Geometric theory of inversion and seismic imaging II: INVERSION + DATUMING + STATIC + ENHANCEMENT

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Abstract

The goal of seismic processing is to convert input data collected in the field into a meaningful image based on signal processing and wave equation processing and other algorithms. It is normally a global approach like tomography or FWI (full waveform inversion).

Seismic imaging or inversion methods fail partly due to the thin-lens effect or rough surfaces. These interfaces are non-invertible. To mitigate the problem, we propose a more stable method for seismic imaging in 4 steps as layer stripping approach of INVERSION + DATUMING + STATIC + ENHANCEMENT.

Introduction

Inversion methods fail partly due to geologic complexities like thin lens or rough surfaces ([1, 7, 2, 3, 4, 5, 6]). Thin lenses (e.g. thin gas units) are not invertible by decoupling velocity and thickness. They are beyond resolution. However, we could combine the two variables of velocity and thickness into one term as static = thickness/velocity. Static as local time shifts will make the inversion more stable.

Rough surfaces have difficulties with non-differentiable points (sharp corners) and wave equation is numerically unstable. If we use wave equation with derivatives on non-differentiable points, we have to smooth the sharp surfaces and apply wave equation. The error between sharp surface and smooth surface could be compensated by static.

We will use two simple models to illustrate thin lens and rough surfaces, and then demonstrate the effectiveness of re-datuming wavefield recordings by using synthetic and field data examples.

Thin lens and rough top of salt

We show two examples of small travel time errors on the seismic recording. The first example is from our SEG paper ([2]) "Seismic prediction and micro-tomography: a case study of small traveltime error and waveform distortion" which shows thin gas lens could distort the traveltime in the target and time shifts could correct for the false anisotropy (Figures 1, 2, and 3).

The second example is from Pluto 2D model ([8]) in Figure 4. The top of salt is rough and could have triangles and trapezoids with sharp corners. The sharpness is due to geologic faults on top of salt body (Figure 5). Salt is lighter than normal sediment. So the fault weakness allows salt to float along fault. The triangle/vertices are sharp terminations.

Synthetic and field data examples

The synthetic model is a simple layered medium with four Cantor "scatters" at a depth of 800m (Figure 6). Top of the two flat thin-layers are at 1000m and 1500m, respectively. A surface acquisition geometry is simulated with finite-difference method. A second "recording" is also created by "re-datuming" the surface sources and receivers to a subsurface depth of 800m, right above the fast-velocity "scatters", which allows for the application of subsurface-consistent statics caused by these scatters. For the surface recording, Figure 7 shows a migrated section of a near-offset stack. There are visible statics on both levels of the flat reflectors due to the fast-velocity scatters. Figure 8 shows a migrated section of the "re-datumed" recordings after applying statics correction on the scatters. This demonstrates that the subsurface statics caused by the scatters is reduced at the flat reflectors, by applying a process of datuming and statics correction.

The field data example is from an offshore area. The data appears to show severe, short-scale lateral velocity variations in the subsurface (Figure 9). Figure 10 compares migrated stacks before and after applying the technique of re-datuming and statics correction at a shallow subsurface to reduce the thin-lens effect.

Conclusion

The results of seismic imaging and seismic inversion should be geologically meaningful. Artifacts from seismic imaging or inversion cause significant mis-interpretation of the geology. Seismic data in general will have higher signal in the shallow data and poorer signal at depth. If we take care of one macro-layer at a time, we can use static to handle non-invertible thin lenses. Enhancement is needed for each macro-layer as we datum to deeper level. The deeper noise will make imaging/inversion unstable and create significant artifacts.

We have demonstrated that the 4-step method of **INVERSION + DATUMING + STATIC + ENHANCEMENT** can overcome some of the non-invertible problems of seismic imaging or seismic inversion. The diagram in Figure 11 captures the processing flow.

References

[1] Etgen , J.T., I. Ahmed, M. Zhou, 2014, Seismic Adaptive Optics, SEG Annual meeting expanded abstracts, p. 4411-4415

[2] Lau, A., C. Yin 2003, Seismic prediction and micro-tomography: A case study of small traveltime error and waveform distortion, SEG Annual meeting expanded abstracts 2003, pp. 1774-1776.

