Hydrocarbon discrimination with AVO analysis

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Motivation

- Summarize various hydrocarbon indicators
- Which indicator can easily discriminate the gas/oil sand from the background
- Which indicator is more sensitive to pore-fluid content

Outline

- Hydrocarbon indicators
- Sensitivity analysis for hydrocarbon indicators
- $(V_p/V_s)_{dry}^2$ value analysis
- Conclusion & future work

Hydrocarbon indicator

Rp-g*Rs

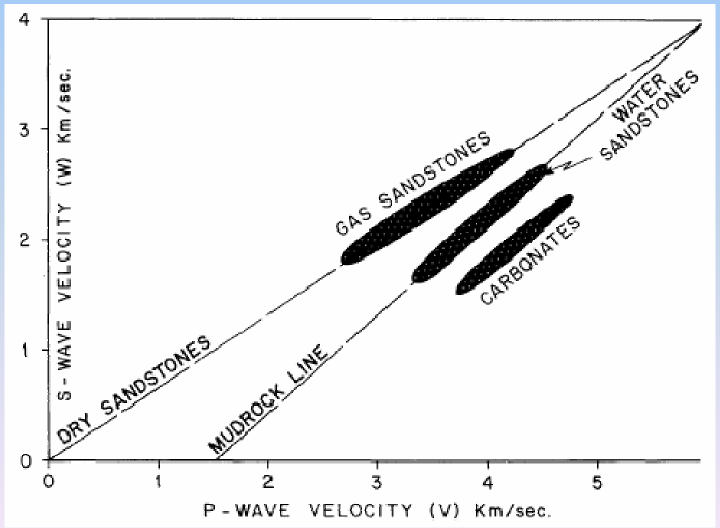
(Smith, Gidlow, 1987 and Fatti, 1994)

$$\Delta F = Rp - 1.16\frac{Vp}{Vs} * Rs$$

Smith and Gidlow (1987)

For gas saturated rocks, ΔF < 0

For water saturated rocks, ΔF ≈ 0



$$V_p \approx 1360 + 1.16 V_s$$

Castagna et al. (1985)

Hydrocarbon indicator

The Elastic Constants

(Russell, Gray and Hampson, 2006)

$$R(\theta) = [\frac{1}{4} - \frac{1}{2}\frac{\beta^2}{\alpha^2}]\sec^2\theta\frac{\Delta\lambda}{\lambda} + \frac{\beta^2}{\alpha^2}[\frac{1}{2}\sec^2\theta - 2\sin^2\theta]\frac{\Delta\mu}{\mu} + [\frac{1}{2} - \frac{1}{4}\sec^2\theta]\frac{\Delta\rho}{\rho}$$

$$R(\theta) = [\frac{1}{4} - \frac{1}{3}\frac{\beta^2}{\alpha^2}]\sec^2\theta\frac{\Delta K}{K} + \frac{\beta^2}{\alpha^2}[\frac{1}{3}\sec^2\theta - 2\sin^2\theta]\frac{\Delta\mu}{\mu} + [\frac{1}{2} - \frac{1}{4}\sec^2\theta]\frac{\Delta\rho}{\rho}$$

$\kappa \quad \lambda \quad \mu \quad \rho$

λ = incompressibility
μ = rigidity

Low λ suggests gas saturation
High μ suggests sand

The LMR Parameters

(Goodway, et al., 1997)

$$R(\theta) \approx (1+\tan^2\theta)R_p - (2\sin^2\theta)R_s$$

↓

Reflection amplitude: R_P R_S

↓

Acoustic Impedance / Shear Impedance: I_P I_S

↓

Elastic constants: $\lambda\rho$ $\mu\rho$

$$\lambda\rho \approx I_P^2 - 2I_S^2$$
$$\mu\rho = I_S^2$$

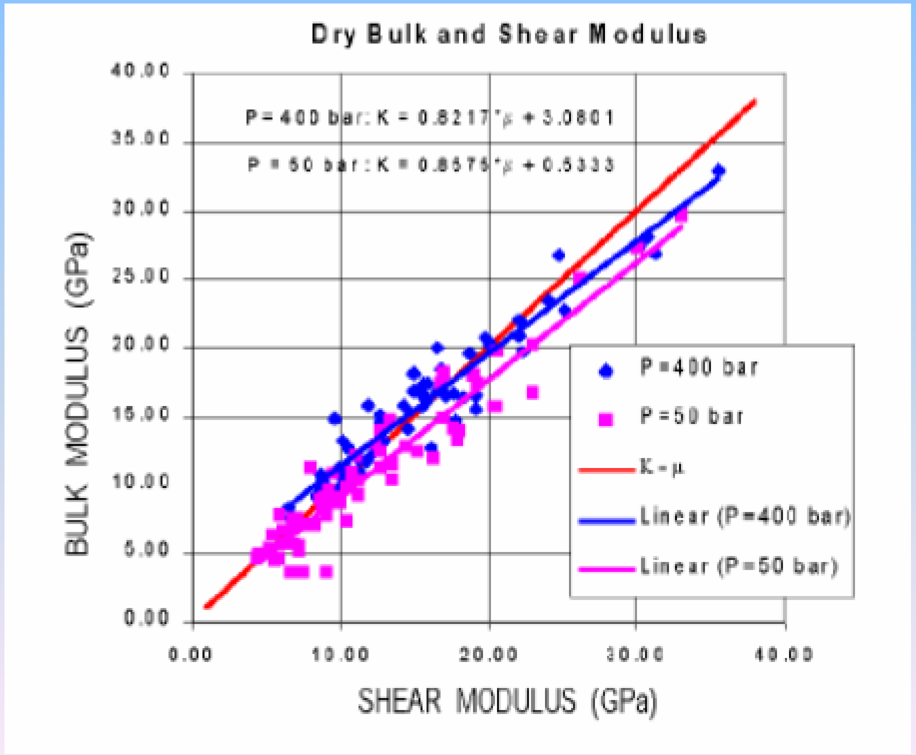
Hydrocarbon indicator

(K - μ)

(Batzle, Han,and Hofmann, 2001)

$$K_{sat} - \mu = K_{dry} + \Delta K - \mu$$

$$= \Delta K \qquad \text{when } K_{dry} \approx \mu$$



Hydrocarbon indicator

Ip^2-c*Is^2

(Russell et al., 2003)

