Unconventionals Update: Challenging the Assumptions*

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Abstract

We have learned a great deal about shale and unconventional reservoirs in the last several years, and many of our beliefs turned out to be flawed assumptions. The goal of this presentation is to identify the consequences of making drilling and completion decisions based on flawed assumptions, and then to point out the newly recognized realities. Most of the assumptions have to do with fluid transport mechanisms, especially in the case of shale gas. We are now able to see that the reservoir is very dynamic, with pore architecture constantly changing as the pressures, surface tension, temperatures, nano-charges, and chemical conditions fluctuate. Changes in any or all cause reservoir models that involve conductivity, adsorption, and connectivity to need constant revision, and all decisions based on reservoir models to be reconsidered.

References Cited

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Unconventionals Update: Challenging the Assumptions

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Beliefs About Unconventionals Turned out to Be Flawed Assumptions

Decisions made on flawed assumptions have led to:

- Going out of zone while drilling
- Using the wrong kind of drilling fluid
- Using the wrong kind of frac fluid
- Using the wrong proppants

Let’s Focus on Fluid/Gas Transport Mechanisms

Key Questions:

- How does gas flow through the rock?
- What causes conduits to be connected?
- Why does the fluid flow in the first place?

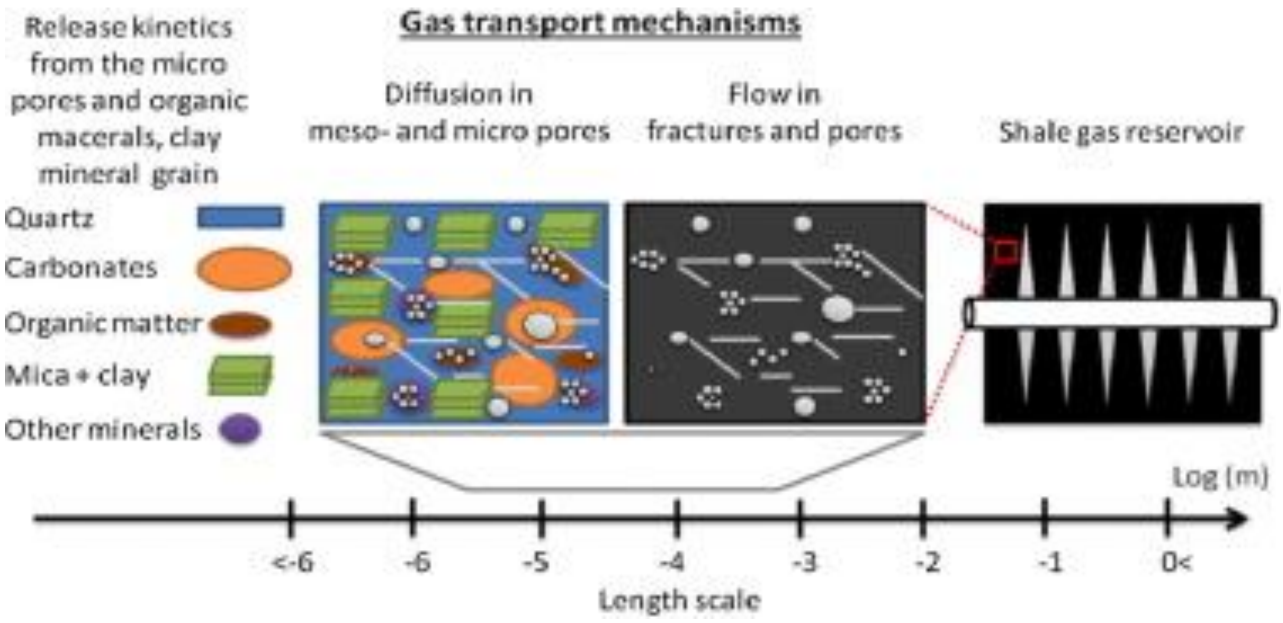
Challenged Assumption #1: All flow is Darcy flow

Fluid Transport Systems in Sedimentary Rocks

The most efficient fluid transport mechanism in the matrix system of sedimentary rocks is pressure-driven volumetric flow (which obeys Darcy’s law) through interconnected pores (Gensterblum, 2015, p. 99)

In reality, shale gas flow is nano-scale and non-Darcy

Shale Gas Transport Dynamics



Many of the transport mechanisms are quite subtle and occur on a nano-scale, often below the ability to detect the magnitude of changes.

