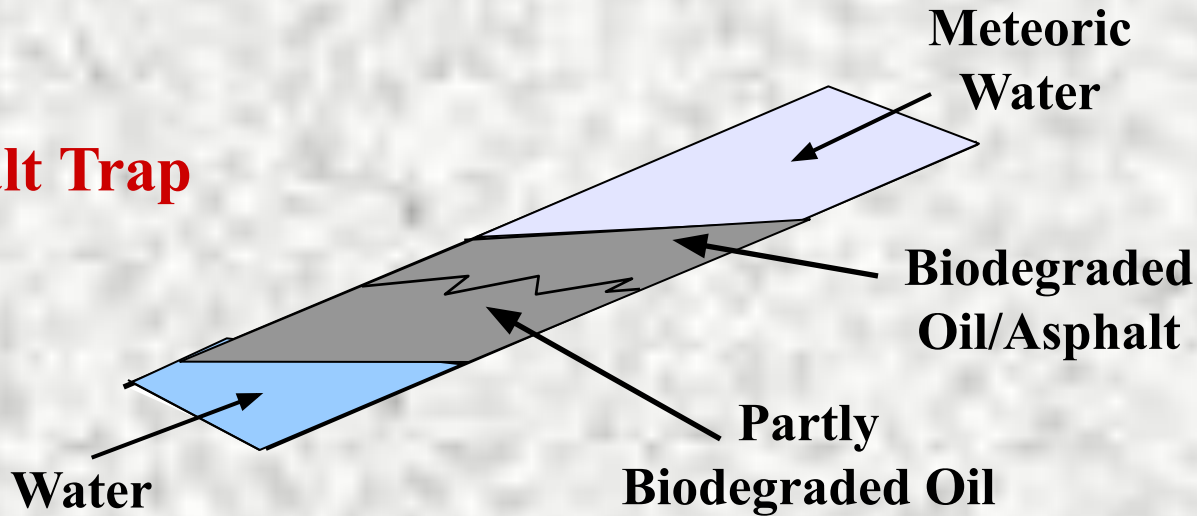


Channel Pinch Out

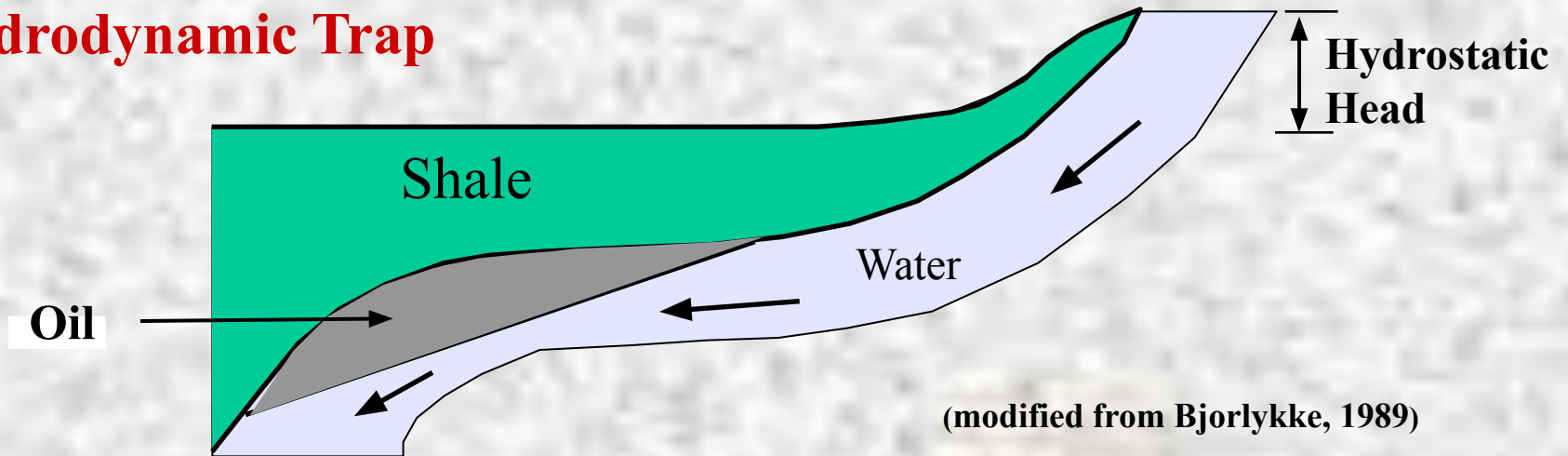


Other Traps

Asphalt Trap

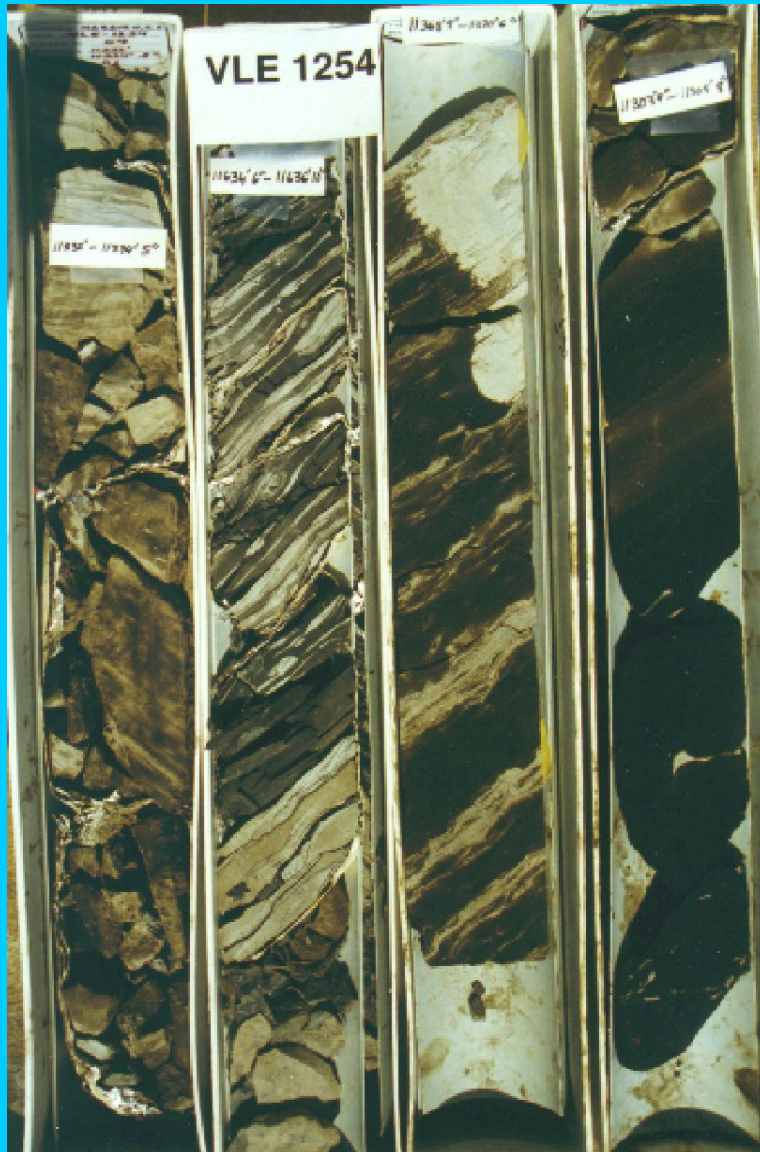


