Well-tie calculus

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Welcome to the third tutorial in this series. Evan Bianco has put together a terrific look at 1D synthetic seismograms — the critical connections between well data and seismic data that make geologic interpretation possible. Most of us use proprietary software for this part of the workflow, but do you really know what's going on in there? My challenge is: Take a couple of hours, install IPython from ipython.org, and see if you can work your way through Bianco's Notebook at github.com/seg/tutorials — I guarantee you will learn something. If you get stuck, please reach out to him.

If you have an idea for a tutorial, please drop me a line. Better yet, if you would like to write one, read the author guidelines at ageo.co/TLEtutorials.

— *Matt Hall, matt@agilegeoscience.com*
Tutorial coordinator

Synthetic seismograms can be created by doing basic calculus on traveltime functions. Integrating slowness (the reciprocal of velocity) yields a time-depth relationship. Differentiating acoustic impedance (velocity times density) yields a reflectivity function along the borehole. In effect, the integral tells us where a rock interface is positioned in the time domain, whereas the derivative tells us how the seismic wavelet will be scaled.

The code and data required to reproduce the results and figures in this tutorial are in an IPython Notebook at github.com/seg/tutorials. For this tutorial, we will make use of the open-source Python libraries NumPy (for computation niceties) and Matplotlib (for graphics).

As an example, I will use the sonic and density log from the Penobscot L-30 well offshore Nova Scotia, Canada. It has a standard suite of petrophysical logs, but we will make use only of P-wave sonic and bulk density. This vertical well is in the same volume of 3D seismic data that Matt Hall used in his tutorial on horizon smoothing.

Dealing with incomplete, noisy logs

To deal with the shallow section, we first need to adjust the depths relative to sea level by subtracting the KB elevation (30.2 m) from the measured depths.

If we now integrate the sonic log, we see that time = 0 s corresponds to a depth of 347 m TVDSS. To position the top of the log at the correct traveltime on the seismic section, we need to use the thickness and replacement velocities for the water column (137.5 m at 1480 m/s) and the section above the log (179.8 m at 1600 m/s), respectively.

Both the sonic and density curves have some spikes and null values that need to be dealt with. To cope with these, I applied a rolling median filter to identify spikes and then clipped them.

Computing the time-depth relationship

The time-depth relationship is obtained by scaling the sonic log by the sample interval (6 inches, or 0.1524 m), integrating it with `np.cumsum()`, and shifting it to the start time of the sonic log.

```
scaled_sonic = 0.1524 * DT / 1e6
t_int = 2 * np.cumsum(scaled_sonic)
td = t_int + log_start_time
```

As you can see in Figure 1, the time-depth relationship is good down to the Logan Canyon Formation. Beneath that, however, the Lower Missisauga, Abenaki, and mid-Baccaro Formations are mispositioned by a half-cycle or so in the fast direction. We could further adjust the time-depth relationship by stretching and squeezing between anchor points and so on, but that would break the direct equivalency to the measured slowness log. As Newrick (2012) wrote, "With each modification to the synthetic we should think about why we are applying a certain process, what the effect is, and whether it makes sense." For now, we will live with the mistie.

Computing reflection coefficients in time

The P-wave normal-incidence reflection coefficient at a sample i is given by

$$R_i = \frac{Z_{i+1} - Z_i}{Z_{i+1} + Z_i}.$$

This does not have to be computed over and over, iterating over the impedance array in a `for` loop, say. Because we have the acoustic-impedance function stored as a NumPy array, we can slice the array with a one-sample shift to carry out the calculation in a single operation:

```
RC = (Z[1:] - Z[:-1]) / (Z[1:] + Z[:-1])
```

To make a synthetic seismogram, we would like to convolve this reflection-coefficient series with a seismic wavelet. However, seismic is recorded in the time domain, and the convolution operator requires inputs to have the same sample rate, so we must resample the reflection coefficients using our time-depth relationship.

First we define a regularly sampled time vector t that goes from 0 to 3 s with a sample rate of 4 ms:

```
t = np.arange(0, 3, 0.004)
```

Next, to obtain the reflection coefficients as a function of time `RC_t`, we pass three inputs to NumPy's interpolation function: the regularly sampled time axis `t`, the time-to-depth relationship `td`, and the depth-domain reflectivity series `RC`:

```
RC_t = np.interp(t, td[:-1], RC)
```

The synthetic seismic experiment

We need a wavelet. In the IPython Notebook, you can see how to create a Ricker wavelet `w` with a dominant frequency of 25 Hz and convolve that with the reflection-coefficient series:

```
synthetic = np.convolve(w, RC_t, \
 mode='same')
```

We chose this Ricker wavelet because 25 Hz sits more or less in the middle of the seismic band (not shown in Figure 1) within the interval encountered by the well log. Furthermore, the water-bottom reflection is a peak (black) with symmetric side lobes, which indicates that the data are normal polarity and close to zero phase.