Challenged Assumption #2: Pore Systems Can Be Mapped Once and All Is Good

Pore Systems and Pore Architecture

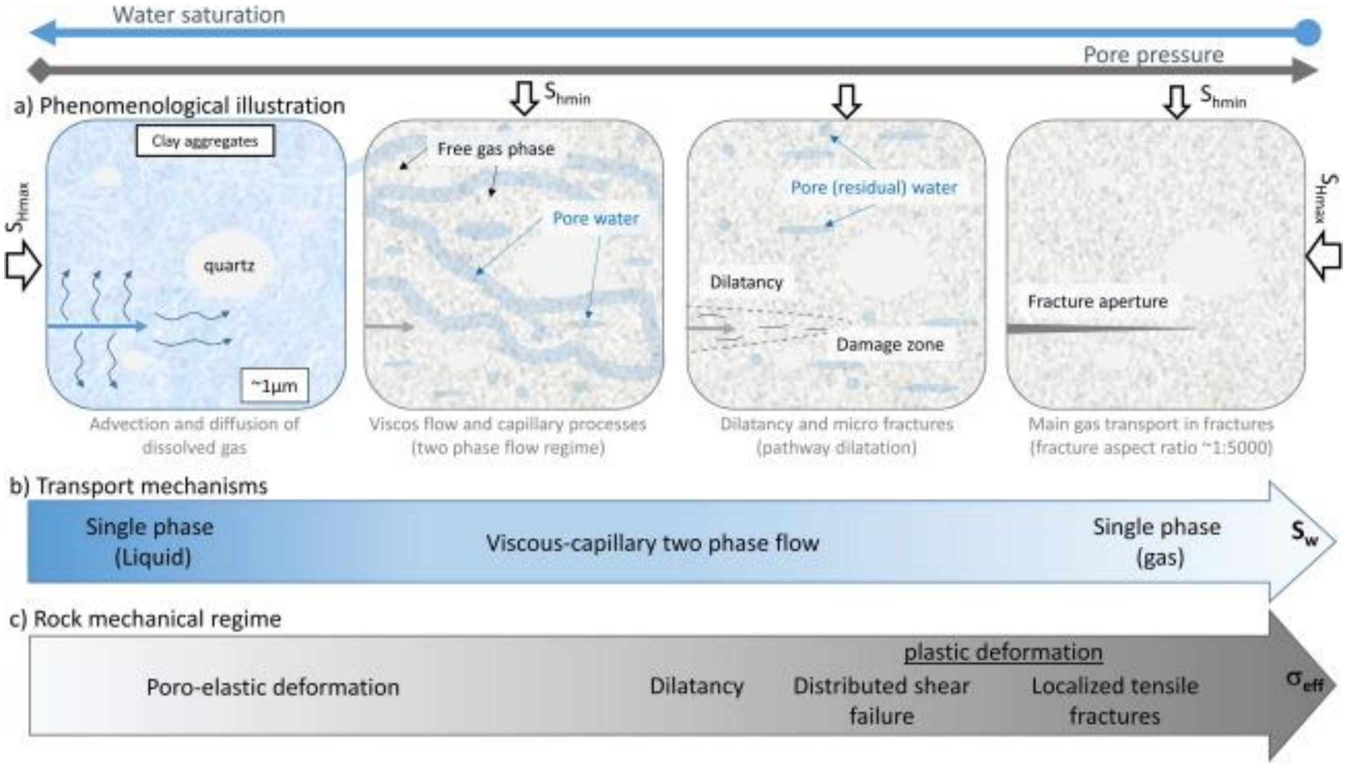
A completely dynamic system, with changes due to pressure, temperature, chemistry, and more

