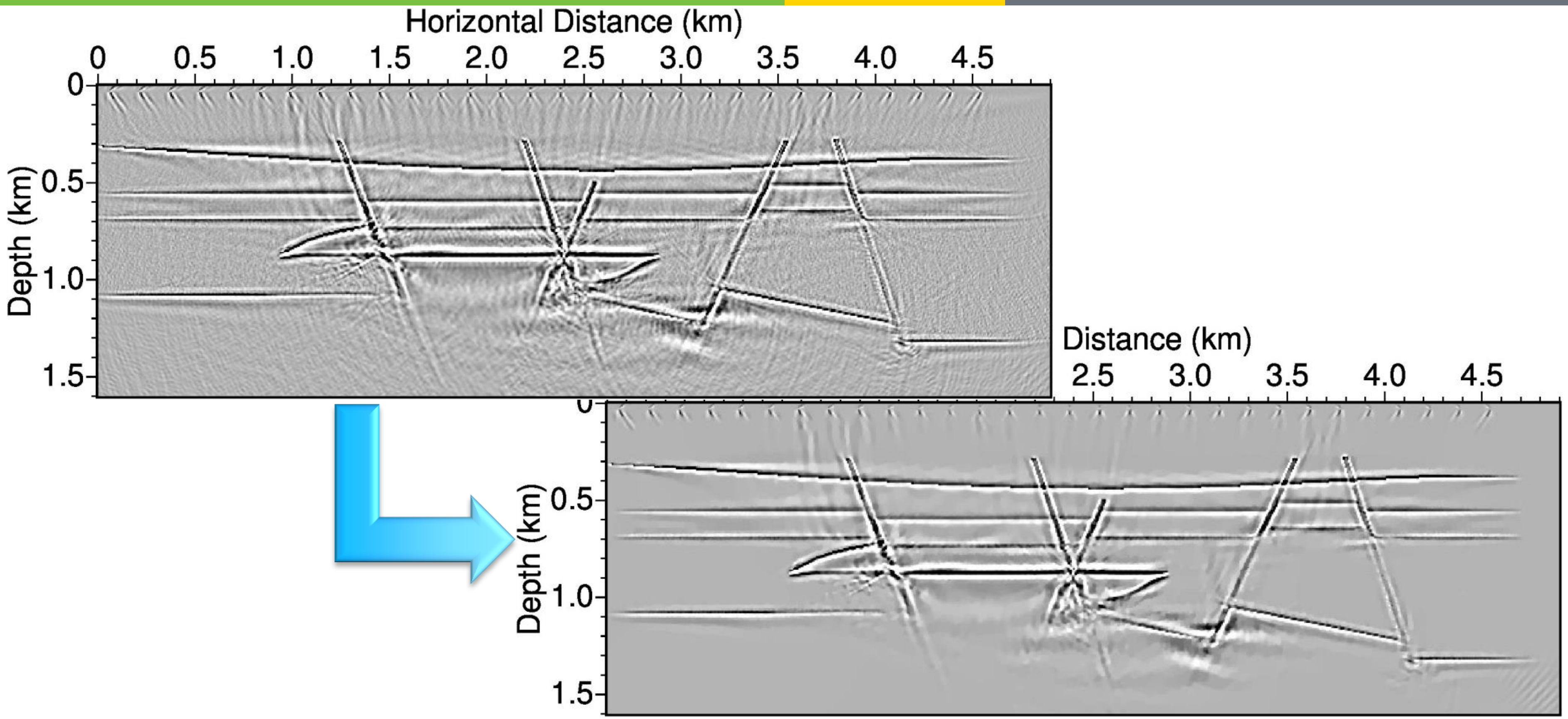


Imaging Fault Zones Using A Novel Elastic Reverse-Time Migration Imaging Technique

