AAPG EXPLORER

GEOPHYSICAL CORNER

Log Ties Seismic to 'Ground Truth'

The Geophysical Corner is a regular column in the EXPLORER, edited by R. Randy Ray. This month's column is the first of a two-part series titled "Seismic to Well Ties with Problematic Sonic Logs."

By DON BURCH

One of the best ways to tie seismic data back to a "ground truth" is through comparison with a sonic log. This comparison is the link between seismic travel time and depth from the well log.

Although this link may seem obvious, there are influences in both data types that may make the tie difficult to make.

This first part of a two-part discussion serves as a guide for the geologist or geophysicist to use when addressing issues with a problematic well to seismic tie in compacted rock environments.

Overview

Let's briefly examine the differences in the way seismic data and sonic logs measure "the same thing."

First, seismic velocities are deduced statistically to provide the best stack of the reflectors in the data. Stacking is done to collapse a volume of measurements into a single vertical reflectivity profile. This may involve the sampling of hundreds of thousands of cubic feet of rock for any one stacked trace.

Due to the large amount of data required to produce any single seismic trace, the statistics are quite robust.

A sonic log, as opposed to seismic, measures velocity more directly. The actual borehole measurement made is interval transit time (reciprocal velocity). All sonic log measurement methods sample a volume very near the well bore, over a short vertical interval and amount to sampling perhaps a few thousand cubic feet of rock for an entire well.

Assuming that the well bore is in good condition and that there are no other known problems with the logging environment, the sonic tool is capable of recording a very accurate interval transit time profile with depth.

Clearly, each of these measurement techniques has sampled very different volumes of rock in order to determine velocity and reflectivity at the same physical location. Therefore, we should not necessarily expect there to be a 1:1 correspondence between all reflectors seen in these two data sets.

Because the well to seismic ties are done mostly after final seismic processing, we will assume that the seismic data are of high quality with no significant AVO effects, and that the velocity profile associated with each trace cannot easily be improved. However, there are several items that need to be addressed with the sonic log velocity profile before we can expect a good tie.

