Mission-Oriented Seismic Research Program

Update, Issues and Plan Forward

September 7, 2001

University of Houston

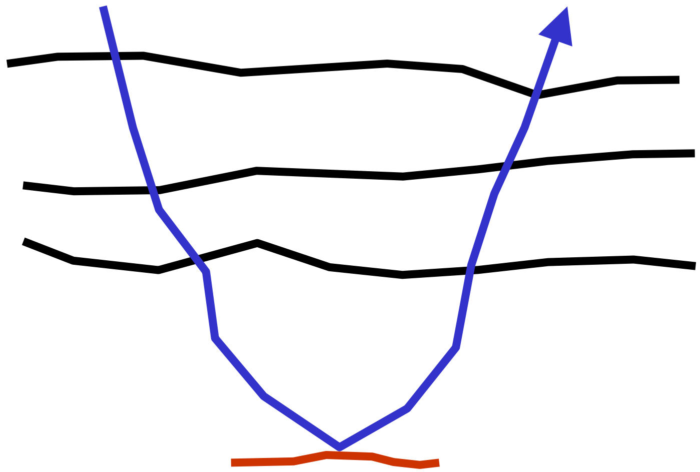
Objectives

- Develop and evaluate methods to: (1) image beneath complex media, and (2) identify large contrast structurally complex (e.g., curved, corrugated diffractive) targets

- Develop and evaluate methods for satisfying the intrinsic and practical prerequisites of these techniques

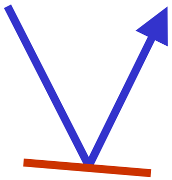
Overall Strategy

Locate

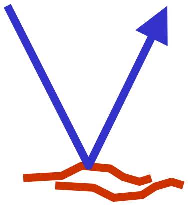


Accurately locate target (space) beneath complex medium

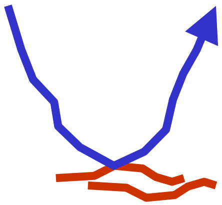
Identify (invert)



Invert at ocean bottom



Invert where time migration is adequate (e.g., 4-D)



Locate beneath complex medium and then invert a complex target

Projects

- Velocity Analysis
- Imaging at depth without the velocity model
- Inverting large-contrast and complex targets
- Prerequisite satisfaction
  - Data mapping
  - Near-source traces in shallow water
  - Wavefield above cable and wavelet from the Extinction Theorem (E.T.)
  - Deghosting (E.T.)
  - Comparing subtraction techniques for 2-D – 3-D models: pattern recognition, energy minimization and wavelet estimation (E.T.)

Graduate Students (all Ph.D. candidates)

Francisco M. Fernandez	Physics
Zhiqiang Guo	Geophysics
Kristopher Innanen	Geophysics (UBC)
Walter Kessinger	Geophysics
Simon Shaw	Geophysics
Haiyan Zhang	Physics
Jingfeng Zhang	Physics

Projects

- **Velocity Analysis (W. Kessinger)**
- **Imaging at depth without the velocity model (S. Shaw, K. Innanen)**
- **Inverting large-contrast and complex targets (H. Zhang)**
- **Prerequisite satisfaction**
  - **Near-source traces in shallow water (H. Zhang), (M. Sen, P. Stoffa, U.T. Austin)**
  - **Wavefield above cable and wavelet from the Extinction Theorem (Z. Guo)**
  - **Deghosting (S. Shaw)**