Gassmann Equation: $K_{sat} = K_{dry} + \Delta K$

Basic equations for Vp and Vs in isotropic, elastic media

$$V_p = \sqrt{\frac{K_{dry} + 4/3\mu + \Delta K}{\rho_{sat}}} \qquad Vs = \sqrt{\frac{\mu}{\rho_{sat}}}$$

$$Ip^2 - cIs^2 = \rho_{sat}(\Delta K + K_{dry} + 4/3\mu - c\mu)$$

When $c = \frac{K_{dry}}{\mu} + \frac{4}{3} = \left[\frac{V_p}{V_s}\right]^2_{dry}$

$$Ip^2 - cIs^2 = \rho_{sat}\Delta K$$

Fluid Term

Are they related to each other?

$$\lambda\rho_{sat} = Ip^2 - 2Is^2$$

Goodway et al. ,1997

Implies that c=2 and Poisson's ratio is 0.

$$K_p - \mu = Ip^2 - 2.233Is^2$$

Hedlin, 2000

when ratio of K_{dry} to μ is equal to 0.9, which implies that c=2.233

$$K - \mu \approx (\mathrm{K_{dry}} + \Delta\mathrm{K} - \mu)\rho = Ip^2 - 2.333Is^2$$

Batzle et al. ,2001

when $K_{dry} \approx \mu$, which Implies that c=2.333

Sensitivity analysis

Clean sand

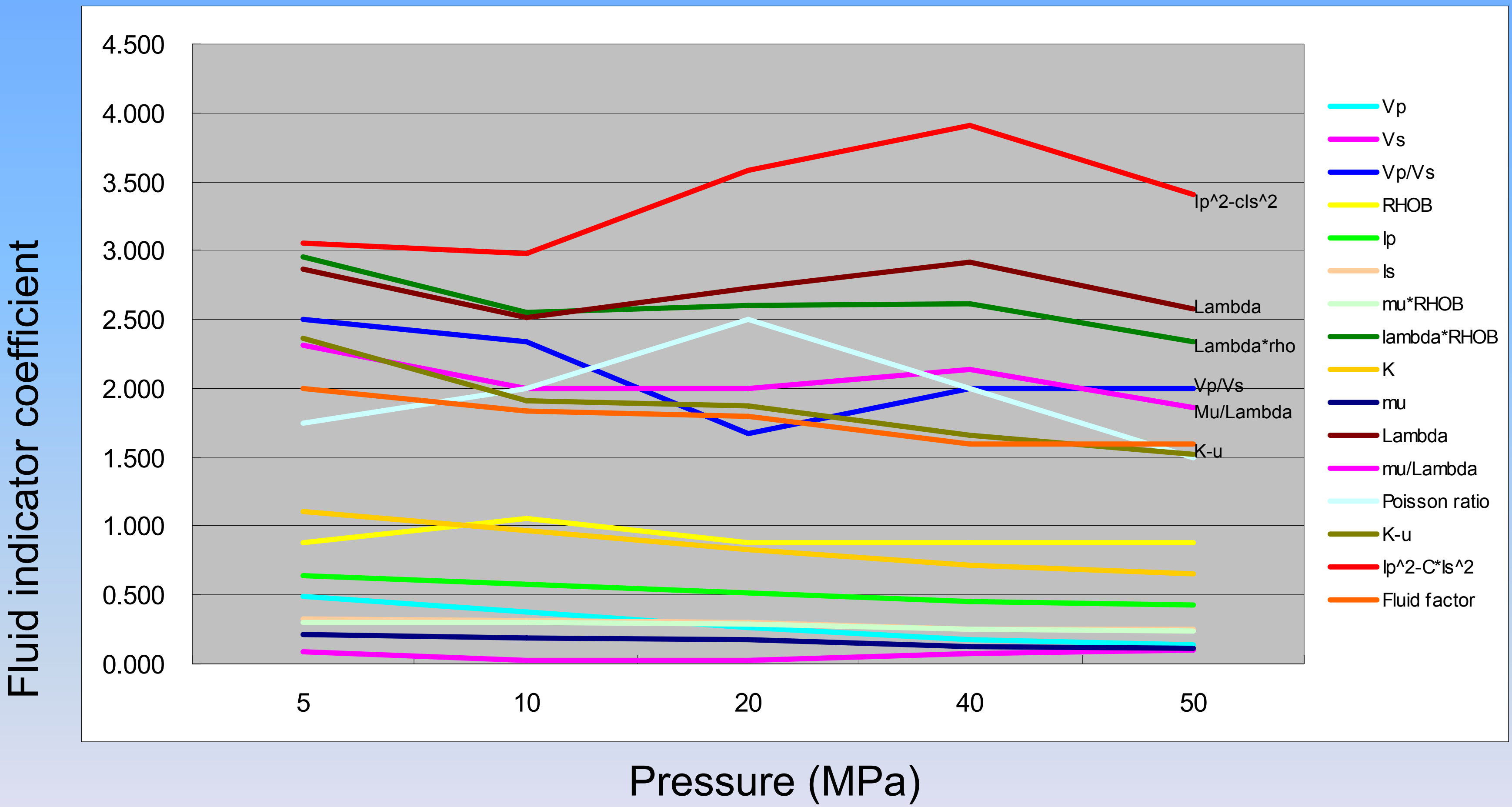
	Hydrocarbon indicators		Vp (km/s)	Vs (km/s)	Vp/Vs (-)	ρ (g/cc)	Ip (km/s.g/cc)	Is (km/s.g/cc)	uρ (GPa.g/cc)	λρ (GPa.g/cc)
5MPa	Dry	Mean value	4.39	2.91	1.51	2.26	10.01	6.63	46.07	12.4
		Std.dev.	0.66	0.46	0.04	0.17	2.18	1.52	21	5.28
	Wet	Mean value	4.71	2.95	1.61	2.41	11.4	7.13	52.47	27.99
		Std.dev.	0.56	0.44	0.06	0.1	1.85	1.36	20.02	5.88
	Fluid indicator coeffient		**0.48**	**0.09**	**2.50**	**0.88**	**0.64**	**0.33**	**0.30**	**2.95**
	Hydrocarbon indicators		**K (GPa)**	**u (GPa)**	**λ (GPa)**	**u/λ (-)**	**σ (-)**	**K-u (GPa)**	**Ip^2-cIs^2 (GPa.g/cc)**	**Fluid Factor (-)**
	Dry	Mean value	18.71	19.9	5.45	0.29	0.11	-1.19	0.89	-0.3
		Std.dev.	6.51	7.73	2.14	0.13	0.04	2.37	4.57	0.07
	Wet	Mean value	25.94	21.53	11.58	0.59	0.18	4.41	14.87	-0.16
		Std.dev.	5.88	7.33	2.08	0.19	0.04	2.67	5.53	0.07
	Fluid indicator coeffient		**1.11**	**0.21**	**2.86**	**2.31**	**1.75**	**2.36**	**3.06**	**2.00**

