Seismic Modeling, Migration and Velocity Inversion

Data and Gathers for Velocity Analysis

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Outline

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Available Data

- Vast majority is surface measured compressional data
  - Modern acquisition is changing that
- Three or four component data is becoming ”the thing”
  - At best its difficult to interpret
  - At worst is impossible to process
    - Poor acquisition
    - Low cut to high for shear data

Available Data

- Marine:
  - Generally high fold
  - Lots of narrow azimuth data
  - Since 2007 increasing amount of WAZ data
  - Large amount of perhaps poorly understood OBC data
    - Four component vector data including two shear phones
    - Difficult to process
    - Land data ”qualities”
  - Pioneering work done by AMOCO (BP) at Valhall in Norway
    - Anisotropic
    - Chalk

Available Data

- Land:
  - Poorly understood near surface
    - Demands costly small spatial sampling
    - For velocity analysis and noise suppression
  - Poorly sampled
  - Lots of 2D and coarse 3D
  - Multi-component extremely difficult to process

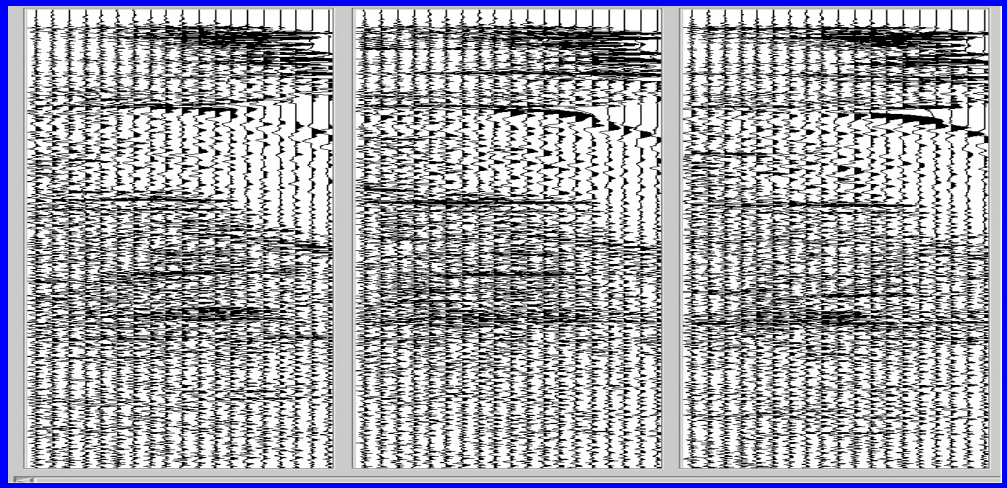
Available Data

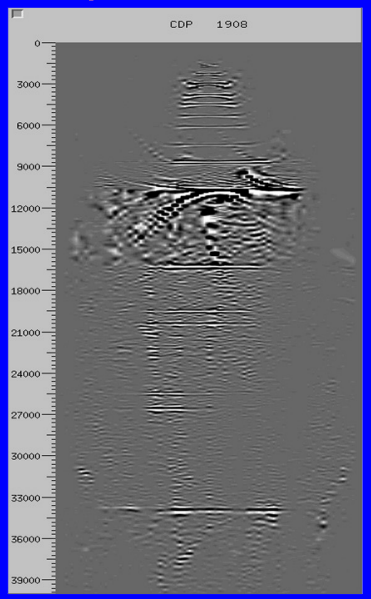
- Sparse borehole data
  - Generally located around producing fields
  - Frequently very old
- VSP, Walkaways
  - Sometimes considered an expensive unnecessary after-the-fact option
  - Could be crucial in determining local anisotropic parameters
- 3D VSP
  - See first sub-item above
- Checkshots
  - Relatively inexpensive but still considered to be an unnecessary option

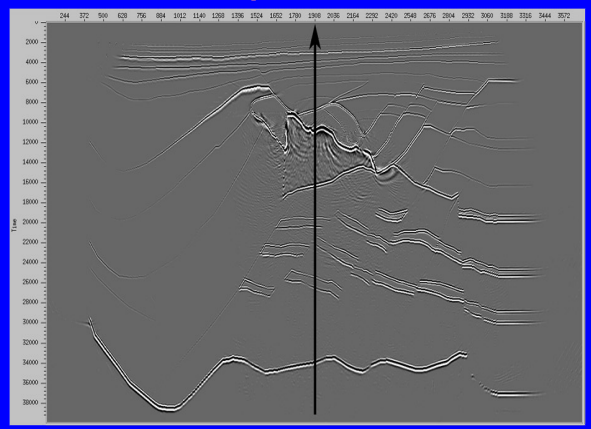
Outline

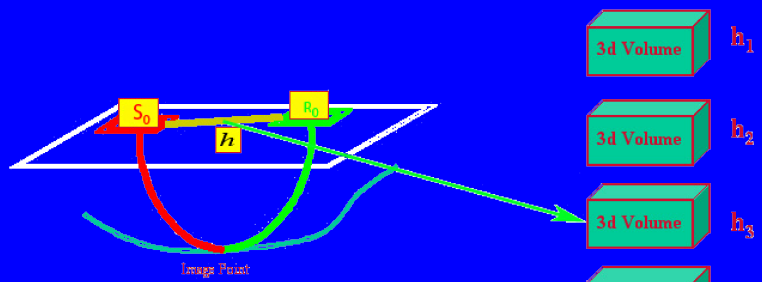
Surface Gathers

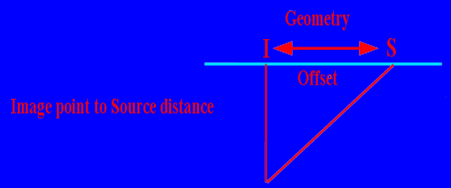
- Common source
- Common receiver
- Surface mid-point (CDP)
  - Time or Depth
- Source-receiver offset
  - Time or Depth
  - Common offset (COG)
  - Common image (CIG)
    - After migration
- Source to image distance
  - Depth only





