

# <sup>GC</sup>Understanding Seismic Amplitudes\*

By  
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## General Statement

Seismic interpretation is fundamentally based on interpreting changes in amplitude. The changing amplitude values that define the seismic trace are typically explained using the convolutional model. This model states that trace amplitudes have three controlling factors:

- The reflection coefficient (RC) series (geology).
- The seismic wavelet.
- The wavelet's interactions through convolution.

Large impedance (velocity x density) contrasts at geologic boundaries will generally have higher amplitudes on the seismic trace. Interpreters associate changes in seismic amplitudes with changes in the geology; this is a good assumption only if all of the factors that affect trace amplitudes have been considered.

This article is intended to provide the interpreter with a checklist of the factors that should be considered when associating amplitude changes on the seismic trace with changes in geology. First, it presents the major effects that interpreters need to understand about seismic acquisition, where the wavelet is generated and the field trace recorded, and the interaction of the wavelet with the geology. Of 21-listed factors that affect seismic amplitudes through seismic acquisition and the earth, five are most important. One of the primary goals of seismic processing is to compensate for curved ray spherical divergence, which is one of the five factors. The other four factors before processing remain in the seismic data, as they are not normally corrected in seismic processing.

Second, this article discusses the factors affecting amplitudes in seismic processing and interpreter controls on the workstation (loading, processing, and display). When all these factors have been considered, then the changes in amplitudes can be more reliably related to changes in geology.

## Factors Affecting Amplitude Before Seismic Processing

Factors that affect amplitudes, before seismic processing, are illustrated in Figures 1 and 2. A checklist of 21 factors, along with brief comments describing the factors and an estimated magnitude of the effect, comprises Table 1. The magnitude of most of these can only be estimated, and removing their effects to obtain absolutely true amplitudes is impossible. Fortunately, relative changes in amplitude have been shown to be adequate and have been

successfully applied for reducing risk, such as direct hydrocarbon indicators, estimating lithofacies, etc.