Fluid indicator coefficient: $$\frac{\left| Mean_{dry} - Mean_{wet} \right|}{Std_{wet}}$$

(Han's dataset)

Sensitivity analysis

Clean sand



The most sensitive indicators: Ip^2-c*Is^2, Lambda, Lambda*rho, Mu/Lambda

Sensitivity analysis

Whole dataset

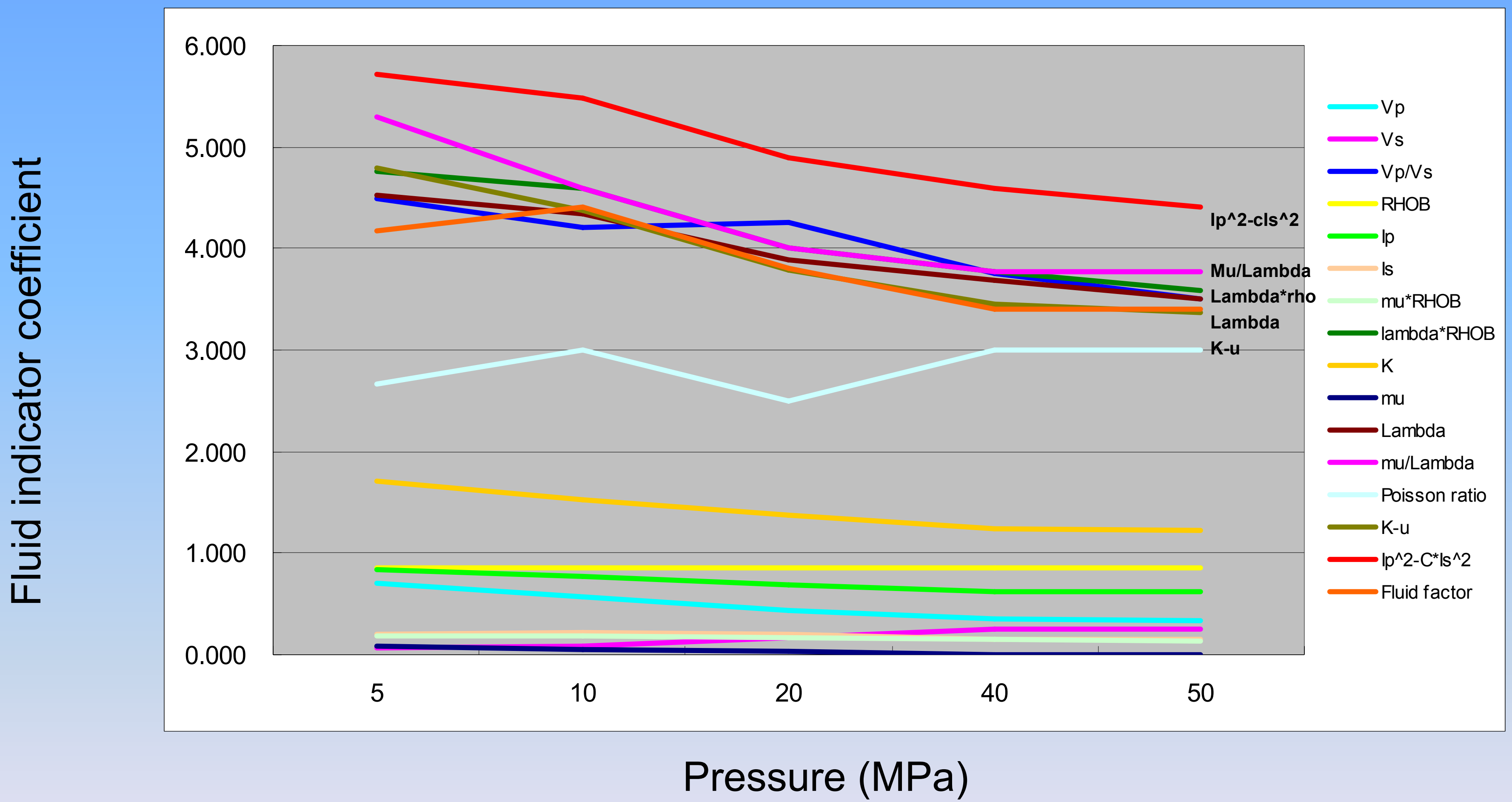
	Hydrocarbon indicators		Vp (km/s)	Vs (km/s)	Vp/Vs (-)	ρ (g/cc)	Ip (km/s.g/cc)	Is (km/s.g/cc)	uρ (GPa.g/cc)	λρ (GPa.g/cc)
5MPa	Dry	Mean value	3.33	2.22	1.5	2.2	7.4	4.94	26.34	6.29
		Std.dev.	0.73	0.49	0.06	0.2	2.07	1.41	15.74	4.68
	Wet	Mean value	3.84	2.19	1.77	2.37	9.15	5.22	29.19	28.59
		Std.dev.	0.6	0.48	0.12	0.13	1.8	1.34	15.76	6.97
	Fluid indicator coeffient		**0.70**	**0.06**	**4.50**	**0.85**	**0.85**	**0.20**	**0.18**	**4.76**
	Hydrocarbon indicators		**K (GPa)**	**u (GPa)**	**λ (GPa)**	**u/λ (-)**	**σ (-)**	**K-u (GPa)**	**Ip^2-cIs^2 (GPa.g/cc)**	**Fluid Factor (-)**
	Dry	Mean value	10.61	11.62	2.86	0.26	0.1	-1.01	-0.29	-0.29
		Std.dev.	5.5	6.13	2.01	0.17	0.06	1.86	3.85	0.06
	Wet	Mean value	20.03	12.11	11.96	1.16	0.26	7.92	21.29	-0.04
		Std.dev.	5.35	6.07	2.42	0.42	0.05	2.6	6.31	0.08
	Fluid indicator coeffient		**1.71**	**0.08**	**4.53**	**5.29**	**2.67**	**4.80**	**5.61**	**4.17**

Fluid indicator coefficient: $$\frac{\left|Mean_{dry} - Mean_{wet}\right|}{Std_{wet}}$$

(Han's dataset)