Project Officer: Mark Ziegenbein

Total Project Funding: $1M

May 11, 2015

Lianjie Huang

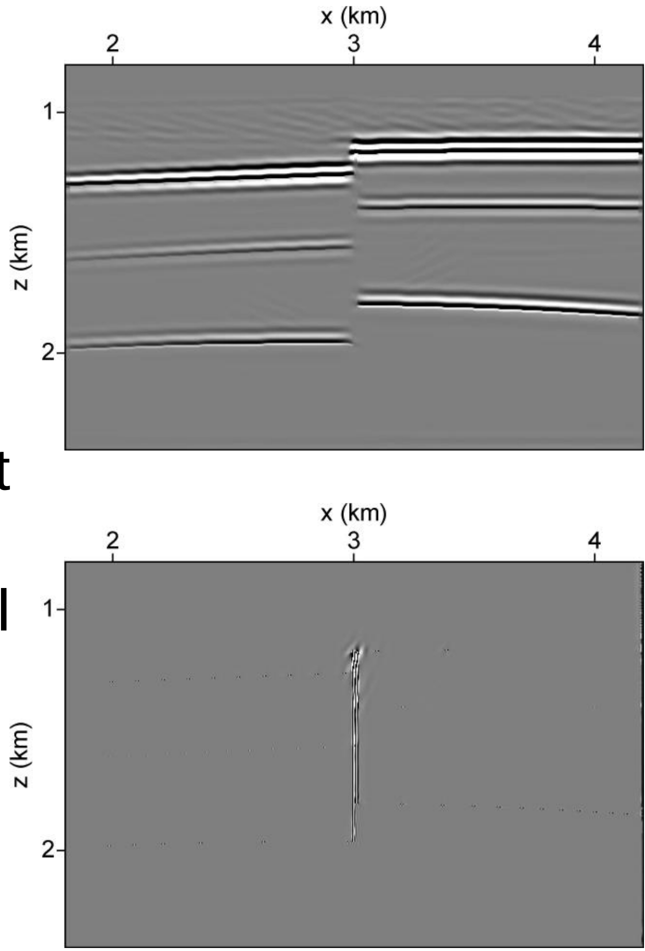
Los Alamos National Laboratory

Track 2: HRC

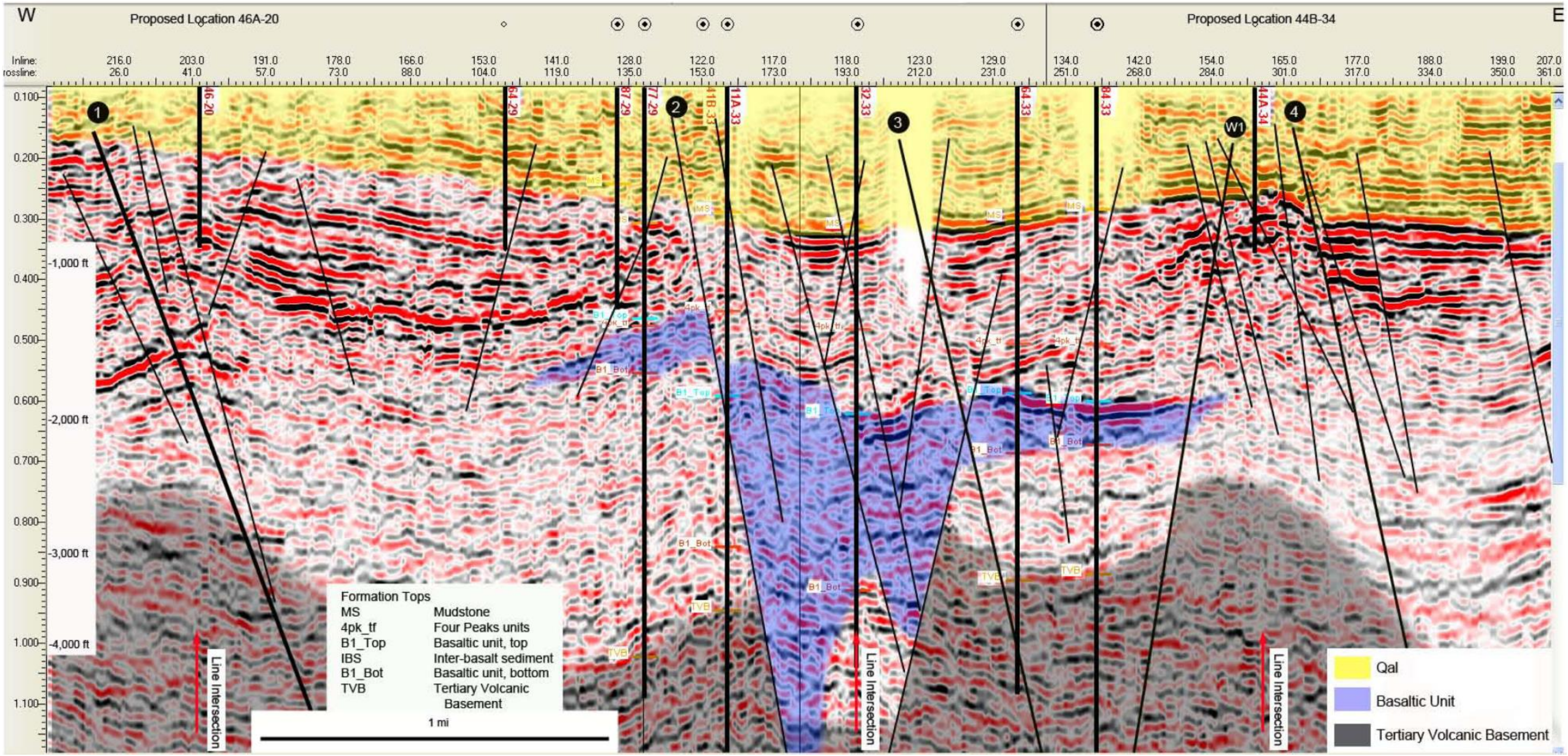
Relevance/Impact of Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- One of the major challenges to geothermal exploration is the ability to image steeply-dipping fault zones. Fault zones may control the flow paths of hot water, or confine the boundaries of geothermal reservoirs. Therefore, imaging fault zones is crucial for geothermal exploration.
- Research gap: Conventional migration cannot directly image steeply-dipping fault zones. Interpretation of fault zones from conventional migration images is often subjective.
- The primary goal of this project is to develop a novel elastic reverse-time migration method to directly image steeply-dipping fault zones, and improve detection of fault zones.



