Petrophysical Study of UAE Carbonates*

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Abstract

More than sixty percent of world's hydrocarbon reserves are found in carbonates; however, there have been few laboratory experiments to analyze and understand the complex pore system of carbonates and its effect on petrophysical properties. The understanding of complexity of pore system in carbonates can help in modeling the seismic response and in inferring petrophysical properties. We present a laboratory study of twenty five outcrop carbonates samples from UAE which include quantitative mineralogy, total and effective porosity, permeability and compressional, and shear wave velocity as a function of effective pressure. The relationships between porosity and velocity with effective pressure as well as velocity with porosity agree with previous findings. The velocity of samples also showed a dependency on mineralogy. The presence of dolomite decreased the Vp/Vs ratio and increased the Vp and Vs in dry and in saturated (brine and dodecane) samples.

Biot-Gassmann equations are used to model saturated velocities from dry measurements. The model overestimates the Vp by as much as 11% in both brine and dodecane saturated cases. The magnitude is observed to be a function of porosity. The samples with higher porosity had the least differences in calculated and modeled responses. 80% of dodecane saturated samples and 65% of brine saturated samples showed increase in shear modulus thus agreeing with the Biot-Gassmann model.

References

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Website

Location map of United Arab Emirates and its major oil field: Web accessed 6 August 2012.
http://paleopolis.rediris.es/cg/CG2003_A05_BG_etal/CG2003_A05_BG_etal_Fig_01.htm

Petrophysical Study of UAE Carbonates

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Outline

- Objective
- Geological Background
- Experimental set-up and Procedure
- Results and Data Analysis
- Conclusions

Objective

- Calculate surface relaxivities –NMR and MICP responses
- Measure Vp and Vs on carbonates with 3 different saturants
- Evaluate frame weakening (Baechle et al. 2005)
- Evaluate Biot-Gassmann theory

Geography

Al-Ain Area

Jabal Hafit

Regional Reservoirs

Zakum

Ghasha

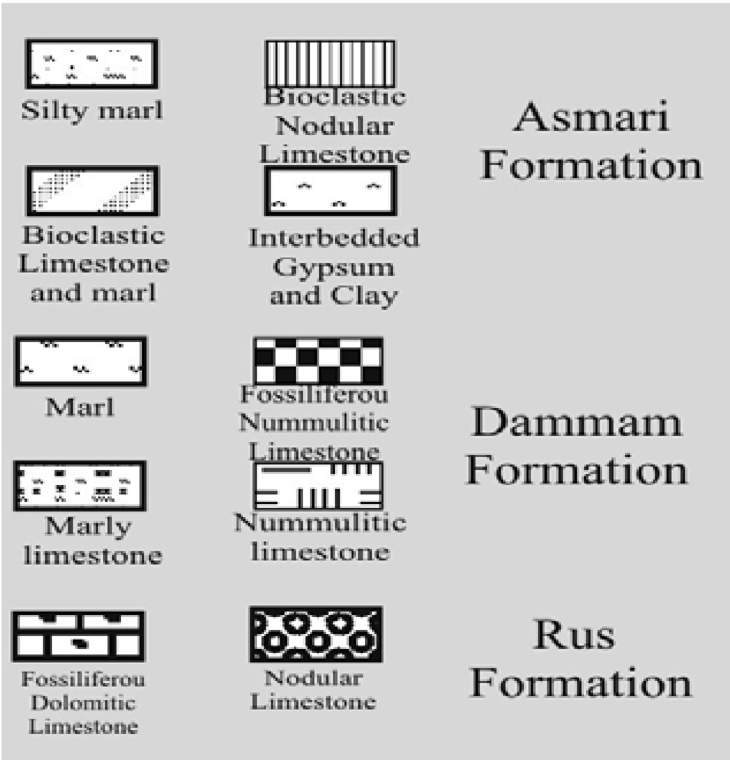
Asmari Formation

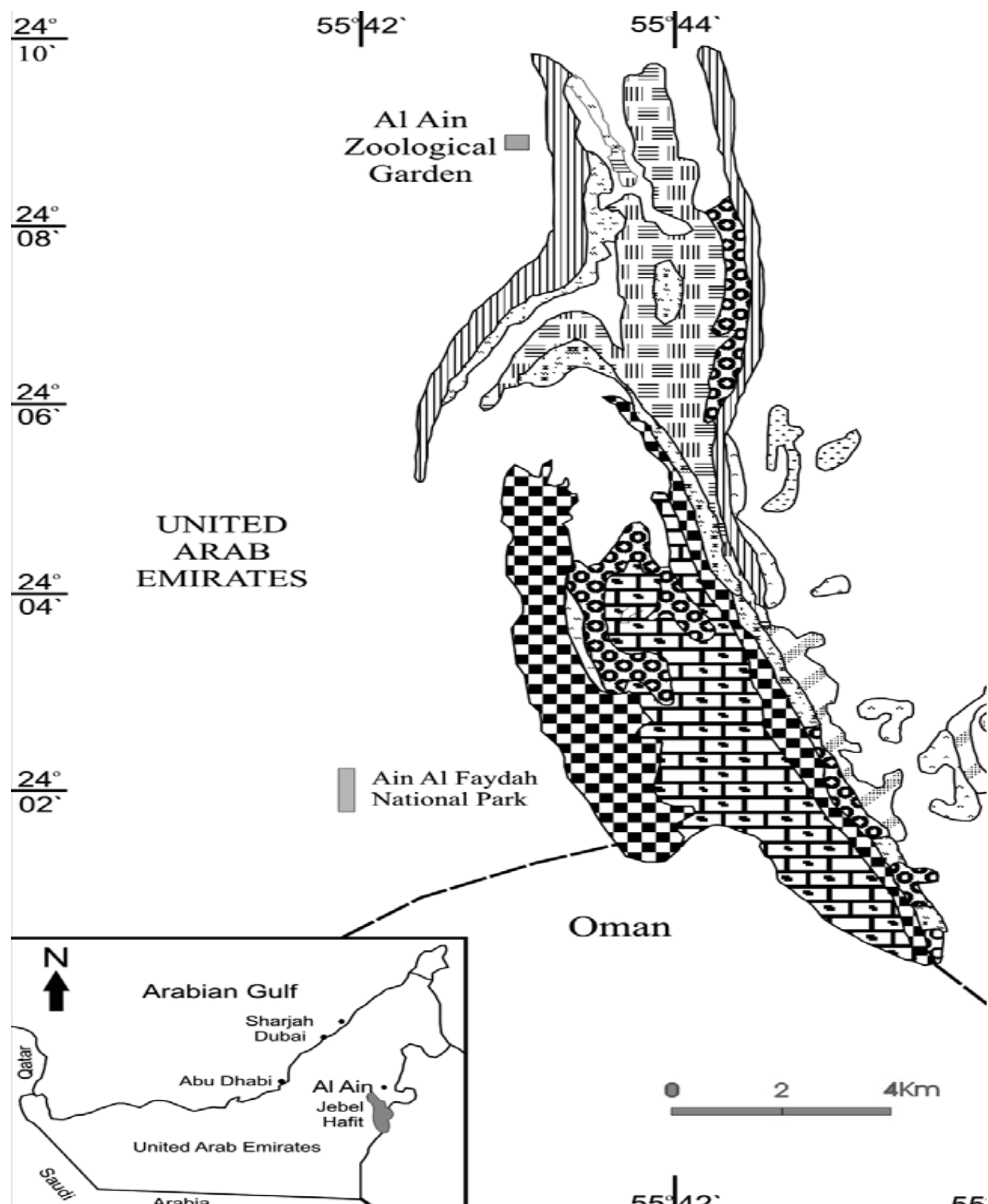
Dammam Formation

Rus Formation

http://paleopolis.rediris.es/cg/CG2003_A05_BG_etal/CG2003_A05_BG_etal_Fig_01.htm

Geological Background





El-Saiy et al. 2007

Depositional time frame

DIVISIONS OF GEOLOGIC TIME				Age(approx)
Eon	Era	Period	Epoch	in million of yrs
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01
				1.6
			Pleistocene	235
		Tertiary	Pliocene	35
			Miocene	57
			Oligocene	65
			Eocene	97
			Paleocene	146
	Mesozoic	Cretaceous	Late	157
			Early	178
		Jurassic	Late	208
			Middle	235
			Early	241
		Triassic	Late	245
			Middle	256
			Early	290
	Paleozoic	Permian	Late	303
			Early	311
		Pennsylvanian		323
		Mississippian	Late	345
			Early	363
		Devonian	Late	377
			Middle	386
			Early	409
		Silurian	Late	424
			Early	439
		Ordovician	Late	464
			Middle	476
			Early	510
		Cambrian	Late	517
			Middle	536
			Early	570