In reality, pore systems are dynamic, and understanding the connectivity and flow requires constant vigilance

Pore Systems Are Not Static

Burial
Compaction
Diagenetic alteration
Pore pressure
Poro-elasticity
Micro-fractures and fissures

Phenomenological Illustrations of Flow Regimes



Assumption 3: All shale plays produce in the same way

Unconventional Reservoir Findings, 1

Unexpectedly long tail-off of gas production curves (steep decline curves)

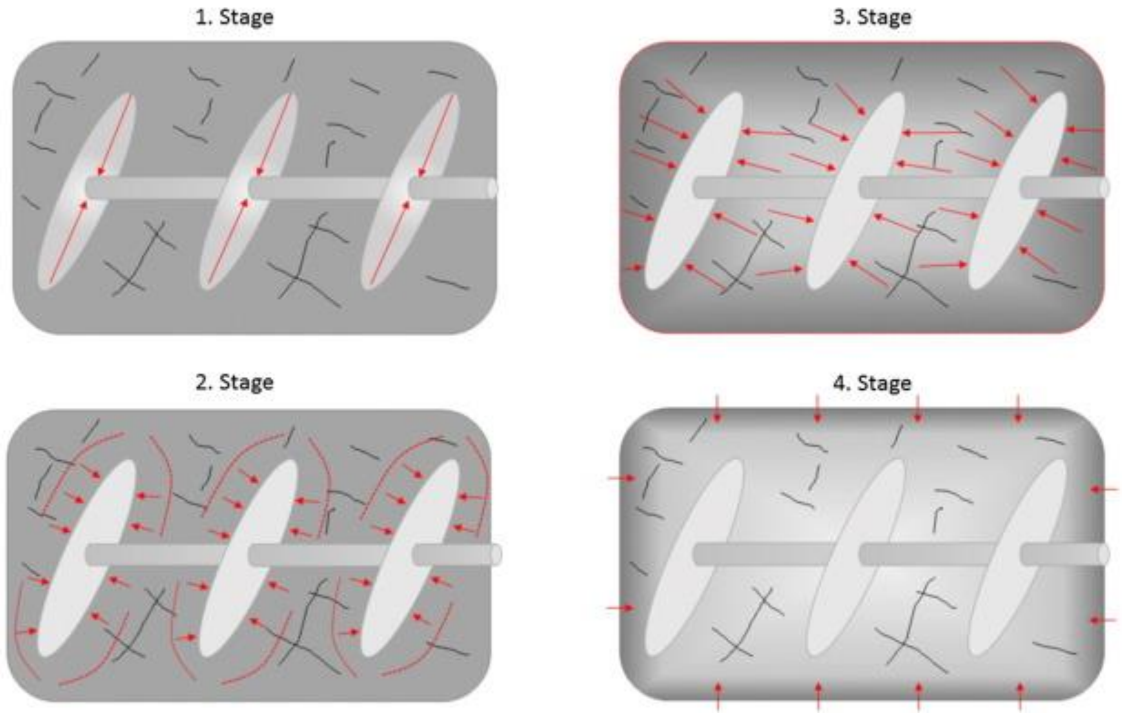
Low recovery factors

Low flowback recoveries during hydraulic fracturing

Micro and meso pore throat distribution

Very low (nano-scale) matrix permeability

Transport Process during Depletion of Shale



(Clarkson and Williams-Kovacs, 2013)

Red arrows: main flow orientation and origin

Notice how the flow tends to move out of the fractures, and into recharging the stimulated rock space

