[GC]Seismic/Geology Links Critical*

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General Statement

Seismic data today, particularly 3-D, contain a great amount of information and can yield maps of considerable accuracy. All seismic information, however, is relative, so to give it the greatest possible accuracy we must calibrate it to the local geology.

Since seismic data respond to the acoustic properties of rocks, the geology needs to be expressed in some comparable form. Thus sonic (acoustic) logs and density logs from wells have become the established form of subsurface information used for making seismic ties.

In this article, we shall review the traditional technique for tying well logs - and thus the rocks penetrated by the well - to seismic data.

Tying Well Logs to Seismic Data

Assuming we have both a sonic log (A) and a density log (B), they are multiplied together point-by-point to give an acoustic impedance log (C, Figure 1). This is converted from depth to time using some velocity function. By subtracting one acoustic impedance value from another progressively down the log, now in time, we obtain acoustic impedance contrasts, which are a direct expression of seismic reflectivity (D). This is a series of spikes, which implies a very high frequency content; this is, of course, what we expect, because the information came directly from well logs measured down a borehole only centimeters from the rock under study.

Seismic data have a lower frequency content because the energy has traveled from the surface and back again. Because of this lower frequency content, the seismic energy pulse is rather broad. Some estimate of the shape of this pulse, or wavelet, is then made, and each spike on the reflectivity log is given this broader shape (E).

The superimposition of the resulting many wavelets provides the synthetic seismic trace, or synthetic seismogram (F). This is compared to the real seismic trace at the well location and a match is made.

Because of velocity error, some relative sliding up and down may be necessary to help the match. In this way we transfer some geological identity onto the seismic section. Although this is a time-honored approach, the similarity between the synthetic seismogram and the seismic trace is often poor - leaving considerable uncertainty as to how to make the match. The causes of these dissimilarities and difficulties are not simple and may include the information given below.

The tying of well and seismic data is overall an immensely complicated business - we have often over simplified it. The more detailed our seismic interpretations become (using 3-D and other modern technologies) and the more we seek stratigraphic and reservoir information, the greater is the need for an accurate link between seismic and geology.

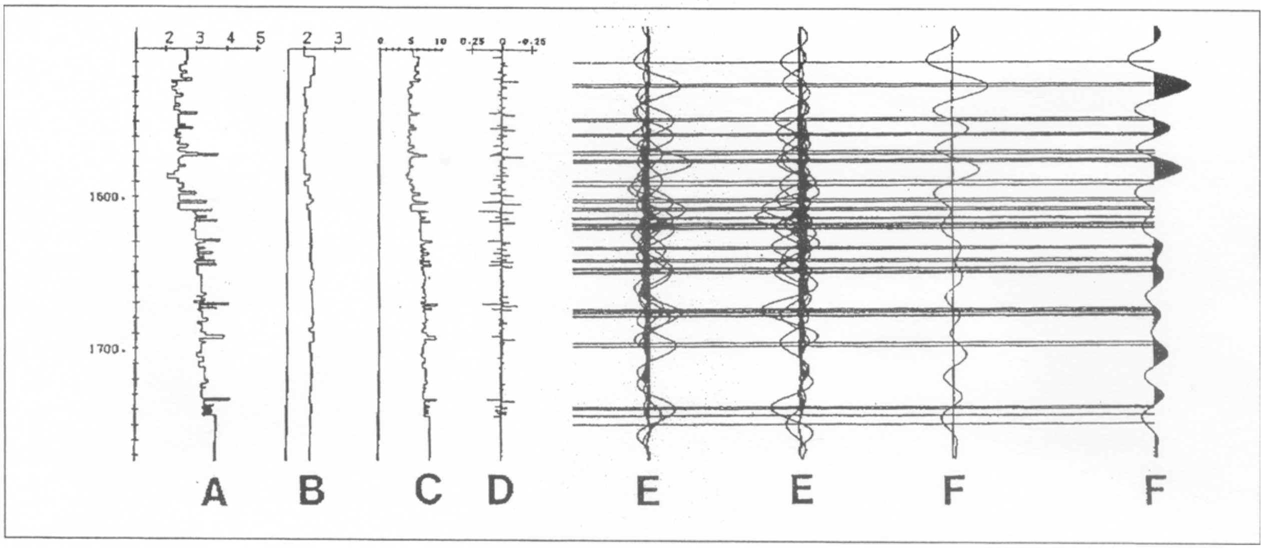

Figure 1. Well log data to synthetic seismic seismogram. A. Sonic log. B. Density log. C. Acoustic impedance log. D. Log of seismic reflectivity. E. Broader shape of seismic energy pulse, derived from reflectivity log. F. Synthetic seismogram.