Hydrodynamic Trap



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

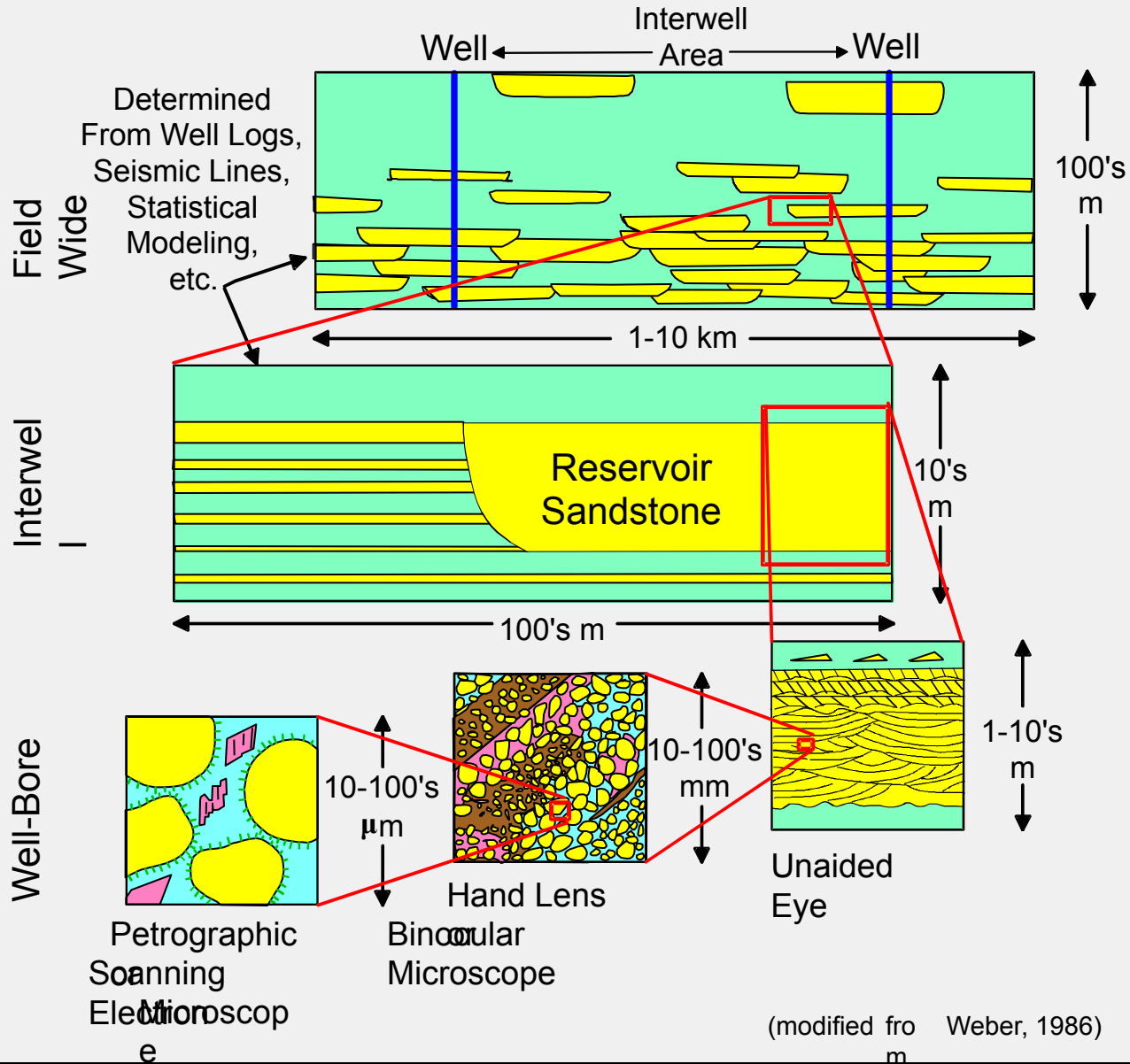
(Whole Core Photograph, Misoa Sandstone, Venezuela)

Geologic Reservoir Heterogeneity

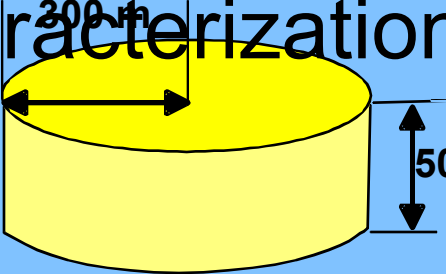
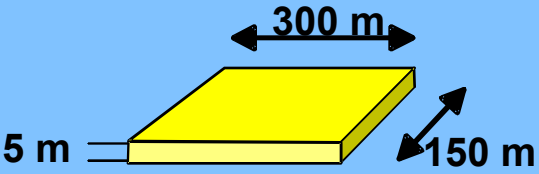
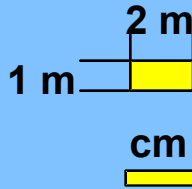
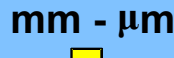


