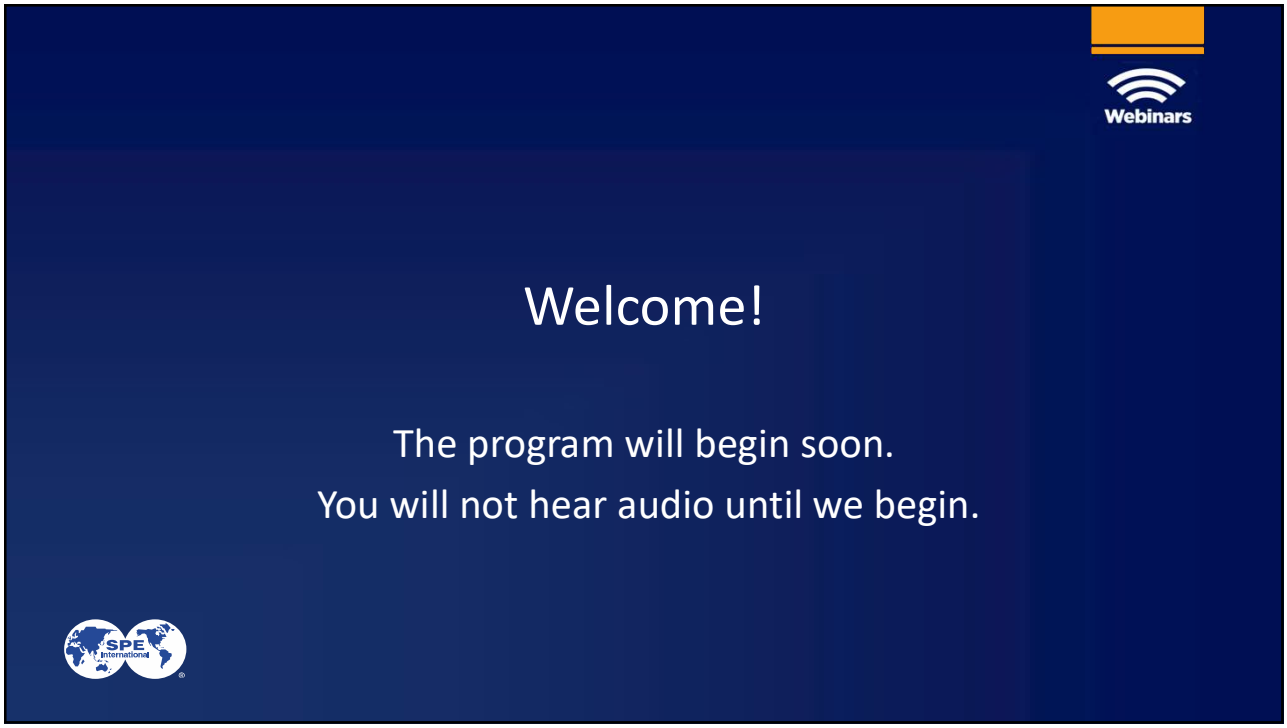

Webinars
Welcome!
The program will begin soon.
You will not hear audio until we begin.
SPE International

1

Webinars

Multiple porosity/fractal/anomalous diffusion models, for heterogeneous complex reservoirs