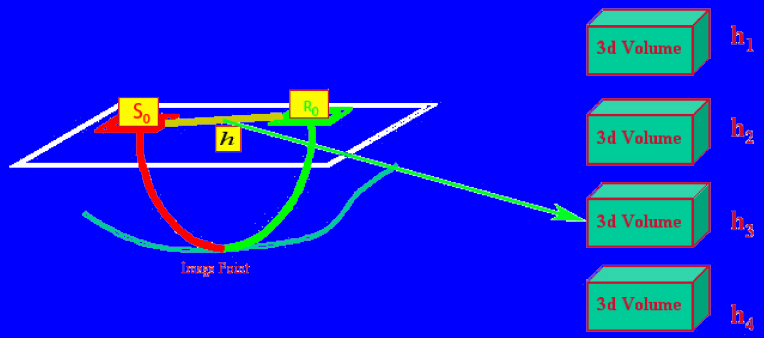


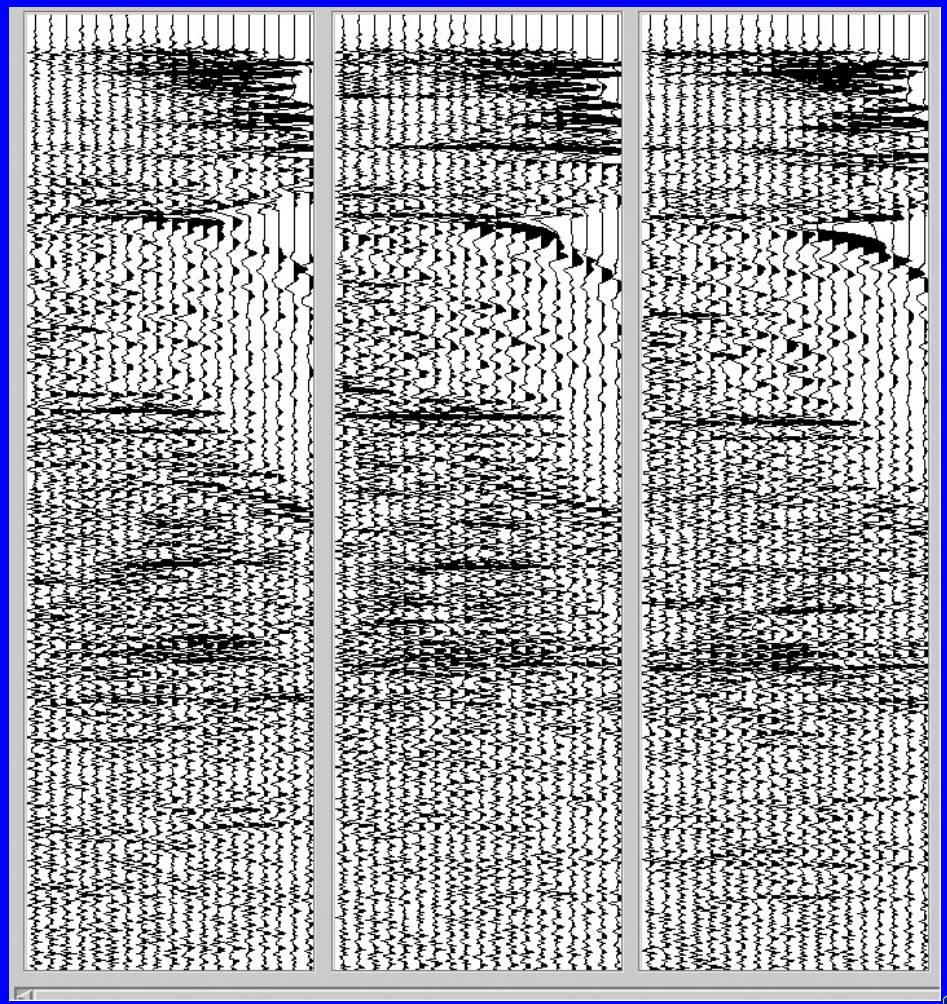




Common Image Gathers

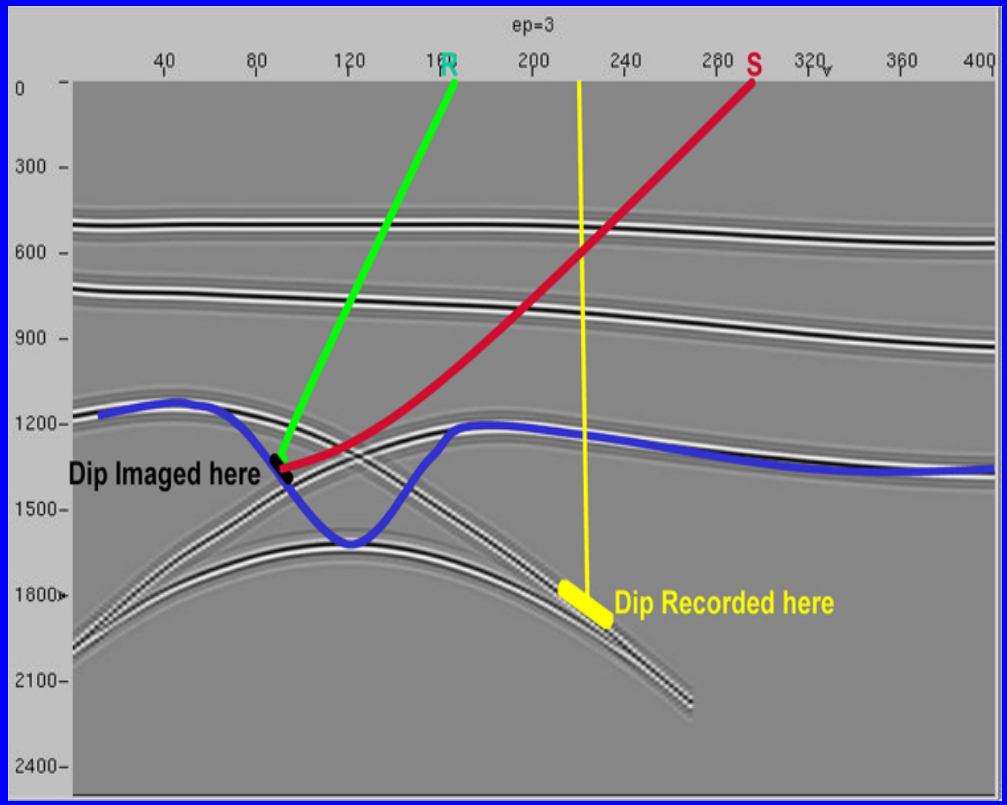
- Offset-by-offset migration
- Mid-point sort
- Gather at each XLINE/LINE





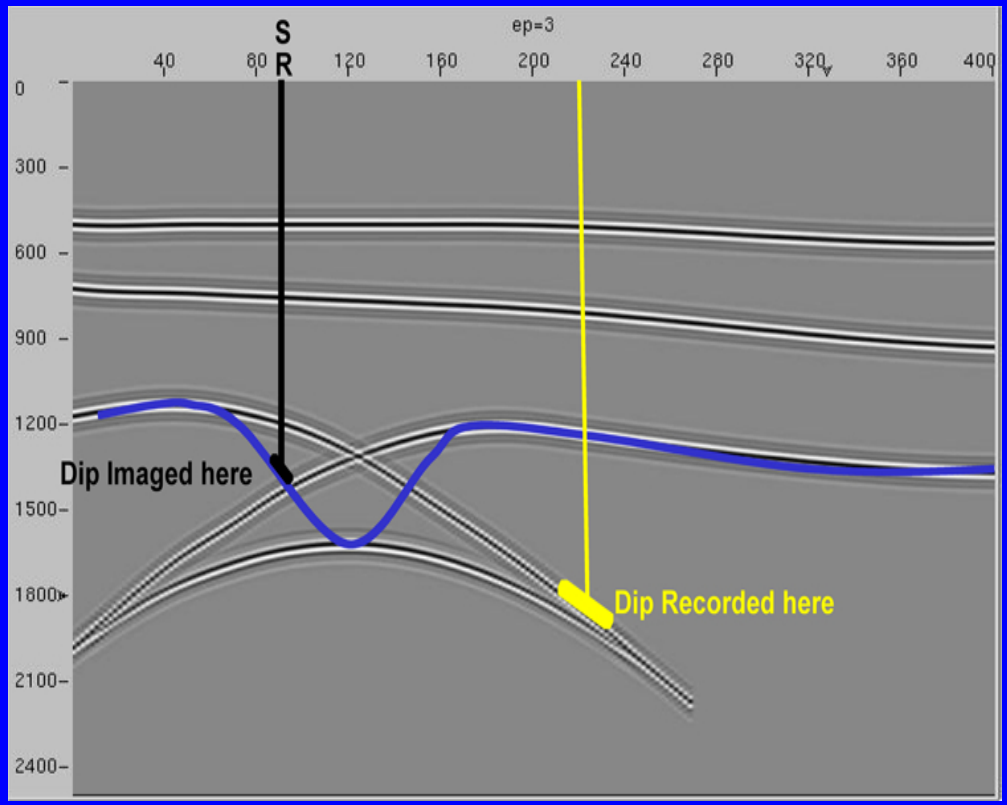
Gather Geometry

- Prior to migration
  - Reflection at midpoint
- After migration
  - Reflection at image point
- Incorrect Velocity
  - Reflection $\approx$ image point