Eolian Sandstone, Entrada Formation, Utah, USA

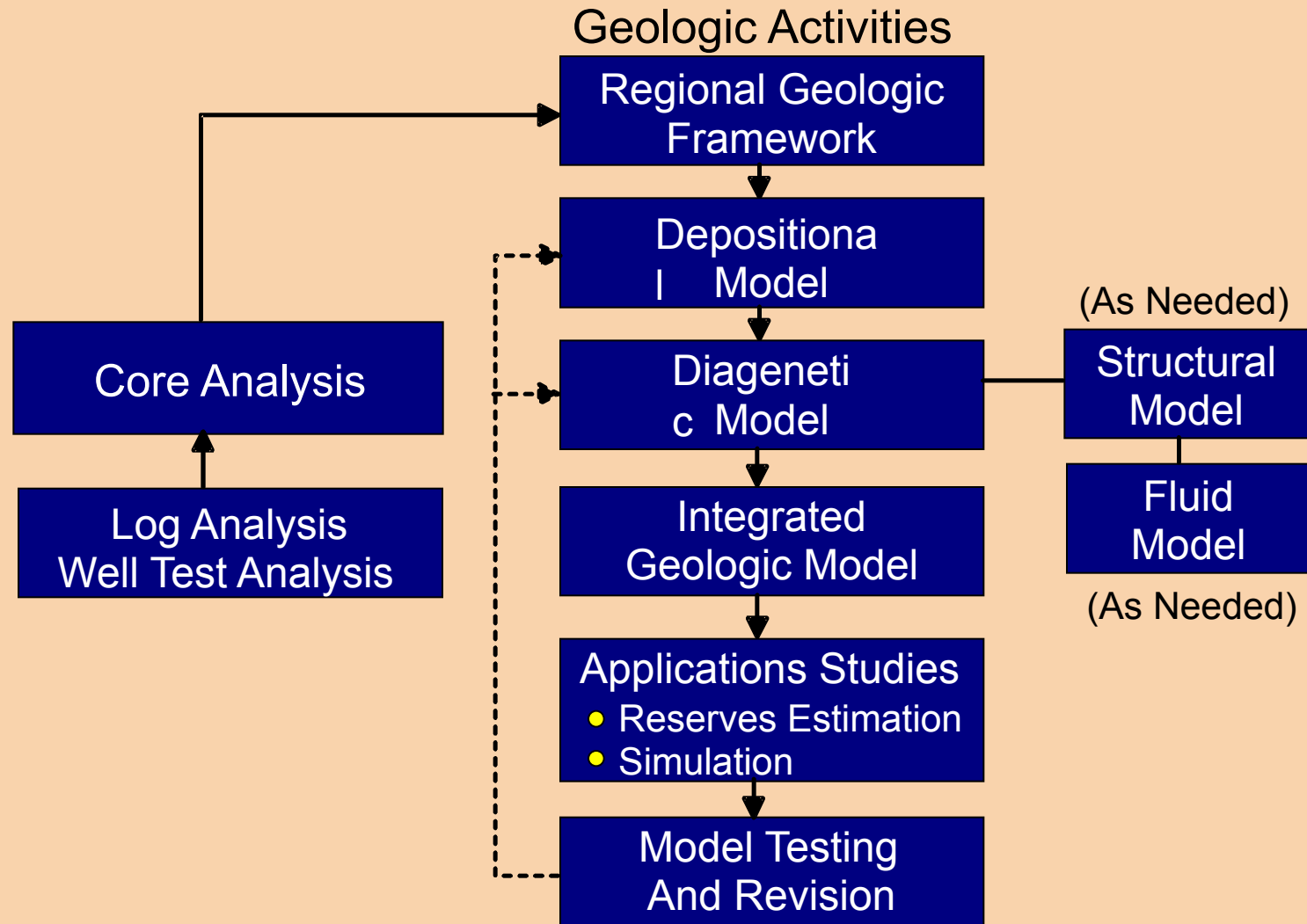
Scales of Geological Reservoir Heterogeneity



Scales of Investigation Used in Reservoir

	Characterization		Relative Volume
Gigascopeic		Well Test	10^4
Megascopeic		Reservoir Model Grid Cell	2×10^2
Macroscopeic		Wireline Log Interva Core Plug	3×10^7 5×10^2
Microscopi		Geological Thin Section	1

Stages In The Generation of An Integrated Geological Reservoir Model





Oil and Gas Formation.mp4