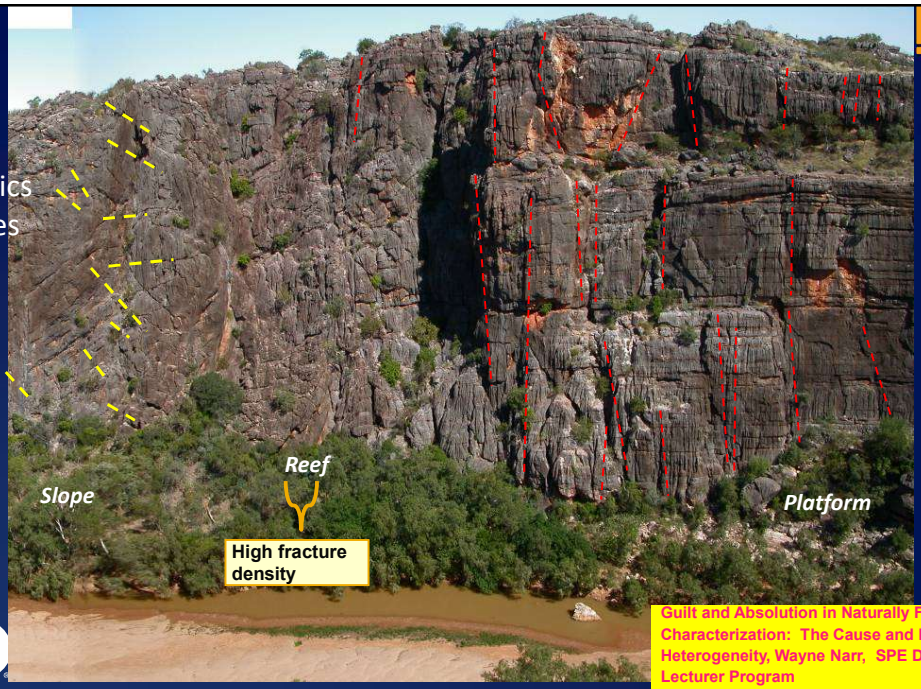
Rodolfo Camacho-Velázquez

October 13th, 2022

2

3

Fracture Characteristics due to facies change



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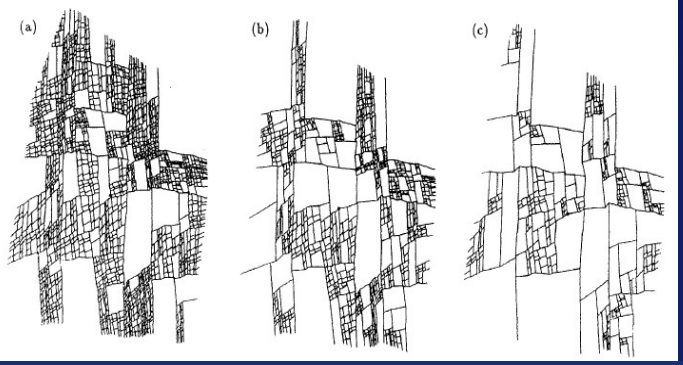
Guilt and Absolution in Naturally Fractured Reservoir Characterization: The Cause and Devilish Effect of Heterogeneity, Wayne Narr, SPE Distinguished Lecturer Program

4

Fractal NFR, Single or Dual-Porosity Model

Fractures occur on a wide range of scales. There are areas with clusters or corridors of fractures and others where fractures are scarce.



d_{mf}=1.78 d_{mf}= 1.65 d_{mf}= 1.47

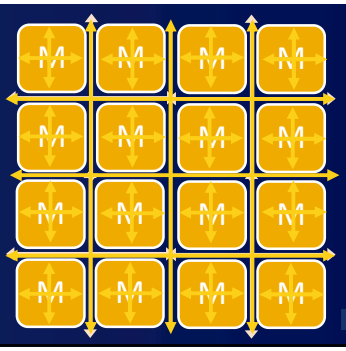
d_{mf}= log(N) /log(L)

Acuña & Yortsos, SPEFE 1995

Traditional NFR, Dual-Porosity Model

Assumptions:

- **Fractures at a single-scale**
- **Uniformly Distributed Fractures**
- **All interconnected fractures**



5

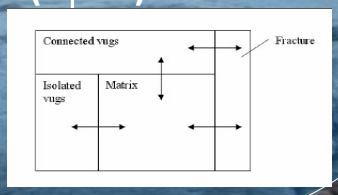
Motivation

Webinars

Naturally Fractured Reservoirs

Fractal

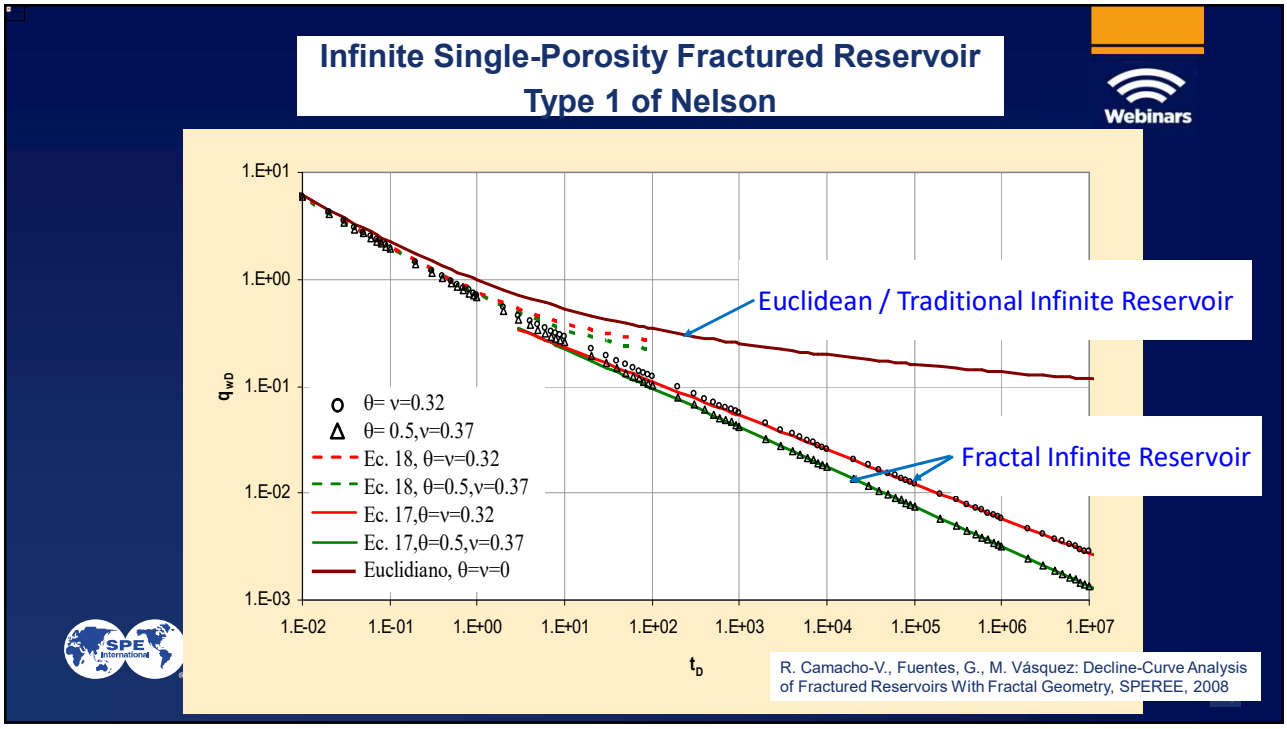
Fractured-Vuggy
(3ϕ-2k)