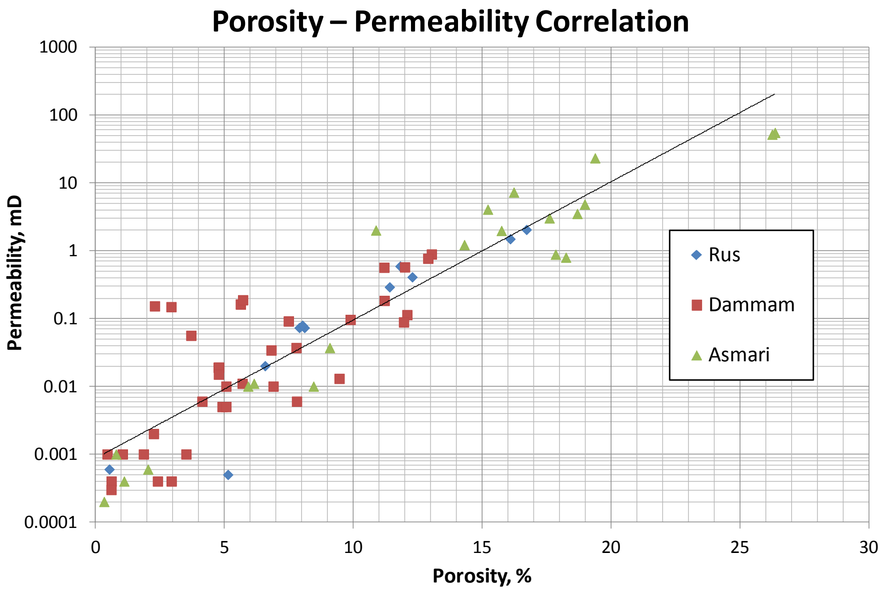
UAE Carbonates

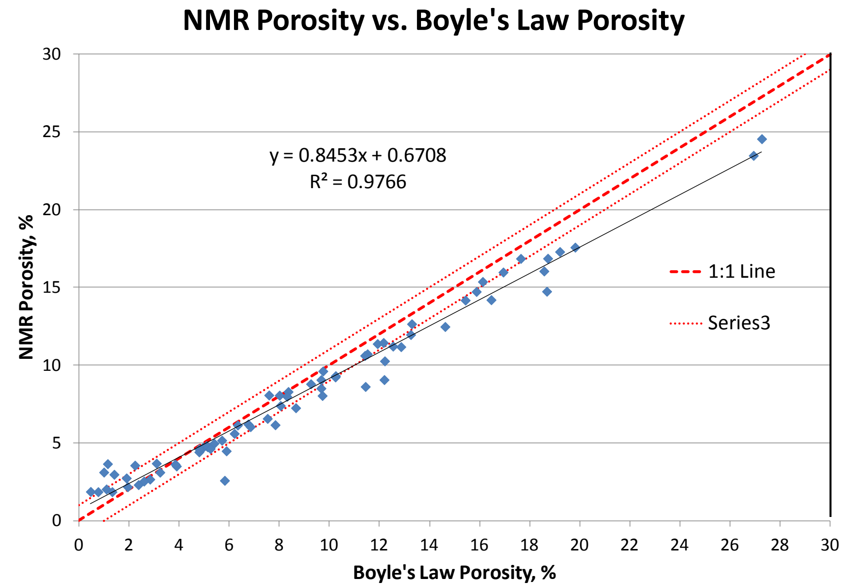
Epoch	Age	Formation
Oligocene	Middle	Asmari
	Early	
Eocene	Late	Dammam
	Middle	
	Early	Rus

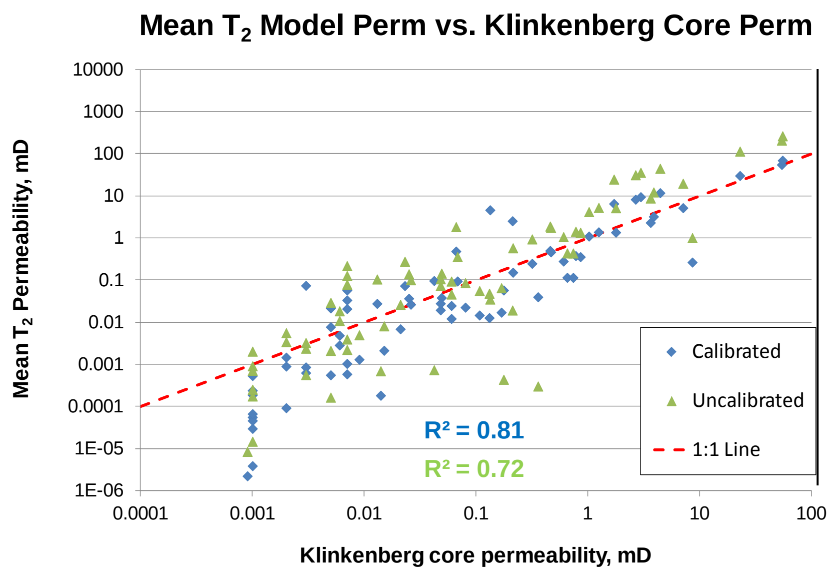
ϕ , %	K , md
4 - 17	0.003 - 18

@ 1000psi

Past experiments







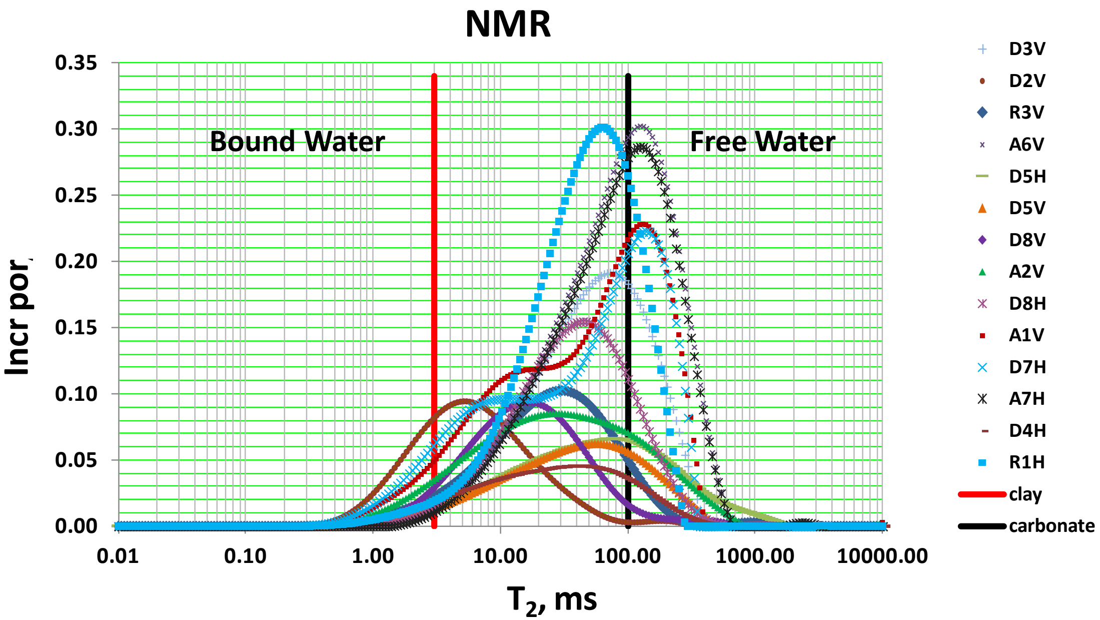
Wampler, 2010

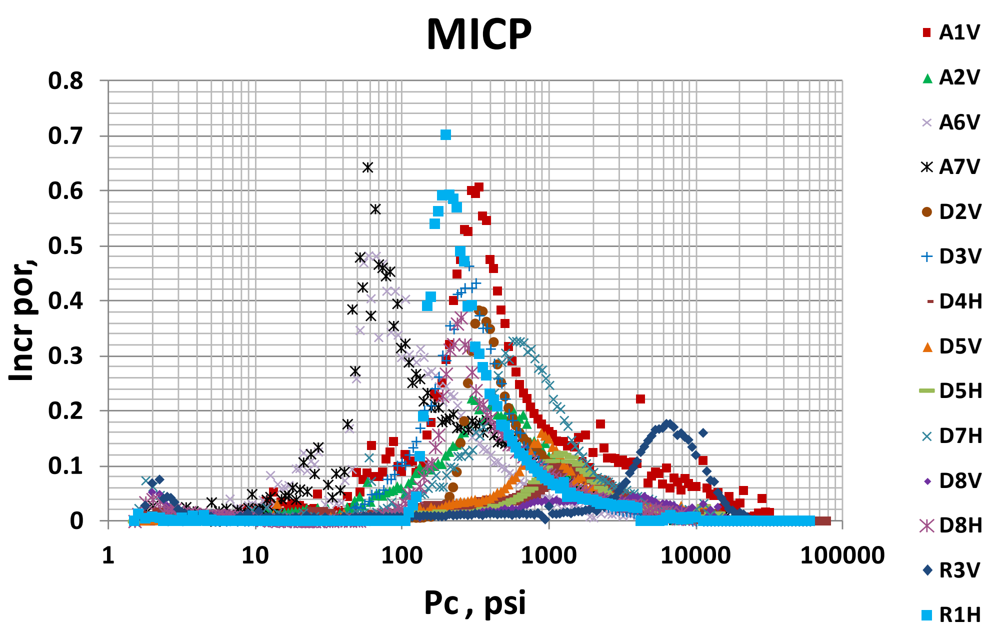
Experimental Equipment

Nuclear Magnetic Resonance (NMR) (2 Mhz)