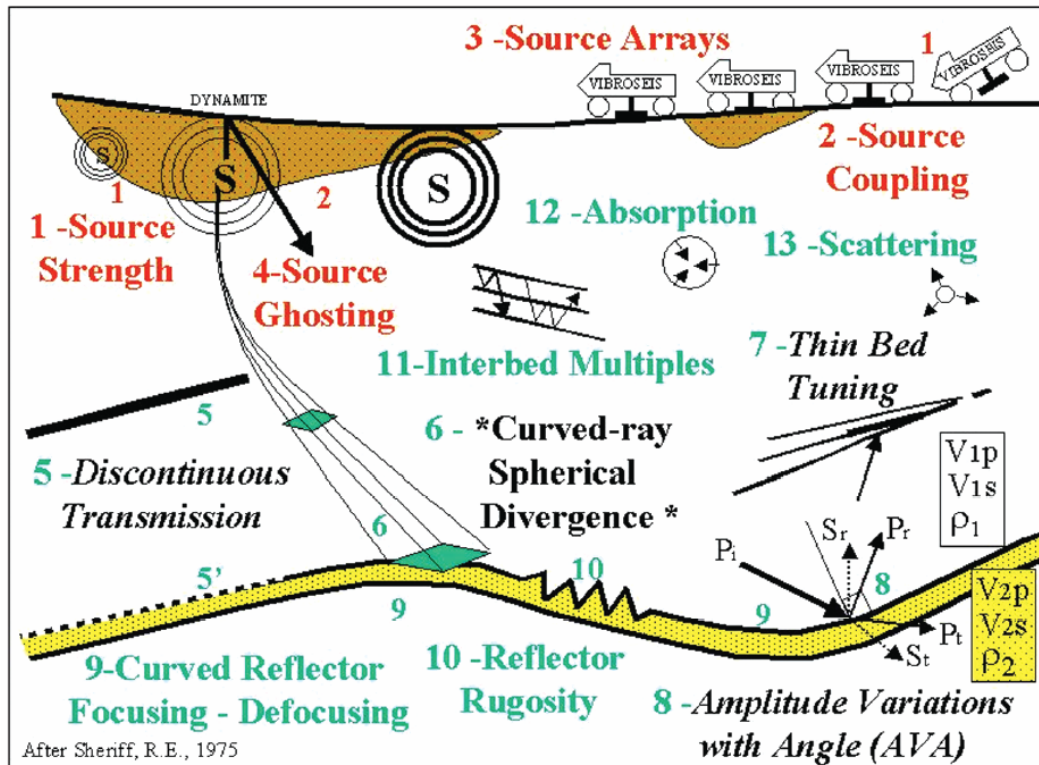


Figure 1. Factors affecting amplitudes are shown in red for the sources, and cyan for those in the earth. Numbers refer to Table 1, where bold lettering (F5-F8) indicates increased importance.

Although only the moderate and major effects are discussed here, it is important to keep in mind how the amplitudes are being used in the interpretation. If a well is being proposed based solely on an amplitude anomaly, even a minor to moderate effect would need to be examined, as it could have a significant impact.

The five factors that have a big effect on amplitudes during the acquisition of field data are shown in black lettering in Figures 1 and 2. The most important of these factors is the loss of energy due to curved-ray spherical divergence (**F6**). This effect on amplitudes is often approximated by the inverse square of distance, which for constant velocity is the inverse square of time. This factor is smaller for reflectors that are separated by less time, and minor for most lateral changes. For the real, non-constant velocity earth, this effect is greater ( $1/v^2t$ ) but still inadequate for recovering true amplitudes of deep reflectors.

Laterally discontinuous (**F5**) high impedance geologic features can greatly reduce the amount of energy transmitted to the underlying geology. This reduces the amplitude of otherwise high amplitude reflectors beneath and over a lateral distance of half a spread length off the sides of the anomaly. In extreme cases (e.g. salt, volcanics), the amplitudes of underlying reflectors can be reduced to below the noise level and disappear from the data.

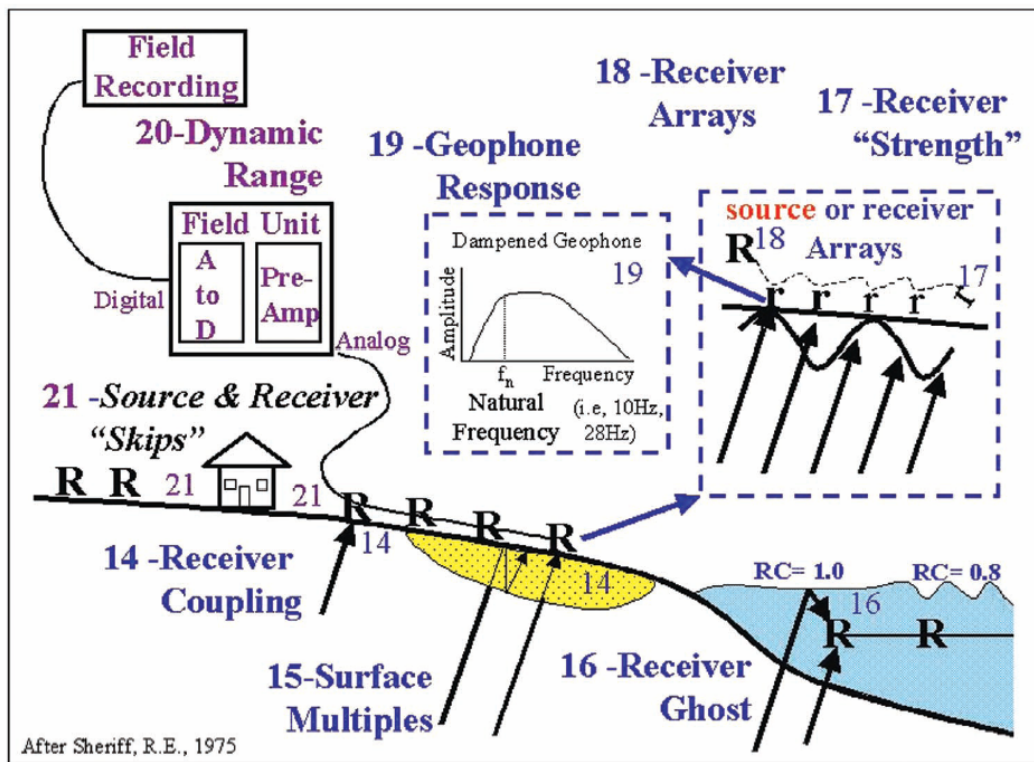


Figure 2. Factors affecting amplitudes are shown in blue for the receivers and violet for the recording systems. Numbers refer to [Table 1](#), where bold lettering (F21) indicates increased importance.