Traditional Dual-Porosity

More general continuous models

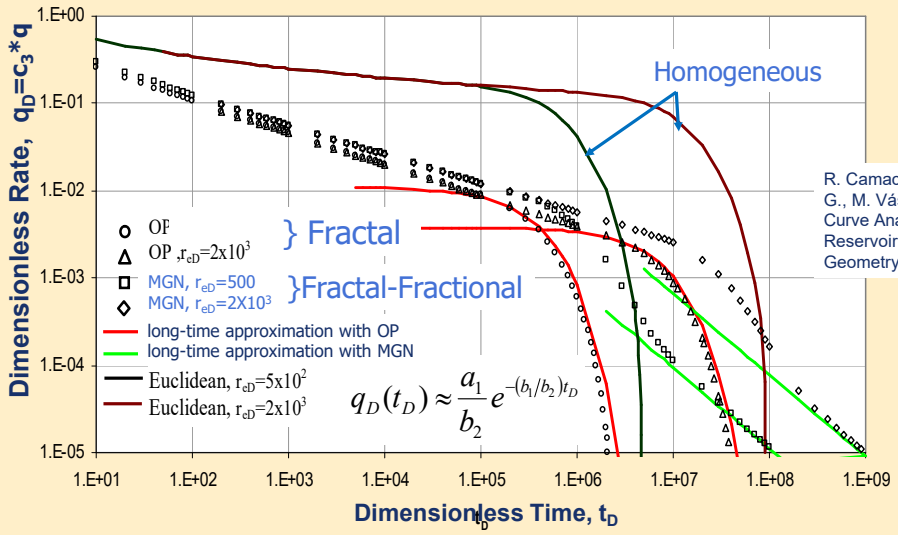
6


Infinite Single-Porosity Fractured Reservoir
Type 1 of Nelson
Webinars
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
q_{wD}
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
t_D
θ= ν=0.32
θ= 0.5,ν=0.37
Ec. 18, θ=ν=0.32
Ec. 18, θ=0.5,ν=0.37
Ec. 17,θ=ν=0.32
Ec. 17,θ=0.5,ν=0.37
Euclidiano, θ=ν=0
Euclidean / Traditional Infinite Reservoir
Fractal Infinite Reservoir
R. Camacho-V., Fuentes, G., M. Vásquez: Decline-Curve Analysis of Fractured Reservoirs With Fractal Geometry, SPEREE, 2008

7

Results with fractal modeling

1-ϕ Fractured Reservoirs, Decline Curves, Bounded

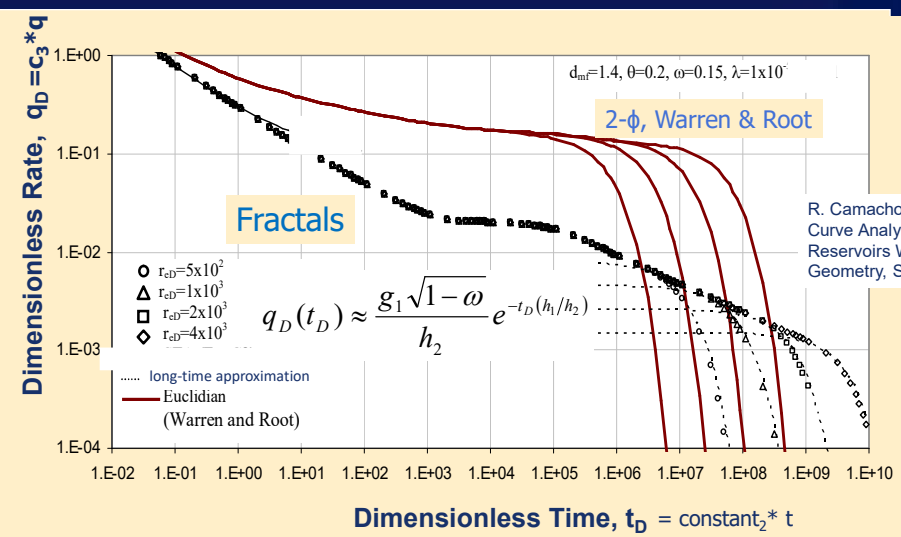


R. Camacho-V., Fuentes, G., M. Vásquez: Decline-Curve Analysis of Fractured Reservoirs With Fractal Geometry, SPEREE, 2008

OP-- O' Shaughnessy & Procaccia. 1985. Physical Review; **MGN**--Metzler et. al. 1994. Physica