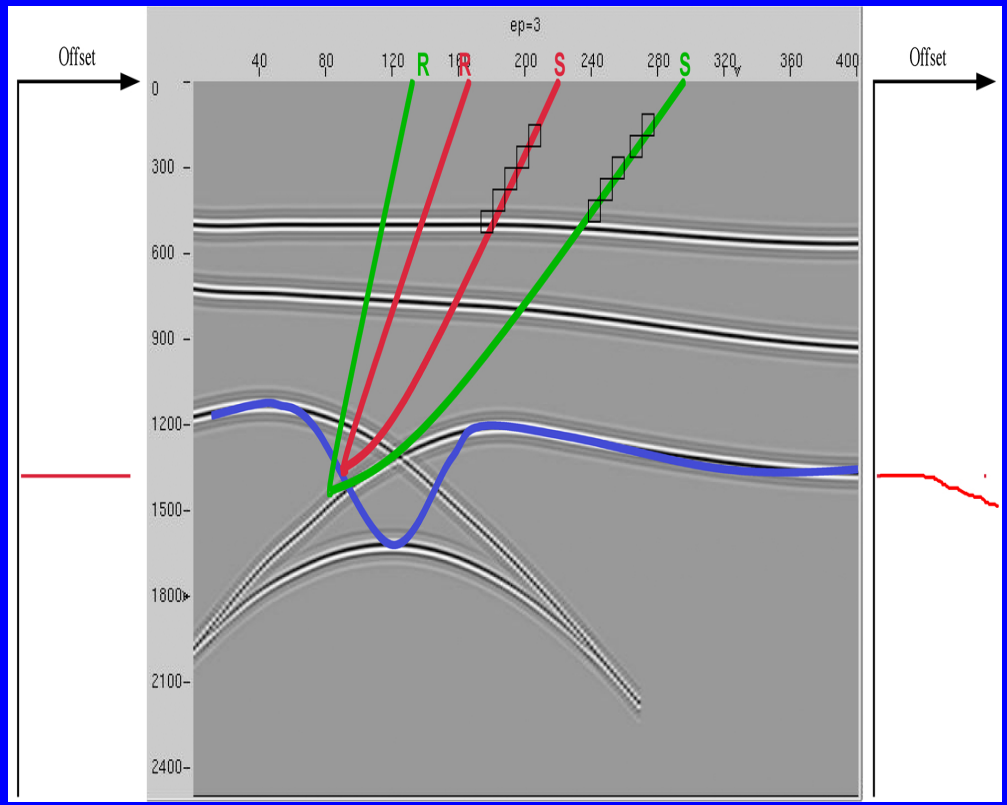
Gather Geometry

- After migration
  - Source = Receiver.
  - Zero-offset section
  - Offsets
    - Lost
    - Migrated independently



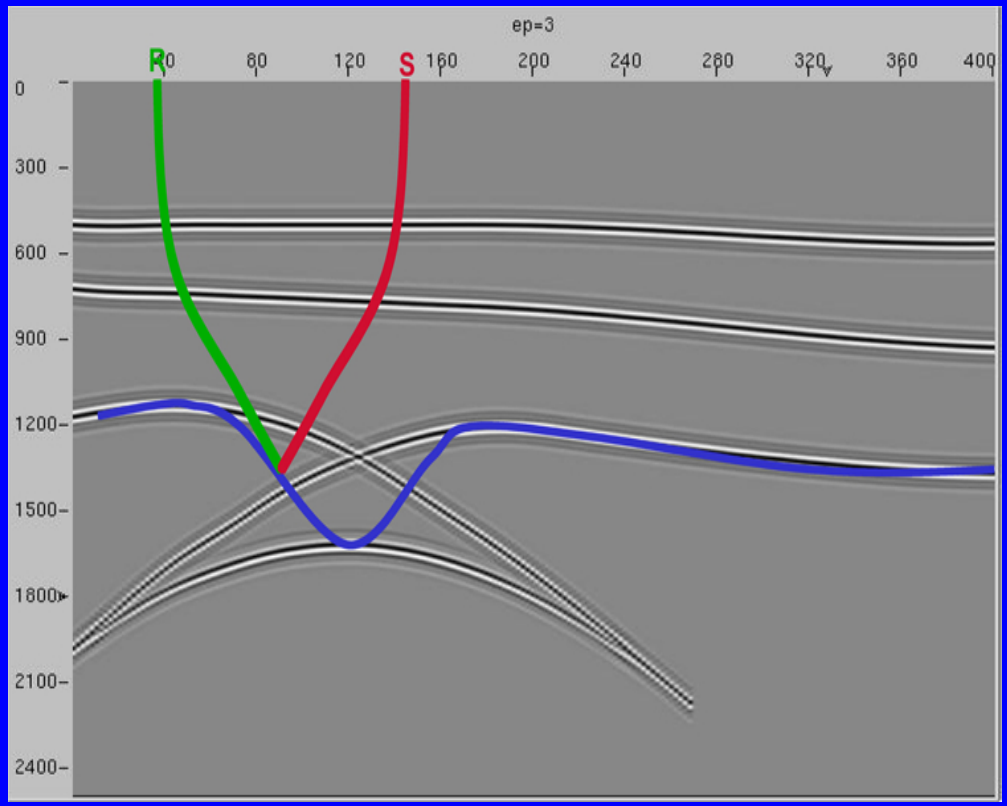
Gather Geometry

- Correct Velocity
  - Image point depth fixed
  - Both red and green offset
  - Offset gather flat
- Incorrect Velocity
  - Image point depth varies
  - Red shallower then green
  - Offset gather not flat
- Velocity error
  - At image point
    - Not vertically above
    - Close?
  - Along ray paths



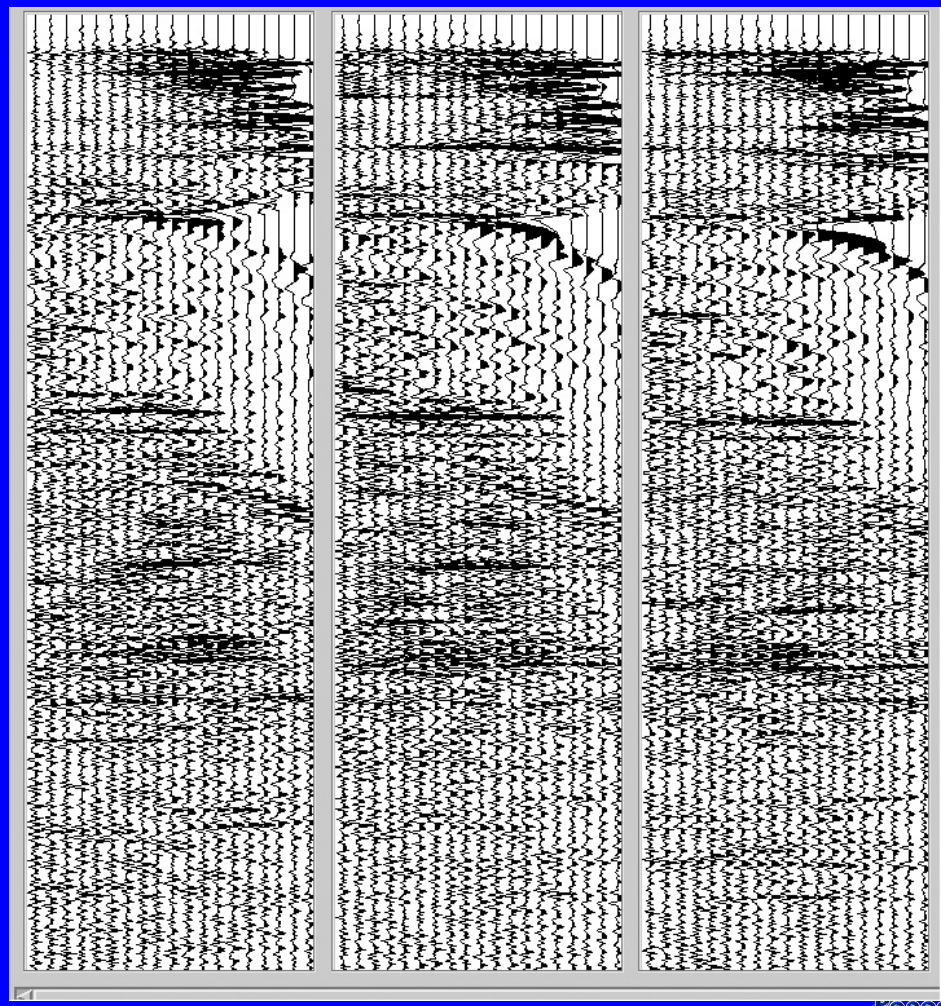
Offsets

- Assumptions
  - Offset=$|S - R|$ preserved
  - Midpoint above image point
- Basis for MVA



