GEOPHYS 242: Near Surface Geophysical Imaging

Class 5: Refraction Migration Methods
Wed, April 13, 2011

- Migration versus tomography
- Refraction traveltime and wavefield migration
- The theory of interferometry
- Refraction wavefield interferometry

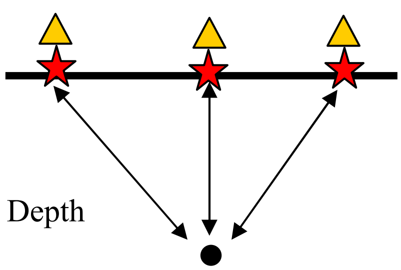
Seismic migration is mostly referred to subsurface imaging with reflection data. However, the idea can be also applied to refraction data. This class shall discuss the concepts of migration and tomography, their differences, and advantage and disadvantage of each approach. It also introduces the most recent development – applying interferometric approach to convert refraction data to "reflection data" and then to image the near-surface structures by applying migration to the converted "reflection data".

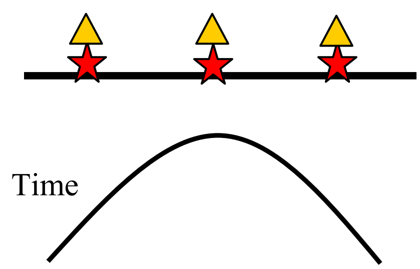
Migration versus Tomography

Tomography is to reconstruct the velocity model in the subsurface, while migration is to place an image on the reflection interface by using the velocity model as an input.

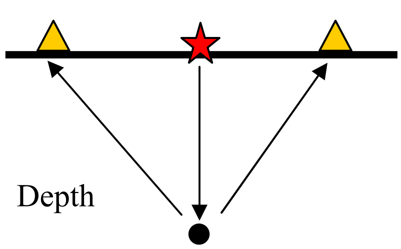
Migration Theory

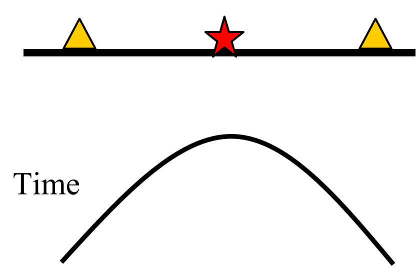
Zero-offset data (stacked) – through conventional seismic data processing





Prestack shot gather





Time Migration: collapse hyperbola to a reflection point in time by using RMS velocity
Depth Migration: collapse hyperbola to a reflection point in depth by using Interval velocity

Zero-offset data:
You have this through data processing by CMP sorting, NMO, and stacking. This does not really produce "zero-offset data," but close.

Post-stack time migration → produce time image
Post-stack depth migration → produce depth image

Prestack shot gathers (close to raw data):
It is natural. You may apply signal processing to remove noise and surface waves, but without changing geometry or *slight* changes in geometry with regularization.

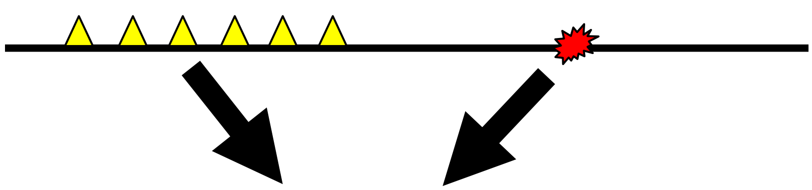
Prestack time migration (PSTM) → produce time image
Prestack depth migration (PSDM) → produce depth image

PreStack Depth Migration (PSDM):

Input: shot gathers, Interval velocity model
Output: migration image

Process:

Downward continue shot wavefield
Downward continue receiver wavefield
Apply cross-correlation at each depth

