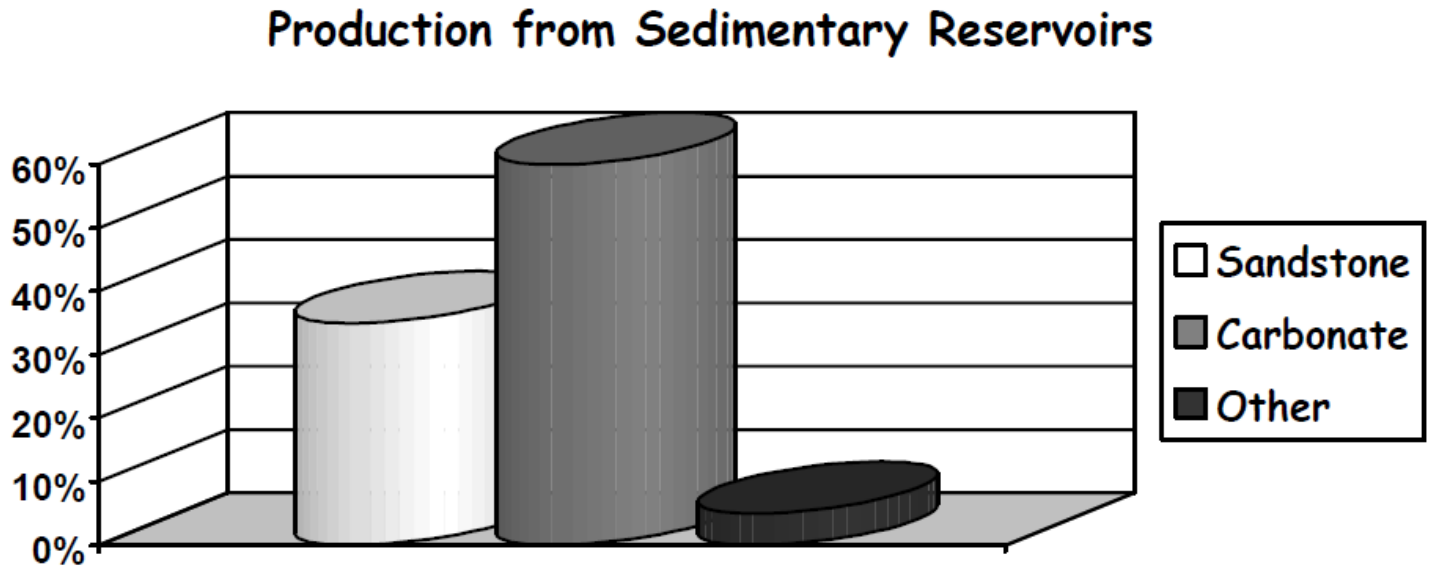
Reservoir, seal

Velledits Felicitász

Reservoir rock

is a rock, that both store and transmits fluids, it must have porosity and permeability.

Sandstones and carbonates contain the major known reserves,
although fields occur in shales and igneous and metamorhic rocks, if they are fractured.

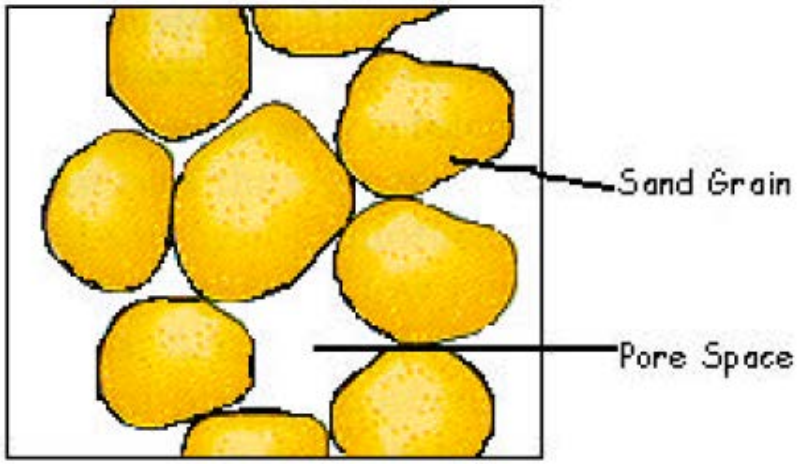


Halliburton 2001

Porosity: Φ

- Is the percent volume of the rock that is not occupied by solids.
- Porosity: is the ratio of void space in a rock to total volume of rock, and reflects the fluid storage capacity of the reservoir.

Φ=volume of void space/total volume of rock x 100



Halliburton 2001

- **„Oil and gas does not occur in lakes or caverns under the ground (unfortunately), but in such pores, often too small to be seen with the naked eye, yet large enough to do the job.”**

Robert Stoneley

- Primary porosity: amount of pore space present in the sediment at the time of deposition, formed during sedimentation.
- Secondary porosity: post depositional porosity. Such porosity results from groundwater dissolution, recrytallization and fracturing.
- Effective porosity: is the interconnected pore volume available to free fluids.
- Total porosity: all void space in a rock and matrix whether effective, or none effective

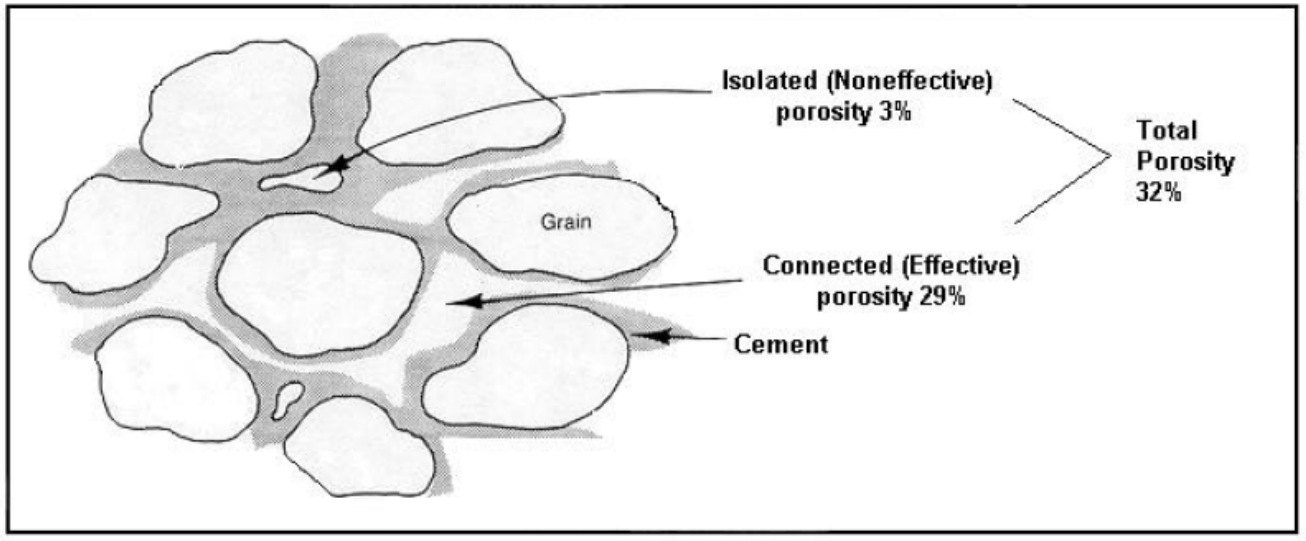


Figure 17 Effective vs. noneffective porosity

Halliburton 2001

Fracture porosity:

the openings are produced by breaking the rocks.

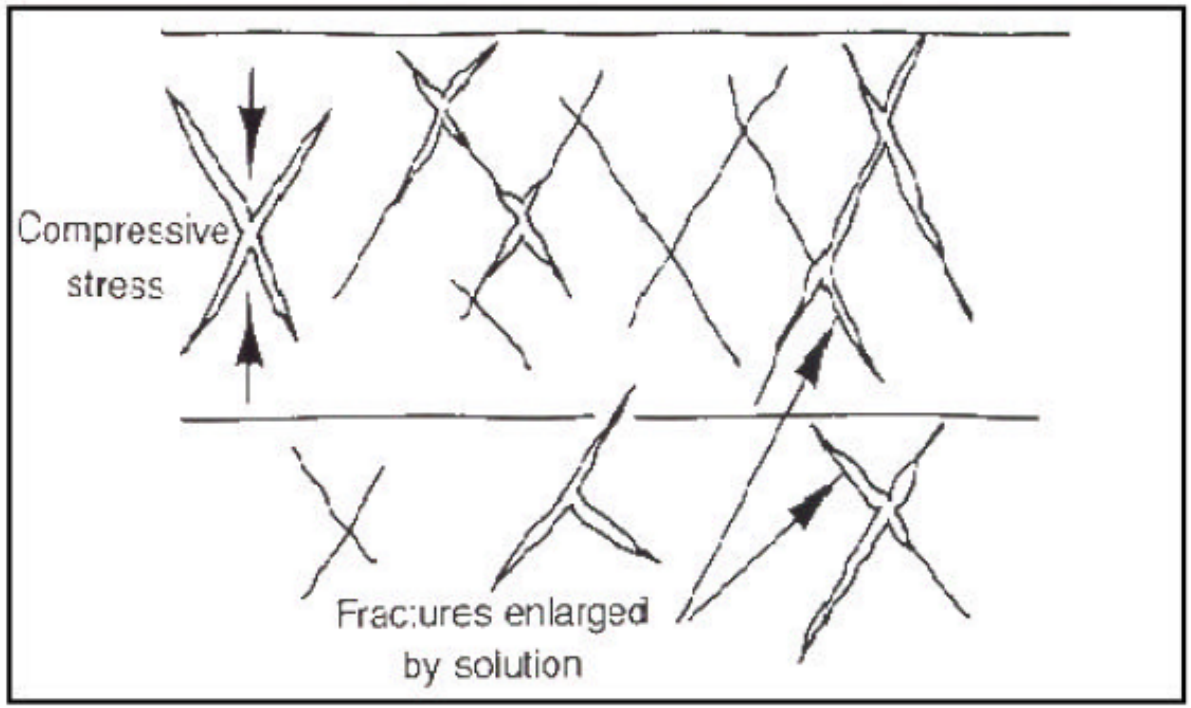
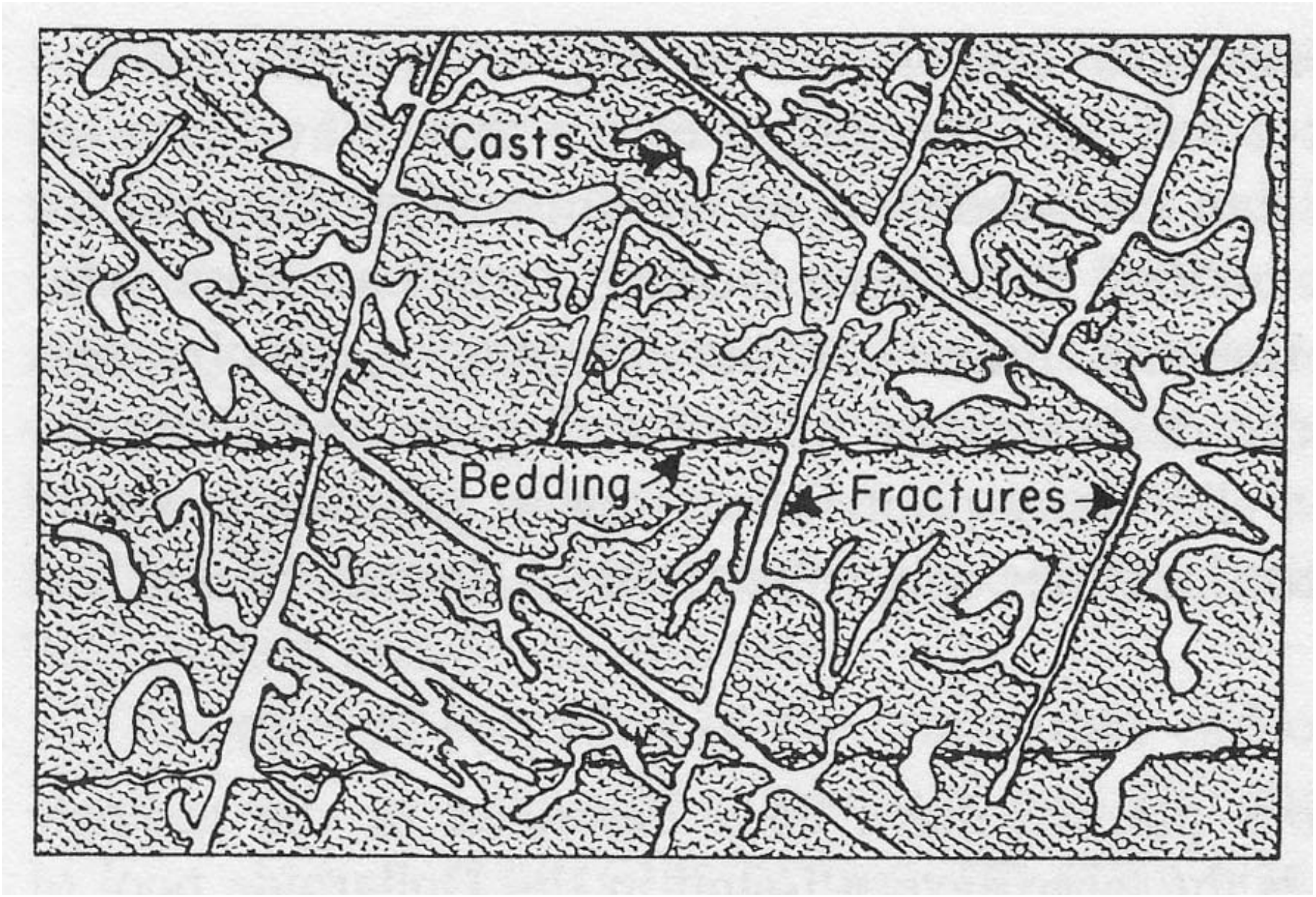
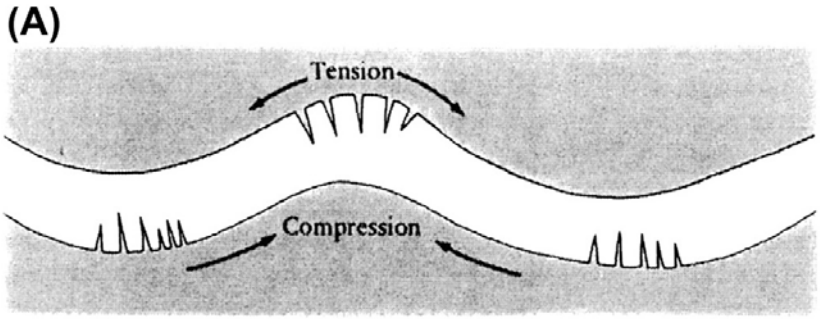