Visiting Assistant Professors

Dr. Gustavo Correa (p.t.)	Geophysics
Dr. Bogdan Nita	Physics

Associated Faculty

Prof. D. Kouri	Physics
Prof. C. Ordonez	Physics

The Four Tasks of Direct Inversion

(1) Free surface demultiple

(2) Internal demultiple

(3) Image reflectors at depth

(4) Determine medium properties

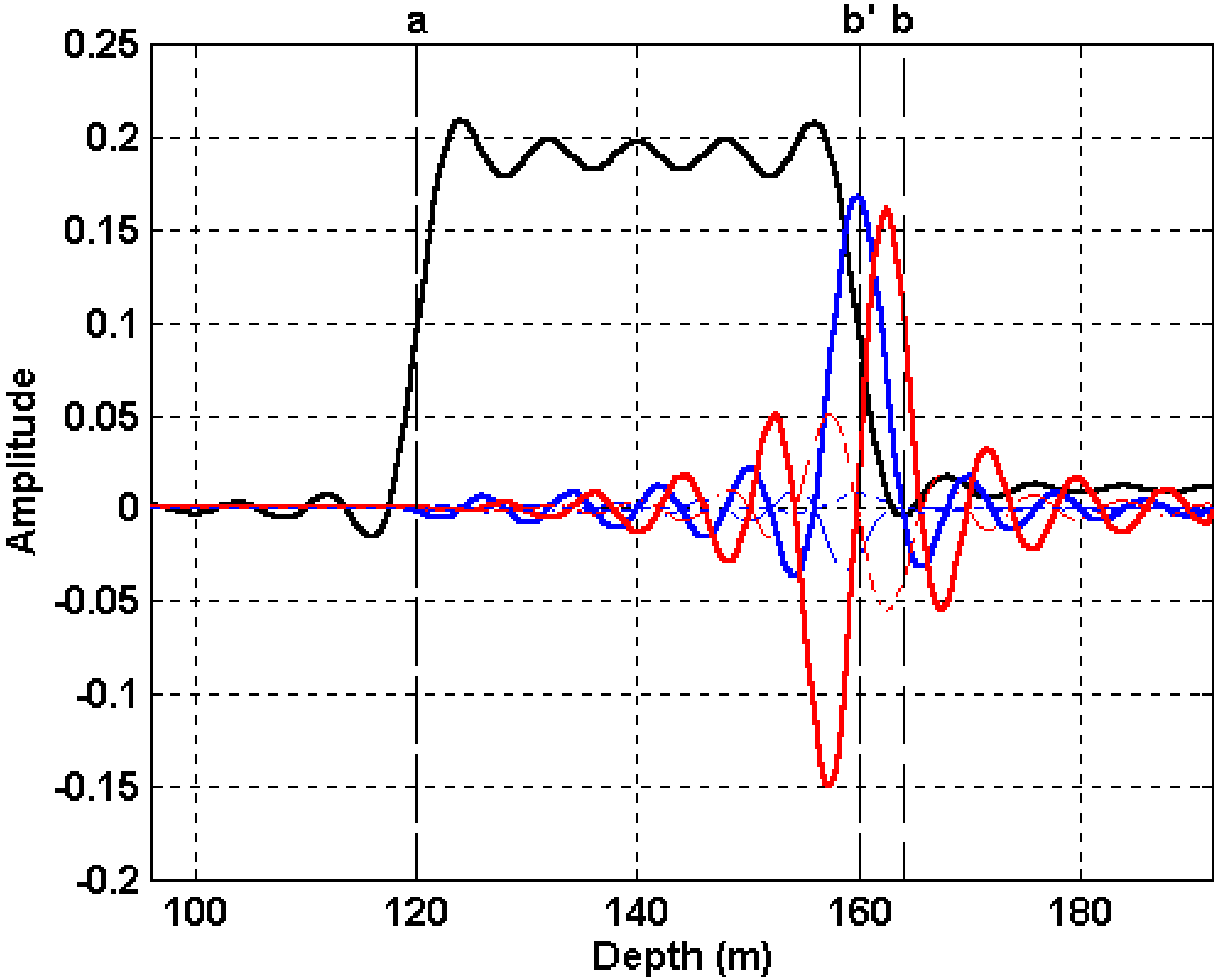
Imaging at Depth Without A Velocity Model

- **Seek uncoupled, task-specific subseries that act as though there were no subsequent tasks to perform**
- **Taken as a whole, the series acts as though these tasks are coupled. Each term in the series receives the data with all of its problems**

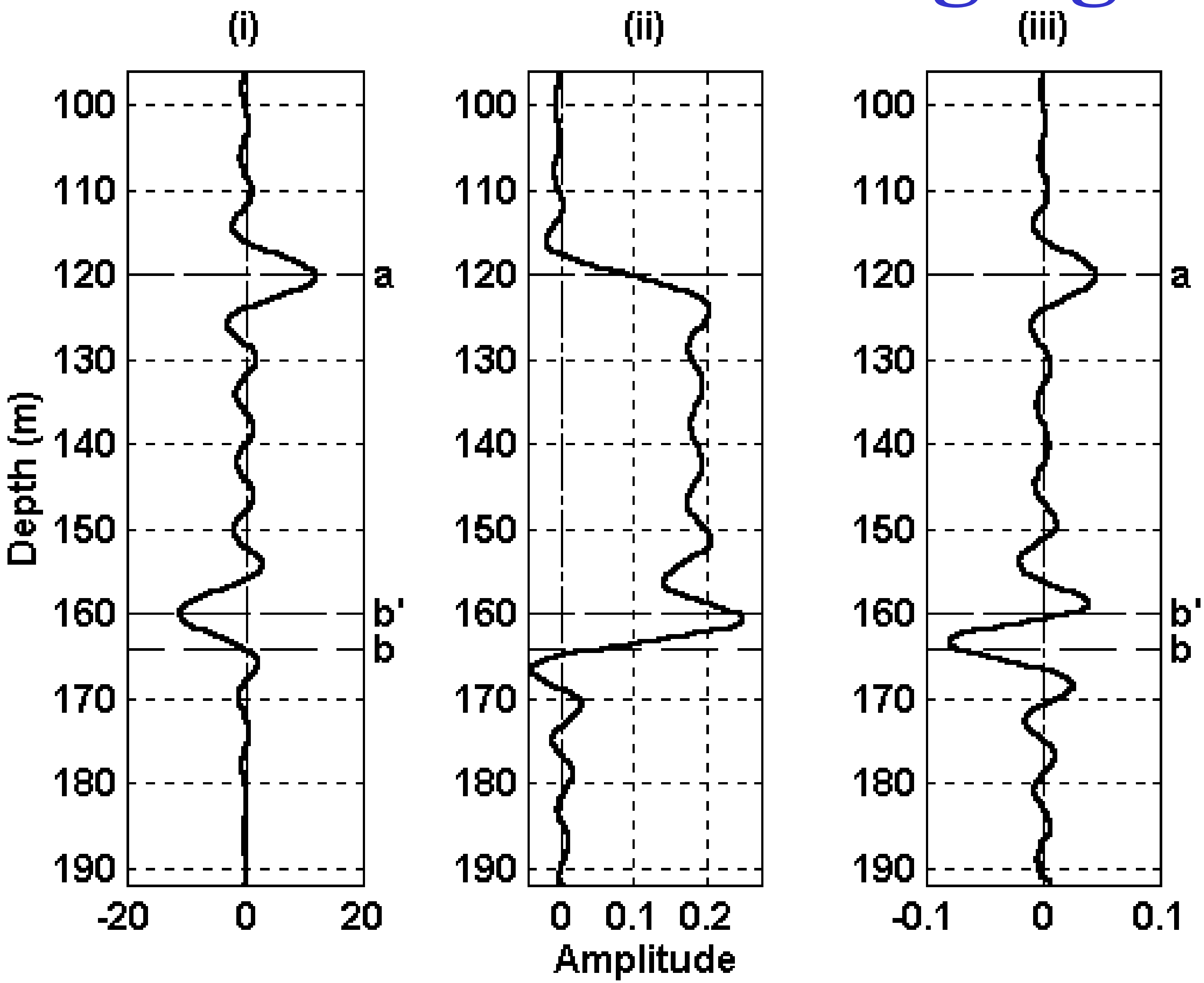
Imaging at Depth Without A Velocity Model