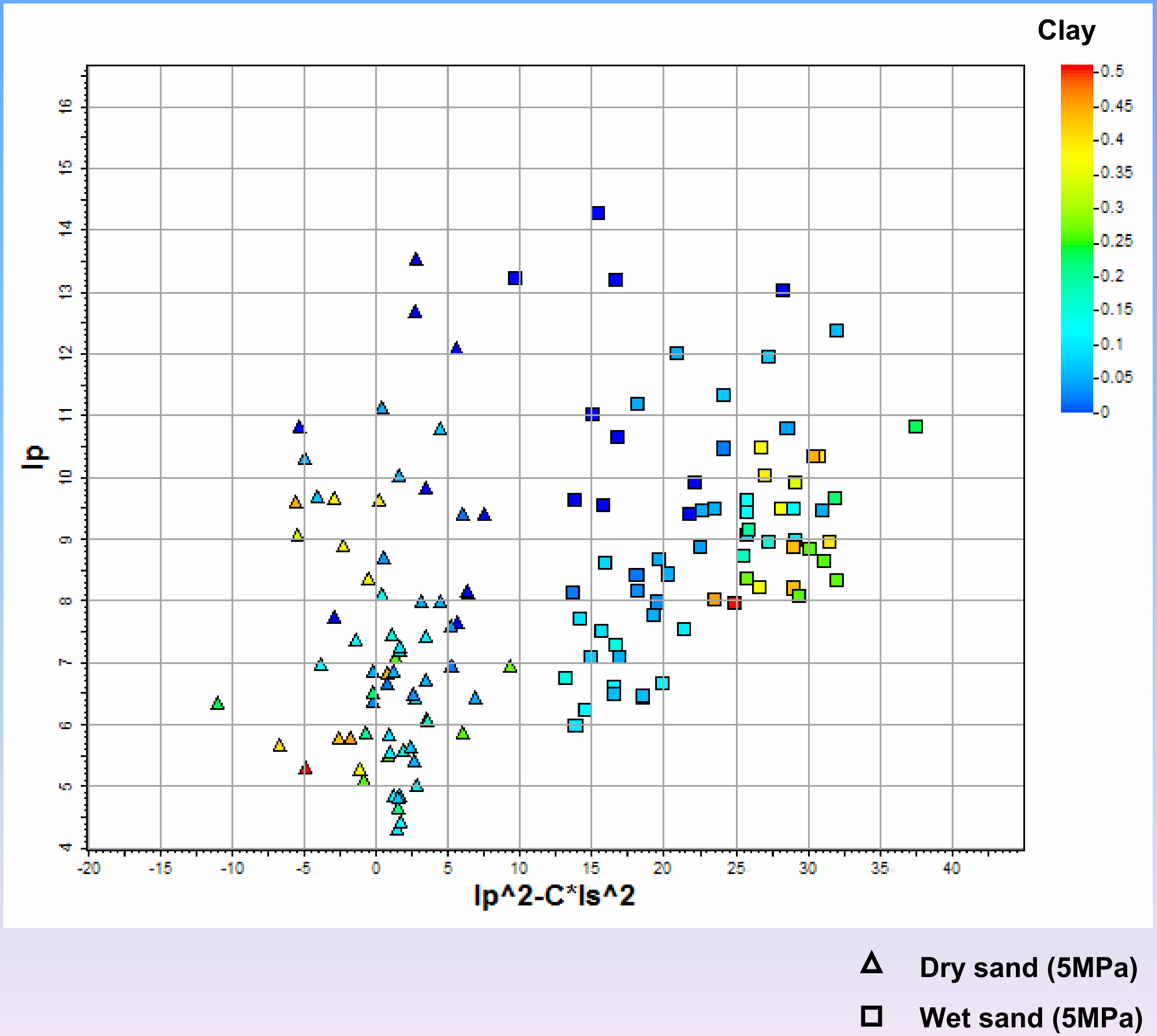
Sensitivity analysis

Whole dataset

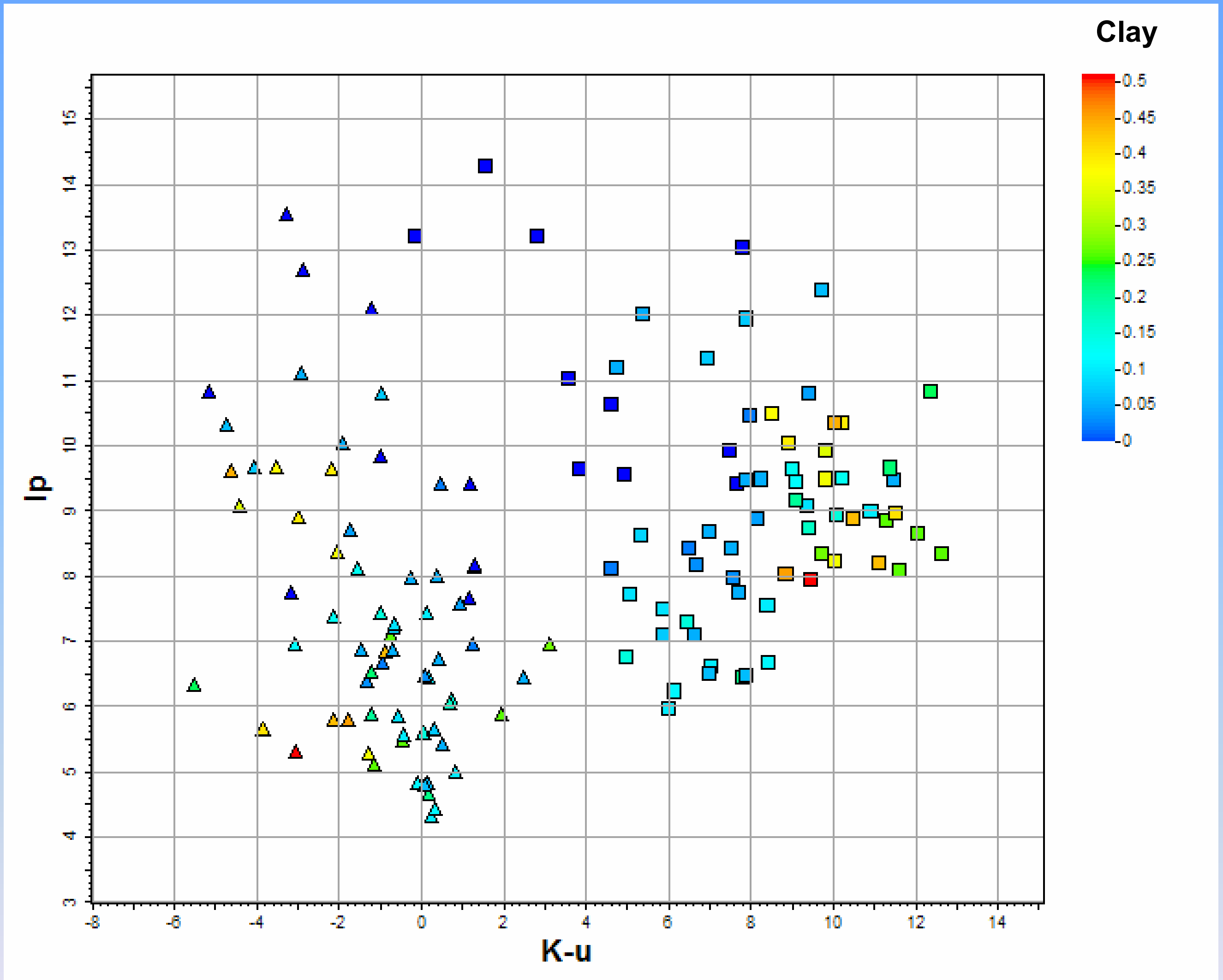


The most sensitive indicators: Ip^2-c*Is^2,Lambda,Lambda*rho,K-u

Sensitivity analysis



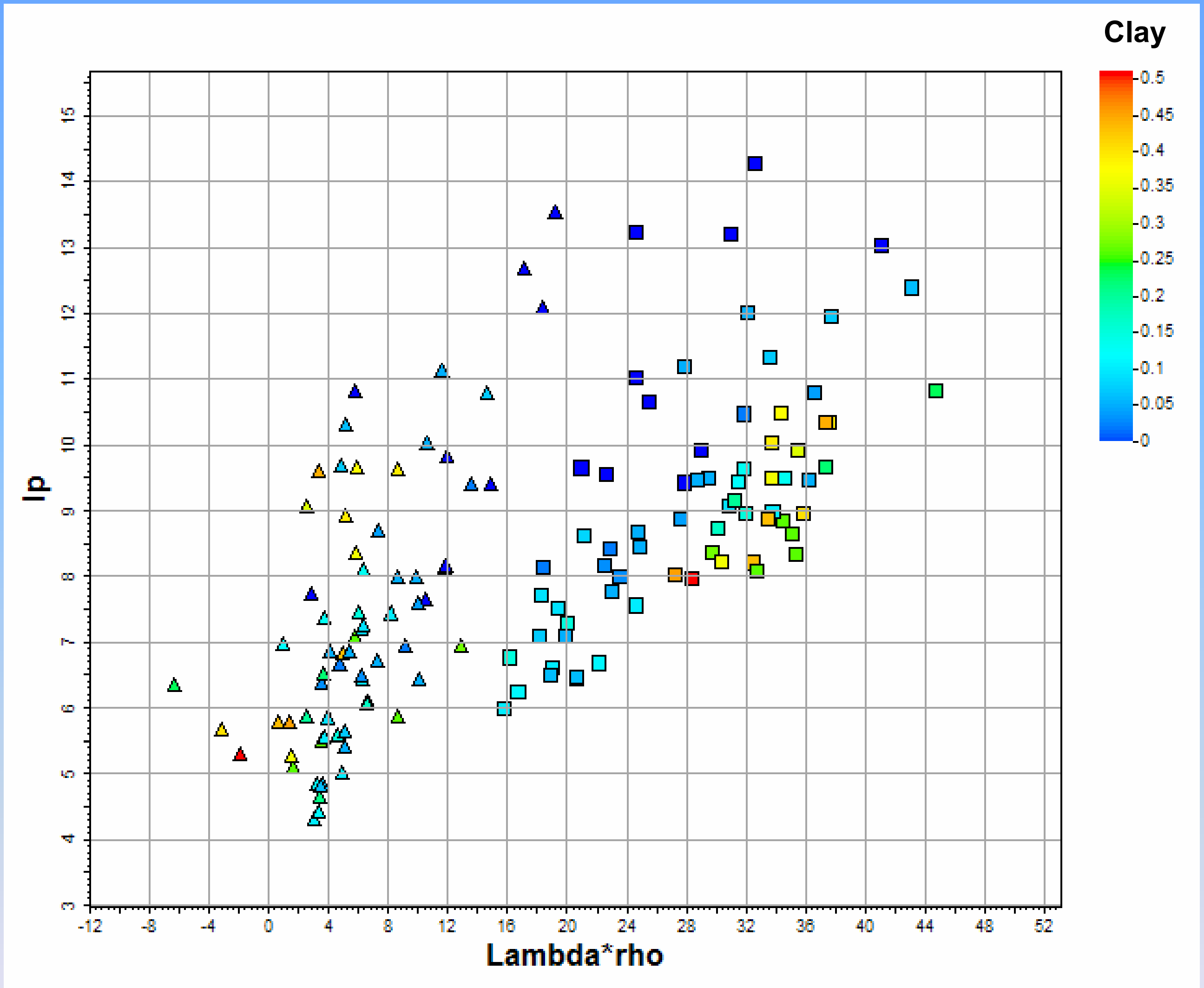
Sensitivity analysis



△ Dry sand (5MPa)

□ Wet sand (5MPa)