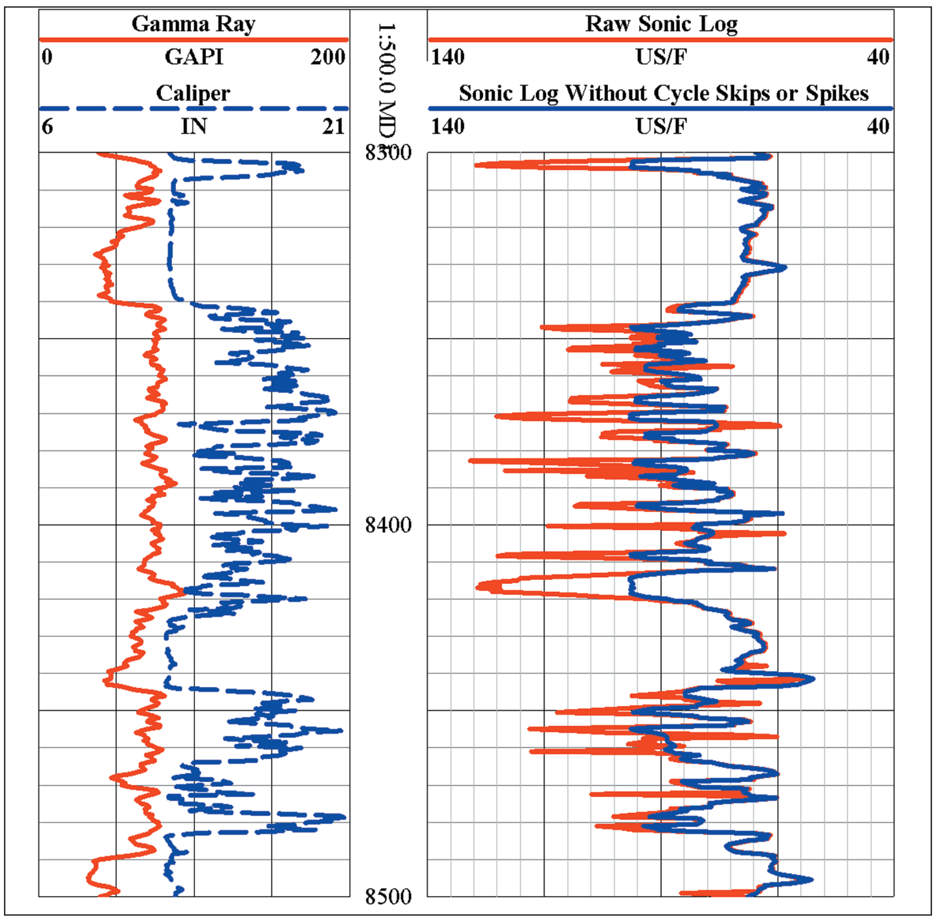

Figure 1 – Comparison of a raw sonic log (red curve, right track) that has problems with cycle skips and noise due to the poor borehole condition, and the same sonic log after replacement (blue curve, right track) of bad data with pseudo sonic data modeled from the conductivity. Note the poor borehole condition as seen on the caliper log (left track).

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What we do not want to do is to stretch and squeeze the synthetic seismogram to force a match with the seismic, as this will litter the sonic log with unreasonable velocity artifacts.

Instead, we need to deterministically edit and calibrate the sonic log, by comparing the sonic log to other wireline data as well as the seismic data.

Sonic Log Problems

It is important to note that using a sonic log to tie to the seismic data is a very sensitive numerical operation.

Because we wish to know the cumulative time from the surface down to any reflector, we need to sum the sonic log in time. By summing, we greatly exaggerate any systematic problems with the sonic log.

With the exception of noise spikes, all of the problems with sonic log data discussed below make the transit time too slow. When combined and summed, these errors can render a sonic log useless.

Raw sonic log problems include:

❒ Cycle skips and noise.

❒ Short logging runs, or gaps in sonic log coverage.

❒ Relative pressure differences between the drilling fluid and the confining stress of the rocks around the wellbore.

❒ Shale alteration (principally clay hydration from the drilling fluid).