- We have determined the diagram (algorithm) corresponding to task (3) in the series
- We are looking at the issue of isolating task (3) from task (4). We know where task (4) is on its own
- Initial 1-D testing of algorithm corresponding to the simplest realization of the diagram and bandlimited data is encouraging (S. Shaw)
- Plan to extend testing to more complicated pre-stack 1-D models. Determine quantity to take through diagram that is best suited for imaging

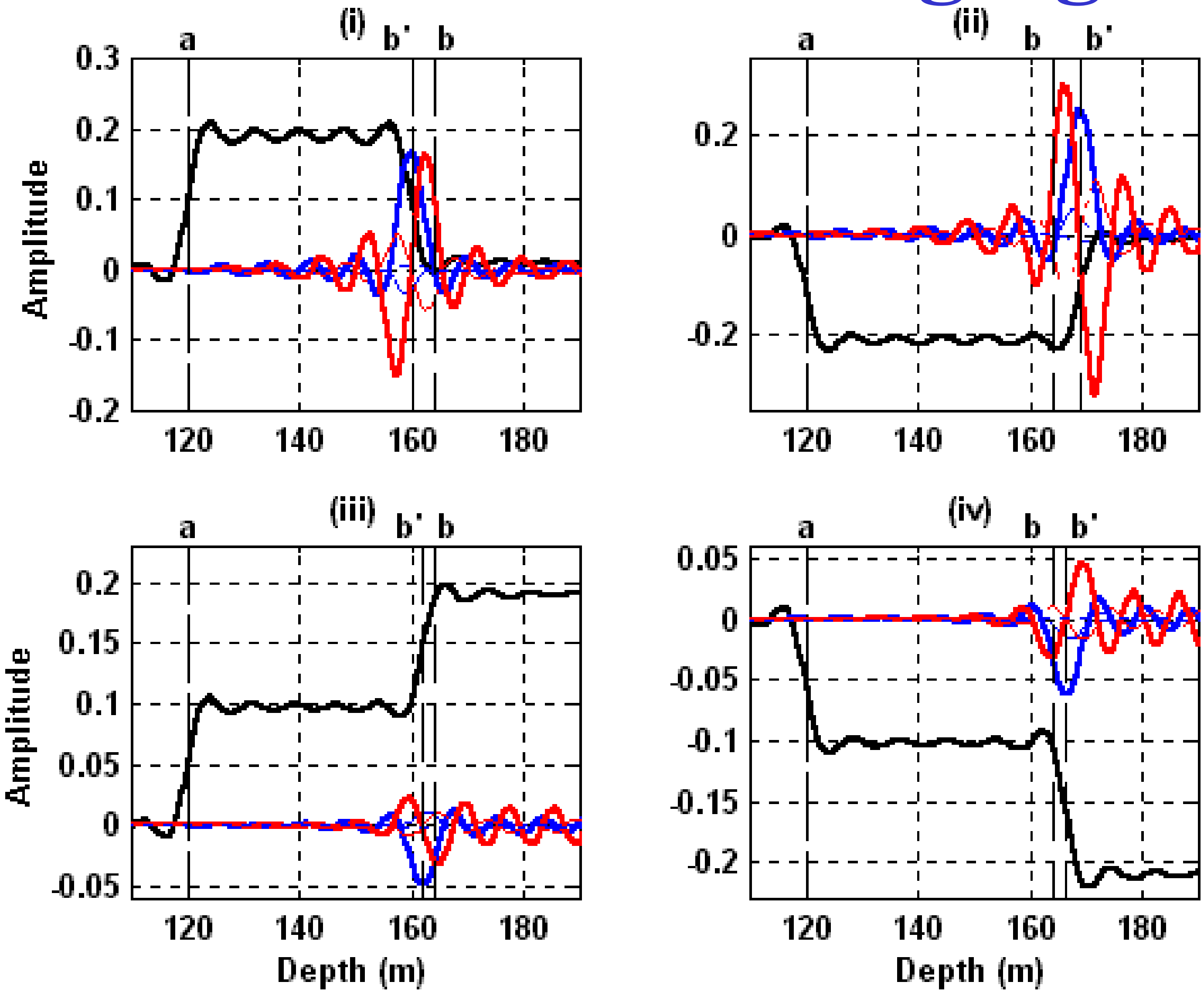
Inverse Series Imaging



Inverse Series Imaging



Inverse Series Imaging



Imaging Without Velocity – Plan

1. Complete fundamental analysis of task isolation and related issues

2. V(z) reference:
    - Analytic WKBJ migration
    - Test with synthetic 1-D and 2-D media, field data test

3. V(x,z) reference:
    - Use phase-screen migration (Ru-Shan Wu)
    - Exchange migration and imaging series results without exchange of code
    - Test and evaluate

