Petrophysics

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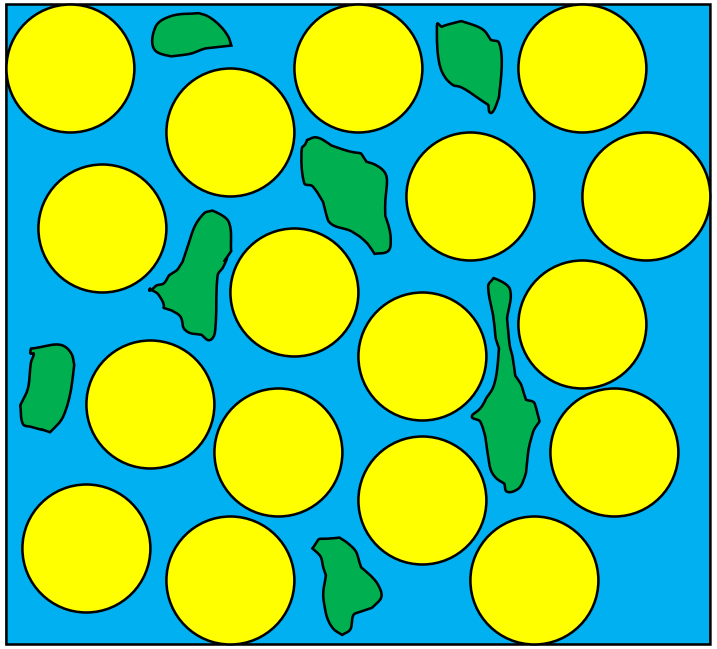
Introduction

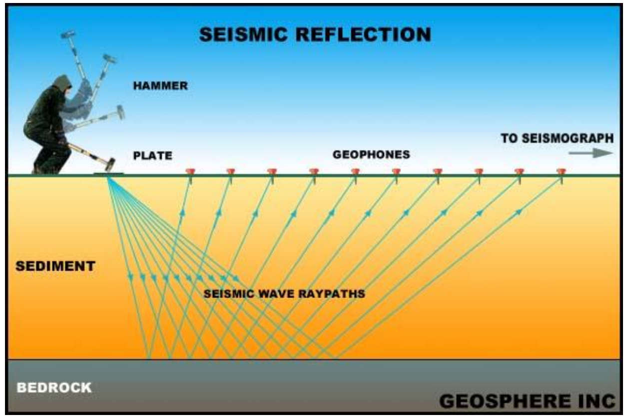
- What is petrophysics?
- What is porosity?
- What is the distribution of pore sizes?
- Where is the hydrocarbon located?
- How much of it is present?
- How much of each fluid is present?
- How easily does each fluid move in the subsurface?
- What does a petrophysicists do in an oil company?



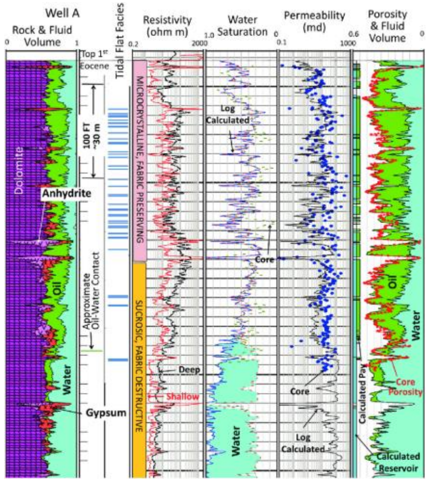
Petrophysics

- Petrophysics is suggested as the term pertaining to the physics of a particular rock type, whereas geophysics pertains to the physics of larger rock systems composing the earth.
- It studies physical and chemical rock properties; pore size distribution and their interaction with fluids; fluid distribution of each phase (oil, gas, water) within the pores of the rock.
- The petrophysical properties that are discussed include: porosity, saturation, absolute-effective-relative permeability, capillary pressure, wettability, compressibility, mineralogy, etc.
- Petrophysicists are employed to help reservoir engineers and geoscientists understand the rock properties of the reservoir, particularly how pores in the subsurface are interconnected, controlling the accumulation and migration of hydrocarbons.
- A key aspect of petrophysics is measuring and evaluating these rock properties by acquiring well log measurements, core measurements and seismic measurements.
- These studies are then combined with geological and geophysical studies and reservoir engineering to give a complete picture of the reservoir.