Conventional migration shows only images of horizontal strata/layers



Relevance/Impact of Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- The technical challenges addressed during the Phase II of the project include:
  - Obtaining improved velocity models for migration imaging; and
  - Demonstrating practical feasibility of imaging steeply-dipping fault zones.
- Impact: The new imaging technique will uncover fault zones overlooked by geologic studies and/or conventional seismic migration. The clear, direct images of fault zones will enable us to accurately design production well locations, reduce drilling risk, and improve geothermal resource discovery/recovery.

Scientific/Technical Approach

- To obtain improved subsurface velocity models for migration imaging, we will develop novel elastic-waveform inversion algorithms with edge-guided regularization and modified total-variation regularization.
- To demonstrate the practical feasibility of imaging steeply-dipping fault zones, we will apply our newly developed reverse-time migration algorithms to 3D surface seismic date acquired at Soda Lake geothermal site.
- The unique aspect of the approach is establishing the unprecedented capability of directly imaging steeply-dipping fault zones using surface seismic data.

- We have developed novel acoustic- and elastic-waveform inversion algorithms with edge-guided regularization and modified total-variation regularization, validated the algorithm using 2D synthetic data, and showed that the algorithms can produce high-resolution and high-fidelity subsurface velocity models for migration imaging.
- We have further improved the computational efficiency of elastic reverse-time migration by combining the wavefield-separation imaging condition and the Poynting vector method for polarity corrections in converted-waved imaging (P-to-S or S-to-P imaging).
- We have developed an excitation amplitude imaging condition for elastic reverse-time migration. The new imaging condition effectively removes migration artifacts for both PP and PS images, and significantly improves the computational efficiency and reduces the computer-memory requirement for elastic reverse-time migration.

- We have developed an improved least-squares reverse-time migration method with modified total-variation regularization.
- We have developed a new staggered-grid finite-difference scheme optimized in the time-space domain for modeling 3D scalar-wave propagation. This modeling tool is essential for 3D full-waveform inversion and 3D reverse-time migration.
- We have developed a new boundary-wavefield extrapolation method for reducing the computer memory requirement for 3D reverse-time migration and full-waveform inversion.
- We have developed and implemented a 3D least-squares reverse-time migration algorithm.
- We have extended our 2D elastic reverse-time migration code to 3D, and implemented on parallel computers.
- During Phase II, we have published 5 journal papers and 7 proceedings papers, have given 7 conference presentations, and have submitted one additional paper for journal publication and one conference paper.

