Pseudo-sonics, Synthetics and the Lay of the Land

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Introduction

The role of the synthetic seismogram(SS) as a supporting element of prospect presentations involving seismic data is well established, as a bridge between the domains of time and depth it's functionality is essential for rigorous interpretation of a seismic profile.

A SS for a well is computed from a sonic log(DT) taken in the open borehole, with the bulk density log(RHOB) making a supplemental contribution. Log curves, as discussed here, are in the form of digital Log Ascii Standard(LAS) files, a handy format for loading, viewing and augmenting well log data in a workstation environment. More information and useful software for manipulating LAS files are available at the website of the Canadian Well Logging Society (www.cwls.org).

Sonic Log to Synthetic Seismogram

The first step in computing a SS is to integrate(sum the values) of the DT curve in order to convert the log from DT vs. depth to Interval Velocity(VI) vs. time, the resulting velocity values being equally spaced at discreet time intervals, usually 1ms. This transform establishes a time vs. depth relationship over the logged segment of the well, the result being only as accurate as the DT curve. Since the DT curve seldom starts at the surface, or datum of the seismic, an estimate of the shallow velocity is applied to establish the seismic time at the start of the DT log.

From the integrated log at discreet time intervals, and an RHOB log if available, reflection coefficients are computed which, when convolved with a suitable wavelet, will yield a SS trace. This trace, plotted at the correct display scales, should resemble the seismic data at the well location. It is not uncommon for stretching or squeezing of the SS to be required to achieve a properly tied result. Reflection character matches between the SS and the seismic data determine where adjustments are needed. A refined SS will provide an accurate time/depth function at the well tie point and positive identification of geologic horizons in the seismic data. It may also be used to model changes in lithology and fluid content in formations of interest.

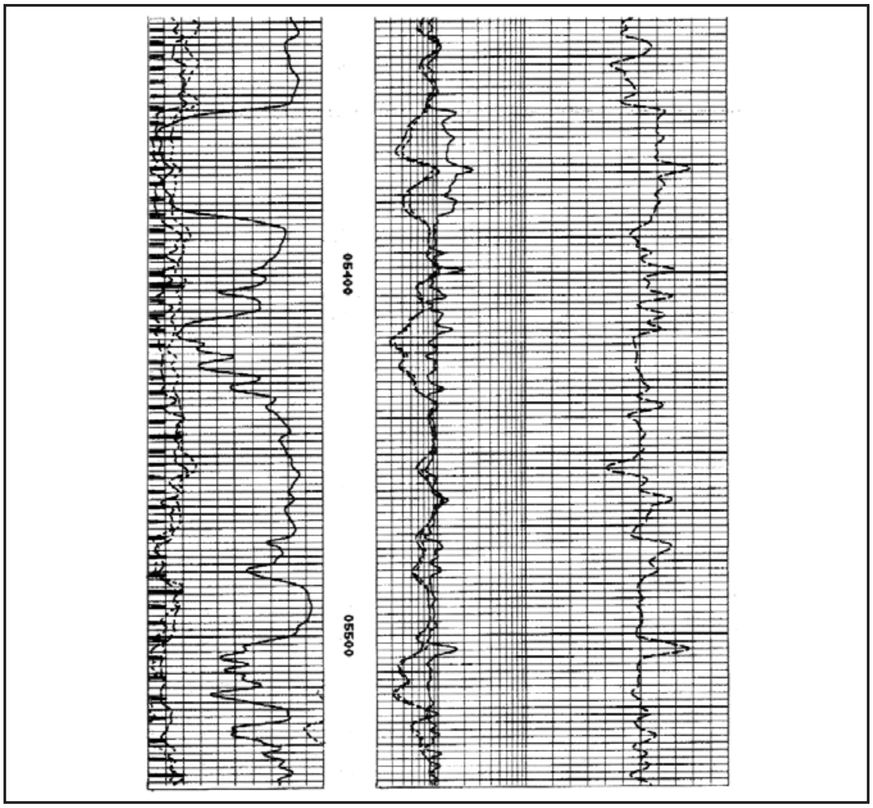

Figure 1. Induction-Acoustic detail log over a sand interval in a Jim Hogg Co., TX well. Curves of interest from left to right are SP, Rild, Rsfl and DT (dashed).

Pseudo-Sonic Logs

It is often the case that wells near a prospect had no sonic log run, have large gaps in the log, or was not released. Any of these situations create a need for an effective and accessible method for computing an accurate pseudo-sonic(DTP). DTP being the name applied to an approximation of a sonic log that is derived from a different log type. An accurate DTP will make a useful SS in the absence of a DT log. The DTP may also be used to fill gaps in a DT or to replace poor quality DT data zones.