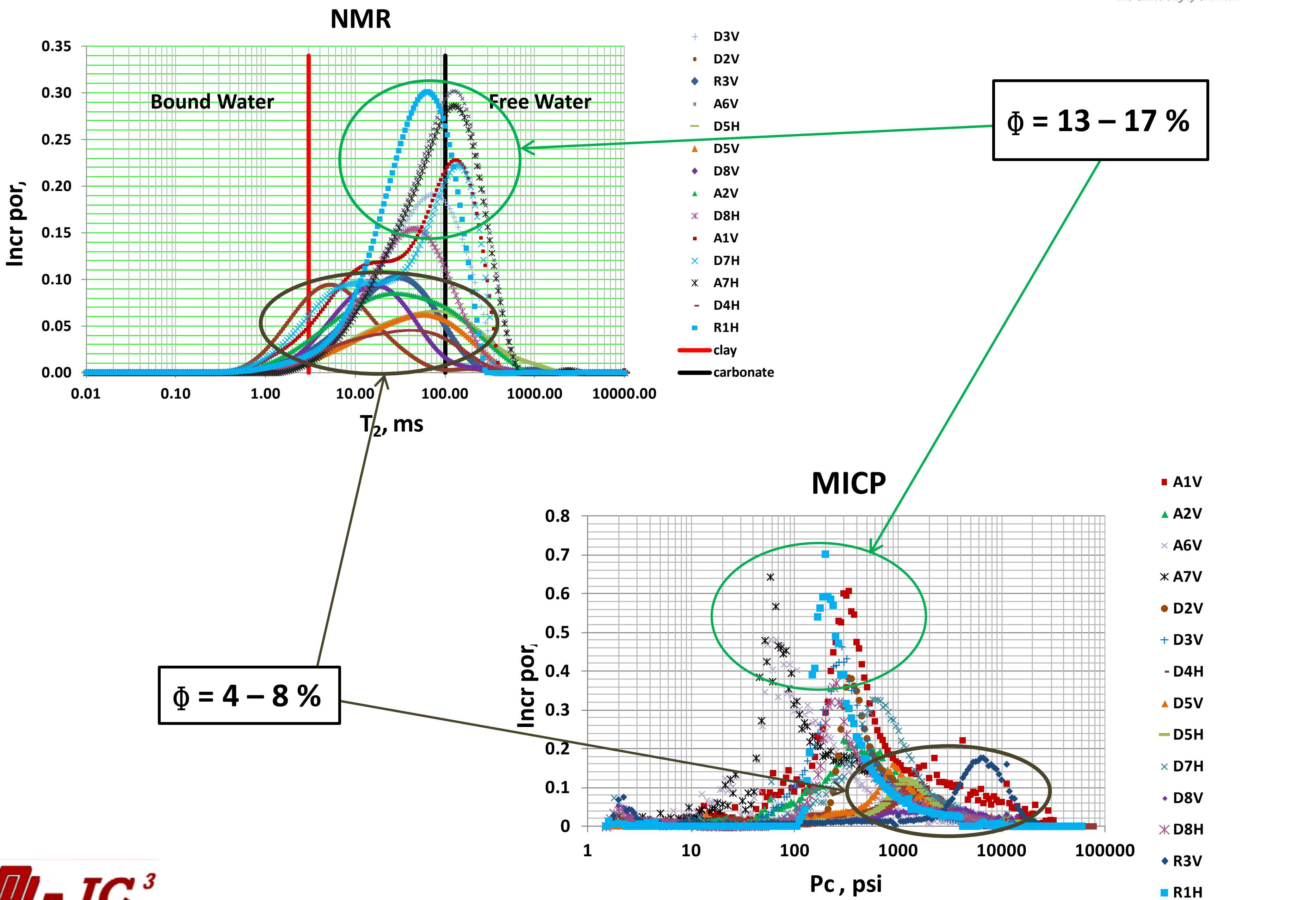
Mercury Injection Capillary Pressure (60,000 psi)

NMR and MICP


NMR
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Bound Water
Free Water
Incr por,
0.01
0.10
1.00
10.00
100.00
1000.00
10000.00
T2, ms
D3V
D2V
R3V
A6V
D5H
D5V
D8V
A2V
D8H
A1V
D7H
A7H
D4H
R1H
clay
carbonate


MICP
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Incr por,
1
10
100
1000
10000
100000
Pc , psi
A1V
A2V
A6V
A7V
D2V
D3V
D4H
D5V
D5H
D7H
D8V
D8H
R3V
R1H

NMR and MICP



NMR
Bound Water
Free Water
Incr por,
T2, ms
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.01
0.10
1.00
10.00
100.00
1000.00
10000.00
D3V
D2V
R3V
A6V
D5H
D5V
D8V
A2V
D8H
A1V
D7H
A7H
D4H
R1H
clay
carbonate
ϕ = 13 – 17 %
ϕ = 4 – 8 %
MICP
Incr por,
Pc , psi
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
10000
100000
A1V
A2V
A6V
A7V
D2V
D3V
D4H
D5V
D5H
D7H
D8V
D8H
R3V
R1H

Surface Relaxivity

Surface Relaxation equation for cylindrical pores

$$\frac{1}{T_2} = \rho \frac{2}{r_b}$$

Washburn equation

$$P_c = \frac{2\gamma Cos\theta}{r_{th}}$$

If we assume the pore body and pore throat to be cylindrical then,

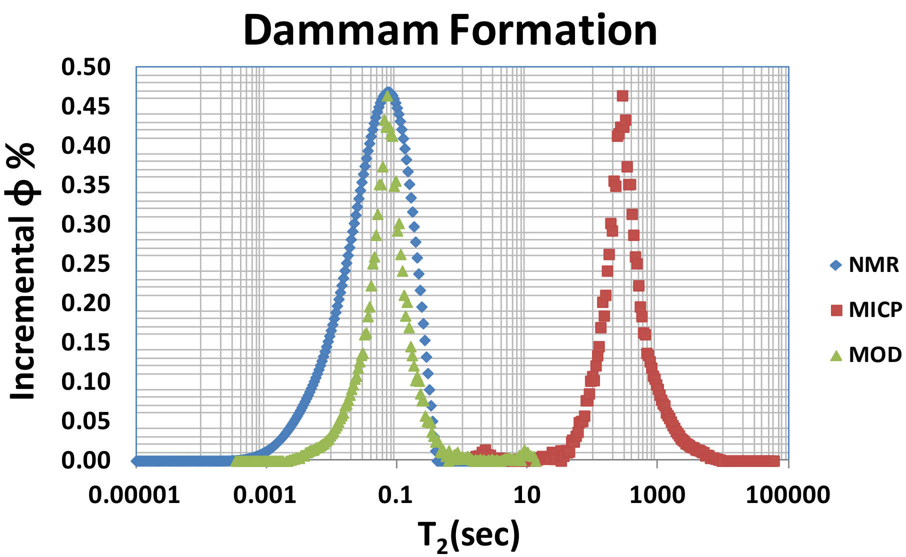
$\mathbf{r_{th} = r_b}$ and

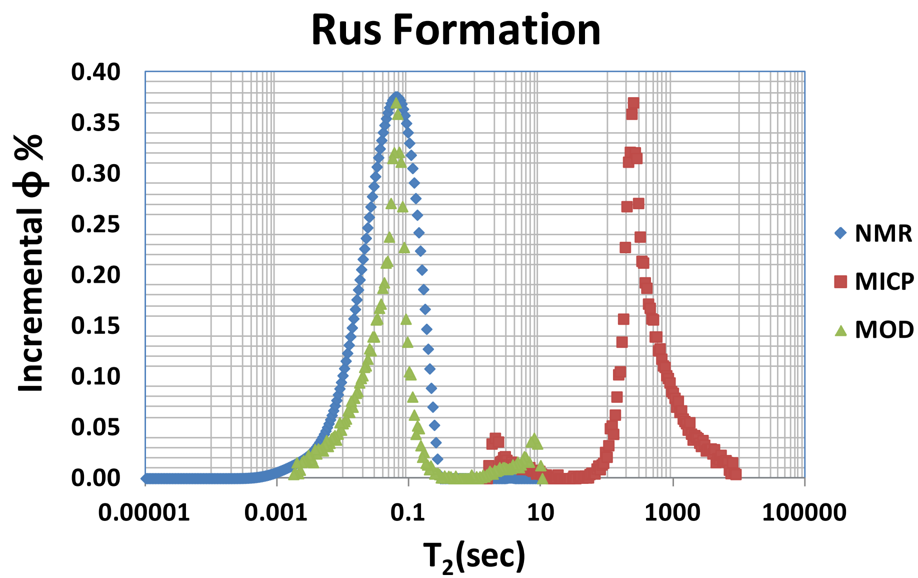
$$\rho_e = \frac{\gamma Cos\theta}{P_c T_2}$$