Results with fractal modeling

2- ϕ, Influence of r_{eD}, closed reservoir



R. Camacho-V., et.al.: Decline-Curve Analysis of Fractured Reservoirs With Fractal Geometry, SPEREE, 2008

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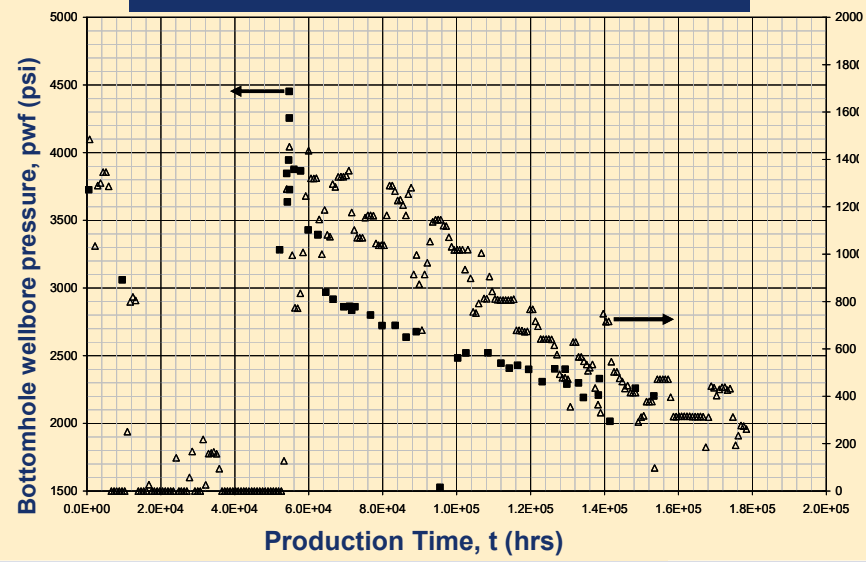
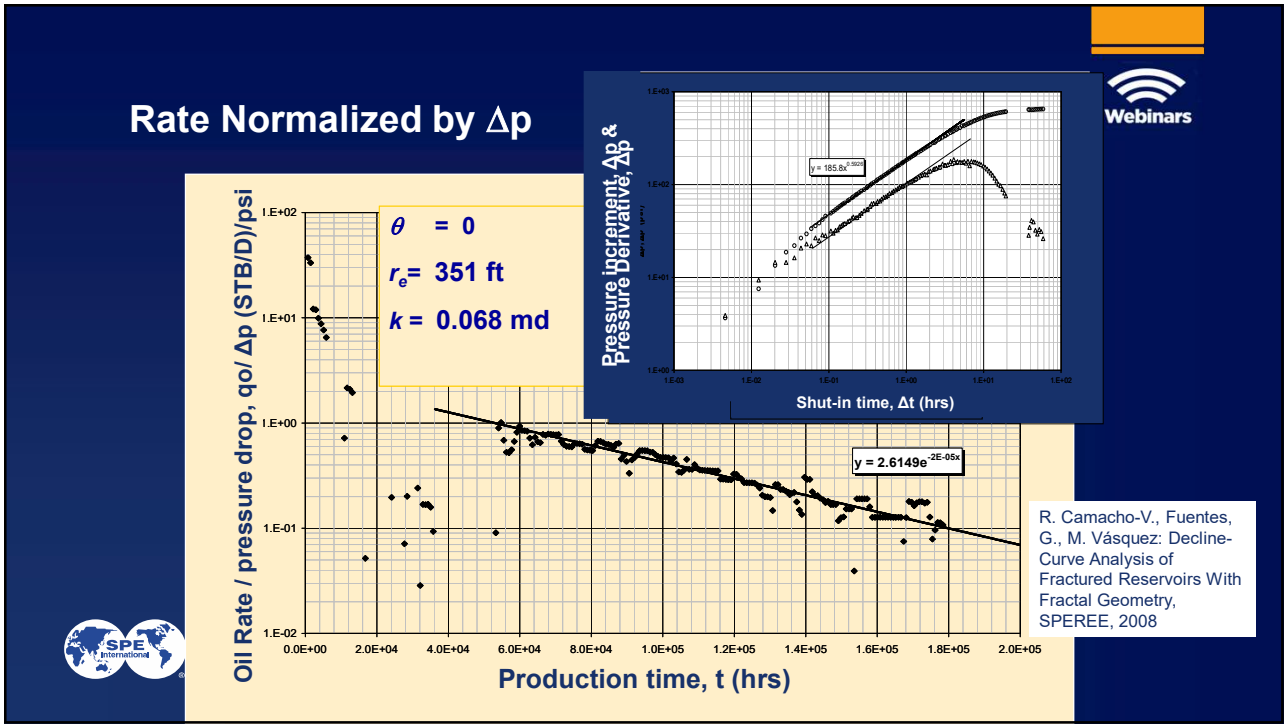
R. Camacho-V., et.al.: Decline-Curve Analysis of Fractured Reservoirs With Fractal Geometry, SPEREE, 2008

Field Pressure & Production histories



10

Rate Normalized by Δp



R. Camacho-V., Fuentes, G., M. Vásquez: Decline-Curve Analysis of Fractured Reservoirs With Fractal Geometry, SPEREE, 2008

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Pressure Transient Analysis of a Field Case & Predicted Production Behavior

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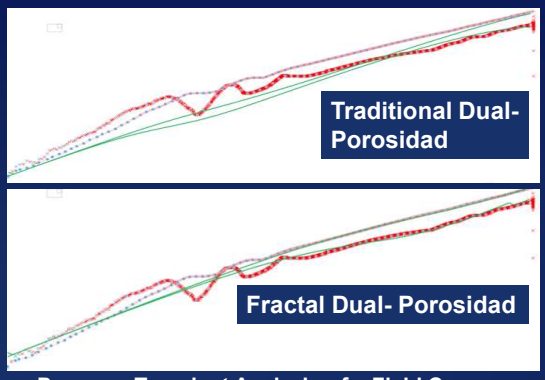
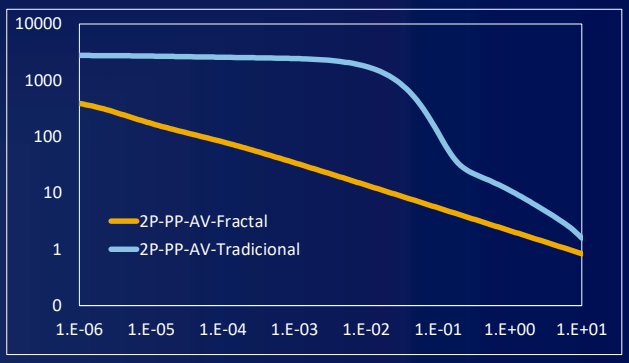
Comparison of Traditional & Fractal Dual-Porosity models and their respective Productions