References listed are a selection of titles the reader may explore to appreciate the history of this field of research. DTP algorithms are generally developed by the application of non-linear numerical analysis techniques to empirical data sets in the form of log cross-plots and may evoke a glassy-eyed response.

In the absence of a DT log, which normally appears only on the detail display of a sonic log, it is usually the case that either an Induction log at correlation scale(1"/100') or a Density/Neutron porosity log will be available. It is the purpose of this article to explore options for using these log types for DTP calculation.

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DTP From Resistivity Logs

A common method for DTP calculation is to use Faust's Equation to calculate the pseudo-sonic from a resistivity log. This algorithm is typically available in interpretation software packages that have SS capability. The algorithm is easy to use but often fails to give accurate results since it is a "one-size fits all" approach with limited user control. The best geologic setting for using Faust's Equation are those regions where velocity increases uniformly with depth without abrupt changes in formation age or lithology, south Louisiana being an example.

Successful use of a resistivity log for DTP calculation starts with the decision of which resistivity curve to employ. With an induction log at 1"/100' correlation scale one may only have shallow(SFL or SN) and deep (ILD) curves to choose from. Consider **Figure 1** (shown on page 29), a detail log interval of Induction/Acoustic from Jim Wells Co., TX. The curves of interest from left track are: SP(solid), middle track, ILD(long dash) and SFL(solid), and right track, DT(dash). Note that the SFL follows the character of the DT curve very closely across the entire interval. The ILD, however, diverges sharply at the sand beginning around 5354' and continues to read low values throughout the sand interval. This phenomenon often occurs when the well bore penetrates high porosity wet sands in a clastic setting, the Gulf Coast onshore being typical. The deep induction log is "seeing" a large volume of salt water in the porous sand and is recording the resistivity of the formation fluid. The SFL, contrastly, is measuring in a much smaller volume, near the path the sound wave from the sonic log travels. Observation suggests that using the ILD will create a much slower DTP in sands, resulting in a slower integrated DTP and a negative reflection at the top of the sand which should be positive, leading to mis-correlation of the SS to the seismic data. This can be a source of significant DTP error in wells where a high percentage of thick, porous sands have been logged, as in the Miocene of the Gulf Coast onshore.

Cross-Plot Technique

Cross-plots between the resistivity(RS) and sonic(DT) logs in a pilot well may be used to determine a scale function, or mathematical relationship, between the log types. The scale function may be applied to wells with the same type RS log which are in a similar geologic setting to calculate a DTP. Scale functions can be determined in a depth varying fashion with consideration to formation age and lithology changes. This method allows more refined control of the scale functions than does Faust's Equation and often provides superior results.

The cross-plot data points are the average resistivity value associated with each DT value that occurs in a specified depth interval of the pilot log. It is informative to differentiate the values by referencing a lithology log at each data point to determine if it was recorded in shale or sand. This allows scale function differences due to lithology to be observed.

Figure 2 is a cross-plot between Rsfl and DT in the Jim Wells Co. well in Figure 1. The sand interval is included in the 600' cross-plot zone as indicated by the depth range. This plot reveals a nearly smooth relationship between the Rsfl and DT in sand or shale, giving confidence that a useable scale function can be obtained by fitting the distribution on the cross-plot with a Least Mean Square(LMS) polynomial. In this case a second order LMS function like DTP = 93. - (Rsfl) * 90. + (Rsfl^2.) * 53 is a close fit. By repeating the cross-plot along the range of logged data a depth varying function can be determined which can be used to create an accurate DTP for nearby wells with a similar type RS curve. An inventory of such functions for different areas can be a valuable addition to the interpreter's toolkit.