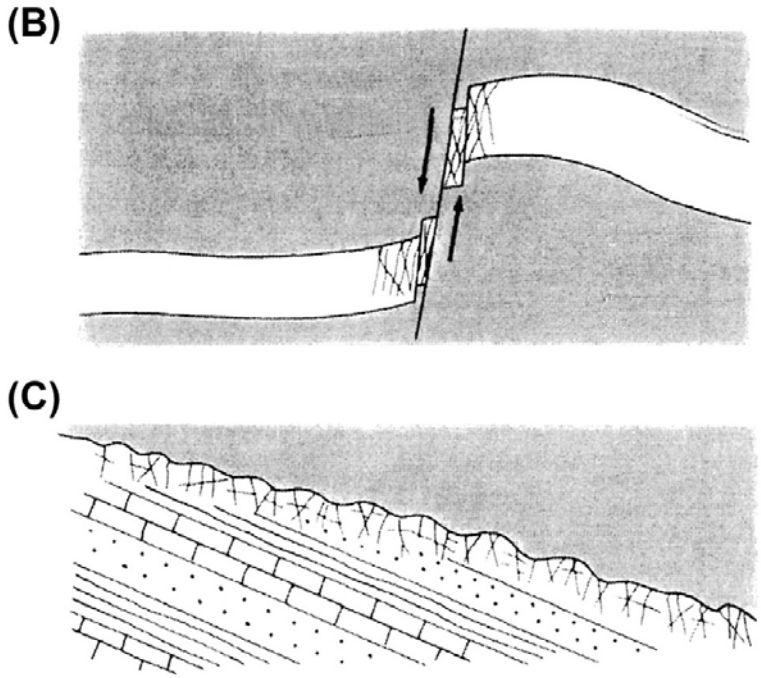
Figure 18 Fractures in rock material Halliburton 2001



Fractures increase permeability!

Levorsen 2001





Fractures

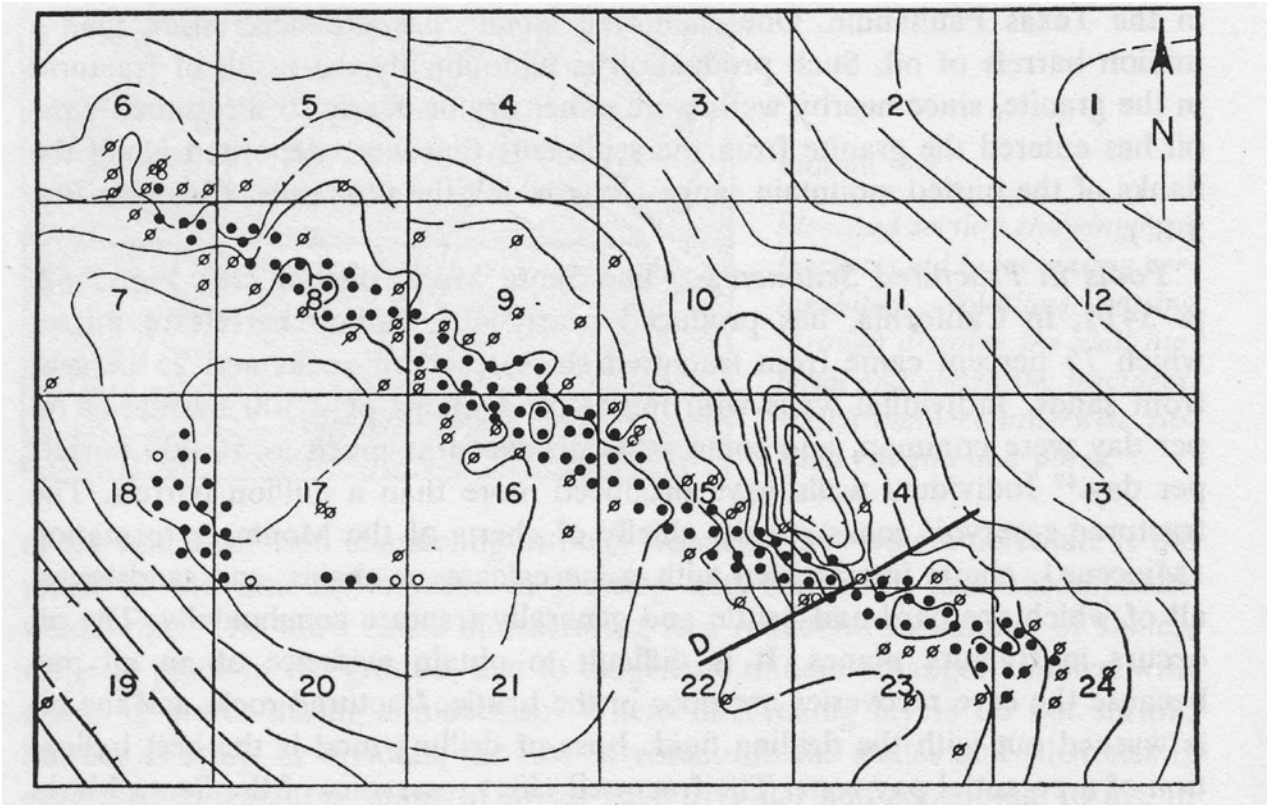
Brittle rocks tend to fracture in three geological settings:

(A) Fractures may develop on the crests of anticlines and the nadirs of synclines.

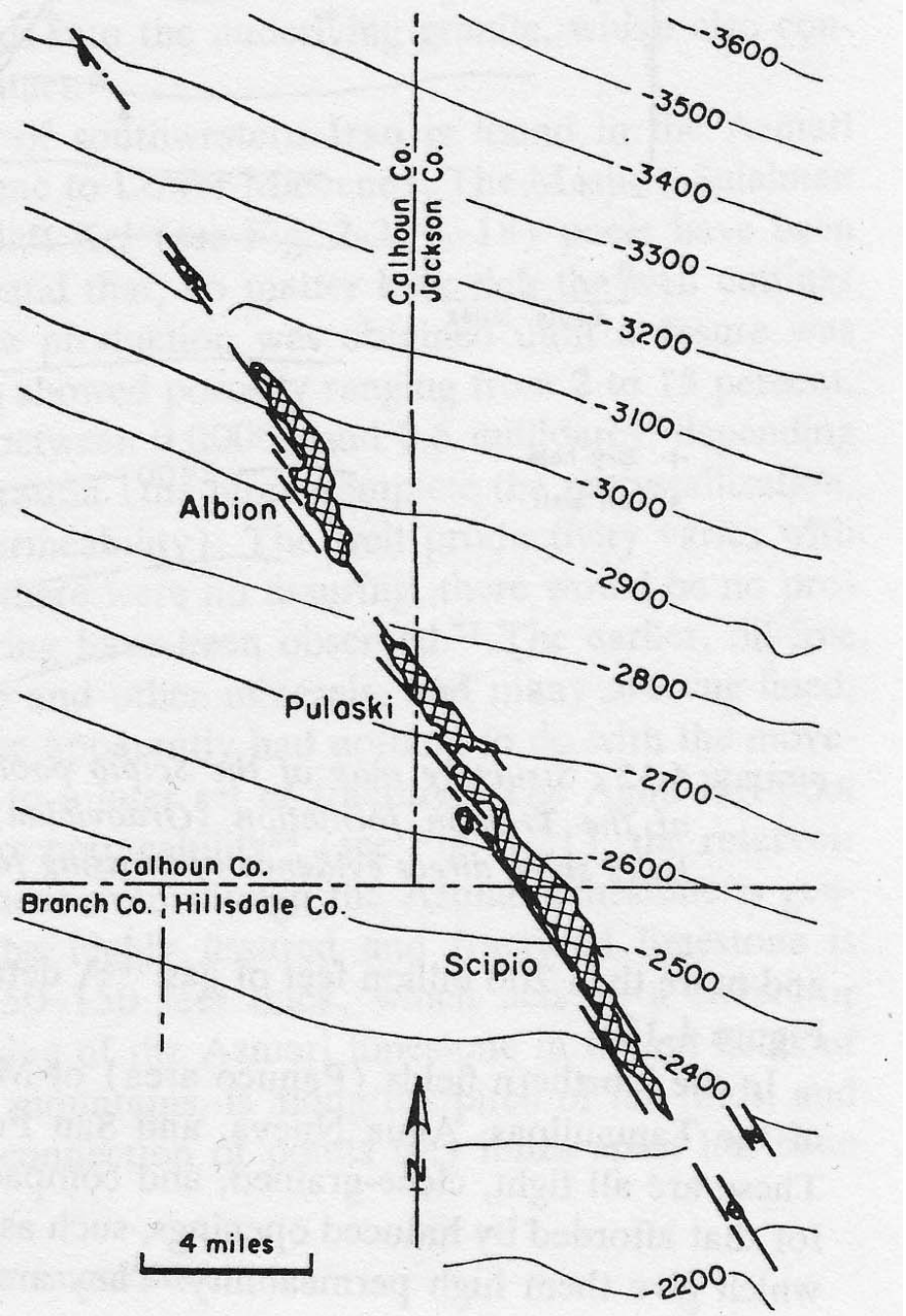
(B) Fractures may develop adjacent to faults.

(C) Fractures may occur beneath unconformities.

