Seismic Modeling, Migration, and Velocity Inversion

Available Data and Migration

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Outline

1. **A Preliminary Workflow**
   - Isotropic Workflow
   - Anisotropic Workflow
2. **Available Data**
   - Reflection Seismic
     - Land
     - Marine
   - Borehole Seismic
     - Well Logs
     - Dipole Sonics
     - VSP's and Checkshots
3. **Migration**
   - Kirchhoff
   - Wave Equation
4. **Aliasing**

Outline

Isotropic Workflow

- Find v_{nmo}
  - Best isotropic imaging velocity
  - Done with available data
- If no anisotropy, DRILL
  - Acquire Sonics, Dipole Sonics, VSP, 3D VSP, Walkways, check shots
  - Determine just how bad your depth estimates really were
  - If depths an fault positioning is off — ANISOTROPY

Anisotropic Workflow

- Given v_{nmo} find δ
  - Miss tie analysis
    - Assumes one has a well and can determine the miss ties
    - δ scans to make markers tie image
  - Local inversion of Walkaway or 3D VSP (see FWI)
  - Guess based on experience
  - Extrapolation of sparse well bore data
- Find ϵ
  - Scans
  - Residual depth analysis
- Determine the two symmetry angles
  - Some fraction of the dip normal
  - Automatic dip determination
- Iteratively migrate until you're blue in the face

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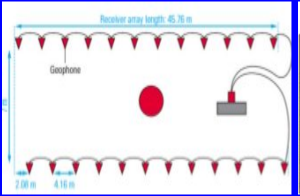
Reflection Seismic

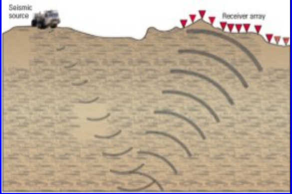
For imaging the subsurface, seismic (sonics) is the most important and useful data we acquire. It provides us with the redundancy necessary to estimate background subsurface sound speeds (velocities). While frequently acquired using schemes designed to optimize fold, the shot array is mathematically the most important ingredient for achieving optimum seismic acquisition. To avoid aliasing and enhance migration dip responses sampling increments must be chosen carefully.

Sources and Receivers

(a) Source Arrays



(b) Receiver Arrays



(c) Receiver Takeouts

- Seismic acquisition usually uses source arrays, receiver arrays, and receiver takeouts
  - The underlying mathematical physics assumes point sources and point receivers
  - Arrays are not encompassed within the theory
- Data are redundant and digital
- Organized by shot profile and surface offset

Sources and Receivers

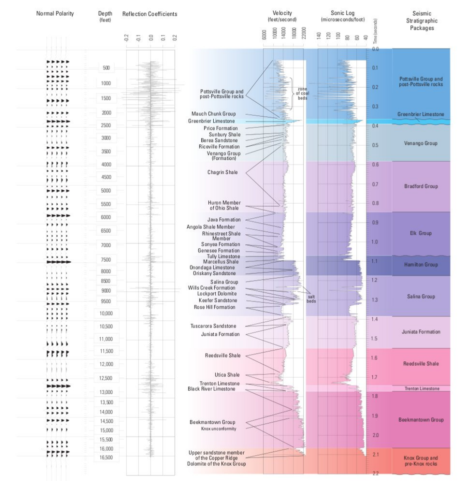
(a) Gunboats for OBC and NODES

(b) Gunboat and Surface Cable(s)

- Marine acquisition uses surface cables, subsurface cables, or fixed nodes
- Data are highly redundant and digital
- Organized by shot profile, receiver profile, and surface offset
- OBC and NODAL data are essentially land acquisition schemes

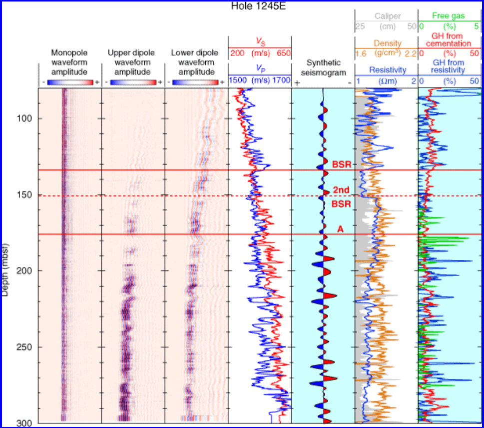
Sonics

- Single source/receiver pair
  - Up borehole
  - Records *dt*
- Uses
  - Time-depth miss ties
  - Vertical sound speed
  - Guess at δ