To view the tie, we plot the synthetic as a wiggle trace on the real seismic amplitudes.

Final thoughts

If you find yourself stretching or squeezing a time-depth relationship to make synthetic events align better with seismic events, take the time to compute the implied corrections to the well logs. Differentiate the new time-depth curve. How much have the interval velocities changed? Are the rock properties still reasonable? Synthetic seismograms should adhere to the simple laws of calculus — and not imply unphysical versions of the earth.

Reference

Newrick, R., 2012, Well tie perfection, *in* M. Hall and E. Bianco, eds., 52 things you should know about geophysics: Agile Libre, 104–107.

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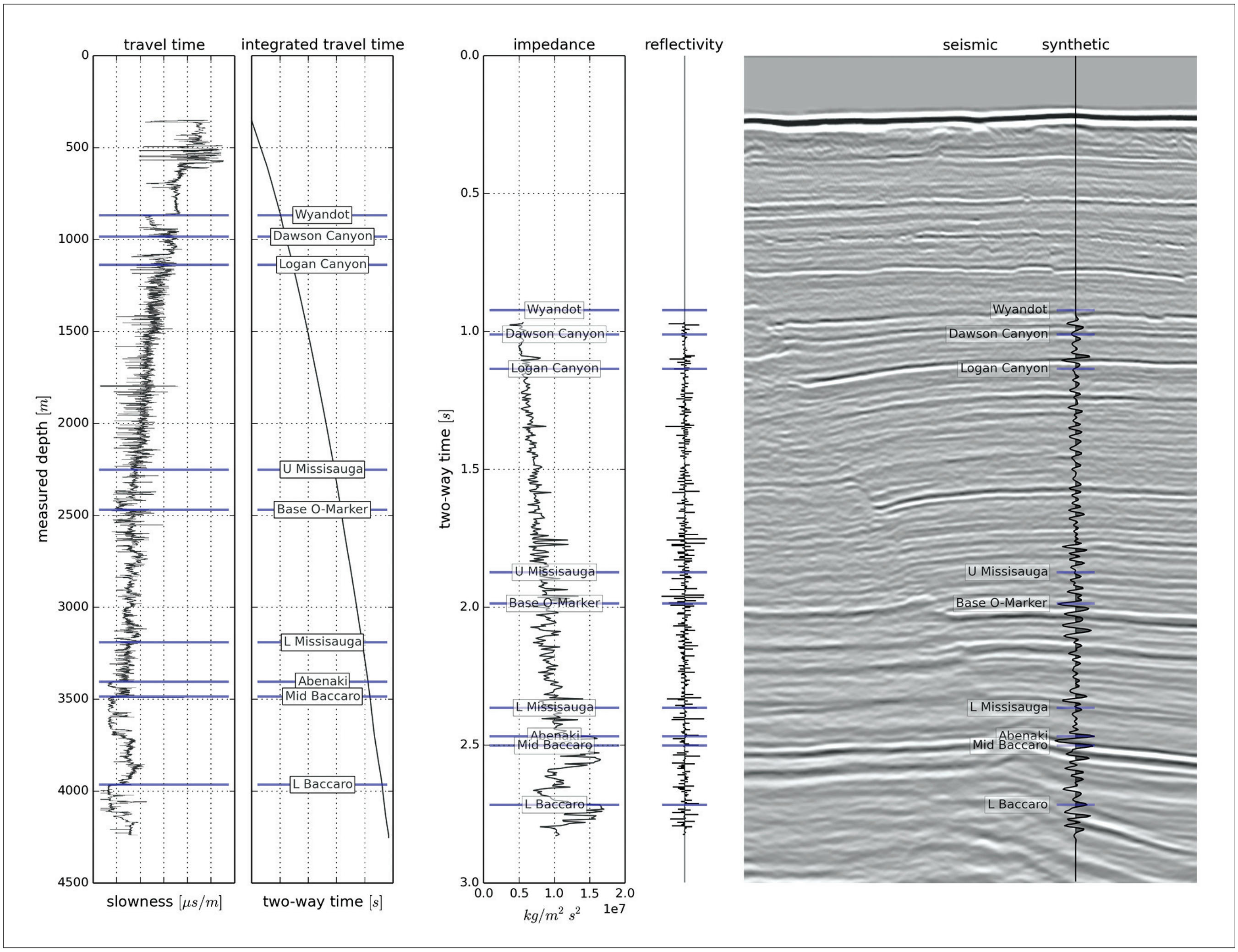

Figure 1. When P-wave traveltime from a sonic log is scaled appropriately, the cumulative sum (integral) of slowness gives the two-way time-to-depth relationship. The stepwise differencing (derivative) of impedance, per the reflectivity equation, gives the reflectivity function used to create the synthetic seismogram for the well tie. Positive amplitudes (peaks) are black on the seismic.

This article has been cited by:

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