Pressure Transient Analysis of a Field Case



Predicted Rate Behavior for a constant bottomhole pressure

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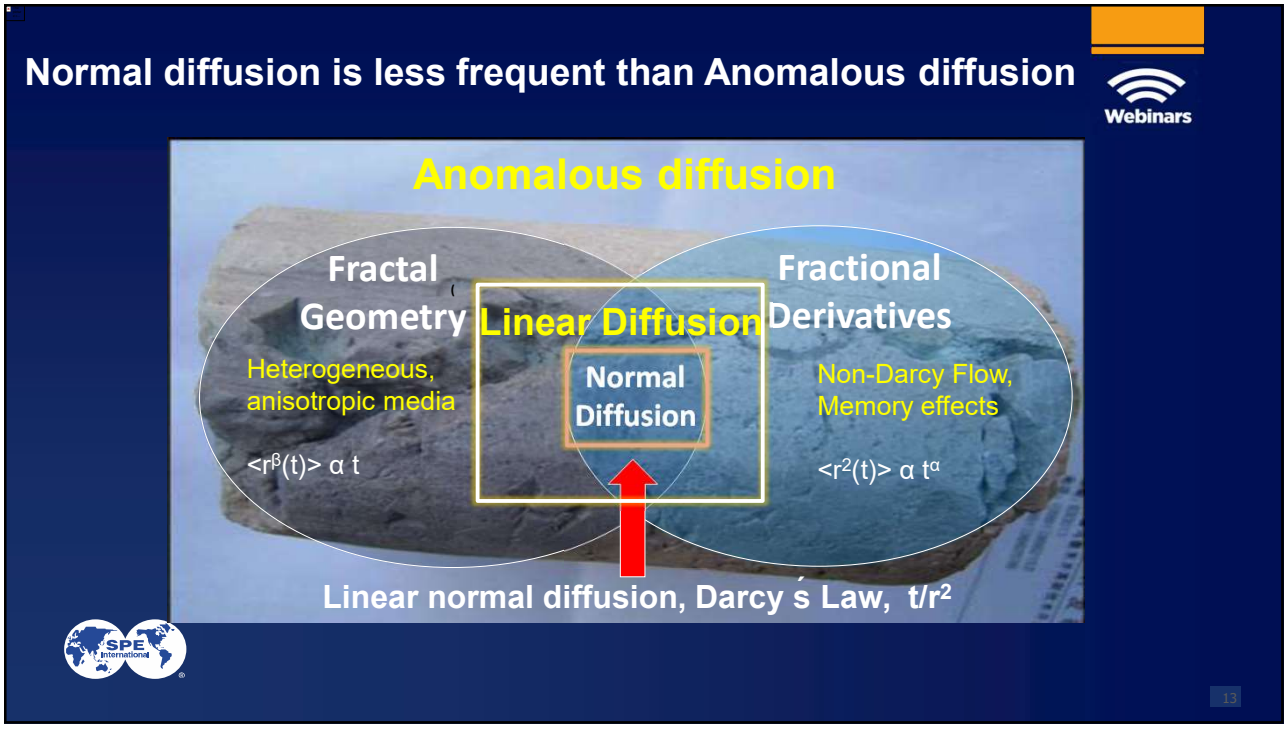
12


Normal diffusion is less frequent than Anomalous diffusion
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Anomalous diffusion
Fractal Geometry
Heterogeneous, anisotropic media
<r^β(t)> α t
Linear Diffusion
Normal Diffusion
Fractional Derivatives
Non-Darcy Flow, Memory effects
<r^2(t)> α t^α
Linear normal diffusion, Darcy´s Law, t/r^2
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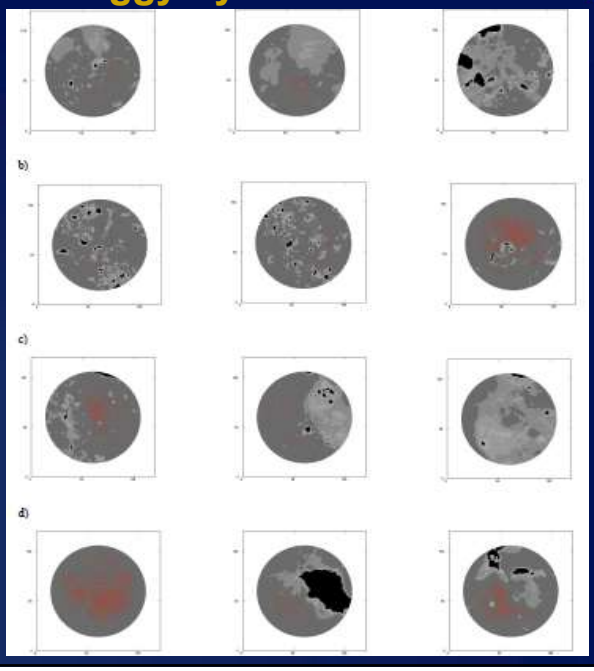
Naturally Fractured Vuggy Systems

During the dissolution process, **vugs can be isolated or connected to each other**. The **connection between vugs can occur through halos of high porosity zones that surround them**.