Seismic Measurements



Well Logs



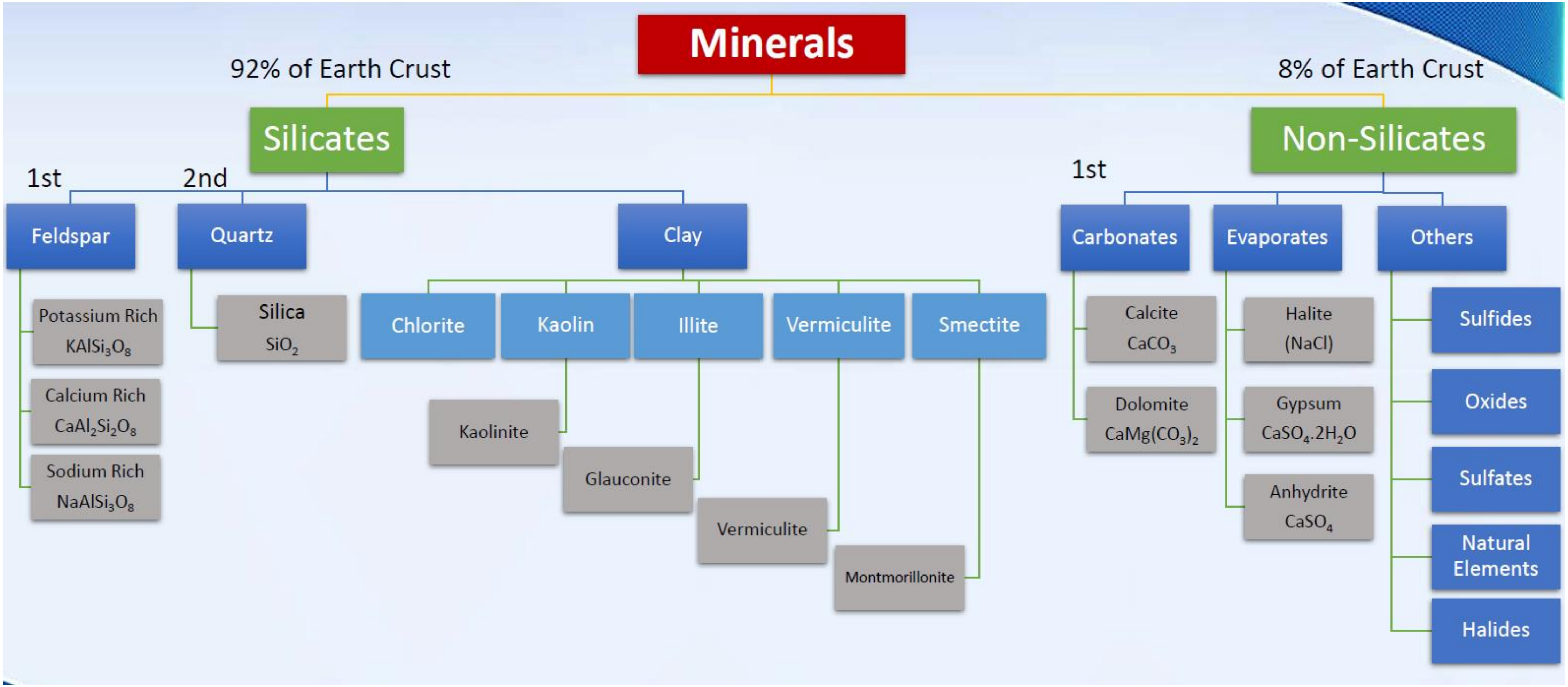
Core Samples

Rock Composition - Minerals

- The physical and chemical properties of rock are the consequences of their mineral composition.
- A mineral is a naturally occurring crystalline inorganic material that has specific physical and chemical properties which are either constant or vary within certain limits.
- Rock-forming minerals of interest in petroleum engineering can be classified into the following families:
    - silicates, carbonates, oxides, sulfates, sulfides, chlorides.
- Silicates are the most abundant rock-forming minerals in the Earth's crust.