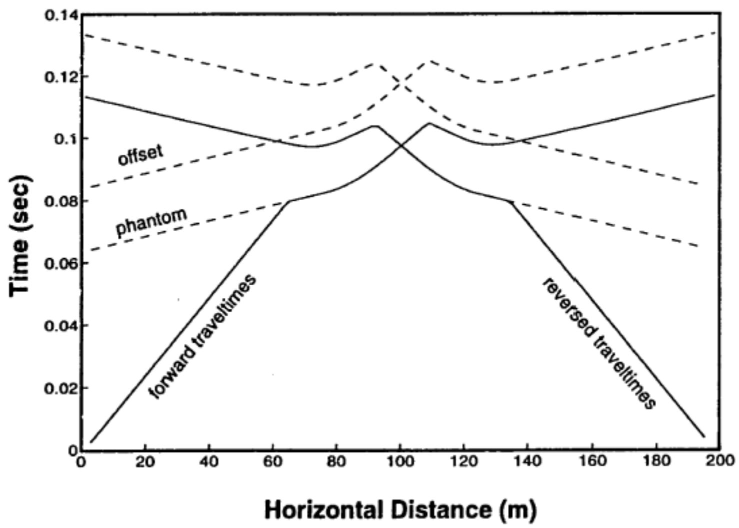


At every depth: $I(\omega) = R(\omega)\, S(\omega)$

Reference: *Imaging the Earth's Interior*, by Jon Claerbout
Free web version: http://sepwww.stanford.edu/sep/prof/iei/toc_html/

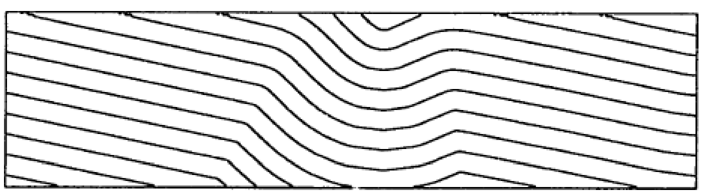
Refraction Traveltime Migration:

1) Phantom refraction data: to remove direct waves

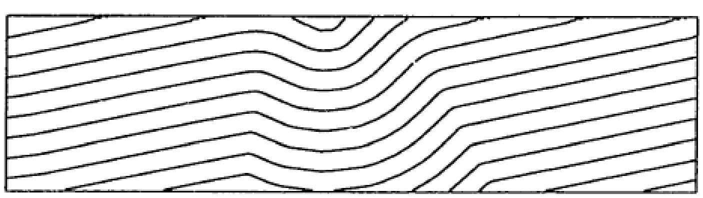


2) Downward continue both the forward and reverse shots through the entire model (Apply wavefront tracing with a line source)

a) Downward continuation of the forward traveltimes

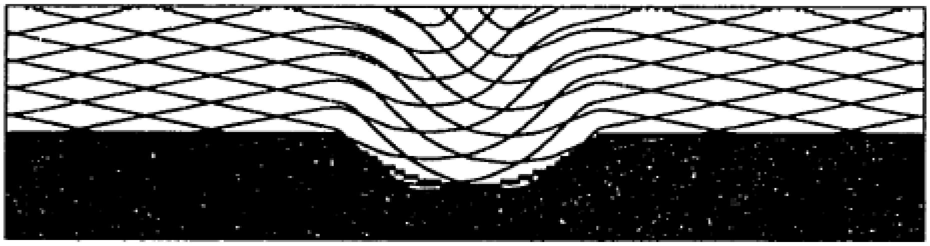


b) Downward continuation of the reverse traveltimes

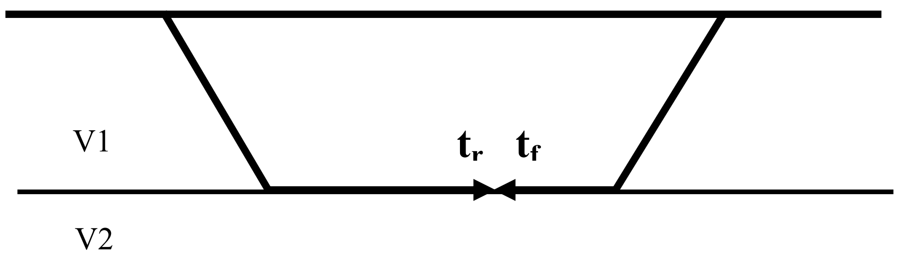


3) Apply refraction imaging principle: check the sum of the two traveltime panels, where the sum is equal to the reciprocal time.

c) Superposition of the two reconstructed wavefronts



Refraction Imaging Principle:



Refraction wavefield imaging by downward continuation:
(Hill, 1987)