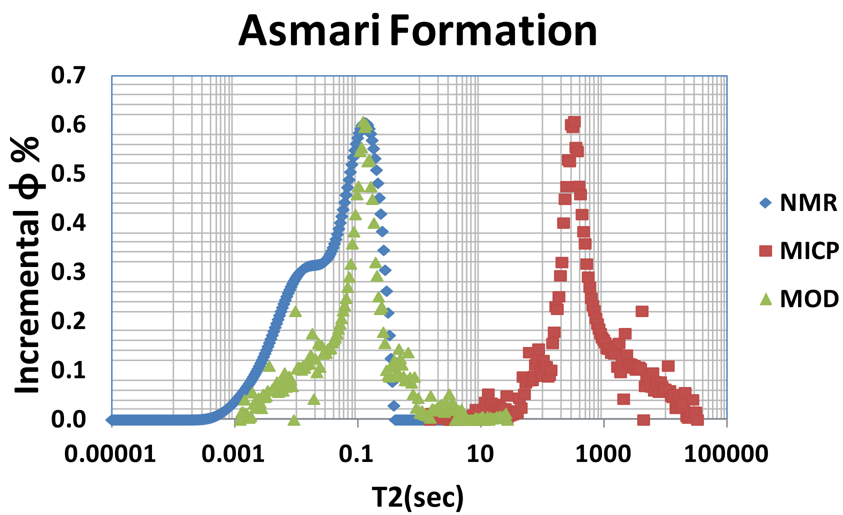
Where, $\boldsymbol{\rho_e}$ is Surface Relaxivity

Kleinberg, 1996

NMR and MICP for 3 samples







Kleinberg method

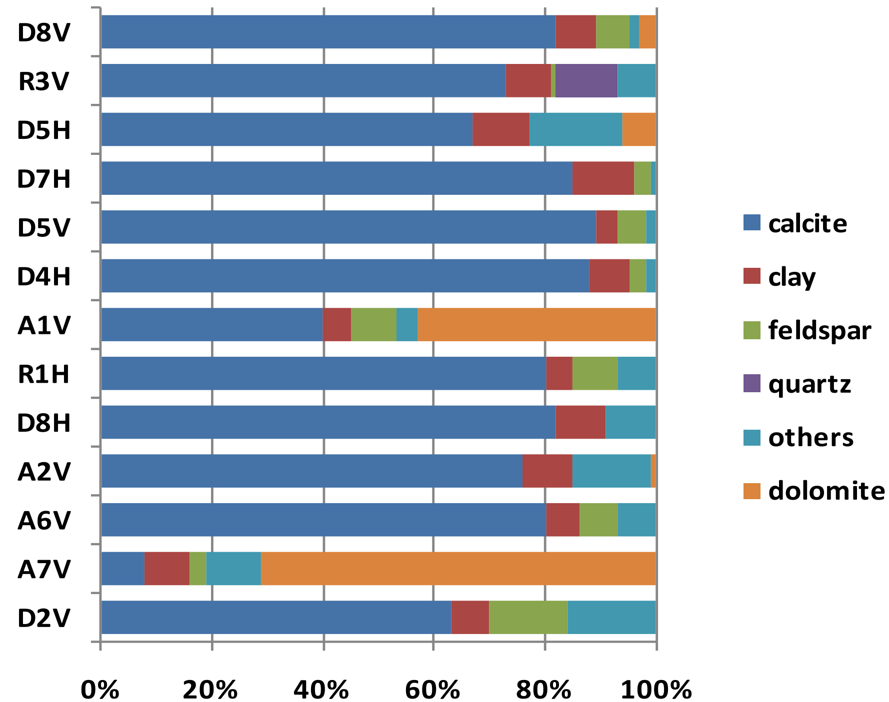
Surface Relaxivity

Samples	ρ, μs
D2V	**14.36**
D8H	2.35
D4H	0.65
D5V	0.52
D7H	0.33
D5H	0.29
D8V	0.09
A7V	3.45
A6V	2.58
A2V	2.35
A1V	0.72
R1H	1.67
R3V	0.13