Quartz Belonging to Silicates

Rock Composition - Minerals



Rock Types

- Igneous Rocks

These are rocks formed from molten material called magma that solidified upon cooling either at the surface or below the surface. Igneous rocks are the most abundant rocks on the Earth's crust.

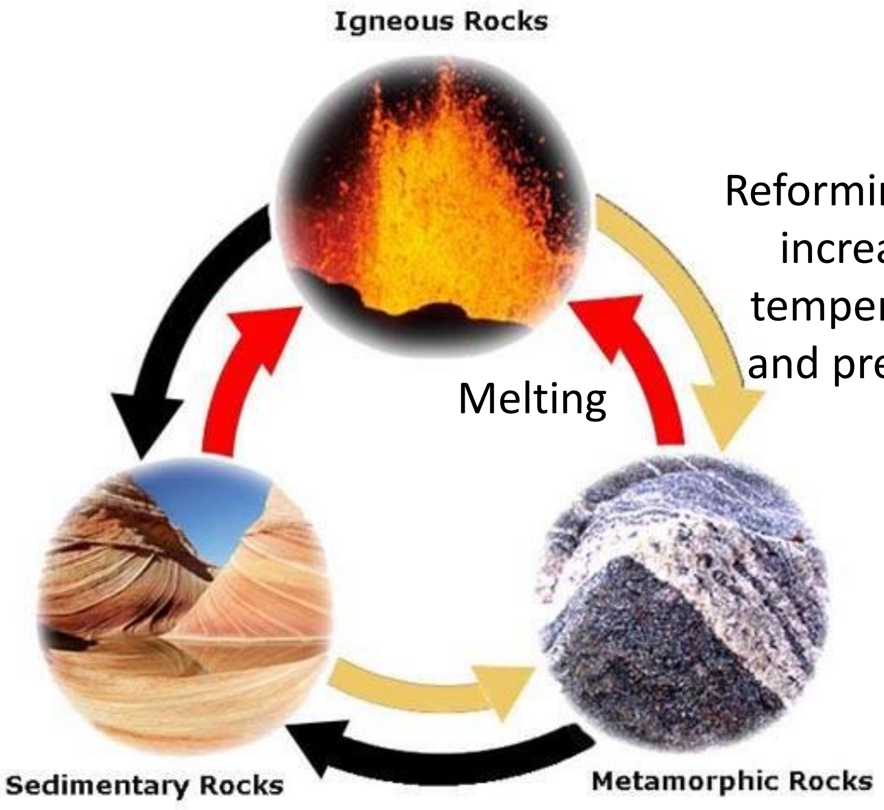
- Metamorphic Rocks

These are rocks formed by transformation, generally in the solid state, of pre-existing rocks beneath the surface by heat, pressure, and chemically active fluids.

- Sedimentary Rocks

These are rocks formed at the surface of the Earth either by accumulation and consolidation of minerals, rocks, organisms and vegetation, or precipitation from solution. Sedimentary rocks are the source of petroleum and provide the reservoir rock and trap to hold the petroleum in the Earth's crust.