Increasing ϕ and k may be due to directly connected vugs & vugs connected through their halos. Vuggy kv may be > fracture kf.



R. Casar & V. Suro: Stochastic Imaging of Vuggy Formations, SPE 58998

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Naturally Fractured Vuggy Systems

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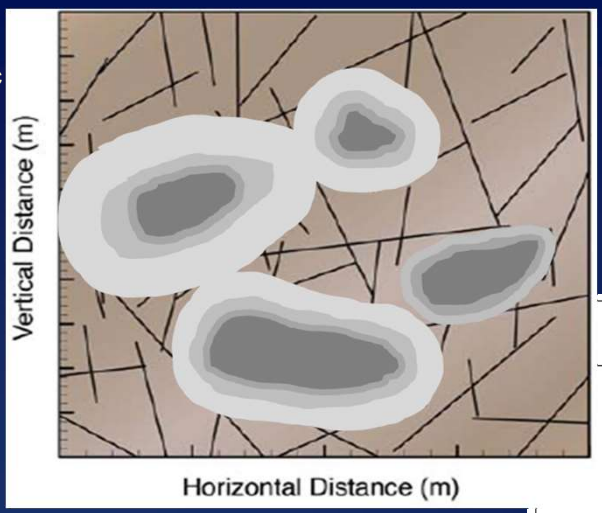
Schematic modified diagram from a fractured vuggy system



Z. Kang, et.al.: Modeling Multiphase Flow in Naturally Fractured Vuggy Petroleum Reservoirs, SPE, 2006.

Lucia's Classification (1983) for Vuggy Porosity

An important contribution of **Lucia's classification is its emphasis on the petrophysical significance of separate & touching vugs.**

	Interparticle (P)			Vuggy (V)	
	Particle size			Connection	
	Fine (F) < 20 μ	Medium (M) 20–100 μ	Large (5) > 100 μ	Through interparticle Pores separate (5)	Through other VUG5 touching (T)
Porosity No (n)				Porosity (%)	
Porosity Yes (y)	P_d > 70 psia	P_d 70–15 psia	P_d < 15 psia		

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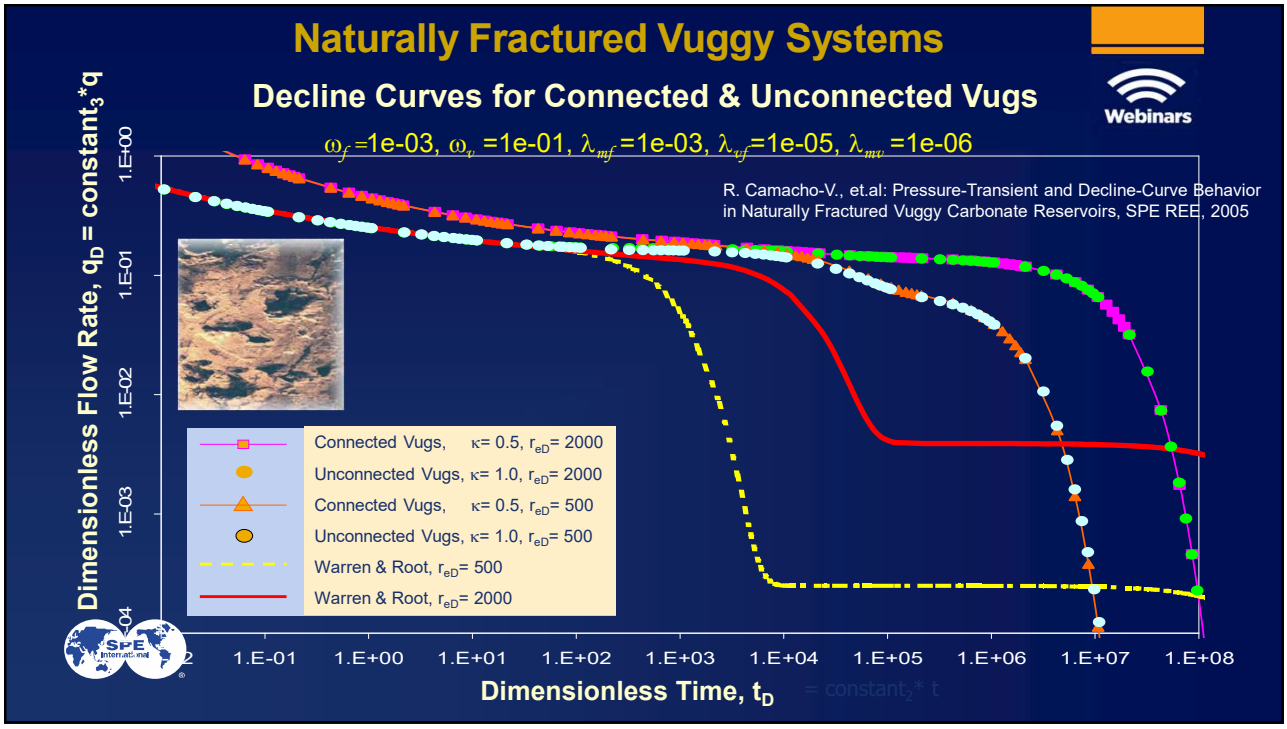
Naturally Fractured Vuggy Systems
Decline Curves for Connected & Unconnected Vugs
ω_f =1e-03, ω_v =1e-01, λ_{mf} =1e-03, λ_{vf}=1e-05, λ_{mv} =1e-06
R. Camacho-V., et.al: Pressure-Transient and Decline-Curve Behavior in Naturally Fractured Vuggy Carbonate Reservoirs, SPE REE, 2005
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Connected Vugs, κ= 0.5, r_{eD}= 2000
Unconnected Vugs, κ= 1.0, r_{eD}= 2000
Connected Vugs, κ= 0.5, r_{eD}= 500
Unconnected Vugs, κ= 1.0, r_{eD}= 500
Warren & Root, r_{eD}= 500
Warren & Root, r_{eD}= 2000
Dimensionless Flow Rate, q_D = constant$_3$*q
1.E+00
1.E-01
1.E-02
1.E-03
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
1.E+08
Dimensionless Time, t_D = constant$_2$* t