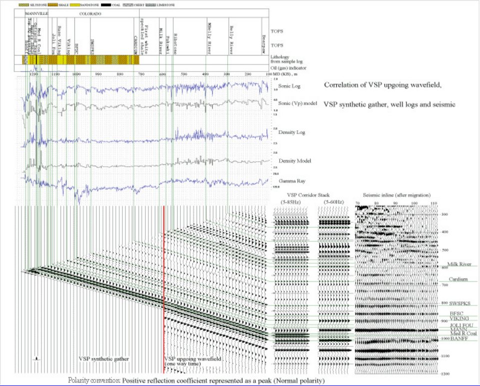
Dipole Sonics

- Source and receiver array
  - Moves up (down) borehole
  - Borehole reflection method
- Determination of
  - Time-depth ties
  - Depth migration miss ties
  - Vertical P & S velocities
  - Estimation of δ
  - Estimation of γ
    - With $v_{s_{nmo}}$

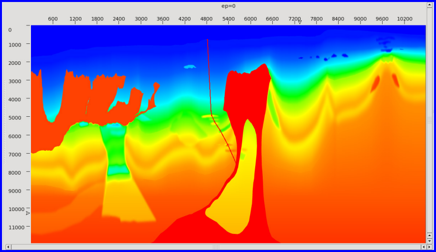


VSP's and Checkshots

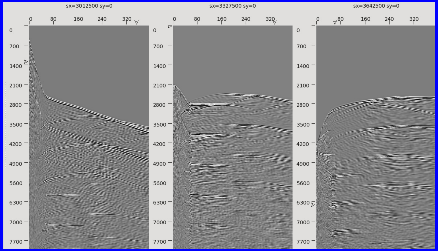
- Surface sources borehole receivers
  - 4-8 sources per receiver string
- Best for determination of
  - Time-depth ties
  - Vertical P and S velocities
  - Estimation of δ
  - Estimation of γ
    - With a shear image
    - v_{Snmo} required
- Revising the current Earth Model
- Checkshot is poor man's VSP



Walkaway Synthetic VSP

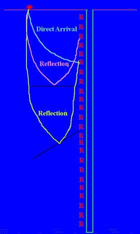


(c) Model and Borehole

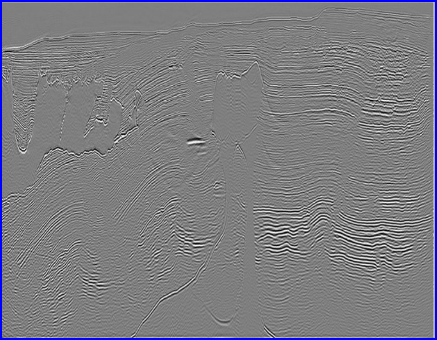


(d) Example VSP's

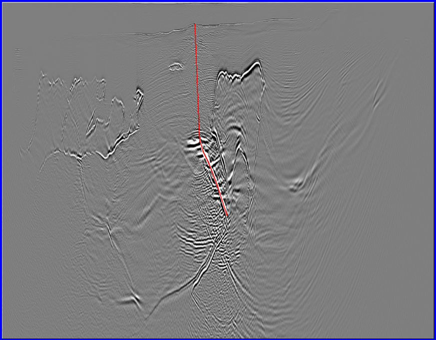
- Velocity model and with borehole (a)
- Sample VSP's (b)
- Source at water bottom
- Borehole receivers
    - Small number for each shot