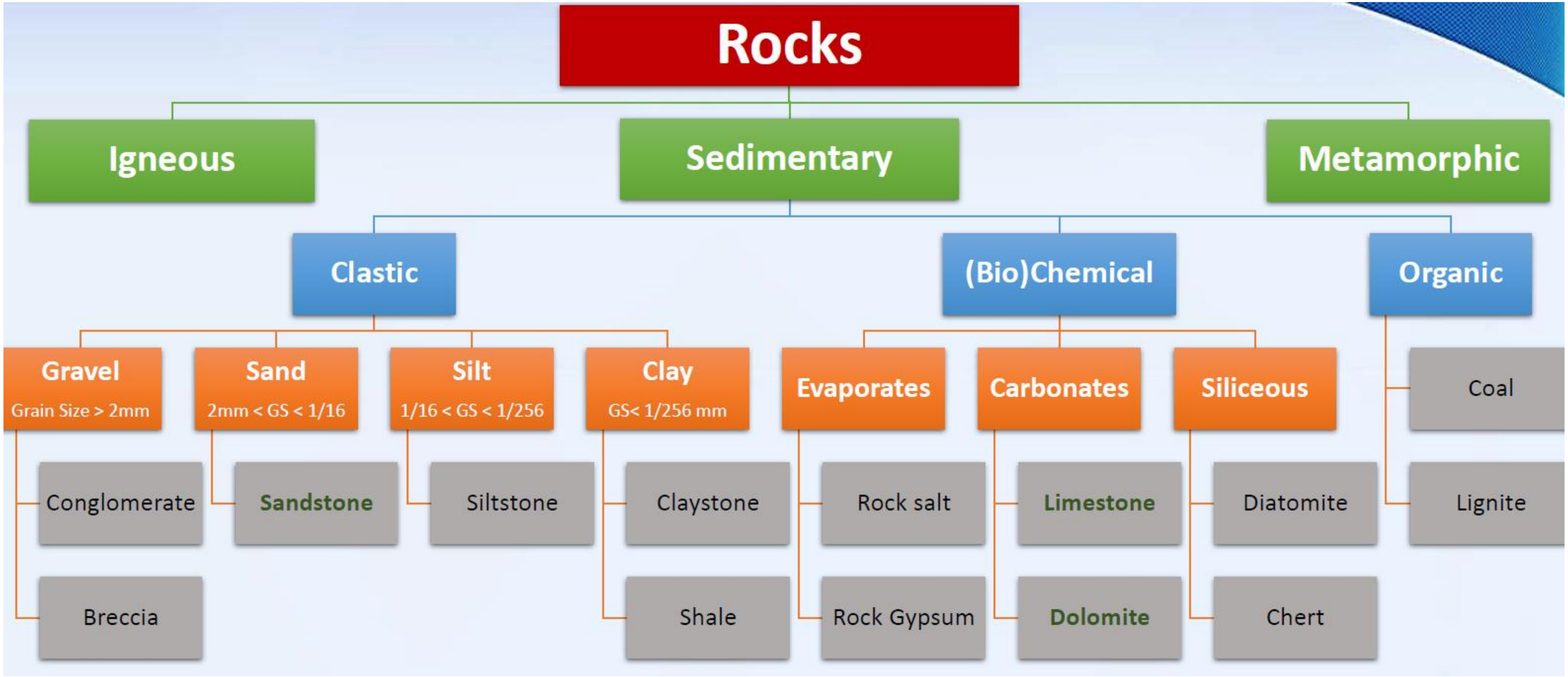
Rock Cycle



Reforming with increased temperature and pressure

Weathering

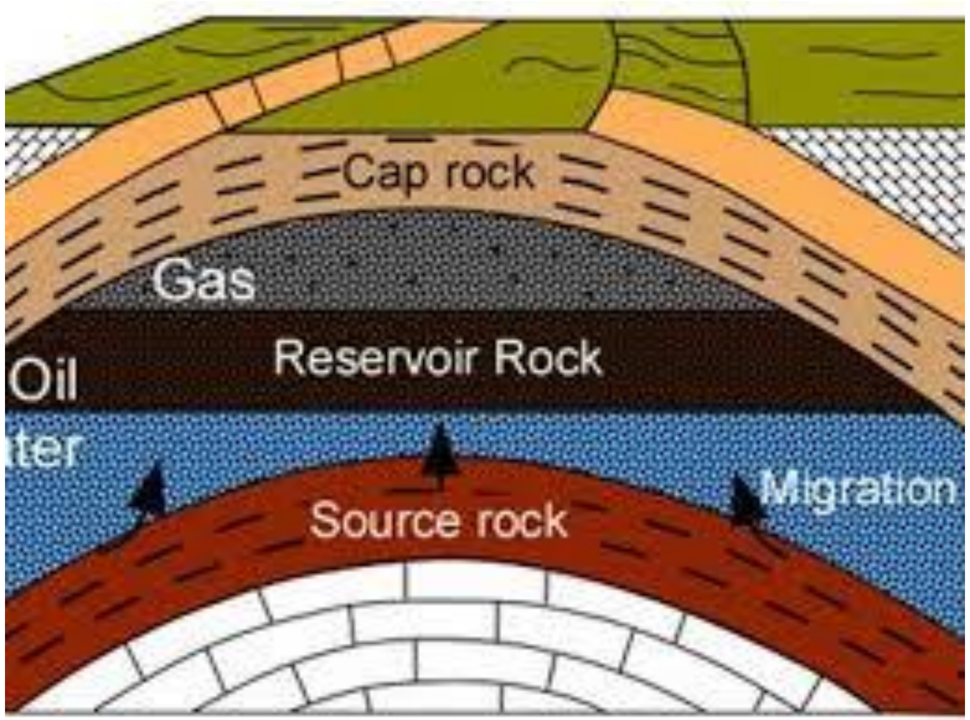
Rock Types



Rocks
Igneous
Sedimentary
Metamorphic
Clastic
(Bio)Chemical
Organic
Gravel
Grain Size > 2mm
Sand
2mm < GS < 1/16
Silt
1/16 < GS < 1/256
Clay
GS< 1/256 mm
Evaporates
Carbonates
Siliceous
Coal
Conglomerate
Sandstone
Siltstone
Claystone
Rock salt
Limestone
Diatomite
Lignite
Breccia
Shale
Rock Gypsum
Dolomite
Chert

Reservoir Rock - Conventional

- A rock capable of producing oil, gas and water is called a reservoir rock.
- To be of commercial value, a reservoir rock must have sufficient thickness, areal extent and pore space to contain a large volume of hydrocarbons and must yield the contained fluids at a satisfactory rate when the reservoir is penetrated by a well.