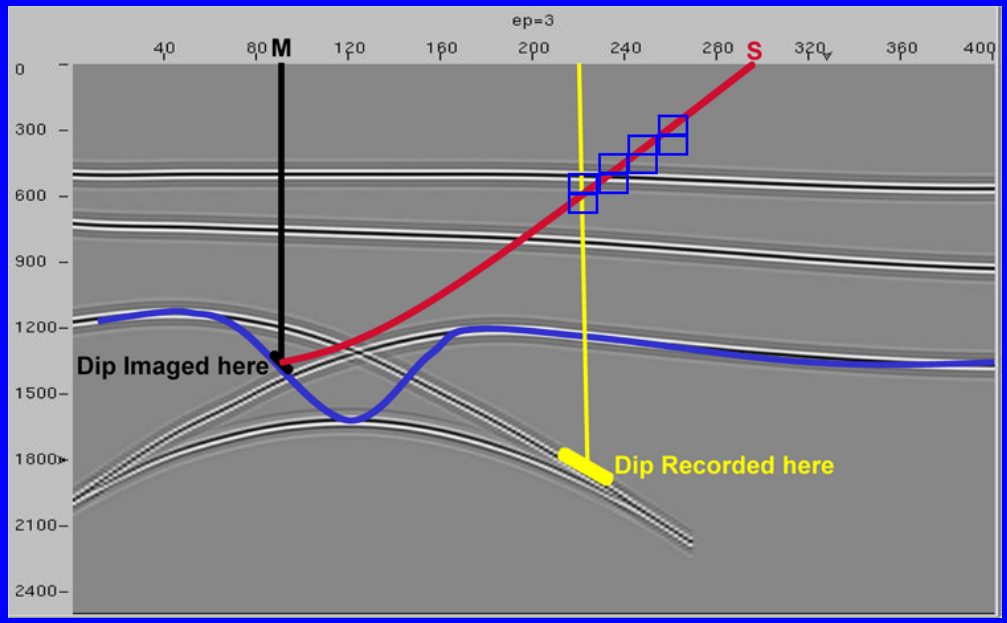
Common Offset Image Gather

- Typical CIG's.
- Smallest offset trace on left
- Largest offset trace on right
- Low amplitudes indicate presence of salt



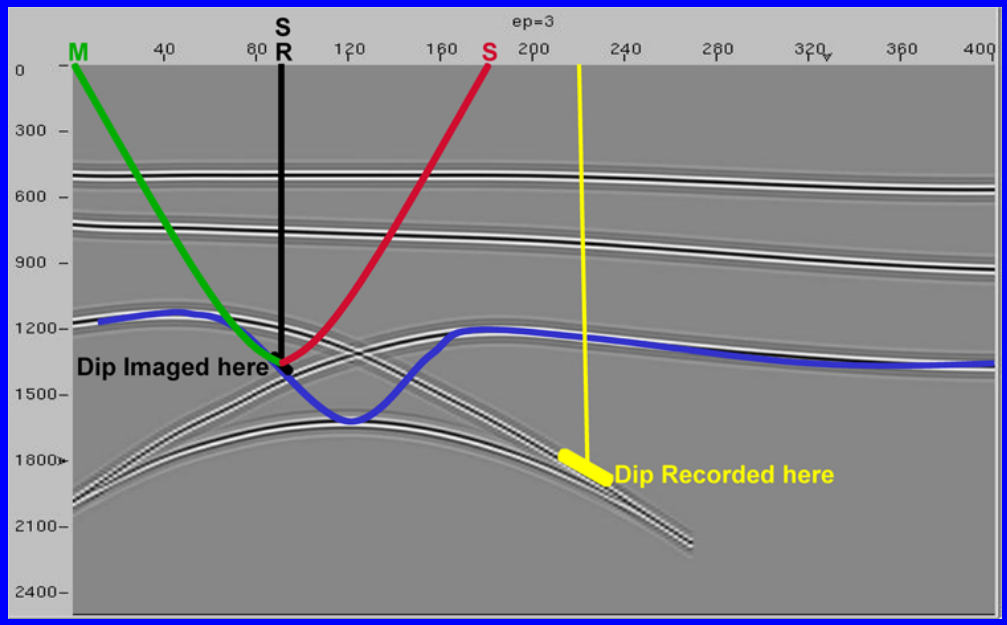
Shot Profile Image Gathers (SPIG)

- Shot Profile Migration
  - Receiver location lost
  - Shot location kept
- For any midpoint M
  - $|S - M|$ is an offset
- Correct Velocity
  - Flat $|S - M|$ gather
- Wavepath is one-sided
  - Velocity errors not local
  - Along shot path

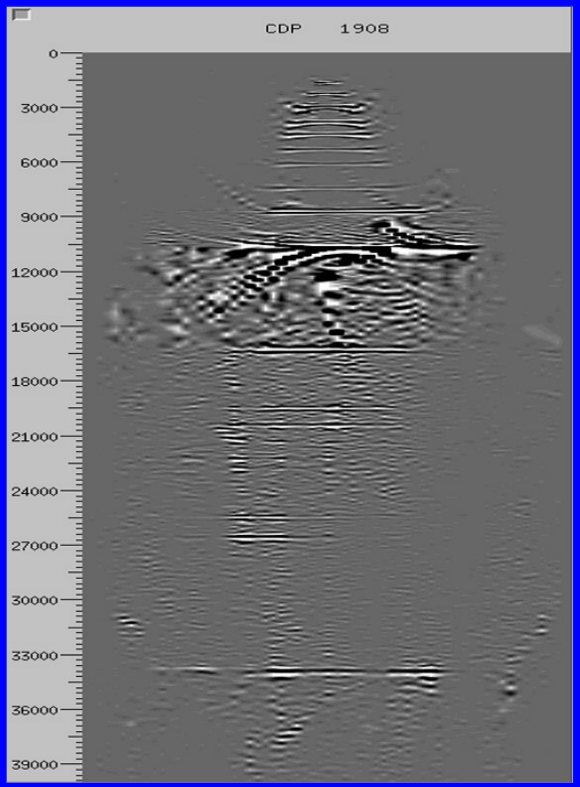


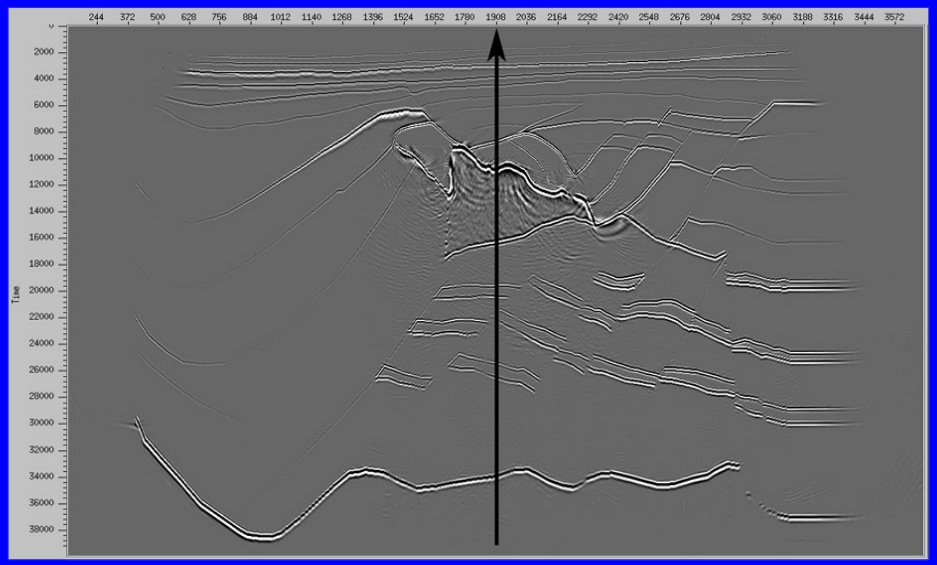
SPIG

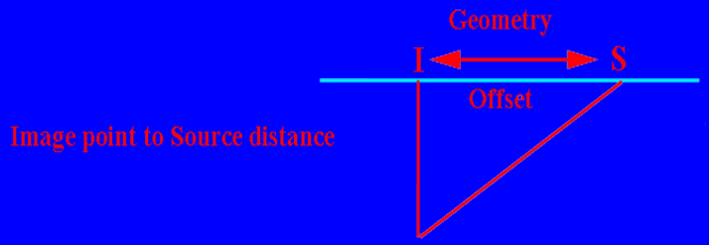
- Gather formation
  - Offset $= .5 \times |S - M|$
- Velocity Correct
  - Gather flat
- Velocity incorrect
  - Gather not flat
- MVA style velocity analysis