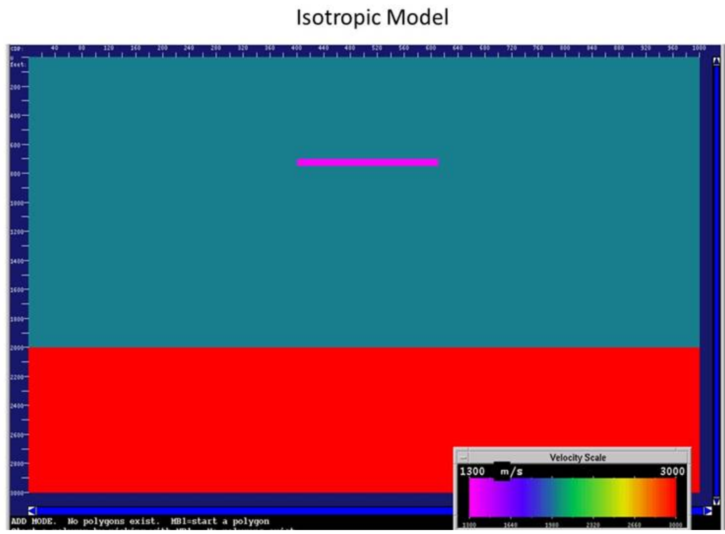

Figure 1: Isotropic model with a thin lens embedded.

[3] Lau, A., C. Yin , R.Coifman, A.Vassiliou 2009, Diffusion semigroups: A diffusion-map approach to nonlinear decomposition of seismic data without predetermined basis, SEG Annual meeting expanded abstracts, p. 2327-2331.

[4] Lau, A. and C. Yin, 2010, L0+L1+L2 mixed optimization: a geometric approach to seismic imaging and inversion using concepts in topology and semigroup, arXiv:1007.1880v1.

[5] Lau, A. and C. Yin, 2012, Seismic Solvability Problems, arXiv:1212.1350v1

[6] Lau, A. and C. Yin, 2015, Geometric theory of inversion and seismic imaging, arXiv:1506.00463v1

[7] Martini, F. and Bean, C., 2002, Interface scattering versus body scattering in subbasalt imaging and application of prestack wave equation datuming, Geophysics, vol. 67, No. 5, September-October 2002, p. 1593-1601.

[8] Bergsma, E., 2000, Pluto1.5 2D synthetic dataset, www.delphi.tudelft.nl/SMAART/pluto15.htm.

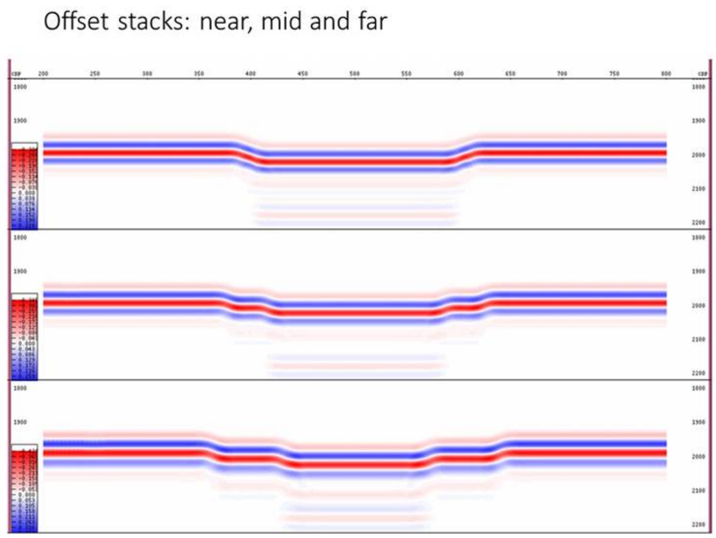

Figure 2: Common offset sections showing the spread of the "inverted V shape"

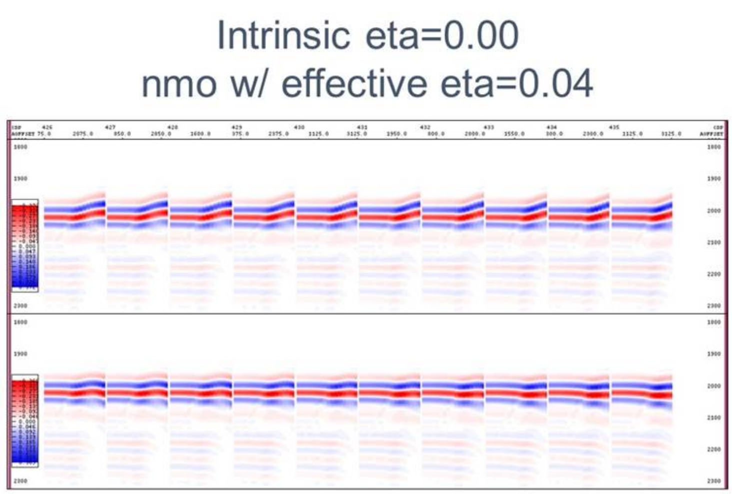

Figure 3: Artificially applying eta to flatten gathers is not the physical explanation of anomaly.