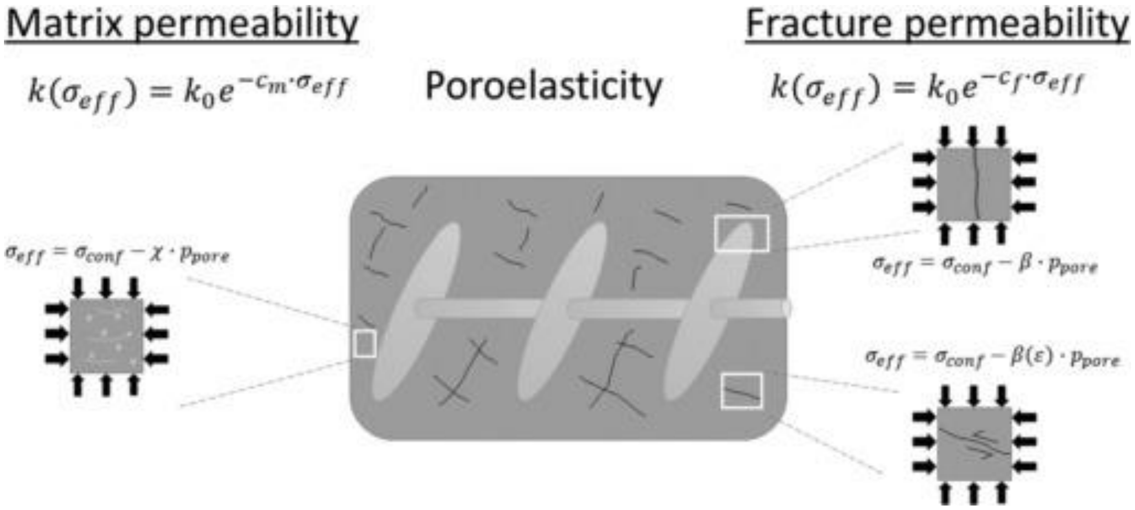
Assumption 4: The flow will stay the same during the life of the well

Unconventional Reservoir Findings, 2

Reality: Flow and gas transport changes during the life of the well. Here is what happens:

- Slip flow effects at low gas pressures (induced fracture collapse)
- High capillary / displacement pressures in matrix
- Multiple fracture surfaces, all with different properties
- Variety of gas and multiphase transport properties

Permeability in a Hydraulically Fractured Shale

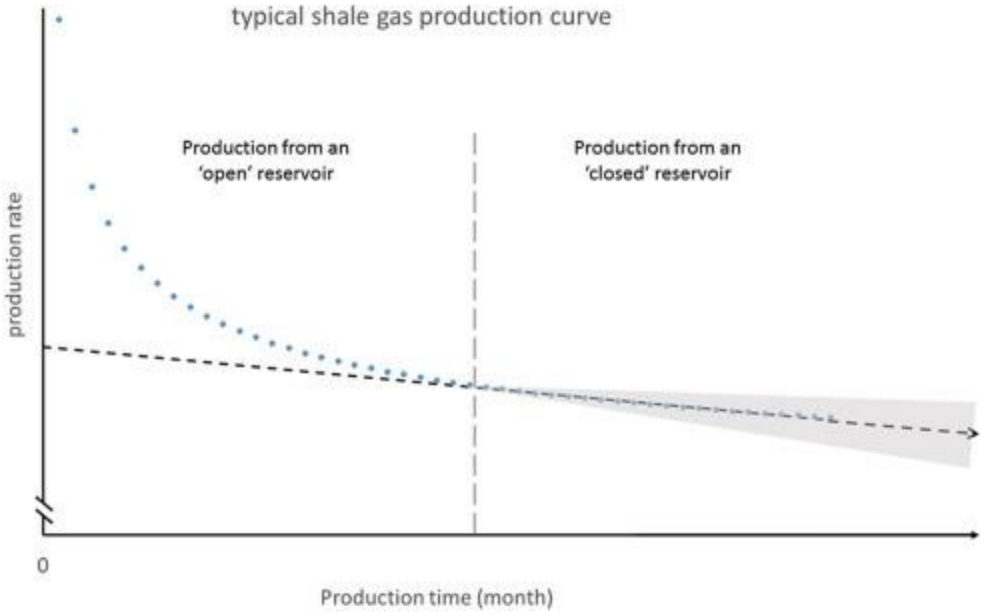


Matrix permeability may be in a different direction than fracture permeability.

