

## About Gamma ratios and their combinations

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### Summary

The ratio between the compressional to shear velocities (Gamma or  $\Gamma = V_p/V_s$ ) is a key parameter in the combination of P and S (or PS) data. It can be derived in several ways. The most obvious are the ratio between the S to P propagation times between associated events ( $\Gamma_T$ ) and the ratio between P to S normal moveout velocities ( $\Gamma_V$ ). Comparing P and S (or P and PS) seismic amplitudes also gives access to Gamma ratio ( $\Gamma_A$ ).

The different derivations have different properties involving or not anisotropy effects: for example, the ratio  $\Gamma_V / \Gamma_T$  detects the effects of anisotropy and can be a lithology indicator. Some other combinations of Gamma ratios are already in use, such as  $\Gamma_{\text{eff}}$ , defining the location of the conversion point in PS propagation.

Equating the values of  $\Gamma_T$  and  $\Gamma_A$  leads to seismic inversion, providing not only the high-resolution definition of  $\Gamma_T$  but also  $V_p$ ,  $V_s$  and densities within the seismic bandpass.

Comparing P and S (or PS) frequency spectra relating to associated P and S (or PS) time intervals provides information between P or PS absorption factors.

### Introduction

Even if unfamiliar with multicomponent processing, seismologists have heard of gamma, the ratio from compressional to shear propagation velocities. Users know that speaking about gamma is not enough, the ratio has different facets aiming at different goals; moreover, a combination of different facets may be required. Since gamma is supposed to compare P or S velocities, the shear mode involved needs to be defined. In the following, considered shear modes can be  $S_H$ ,  $S_V$  or  $P_{SV}$ , splitting effects are supposed to be compensated for, and a VTI environment is assumed for simplicity.

### Gamma ratio derived from transit times

Isotropy (or normal incidence rays in a VTI environment): Once a pair of seismic horizons are identified on records or stacked sections in P and S (or PS) modes, the ratio between the transit times in P or S mode is the reverse of the velocity ratio. The gamma ratio derived in this way is noted  $\Gamma_T$  (sometimes  $\Gamma_0$ , as derived from  $V_{p0}$  and  $V_{s0}$ ). This travel-time ratio was first used by interpreters. It is linked to Poisson's ratio, provides good discrimination between sands and shales, and can discriminate fluids in favorable

conditions. When derived from transit times only,  $\Gamma_T$  has a limited resolution:

- in practice, it is based on the most energetic events,
- it can be safely derived only when P and S (or PS) reflectivity sequences are locally the same, which means that compressibility or rigidity contrasts are very close to each other. This is not always the case, especially at reservoir boundaries.

VTI environment (oblique rays): Normal moveout velocity definition requires oblique rays which means sensitivity to anisotropy. The family of gamma ratios obtained this way are noted  $\Gamma_V$  (could be  $\Gamma_{V(P/S_H)}$  or  $\Gamma_{V(P/S_V)}$  or  $\Gamma_{V(P/PS)}$ ). The relationships between NMO velocities and weak anisotropy parameters were proposed by Thomsen (1986):

$$\left. \begin{aligned} V_{PNMO} &= V_{p0}(1+\delta) \quad ; \quad V_{SHNMO} = V_{s0}(1+\gamma) \\ V_{SVNMO} &= V_{s0}[1+(V_{p0}/V_{s0})^2(\epsilon-\delta)] \\ V_{PSVNMO}^2 &= V_{p0}V_{s0} \left( 1 + \frac{2(\sigma + \Gamma_T \delta)}{1 + \Gamma_T} \right) \end{aligned} \right\} [1]$$

### Combinations of $\Gamma_T$ and $\Gamma_V$

#### Ratio $\Gamma_V/\Gamma_T$ :

Normal moveout velocities contain, as a factor, zero incidence velocities, which are generally unknown, while any ratio between NMO velocities of different modes contains, instead of velocities, the  $\Gamma_T$  factor, which is known from transit times, thus providing a relationship between anisotropy parameters, and hence a step to define them. Besides this possible estimation of anisotropy parameters, this kind of ratio can be used as a lithology indicator, for example  $\Gamma_{VSH}/\Gamma_T$  increases with shale content (Polskov, 1980).