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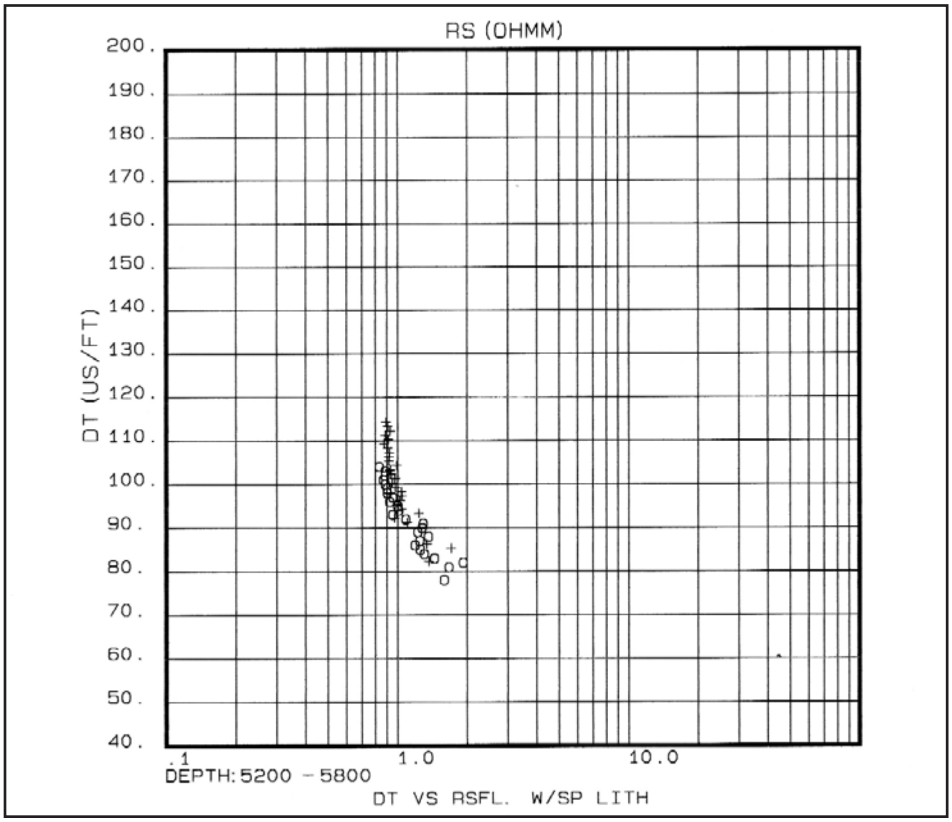

Figure 2. Cross-plot of DT vs. Rsfl over a log interval including Figure 1. Circles(o) represent values taken in sand, plus (+) are values in shale based on the SP. This distribution can be used to determine an accurate scale function.

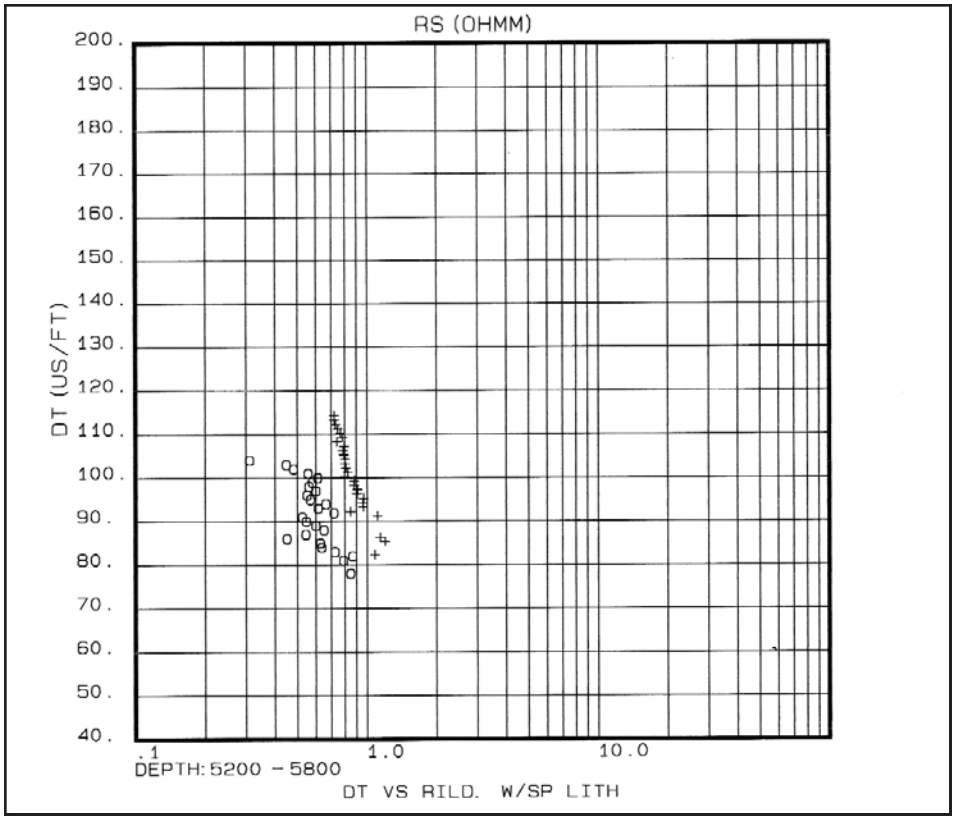

Figure 3. Cross-plot of DT vs. Rild over the same interval as Figure 2. The bifurcation of sand values from shale values suggest that a single scale function cannot be derived from these data points.