Accomplishments, Results and Progress

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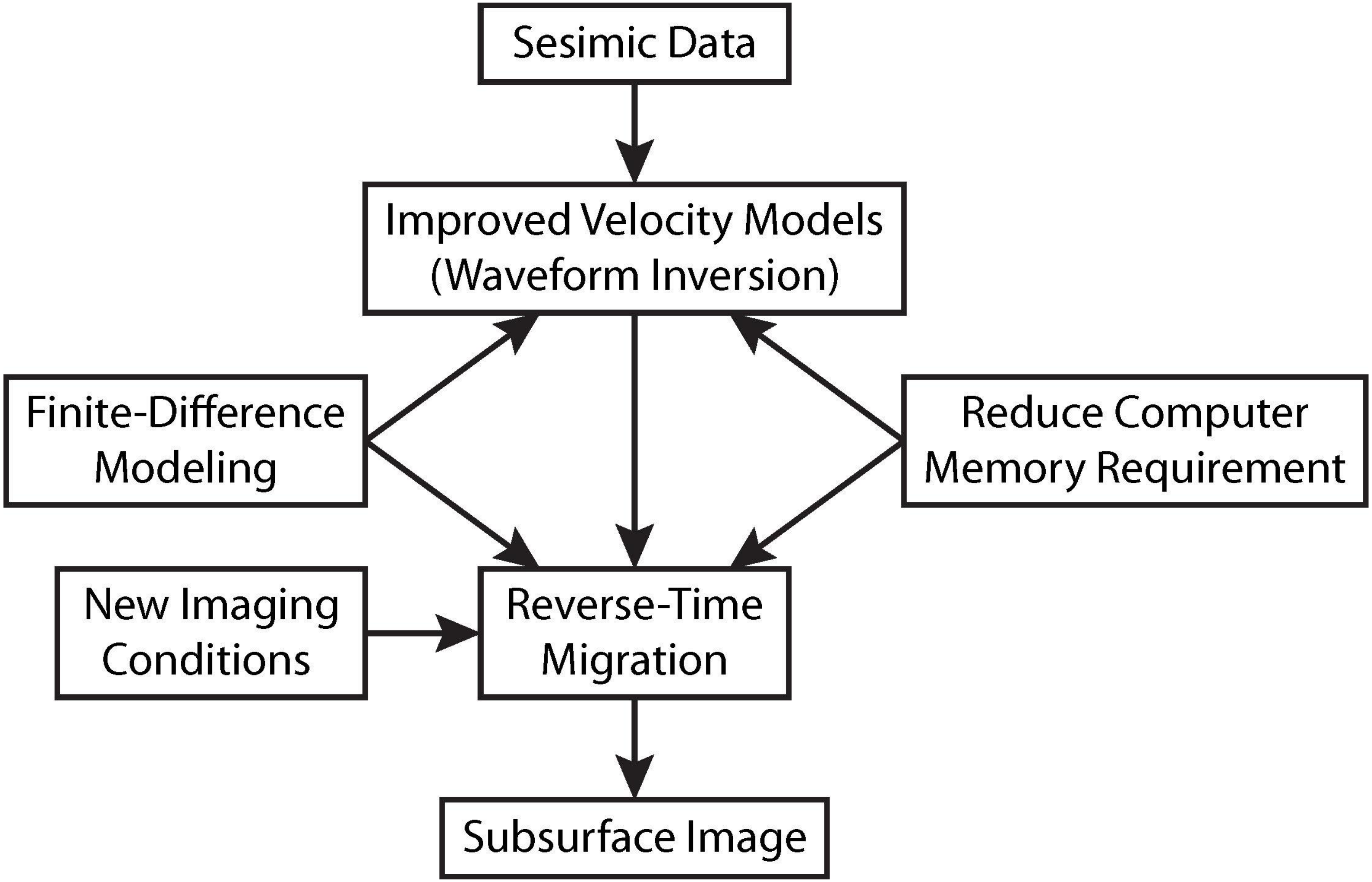