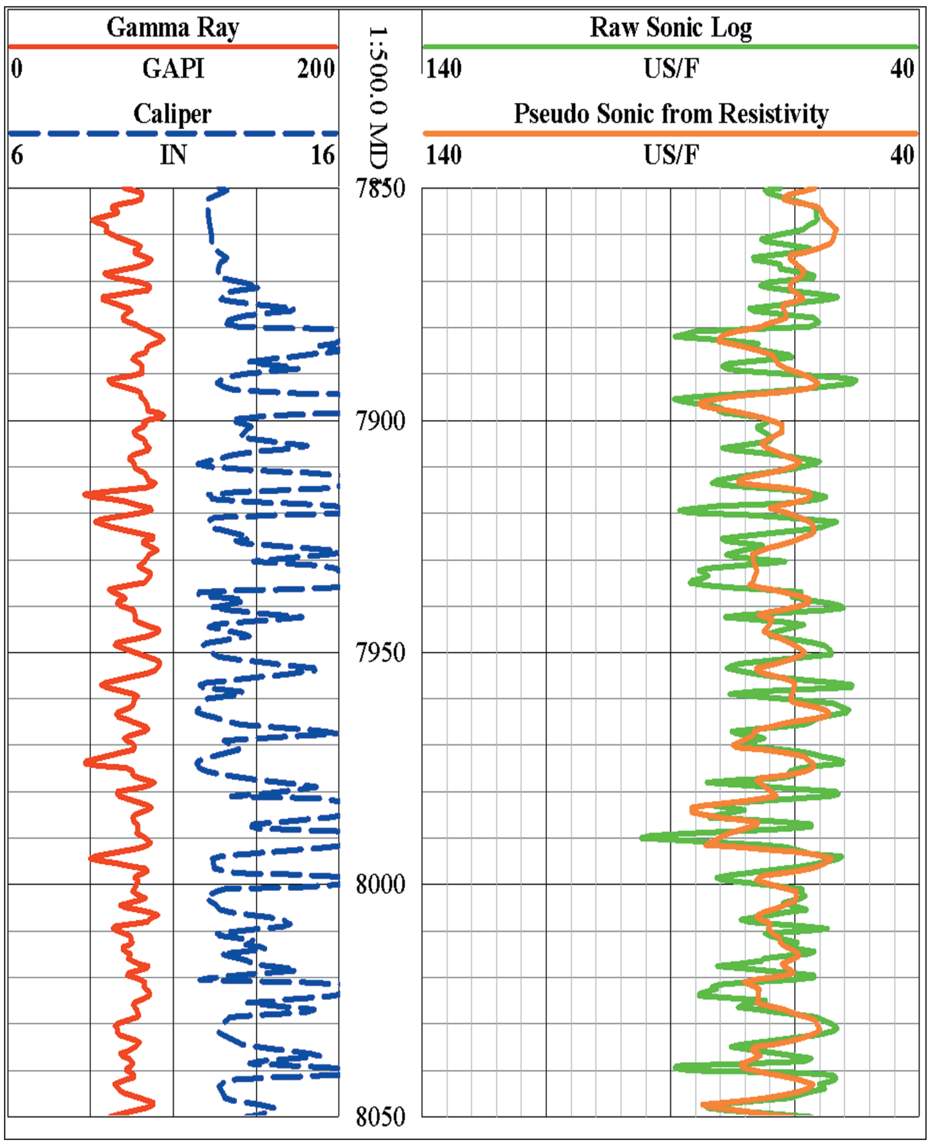

Figure 2 – Depth comparison of raw sonic (green curve) with a pseudo sonic from the conductivity (pink curve). Note the poor borehole condition as seen on the caliper log (in blue).

Specifics

First, in order to be useful, a sonic log must represent actual rock velocities. Spike noise and cycle skips do not represent true rock measurements, and therefore must be removed from the sonic log. Spike noise can be easily removed by "de-spiking."

Cycle skips occur when the sonic tool records an arrival that is not correct (typically one "cycle" in the wave train late). The most common cause of cycle skipping is badly washed out zones. When they represent a significant problem, an intelligent data replacement scheme is required.

Figure 1 (page 26) illustrates a sonic log where the shales are badly washed out, causing frequent cycle skips and some spike noise.

Gaps in sonic log coverage need to be handled smoothly. Often, there are some log data in this gap, just not sonic data. If we can model a pseudo sonic from another curve and then replace the missing sonic data, we will have a well-behaved synthetic seismogram.

If we must model large vertical intervals without real sonic data, we also need to be able to accurately estimate the low frequency component (burial trend) of the earth's velocity profile.

Figure 2 compares actual raw sonic data with a pseudo sonic modeled from the deep resistivity data in an interval where the borehole conditions are not conducive to recording a good sonic log. This pseudo sonic can now be used to replace bad sonic log data or to fill in gaps in sonic coverage where resistivity data exist.

Shale alteration is a problem where the in-situ shales are desiccated. During

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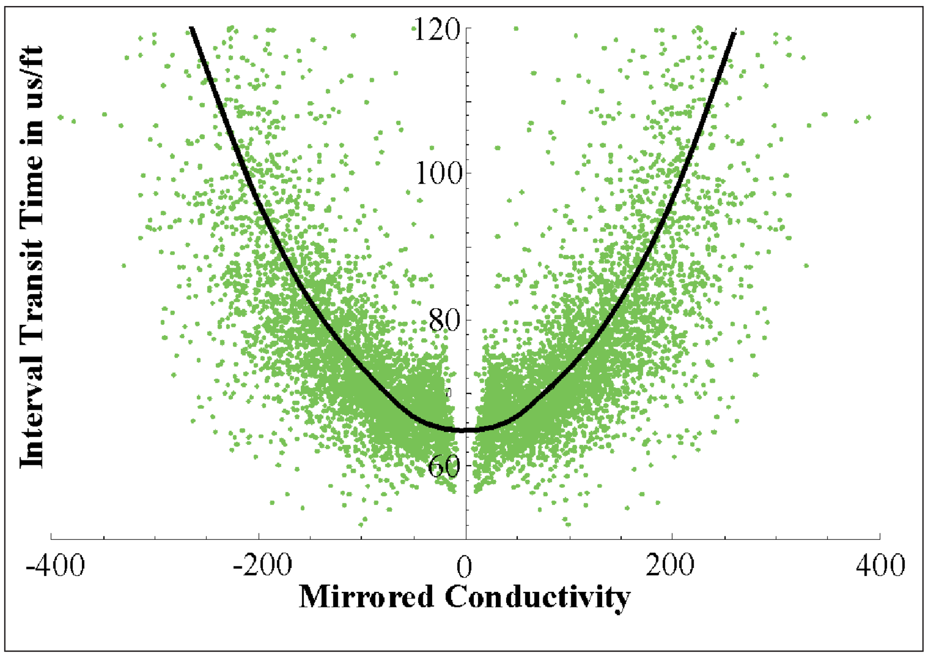

