Incorporating reflection data into refraction statics solution

Bernie Law[1], Daniel Trad[1]
1. Consortium for Research in Elastic Wave Exploration Seismology (CREWES), University of Calgary

Summary

We tested a non-linear optimization workflow where the refraction model is derived from maximizing the coherence of the reflection energy and minimizing the misfit between model and recorded first arrival times. This approach can alleviate inherent limitations in shallow refraction data by using coherent reflection data.

Linear inversion

If the relationship between model parameters **m** and observation **d** is:

$$d = Lm \tag{1}$$

The least square solution of **m** is:

$$m = (L^T L)^{-1} L^T d \tag{2}$$

Delay time equation and generalized linear inversion

$$T_j = \int_1^n 2 \times \frac{Z_i \times cos\theta c_i}{V_{i-1}} + \frac{X}{V_i} \tag{3}$$

$$\triangle T = B \triangle M \tag{4}$$

Least square solution for ΔM is:

$$\triangle M = (B^T B)^{-1} B^T \Delta T$$
$$B = \frac{\partial T_j}{\partial m_i} \tag{5}$$

BP94 statics benchmark model

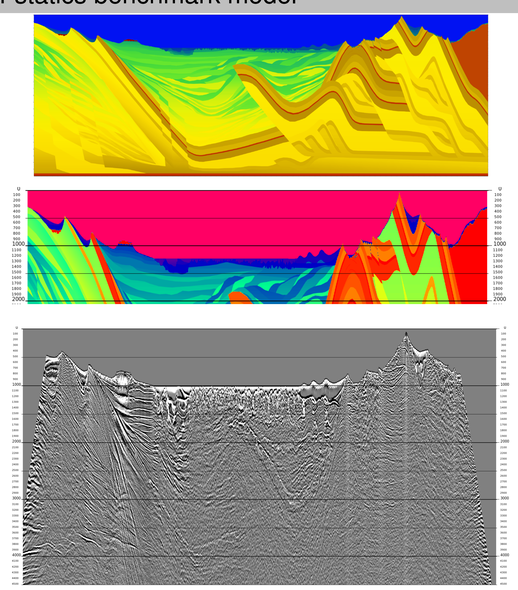


Figure: CDP stack with datum correction

GLI refraction solution

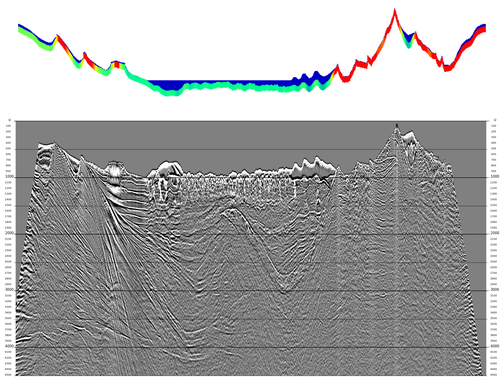
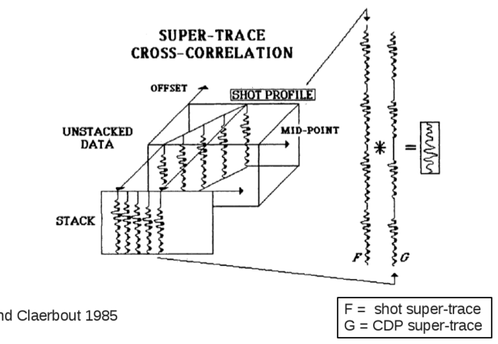


Figure: CDP stack with GLI statics correction

Stack-power Maximization

Surface consistent residual statics by stack-power maximization



Ronen and Claerbout 1985

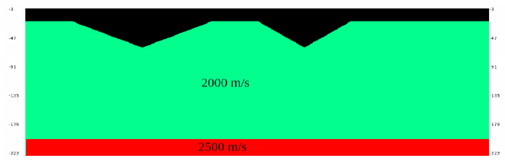
F = shot super-trace
G = CDP super-trace

$$MAX(Power(m,d) - F(m)) \tag{6}$$

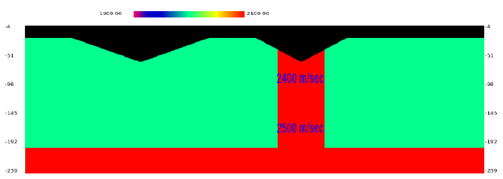
Power(m,d) is the sum of the stack-power of CDP stack traces (d) for each combination of shot and receiver statics (m)and F(m) is the optional penalty function