Factors	Comments:	Magnitude
<b>Seismic Acquisition (Source)</b>		
F1) Source Strength	Size of dynamite, number of working vibrators, number of sweeps, etc.	Moderate
F2) Source Coupling	Source in dry sand, weathering (poor coupling), bedrock, wet soil (good)	Moderate
F3) Source Arrays	Designed to attenuate noise but also attenuates dipping primaries	Minor
F4) Souce Ghost	Reflected signature with opposite sign at free surface	Minor
<b>The Earth</b>		
F5) Discontinuous Trans	When RC large enough (Volcanics, Salt) underlying events not visible	<b>Mod-Major</b>
F6) Curved Ray	Spherical spreading of energy is the <b>MAJOR</b> effect, <b>factor of 10</b> or more	<b>MAJOR</b>
F7) Tuning	Tuning can be major, up to <b>factor of 2</b> , at pinchouts can be down to zero	<b>Mod-Major</b>
F8) AVA	AVA gas effects can be up to a <b>factor of 5</b>	<b>Mod-Major</b>
F9) Curved Reflectors	Focusing and defocused - minor, exceptions include salt lens - mod-major	Minor
F10) Rugosity	At seismic wavelengths most geologic surfaces are "mirror" smooth	Minor
F11) Interbed Multiples	If RC contrasts are high then can be moderate problem, generally minor	Minor
F12) Absorption	Loss of energy to heat, weighted towards high frequencies	Minor
F13) Scattering	Loss of energy due to specular reflections, weighted towards high frequency	Minor
<b>Seismic Acquisition (Receiver)</b>		
F14) Receiver Coupling	Geophones dampened on dry soil, buried or wet soil couples well	Moderate
F15) Surface Multiples	Negative RC at surface, then positive at base weathering	Minor
F16) Receiver Ghost	Reflected RC with opposite sign at free surface, changing surface RC	Minor
F17) Receiver Strength	Poorly placed geophones, partial loss of array	Minor
F18) Receiver Arrays	Designed to attenuate noise but will also attenuate dipping primaries	Minor
F19) Geophone	Response is a filter that reduces amplitudes	Minor
F20) Dynamic Range	Pre-1990 with limited 12-15 bit recorders / filters Moderate, now Minor	Minor
F21) S&R "Skips"	Missing ground positions / offsets, effects # traces and frequency content	<b>Mod-Major</b>

Table 1. Checklist of factors that affect amplitudes before processing. Factors in bold are more important.

Tuning (**F7**) occurs when the separation between RC creates constructive or destructive interference of the wavelet's center and side lobes. This interference can increase or decrease amplitudes and is most evident in areas of geologic thinning such as angular unconformities or stratigraphic pinch-outs. The magnitude of this effect can be major, but normally it does not exceed a factor of 1.5 as determined by the size of the side lobes.

Amplitude variations with angle (AVA or AVO) relate relative amplitude changes (**F8**) in pre-stacked data to combined rock and pore-space fluid properties. This effect can be large for some gas effects. The appearance of this offset-dependent variation will be much less apparent on the stacked trace that contains the summation of all offsets. Overall on the final stack, AVA effects are in the range of a factor of 2-5 compared to no AVA.

The placement of sources and receivers on the surface of the earth is not always uniform, resulting in missing ground positions (**F21**) that can have a moderate to major effect on amplitudes. Often, buildings, platforms, lakes, rivers, etc., must be avoided; stations are skipped; and traces will be missing from the stacking bin. This reduces the ability of stack to reduce random noise -- but the greater effect is a frequency unbalancing.