Imaging at Depth Without A Velocity Model

Development of basic concepts, algorithm development and testing: S. Shaw

Forward series with absorption. Impact of absorption on inverse series. In particular, how would including an estimate of Q with reference medium (Green's function) affect imaging at depth? K. Innanen

Prerequisite Satisfaction

- **Wavefield prediction and wavelet estimation (Z. Guo)**
- **2-D codes complete and initial synthetic testing under way**
- **Deghosting from extinction theorem (S. Shaw)**
- **Tests will include impact on demultiple and imaging**

(Prof. Correa has generated a series of model data sets for evaluation of wavefield prediction, wavelet estimation, and deghosting)

Synthetic seismograms for M-OSRP

Gustavo Correa

Objective and Modeling Technique

- Objective: to produce a synthetic data set to test algorithms:
- Wavelet estimation, deghosting, etc.
- Modeling technique: acoustic 2-D Fourier pseudospectral method
- Grid size: 1024 × 1024 points
- Time step: 100 μs

Model Parameters

- One to three layers:

Material	V_P (m/s)	ρ (kg/m^3)	Depth (m)
Water	1,500	1,000	300
Sediments	2250	2400	750
Basement	4500	2640	-

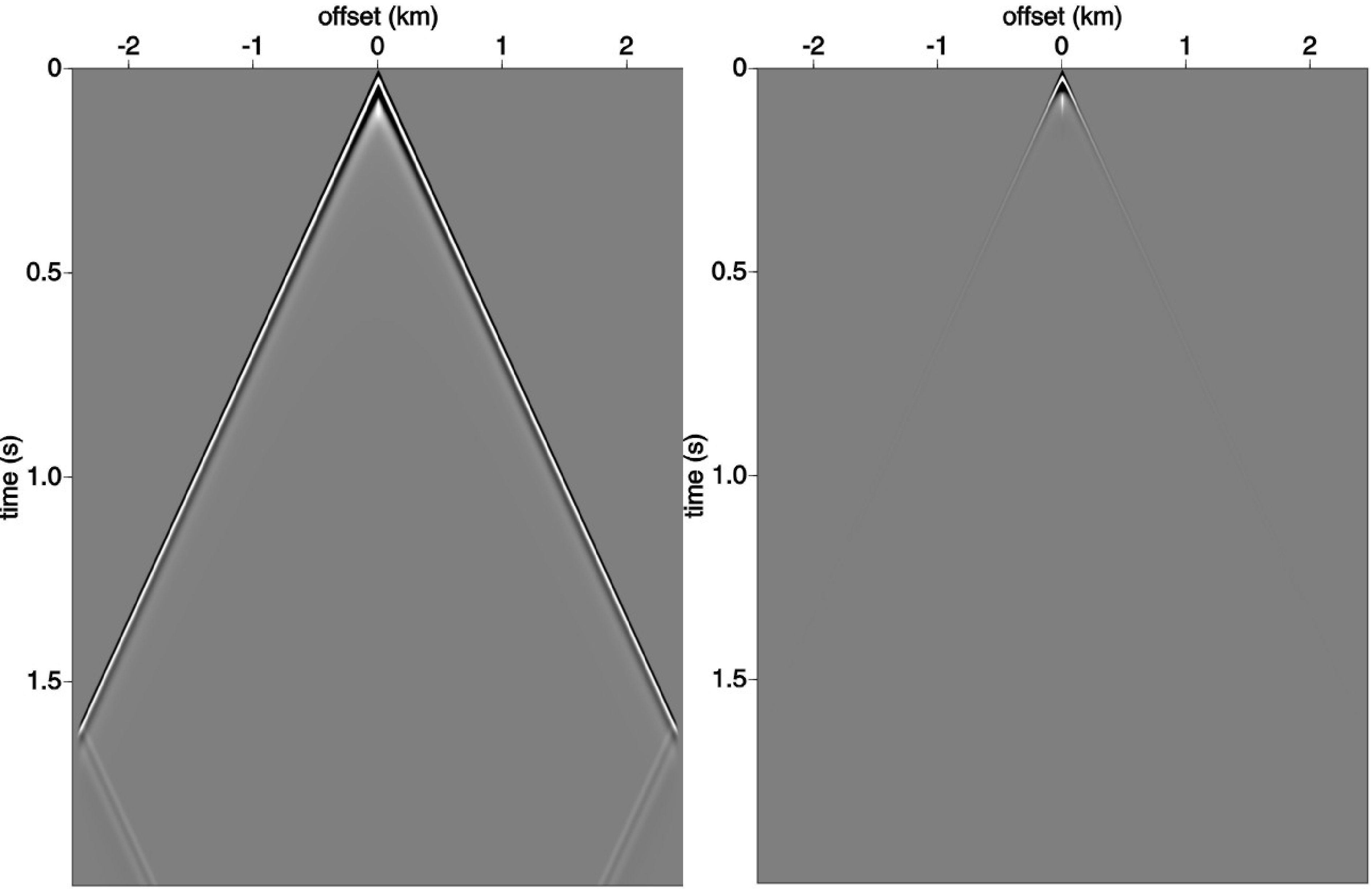
- Basement traveltime = 1st. sea floor multiple traveltime at zero offset.