Deep River Field (Michigen)



- Production is obtained from a dolomite zone enclosed in the Rogers City limestone (Devonian). The fracture permitted to enter the magnesium-bearing solution into the limestone. Dolomite has bigger porosity than limestone. Levorsen 2001

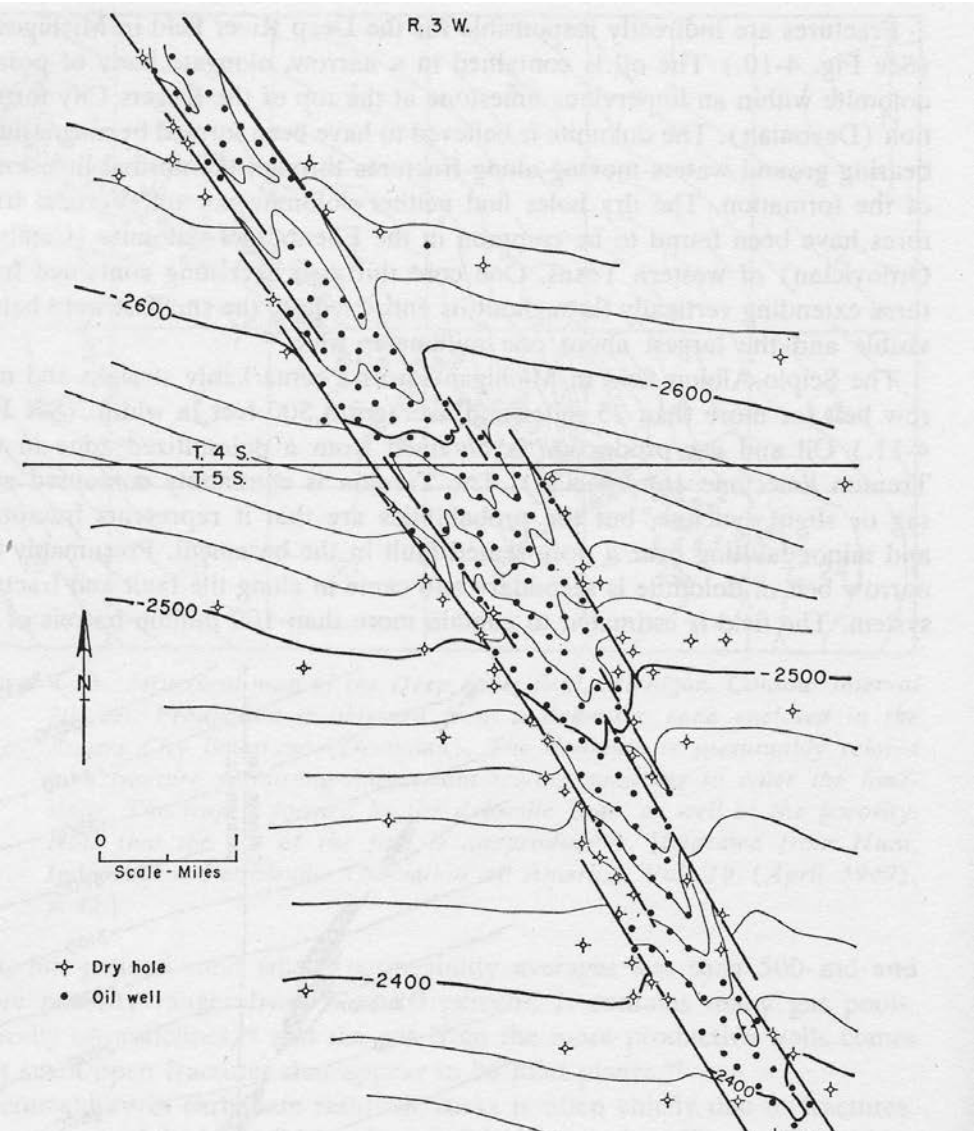


Levorsen 2001

Scipio-Albion field (Michingen)

- Forms a straight and narrow belt.
- Oil and gas is obtained from a dolomitized zone in the Trenton Limestone (Ordovician)
- The narrow belt of dolomite is secondary and came in along the fault and fracture system.

Structure map of the Scipio pool



- Productive well show direct evidence of faults.

Controls on Porosity: 1. Grain packing

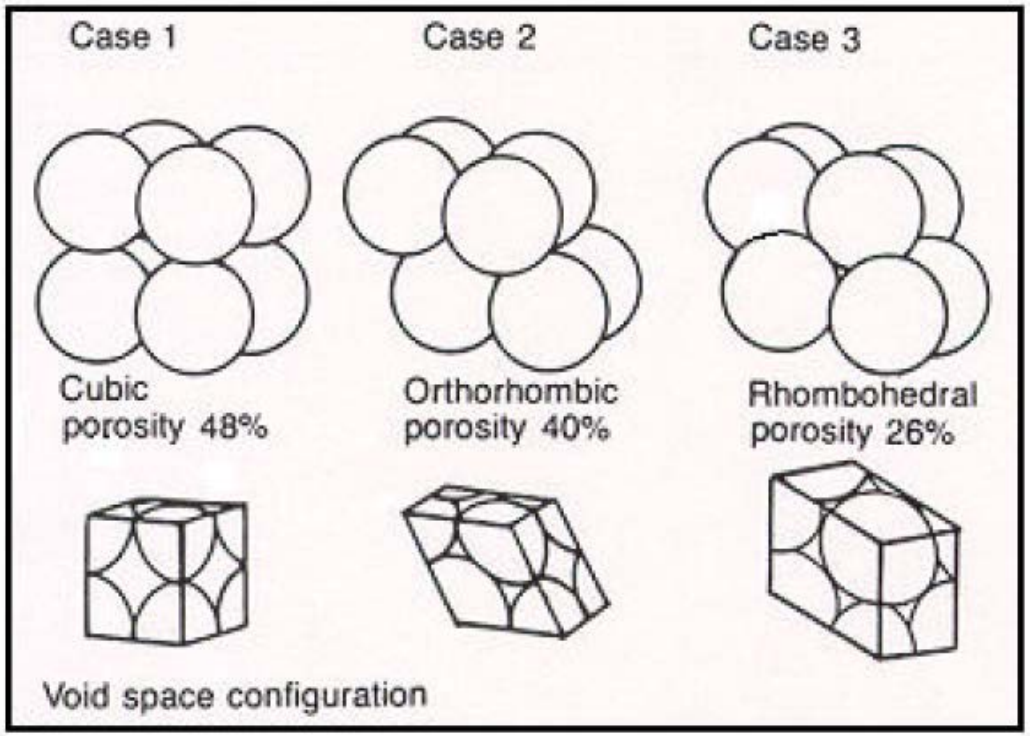


Figure 22 Grain packing and its effect on porosity

Halliburton 2001

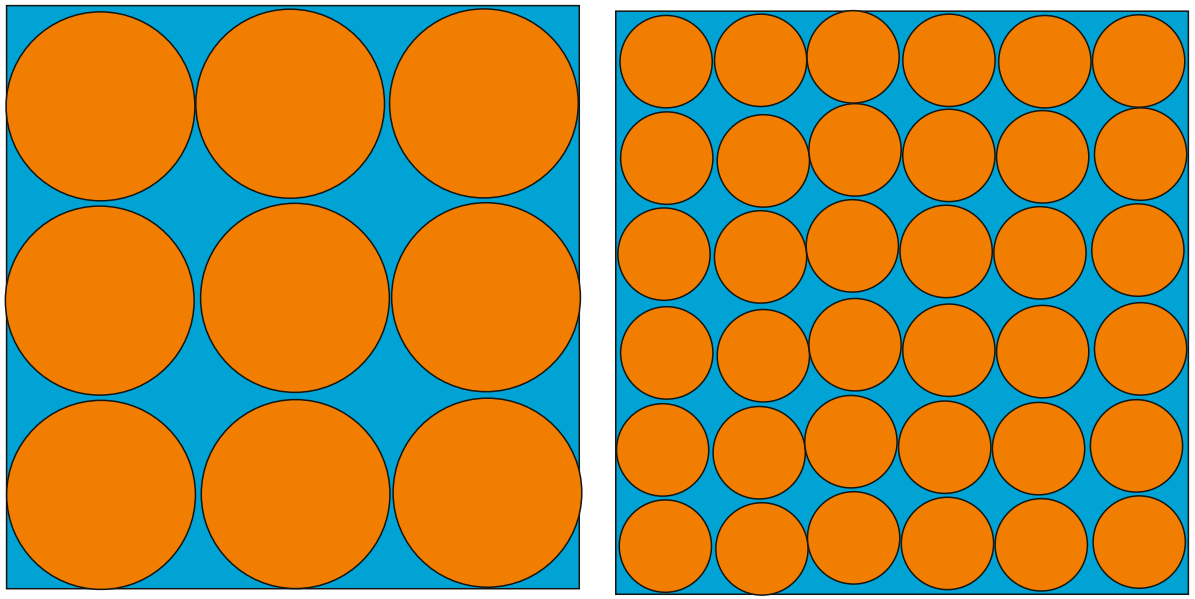
Packing affects the bulk density as well as porosity and permeability.

Cubic packing (open packing) can yield a porosity of 47.6%.

Rhombohedral packing (closed packing) yields ca. 26.0%.

Controls on Porosity: 2. Grain size

Grain size controls porosity and permeability



r=1 r=1/2

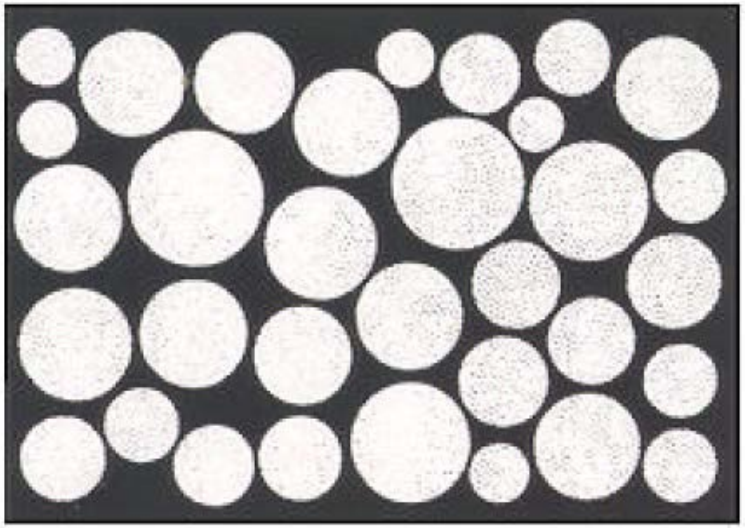
Porosity: $\phi_1 = \phi_2$

Permeability: $k_1 = \frac{1}{4} k_2$

Controls on Porosity: 3. Sorting

In sandstone, porosity is largely controlled by sorting.

Well Sorted Rock



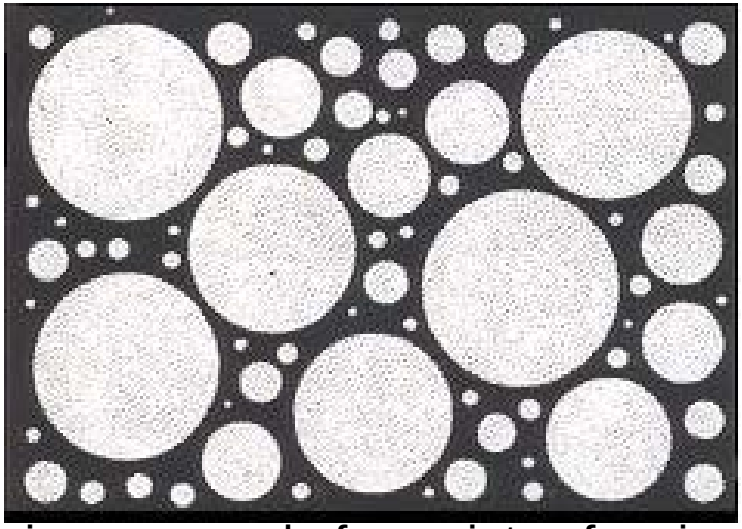
Halliburton 2001

Grains: same size and shape.
If the grains are well rounded and of similar size then they will not fit well together.

Leaving a large amount of pore space between the grains.

Porosity in a well sorted rock is high.

Poorly Sorted Rock

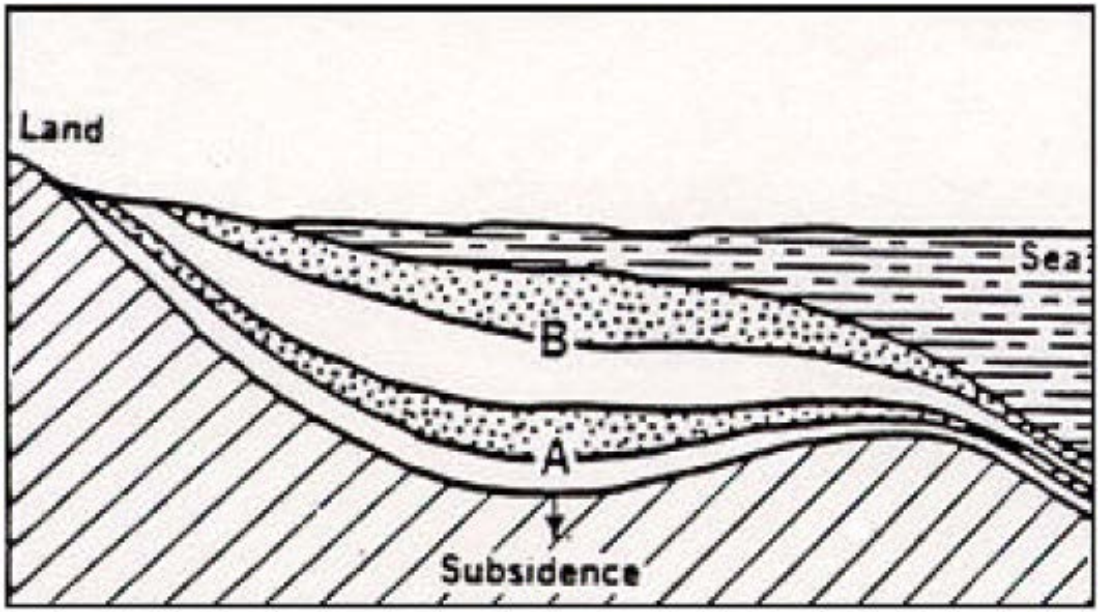


Rock is composed of a variety of grain sizes and shapes.
Porosity can be reduced because smaller grains can be inserted in between the larger grains.