VSP and RTM Image



(e) RTM Image

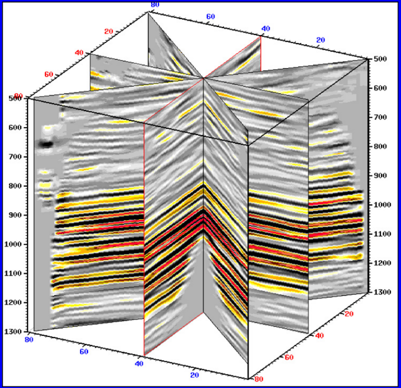


(f) Walkaway VSP Image

- Full RTM image of prestack data using exact model
- Full RTM image of prestack VSP data using exact model

3D VSP's and Walkaways

- Provide
  - Estimates of δ and ϵ over a wide range.
    - Walkways provide data over a line.
    - 3D VSPs provide data over a conical volume
- Significant impact on estimation of full Earth model



Well Bore Data Issues

- Borehole measurements are sparse
- Estimating Thomsen parameters requires mathematical extrapolation
  - The accuracy of such processes is not clear
  - Sometimes done statistically using surface seismic as a guide
- Borehole measurements coupled with surface data
  - Provide good local estimates of δ
  - Provide good local estimates of ϵ
    - With additional sonic type measurements – VSP, walkways, checkshots, $\cdots$

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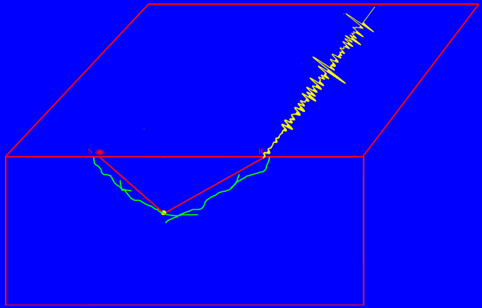
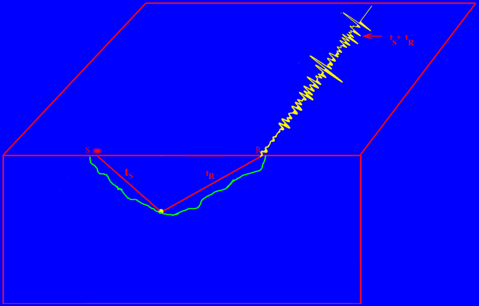
What does seismic migration do?



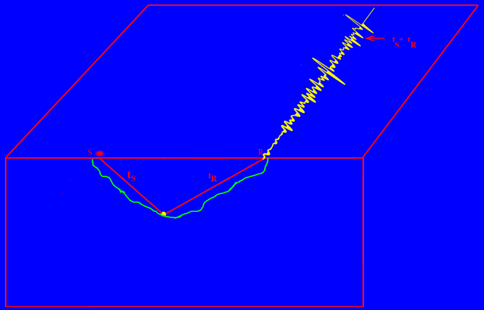
Seismic migration recovers approximate reflection amplitude responses at each subsurface by spraying calculated amplitudes over equal-traveltime (green curve) locations. Equal-traveltime curves need not be smooth. They can be multi-valued.

What does Krichhoff isotropic time migration do?



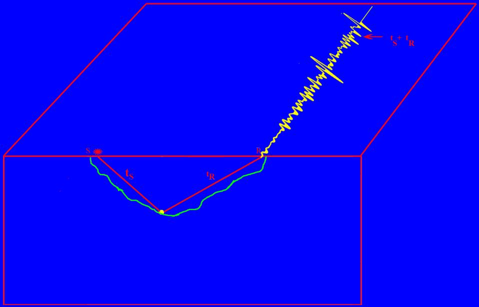
- Computes t_s and t_r using $t = \sqrt{t_0 + \frac{h^2}{v_{rms}^2}}$
- Corrects the trace amplitude at $t_s + t_r$ for energy loss
- Sums the result into the image point (single valued)

What does Krichhoff VTI time migration do?



