Journal of the Nigerian Association of Mathematical Physics
Volume 12 (May, 2008), 279 – 284

Poisson impedance as an enhanced litho-fluid discriminator using crossplot analysis

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Abstract

The Poisson impedance as a tool for fluid and lithology discrimination in an oil-saturated sand reservoir was tested using seismic and well data set acquired from onshore Niger Delta. From the inversion results, AVO attributes such as the fluid factor and Poisson impedance were obtained. The result showed that Poisson impedance as a discriminatory tool between fluids and lithology have a higher amplitude resolution than the Fluid factor and the inverted acoustic impedance. These results agreed very well with the fluid and lithology discrimination using Poisson impedance and fluid factor attributes in an offshore Angola field and Gulf of Mexico

1.0 Introduction

For over a decade research efforts in Quantitative interpretation have been geared towards fluid and lithology discrimination for effective reservoir monitory and evaluation. In seismic inversion studies the commonly derived inversion products are acoustic impedance (AI) with shear impedance (SI) or Poisson's ratio (σ). Density ρ, could also be inverted for separately but with decreased reliability, due to its dependence on accurate far offset amplitude for stable result. However the AI and SI attributes are regularly crossploted to investigate discrimination between lithology and fluids.

In the AI and SI cross plot space, we are interested in a rotated axis that optimizes the desired separation. One of such rotations is the Poisson impedance which has direct link with Poisson ratio and density. The Poisson impedance or PI incorporates both σ information and ρ into a single display attributes which is very useful in reservoir delineation. This is so because low values of these parameters tend to be associated with many of our high quality reservoirs. For example, gas-and oil saturated rocks have low Poisson's ratios and densities than brine saturations. In addition, in the PI space, because density is not been determined separately, but in combination with the Poisson ratio information, it does not have a far-offset data requirement (Quakenbush et al 2006 [3]). The focus of this paper therefore, is to compare the fluid factor attributes as suggested by Good way et al 1997 [4] and Poisson impedance attributes as suggested by Quakenbush et al 2006 [3] as discriminatory tool for lithology and fluid. The data sets used for the inversion consist of seismic and well log data acquired from onshore Niger Delta of Nigeria

2.0 Basic theory

For anisotropic, non-porous medium the P- and S-wave velocity is given by

$$V_p = \sqrt{\frac{K + \frac{4}{3}}{\rho}} = \sqrt{\frac{\lambda + 2\mu}{\rho}} \tag{2.1}$$

and

$$V_s = \sqrt{\frac{\mu}{\rho}} \tag{2.2}$$

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where V_P = P-wave velocity

V_S= S-wave velocity

λ = Lame's parameter

μ = shear modulus

K= bulk modulus

ρ = density

$$V_P\,\rho = \left[\rho\left(s+f\right)\right]^{1/2}$$

But impedance *Z* = velocity *x* density

$$\therefore \quad Z_P = \left[\rho\left(s+f\right)\right]^{1/2}$$

$$and\;\; Z_S = \rho V_S = \left(\rho\mu\right)^{1/2}$$

$$or\;\; Z_P^2 = \rho s + \rho f$$

where ρf = fluid term and ρs = matrix term

$$V_p = \sqrt{\frac{\lambda_{dry} + 2\mu + \beta^2 M}{\rho_{sat}}} = \sqrt{\frac{K_{dry} + \frac{4}{3}\mu + \beta^2 M}{\rho_{sat}}} \qquad (2.3)$$

or

$$V_P = \sqrt{\frac{s+f}{\rho_{sat}}} \qquad (2.4)$$

where *s* is the dry skeleton term

and $\beta^2 M$ = *f* is the fluid term

β = Biot coefficient

M= modulus term

Note that

$$\lambda_{dry} + 2\mu = K_{dry} + \tfrac{4}{3}\mu \qquad (2.5)$$

and

$$\mu = \mu_{sat} = \mu_{dry} \qquad (2.6)$$

$$\rho f = Z_P^2 - \rho s$$

Fatti et al (1994 [2]) derived $\rho s = 2Z_S^2$. Seismically, we have that PI = Z_P - c Z_S. Note that *c* optimizes the rotation.

But

$$\rho f = Z_P^2 - 2Z_S^2 = \left(Z_P - \sqrt{2}Z_S\right)\left(Z_P + \sqrt{2}Z_S\right) = PI\left(Z_P + \sqrt{2}Z_S\right)$$

Since PI = Z_P - cZ_S

$$PI = \left(\left(V_p - cV_s\right)\rho\right)$$

but

$$\left(V_p -_C V_s\right) = V_\sigma \text{ = Poisson velocity}$$

therefore

$$PI = V_\sigma \rho \qquad (2.7)$$

Quakenbush in 2006 [3] derived $\sigma = DV_\sigma$, where *D* is the scaling factor and σ = Poisson ratio.

Therefore,

$$PI = \frac{\sigma\rho}{D} \qquad (2.8)$$

Equation (2.8) establishes the relationship between Poisson impedance PI, Poisson ratio σ and density ρ .