### **Factors Affecting Amplitudes Arising in Processing and Interpretation**

In addition to the 21 factors that could affect seismic amplitudes through seismic acquisition and the earth, 14 other additional factors, listed here (Table 2), arise in seismic processing and interpretation. Again, only the major factors are discussed; unfortunately, any of the factors could be important in interpreting amplitude changes as changes in geology.

It is good practice for interpreters to inform seismic processors (good processors appreciate this) how they will use the data in interpretation (i.e., structural, stratigraphic, AVA, etc.). Processors will appreciate your insights because they will be using tens of processing programs containing hundreds of parameters. Many of the programs and parameters alter seismic amplitudes.

Table 2 summarizes the most important of these amplitude-altering processing steps. You can use this table in amplitude discussions with your processor.

In order to assist in the understanding of workstation amplitudes, the processing of a pair of seismic traces is reviewed. Both the wavelet shape and amplitude from the top of high impedance sands are followed from the raw field traces to their final processed form. To begin this journey, consider a simplified earth in which thick (200m) sands reside in a shale-dominated section (Figure 3). Two of the sand units are flat (sands 1 and 2), and the third is dipping at 15 degrees (sand 3). The normal incidence reflection coefficients for the top of all of the sand units are identical. Ideally, workstation amplitude for these sands would also be identical.

<b>Factors</b>	<b>Comments:</b>	<b>Magnitude</b>
<b>Seismic Processing</b>		
F22) Mute	Within Mute (0-2 sec) number of traces / offsets decrease but compensated	Minor
F23) Amplitude	No "True Amplitudes," Windowed approaches only good for structure	Major
F24) Deconvolution	Minimum Phase assumption incorrect, Designature approaches best	Major
F25) Noise Reduction	Filtering (time varying and spatial dip), multiple attenuation, and many more	Min-Mod
F26) Velocity Analysis	NMO velocity is the primary control on amplitude alignment for stacking	Minor
F27) Normal Moveout	NMO is a time dependent but smooth upward stretching of amplitudes	Minor
F28) Statics / Datum	Corrections are bulk (up or down) time shifts with no amplitude change	Minor
F29) STACK	Summing of traces in CDP or Bin, Amplitudes highly dependent on F26	MAJOR
F30) Deconvolution	Post-stack decon is usually gapped to increase high frequencies, resolution	Moderate
F31a) Noise Reduction	1D Filtering removes "noise," but is generally smoothly varying	Moderate
F31b) Noise Reduction	2D Filtering removes "dips," but can be laterally abrupt	Moderate
F31c) Noise Reduction	F-X Deconvolution removes "unwanted amplitudes"	Min-Mod
F32a) Migration	2D Migration moves dipping reflectors (amplitudes) to "proper" inline position	Min-Major
F32b) Migration	3D Migration moves dipping reflectors (amplitudes) to 3D volume positions	Min-Major
F33) Phase Correction	2D and 3D often require conversion to zero phase	Min-Major
<b>Seismic Interpretation</b>		
F34) Data Loading	Clip level determines max amplitude, squares off peaks and troughs	Min-Major
F35) User Settings	Workstation filters, gains, trace processing, phase adjustments, etc.	Major
F36) KNOWLEDGE	Color bars, attributes, voxels displays all help to find amplitude anomalies, but Users must understand amplitudes to successfully predict geology.	MAJOR

**Table 2. Checklist of factors, in processing and interpretation, affecting amplitudes. Factors in bold lettering are more important.**

Figure 4 shows the wavelets from the top of these thick sands as seen through successive stages of seismic processing. Reading from left to right, first observe the zero-offset, raw field trace before processing. Then notice the changes in the seismic amplitudes due to an idealized processing sequence of:

- Curved-ray, spherical-divergence correction.
- Minimum-phase deconvolution.
- Normal moveout (NMO) correction and stack.
- Migration.

After-migration amplitude values (shown in red) should ideally be identical for all the top sand reflectors. The only amplitudes that are identical are the two from the flat sand 1. The deeper flat sand visible on Trace 1 should have the same amplitude value as the shallower reflector; unfortunately, spherical-divergence correction programs (**F23**) typically under-correct deep amplitudes.