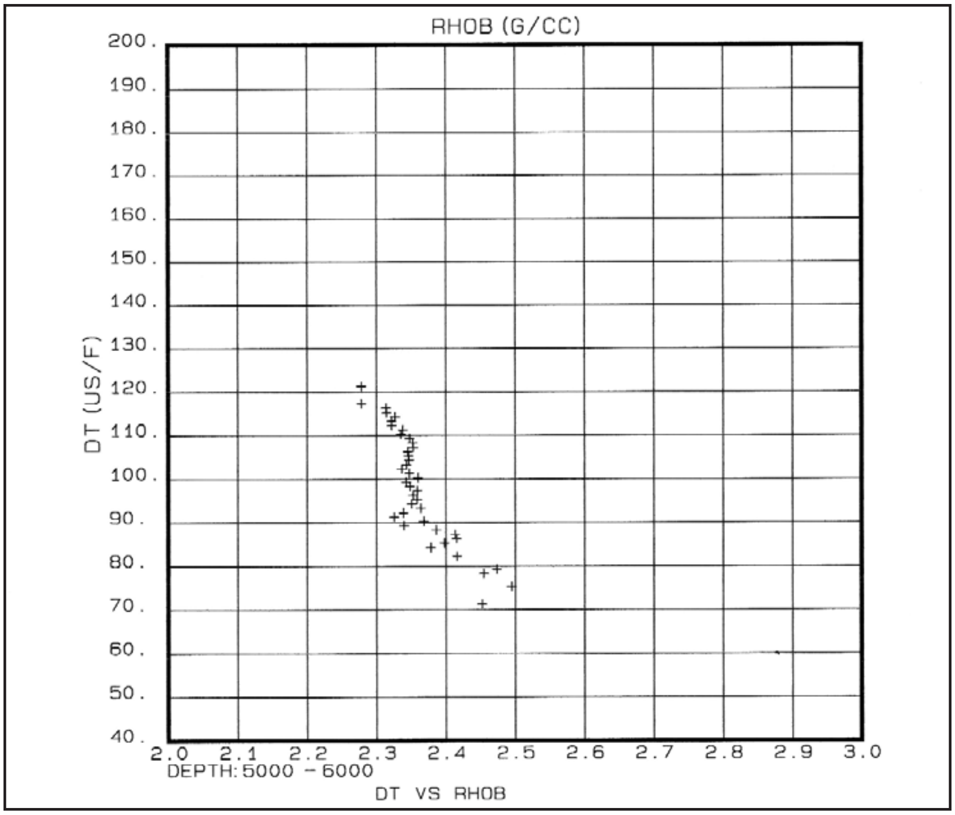

Figure 4. Cross-plot of DT vs. Rhob over a 1000' interval of the well in Figure 1. Note that the DT values associated with a density of 2.35 g/cc range from 110 to less than 90us/f.

Figure 3 is a cross-plot between ILD and DT over the same interval as that in Figure 2. Note the separation between the values recorded in sand from those in shale. This plot confirms statistically what was observed in Figure 1 and suggests that a single scale function cannot describe the ILD to DT relationship in this zone.

It is frequently the case that the SFL, in addition to being a more accurate source curve for DTP calculation in clastics, is better behaved in high resistivity carbonates and delivers more useful data due to it's superior resolution.

DTP from Density/ Neutron Logs

Algorithms for computing velocity from RHOB logs are available. Typically a form of Gardner's equation will be used, i.e., V= (RHOB/C)^4., where RHOB is in g/cc, C=.23 and V is ft/sec. This formula results in a faster velocity with increased density, which is counter to what is observed in a clastic section like the Gulf Coast, where lower density sands may be faster than high density shales.

Figure 4 is a cross-plot between the DT and RHOB curves over a 1000' interval of the Jim Wells, Co. well. The shape of this data distribution is ambiguous, inferring that an accurate DTP could not be derived from the RHOB curve. The sensitivity of the density log to borehole conditions is one of several factors suggesting it may not be suitable for DTP calculation. Other weaknesses of using RHOB to calculate velocity are documented in the literature.