Stack-power Maximization Test

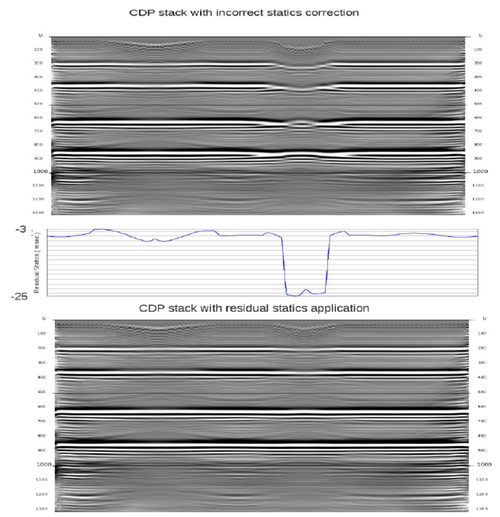
Adding velocity model error to test stack-power maximization



Actual velocity model



Actual velocity model + Error



Incorporating reflection data measurements into refraction statics solution

Introducing Wm and Wd to refraction inversion

$$J = ||W_d d - W_d L W_m m||^2 \tag{7}$$

where : W_m is the model weighting function

$$W_{mvi} = 1 - \frac{E_i}{Z_{i+1} \times P_i} \tag{8}$$

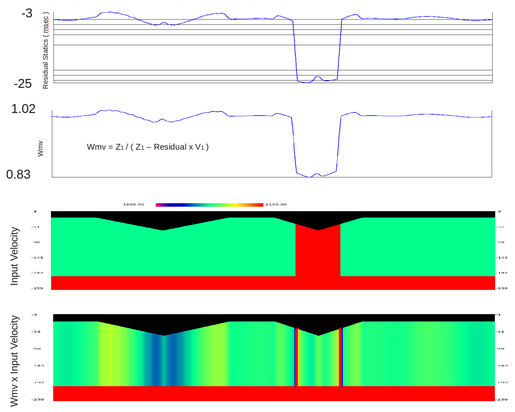
$$W_{mzi} = 1 + \frac{E_i}{Cwx_i} \tag{9}$$

E_i is reflection time error assigned to layer $_i$
Z_i is refractor layer thickness
P_i is refractor slowness
Cwx_i is weathering correction for layer $_i$
$W_{d\ j}$ is the data weighting function for sample $_j$

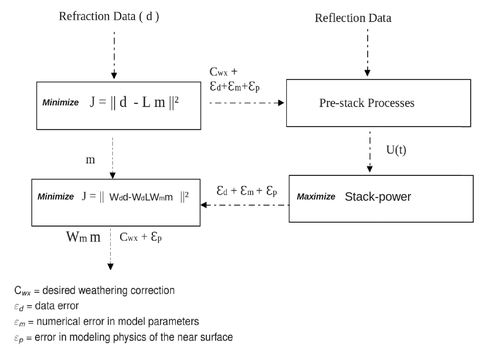
$$Wd_j = \begin{cases} 0 & E_i >= \epsilon \text{ and } \triangle T > N \times \text{stdev}(\triangle T) \\ 1 & \text{otherwise} \end{cases}$$

ϵ is the threshold for reflection error
N is data rejection criterion in terms of standard derivation of $\triangle$T