3.0 Well log example

The well-log example is from Niger Delta area of onshore South- Southern Nigeria (Figure 3.1). The well log data including compressional velocity, *V*p, shear velocity Vs, density log, gamma ray log; caliper log and resistivity log were acquired over the producing zone overlain by cretaceous shale. These well-Log curves were converted to the equivalent pf and *ps* and cross plotted. Again, S- impedance and PI attributes were also cross plotted as shown in Figure 3.3. A closer look at these cross plots shows that in the case of PI attributes the separation between the brine sand (blue) oil sand (red) and shale (brown) is well separated showing a very robust discrimination between shale, oil and brine sands compared to fluid factor attribute.

Figure 3.1: Location map

4.0 Seismic data example

The PI attributes is compared with other attribute section such as fluid factor and acoustic impedance derived from prestack time migrated seismic data for our Niger Delta examples. The deviated well location is indicated by the purple line with the gamma ray log shown in black. The interpreted horizon is in yellow, which is on top of the reservoir of interest. For the three attributes sections as shown

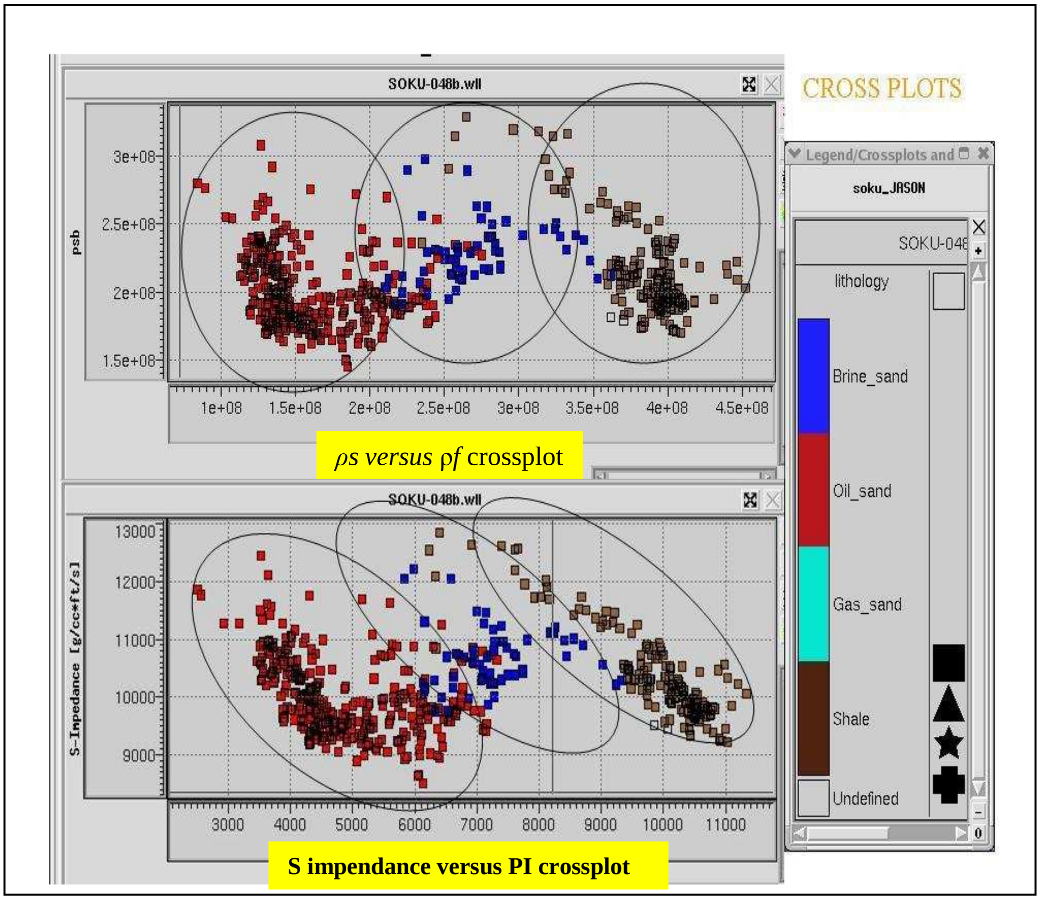

Figure 3.2: Cross-plot analysis

in Figure 4.1, the Poisson impedance PI and fluid factor *pf* shows a better discrimination than the acoustic impedance AI at the edge of the reservoir. However, within the reservoir the PI shows higher amplitudes resolution than the AI. Finally, from the extracted amplitudes of the three attributes as shown in Figure 4.2, the Poisson impedance shows a better litho- fluid discrimination as highlighted in the three sections. In all, Poisson impedance appears to compare favorably against the other two attributes discussed in terms of litho- fluid discrimination.

5.0 Conclusion

The use of Poisson impedance and fluid factor for litho- fluid discrimination in an oil saturated sand have been tested.

Poisson impedance as a discriminatory tool appears to have a better resolution than the n fluid factor and the inverted impedance.