Stimulated rock volume outlined in gray.

Induced fractures: may be vertical, may be horizontal. May be conductive and non-conductive.

Shale Gas Decline Curve



Decline curves are steep, particularly from the "open" reservoir (the stimulated space).

Area for research: which processes are coupled?

- transition from Darcy flow to slip flow
- Stress sensitivity of permeability to pore throat compressibility

Assumption 5: The porosity is the best right after hydraulic fracturing

Unconventional Reservoir Findings, 3

Reality: Porosity can improve during production due to opening of fractures or dissolution (diagenesis) as well as surface tension changes

Displays unusual multiphase flow and relative permeability prediction because of virtually undetectable changes in gas saturation during and after imbibition

Gas affected by desorption kinetics, solution / exsolution

Molecular diffusion of organic matter affects flow along the mineral surfaces

Organic porosity development during maturation causes flow

What Do We Know about the Flow Mechanism?

- Gas movement by solution and/or diffusion (apply Henry's and Fick's Laws)
- Gas flow in original porosity – Darcy flow, 2-phase
- Gas flow along dilatant pathways (micro-fissuring)
- Gas flow along macro-fractures where fracture initiation occurs gas pressure exceeds sum of minor principle stress and tensile strength (flows where the rock is broken)

Typical Production Decline Curve Characteristics

Two different production phases have been identified.

In the first phase, open reservoir depletion, the production rate decays hyperbolically.

The second phase, depletion of a nearly closed reservoir, is characterized by an almost linear decline

Gas Flow Velocities in Shale

Gas flow velocities within the matrix of gas shales and coals may be very low, due to permeabilty coefficients in the nDarcy-range and below.

Viscous Flow Difficulties in Shale

Capillary Forces: Due to the occurrence of wetting fluids (water), viscous flow may be prevented by capillary forces.

Transport by Diffusion: In such cases diffusion becomes the main transport mechanism.

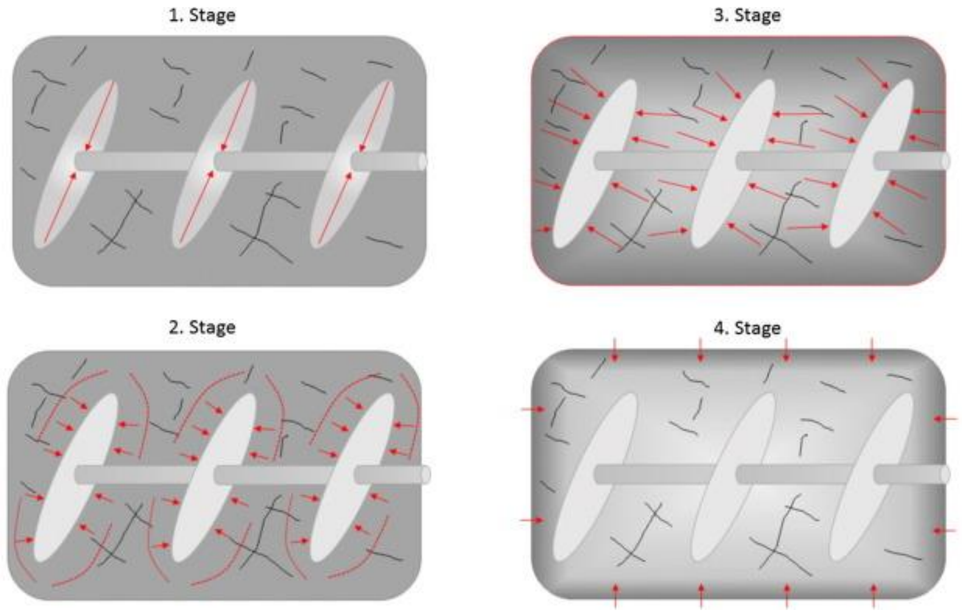
Transport by Sorption Dynamic: Sorption and desorption must be taken additionally into account.