They reduce the amount of pore space.

Porosity in a poorly sorted rock is low.

Controls on Porosity: 4. Compaction



Layer A is compacted by layer B

Halliburton 2001

- The weight of the overlying sediments 1) **squeezes the particles together** into the tightest possible arrangement. The load pressure also 2) **squeezes out the water** that occupies the pore spaces between the particles.

- Compaction affects porosity and permeability by **reducing the amount of interconnected** pore space.

Porosity loss with depth for sandstones from two different geothermal gradients

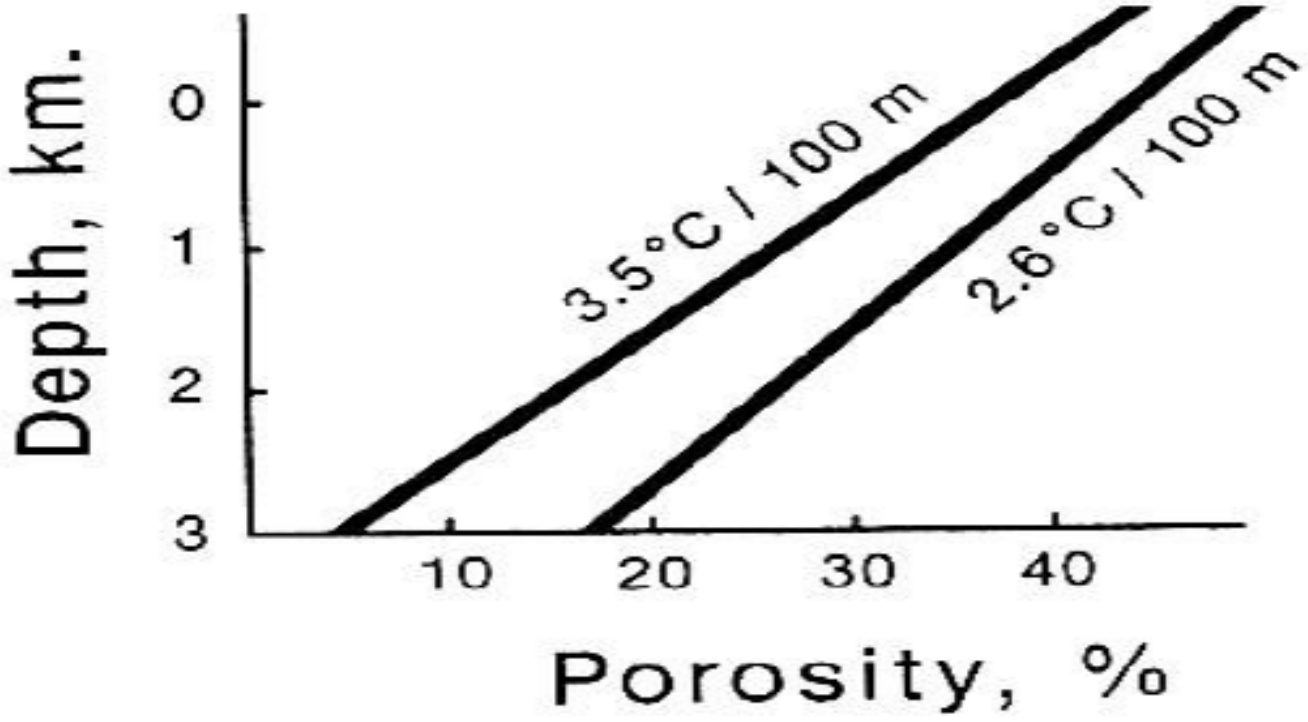


Fig. 19 Porosity loss with depth for sandstones from two different geothermal gradients. (After Galloway, 1974)

Decrease in porosity of different rocks during the same subsidence

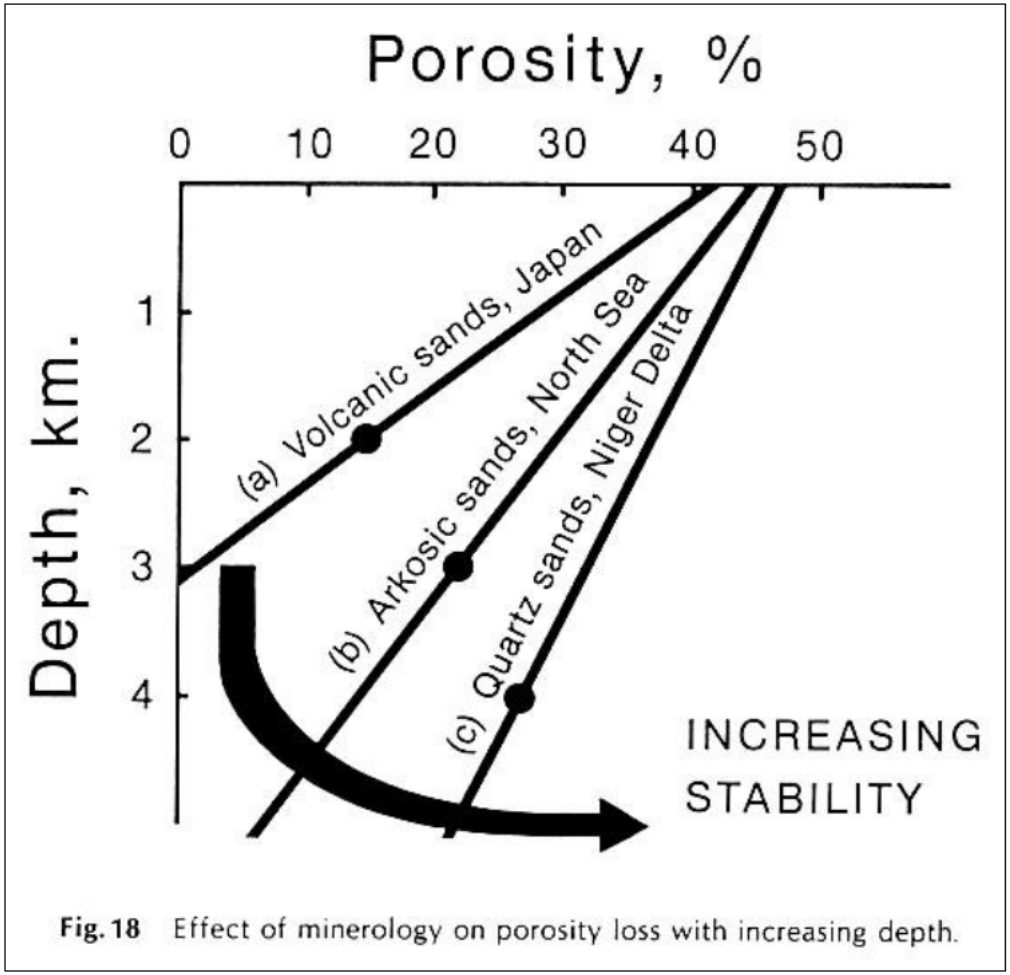
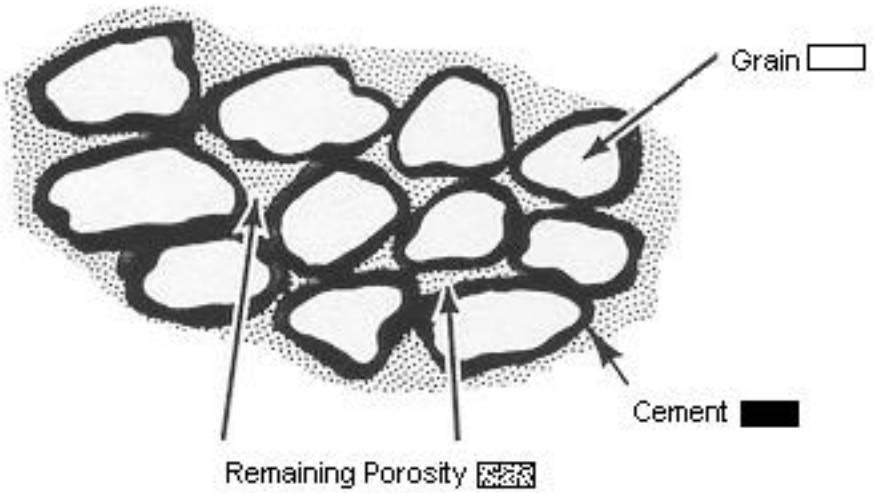


Fig. 18 Effect of minerology on porosity loss with increasing depth.

Controls on Porosity: 5. Cementation



Effect of cementation on porosity

Halliburton 2001

Cementation: is the precipitation of soluble minerals calcite ($CaCO_3$), silica (SiO_2), and iron oxide (Fe_2O_3) in the pore spaces between particles.

Precipitated minerals coat grains and may eventually fill the pore spaces completely. **Porosity and permeability can be reduced significantly due to cementation.**

Reservoir frequency and porosity

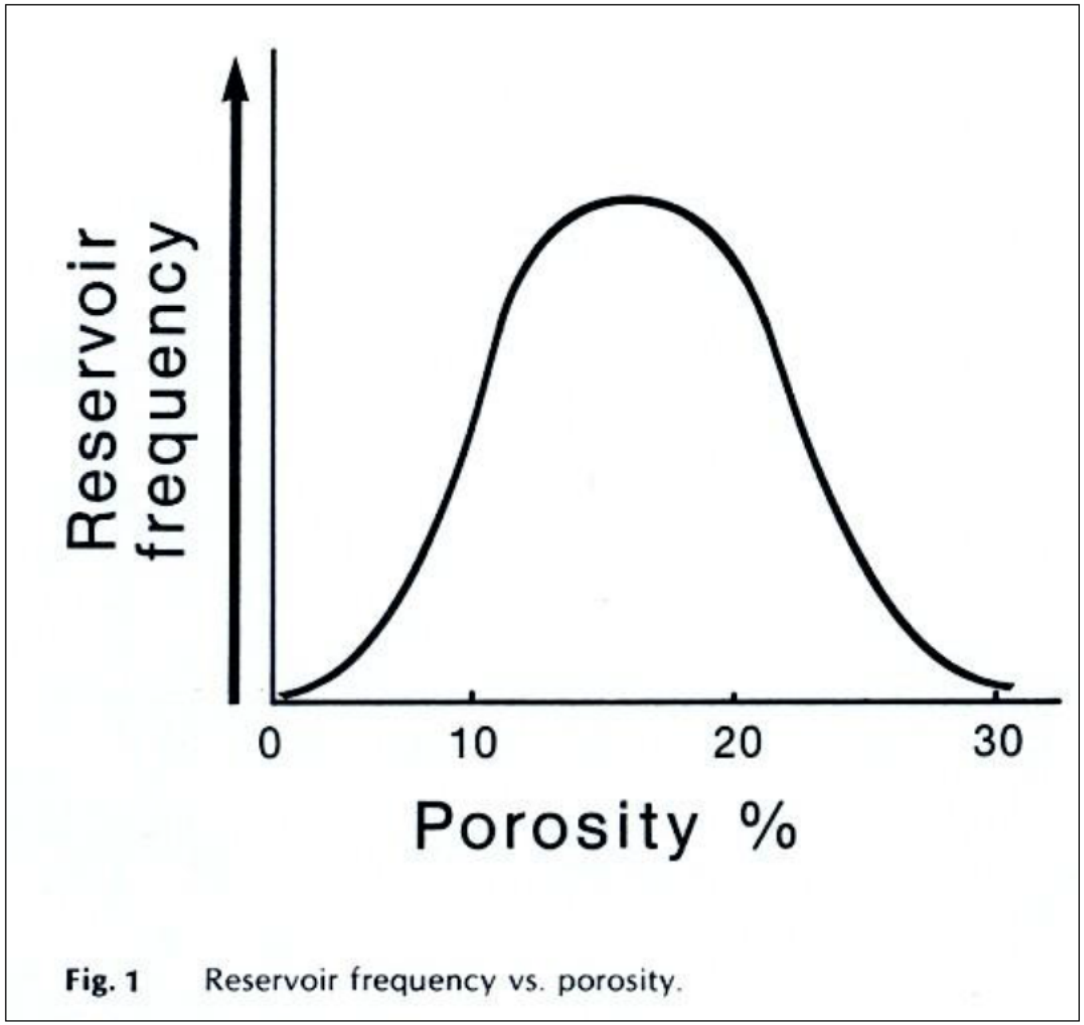


Fig. 1 Reservoir frequency vs. porosity.

Table 9–1. Porosity values for an oil reservoir

0–5%	insignificant
5–10%	poor
10–15%	fair
15–20%	good
20–25%	excellent

(Modified from Levorsen, 1967.)