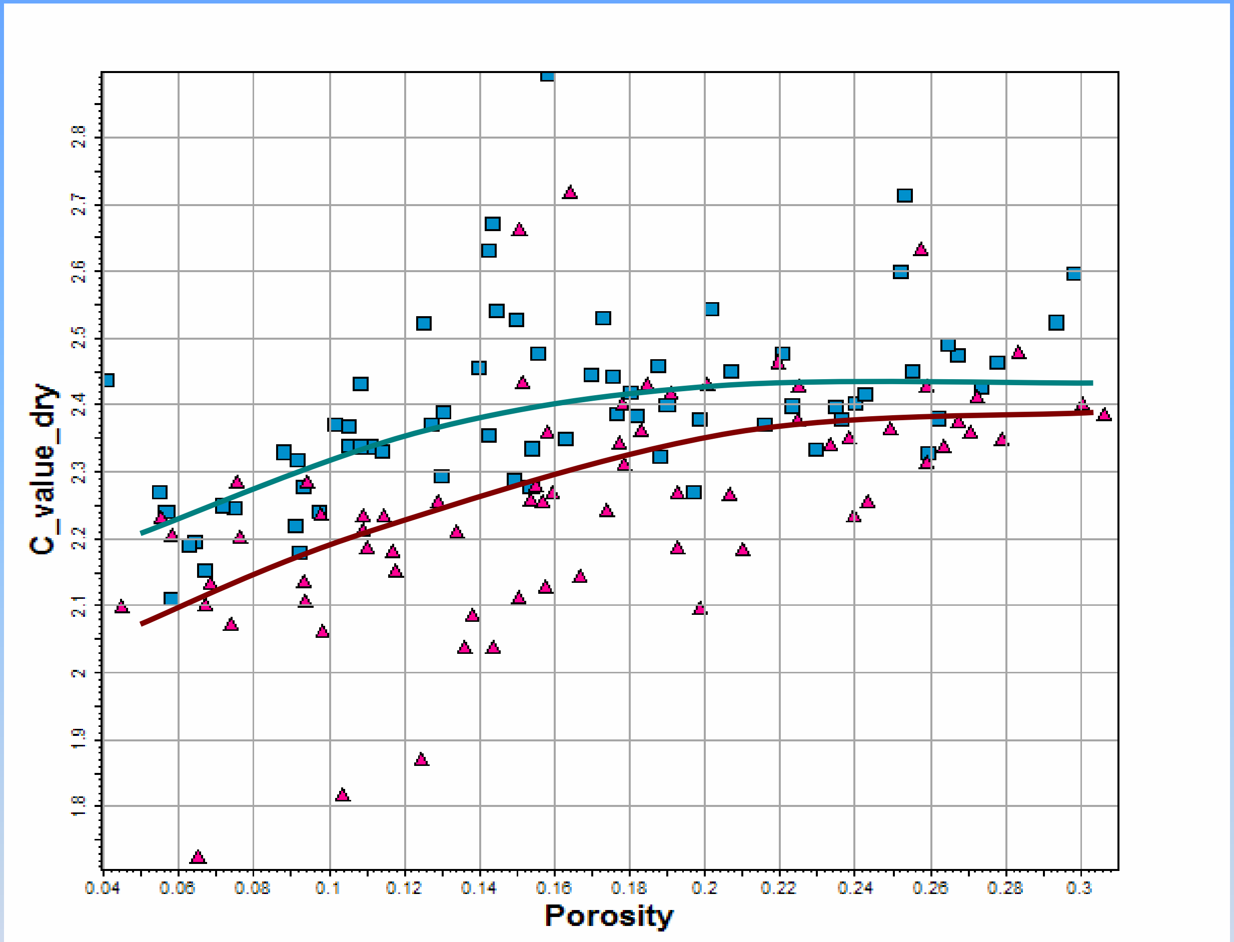
Sensitivity analysis



Δ Dry sand (5MPa)

□ Wet sand (5MPa)