Dammam

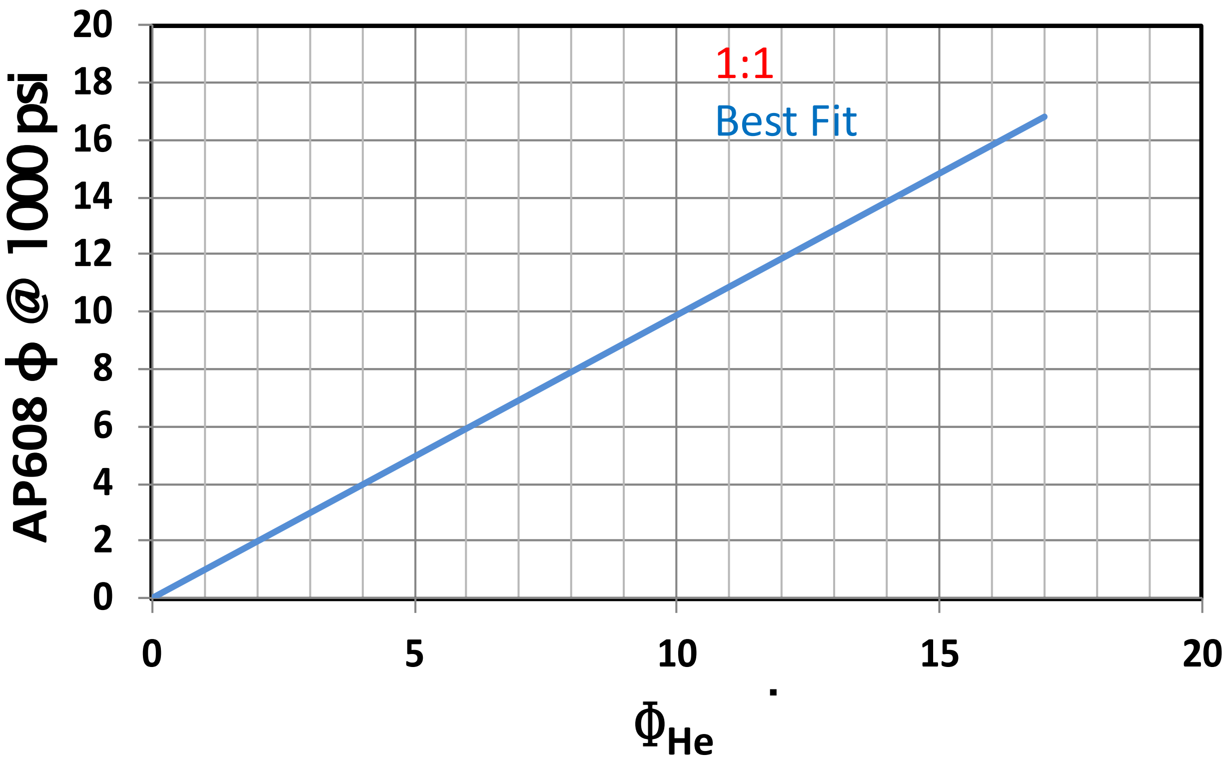
Asmari

Rus



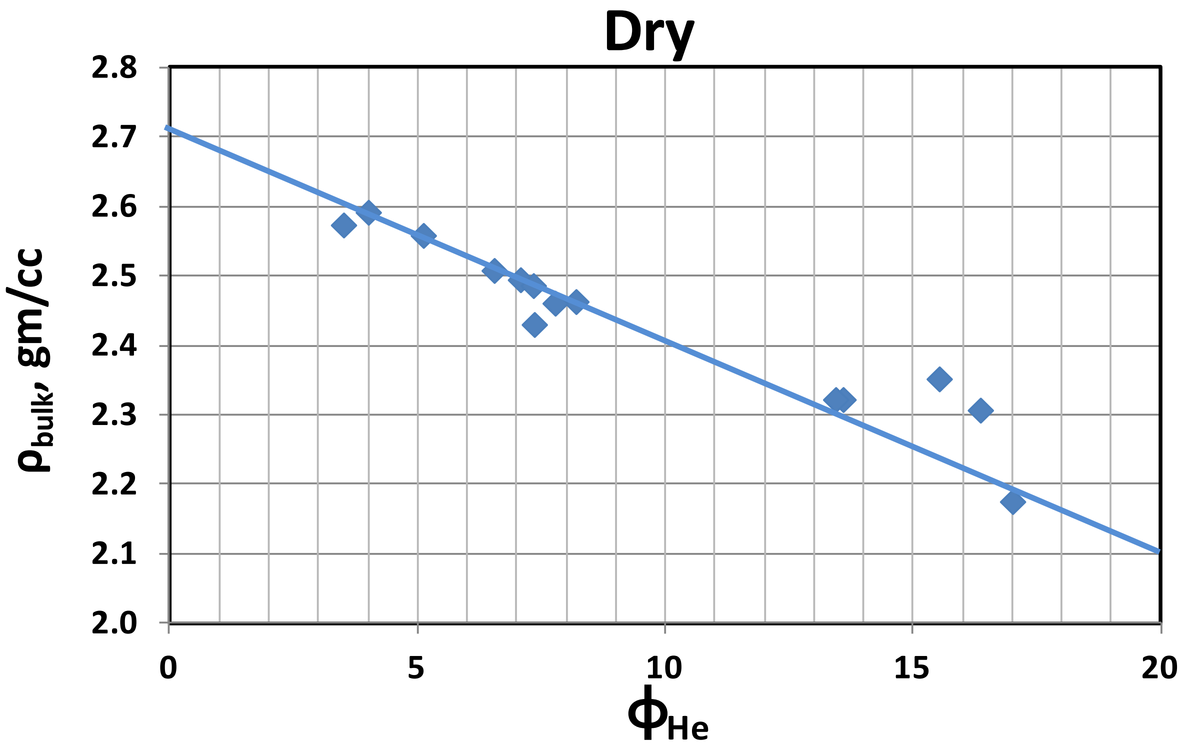
- The surface relaxivities ranged from 0.1 to 3.5 μm/s
- Asmari has higher surface relaxivity compared to Rus and Dammam formation.
- Sample D2V has anomalous surface relaxivity, 14.36 μm/s, and aslo highest feldspar content

ϕ_{1000} vs. ϕ_{He}



High and low pressure porosities agree suggesting a low crack population

ρ vs. ϕ



ρ_{grain} = 2.71 gm/cc

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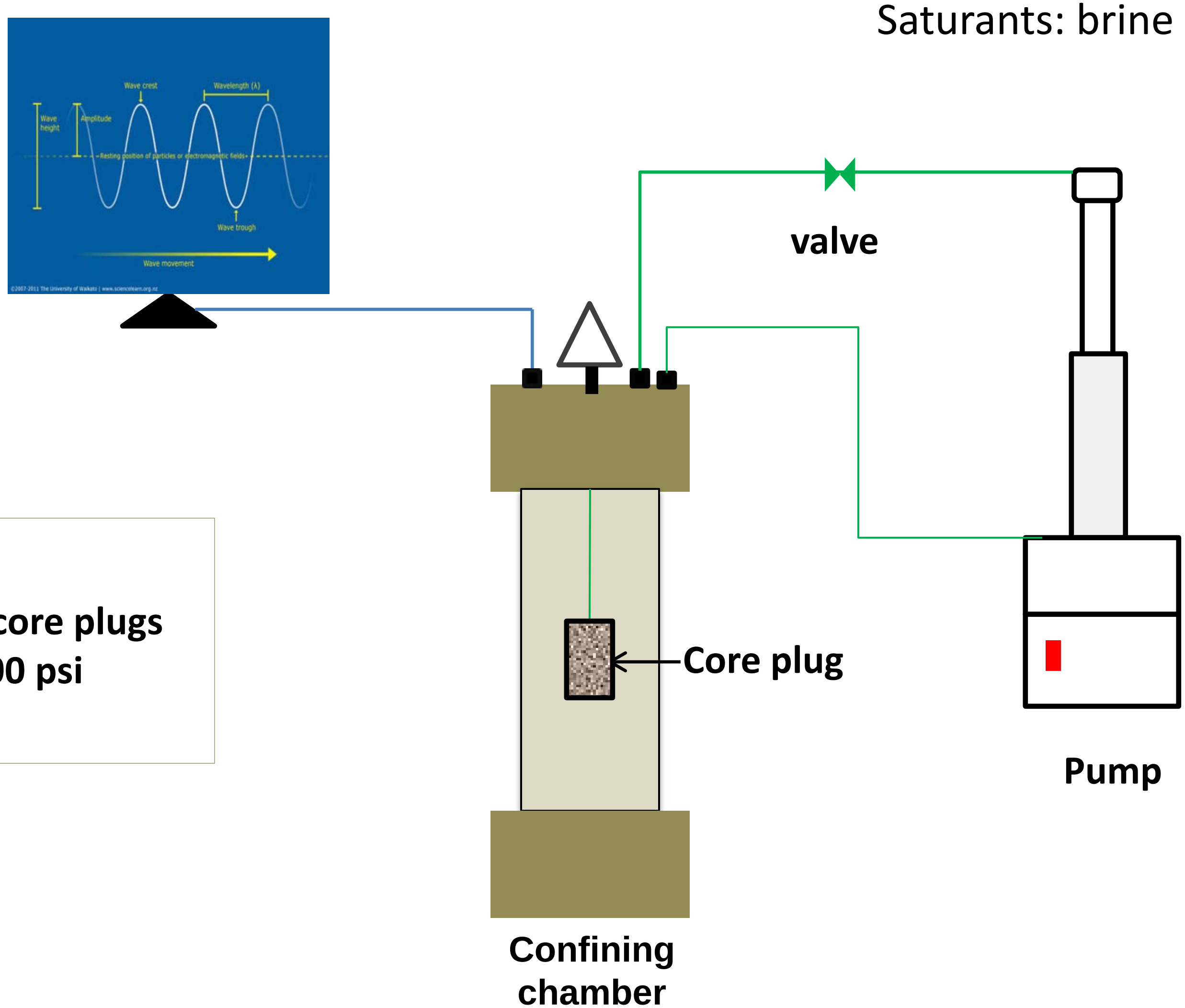
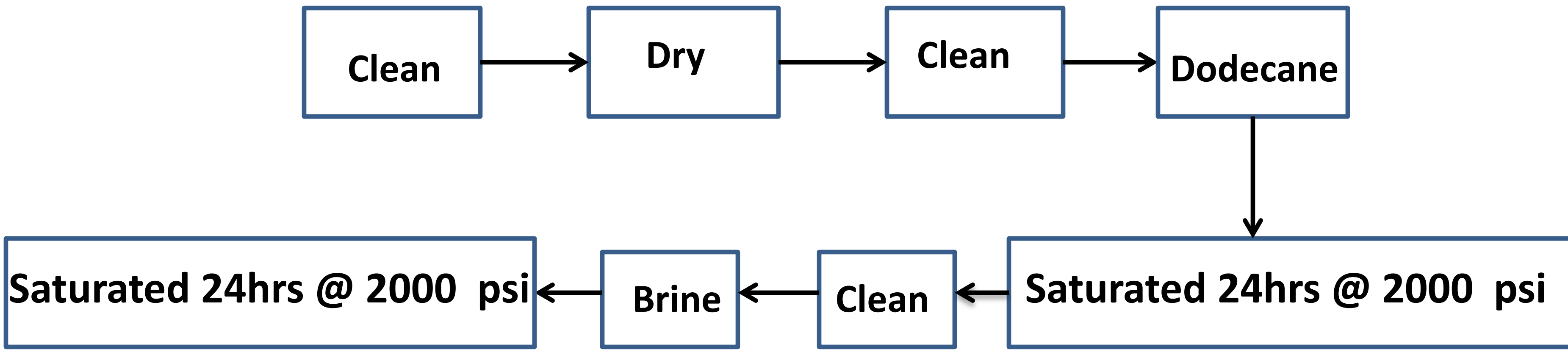
Configuration for velocity measurements