Hyne 2012

Effects of Diagenesis on Sandstone Reservoirs

Deposition: Φ=40-60%

Shallow burial: compaction and minor cementation Φ=20.30%

HC invasion: cementation stops

Leaching: solution of Cement + unstable minerals

Deep burial: Extensive cementation + compaction Φ<10%

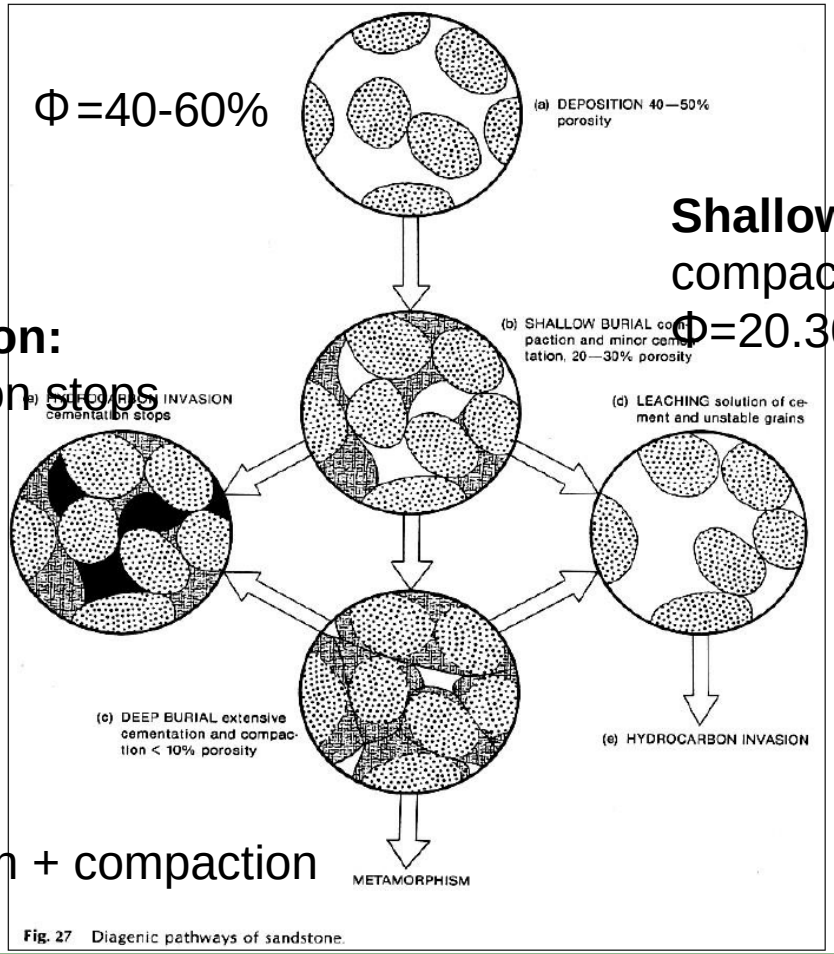
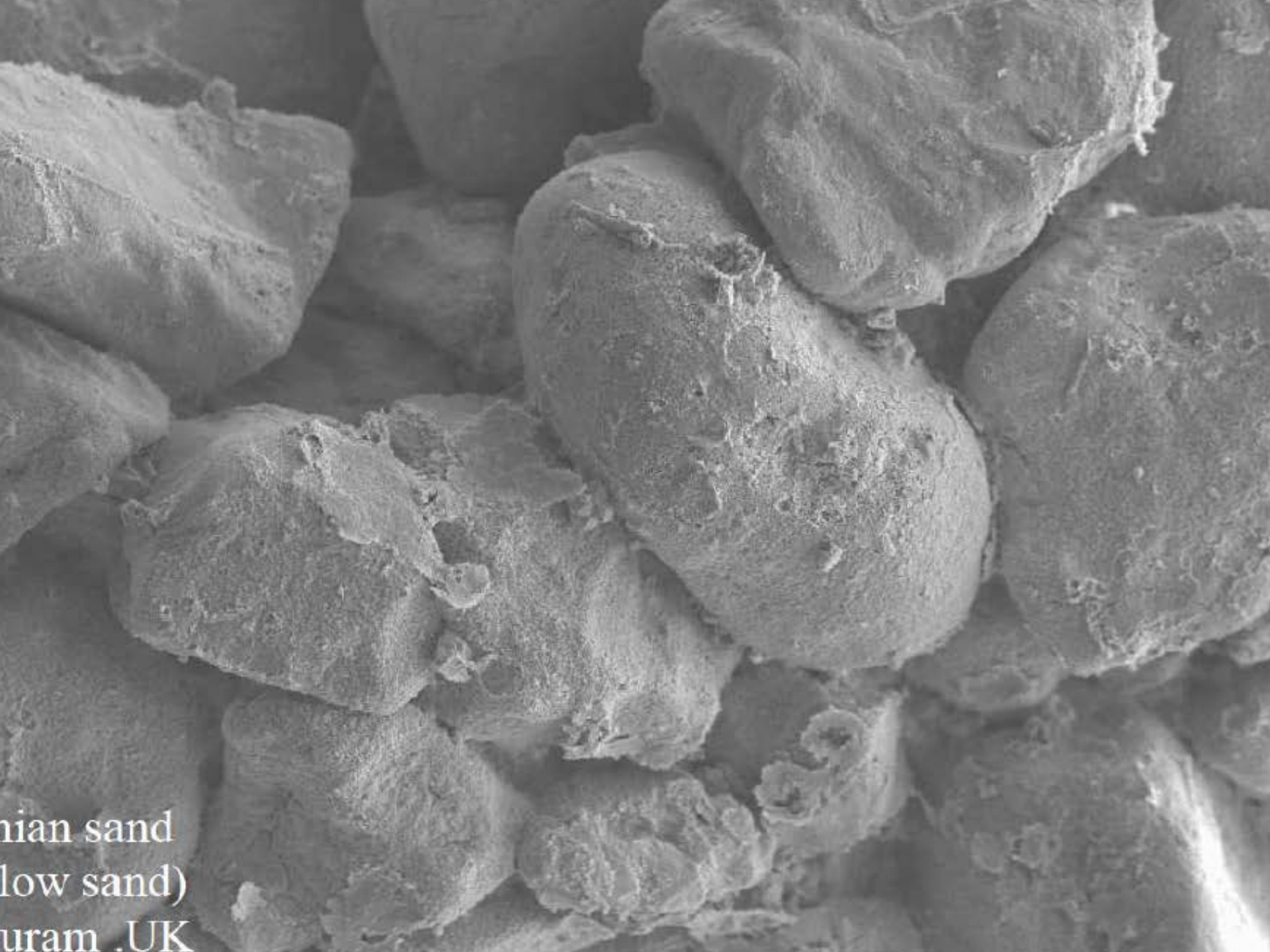
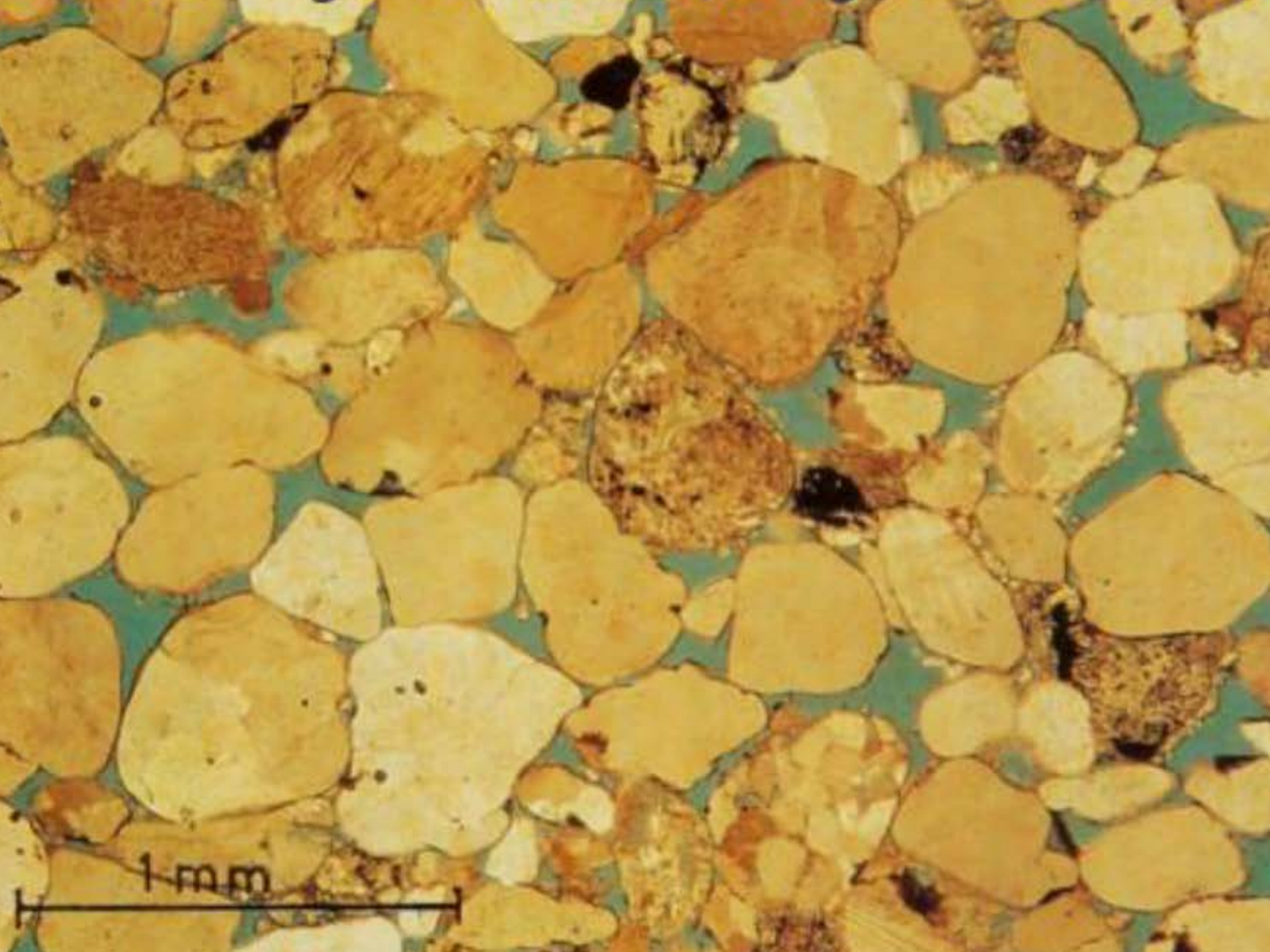


Fig. 27 Diagenic pathways of sandstone.



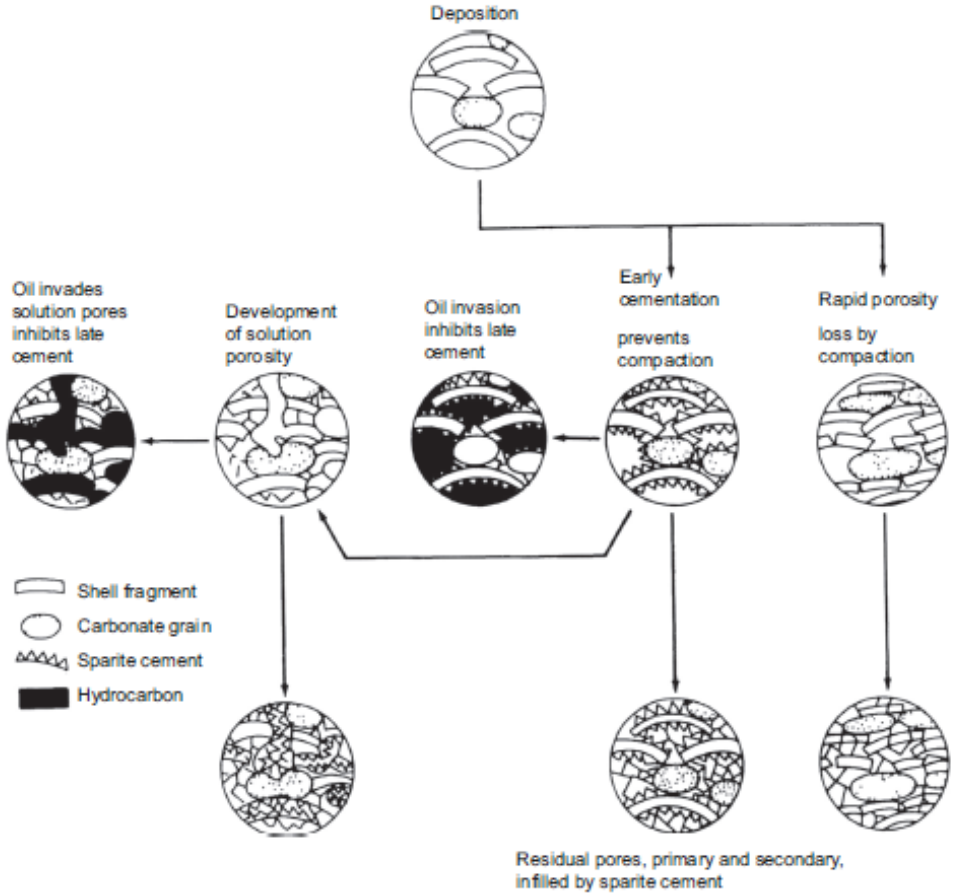
nian sand
low sand)
uram ,UK


1 mm

end graben
bris flow
ne)



Simplified flowchart of the diagenetic pathways of lime sand



Carbonate sands that have not undergone early shallow cementation have less chance of becoming reservoirs!