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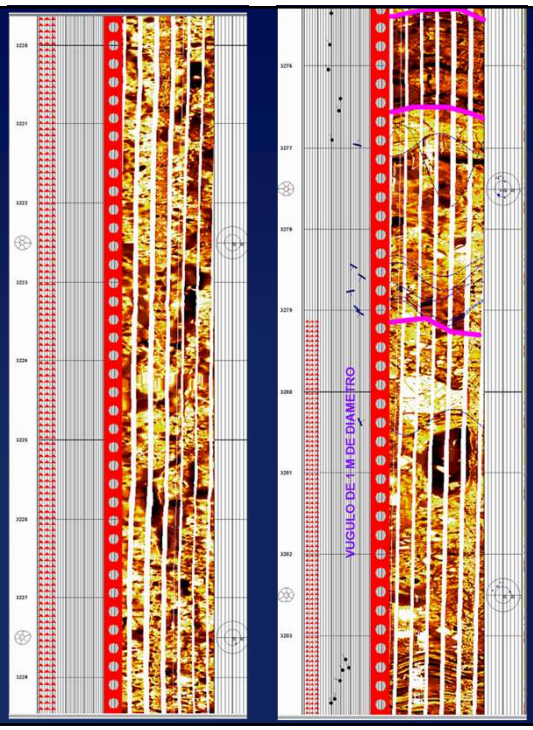
Naturally Fractured Vuggy Systems

Results with 3 ϕ – 2 k model

Breccioid zone showing **connected vugular porosity**.

There is **good vertical communication through the vugs**.



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At 3280 – 3281 m depth there is a **cavern with a vertical length of 1 - 1.5 m**.

Camacho-V., R., et. al., SPE 171078, 2014

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Naturally Fractured Vuggy Systems

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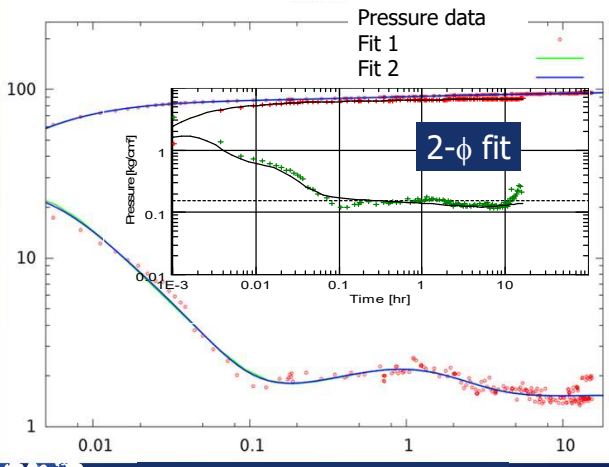
Well 1 Partial Penetration, 3 Φ- 2K Model



Parameter	Fit 1	Fit 2
ω_v	3.53E-02	7.00E-01
ω_f	5.24E-01	2.26E-02
λ_{mf}	1.04E-05	2.34E-05
λ_{vf}	2.49E-05	3.95E-05
λ_{mv}	2.56E-05	1.17E-05
κ_r	3.30E-01	8.08E-01
κ_z	9.99E-01	1.00E-03
C_D	2.21E+00	1.24E+00
S_f	8.20E-01	3.90E-01
S_v	5.92E-01	6.52E-01
h_D	3.86E+02	3.43E+02
h_{1D}	1.83E-01	1.01E-01
h_{pD}	1.71E-01	1.67E-01

Camacho-V., R., et. al.: SPE171078, 2014

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Naturally Fractured Vuggy Systems

Overview of dynamic characterization

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2 ϕ – 1 k, Warren-Root

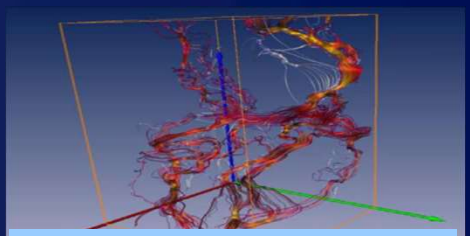
KS: ω= 0.62, KM: ω= 0.40

Values from well logs:

- KS: ω_v= 0.64, ω_f= 0.04 KM: ω_v = 0.63, ω_f = 0.01

3 ϕ – 2 k, partial penetration

- KS: ω_v = 0.7, ω_f = 0.023, κ_r = 0.8, κ_z = 0.001
- KM: ω_v = 0.51, ω_f = 0.12, κ_r = 0.9, κ_z = 0.9