Stage 1

Reservoir: Depletion of primary fractures; considered an “open” reservoir depletion

Mechanisms: Fracture flow / Multi-phase depending on hydraulic fracturing operations; proppant embedment

Timing: Hours to first days

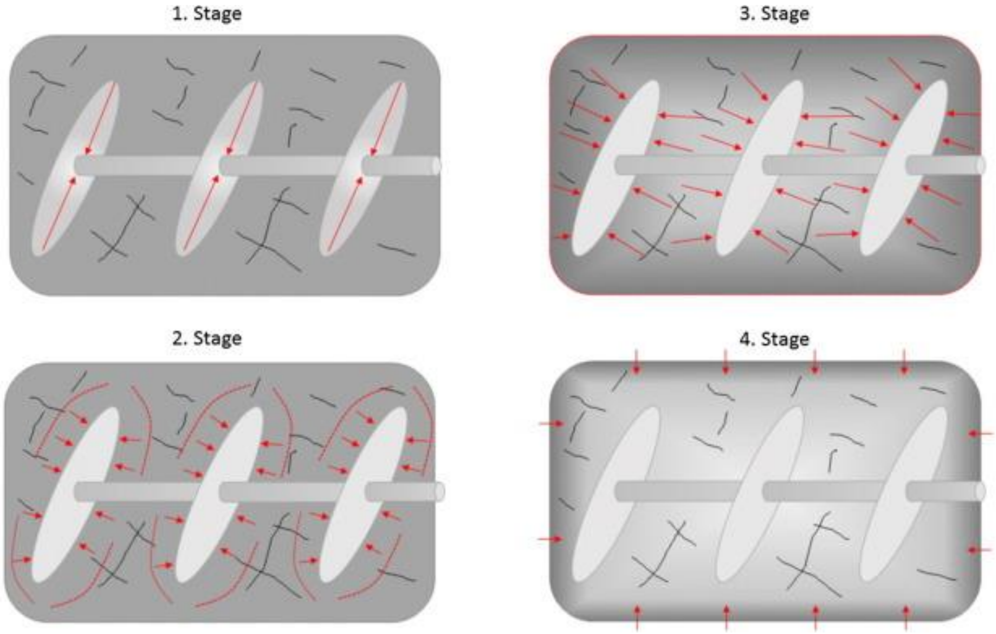


Stage 2

Reservoir: Flow from the matrix through the primary fracture network. The secondary fracture network will be depleted to a level where out-flux and in-flux from the shale matrix are equal. The pressure in the shale fracture system decreases significantly.

Mechanisms: Fracture flow / Matrix permeability (high pore pressure, laminar flow); proppant embedment