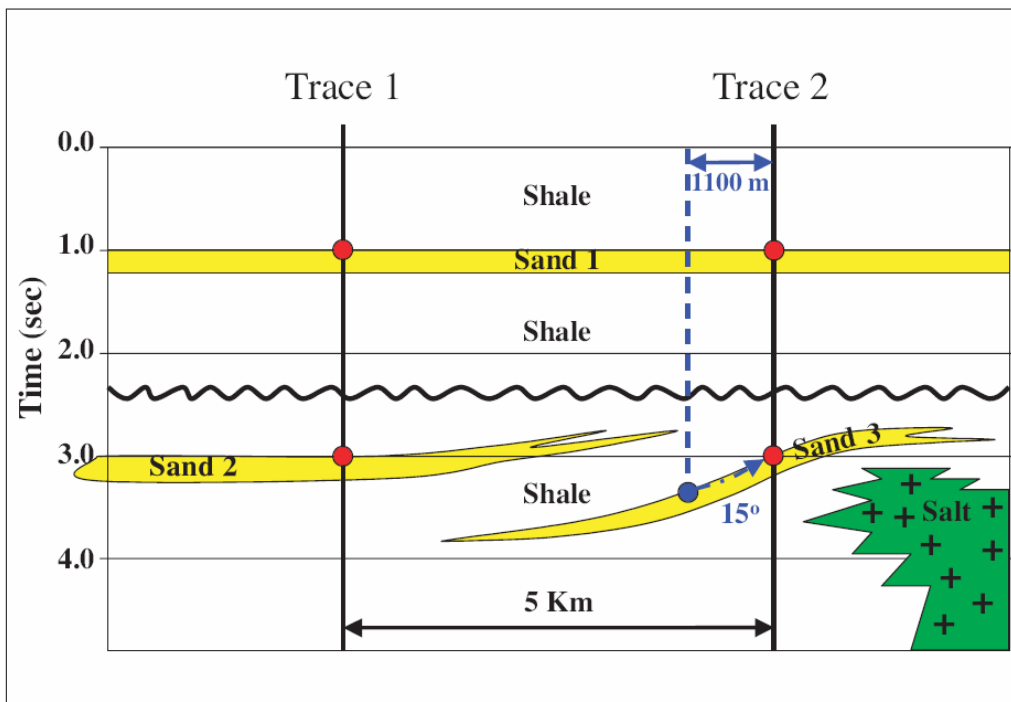


Figure 3. Illustrative earth model. Reflection coefficients for sands are identical. Red dots are where the amplitudes have been calculated in Figure 4. Blue dot is position of amplitude for dipping Sand 3 before seismic migration moved amplitude 1100 m laterally and 275 m (200 ms) vertically updip ( $V_{avg}$ -2860 m/s).