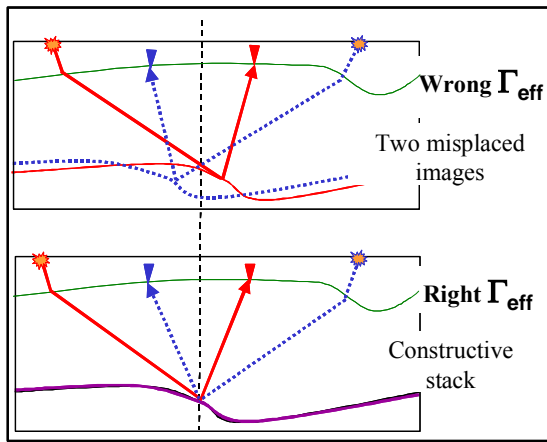
#### Effective $\Gamma$ :

As proposed by Thomsen (1999),  $\Gamma_{\text{eff}} = \Gamma_{\text{NMO}(P/S_V)}^2 / \Gamma_T$  is a key parameter to define the location of the reflection point in PS converted mode.

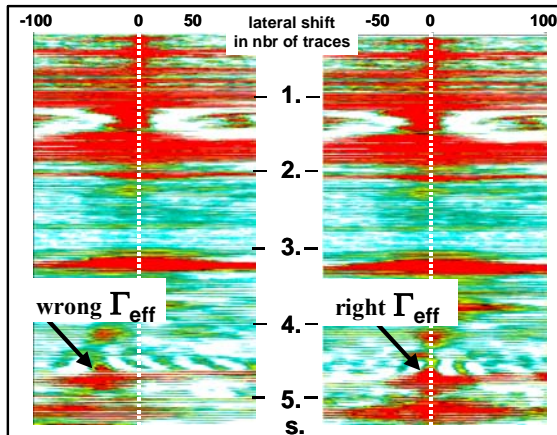
$\Gamma_{\text{eff}}$  corresponds to the fulfillment of two observable criteria (Audebert et al., 1999, 2001). The first is the optimal horizontal correlation between two opposite azimuth stacks, figures 1 and 2. The second, in the case of a dipping reflector, makes symmetrical (at short spread) the move-out

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in a CCP gather.  $\Gamma_{\text{eff}}$ , in the homogeneous isotropic case, has the meaning of a velocity ratio, but in the general case, the meaning is more the ratio of P to S NMO short spread curvatures. As a consequence, in a VTI medium,  $\Gamma_{\text{eff}}$  is in general smaller than  $\Gamma_T$ . A  $\Gamma_{\text{eff}}$  that is clearly different from  $\Gamma_T$  is indicative of effective or even intrinsic anisotropy. In a homogeneous VTI medium, the ratio of  $\Gamma_{\text{eff}}$  to  $\Gamma_T$  describes the relative strength of the P (short spread) anisotropy with respect to the S (short spread) anisotropy.



**Figure 1.**  $\Gamma_{\text{eff}}$  controls the conversion point lateral positioning. Too high a  $\Gamma_{\text{eff}}$  (top) moves the imaged point towards the receiver in the opposite direction according to the shooting direction.



**Figure 2.** The lateral correlation between two opposite azimuth stacks provides the lateral positioning error, which is directly related to the  $\Gamma_{\text{eff}}$ .

### Gamma ratio derived from seismic amplitudes: $\Gamma_A$

Seismic amplitudes depend on relative differences  $\Delta V_P/V_P$  and  $\Delta V_S/V_S$ . Combining zero-offset reflectivities and gradients of P mode with those of S (or PS) mode provides the difference:

$$(\Delta V_P/V_P - \Delta V_S/V_S) = \Delta \Gamma_A / \Gamma_A \quad [2]$$

$\Gamma_A$  ratio is obtained by integration. However, the risk of deviations justifies fitting the result with  $\Gamma_T$  tie points.

### Combination of $\Gamma_T$ and $\Gamma_A$

Derived from transit times, the  $\Gamma_T$  bandpass has no limitation towards low frequencies but is limited around 10-20 Hz. On the contrary,  $\Gamma_A$ , derived from reflectivities, is within the seismic bandpass. Combining  $\Gamma_T$  and  $\Gamma_A$  merges their bandpasses. Thus the bandpass (resolution) of the  $(\Delta T_P/\Delta T_S)$ , resulting from the accurate association of the P and S (or PS) times of the same seismic event, provides the possibility to use in combination the AVO attributes of P and S (or PS) modes. For example, retaining the zero-offset reflectivity and the gradient of P mode with the gradient of PS mode provides the relative differences of  $V_P$ ,  $V_S$  and density for each seismic sample, and then any elastic parameter (Garotta et al., 2000). It should also be mentioned that an equivalent  $\Gamma$  can be derived from elastic inversion of P waves alone (Cambois, 2002). But this  $\Gamma_{\text{EI}}$  derived from impedance does not allow the discrimination between velocities and density directly from seismic data.