Figure 3 – Relationship between interval transit time and deep conductivity in an invaded shale interval. Note that the data are mirrored for visual clarity. This relationship is used to assess the magnitude of the alteration on apparent sonic log interval transit time.

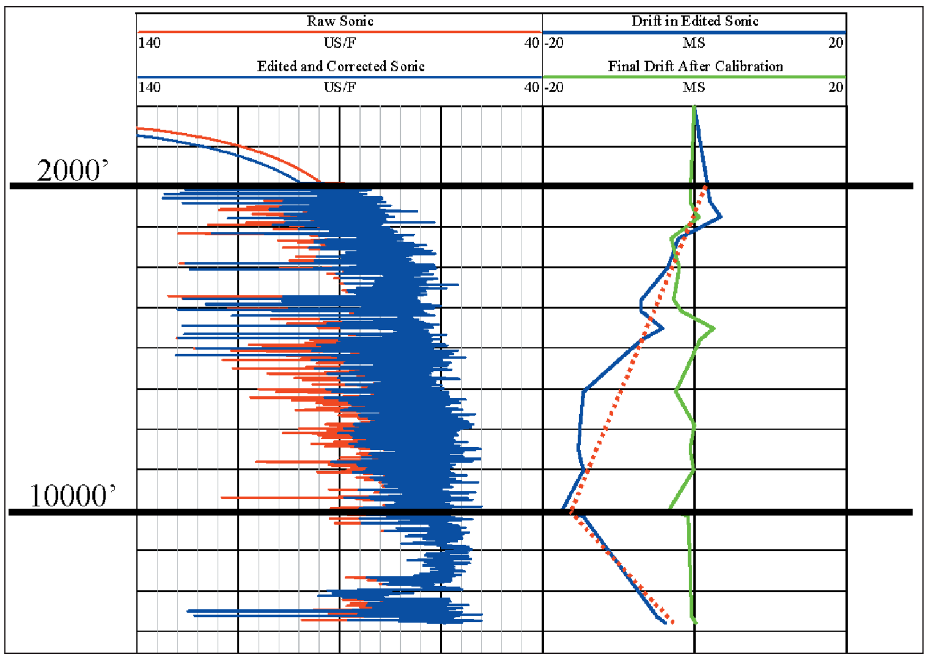

Figure 4 – This plot illustrates the magnitude of changes required of the raw sonic log (red curve in left track) to fully tie to the seismic data (final sonic is blue in left track). The drift between the edited sonic log and seismic data is shown in blue in the right track (scaled from -20 to +20 ms.). The red dotted line indicates that we have two separate calibrations to make. The break in drift slope occurs at a run splice, hence the need to treat separate runs individually. The green curve in the right track shows the final time errors in the tied synthetic seismogram (typically less than 3 ms.).

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the process of drilling, these dry shales are brought into contact with the drilling fluid, which can cause swelling and fracturing of the shales, as well as chemical alteration of the constituent clays.

Figure 3 shows the relationship between interval transit time and deep conductivity. This parabolic trend is used to estimate the magnitude of shale alteration.

Relative pressure differences between the drilling fluid and the confining stress of the rocks around the wellbore will have an effect on the sonic log. Since different logging runs typically use different mud systems, separate sonic log runs will likely need unique velocity calibrations to match the seismic data.