SPIG Example

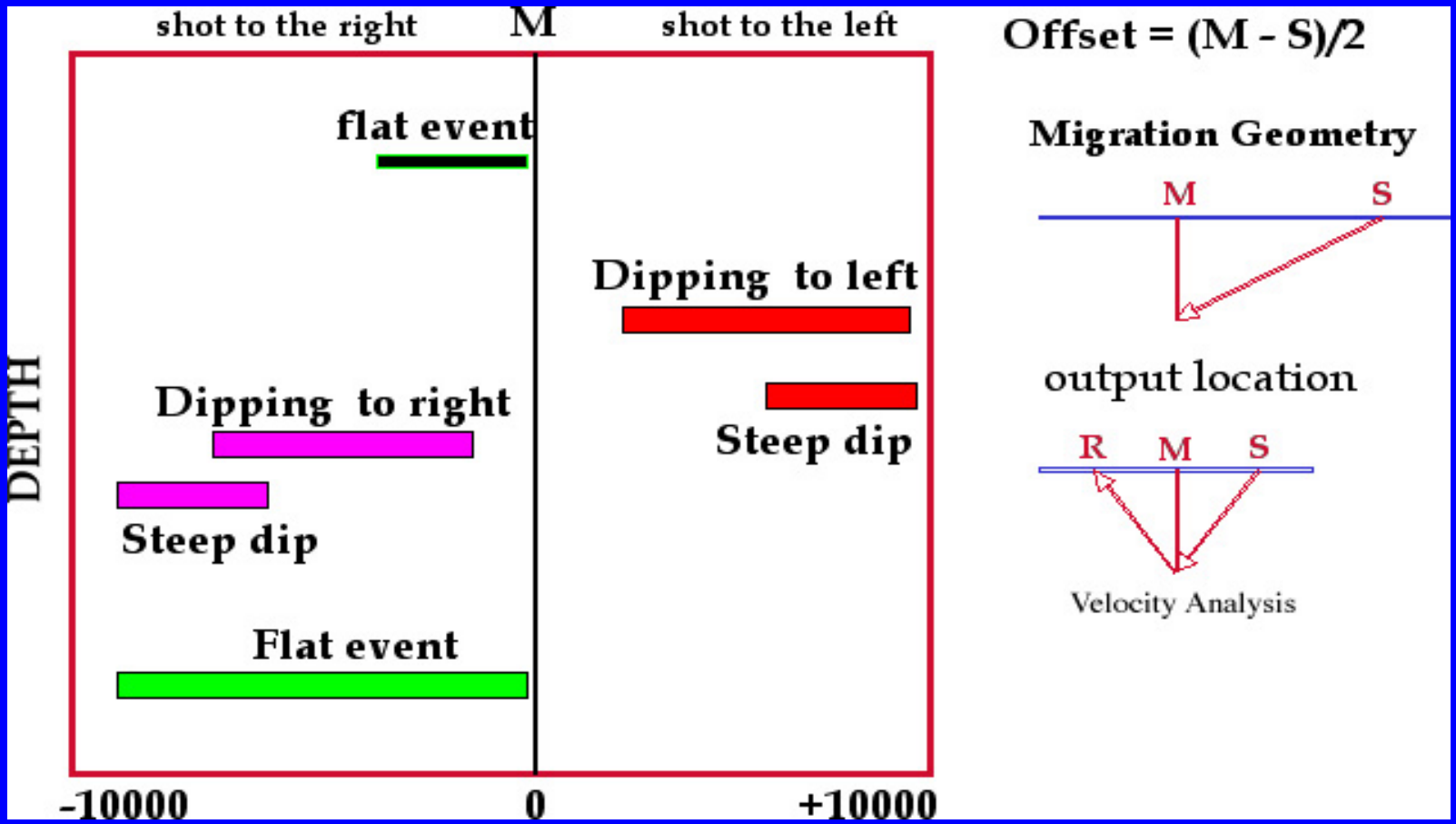






An example shot-migrated-image gather. The velocity model in this image is correct so the arrivals are flat.

SPIG Dip Identification



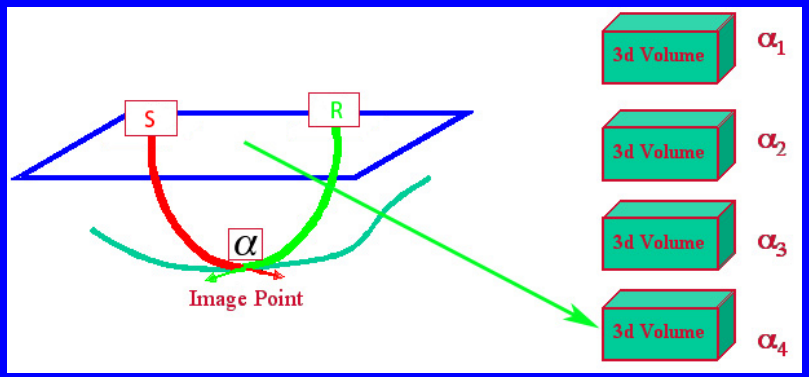
SPIG amplitudes can provide information about arrival direction and horizon dip, but since their unnormalized sum produces the image applying masks to selective amplitude regions has little affect.

CIG Notes

- Common image gathers are not a function of algorithm
- Any algorithm can produce a common offset gather
  - Kirchhoff is best known
    - Trace-by-trace
  - Beam and Gaussian Beam
    - Super gather-by-super gather
  - Shot Profile
    - Trace-by-trace
    - Super-gather-by-super gather
- They just have to be applied to individual traces or super-gathers
- Migration velocity analysis
  - Incorrect but independent of algorithm
    - Inaccuracies assumed to be vertical
    - Velocity inaccuracies occur along wavepaths
    - Hopefully, iterative application, reduces inaccuracies

Subsurface Gathers

- Calculated at Depth after migration
  - Time-Shift
  - Space-Shift
- Produces common angle gathers
  - Holding angle fixed during migration



Each gather trace is index by opening angle.

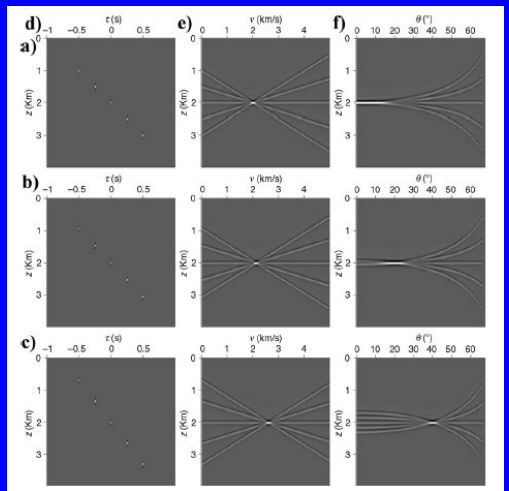


Figure 15. Image-gather formation using time-shift imaging. Horizontal rows depict events at (a) 0°, (b) 20°, and (c) 40°. Vertical columns correspond to subsampled (d) time-shift gathers, (e) slant-stack gathers, and (f) angle gathers.