Saturants: brine & dodecane



1*1 inch
cylindrical core plugs
P_c : 250-5000 psi
Pp = 0

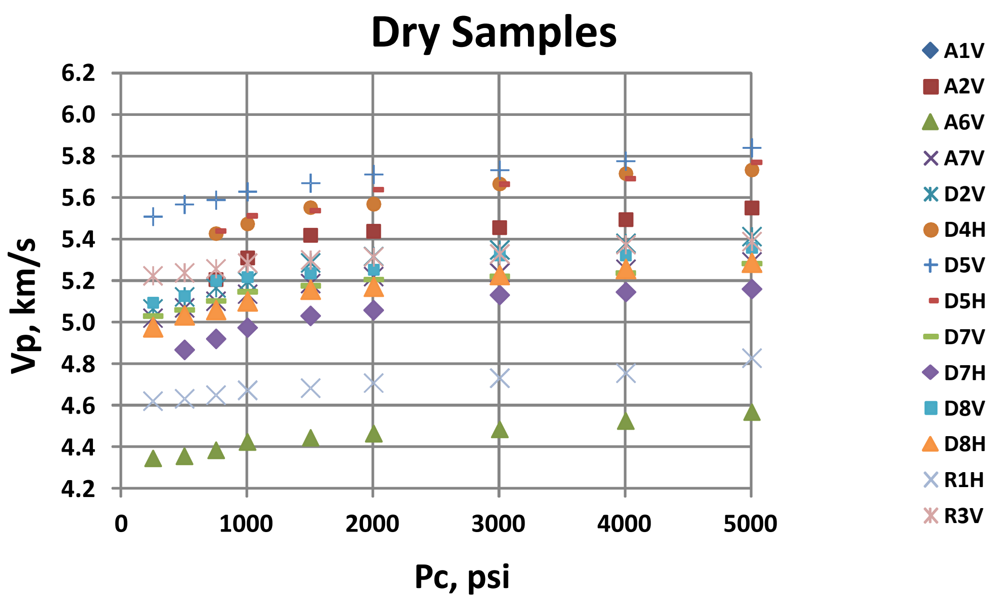
Cleaning and saturation processes

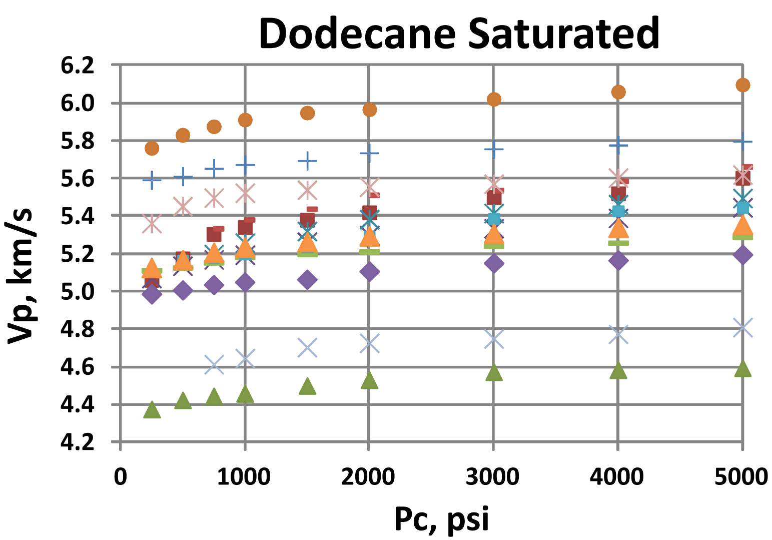


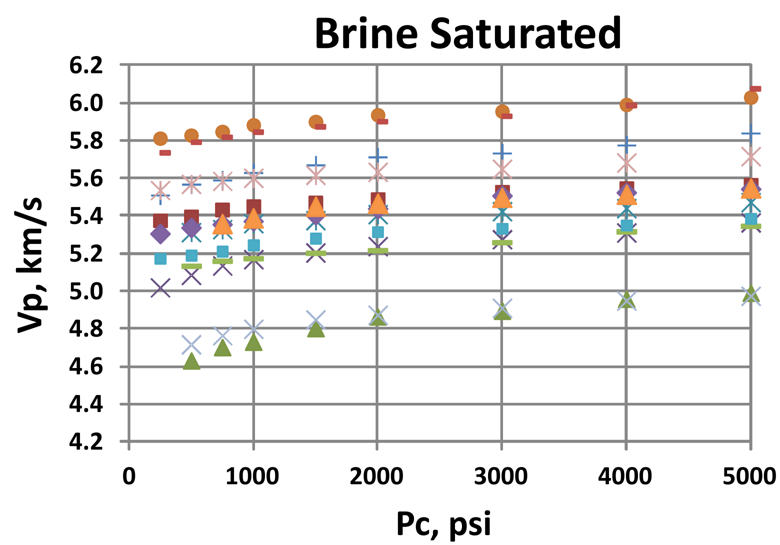
Brine	
NaCl, ppm	$CaCl_2$, ppm
25000	75000

	ρ, gm/cc	K_f, GPa
Brine	1.019	2.417
Dodecane	0.754	1.352

Vp vs. P_{conf}


Dry Samples
Vp, km/s
Pc, psi
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
0
1000
2000
3000
4000
5000
A1V
A2V
A6V
A7V
D2V
D4H
D5V
D5H
D7V
D7H
D8V
D8H
R1H
R3V


Dodecane Saturated
Vp, km/s
Pc, psi
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
0
1000
2000
3000
4000
5000


Brine Saturated
Vp, km/s
Pc, psi
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
0
1000
2000
3000
4000
5000

V_s vs. P_{conf}

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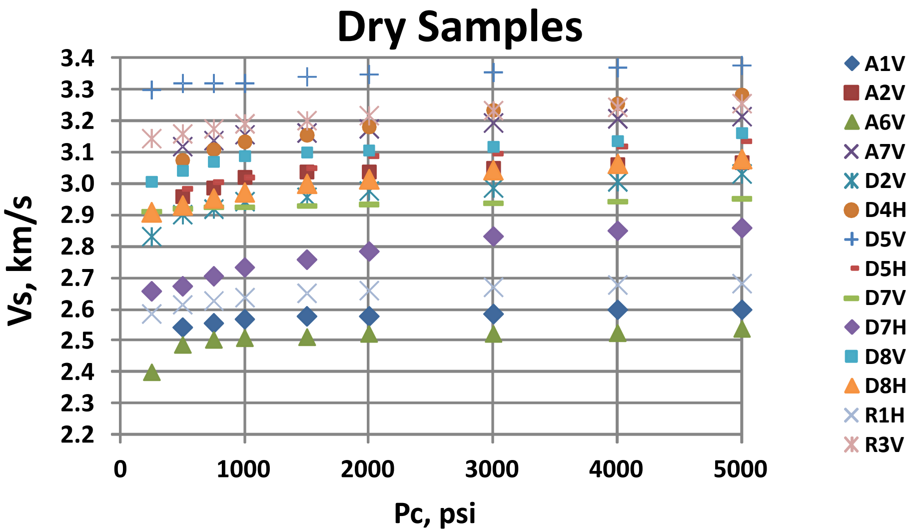
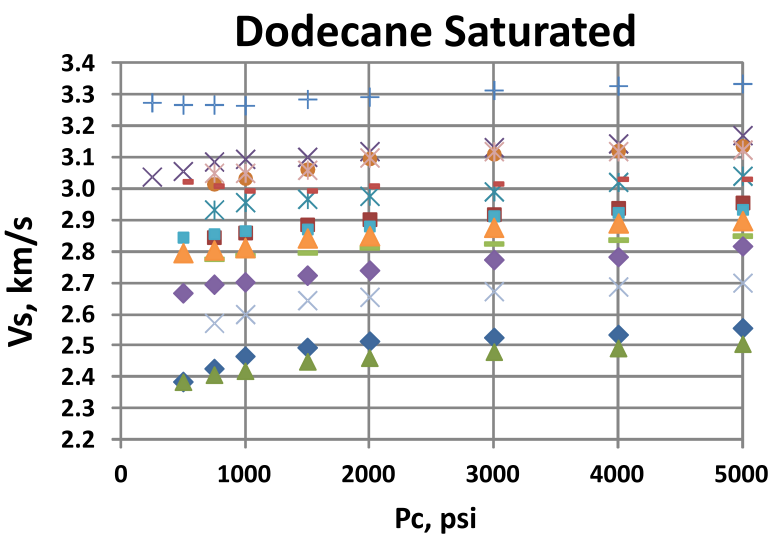
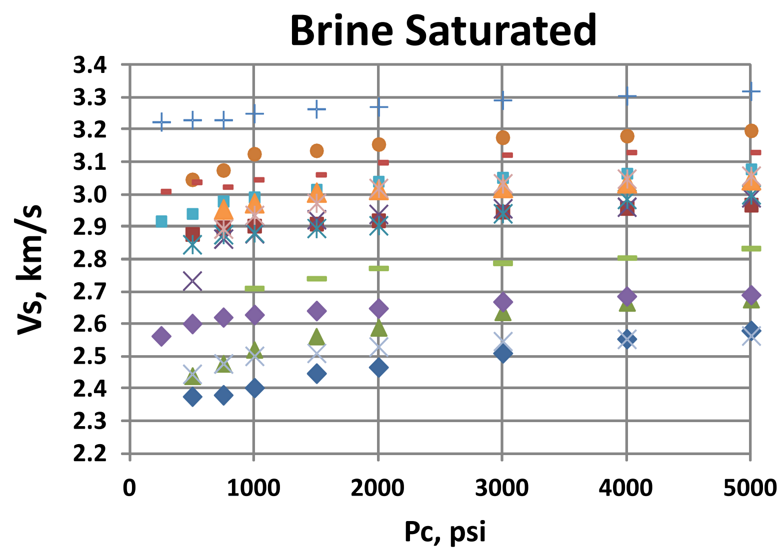
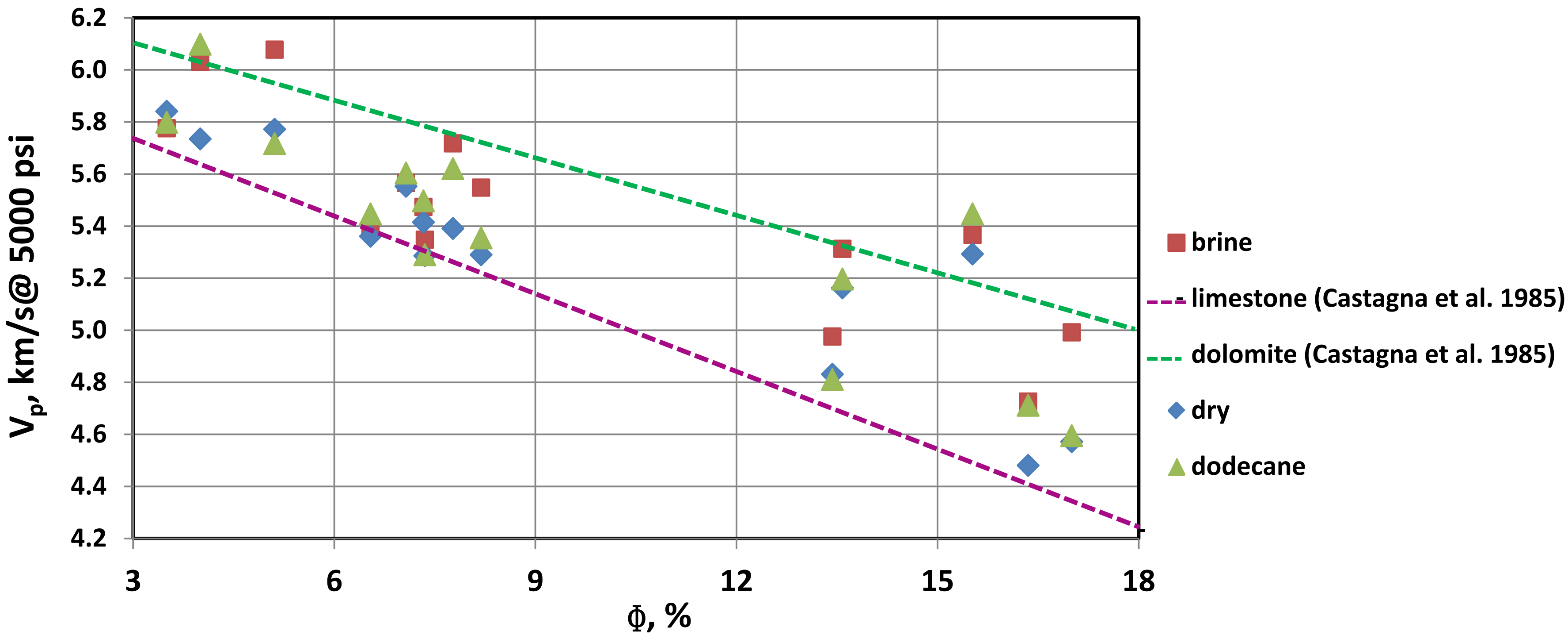