- The movement of the fluids is influenced by gravity and capillary forces.
- Sandstone and carbonates are the most common reservoir rocks. They together contain most of the world's petroleum reserves.
- The formation of petroleum reach rocks is a long geological process where the several crucial components are crucial.



Sedimentary Rocks

Sedimentary rocks may be classified by origin and compositions as:

- Clastic

These rocks are composed of fragments or minerals broken from any type of pre-existing rock. Conglomerate, breccia, sandstone, siltstone and shale belong to this group.

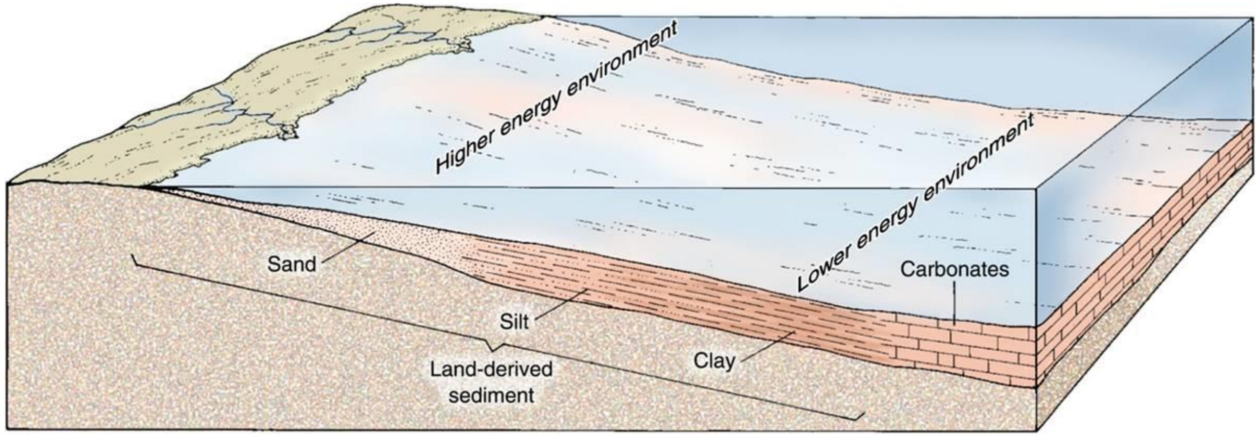
- Chemical

These rocks are formed by chemical precipitation. Carbonates and evaporites belong to this group.