Source, Receivers and Seismograms

- Source depth: 5 m.
- Front-loaded source signature, dominant frequency 30Hz.
- Maximum frequency 80 Hz.
- Two receiver streamers, 10 and 15m deep.
- Receiver spacing: 5 m (to allow single-sensor and array-forming).
- Offsets: 0 – 2450 m split-spread.
- Seismogram length: 2 s
- Seismogram sampling interval: 1 ms

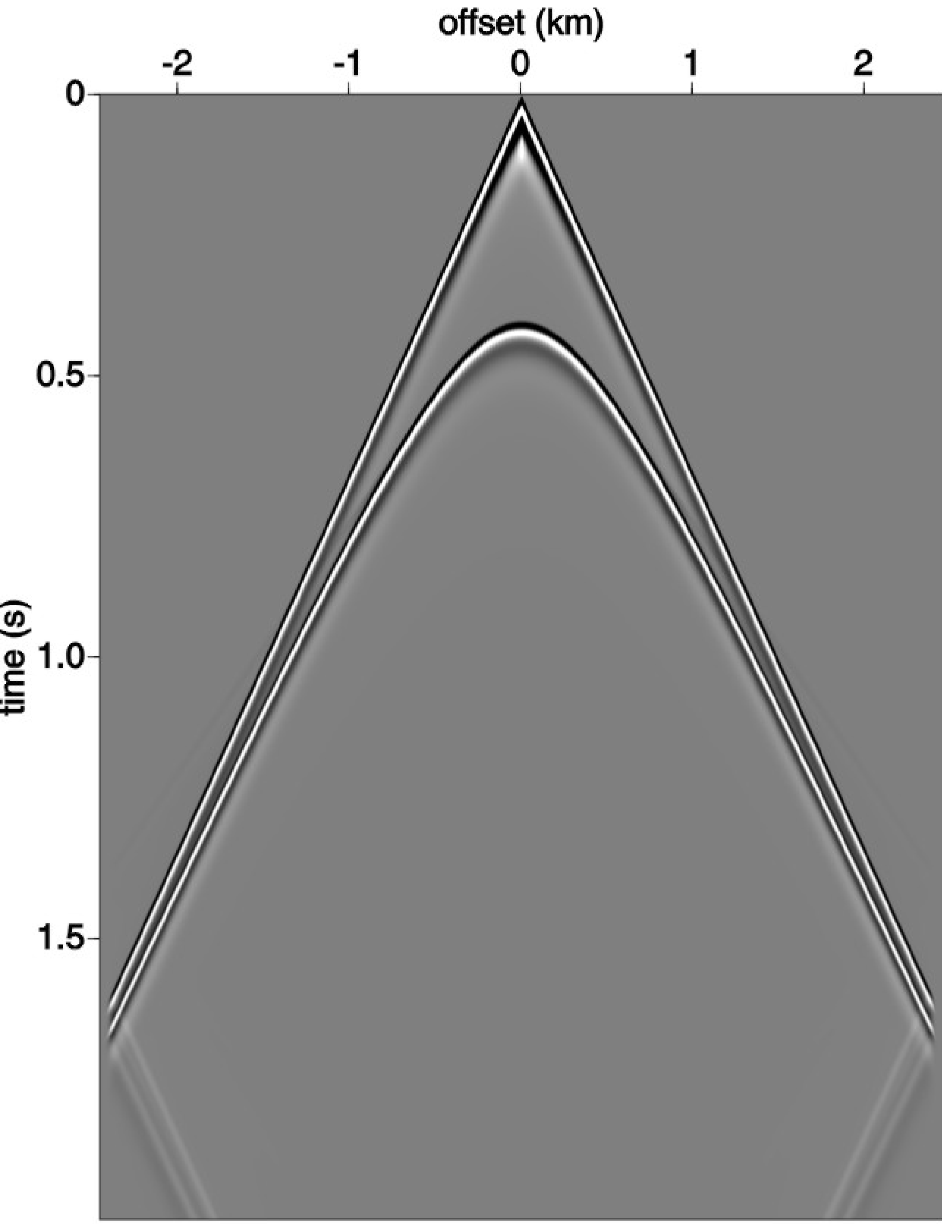
Model Runs

1. **Water, no free surface**
2. **Water, with free surface**
3. **Water and sea floor, no free surface**
4. **Water and sea floor, with free surface**
5. **Water, sea floor and basement, no free surface**
6. **Water, sea floor and basement, with free surface**

