Inverted Density Estimates – Interpretation Elegance in High Fidelity

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Pre-Stack Simultaneous Inversion as per Hampson et al (2005) yields estimates of rock bulk density with enhanced bandwidth compared to the corresponding impedance estimates from the same inversion process for a typical Cretaceous clastic section in the Western Canadian Sedimentary basin (WCSB). This results in a much improved ability to understand, quantify and predict important rock properties such as reservoir porosity thickness. The density estimates from the oil field template data illustrated are derived from convention onshore 3D seismic data utilizing maximum offset angle of 32 degrees.

The example Illustrated traverses 3 different light oil pools in Alberta's Lower Cretaceous clastic section and illustrates a very good correlation to well log measured densities and clear definition of reservoir location and quality.

A comparison of the resultant frequency content of the density estimates compared to the frequency content of the corresponding impedance raises a fundamental question as to why it is there and is it plausible and accurate. For the example illustrated it is shown that the spectral content of the density log compared to the velocity log displays a similar increase in higher frequency content on the density log. While I suspect that this is generally true for the Cretaceous clastics of Western Canada, this has not be tested to a sufficient degree to be confidently stated.

Convincing logical explanations for the increased higher frequency content of the density comes from two different rationales, one a relatively simple mathematical approach, the other from a more complex sedimentary clastic cement rationale.

Since the impedance is the product of the density and velocity, its spectrum is the convolution of the spectrum of the density with the spectrum of the velocity. This results in the impedance spectrum being a complexly smoothed version of the velocity and density spectra.

Rock bulk density is essentially controlled by grain density and porosity but rock p-wave velocity is strongly influenced by diagenetic cements which form around the grain to grain contacts along with rock grain velocity and porosity. The paper by Al-Tahini et al (2007) on velocity sensitivity of the Devonian to Permian age reservoir sandstones of the Ghawar field of Saudi Arabia illustrates the velocity sensitivity of those reservoir sandstones as a function of both the amount of cementation and porosity. The multiple linear regression relation that they calculate for P-wave velocity for quartz cement for those sandstones is given below;

$$VP = 4164 - 2.40*(\text{porosity }\%) + 65.85*(\text{quartz cement }\%)$$

Note that the coefficient for a one percent change in quartz cement is ~ 25 times greater than the coefficient for a one percent porosity change. I believe this irrelevance of porosity to sonic velocity is reason that many clastic mapping geologists working in the WCSB use density logs primarily in their analysis rather than sonic logs.

Sedimentary cements are often controlled by a complex history of diagenesis related to burial depth, temperature and fluid system chemistries. For young Tertiary basins such as the Gulf coast it may not play a large role in determining rock properties but in older sections such as the WCSB or Saudi Arabia it often plays a lead role in determining P-wave velocity but a lesser role in determining density porosity. Diagenetic cements tend to have consistent histories over larger thickness intervals and thus a lower frequency content than the bulk density variability. This is manifest and illustrated in the Cretaceous clastic section of the WCSB.