an excerpt from

52 THINGS YOU SHOULD KNOW ABOUT GEOPHYSICS

EDITED BY MATT HALL & EVAN BIANCO

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Colophon

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Well tie basics

Rachel Newrick

Borehole measurements such as gamma ray, resistivity, sonic and density logs, rock cuttings, core samples, casing points, and biostratigraphic results are all recorded in depth. Conversely, seismic measurements and our interpretations are inherently in seismic travel time.

To convert borehole measurements from depth to time, or to convert the seismic interpretation from time to depth, a time–depth relationship needs to be established. We can use one of many techniques including velocities derived from seismic, a checkshot or VSP, a sonic log, or a combination of any of these. We confirm the time–depth relationship at the borehole location by generating a synthetic seismogram.

To make a synthetic seismogram we need to:

1. Generate a reflectivity series.
2. Apply a time–depth relationship.
3. Convolve with a wavelet and compare to the seismic data.

If the synthetic seismogram is a good match to the seismic we can say that the time–depth relationship is robust, and that the borehole data are located accurately on the seismic section and can be confidently extrapolated outwards.

Generating a reflectivity series

Reflectivity is generated by changes of impedance $I = \rho V_{\mathrm{P}}$ within the earth. Since impedance is the product of velocity (V_{P}) and density (ρ) we can generate a reflectivity series directly from the slowness (DT) and bulk density (RHOB) curves. A full suite of quality velocity and density logs is not always available, so pseudo-curves can be estimated using established relationships like Faust or Gardner, as discussed in *Well tie perfection*.

Estimating the time–depth relationship

We use all the information available to us to generate the time–depth relationship — remember, it is all about the time–depth relationship. Commonly, we start by integrating the sonic log to estimate time–depth pairs, that is, we sum up all the measurements to get a total travel time to each depth in the bore-

A full suite of quality velocity and density logs is not always available so pseudo-curves can be estimated using established relationships like Faust or Gardner.

hole. Because sonic velocities are not the same as seismic velocities, due to the phenomenon called dispersion, and because there are often gaps and spurious measurements in the sonic log, the integrated sonic velocities often leave an incomplete record that provides a poor tie. We can calibrate the sonic velocities with a checkshot survey.

The checkshot survey is a measurement of seismic travel time at a range of depths in the borehole, at least at key stratigraphic boundaries and total depth. With checkshot data, we are saying, in effect, that we know how long it takes for seismic energy to travel to this depth. So the time–depth relationship must include these points.

In a marine setting, another time–depth point is the time and depth of the seabed reflection. The seabed time can be read from seismic and the seabed depth is recorded in the well file.

Pulling it together

We convolve the reflectivity series with a wavelet to give the appearance of the seismic. Using the estimated time–depth relationship, the synthetic seismogram can be compared directly to the seismic. If there is a good set of logs, a wavelet that approximates that of the seismic section, and a good time–depth relationship we should have a good tie between the seismic and the borehole. The synthetic will be a 'good match' to the seismic, with similar frequency content, high amplitudes in the same place, transparent zones in the seismic matched by little reflectivity in the synthetic seismogram, and not much dispute from anyone who looks at the tie.

Often we are not so fortunate. I outline some ways to deal with poor ties in *Well tie perfection*.

Well tie perfection

Rachel Newrick

The beauty of modern well-tie software is that it is easy to pull in a few curves, to add some pin points and to move the synthetic to match the seismic, stretch a bit of the top, perhaps squeeze a bit of the base. So let's think about what we are actually doing when we apply these processes.

Bulk shifting

Often the entire synthetic appears to be too shallow or too deep. There is likely a discrepancy in the datum or the replacement velocity used to anchor the uppermost point of the synthetic. In this case it is valid to apply a bulk shift but always check the datum and review the interval velocities in the near surface to make sure that they are reasonable.

Stretch and squeeze

In my experience this is the most contentious part of the well-tie process because it is easy to abuse. This is not a procedure by which you simply select peaks and troughs and match them to the seismic. You can make anything tie that way.

The idea is that a distinctive reflector on the seismic section is also observed on the synthetic (and is thus observable on the borehole logs) and there is a certainty that it represents the same event. If the event is identified in the borehole as a specific unconformity that has been correlated from other wells on the seismic, so much the better.

There is well-documented dispersion between sonic and seismic velocities. Dispersion is the phenomenon of frequency dependence of acoustic velocity in the rock. We usually need to make a correction for this by reducing the sonic velocities by a small amount. This is most easily undertaken by stretching the synthetic seismogram so that the depth extent occurs over more time. All geophysicists have their own thoughts on the procedure, but I like to first slightly stretch the entire synthetic so that, in effect, a single drift correction is applied and the major reflectors are correlated.

That said, there might be a significant change of lithology (e.g. clastic to carbonate) so a single drift correction may not apply. In this case, you might need to insert some intermediate knee points.

Great match

At this point, it is good to remember that the end game is to correctly place the depth data onto the seismic section so that we can extrapolate away from the borehole or drill a prospect, for example. It is important not just to know where we are in the borehole but to be honest about how certain we are about where we are in the borehole.

Think about what you are doing

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. Anderson and Newrick (2008) highlighted what can and does go wrong with synthetic seismograms and I add to that here:

- Quality check the logs with the help of a petrophysicist. If adequate velocity and density curves are not available, then substitute computed curves when necessary, but be clear about what you did. There are many ways to model missing data (e.g. Gardner, Faust, Smith) so ensure that the one you choose is appropriate for the geological setting. Present a series of synthetics to illustrate the substitution (i.e. the raw curves with gaps; more complete pseudo-curves) indicating where the real data are and where the computed data are.
- Acquire VSPs for a detailed time–depth relationship. This will provide both a corridor stack to match to the seismic and synthetic, and a time–depth relationship. To extract checkshots, select some key impedance boundaries and use those time–depth pairs.
- Check that the interval velocities are reasonable for the expected strata in the borehole, and if they are not, find out why. It could equally be a data problem or interesting geological information.
- Always make a few synthetics with a variety of edited curves, different wavelets, and even different seismic volumes, such as full, near, mid, and far stacks.
- Remember that a poor synthetic tie is not always caused by poor synthetic inputs — the seismic data may not be optimally processed or correctly positioned due to many reasons, including strong velocity variations, anisotropy, or complex structure.
- When the tie just doesn't seem to work consider the amplitudes and zones of interest, i.e. the dim zone generally ties to the low amplitude zone on the synthetic, but in this case be honest about how good the tie is.

References

Anderson, P, and R Newrick (2008). Strange but true stories of synthetic seismograms. CSEG *Recorder* **33** (10), 51. Available online at *ageo.co/HZdznN*.