Ausbrooks, R. et al, SPE 56506

Camacho-V., R., et. al.: SPE171078, 2014

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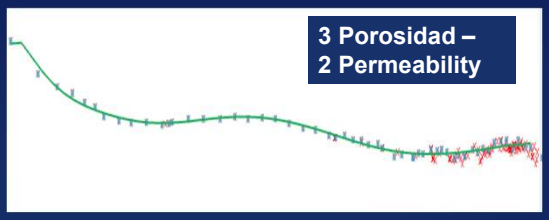
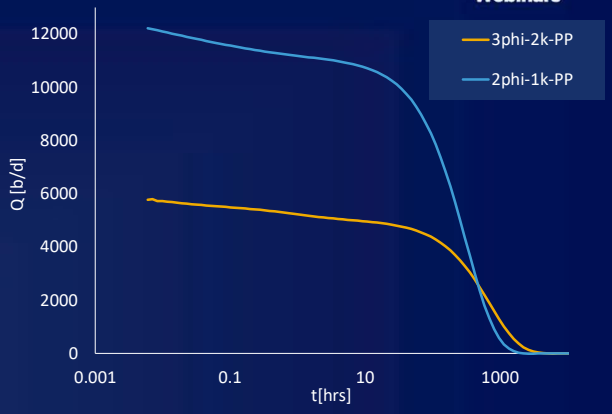
Naturally Fractured Vuggy Systems



Comparison of pressure derivative fits obtained with traditional 2ϕ & 3ϕ-2k models, both with partial penetration.



Rate Prediction using parameters obtained with traditional 2ϕ & 3ϕ-2k models, both with partial penetration

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Naturally Fractured Vuggy Systems

Conclusions

- **3 ϕ - 2 k** ⟶ better match of pressure tests than 2 ϕ model, obtaining more information about 3 media (matrix- fractures - vugs).
- (ωv + ωf) ≠ ω (2 ϕ, Warren-Root) ⟶ use of traditional 2 ϕ simulators for NFVRs is not justified.
- Partial penetration effects ⟶ information about vertical communication of vugs and fractures.
- Confirmed that vugs' vertical communication can be significant, which is relevant for reservoirs with an active aquifer.

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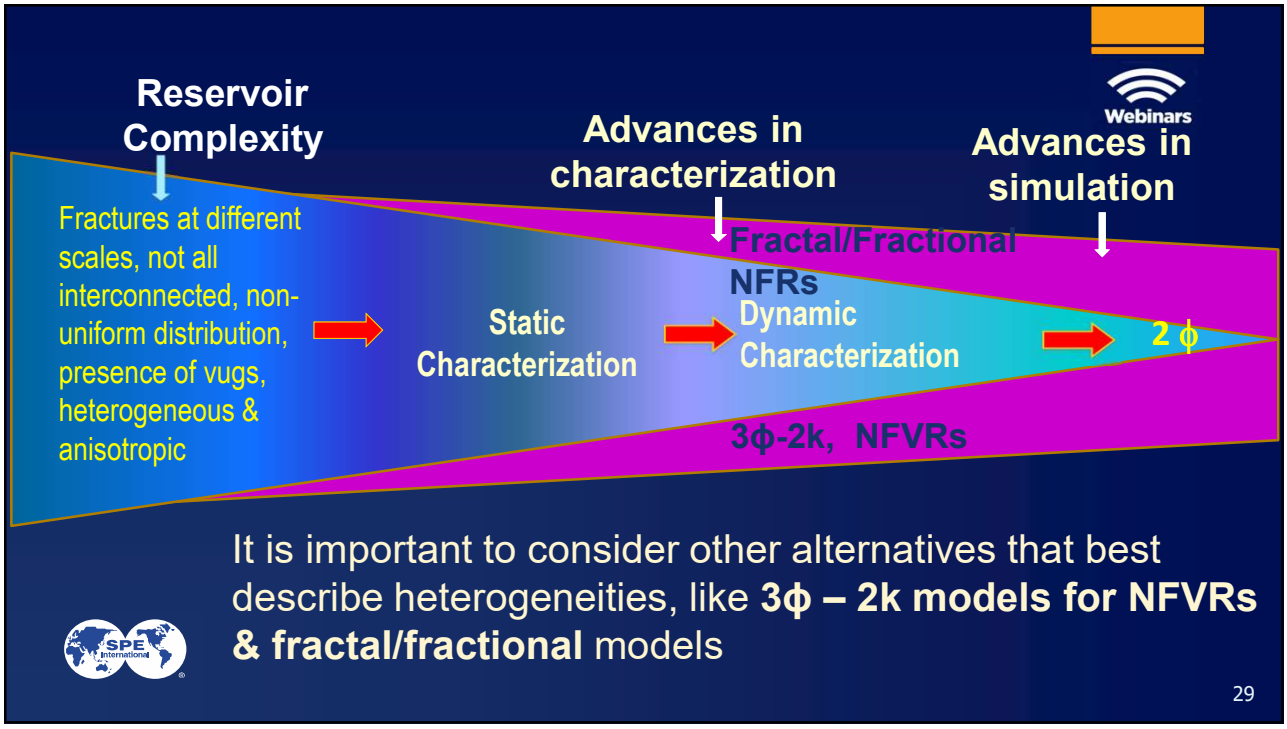
Reservoir Complexity
Fractures at different scales, not all interconnected, non-uniform distribution, presence of vugs, heterogeneous & anisotropic
Static Characterization
Advances in characterization
Fractal/Fractional NFRs
Dynamic Characterization
Advances in simulation
2 ϕ
3ϕ-2k, NFVRs
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It is important to consider other alternatives that best describe heterogeneities, like **3ϕ – 2k models for NFVRs & fractal/fractional** models
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