- Organic

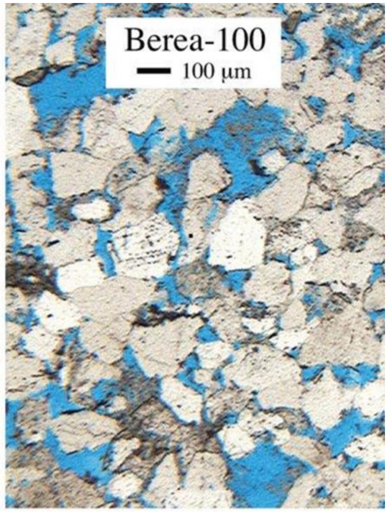
These rocks are formed by biologic precipitation and by the accumulation of organic (plant and animal) material. Peat, coal and diatomite belong to this group. Limestone may also carry the properties of this group.

Idealized case by Levin, 2009

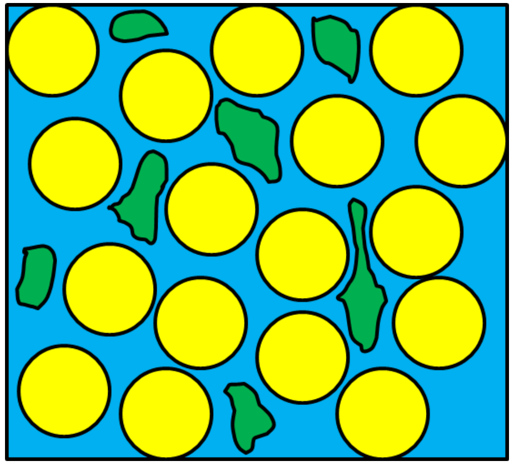


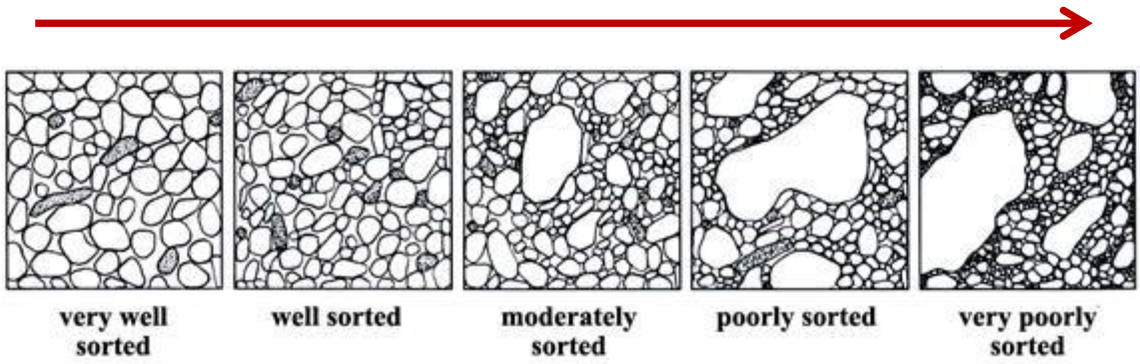
Reservoir Rock - Sandstone

- These reservoirs belong to clastic group.
- The pore space of sandstone reservoirs can be affected by varying degrees of compaction, cementation, solution and replacement.
- Theoretically, grain size has no effect on porosity. This is true only for spherical grains of the same size. However, the arrangement of such spheres has a large effect on the porosity of the pack.
- Porosity is at its maximum for spherical grains but becomes progressively less as the angularity of the grains increases because such grains pack together more closely.
- Porosities of wet packed sands show a general decrease as sorting becomes poorer.
- Compaction and cementation decrease the porosity in the formation process of rock.