Figure 4 illustrates the difference in the corrections required for different logging runs.

Conclusions

If some or all of the problems described above are present in a well, the likelihood of achieving a quality tie to the seismic data is slim. However, if these issues are addressed in a deterministic way and calibrated to the seismic data, high quality informative ties can be made.

High quality ties can be used for many purposes, including phase determination, relative wavelet extractions, seismic inversions, effective stress calculations, etc.

Next month we'll address solutions to these common sonic log problems with real life data comparing synthetic seismograms from a raw sonic log that exhibits all of the problems listed above to the same log after all of the problems have been corrected. ❏

(Editor's note: Don Burch is special projects geophysicist, AXIS Geophysics, Denver.)

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Sonic Logs Need Troubleshooting

The Geophysical Corner is a regular column in the EXPLORER, edited by R. Randy Ray. This month's column is the second of a two-part series titled "Seismic to Well Ties with Problematic Sonic Logs."

By DON BURCH

In last month's column we discussed the most common deleterious problems with sonic logs, and their effect on seismic ties were outlined. These included:

❒ Cycle skips and noise.

❒ Short logging runs, or gaps in sonic log coverage.

❒ Relative pressure differences between the drilling fluid and the confining stress of the rocks around the wellbore.

❒ Shale alteration (principally clay hydration from the drilling fluid).

This month we cover methods to correct these problems and calibrate the sonic log using the seismic data. Proper handling of sonic log problems can result in high quality informative ties that can be used in a variety of disciplines.

Solutions

Clearly, a key to being able to correct common problems with sonic logs requires the ability to replace questionable data with a reasonable estimate. This is important because if we replace bad data with an estimate that is poor, we may not have done much good with respect to the cumulative error, and may have added false reflectivity.

Other wireline data that have a good relationship to velocity include: density, resistivity, gamma ray and spontaneous potential. Unfortunately:

❒ The density tool has a very low tolerance to poor borehole conditions, and will likely not be useful.

❒ Both the gamma ray and spontaneous potential curves are useful, but they tend to be rather bi-modal in their behavior (either sand or shale), and do not adequately capture the dynamic range of actual rock velocities.

The deep resistivity is neither affected by the near borehole environment (rugosity or invasion), nor is it bi-modal, making it the best candidate for the generation of pseudo sonic data and, in most cases, still has adequate vertical resolution to tie to seismic data.

Low Frequency Compaction Model

The sonic log exhibits a large low frequency component from burial compaction, which must be removed prior to modeling with other log data that do not have this same feature, such as the deep resistivity.

A fast and accurate way to model the low frequency component of a sonic log is to fit a polynomial to the entire curve.

Figure 1 shows a typical sonic log from a continental basin with the fitted polynomial on top. When we subtract this trend from the data, the resulting curve will be referred to as the "high pass sonic."

Check shot surveys, VSPs and seismic stacking velocities transformed to interval velocities also can be used to determine the low frequency velocity trend.

All we need to do to make a full pseudo sonic is to add the reflectivity from our model (based on resistivity or gamma ray data) to our burial trend.

Replacement Scheme

Our goal is to make a curve from the resistivity data that looks just like the high

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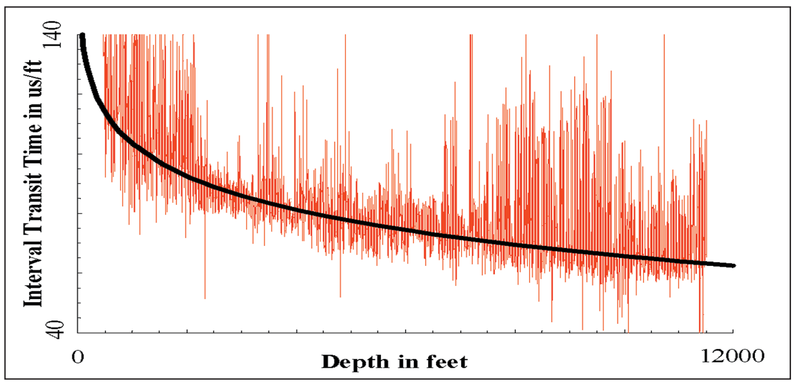

Figure 1(left). Raw sonic log from a continental basin with fitted polynomial showing low frequency burial trend. This trend can also be determined from VSP's, checkshot surveys and seismic stacking velocities.