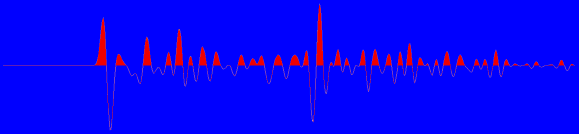
- Computes t_s and t_r using $t^2(h) = t_0^2 + \frac{h^2}{v_{nmo}^2} - \frac{(v_{hor}^2 - v_{nmo}^2)h^4}{v_{nmo}^2(t_0^2 v_{nmo}^4 + 1.2 v_{hor}^2 h^2)}$ or
- $t^2(h) = t_0^2 + \frac{h^2}{v_{nmo}^2} - \frac{2\eta h^4}{v_{nmo}^2(t_0^2 v_{nmo}^2 + (1+2\eta)h^2)}$
- Sums corrected amplitude at $t_s + t_r$ into image point (single valued)

What does Krichhoff depth migration do?

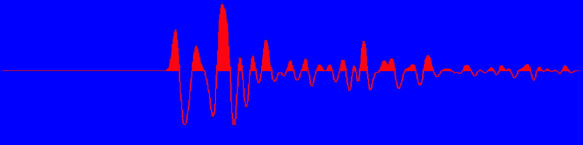


- Raytraces in full 3D Earth Model to compute t_s and t_r
- Corrects the trace amplitude at $t_s + t_r$ for energy loss
- Sums the result into the image point. Can be single or multi-valued

What do wave equation migrations do?



(a) Forward propagated source at image point

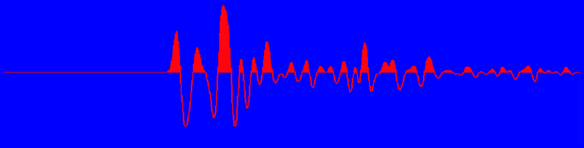


(b) Trace recorded at receiver

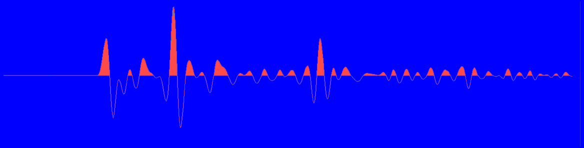
- Forward propagates the source with amplitude E (top) to the image point
- Amplitude at image point is EA_s where A_s is path loss

The decay from the image point to the receiver is denoted A_r

Imaging a Point — Frequency by frequency



(a) Trace recorded at receiver

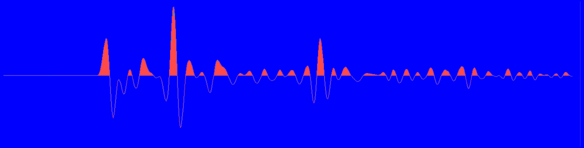


(b) Back Propagated Receiver

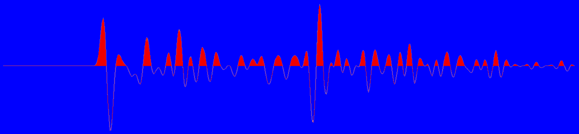
- Back propagates recorded trace to image point removes the A_r decay
- Amplitude of the back propagated trace is thus $\rho v E A_s$

Here ρv is the reflectivity at the image point

Imaging a Point — Frequency by frequency



(a) Back propagated receiver at image point

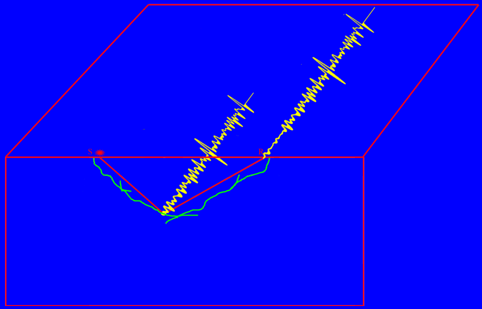


(b) Forward propagated source at image point

- Frequency domain divide of forward by backward traces at image point
- Amplitude at image point $\approx \frac{\rho v E A_s}{E A_s}$

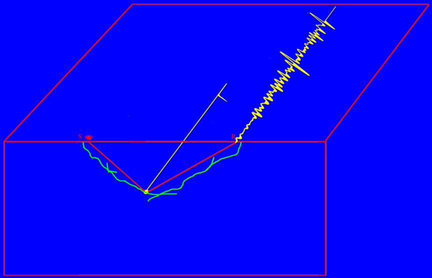
Amplitude at image point is proportional to ρv