$C=(Vp/Vs)_{dry}^2$ value analysis

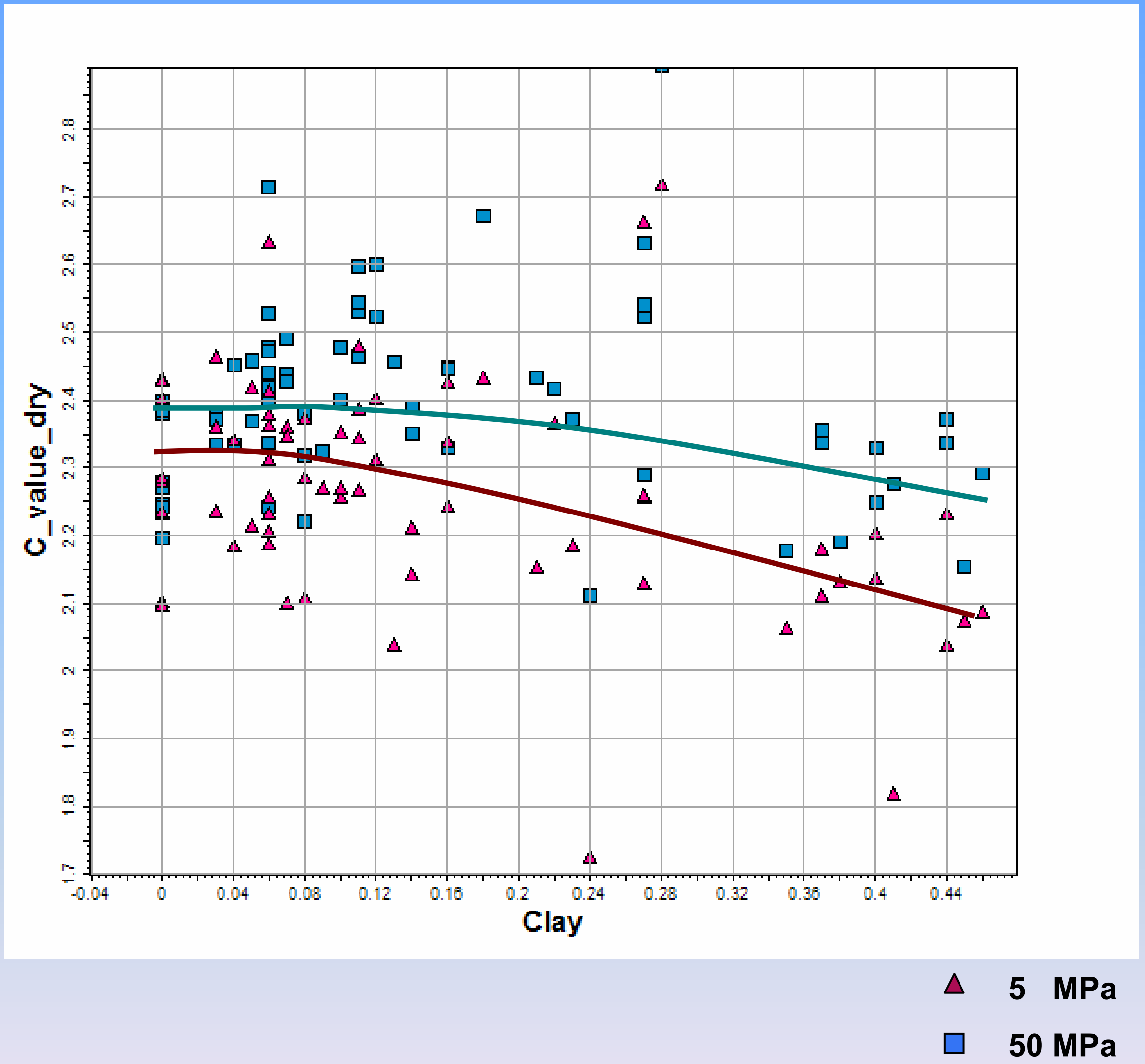


5 MPa

50 MPa

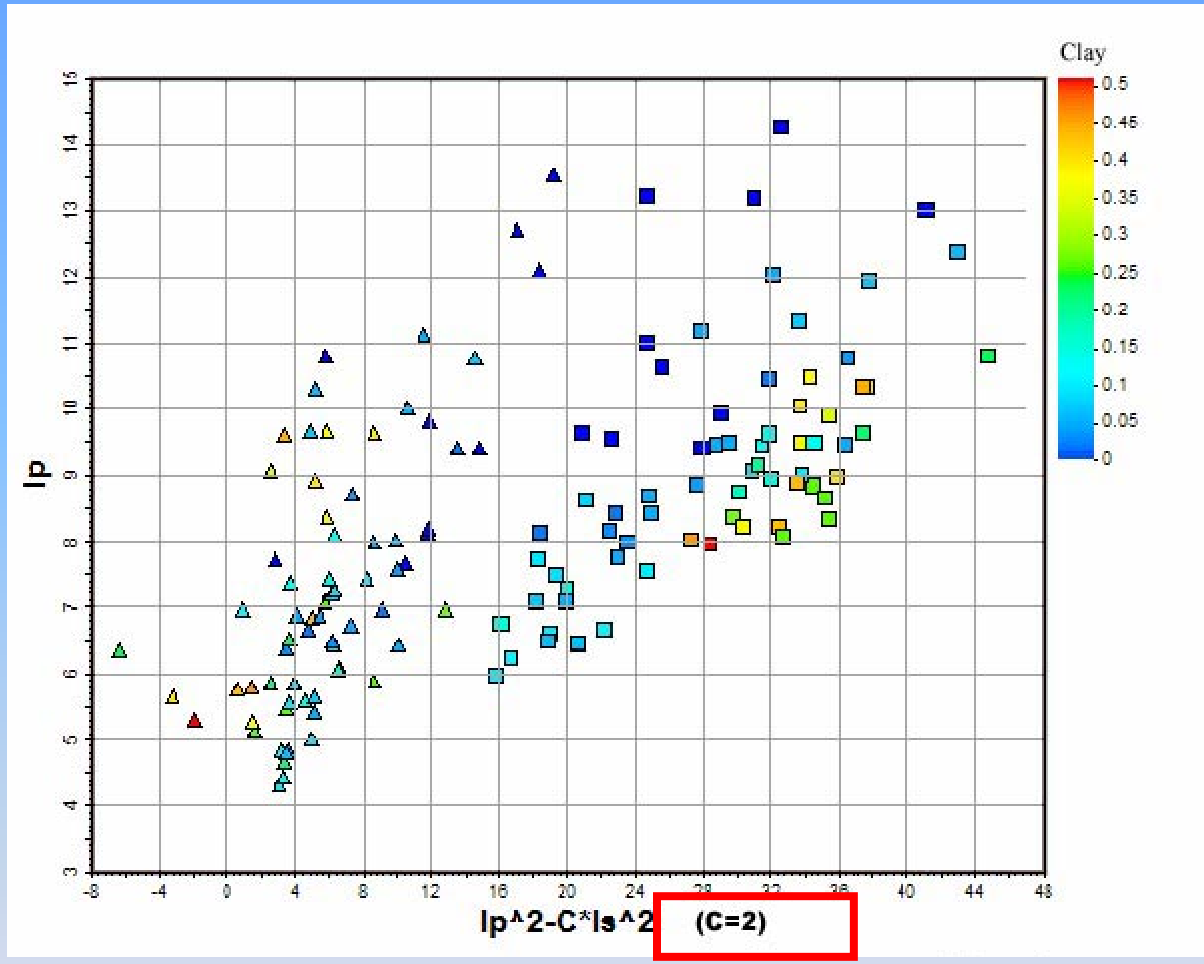
Correlation between C value and porosity for 5 MPa and 50 MPa. Note that C increase with porosity.

$C=(Vp/Vs)_{dry}^2$ value analysis



Correlation between C value and porosity for 5 MPa and 50 MPa. Note that C decrease with clay content.