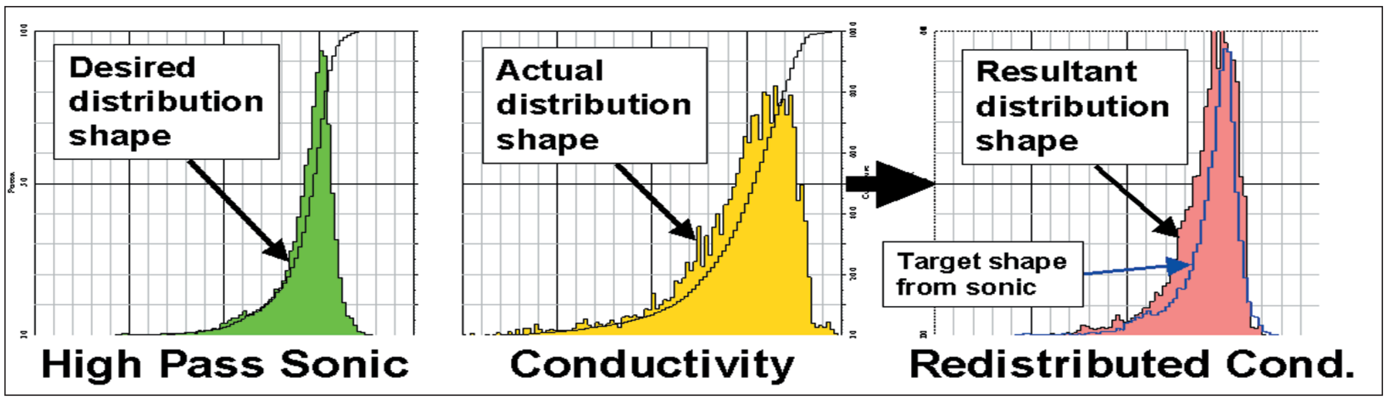

Figure 2 (below). Distribution shapes of the high pass sonic (µs/ft), deep conductivity (mmohs) and redistributed conductivity (µs/ft, now a pseudo sonic). Note, shale is to the left and sand to the right on all histograms.

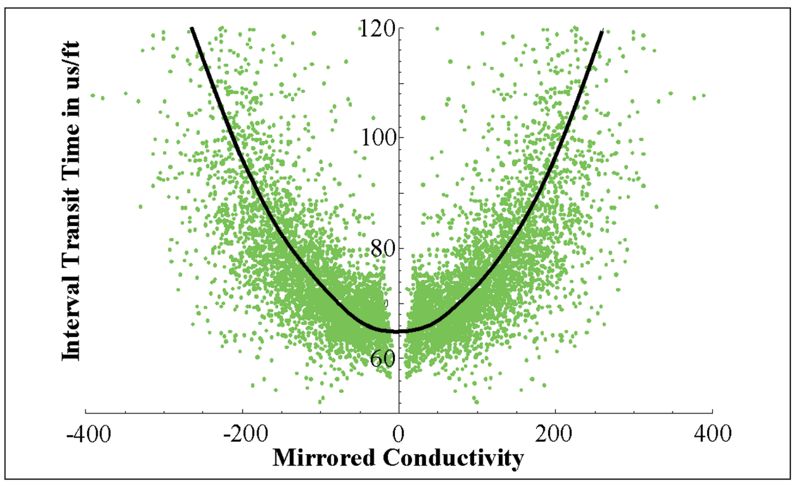

Figure 3 (left). Relationship between interval transit time and deep conductivity in an invaded shale interval. Note that the data are mirrored for visual clarity. To "correct" for the invasion, we remove the parabolic trend and force it to be linear.