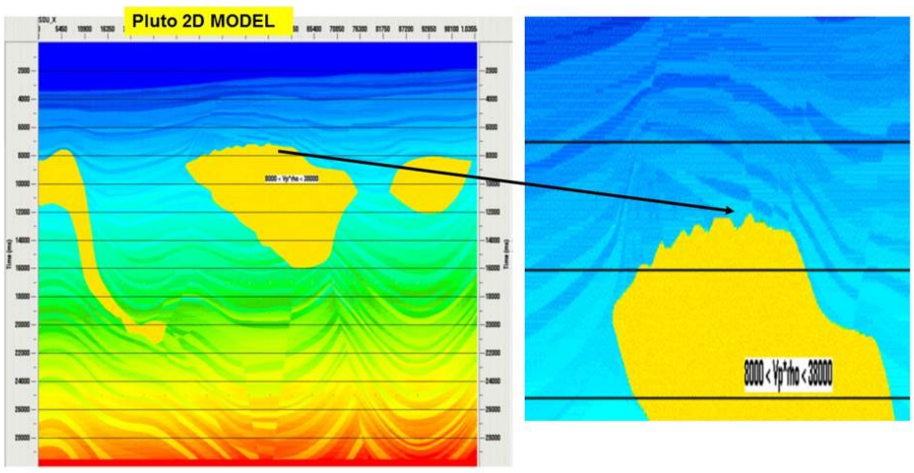

Figure 4: Isotropic salt model shows rough top of salt with triangles and trapezoids.

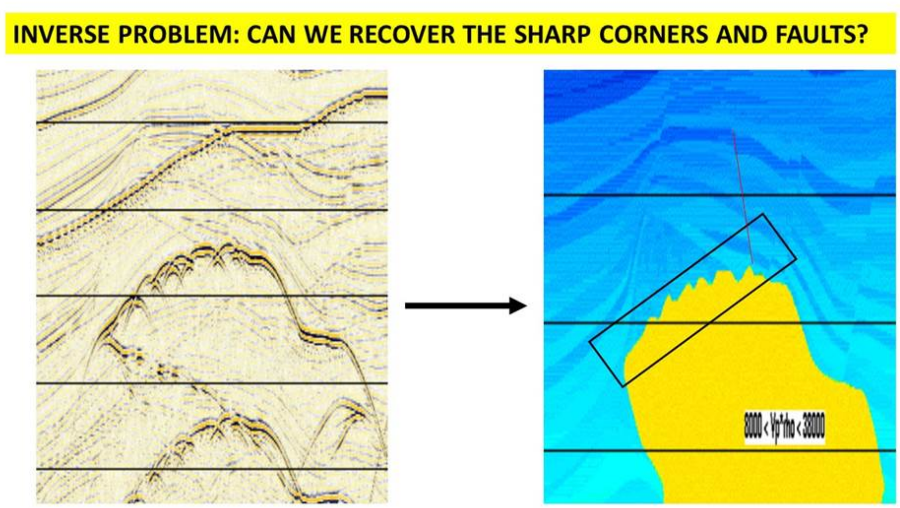

Figure 5: These vertices are non-differentiable which cause problems with any inversion.

