GeoNeurale

**TOMOGRAPHIC INVERSION IN THE PreSDM AND PETROPHYSICAL CONSTRAINTS**

(Prestack Depth Migration and velocity model analysis - constraints beyond the seismic resolution.)

A velocity (V) model is one the most important steps on the seismic processing workflow and a first fundamental phase of seismic imaging.

The refinement of the V model follows in upgraded steps after residual statics corrections, repeated NMO correction, usual application of up to the 4th order moveout term as a function of Thomsen parameters in consideration of local and azimuthal anisotropy.

In the Prestack depth and WE Migration wide use is made of an objective (cost) functions that QC the refinement and convergence of the model to minimize the error through minimum admissible levels. A similar concept can be applied to FWI problems.
In the specific case a PreSDM is performed in the common offset domain with the construction of common image gathers.

A model for an objective function is here presented which integrates rock physics and petrophysical constraint to the macro seismic velocity model, thus relating geomacrosystems and microsystem in a unique model relating migration and formation evaluation concepts as input in the V model.

In general the objective function C(m) is made up of at least 3 terms. An auto-adjusting term which adjusts residual moveout ($\Delta Z$) after new update of V perturbation and anisotropy, a hard constraint term relating seismic reflectors to sonic logs (ties) and a soft constraint term reflecting the geostructural model. Here two terms are introduced, a rock seismic model and a petrophysical constraints term which are interacting upon velocity perturbation parallel with the Jacobian matrix gradient updating the residual moveout.

The process undergoes a large number of iterations until the objective function reaches a minimum. A new step is performed at each location x,y for all migrated depths z and offsets h. Note that we can have more than one event E (reflection) referenced to the same bin (xyz) and offset h.

**1.**

## C(m) =

$$\sum_{xy} \sum_{E} \sum_{h} [\, ZE(h) - ZE(hR)]^2$$

FLATTEN OF COMMON IMAGE GATHERS

$$+ \alpha \sum_{M} \sum_{W} [ZM - ZW]^2 + \beta \sum_{m} [r(mI) - r(mC)]^2 + \gamma \sum_{p,m} [p(mI) - p(mC)]^2$$

SEISMIC TIES FROM LOGS ROCK SEISMIC MODEL PETROPHYSICAL CONSTRAINTS

$Z_E(h) - Z_E(h_R)$ —–> ($\Delta Z$) represents the residual moveout as the difference between the moveout at a specific offset (h) $Z_E(h)$ and a reference moveout $Z_E(h_R)$ which is usually the moveout at zero offset position (h=0) function respective of CIG coordinates x,y,h,m and x,y,h=0,m .
The hard constraint of the ties is calculated for all markers M and all wells W.
The rock seismic model also undergoes perturbation but is more stable than the first term, while the petrophysical model is a local hard constraint and under seismic attributes control outside the local area.

The first term for residual moveout control is expressed as the prior value plus an updating increment.

$$\mathbf{Z_E(h) - Z_E(h_R) \longrightarrow (\Delta Z)}$$

$$\Delta Z_2 = \Delta Z_1 + [\, \delta\Delta Z_j / \delta m_i] [\, \delta m_i \,]$$

It is subsequentially expanded in Taylor series, in our model up to the 1st order without calculating the Hessian. The result bring us to the numerical solution of eq. 2

A rock physical model is the interface between petrophysical measurements properties and the velocity model. This can be interpreted as soft constraint, which is however constant in all the seismic volume.
The petrophysical model is a hard constraint, which can be updated after petrophysical correlation between logs. This term is not influenced from perturbation.
Numerical solution of the problem with the goal to flatten the gathers drifting to the right V model is a “normal equation” of matrix of gradients (**Z/m**) which updates the residual moveout after velocity perturbation represented by **m**.

2.

$$[\, \delta\Delta Z_j / \delta m_i \,]^T \, [\, \delta\Delta Z_j / \delta m_i \,] \, [\, \delta m_i \,] = - [\, \delta\Delta Z_j / \delta m_i \,]^T \, [\delta\Delta Z_j \,]$$

TRANSPOSED JM JACOBIAN MATRIX (JM) TRANSPOSED JM

The Jacobian is a self adjusting component matrix of gradients in the object function and will react to the velocity perturbation each step minimizing the residual moveout with the goal to flat the CIG gathers.

The same velocity perturbation reaches parallel the rock physics effective model, in this case an example is given by the HM (Hertz-Mindlin) derived model which is itself constrained from the petrophysical logs in the seismic volume in terms of elastic properties, velocity, porosity fluid properties.

Our model is directly integrated with petrophysical logs. The effective model is the interface between Geomicrosystems ( ensemble of petrophysical properties, attributes and physical laws ) and Geomacrosystems ( ensemble of seismic properties, attributes and physical laws ).
The effective model and the microsystem are related at the level of the elastic representative elementary volume (REV) stability domain limit for structural and elastic systems, small scale variographic/covariance heterogeneity within the zone of definite impedance contrast.
A large scale heterogeneity is defined outside the zone of definite lateral/vertical impedance contrast.

The effective model and macrosystems are related at the level of macroscale elastric parameters defining velocity: K (bulk modulus) and $\mu$ rigidity which ca be integrated with petrophysical logs attributes:

**3.**

$$K^{(HM)} = \left( \frac{(nw\tau_2)^2 \, (1 - w\tau_2)^2 \, \mu_s^2}{18\,\pi^2 \, (1 - \nu_s)^2} P_c \right)^{1/3} \qquad \mu^{(HM)} = \frac{5 - 4\nu_s}{5(2 - \nu_s)} \left( \frac{3(nw\tau_2)^2 \, (1 - w\tau_2)^2 \, \mu_s^2}{2\,\pi^2 \, (1 - \nu_s)^2} P_c \right)^{1/3}$$

This is derived from the standard HM model:

**4.**

$$K^{(HM)} = \left( \frac{C_o^2 \, (1 - \phi_o)^2 \quad \mu_s^2}{18\,\pi^2 \;\, (1 - \nu_s)^2} \, P_c \right)^{1/3} \qquad \mu^{(HM)} = \frac{5 - 4\nu_s}{5(2 - \nu_s)} \; \frac{3C_o^2 \, (1 - \phi_o)^2 \; \mu_s^2}{2\,\pi^2 \;\, (1 - \nu_s)^2} \; P_c^{\;1/3}$$

$\nu_s$ (Poisson Number)
$P_c$ (Overburden Pressure)
$\phi_o$ (Critical Porosity)

This is a function of coordination number, for the most compacted form, porosity, rigidity and Poisson number of the grains and overburden stress.
In this context an additional issue to increase the flexibility and realistic behaviour of the model arises as we can introduce petrophysical/rock physics self adjusting constraints. These can be directly realted to the velocity field and can be calibrated within the results of the seismic experiment.

Model calibration/verification at the microsystem level are core tests, electro-density elastic attributes, sonic and VSP velocity correlation, on the macrosystem level AVO analysis A,B,C attributes defining AVO Product, scaled Poisson Ratio, Shear Reflectivity, Fluid Factor, Rp, Rs, $Rp_0$, $Rs_0$, Lambda/Mu/Rho, Mud Rock parameters, inversion attributes.

The problem is solved as a least square solution where an event dm would drift the sum of the squares of $\Delta Z$ to a minimum approximating zero.

The memory requirements for a 30x30 km survey on a grid of x,y,z = 100 meters until 10 km depth would be a few billions equations.

## GeoNeurale Research

We welcome comments and discussion. Please address your comment at:

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