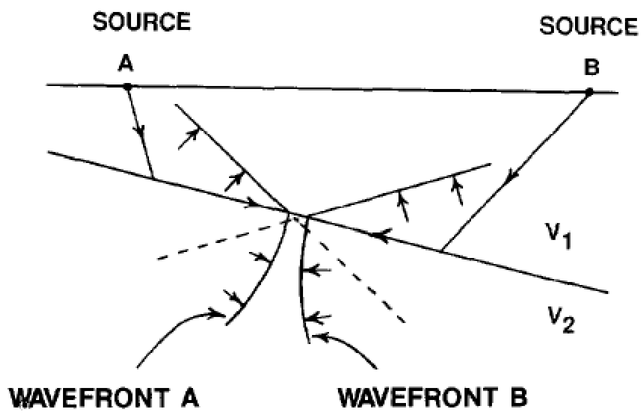


FIG. 1. Wavefronts for reversed refraction profiles. The unrefracted wavefronts (dashed line extensions) cross on the refractor boundary when $t_a + t_b = t_r$, where t_r is the traveltime from source A (source B), along the refractor, to detector B (detector A).

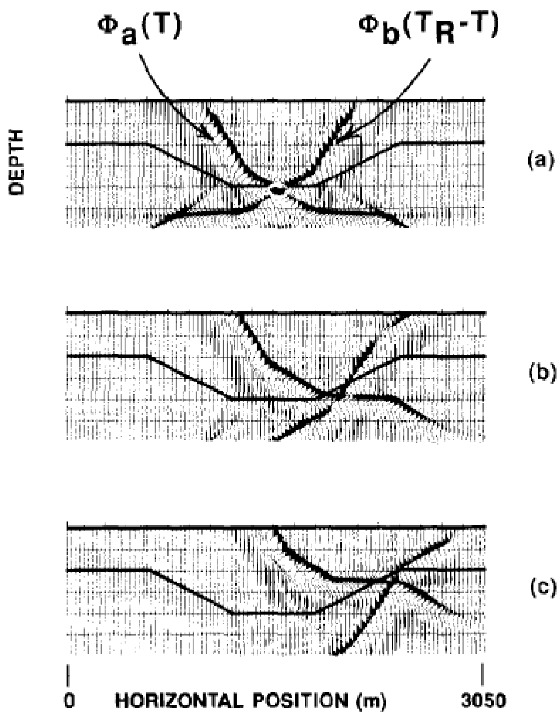


FIG. 5. Wavefronts obtained by downward continuation of the arrivals in Figure 4. The sum of the time instants of the wavefronts in each frame is equal to the reciprocal time. Frames a, b, and c correspond to $t = 0.5\ t_r$, $t = 0.6\ t_r$, and $t = 0.7\ t_r$. The wavefronts always cross on the refractor boundary.

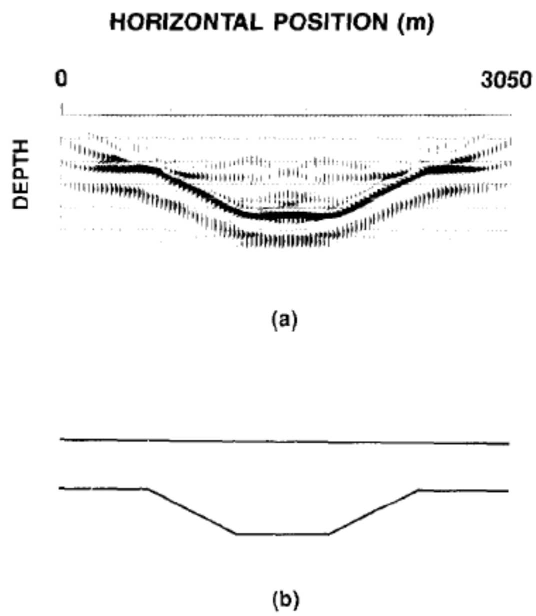
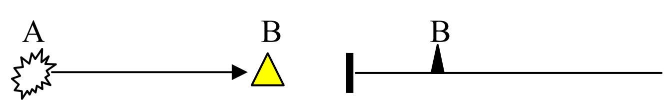


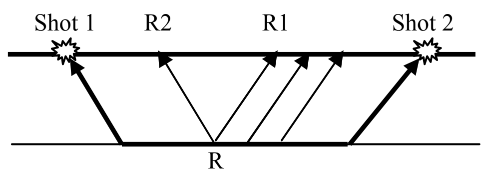
FIG. 6. (a) Image of the refracting interface obtained by downward continuation of the refracted arrivals of the forward and reversed gathers. (b) The original model.

The Theory of Interferometry: phase of common raypath cancels.