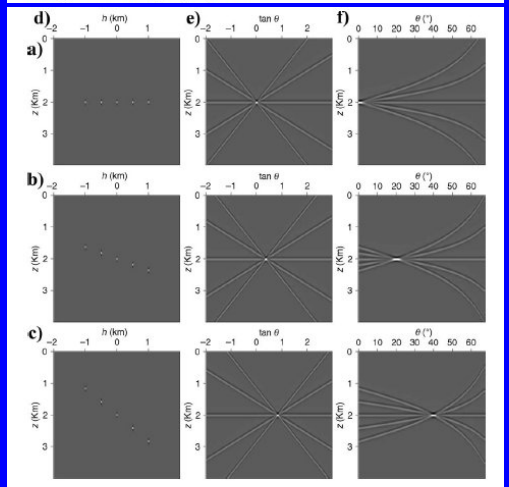
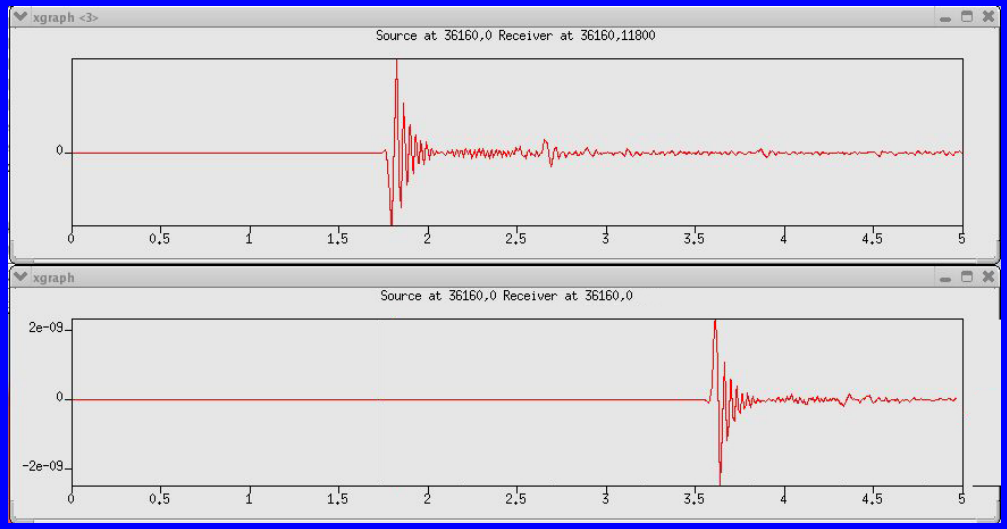


Figure 16. Image-gather formation using space-shift imaging. Horizontal rows depict events at (a) 0°, (b) 20°, and (c) 40°. Vertical columns correspond to subsampled, (d) space-shift gathers, (e) slant-stacked gathers, and (f) angle-gathers.

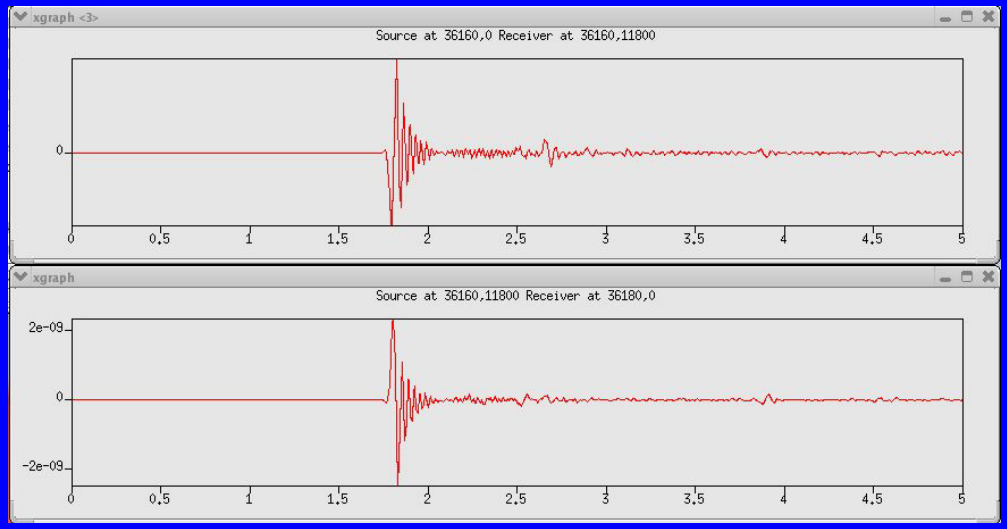
Shift Gathers

- Top - image point source trace
- Bottom - receiver trace



Exploding a Point Reflector

- Top - image point source trace
- Bottom - receiver trace
  - After back propagation
  - With correct velocity



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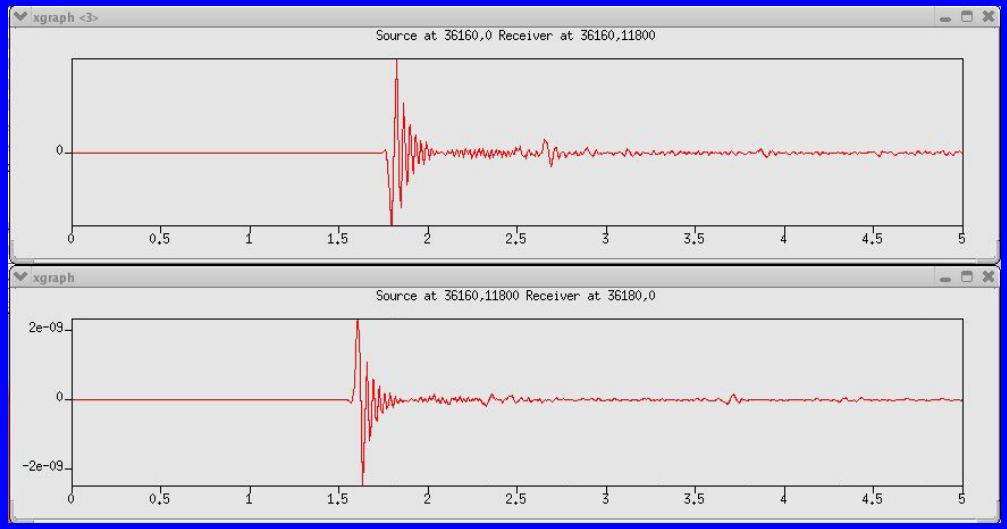
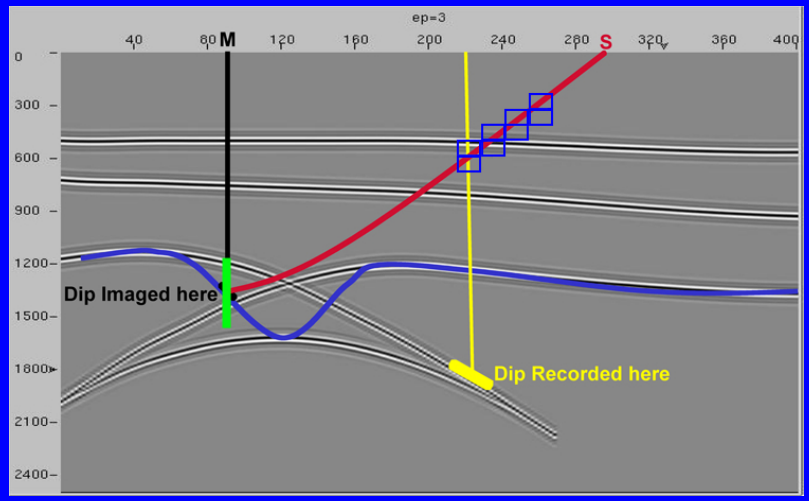
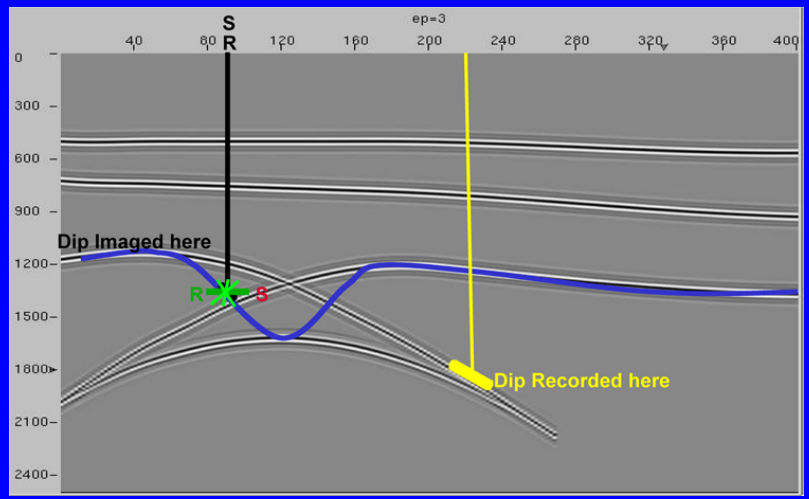