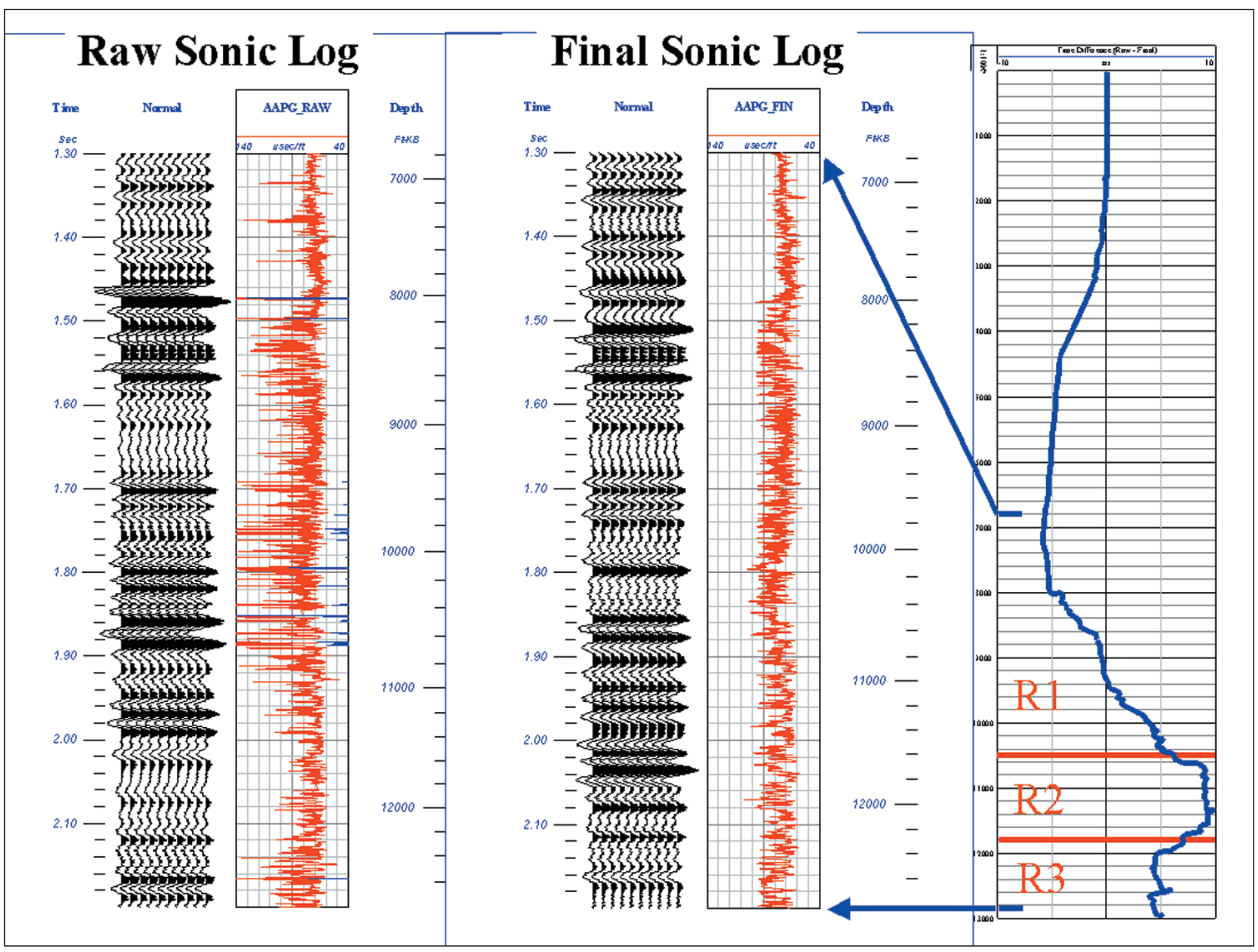

Figure 4 (below). Compare the synthetic seismogram generated from the raw sonic log (left) vs. that made with the final corrected and calibrated sonic log (right). In the far right track, the drift curve shows the difference in two way time between the raw and final sonic logs. Note the changes in required calibration at the logging run junctions, R1, R2 and R3.

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pass sonic.

In most cases, a Faust transform or neural net solution will fail to have the required accuracy for large vertical replacement intervals. When using these techniques, one often finds that far too much transit time is removed from the sonic log, especially in poorly constrained intervals of the model.