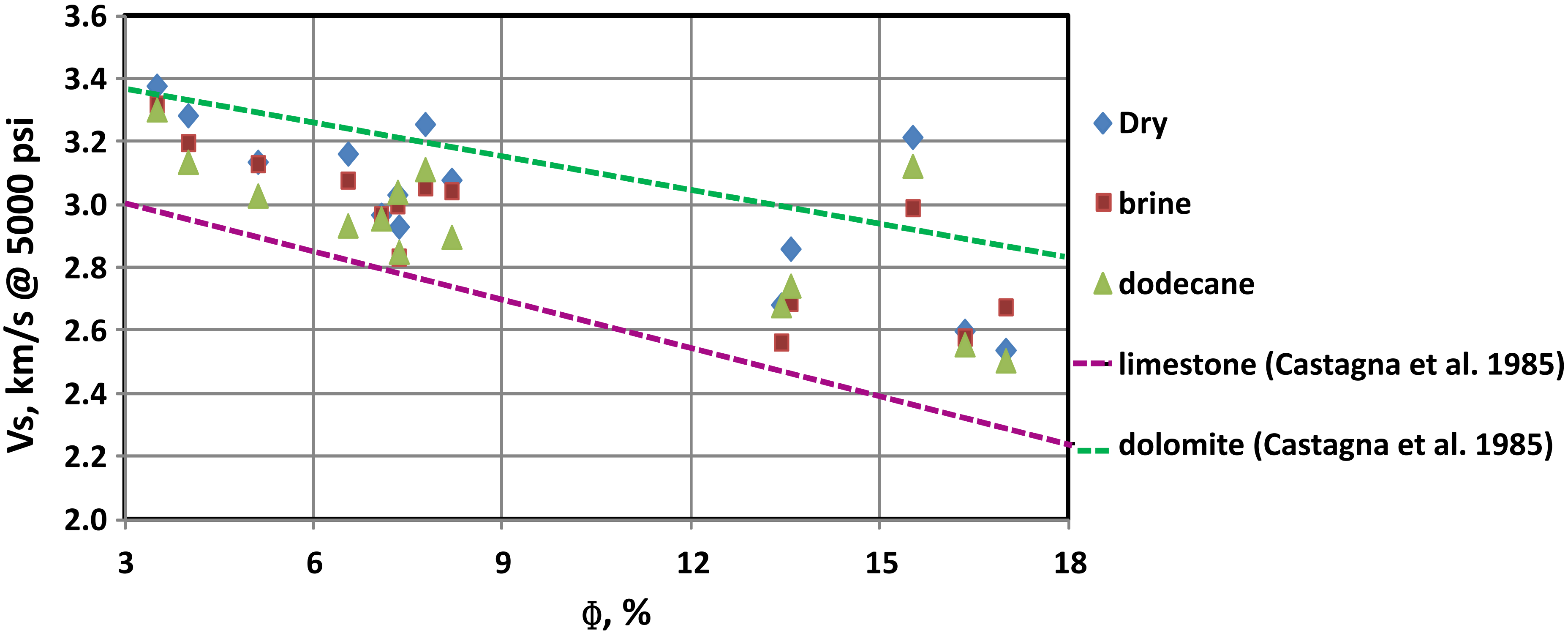
OU - IC³

Vp and ϕ

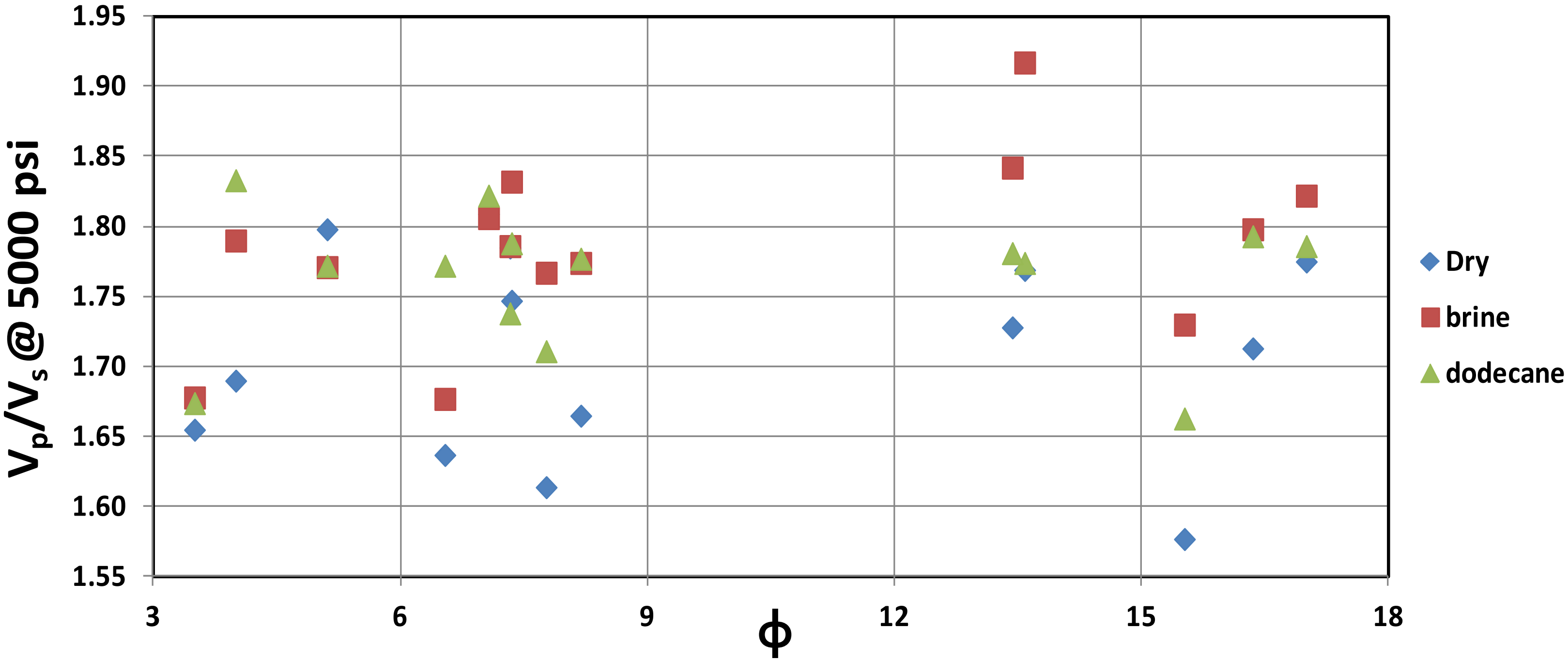


6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
V_p, km/s@ 5000 psi
3
6
9
12
15
18
ϕ, %
brine
limestone (Castagna et al. 1985)
dolomite (Castagna et al. 1985)
dry
dodecane

Vs and ϕ


Vs, km/s @ 5000 psi
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
3
6
9
12
15
18
ϕ, %
Dry
brine
dodecane
limestone (Castagna et al. 1985)
dolomite (Castagna et al. 1985)

V_p/V_s vs. ϕ



- Vp/Vs is independent of ϕ but dependent on saturation.
- Average Vp/Vs for **dry** is **1.71**, **dodecane** is **1.76** and **brine** is **1.79**.