Subsurface Shift Gathers

- Time shift range
  - Indicated by green bar
  - Shift only in time
- Space-time shift gathers
  - All direction shift
  - Function of $(x, y, z, h_x, h_y, h_z, t)$
  - Seven dimensional!
  - Huge data volume
- Angle gathers
  - Through slant stacks
  - Produces opening angle
  - And local dip

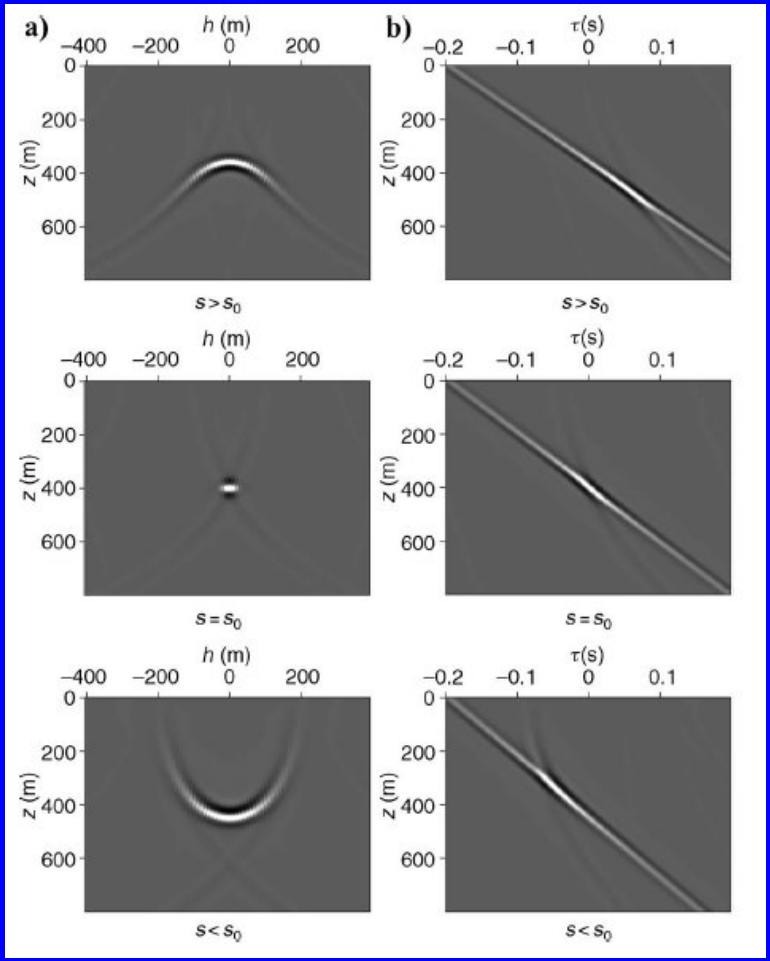


(a) Time Shift

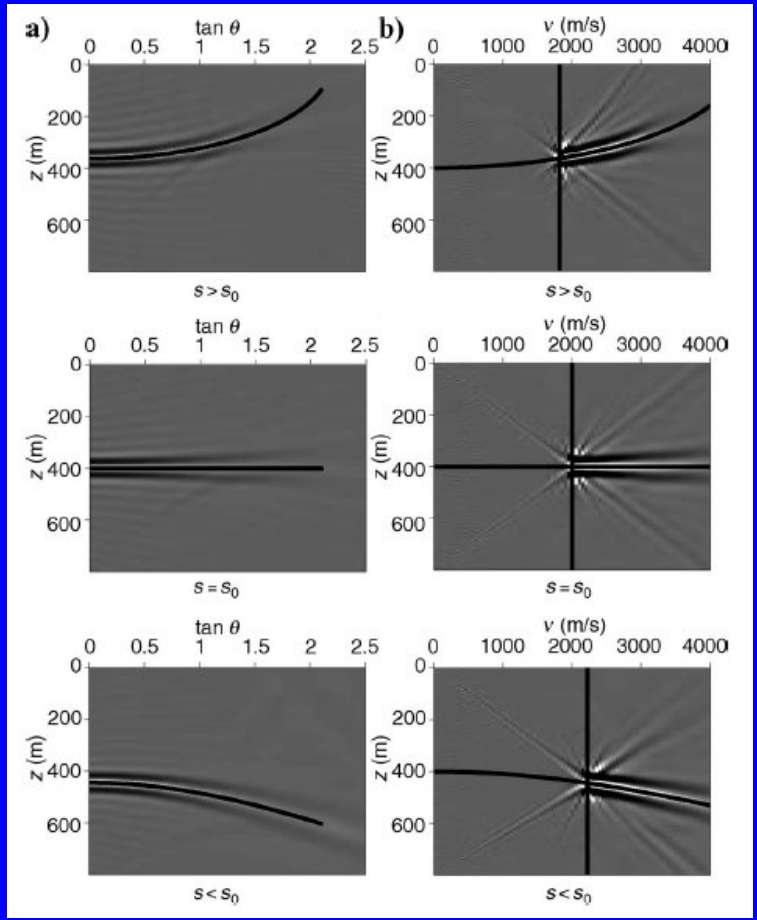


(b) Space Shift

Shift Gathers (Sava and Fomel 2006)



Space-shift (a) and time-shift (b) gathers



Slant stacks of space and time-shift gathers

Shift Gathers (Sava and Fomel 2006)

