3D Multicomponent Seismic: Joint Inversion in the Seismic-Petrophysical Integration context

What has the driller in common with the problematic of Seismic-Petrophysical Integration finalized to the refinement of the seismic inversion process ? Could we say that the driller is the first person in the exploration world realizing the reassessment of the stress field within the borehole environment by seeing anomalous dimension cutting breaking out of the borehole wall ? Wellbore stability is a critical problem encountered in the drilling process.

In the specific case of well logging, the stressfield change has a major impact on changing the P and S waves velocities (and polarization) on the sonic measurements. The stressfield undergoes a new reassessment into the cylindrical geometry of the wellbore. Each case has to be studied in function of inclination and azimuth i.e. orientation angle towards main overburden maximum stress (Sigma1), secondary stress (Sigma2) and minimum stress (Sigma3).
Expecially S waves are higly effected as the stressfield can split and polarize the energy in fast and slow polarized S waves.
Another critical factor at the sonic frequencies is the different interaction between wave propagation and heterogeneity. Rigidity is highly affected by corresponding heterogeneity scale relative to wavelength. At increasing grades of heterogeneity, dispersion can be an issue.

In seismic inversion we consider the sonic and VSP measurements for calculation of Seismic Impedance, but in the Multicomponent Seismic Inversion the derivation of S wave velocity is a critical problem.

In Seismic Joint Inversion Reflectivities are a weighted sum of normalized P and S Impedances, I and J:

$$R_{PP}(\theta) = A(\theta)\frac{\Delta I}{I} + B(\theta)\frac{\Delta J}{J}$$

$$R_{PS}(\theta, \varphi) = C(\theta, \varphi)\frac{\Delta I}{I} + D(\theta, \varphi)\frac{\Delta J}{J}$$

Where weights are functions of P and S velocities and incident angles for reflected and converted waves:

$A(\theta) = f(\theta)$

$B(\theta) = f(\alpha, \beta, \theta)$

$C(\theta, \varphi) = f(\alpha, \beta, \theta, \varphi)$

$D(\theta, \varphi) = f(\alpha, \beta, \theta, \varphi)$

Aki and Richard proposed the linearizations of the Zoeppritz equation for all PP,PS,SP,SS Reflectivities.

After successive developments by Smith, Gidlow, Ferguson, Stewart, with important contributions at CREWES by Margrave, Xing Lu, Potter, Larsen et al. new metods were described by minimizimg the error function determined by the difference between model and measurement.

The new methods of joint inversion bring to the following results for the PP and PS case:

$$\frac{\Delta I}{I} = \frac{\sum_i R_{PPi}\ A_i \sum_i H_i - \sum_i R_{PPi}\ B_i \sum_i K_i}{\sum_i L_i \ \sum_i H_i \ - \ [\sum_i K_i\ ]^2} + \frac{\sum_i R_{PSi}\ C_i \sum_i H_i - \sum_i R_{PSi}\ D_i \sum_i K_i}{\sum_i L_i \ \sum_i H_i \ - \ [\sum_i K_i\ ]^2}$$

$$\frac{\Delta J}{J} = \frac{\sum_i R_{PPi}\ B_i \sum_i L_i - \sum_i R_{PPi}\ A_i \sum_i K_i}{\sum_i L_i \ \sum_i H_i \ - \ [\sum_i K_i\ ]^2} + \frac{\sum_i R_{PSi}\ D_i \sum_i H_i - \sum_i R_{PSi}\ C_i \sum_i K_i}{\sum_i L_i \ \sum_i H_i \ - \ [\sum_i K_i\ ]^2}$$

Where synthetic weights H,K,L are a combination of effective weights A,B,C,D:

$H = B_i^2 + D_i^2$

$K = A_iB_i + C_iD_i$

$L = A_i^2 + C_i^2$

Due to the sensitivity to S waves, when applying sonic logs, the sonic measurement need to minimize the travelpath through the stress-disturbed volume and maximize the travelpath through the undisturbed formation volume. Another issue is the correction for anisotropy effects.

This approach assumes well log data as input for velocity and density, reflectivity is the only seismic contribution. A critical point appears in the PP or PS reflectivity combinations that are valid only when PP or PS reflection times relate rigorously to the same interface. This situation can be satisfied at the well location but is more and more conditioned by the data quality and the interpreter experience on extrapolating data at some distance from the well.
Another approach is possible: the “Garotta seismic data based” :
Extracting elastic parameters bin by bin by optimizing the consistency of the amplitudes and the transit times of PP and PS data at each seismic sample bring significant new results which can be synthetized as follows:
- Combining PP and PS reflectivities can deliver a value of gamma (Vp/Vs), said gamma-A
- Comparing PP and PS transit times also deliver a value of gamma, said gamma-T

- Physically, these values have to be the same. The algorithm simply minimizes the differences between their square values.

Elastic parameters and other rock properties linked to azimuthal or axial anisotropy are delivered directly from 3D seismic Multicomponent data, without considering well data (which will be taken in account for quality control purposes and to simulate the higher frequencies propagation in the micro-scale), provided data quality is good enough and PP or PS frequency spectra have a wide common bandpass.

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