Timing: First days to weeks

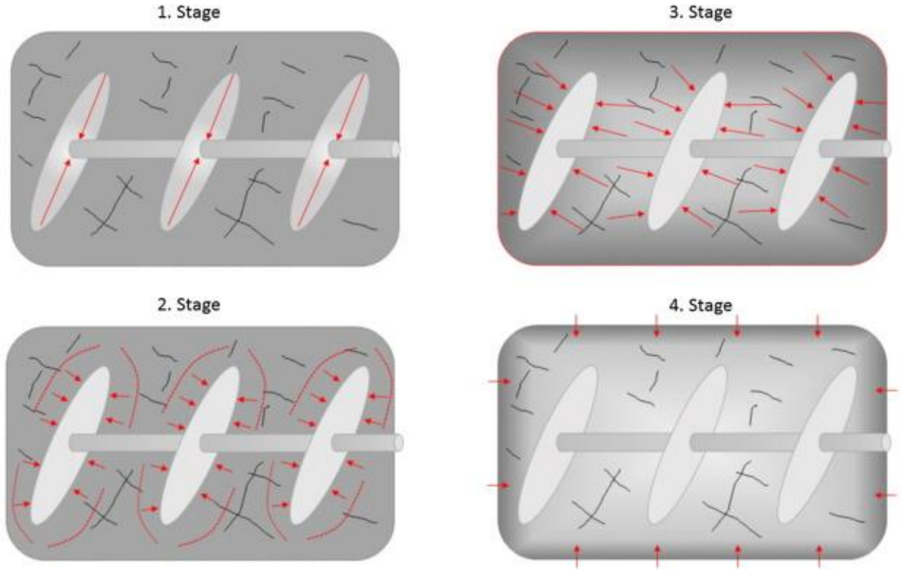


Stage 3

Reservoir: The drainage area expands deeper into the shale matrix; drainage areas of different fractures start to overlap. The pressure in the shale matrix starts to decrease significantly. At this stage the reservoir is considered nearly “closed”

Mechanisms: Matrix flow (low pore pressure) / Slip flow, diffusion, Single phase flow

Timing: Months to years

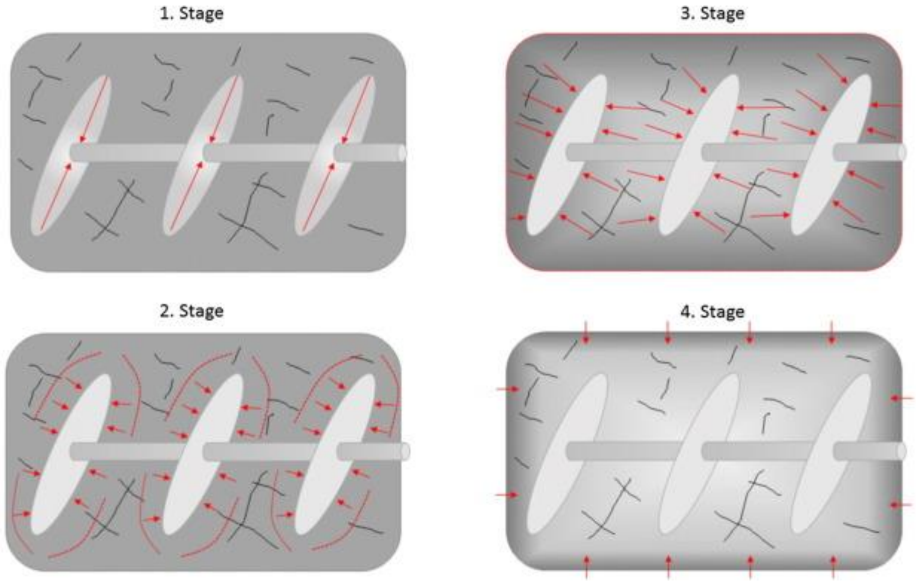


Stage 4

Reservoir: Boundary flow and depletion of the shale matrix. The drainage area reaches its maximum. The reservoir is considered “closed”, depletion is similar to the depletion of a tank

Mechanisms: Matrix flow (low pore pressure) / Slip flow, diffusion, Single phase flow

Timing: Years to decades



Conclusions

- **Most erroneous assumptions about flow have to do with a fundamental misunderstanding about the dynamic nature of the reservoir, and the constantly changing pressure and also surface tension along the pore spaces**

- **Nano-level behavior is affected by nano-charges, many of which are not taken into consideration in flow modeling**

- **Pore architecture changes constantly due to pressure & flow (collapse, opening fractures, connectivity, conductivity) and also diagenesis**