Porosity cutoff (a minimum porosity value)

- A *porosity cutoff* (a minimum porosity value) is often used to help decide whether to complete an oil well.
- For sandstones, a typical porosity cutoff is 8 to 10%.
- Limestones often 3 to 5% is used. Limestones have fractures that drain larger areas.
- These values vary depending on the depth and economics of the well.

Permeability: K

- The second requirement for a reservoir rock.
- Porosity alone is not enough; the pores must be connected.
- **Permeability** is the ability of fluids to pass through a porous material.

  The unit of permeability is the Darcy. This is defined as the permeability that allows a fluid of 1 centipoise (cP) viscosity to flow at a velocity of 1 cm/s for a pressure drop of 1 atm/cm.

Darcy' law

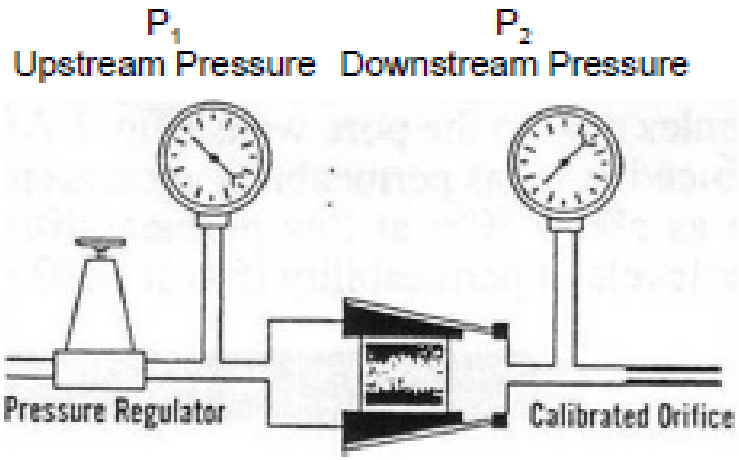
$$Q = \frac{K(P_1 - P_2)A}{\mu L},$$

where

Q = rate of flow;
K = permeability;
$(P_1 - P_2)$ = pressure drop across the sample;
A = cross-sectional area of the sample;
L = length of the sample;
μ = viscosity of the fluid.

Measurement of permeability

Permeability is measured in the lab by flowing a fluid (usually air) of known viscosity through a cylindrical sample of known length and cross-sectional area.



Schematic Flow diagram
(Core Laboratories)

Air is used because there is little reaction with the rock sample (**air permeabilities** may be converted to equivalent liquid permeabilities).

Measurements are performed **perpendicular** and **parallel** to bedding planes.

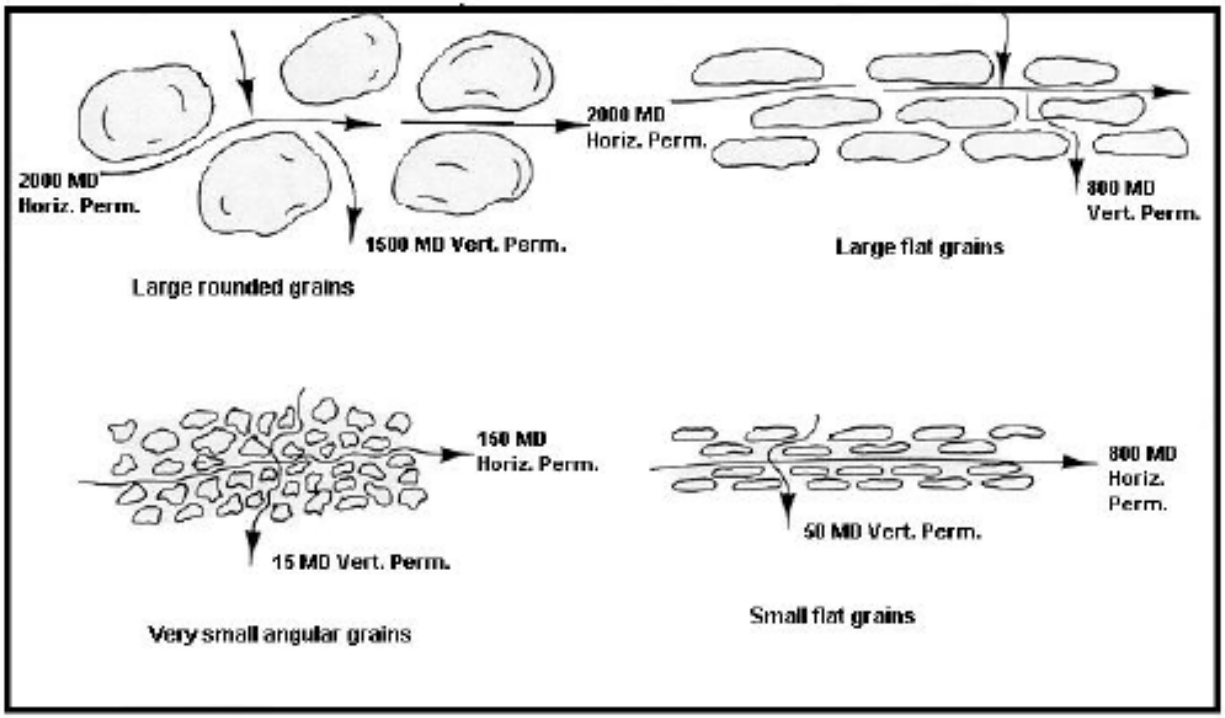
Problems with **unconsolidated** rocks.

Accuracy: Service companies quote an accuracy of +/-5%. (This is very optimistic).

Permeability is determined by

1) **the pressure exerted on the fluids**.
The more pressure exerted on a fluid, the higher the flow rate.
2) **viscosity of the fluid:**
Viscosity refers to a fluid's internal resistance to flow (it's internal friction).
For example, it is much more difficult to push honey through a rock, than it is to push air through it.
The more viscous the fluid, the more difficult it is to push through the rock.

Permeability is measured in **darcies.**
Most reservoirs have permeabilities much less than a Darcy, therefore the millidarcy (md) is commonly used.
Average permeabilities in reservoirs are commonly in the range of 5 to 500 md.



Permeability and grain size and shape Halliburton 2001

Horizontal permeability:
parallel to the bedding planes. This is the main path of the flowing fluids into the borehole.
Vertical permeability is measured across the bedding planes.
Is less than horizontal permeability.
The reason lies in the arrangement and packing of the rock grains during deposition and subsequent compaction. For example, flat grains may align and overlap parallel to the depositional surface, thereby increasing the horizontal permeability.
High vertical permeabilities are the result of fractures and/or solution along the fractures. Found in carbonate rocks and uncemented sandstones.

Table 9–2. Permeability values for an oil reservoir

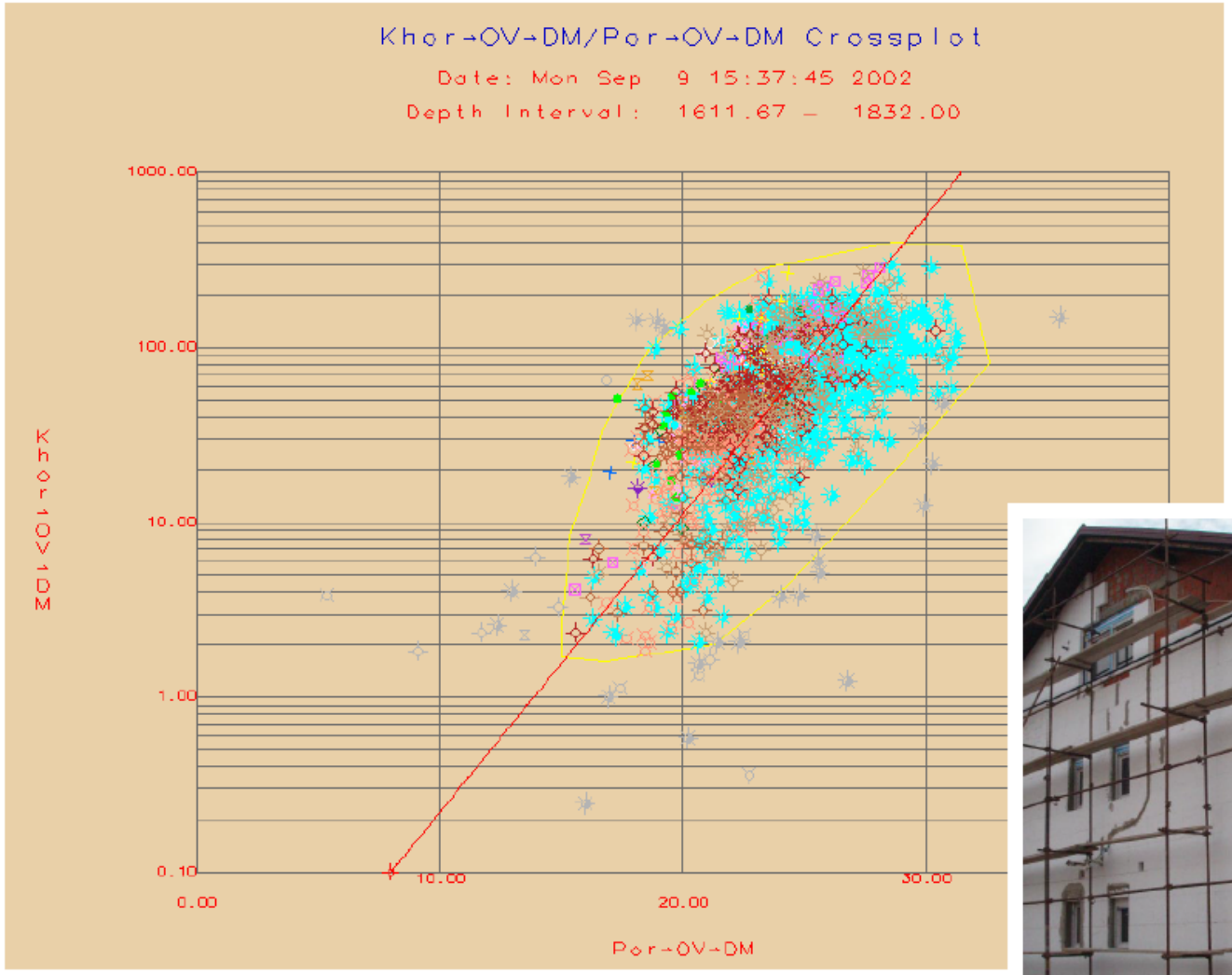
1–10 md	poor
10–100 md	good
100–1,000 md	excellent

(Modified from Levorsen, 1967.)