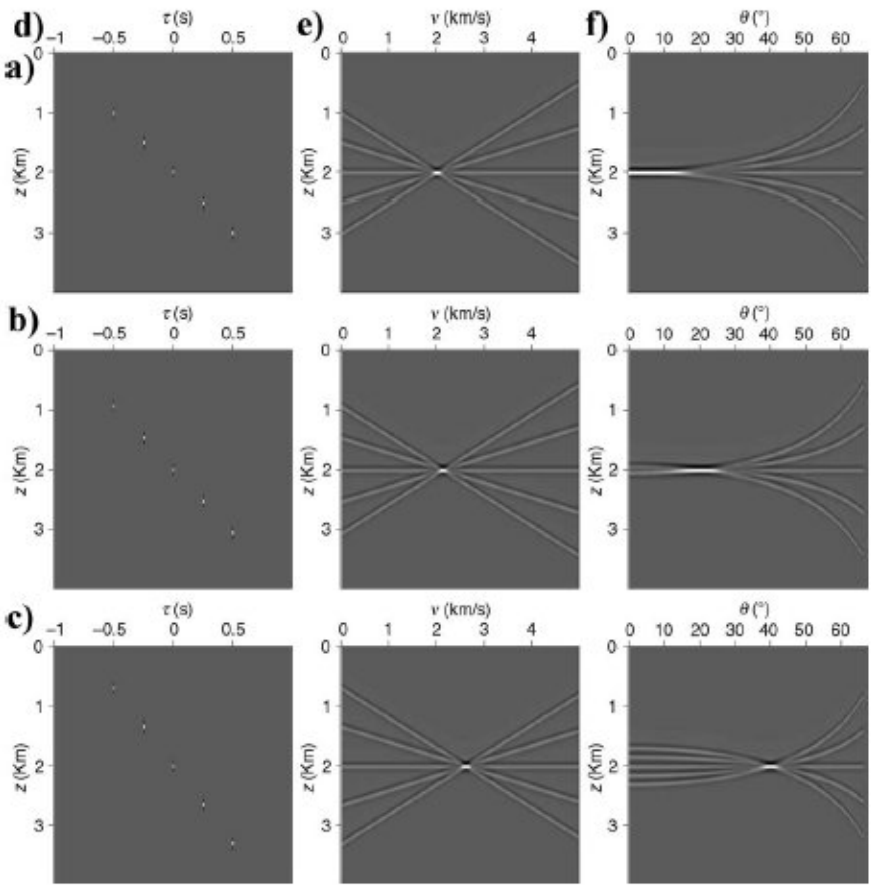
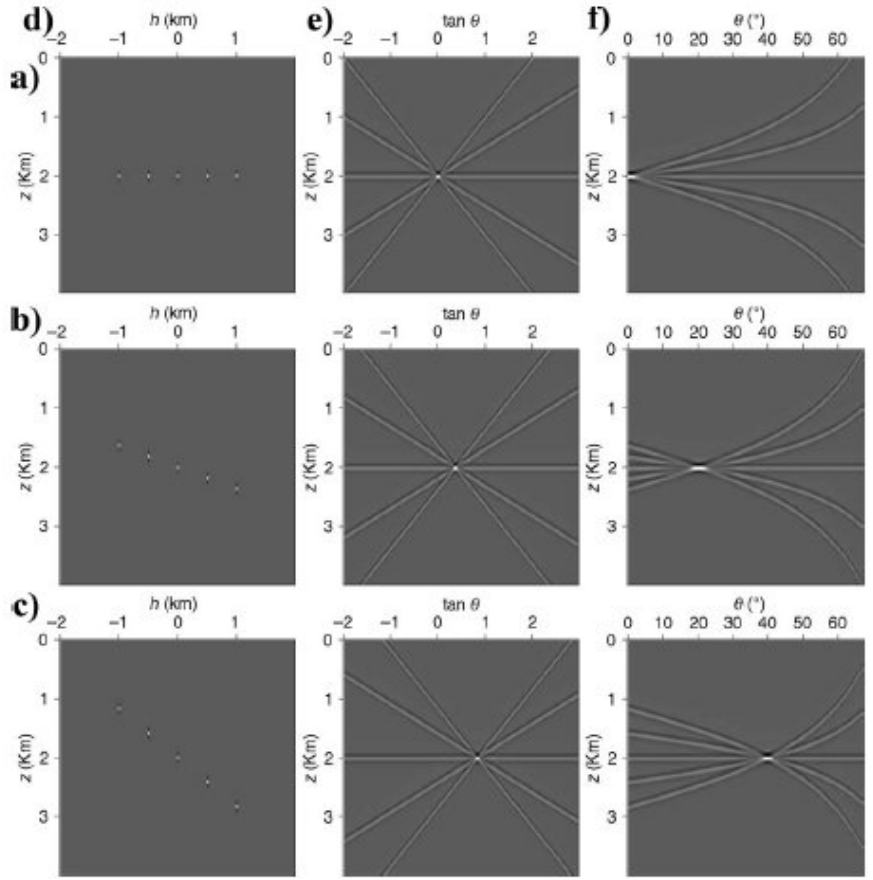


Figure 15. Image-gather formation using time-shift imaging. Horizontal rows depict events at (a) 0°, (b) 20°, and (c) 40°. Vertical columns correspond to subsampled (d) time-shift gathers, (e) slant-stack gathers, and (f) angle gathers.



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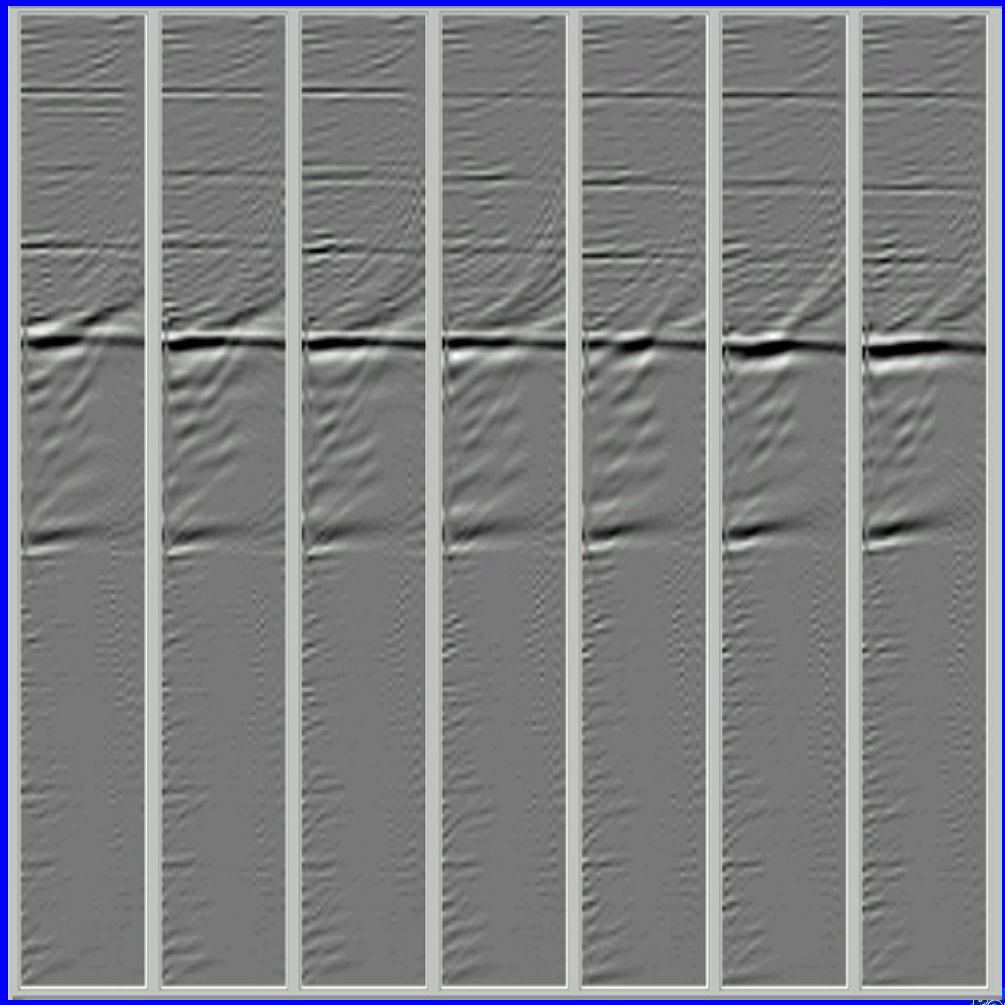
Shot Profile Angle Gathers

- Can be produced from any migration algorithm
  - Beam, Kirchhoff, WEM, RTM, $\cdots$
  - Done via a slant-stack
  - Performed on PSDM volumes
- Difficult math

Wave Equation Common Angle Gathers

- Left trace at 2 degrees
- Right trace at 60 degrees
- Angle info lost
  - As function of depth
  - Below strong contrasts



Outline

Gather Summary

- Two gather types
  - Offset based gathers
    - From virtually all algorithms
    - Traditionally done with Kirchhoff
  - Angle gathers
    - From virtually all algorithms
    - Traditionally done with wave equation methods
- Vertical updates
  - Velocity change along wavepaths ignored
  - Assumes velocity change is vertically above image point
  - Assume error reduce through iteration

Questions?