Accomplishments, Results and Progress

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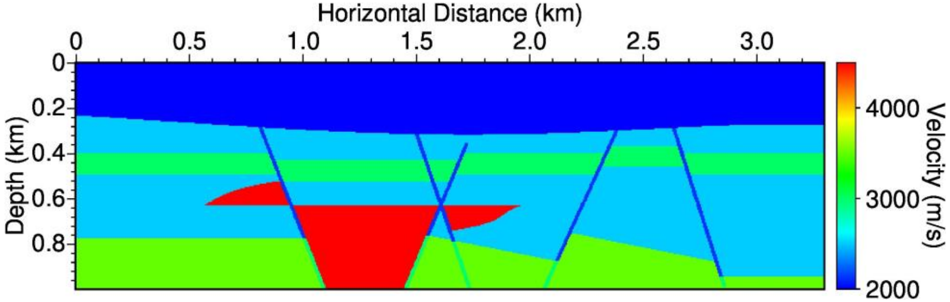
- **Challenges to Date:** The schedule of the Phase II project is delayed because of lack of prestack seismic data and the delay of data processing by a company. LANL found another company to process the data. Processing of the PP-component of the data is nearly completed, processing of the PS-component of the data is in progress and will be completed in May, 2015.

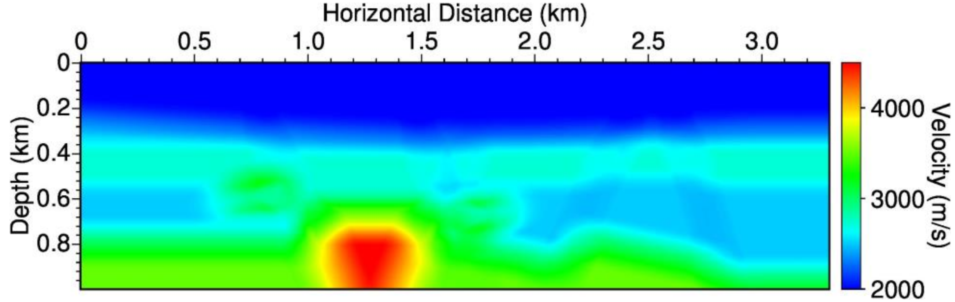
Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Develop a novel 2D elastic reverse-time migration imaging technique with an angle-domain imaging condition	Same milestone	03/31/2013
Verify the 2D elastic reverse-time migration imaging technique using synthetic data	Same milestone	03/31/2013
Go/No-Go Decision: DOE-GTO approved to proceed to Phase II		03/31/2013

Elastic-waveform inversion with edge-guided regularization

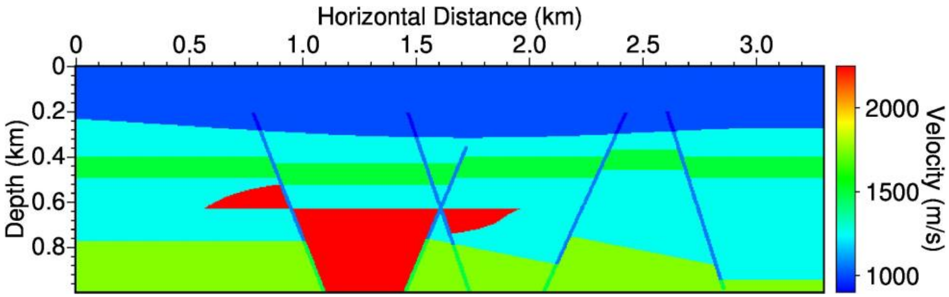
Elastic models for Soda Lake geothermal site