Hyne 2001

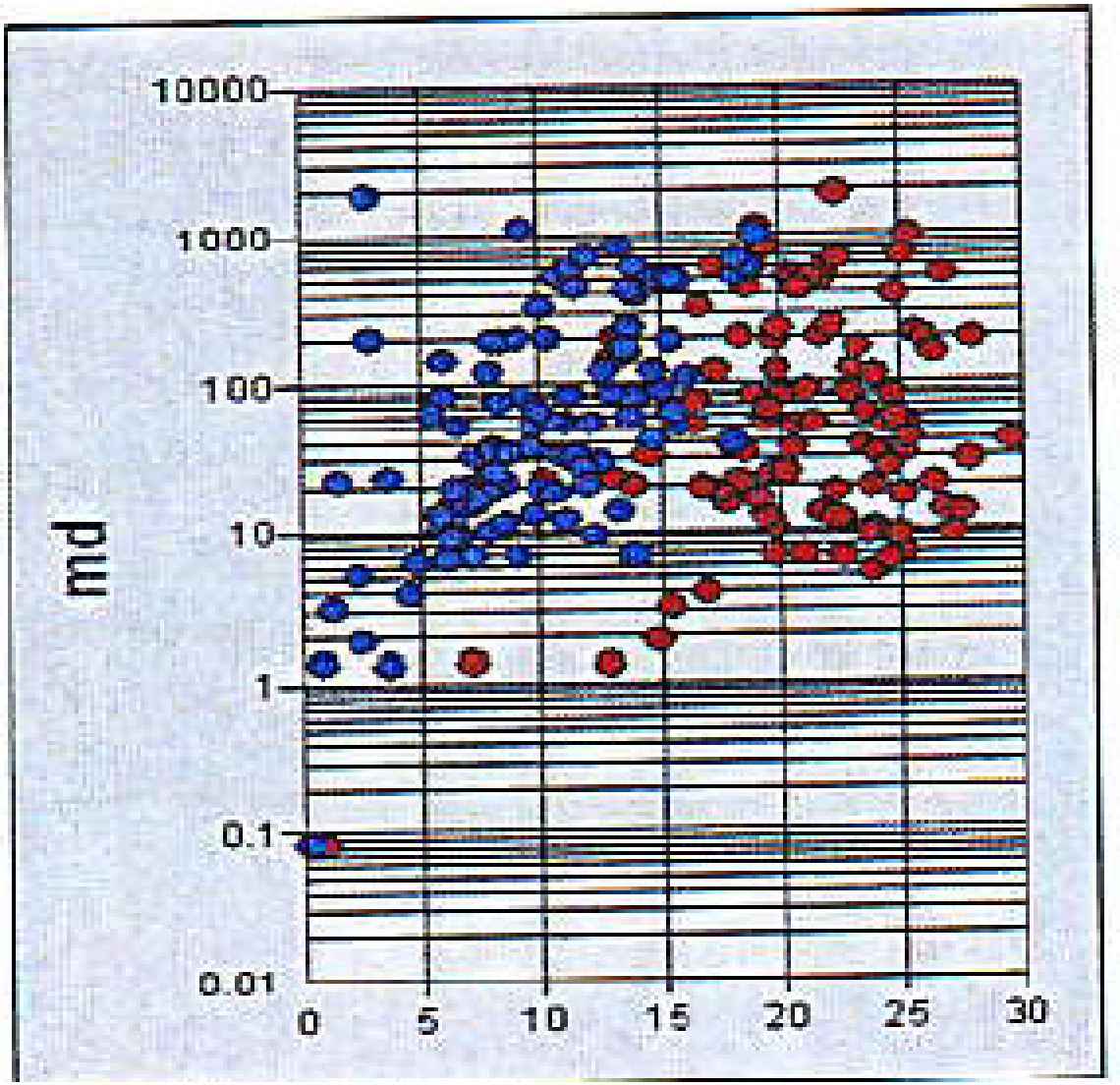
Poro – perm relationship

Sandstone



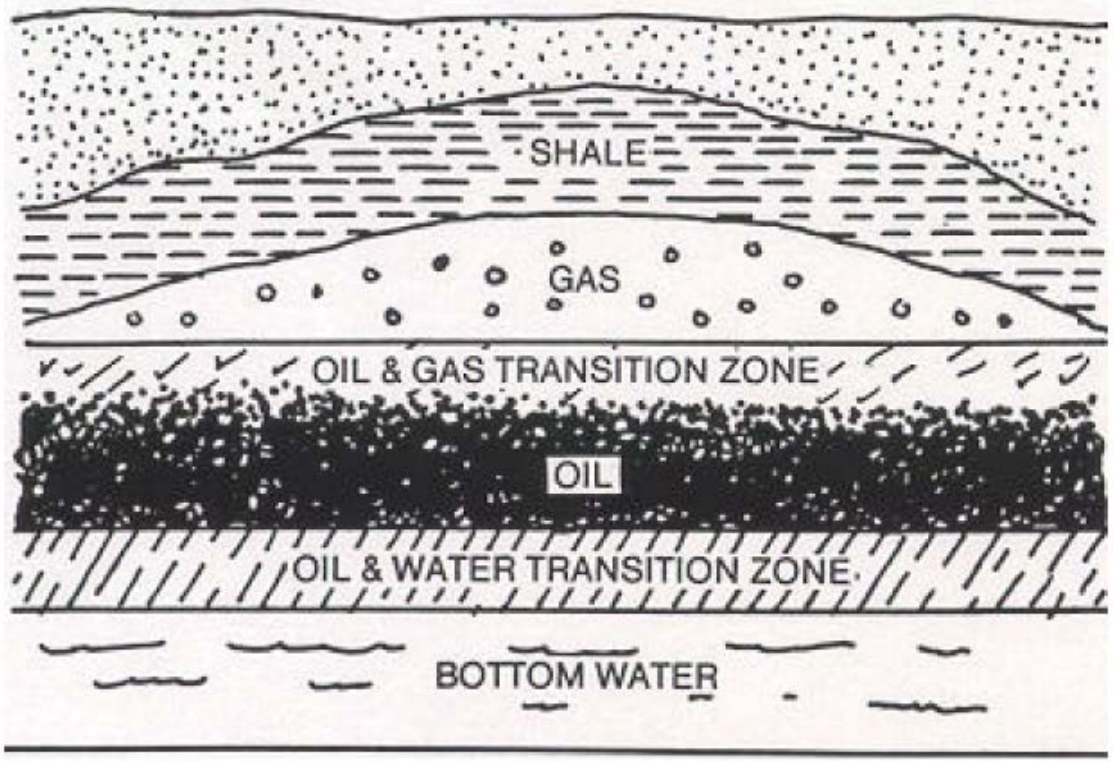


Poro-Perm relationship: carbonates



Fluid distribution within a reservoir

Petroleum reservoirs generally contain a combination of three fluids: gas, oil, water



Any formation that contains hydrocarbons will also contain some amount of water.

During logging (resistivity log) we measure the resistivity of this water.

The lighter fluids, the gas, rises to the top of the reservoir.

A thin transition zone: gas to oil

Oil accumulation: contains crude oil and possibly saturated gas.

Oil-water transition zone of varying thickness, partly filled with water and oil.

The formation is completely saturated with water

Reservoir Fluids

- To understand how reservoirs behave, how oil, gas, and water interact with each other and with the rock is determined by wettability, capillary pressure, and relative permeability.

Wettability

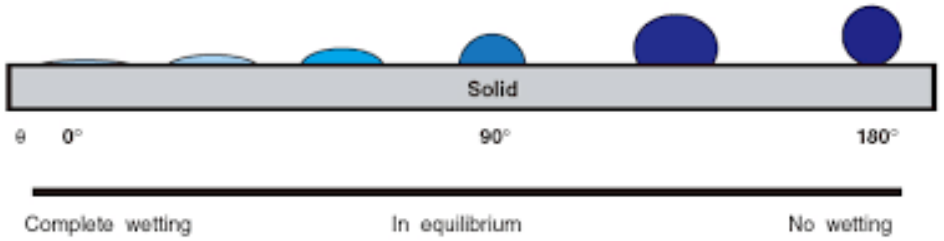
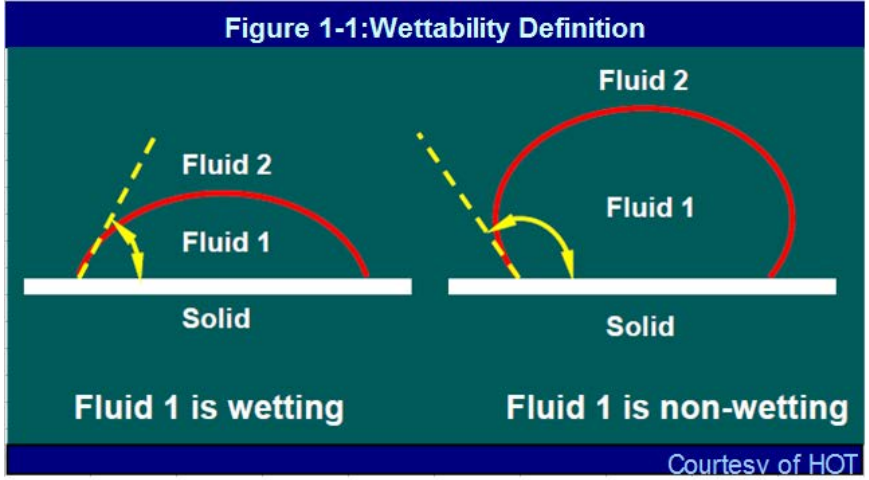


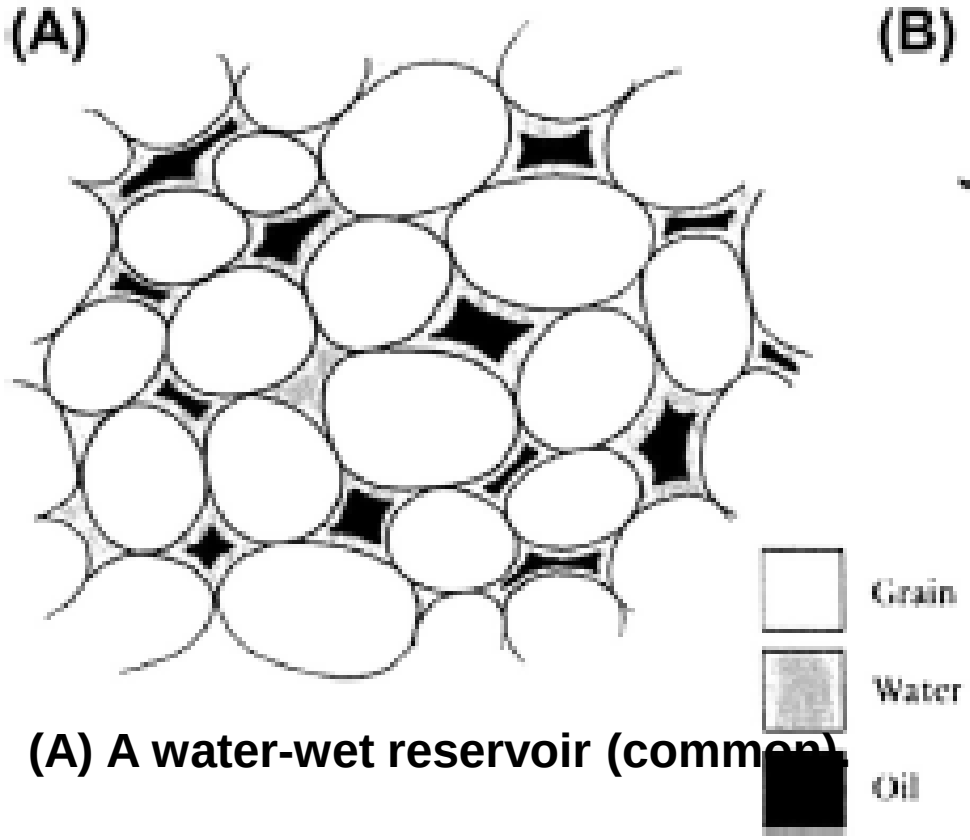
Figure 1 Contact angles and wettability.

- **is the tendency for one fluid to be better attracted to a solid surface, than the other fluid**.
- Wettability is a surface effect. The fluid that occupies the outside of the pore and is in contact with the rock surface is called the **wetting fluid**.
- Where a reservoir rock is **water wet**, the water forms a thin film over most of the grain surfaces and will also fill the smaller pores. The oil or gas will occupy the remaining, more central volume of the pore system.
- Conversely, in a reservoir that is **oil wet**, it is the oil that covers the grain surface and occupies the smaller pores; the water is located centrally within the pore structure
- Sandstones are water-wet, carbonate are oil-wet or intermediate-wet.

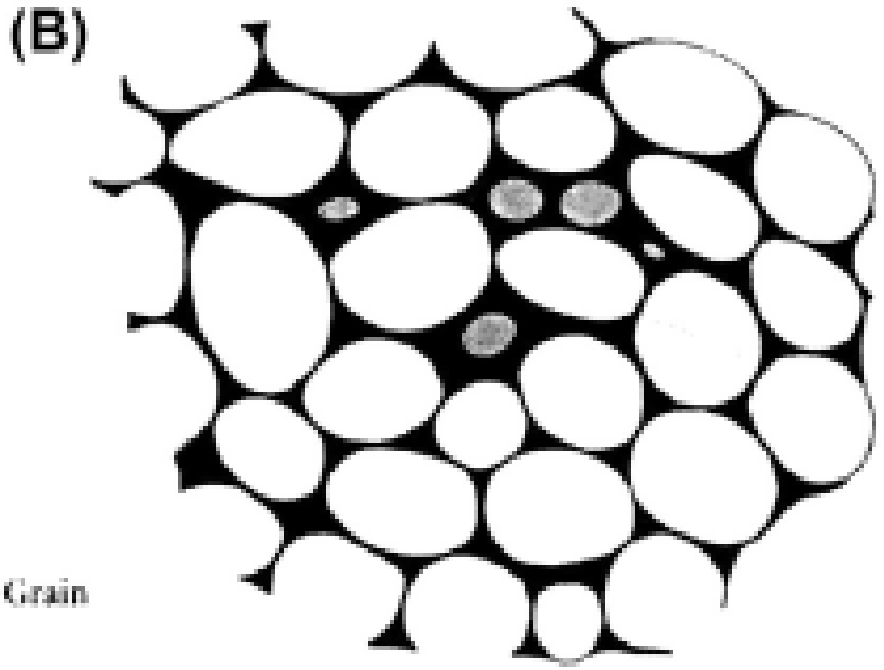
Oil



Mercury (Hg)



(A) A water-wet reservoir (common).