G(A|*x*) ∗ G(*x*|B) = *Im*(G(A|B))



Refraction Wavefield Interferometry:



The total refraction traveltime from Shot 1 to Shot 2 is T_R. We want to derive a reflection wavefield with a path from R2 to R and then R1, converting R2 to a source point. If we denote this reflection traveltime as T_{rfl}, then:

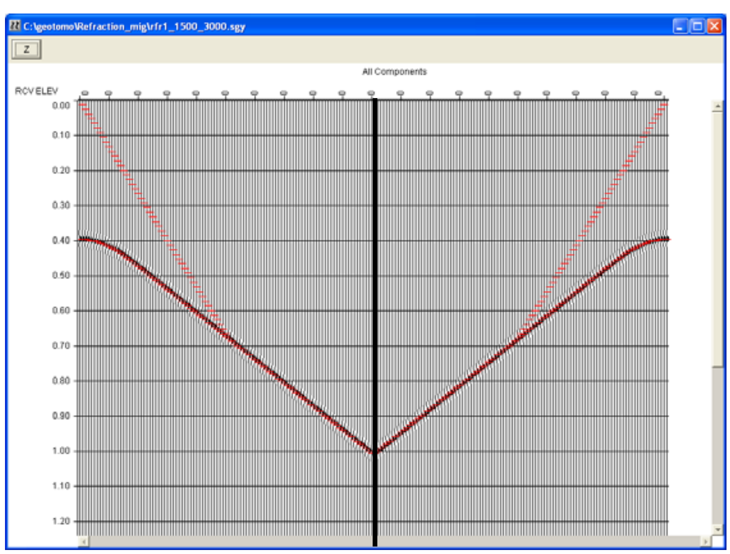
$$T_{rfl}=T_{R1}+T_{R2}-T_R \qquad (1)$$

Where, T_{R1} is the refraction traveltime from Shot 1 to receiver R1, and T_{R2} is the refraction traveltime from shot 2 to R2. We can rearrange the above equation (1) to the following:

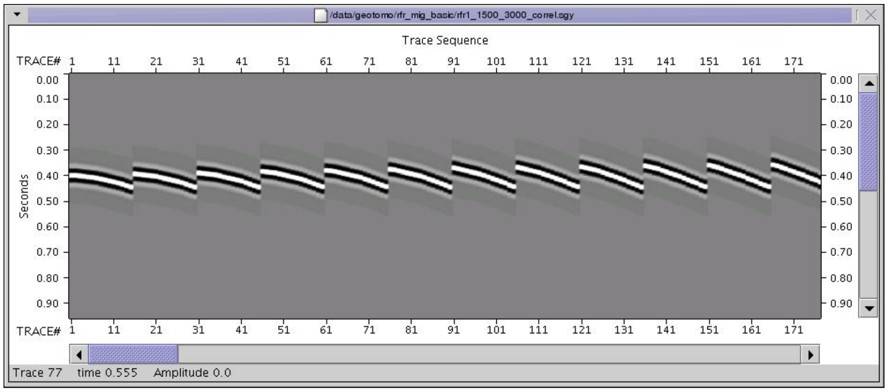
$$T_{rfl}=T_{R2}-(T_R - T_{R1}) \qquad (2)$$

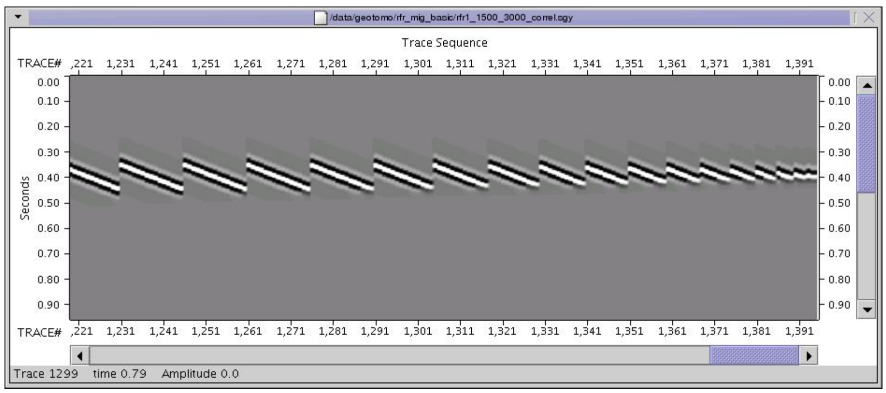
Above equation suggests that we can create reflection gathers from two shot records by performing two loops of correlations. First, the last trace of shot 1 (at the point of shot 2) is correlated by every trace in the shot 1 record, and place the results at each trace location. This correlation will create (T_R - T_{R1}) gathers. And then every *ith* trace in the record of shot 2 will be correlated by those correlated traces of shot 1 on the right side of the *ith* receiver. This loop creates gathers with events following $T_{R2}-(T_R - T_{R1})$.