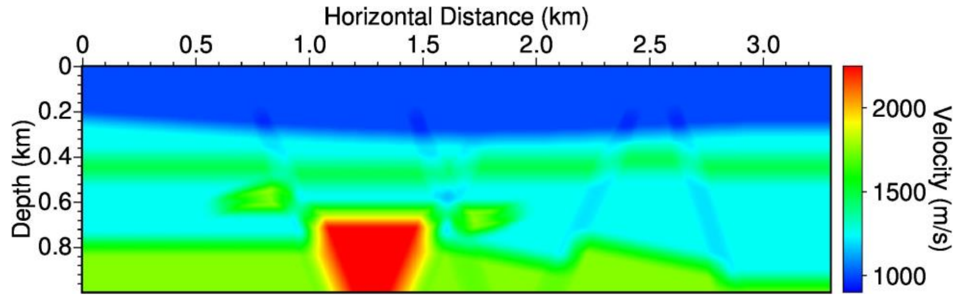
V_p



Initial V_p for inversion



V_s



Initial V_s for inversion

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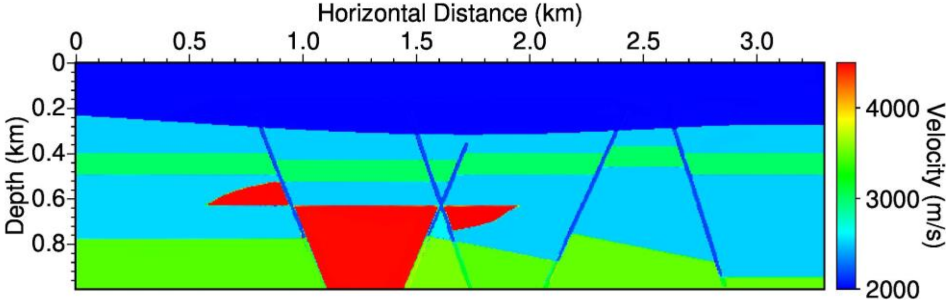
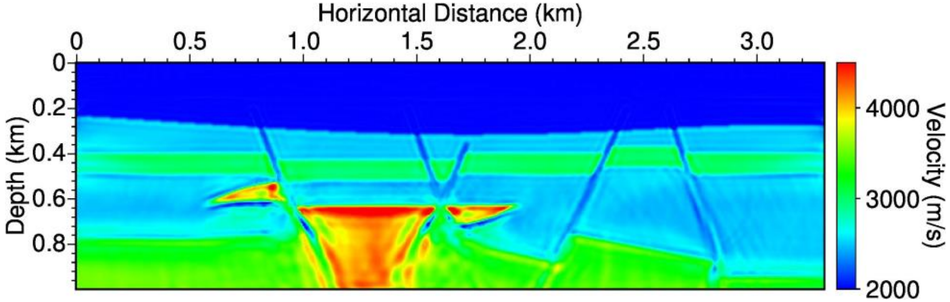
Elastic-waveform inversion with edge-guided regularization

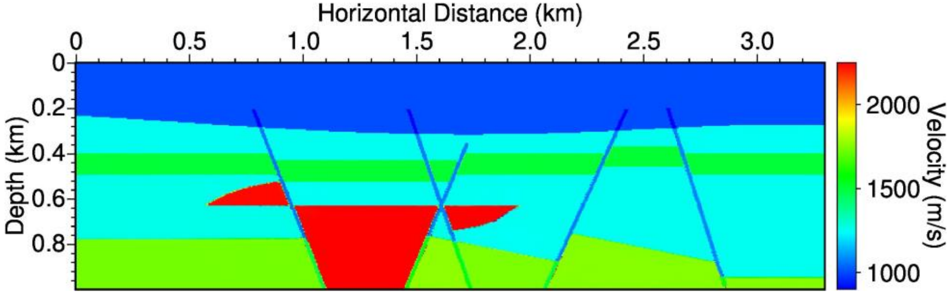
Inversion with synthetic surface seismic data