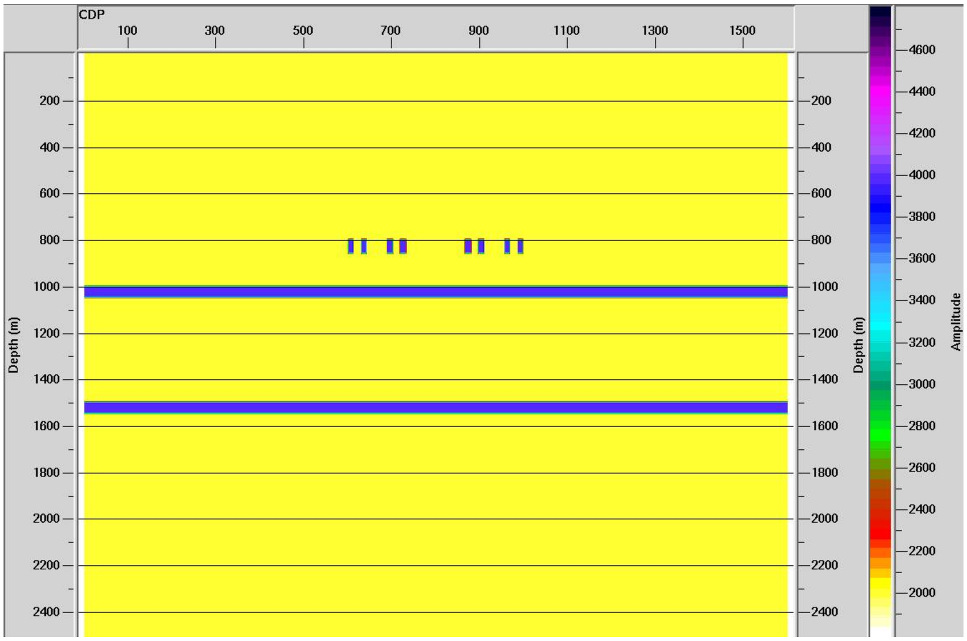

Figure 6: A velocity model with "scatters" near 800m in the subsurface.

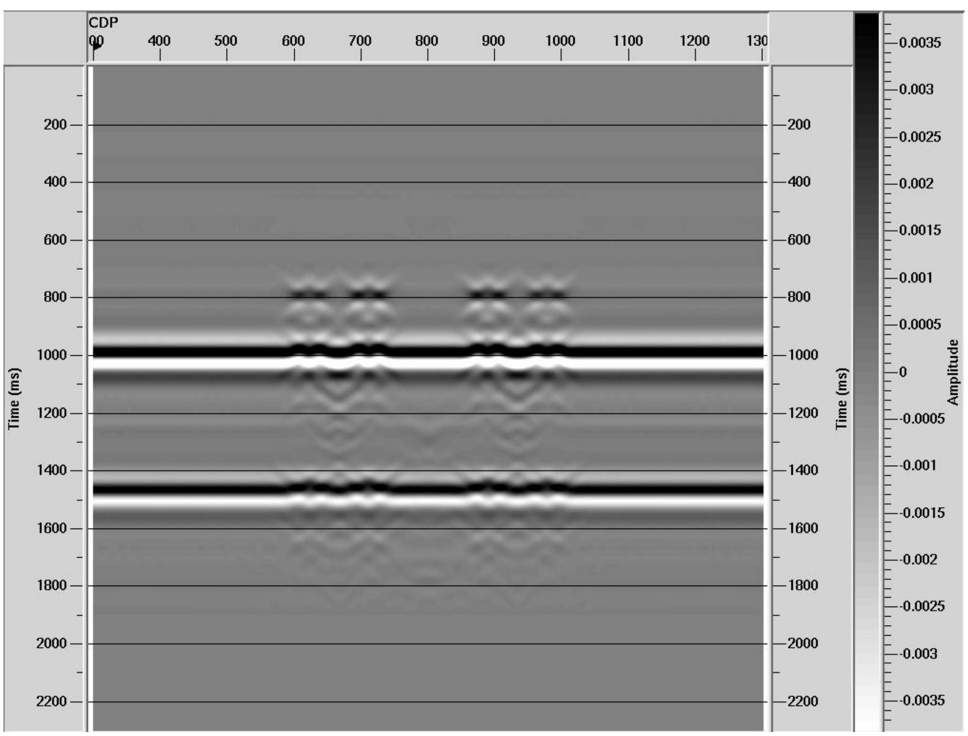

Figure 7: A migrated section of a near-offset stack derived from the surface recording.