Since resistivity data are logarithmically distributed, and our high pass sonic is normally distributed, we must transform from resistivity to conductivity (reciprocal resistivity) before meaningful statistical work can be done. What we wish to do is examine the shape of the histogram of high pass sonic data compared to the shape of the conductivity histogram over the same interval.

Now, we will simply reshape the conductivity histogram to match the high pass sonic. This reshaping forces the asymmetrical shale-sand velocity response of the sonic log onto the conductivity data, thus making a pseudo sonic log. Zoning the well can improve the result, as the model will be forced to accommodate less geologic change (three to five zones should suffice).

Figure 2 shows the results of the redistribution.

Now we add the low frequency component back in (from our polynomial fit to the raw sonic) to obtain a full usable pseudo sonic log – and replacement of poor data now can be done with some confidence.

In compacted rocks, most of the problems described occur commonly in the shales and much less commonly in sands. Because sands have resistivity signatures that are highly dependant on hydrocarbon saturation, replacement of real sonic data in sands using a model based on the resistivity data should be done with care.

In cases where the sonic log is poor in a sandy interval, the gamma ray or spontaneous potential logs may be more suitable choices for modeling.

Shale Alteration

Desiccated shales can imbibe drilling fluid, thus producing an invaded zone. Within this invasion zone mechanical change occurs due to swelling of the shale. This may take the form of elastic swelling, or swelling with some fracturing. Subtle chemical alteration of the clay minerals may also occur. Both of these phenomena cause a reduction in apparent velocities as seen by the sonic tool.

Because it is difficult to directly determine invasion in shales using traditional resistivity analysis, we must try to develop an invasion indicator that we can use to correct the data.

If we cross plot interval transit time (high pass sonic) vs. conductivity in an interval that is believed to be invaded, we see a non-linear relationship (the fitted curve is a parabola).

Figure 3 shows such a cross plot. Note the data have been mirrored about the interval transit time axis for visual clarity.

If we assume that the parabolic behavior is related to an invasion profile (this is a good assumption because ray path bending in a layered media approaches a parabolic function), we can use the fitted parabola to correct the sonic data.

To do this, we simply scale the sonic data toward faster velocities using the fitted parabola. This correction alone can account for as much as 100 ms. of time in a 10,000-foot well. The correction is non-linear, thus its affect on the synthetic seismogram is not easy to predict.

We have found, however, that wells having had this correction applied tie to the seismic better over larger intervals with higher frequency, resulting in higher quality wavelet extractions.

Calibration to the Seismic Data

Now that we have a sonic log that has been treated with deterministic editing and corrections, we are ready to tie it to the seismic data.

Once the sonic log has been placed correctly in time with the seismic data, there are frequently small residual errors in the location of correlative events in time. If we can relate the observed errors to geologic packages and apply corrections only to those large intervals, we will not introduce harmful artifacts into our sonic log.

Figure 4 has raw and final synthetic seismograms from a sonic log that required a lot of data replacement (mostly between 8,000 and 11,000 feet).

Note the dramatically different character in the synthetics. While the raw version bares little resemblance to the seismic data, the final version ties quite nicely over the entire well. The drift curve in the far right track shows the difference in cumulative time between the raw and final corrected sonic logs.

The logging run numbers (R1, R2, R3) at the bottom of the well correspond to clear differences in final velocity calibration to the seismic. Separate runs may need to be treated differently due to tool and mud system changes.

Conclusions

✓ Most sonic logs have problems that need to be addressed prior to tying to seismic data.

✓ Due to the summing of errors in the sonic log, correction schemes need to be robust.

✓ Building a good pseudo sonic log to substitute for poor or missing real sonic data is a must if we do not wish to introduce additional problems through non-deterministic editing.

✓ Shale alteration can be empirically corrected, resulting in a superior tie to the seismic data.

✓ The final calibration to the seismic data through drift analysis compensates for the effects of pressuring the near-wellbore environment with the drilling fluid.

(Editor's note: Don Burch is special projects geophysicist, AXIS Geophysics, Denver.) ❏