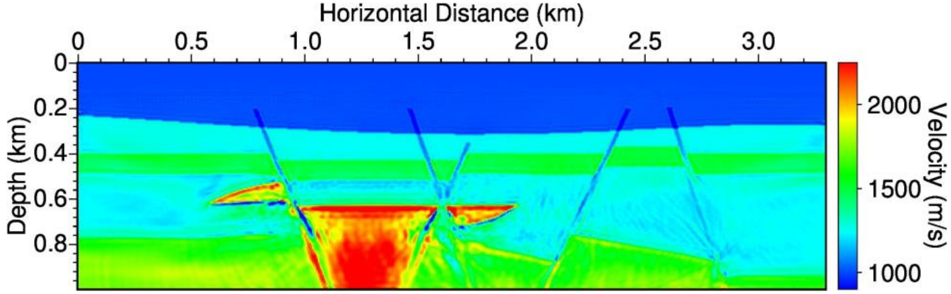
V_p obtained using new EWI



V_p obtained using old EWI



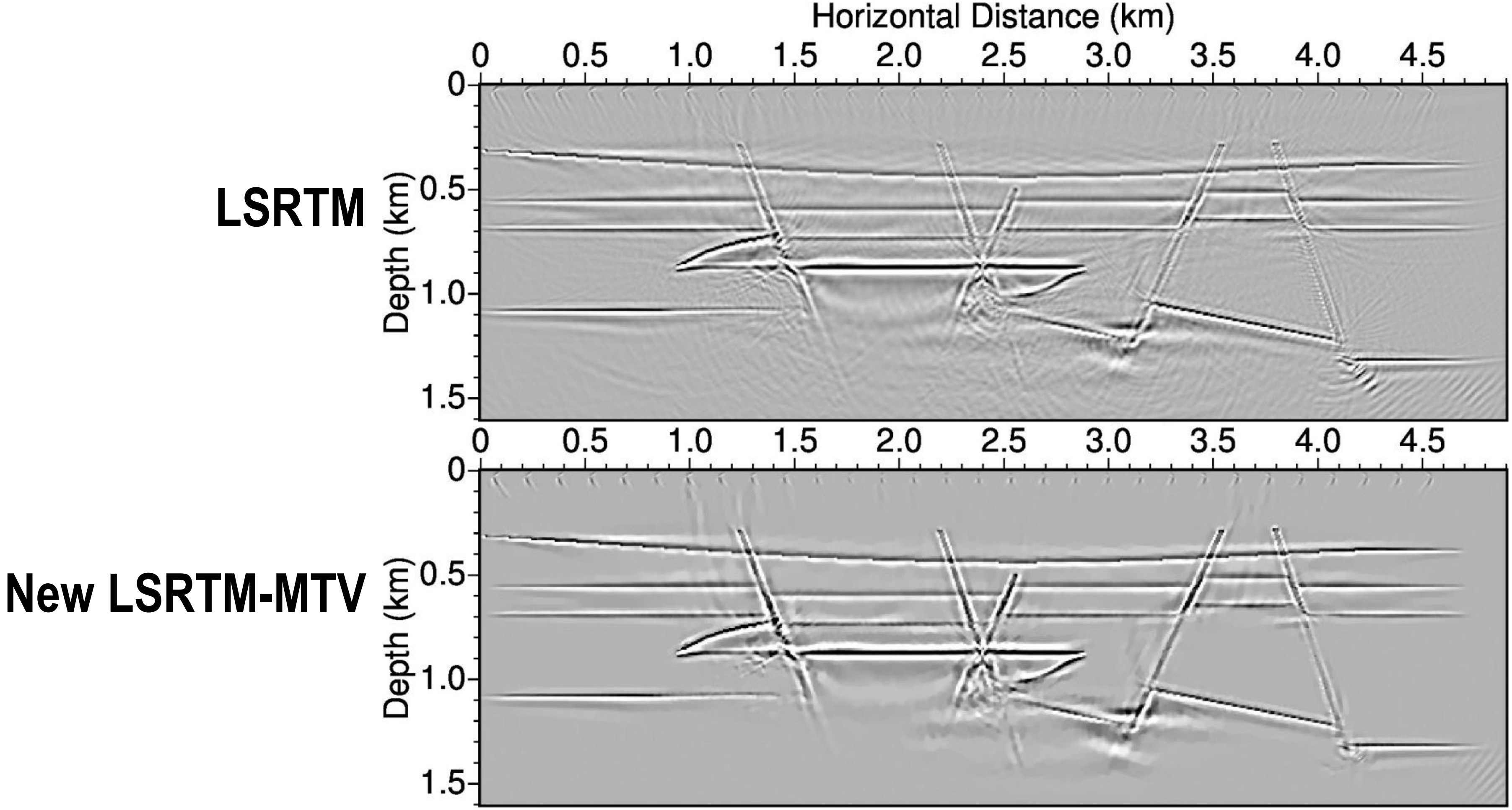
V_s obtained using new EWI



V_s obtained using old EWI