$C=(Vp/Vs)_{dry}^2$ value analysis

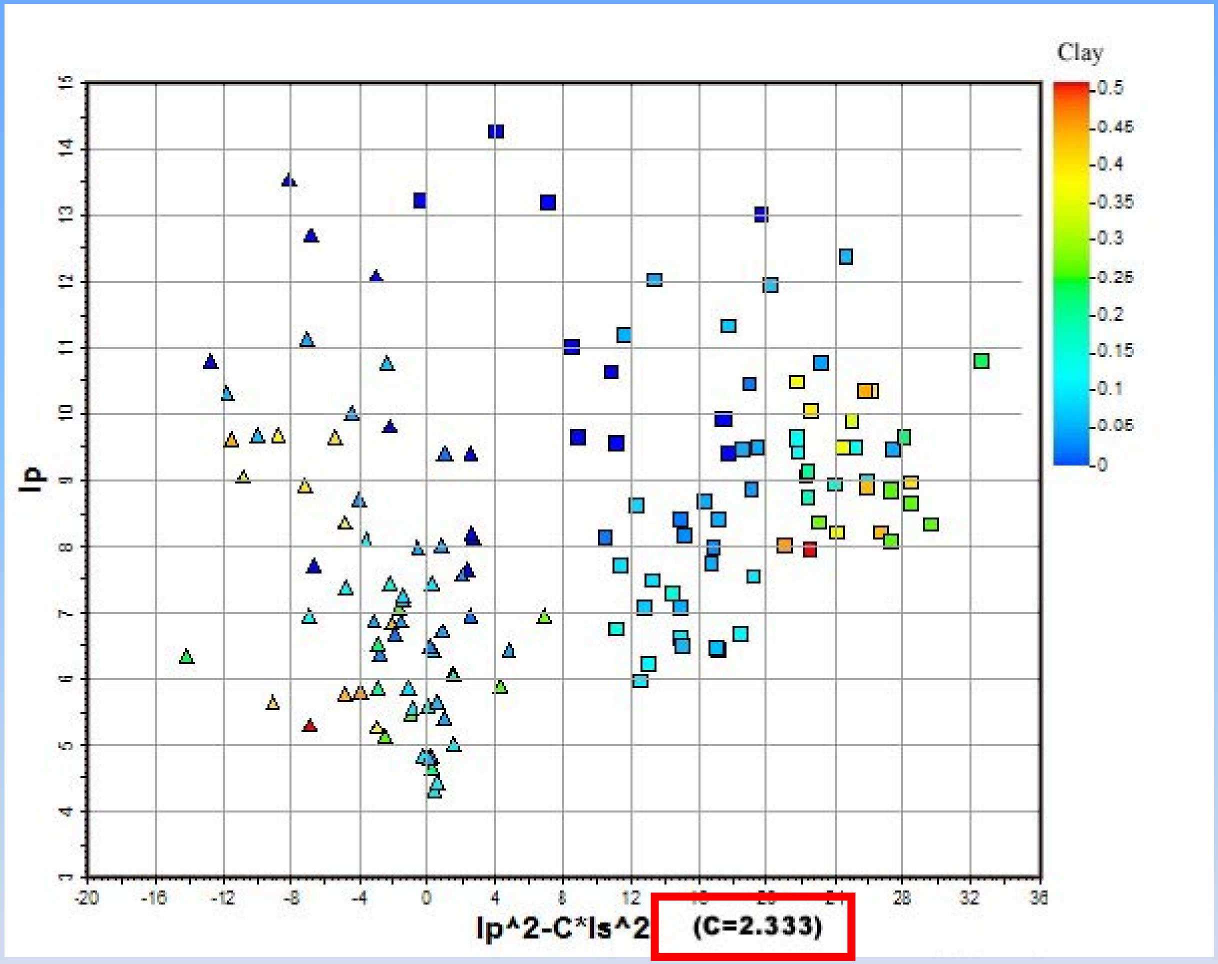


△ **Dry sand (5MPa)**

□ **Wet sand (5MPa)**

Crossplot of Ip^2-$c*Is^2$ versus Ip for 5 MPa pressure with different c value. Observe that there is a best separation between dry sand and wet sand for c=2.233

$C=(Vp/Vs)_{dry}^2$ value analysis



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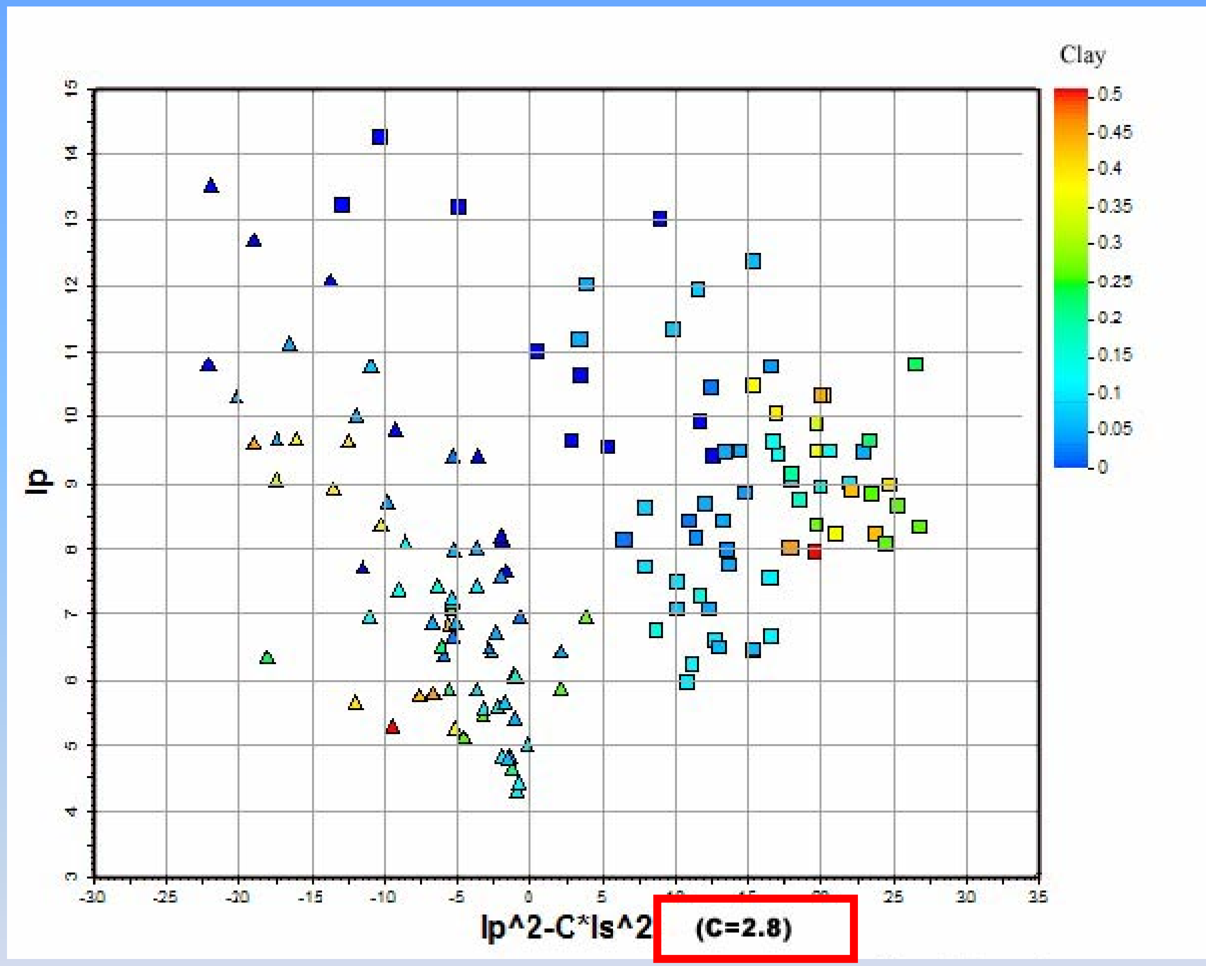

Δ Dry sand (5MPa)

□ Wet sand (5MPa)

Crossplot of Ip^2-$c*Is^2$ versus Ip for 5 MPa pressure with different c value. Observe that there is a best separation between dry sand and wet sand for c=2.233

Conclusions

- Sensitive indicators for pore fluid are

  $$Ip^2 - cIs^2$$

  $$K_{sat} - \mu$$

  $$\lambda\rho$$

- $(Vp/Vs)_{dry}^2$ value depend on porosity, clay content and pressure. The best C value need to be calibrated and tested for the local situation.

Future work

- Continue studying on the quantitative estimation of fluid indicator by using well logs and seismic data.
- Apply AVO inversion to the seismic data to derive all these fluid indicators to study the reservoir fluid properties.

Acknowledgments

- CREWES sponsors