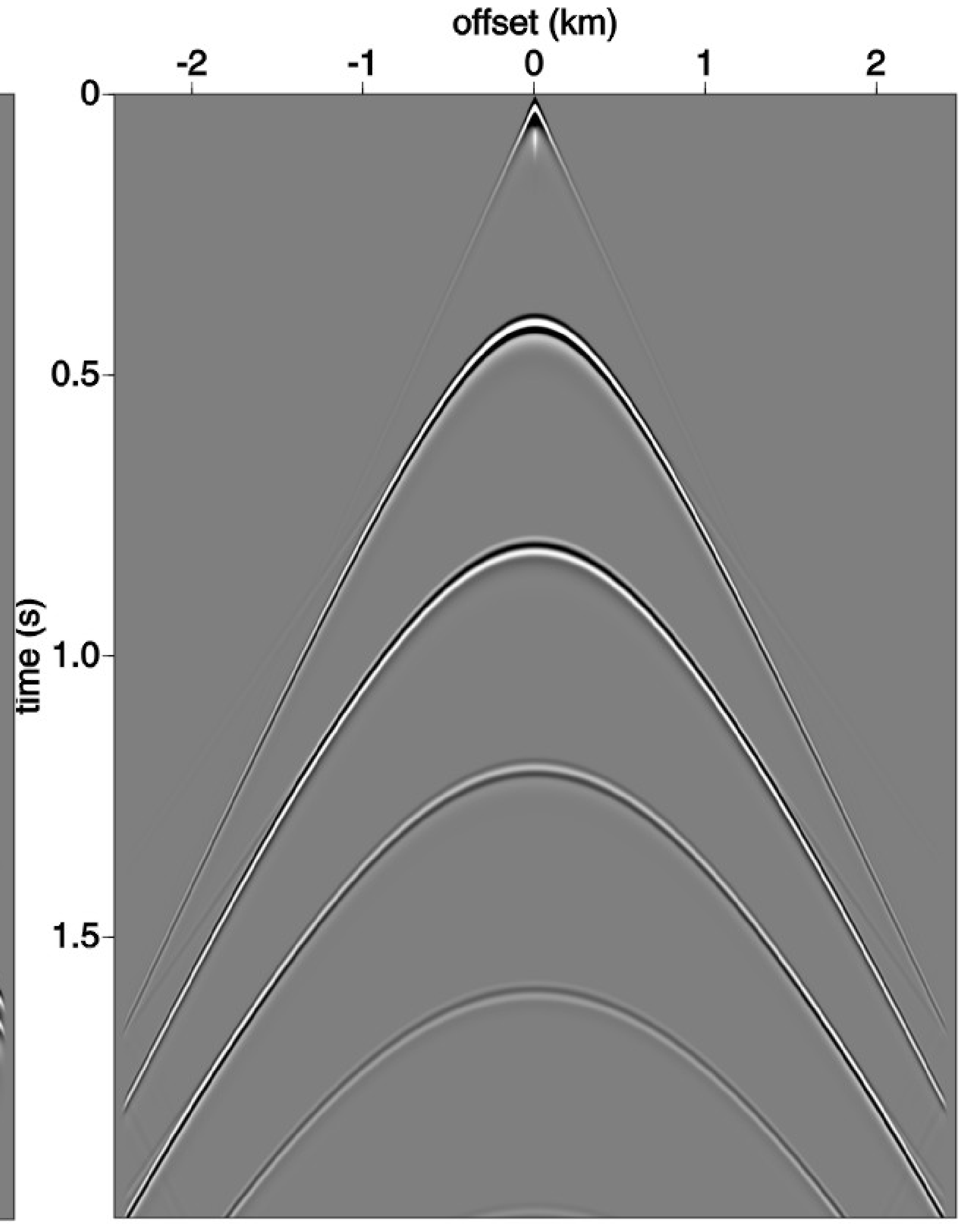


Water, no free surface

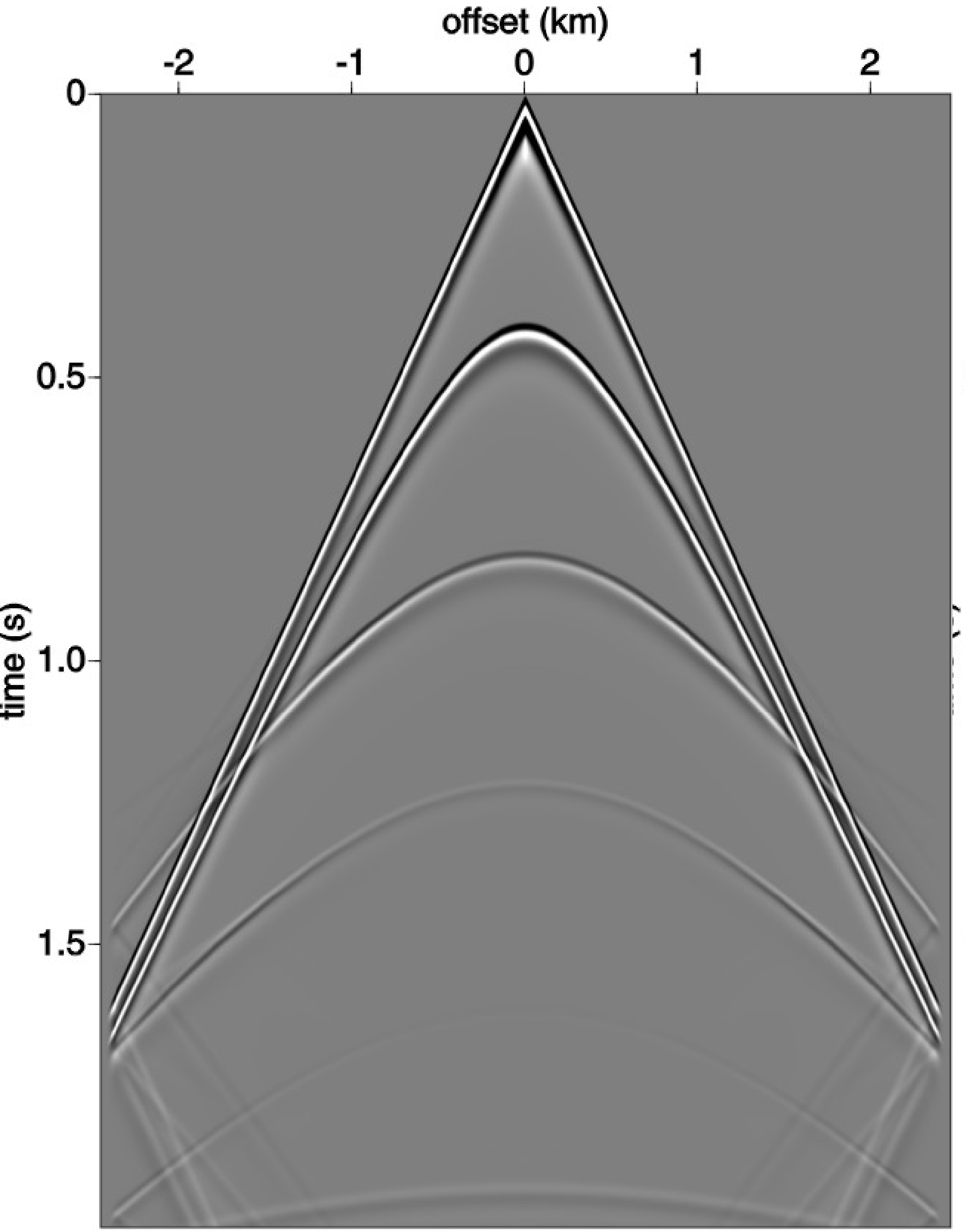
Water, with free surface



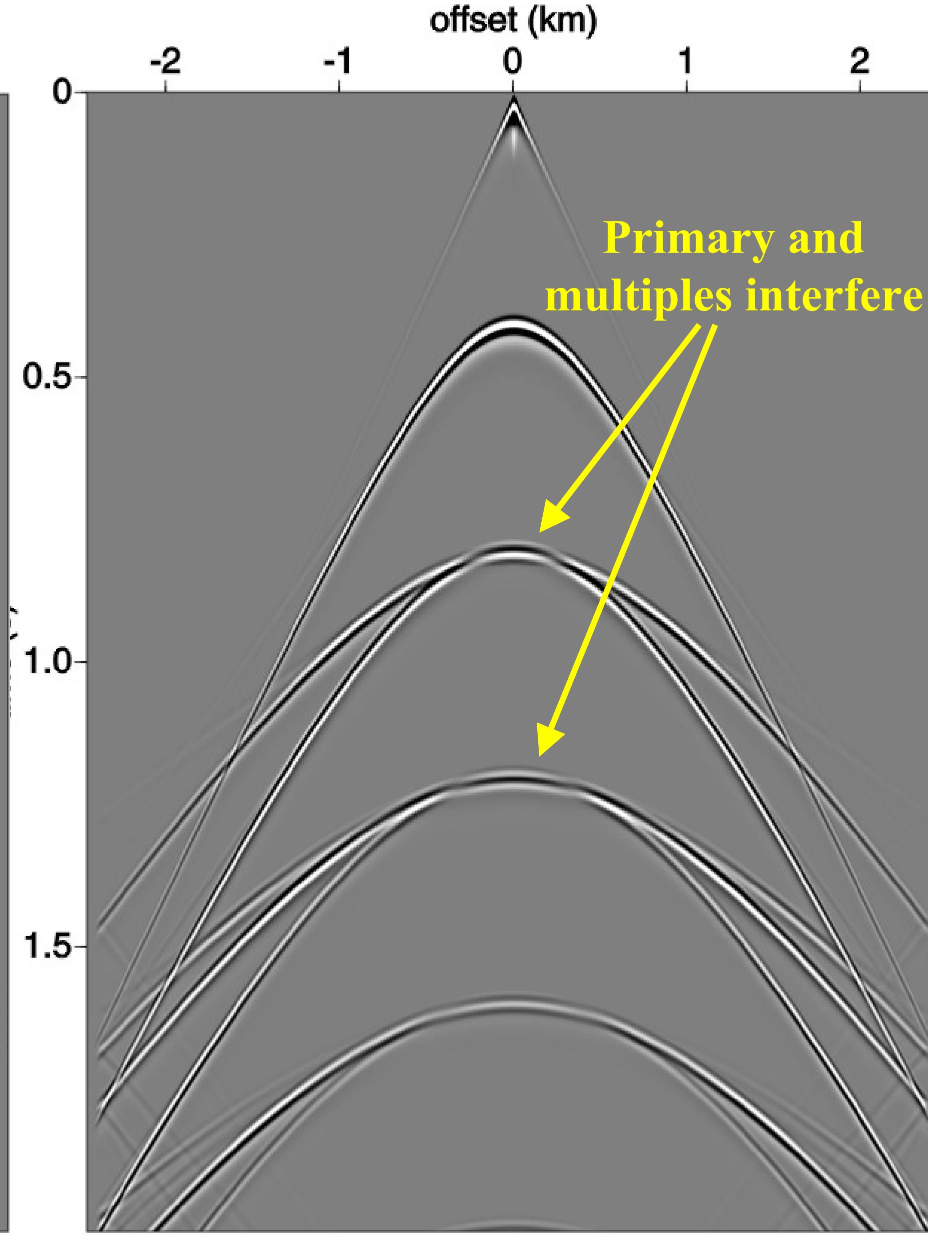
Water & sea floor, no free surface



Water & sea floor, with free surface



Water, sea floor & basement, no free surface



Water, sea floor & basement, with free surface

Prerequisite Satisfaction (cont'd)

- A comparison of pattern recognition, energy minimization, and wavelet estimation for a set of 2D and 3D models – for multiple attenuation
    - Working team will meet in October

- Data mapping – working team
    - Met at ADS in July 2001, will meet again in October

Prerequisite Satisfaction (cont'd)

- **Velocity Analysis (W. Kessinger)**
  - **Exchange of talks with W. Symes (Rice – TRIP)**
  - **All current constant offset, shot, or angle at target partial migrations show serious artifacts, even with perfect velocity**
  - **We have new (very recently developed) candidate method for MVA with potential to overcome these current obstacles to effectiveness. Will test and evaluate**