Causes of Dissimilarities

1. The seismic wavelet used to construct the synthetic seismogram may be wrong - it needs to be close to the same as the actual wavelet in seismic data in:

Polarity.
Phase.
Frequency content.

Synthetic seismograms are commonly made with both polarities so that polarity errors should be recognized - but with a poor match, an all too common event, they may not be. Experiments with different frequency contents are commonly conducted to help the character match. However, we often do not properly consider phase. We assume the data is zero phase - and perhaps it is not. A zero phase (symmetrical) wavelet was used in the step D to E in Figure 1. This is what we always hope to be the correct wavelet.

2. Well logging errors and variable borehole conditions (washouts, mud cake, etc.) may mean that the logs are not measuring the properties of the unaltered rock away from the borehole as intended.

3. Seismic data and well log data measure the properties of very different sized rock volumes because of their different resolution. A single well log value will be measuring the property of about 10 m^3 of rock. A single seismic value will be measuring the property of about 100,000 m^3 of rock.

4. There may be significant positioning errors of either the well or the seismic data. Surveying on land, navigation at sea, and well deviation are all subject to error. Many old wells have been found to be seriously mislocated.

All this, of course, affects which seismic trace should be used for the well tying exercise.

5. Amplitude-Variation-with-Offset (AVO) effects in the data before stacking may mean that the stacked output trace which we are trying to tie has amplitudes that are fundamentally wrong.

Comments

1. In addition to questioning polarity and frequency content, we should think critically about data phase. We should not necessarily believe the data phase is what it is supposed to be, but rather we should analyze the phase to our own satisfaction. This can be done analytically or interpretively - and different people prefer different approaches.

Knowledge of the data phase tells us the wavelet we should use in constructing the synthetic seismograms. Several common wavelets are shown in Figure 2. They are obviously very different, so using the right one clearly has a major impact on the character match. In fact, because of the all-too-common problems of data phase, instead of using a synthetic seismogram, one can use a general understanding of the geology or a time-converted well log directly on top of the data. In this way, it is possible to visualize the shape of the wavelet needed to link the two together.

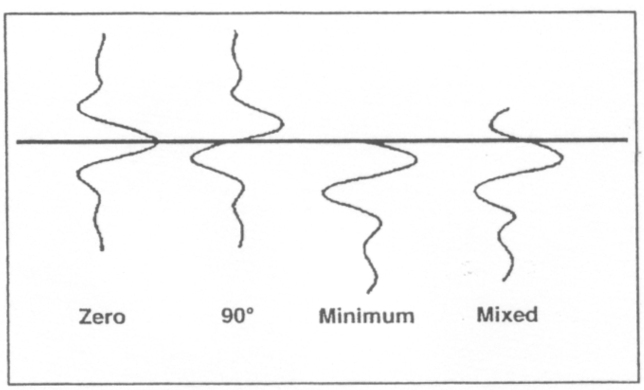

Figure 2. Common wavelets.

2. We should try to use modern well logs recorded with long-spaced tools, and we should be cognizant of the borehole conditions.

3. The difference in resolution between seismic data and well data follows from the fundamental laws of physics and thus is not under our control.

4. We should question the location of each well with respect to the seismic grid. I know of mislocations by as much as 700m. Even for modern, accurate well and seismic data there is some positional uncertainty, and we should consider incorporating into our tying methodology uncertainties in the range of 30m to 100m.

5. AVO effects cannot be comprehended for normal stacked data. In the future more well tying will be conducted using unstacked traces of different shot-to-receiver offsets and the synthetic equivalent, constructed using both normal sonic logs and shear wave sonic logs.