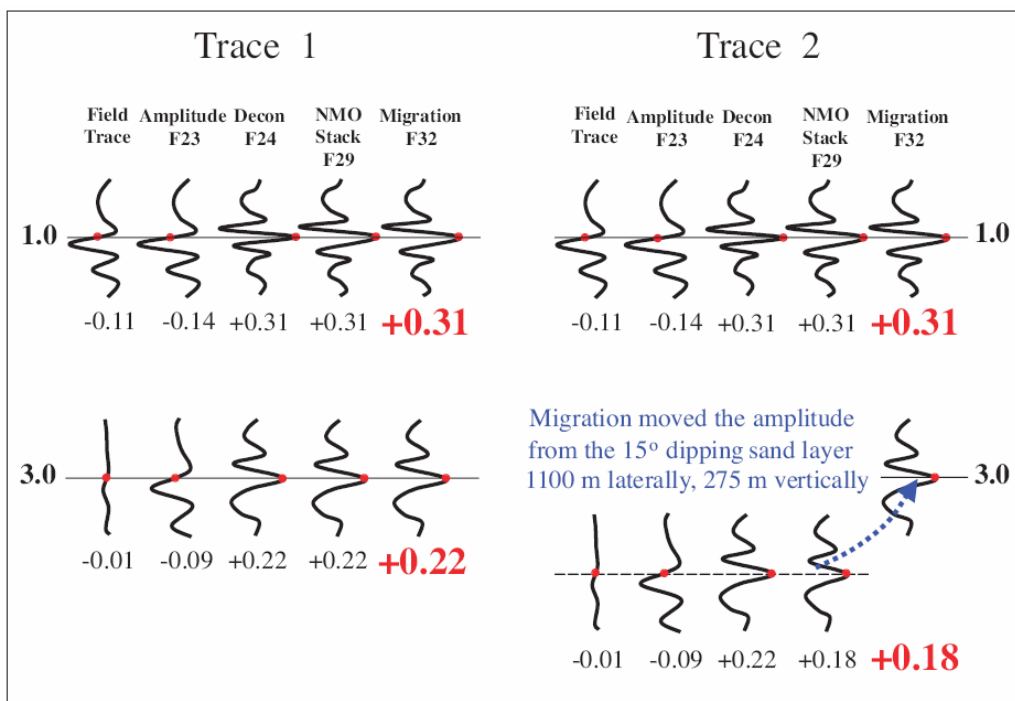


Figure 4. Notice the changes in amplitude values through the application of a typical seismic processing sequence. This illustrates the changes for the zero-offset trace at the top sand reflectors shown in Figure 3. Observe the amplitude decreases with depth, and the major amplitude changes due to the amplitude correction, and deconvolution. Amplitudes from the dipping sand also change with NMO and Stack, and move with migration to proper location.

This correction only accounted for one of the many amplitude-altering factors encountered by the wavelet during its round-trip between the surface and the top of sand 2. The observed amplitude at sand 2 also is a function of the phase and frequency content of the wavelet (**F24**), which is different from sand 1 due to attenuation and maybe assumptions in deconvolution.

On the migrated version of Trace 2 we view the dipping-reflector from sand 3 at the same time as sand 2 on Trace 1. The dipping sand has lower amplitude than the flat sand, due to NMO (**F26**) combined with stack (**F29**).

In our simple model, we assume that a flat-reflector value was used for the NMO correction. Thus, NMO is correct only for flat reflectors so that the stack process attenuates the amplitude of dipping reflectors, due to uncorrected dip contamination of the NMO velocities. In addition, dipping reflectors are displaced from their apparent location on the stacked section. Thus, they must be migrated (**F32**) to their proper subsurface positions. As shown in Figure 3, the amplitude that will be displayed on the workstation for Trace 2 at 3.0 sec. was actually from a point 1100 m laterally and 275 m vertically down dip.

The journey of these amplitudes is not yet completed, as we must load the data onto the workstation for our interpretation. In the loading process, a percentage of the largest peaks and troughs may be clipped (squared off) to improve the visual dynamic range (**F34**). Only the largest amplitudes are affected, but these are often of the greatest interest as possible direct hydrocarbon indicators.

With the seismic data now loaded, interpreters have many opportunities to alter amplitudes further (**F35**). For example, 2-D line balancing programs change gains, timing, frequency, and phase. In addition, user-applied settings for filtering, phase rotation, and even the selection of color bars change how amplitudes are perceived.

### **Concluding Remarks**

Amplitudes are the basic input to seismic attribute analysis calculations.

Factors have been described that affect seismic amplitudes through seismic acquisition, the earth, seismic processing, and seismic interpretation. Seismic interpretation contains most of the major amplitude factors (Table 2), and the interpreter controls these based on knowledge (**F36**). By not understanding the factors that affect amplitudes, drilling decisions can be in error.

On the other hand, relative amplitudes provided to interpreters are, with care, being successfully used for reducing risk and discovering hydrocarbons. You can improve your amplitude-based interpretations by considering the factors described. Your interpretation is on the firmest foundation by comparing amplitudes that are at approximately the same two-way time and have similar overlying geologic sections. Relating amplitudes to geology on vertically separated reflectors, or in areas of laterally changing geology, is risky -- and a reason for many unsuccessful wells.

### **Reference**

Sheriff, R. E., 1975, Factors affecting seismic amplitudes: Geophysical Prospecting, v. 23, p. 125-138.