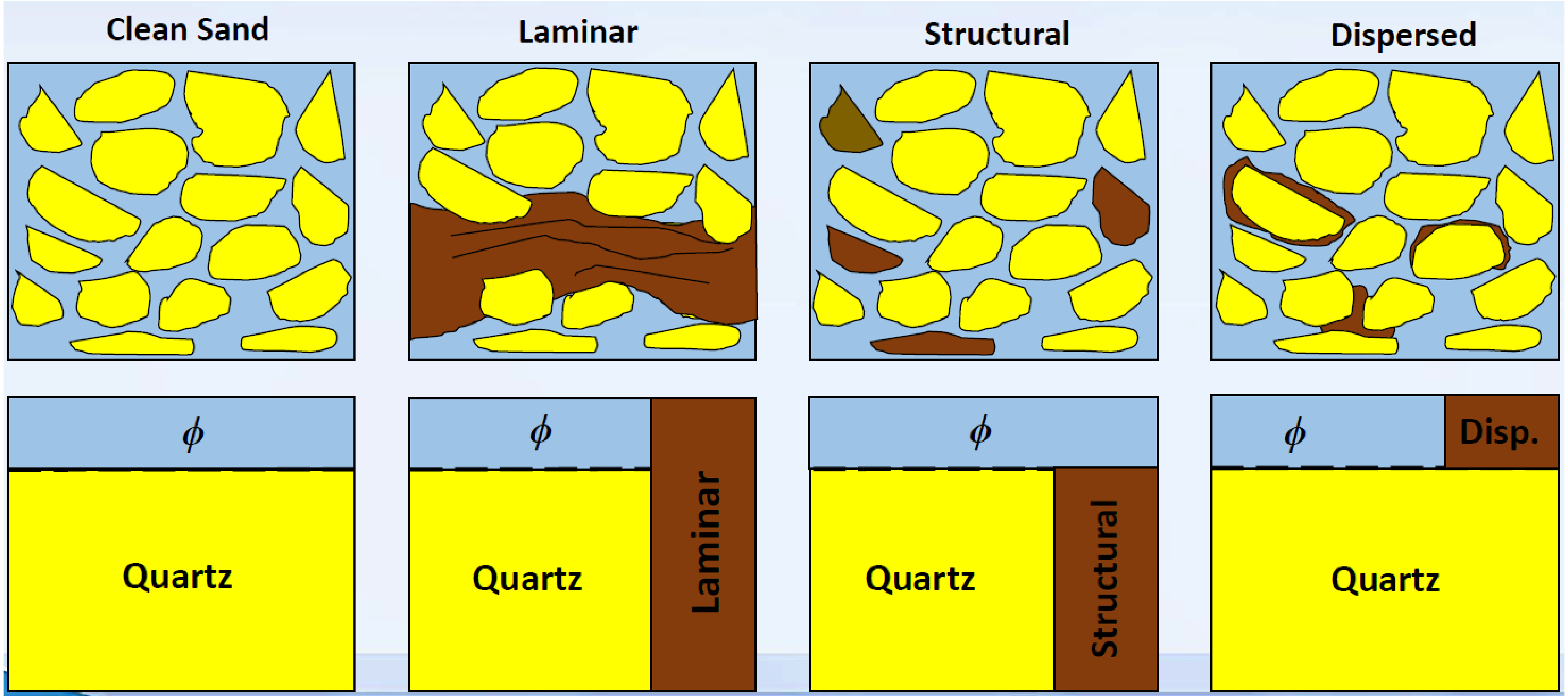


Song, *Vadose Zone Journal*, 2010





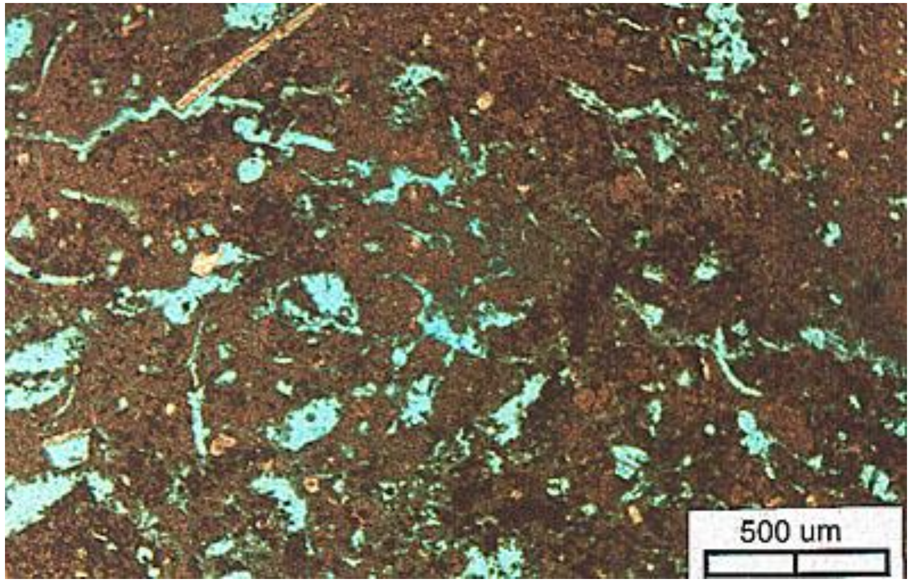
Shale Distribution in Sands



Reservoir Rock - Carbonates

- These reservoirs belong to chemical group.
- They differ from clastic group in that they are deposited as lime particles which are produced locally, whereas sandstones are composed of particles transported from an outside source by water currents.
- They differ even more importantly from sandstones by being subject to more post-depositional diagenesis ranging from simple cementation of original particles to complete recrystallization or replacement by dolomite or chert.
- Diagenesis is the process of physical and chemical changes in sediments after deposition that convert them to consolidated rock such as compaction, cementation, recrystallization, and perhaps replacement of original mineral as in the development of dolomite.
- Good porosity in carbonate reservoirs is usually due to dolomitization. Dolomitization $\mathrm{CaMg(CO_3)_2}$ occurs from the substitution of magnesium for calcium in carbonate crystal ($\mathrm{CaCO_3}$). A volume loss of 12-13% results in corresponding increase in porosity.
- Natural fractures can exist in essentially any type of rock although they are particularly common in carbonates.

UT-BEG



Reservoir Rock - Unconventional

- Unconventional reservoirs are essentially any reservoir that requires special recovery operations outside the conventional operating practices.
- They include reservoirs such as tight-gas sands, gas and oil shales, coalbed methane, heavy oil and tar sands and gas-hydrate deposits.
  - Tight gas is the term commonly used to refer to low-permeability reservoirs that produce mainly dry natural gas.