- **Inversion for large contrast, complex target identification: Task (4) (H. Zhang)**

- **Shallow water near trace interpolation; with M. Sen, P. Stoffa (UT Austin)**
  - **For 2-D (3-D) water bottom, H. Zhang thesis**

Velocity Model Independent Imaging for Complex Media

(SEG Workshop, San Antonio, Sept. 14th)

- **Invited overview talk – how do all of these imaging without the velocity methods relate to each other and to the imaging series and M-OSRP plans?**

SEG Workshop Overview (cont'd)

Wave-theoretic migration or asymptotic approximation (Kirchhoff) migration, Green's Theorem

Interval velocity model needed to find the reflectivity map at depth

No interval velocity ⇒ no depth image of reflectivity

Stacking:
- NMO STK, DMO STK
- CFP, CRS, CRE, time migrtn.

All stacking methods seek compromise: can we find image without depth or reflectivity with a kinematic set of parameters to sum a moveout pattern

Inverse Scattering Series

Interval velocity model not needed to find the reflectivity map at depth

For rapid rate of convergence a proximal velocity is useful

SEG Workshop Overview (cont’d)

- CFP, CRS, CRE, … represent approaches to imaging when estimated medium wave velocity is far from adequate

SEG Workshop Overview (cont’d)

- **NMO-STK and time migration concepts:**
  - **NMO-STK requires a stacking velocity ~RMS velocity**
  - **Put this in the Dix equation, and unphysical interval velocity can be predicted**
  - **Is this a problem? No – it just shows that you can find an NMO-STK ‘image’ without the velocity!**
  - **This is the original ‘velocity independent’ imaging**
  - **For a curved and dipping reflector need (to search and determine) more than one parameter to fit the moveout pattern (but those parameters are not the velocity), so you have velocity-independent imaging, once again!**

SEG Workshop Overview (cont’d)

- In the face of inability to provide (for complex media) a near-adequate velocity model for depth migration – redefine objective (and declare a success)
- “Image” – a likeness

SEG Workshop Overview (cont'd)

- Imaging reflectors in seismic – many different definitions of 'likeness' to a reflector

- If the medium has simple velocity, and a (not necessarily close but) simple velocity estimate is used (in a Kirchhoff or wave equation migration), will often result in an image – mislocated and amplitude challenged, but an image nonetheless

SEG Workshop Overview (cont'd)

- **If a simple velocity estimate is used to image beneath a complex medium, then depth migration can provide a blur at target**
- **Given a choice between a dispersed target or fog (using a well-defined wave imaging physics but with serious violation of velocity prerequisites) or a clearer (localized) but somewhat ill-defined entity (in location, shape, and amplitude) – most would choose the latter**

Comments on Velocity-Independent Imaging Overview (cont'd)

- **From the inverse subseries perspective we don't yet know degree of proximity and relation to rate of convergence, under complex conditions**
- **We know that a well-resolved but mislocated reflector can be moved to a correctly-located reflector, without the velocity being determined under the simple conditions that we have tested. We don' t know if a blurry ill-defined image can be turned into a well-located reflector by using the imaging series**

Comments on Velocity-Independent Imaging Overview (cont'd)

- It could turn out that under the soup-fog condition that we begin with one of these "stack to something (really, anything anywhere) coherent" images as the first step in the imaging series
- However, for the CFP, CRS, … methods to be used as an intermediate step or a hand-off to methods of greater ambition it would be useful to have as clear a definition as possible of the physical meaning of these outputs, from a wave-theoretical point of view

Comments on Velocity-Independent Imaging Overview (cont'd)

- **E.g., the downward continuation of only receivers in time outputs the radiating portion of the scattering source – not a simple (or generally spatially localized) quantity easy to physically interpret**
- **Principle of equal traveltime can have problems with multi-pathing where several arrivals and traveltimes are associated with one source, one receiver and one reflection point**
- **And stacking techniques can produce smooth but unphysical (ungeological) image results**

Comments on Velocity-Independent Imaging Overview (cont'd)

- The imaging sub-series holds the promise of providing an adequate, well-defined, well-located image in depth directly in terms of an inadequate velocity – how close, how complex, how rapidly convergent – are yet to be determined. This is our key immediate focus.
- Encourage support of all of these velocity-independent imaging efforts – with open discussion of objectives, assumptions, strengths and pitfalls, and looking for ways that strengths of different approaches could be combined to provide stronger composite tool

SEG Workshop Summary

- There are several fronts in the campaign to image beneath complex media
- When ability to estimate velocity is closer to adequate – the issue of Kirchhoff versus Wave Theory is relevant and the subseries could bring a 95% image with an 85% velocity using a Wave Theory migration for "α_1"
- When ability to estimate the velocity is far from adequate, then one of the stacking methods CFP, CRS, CRE, … could provide not only a launch for the Delft, Karlsruhe, Campinas, Tel-Aviv,… efforts that then use the stacked result to seek a macromodel and depth image BUT also to use the "stack" as an "α_1" in the imaging subseries for seeking velocity-independent depth imaging without finding the macromodel

SEG Workshop Summary

- **We plan joint – cooperative – efforts with the leading-edge Wave-theory migration and Kirchhoff methods on the near side and the stacking efforts on the far side of the velocity estimation problem**

- **We also plan to pursue our effort into a funademntally new migration-velocity analysis procedure**

Yearly review will be in early December at UH