Raytracing for refractions: forward and reverse shots

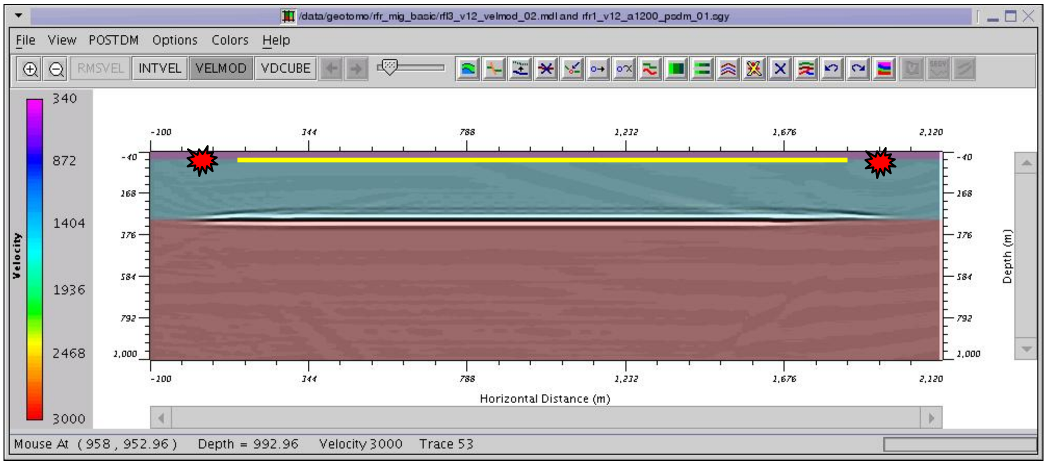


Refraction Interferometric Gathers:

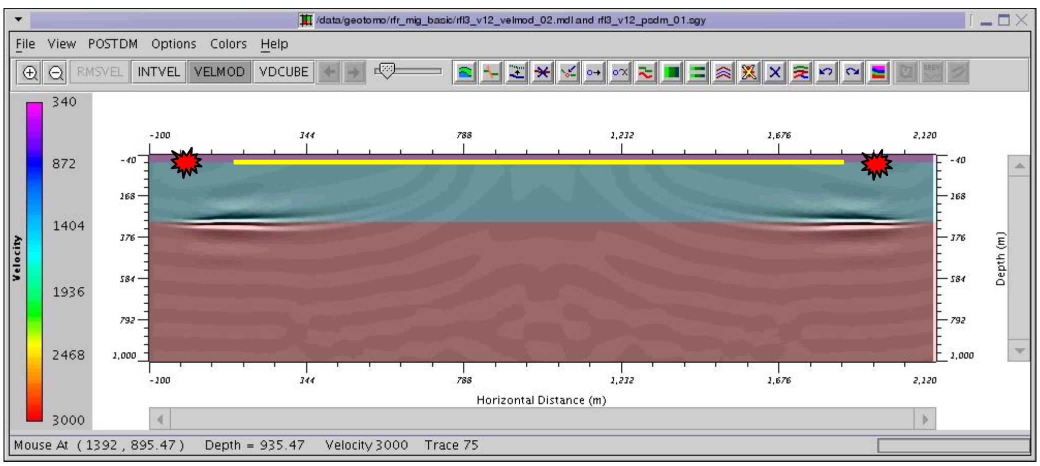




Apply PSDM to Refractions with overburden velocity for migration:



Migrate Reflections with PSDM:



References:

Rockwell, D. W., A general wavefront method, in Musgrave, A. W., Ed., Seismic refraction prospecting, *Soc. Expl. Geophys*., pp. 363-415, 1967.

Hill, R., 1987, Downward continuation of refracted arrivals to determine shallow structures, *Geophysics*, Vol. 52, No. 9, 1188-1198.

Zhang, J., 2006, Refraction migration: imaging multiple refractors automatically, *Expanded Abstract*, SEG 71st Annual Meeting in New Orleans, Louisiana, p2426.