  - Shale oil refers to hydrocarbons that are trapped in formations of shale rock.
  - Oil shale is different than shale oil in that oil shale is essentially rock that contains a compound called kerogen, which is used to make oil.
  - Coalbed methane is a form of natural gas extracted from coal beds.
  - Tar sands (also called oil sands) are a mixture of sand, clay, water, and bitumen. Bitumen is a thick, sticky, black oil that can form naturally in a variety of ways, usually when lighter oil is degraded by bacteria.
  - Gas hydrates are ice-like crystalline minerals that form when low molecular weight gas (such as methane, ethane, or carbon dioxide) combines with water and freezes into a solid under low temperature and moderate pressure conditions.
- These reservoirs require assertive recovery solutions such as stimulation treatments or steam injection, innovative solutions that must overcome economic constraints in order to make recovery from these reservoirs monetarily viable.

Petrophysics – Soft Rocks

- Introduction to Petrophysics
- Porous Media Description: porosity, saturation
- Flow Properties: absolute permeability, dispersivity, wettability, capillary pressure, relative permeability
- Electrical Properties: resistivity
- Mechanical Properties: pore compressibility, elastic constants, acoustic velocity
- Thermal Properties: thermal conductivity
- Petrophysical modeling: net pay cut-offs, formation evaluation and quality control, porosity and permeability law, net to gross and porosity modeling, permeability predictor and horizontal permeability modeling, vertical permeability modeling, reservoir characterization from seismic, water saturation modeling
- Data Integration: comparing well test and plug permeability, integration of geology and petrophysics, geochemistry and petrophysics