G_{wet} vs. G_{dry} @ 5000 psi

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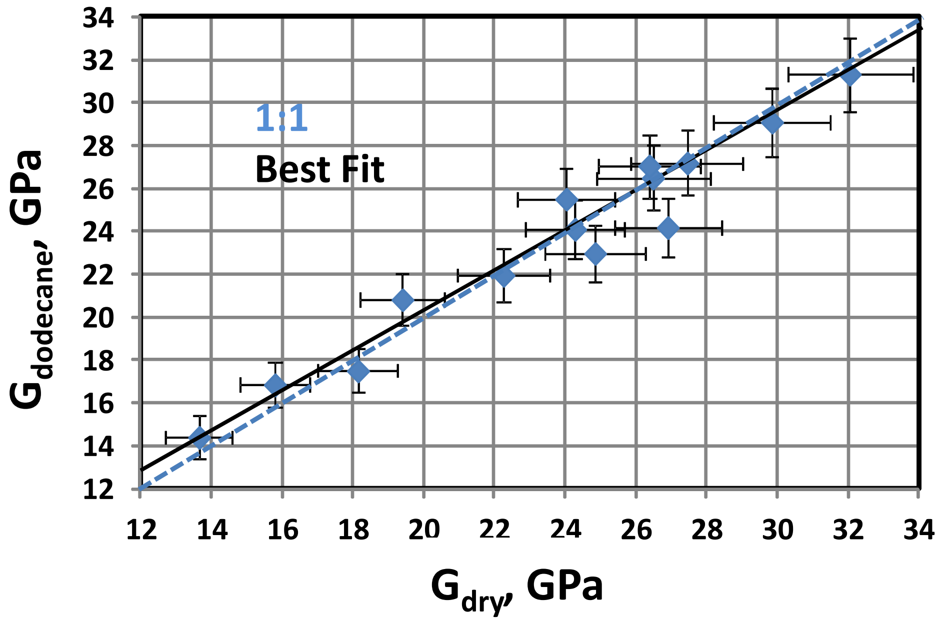

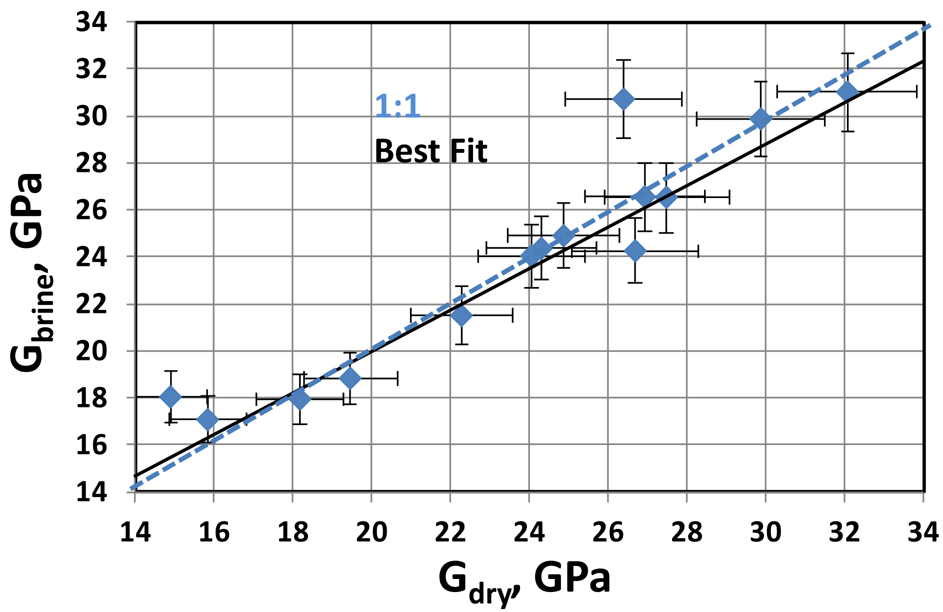

OU - IC³

$K_{predicted}$ vs. $K_{measured}$ @ 5000 psi

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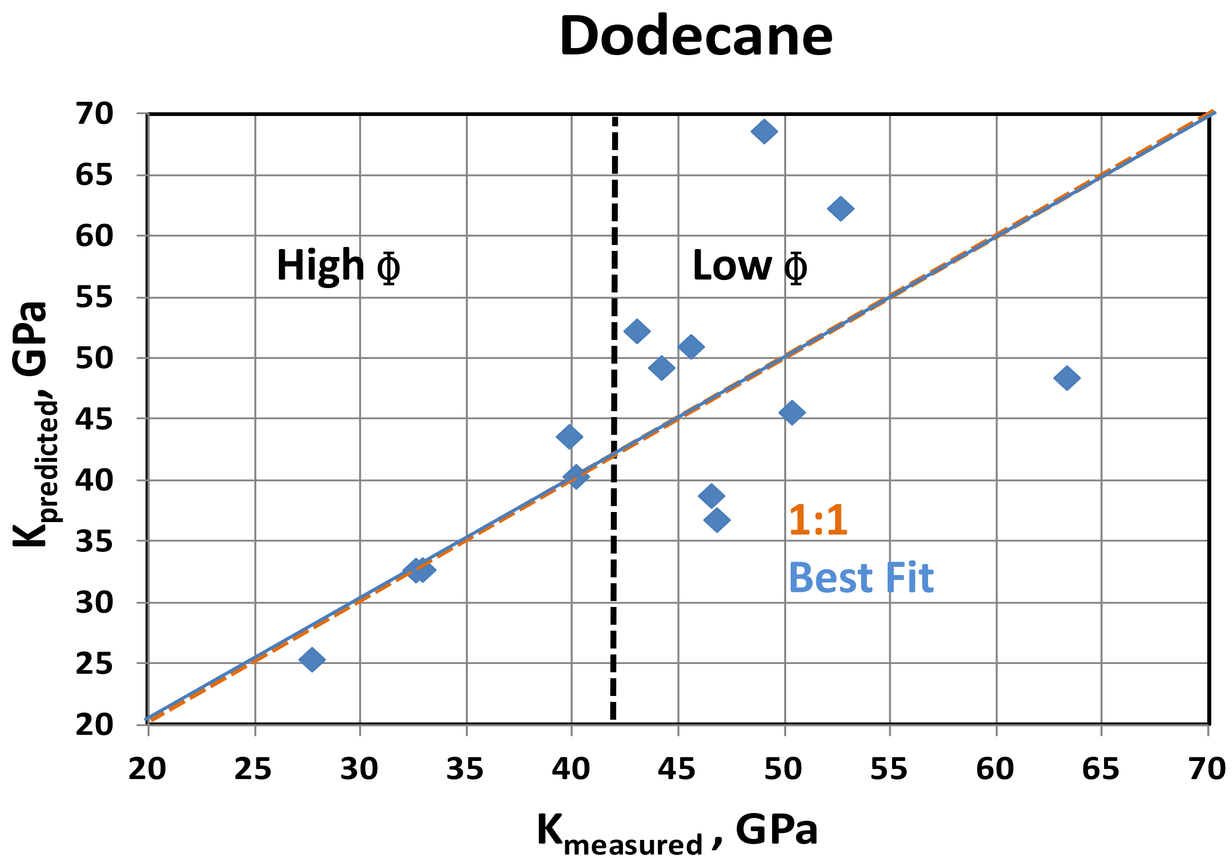

$\phi_{cutoff} = 8\%$

OU - IC³

Conclusion

- Measured surface relaxivities vary from 0.1 to 3.5 µm/s
- Mineralogy anisotropy was observed
- No frame weakening observed when dissolution is prevented
- $\mathbf{G_{dodecane} = G_{brine} = G_{dry}}$ consistent Biot-Gassmann
- $\mathbf{K_{predicted}} = \mathbf{K_{measured}}$ at high porosity

Thank you!

My co-advisor: Dr. Chandra Rai

&

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from IC^3 for their support!