(B) An oil-wet reservoir (rare).

Irreducible Water Saturation

- The pores of the fluid saturated sedimentary rocks contain oil and/or gas, but water is always present.
- **Water saturation** is defined as the fraction of that porosity that is occupied by water. If the pore space is not occupied by water, then it must be occupied by hydrocarbons.
- If we can determine the value of water saturation from porosity and resistivity measurements, then it is possible to determine the fraction of pore space that is occupied by hydrocarbons: **hydrocarbon saturation**.

Irreducible water saturation

- In any reservoir, there is a certain value of water trapped by adsorption of water on the surface of rock grains, and/or by capillary pressure this is referred: **irreducible water saturation (Swirr).**
- At irreducible water saturation, all of the water within the reservoir will be immovable, and hydrocarbon production will be water-free.

Reservoir Pressure

- Reservoir pressure or formation pressure:

the fluids in the pores of the reservoir rock are under a certain degree of pressure, it is called reservoir pressure.

A normal reservoir pressure at the oil water contact approximates very closely the **hydrostatic pressure** of a column of saltwater at that depth. H**ydrostatic pressure** is the normal, predicted pressure for a given depth

Abnormally low pressure might occur in areas where fluids have been drained, such as a depleted hydrocarbon reservoir.

Abnormally high pressure might occur in areas where burial of water-filled sediments by an impermeable sediment such as clay was so rapid that fluids could not escape and the pore pressure increased with deeper burial.

Reservoir Fluids

- Petroleum reservoirs usually contain three main fluids; crude oil, natural gas, and water, with minor constituents being acid gases (carbon dioxide and hydrogen sulphide) and hydrocarbon solids (bitumen, asphalt, etc.).

Reservoir Fluids: 1. Crude Oil

- Only a small quantity of the fluids in a reservoir is crude oil (petroleum), but this small fraction is the most important in terms of production.
- Crude oil is a general term for unrefined petroleum or liquid petroleum.
- Crude oil is a liquid composed of over one hundred different types of hydrocarbon molecules. The molecules rang from 5 to more than 60 carbon atoms in length.
- Based on chemical composition:

- “paraffin-based” saturated, straight-chained hydrocarbons: C_nH_{2n+2},

termed light oils

- - “naphthalenic-based”, saturated, closed-ring hydrocarbons: C_nH_{2n}, tend to be both heavy and sour crudes.
- - “aromatic-based”, or benzene series. These are strong smelling, unsaturated,
- closed-ring hydrocarbons: $C_nH_{2n-}6$.
- Other minor constituents of crude oil 1) sulphur, as free sulphur, hydrogen sulphide, 2) nitrogen, 3) oxygen, and 4) minute amounts of solid organic and inorganic materials.

- GOR: Oil within the reservoir contains dissolved gas. The ratio of produced gas to produced oil is the GOR.
- The amount of gas that may be dissolved in oil depends on pressure.
- If we increase the pressure the volume of dissolved gas will increase, and this will continue until the saturation pressure is reached. This pressure is called "**the bubble point",** and when the pressure falls below this point, gas will come out of solution. This pressure is called **bubble point**.
- **Shrinkage factor**: the decimal amount to which a barrel of reservoir oil shrinks to on the surface of the ground after the pressure has dropped and the gas has bubbled out of the oil.

Reservoir Fluids: 2. Natural Gas

- In addition to the hydrocarbon gases,

there may be gaseous impurities consisting of hydrogen sulfide, nitrogen, and carbon dioxide.

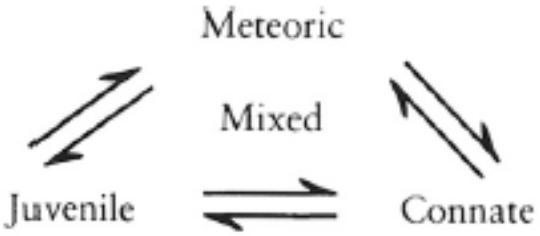
- The gas in reservoirs is made up of the lower end of the alkane series of hydrocarbons (the two main gases being methane and ethane). The remainder of the low end, propane, butane, pentane and hexane will either be gases or liquids, depending on the temperatures and pressures (since the temperature of a reservoir is more or less constant, pressure changes usually determine whether the fluid is a gas or liquid).
- When in the reservoir the oil becomes saturated, the excess gas will form a “gas cap” above the oil.
- Classifications of gas:

- **dry gas:** it is a gas under both subsurface reservoir and surface condition. Pure methane (CH_4 gas).
- **wet gas**: a liquid condensate separates from the gas after production under surface conditions but not in the reservoir. Contains less methane (typically less than 85% methane) and more ethane and other more complex hydrocarbons.

Reservoir Fluids: 3. Subsurface water

- Two types of water can be recognized in the subsurface by their mode of occurrence:
- 1. Free water
- 2. Interstitial, or irreducible, water (a discrete water film on the grain surfaces)

SUBSURFACE WATERS



Meteoric waters: near the earth's surface and are caused by the infiltration of rainwater. Their salinity is negligible, and they tend to be oxidizing. Meteoric waters are often acidic because of dissolved humic, carbonic, and nitrous acid (from the atmosphere).

Connate waters have several definition.

1) Originally thought of as residual seawater that was trapped during sedimentation.
2) Current definitions: interstitial water existing in the reservoir rock prior to disturbance by drilling
3) Waters which have been buried in a closed hydraulic system and have not formed part of the hydraulic cycle for a long time".

Juvenile waters are of magmatic origin.

Mixed waters: may be caused by the confluence of juvenile, connate, or meteoric waters.

Relative permeability

- **Absolute permeability**:

The permeability, when a single fluid or phase is present in the rock.

- **Relative permeability**

When more than one fluid phase is present, the permeability of one phase is reduced by the presence of the other phases within the pore system.

The greater the water saturation the less permeable the reservoir will be to oil and gas.

- Relative permeability curves display these relationships.

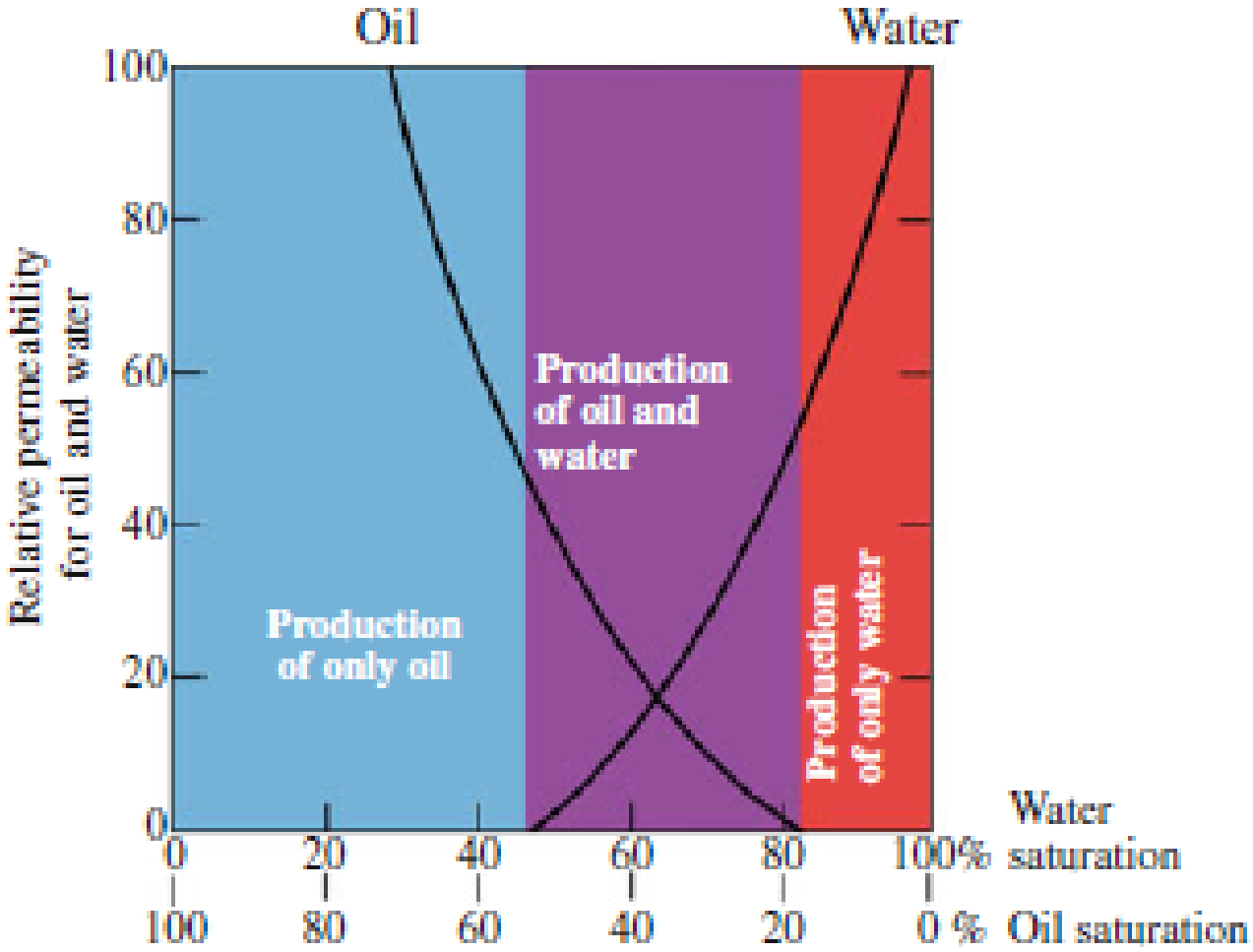
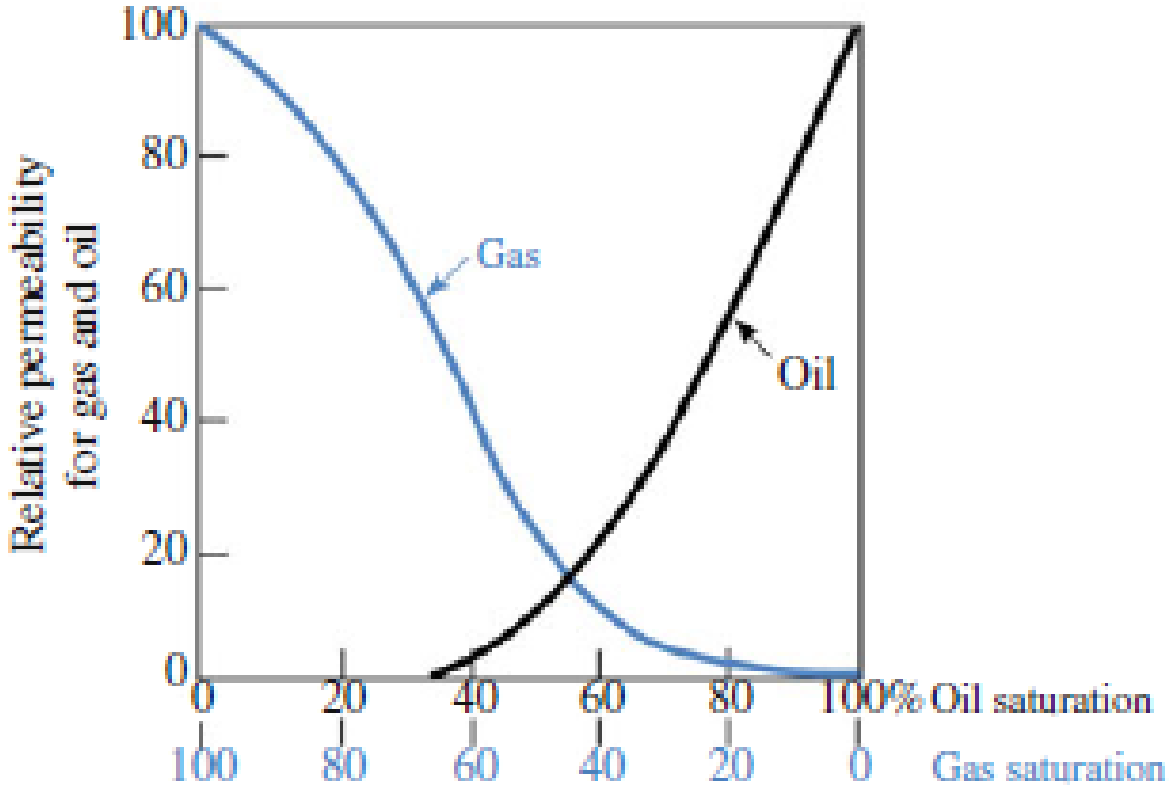


Diagram showing the relative permeability with a mixture of water and oil.

Bjorlykke 2010

Relative permeability of oil and gas



If the oil saturation is less than about 35% only gas will flow. Even with high oil saturation (80%) there will still be some production of gas.