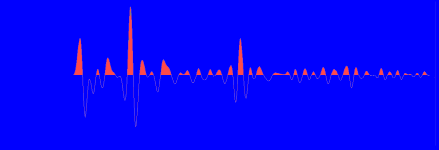
So wave-equation migrations



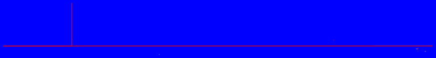
- Forward propagates the source to a trace at the image point
- Back propagates receiver trace to image point
- Cross-correlates (frequency domain divide) the two traces
- Sums the zero-lag cross-correlation into the image point
  - Multiple arrivals

Actually they both work the same way





(a) Back propagated receiver at image point



(b) Forward propagated source at image point

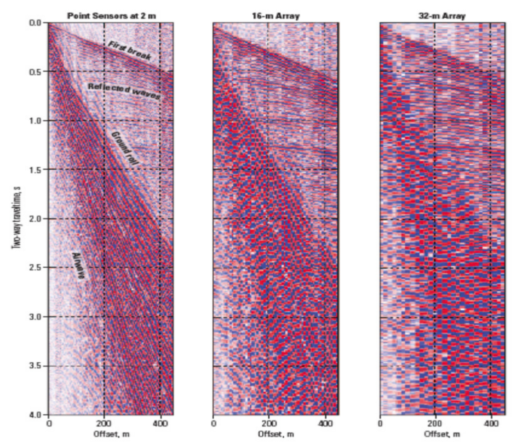
Outline

What is Aliasing

Aliasing is what happens when the digital sampling interval is too large. Because movie images are sampled at 30 frames/sec, automobile or wagon wheels may appear to rotate slower or in reverse direction of the rate of revolution is greater then 30.

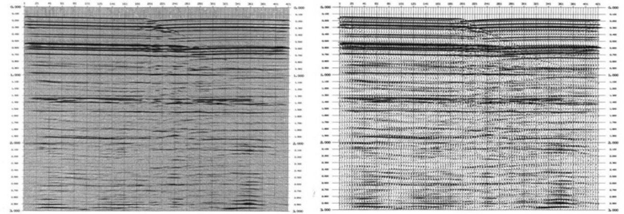
Aliasing during Acquisition

- Array effects
  - Left
    - Little
  - Middle
    - Strong
    - Mixed
    - Low frequency
  - Right
    - Severe
    - Severe mixing
    - Lower frequency
- Suppression
  - Left - Easy
  - Middle - Difficult
  - Right - Impossible



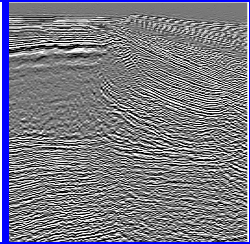
Ground roll here is traveling at approximately 160 m/s.

Aliasing during processing



(a) Zero offset section. CDP spacing = 27.5' (b) Zero offset section: CDP spacing = 110'

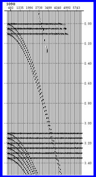
(a) Stacked Sections



(b) Migration

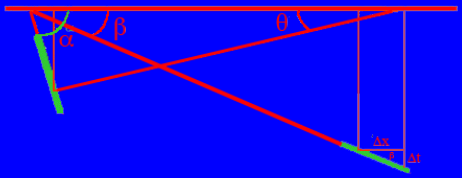
Aliasing in seismic data can take many forms.

- Offset (pre-stack)
- Aliasing in time (pre- and post-stack)
- Aliasing in depth (after migration)



(c) Offsets

Rules of Thumb



To avoid aliasing

$$\tan\beta \geq \frac{2v\Delta x}{\Delta t}$$

With $f_{max} = \frac{.5}{\Delta t}$ and $\sin\alpha = \tan\beta$

$$\begin{aligned} \Delta x &\leq \frac{v}{4f_{max}\tan\beta} = \frac{v}{4f_{max}\sin\alpha} = \frac{v}{4f_{max}\cos\theta} \\ f_{max} &\leq \frac{v}{4\Delta x\tan\beta} = \frac{v}{4\Delta x\sin\alpha} = \frac{v}{4\Delta x\cos\theta} \end{aligned}$$

Questions?