These results agreed very well with the fluid and lithology discrimination using Poisson impedance and fluid factor attributes in an offshore Angola field and Gulf of Mexico

This PI attributes should be effective for reservoirs where Poisson's ratio and density values are either anomalously low or anomalously high.

For consolidated reservoirs at depth, lower contrast values for Poisson's ratio and density which offer insufficient reservoir discrimination individually, will combine in the PI attribute to give good discrimination.

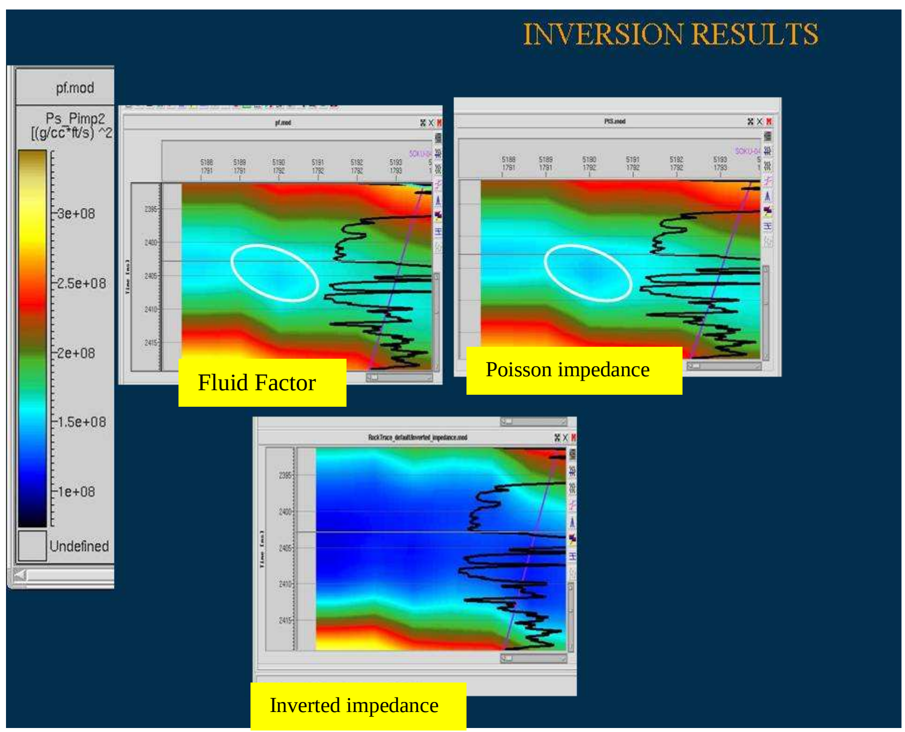

Figure 4.1: Inverted sections

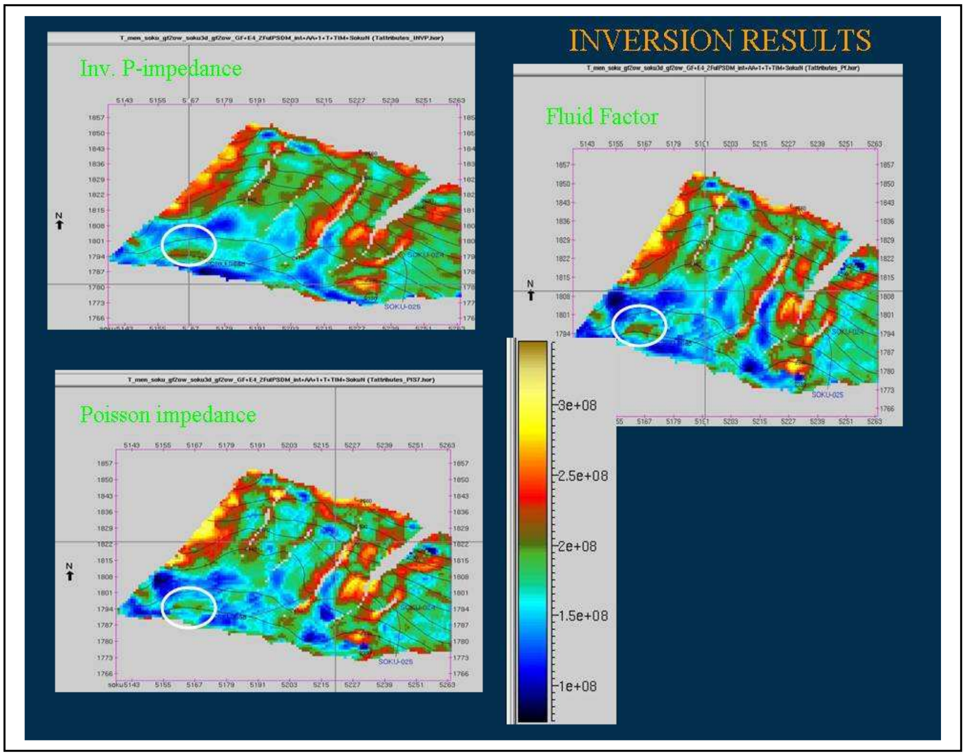

Figure 4.2: Extracted amplitudes

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