Inversion Procedure



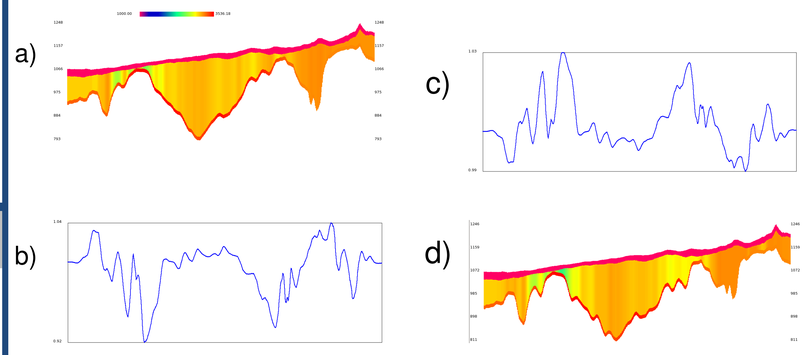
Non-linear optimization of near surface velocity model using reflection data



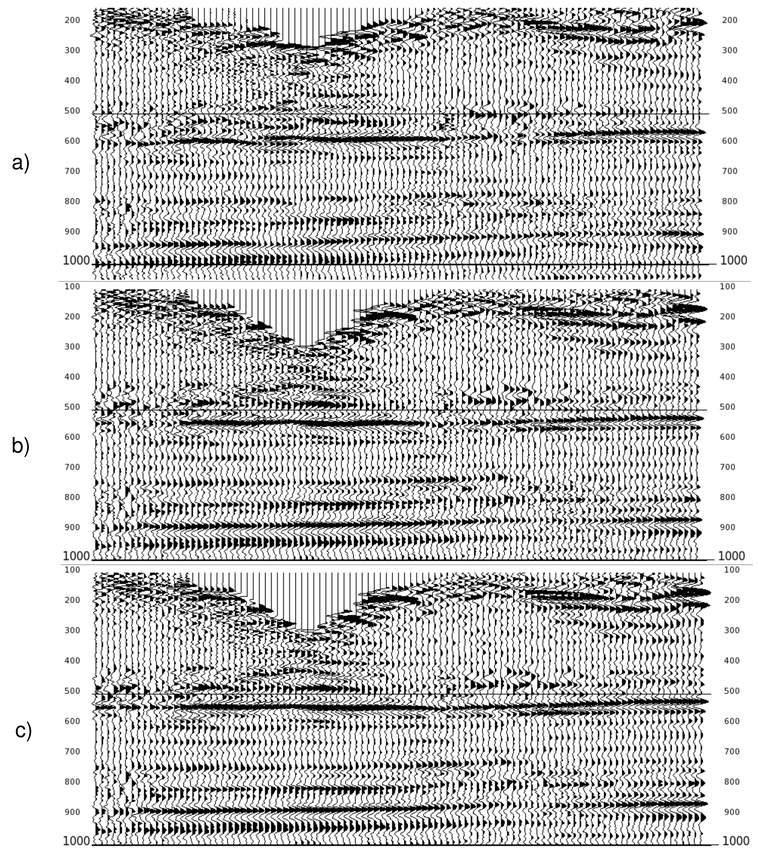
C_{wx} = desired weathering correction
ε_d = data error
ε_m = numerical error in model parameters
ε_p = error in modeling physics of the near surface

Spring Coulee 3C-2D P-wave data

Spring Coulee line 2008-SC-01 was acquired in January 2008 near Spring Coulee, Alberta. Only P-wave data is used for this test. To impose data limitation on the solution, we decimated the data by 75% using only every 4th shot point for GLI algorithm.



a) GLI solution (CDP 202-1304) b) W_{mv} (0.92 - 1.04) c)W_{mz} (0.99 - 1.03) d) GLI solution with W_{mv} and W_{mz} update



a) datum statics corrected CDP stack (CDP 300-500) b) GLI statics corrected stack c) CDP stack with stack-power maximization and GLI solution with W_m update

Future work

Refraction tomography that is better suited for complex near surface geology will be investigated with this workflow using BP94 statics benchmark model.

Acknowledgments

We thank the sponsors of CREWES and NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 461179-13 for supporting this project.