Figure 5 (shown on page 32) is a cross-plot between DT and NPHI curves over the same interval as Figure 4 and reveals a nearly linear relationship between these curves in the subject well. This type of distribution can be approximated with a scale function of the form DTP = A * NPHI + B, where A is the slope of the curve and B is the DT axis intercept point. A

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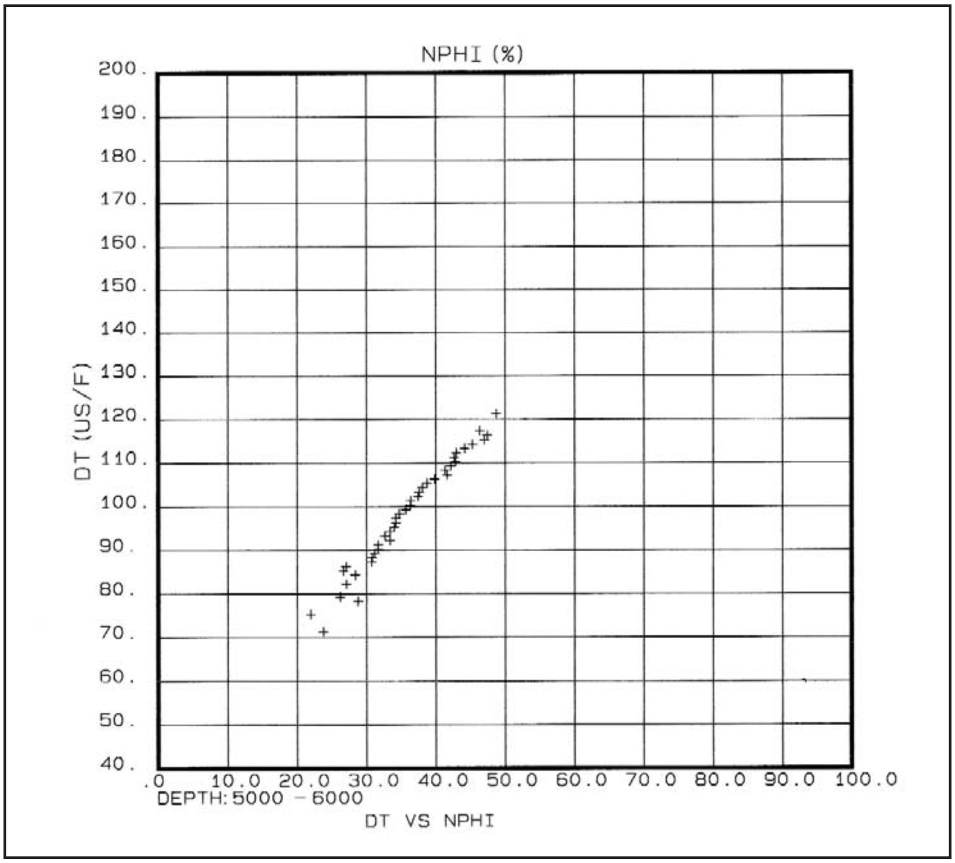

Figure 5. Cross-plot of DT vs. Nphi over the same interval as Figure 3. In this case a near linear distribution of points makes a simple and accurate scale function possible.

and B can be calculated by inspection from the cross-plot. In the case above values of A=1.65 and B=40. result in a very close fit to the distribution. This type of linear scale function between the DT and NPHI has been observed in several mature basins and is reliable for DTP calculation. Small adjustments in the slope and intercept are needed in different areas but the linearity is a consistent feature of this relationship. Developing depth variant functions in a pilot well is possible using spreadsheet type software and the DT vs. NPHI relationship.

Caveats

The presence of hydrocarbons in the formations logged will distort the results of either of the methods for calculating the DTP that have been described. It is necessary to manually edit those zones where gas effect is present in the NPHI values or hydrocarbon resistivity in the RS curves. This is normally handled by referring to a wet zone of comparable lithology and adjusting the DTP values to model the conditions present. Wyllie's equations are useful for making these modifications.

Modern full-array resistivity logs are recorded using multiple transducers of varying length and depth of investigation, the data are combined, or mixed, in a fashion not known to the customer, a result being that the qualities of the short investigation tool that are useful for DTP calculation in older logs are diminished in newer ones. Given a choice of using a contemporary full array log or an eighties vintage induction log to compute a DTP the later is the better option.

Conclusions

Calculating an accurate DTP is not always an easy task but can be accomplished with patience and attention to the limitations of the log types available to use.

In the case of resistivity logs, a shallow investigation curve type is superior to the deep for this purpose.

A custom designed, depth varying scale function that considers formation age boundaries will yield more accruate results than a general purpose algorithm.

The neutron log is a superior option to the bulk density log for calculating a DTP when only a porosity log is available.

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