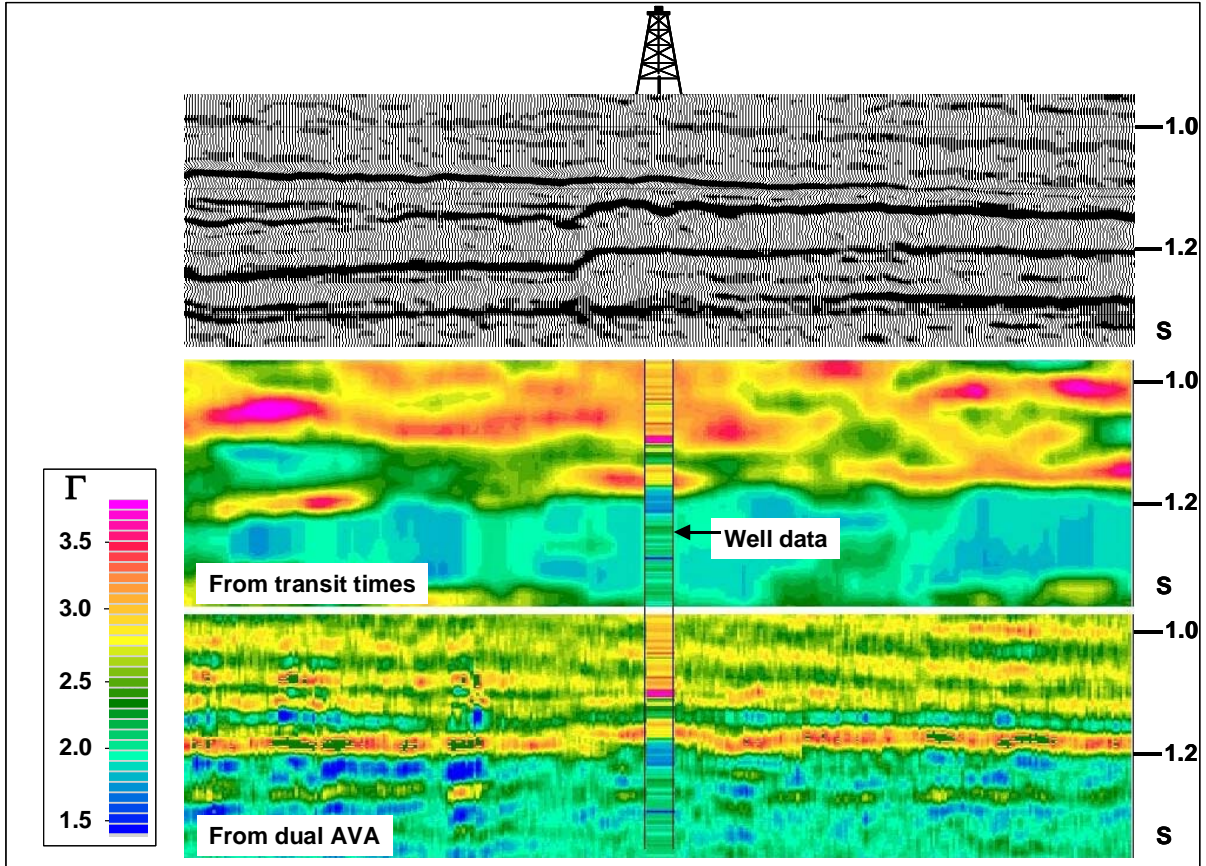
In figure 3 the  $\Gamma_T$  from the P to PS time correlation shows limitations in resolution and accuracy, while the combination of  $\Gamma_T$  and  $\Gamma_A$  leads to clear improvements confirmed by data from a well at some distance from the line.

### Gamma ratio derived from frequency spectra: $\Gamma_S$

Since a frequency spectrum is not a scalar, the derivation of a  $\Gamma_S$  ratio from frequency spectra is not as obvious as for transit times, NMO velocities or amplitudes: the main characteristics of frequency spectra, such as peak value or width at a given level, do not seem to be of particular interest for P to S (or PS) mode comparison. The retained parameter noted  $\Gamma_S$  is the ratio of the slopes of the spectra towards high frequencies, which is linked to the quality factor (Kleitzi, 1999).