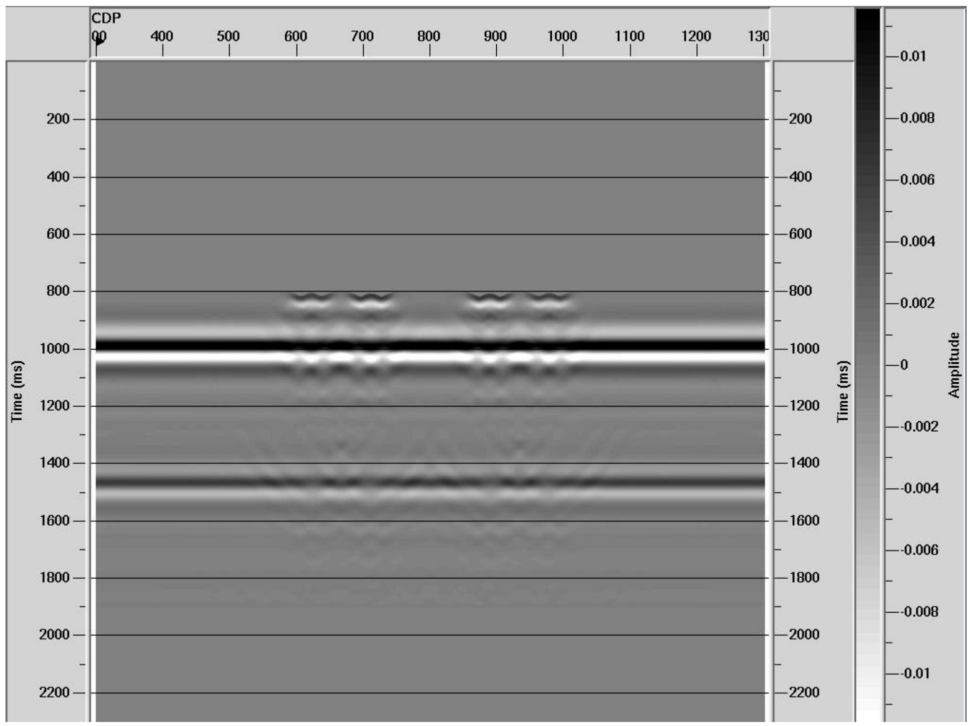

Figure 8: A migrated section of a near-offset stack derived from the ”re-datumed” subsurface recording, after applying statics corrections on the scatters.

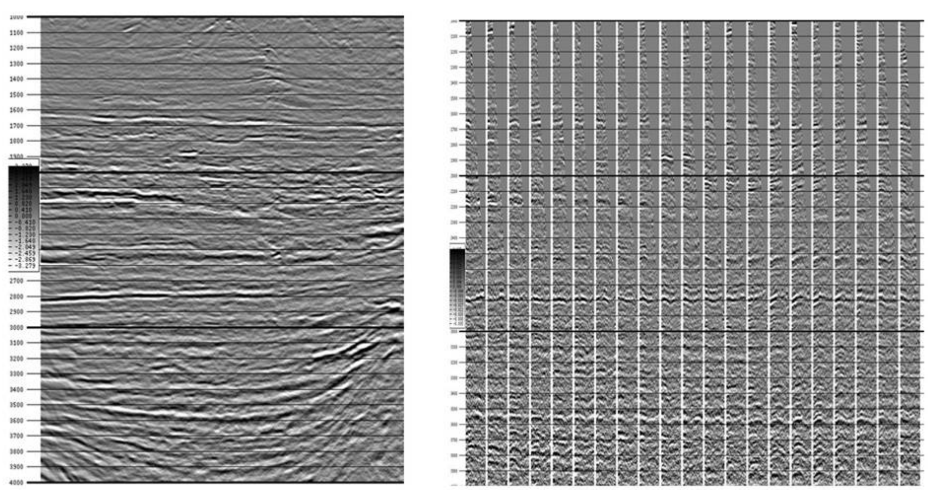

Figure 9: Left is input stack and right is gathers showing a lot of ”wobbles” in the moveout.

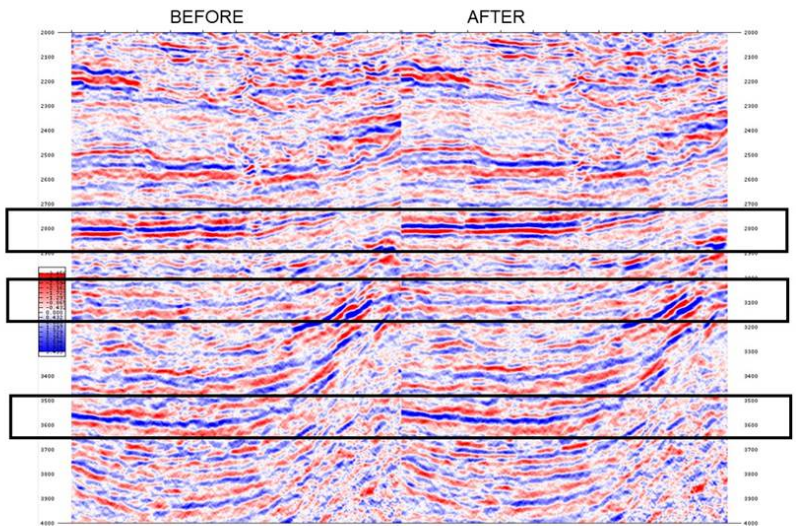

Figure 10: Left is original migration and right is after applying static at a shallow surface as "thin lens".

Input data for (INVERSION+DATUMING+STATIC+ENHANCEMENT)

INVERSION for first macro layer (inversion could be tomography/waveform inversion)

Downward continue to first datum/surface

Run residual STATIC

Run ENHANCEMENT (signal processing/Radon demult etc)

INVERSION for second macro layer

Downward continue to second datum/surface

Run residual STATIC

Run ENHANCEMENT (signal processing/Radon demult etc)

INVERSION and final migration if 2 surfaces are sufficient

Figure 11: A proposed processing flow.