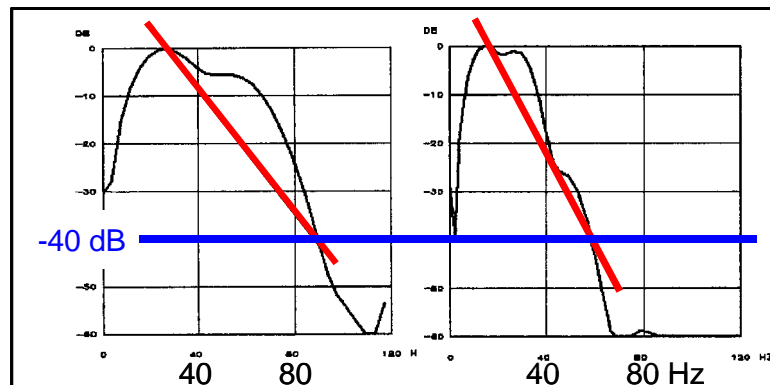
Figure 4 shows examples of frequency spectra computed in time gates corresponding to the same event in P and PS modes. The slopes of the amplitude spectra towards high frequencies are linked to the quality factor  $Q_{PP}$  and  $Q_{PS}$ . In figure 5 the  $Q_{PP}/Q_{PS}$  ratios correspond to computations within small windows. Comparison of the results between sliding windows from the VSP data and the main reflectors of the surface seismic shows a good consistency.

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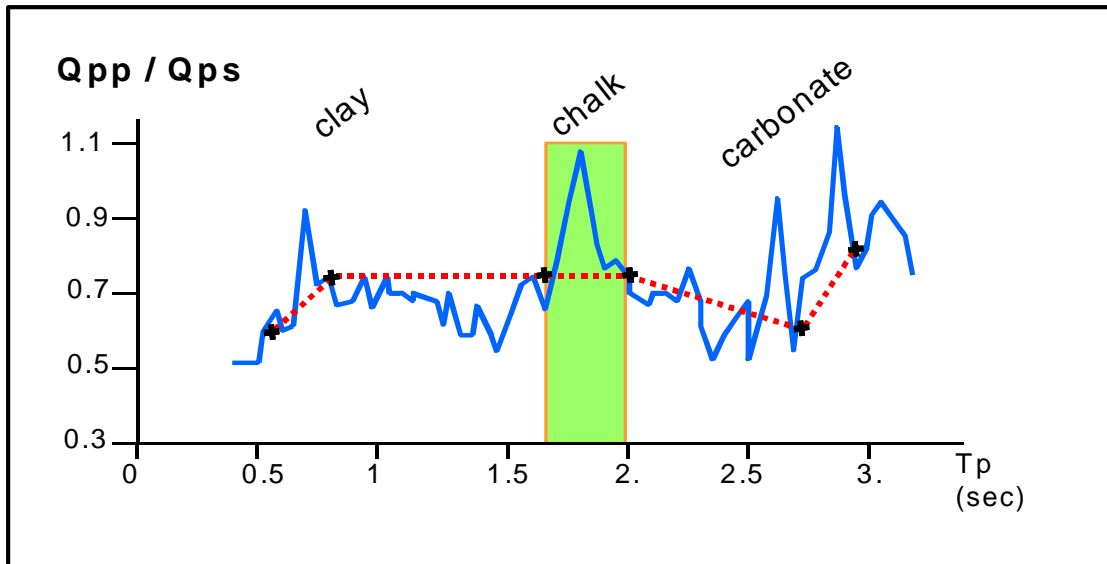


**Figure 3.** Top: P mode section in the target area.  
 Middle:  $\Gamma$  ratio derived from correlation between P and PS data.  
 Bottom:  $\Gamma$  ratio derived from  $\Gamma_T$  and  $\Gamma_A$  combination showing higher resolution and a good match with derived values from well dipole sonics.

**Figure 4.** Frequency spectra of P mode data (left) and PS mode data (right). The red slope used for deriving Qpp/Qps ratios is obtained by joining the maximum value of the spectrum and the high frequency crossing with -40dB.



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**Figure 5.** Qpp/Qps ratios derived from VSP data (solid blue line) and from the main horizons of the seismic line (dotted red line). The six discrete values from the surface data fit with the well data results.

### Conclusions

Gamma ratios are at the heart of any combination of P and S (or PS) data. This magic value, when it is derived sample by sample, is a piece of information by itself. It bridges the gap between the time-scale of the various wave modes and allows accurate seismic event registration. Different gamma derivations involve transit times, NMO velocities, reflectivities or frequency spectra. Combining different issues provides processing parameters as well as lithology indicators whose full potential remains to be exploited.

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