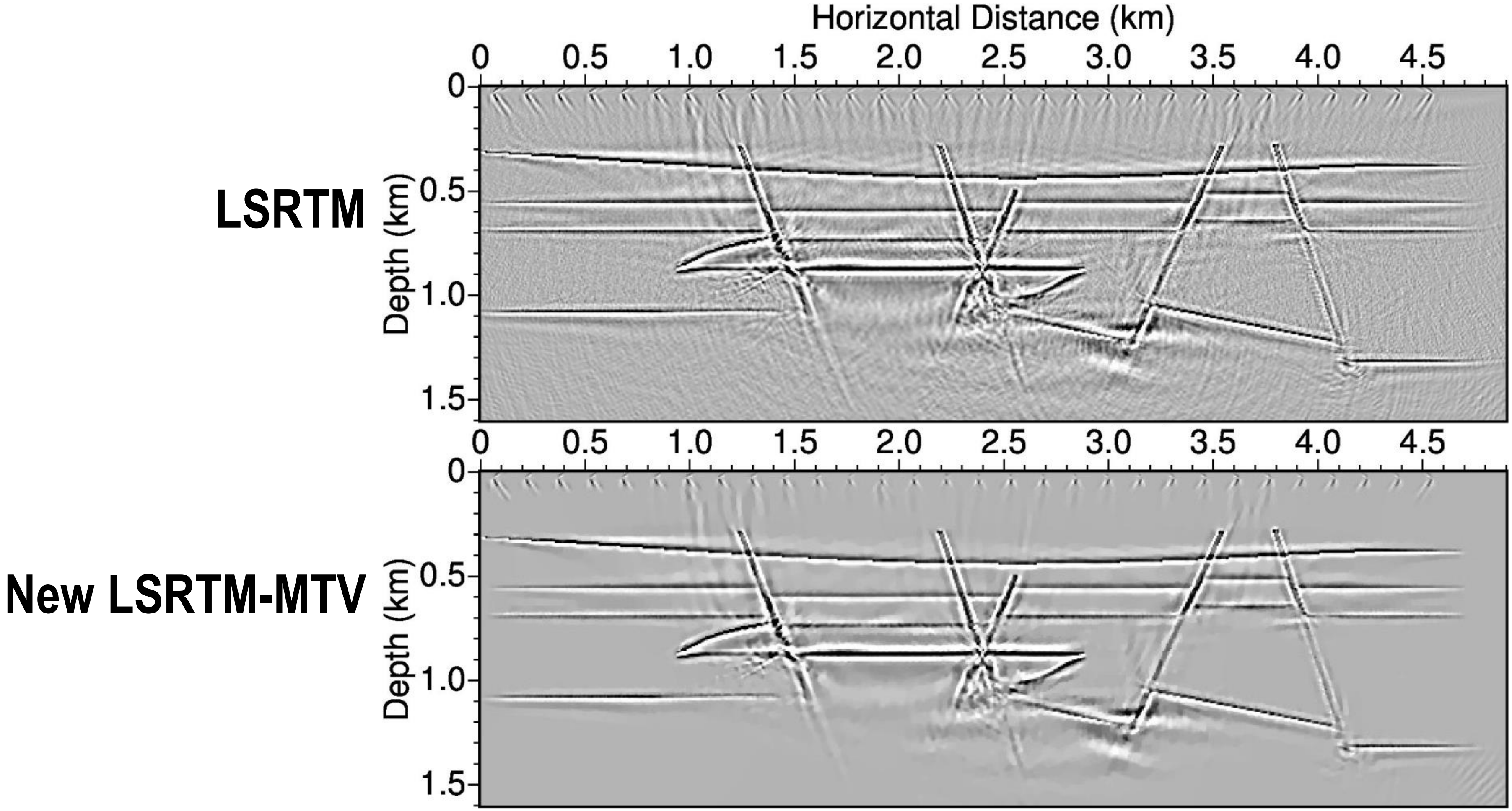
Least-squares reverse-time migration with modified TV regularization

Migration with **noise-free** synthetic surface seismic data for **30** shots



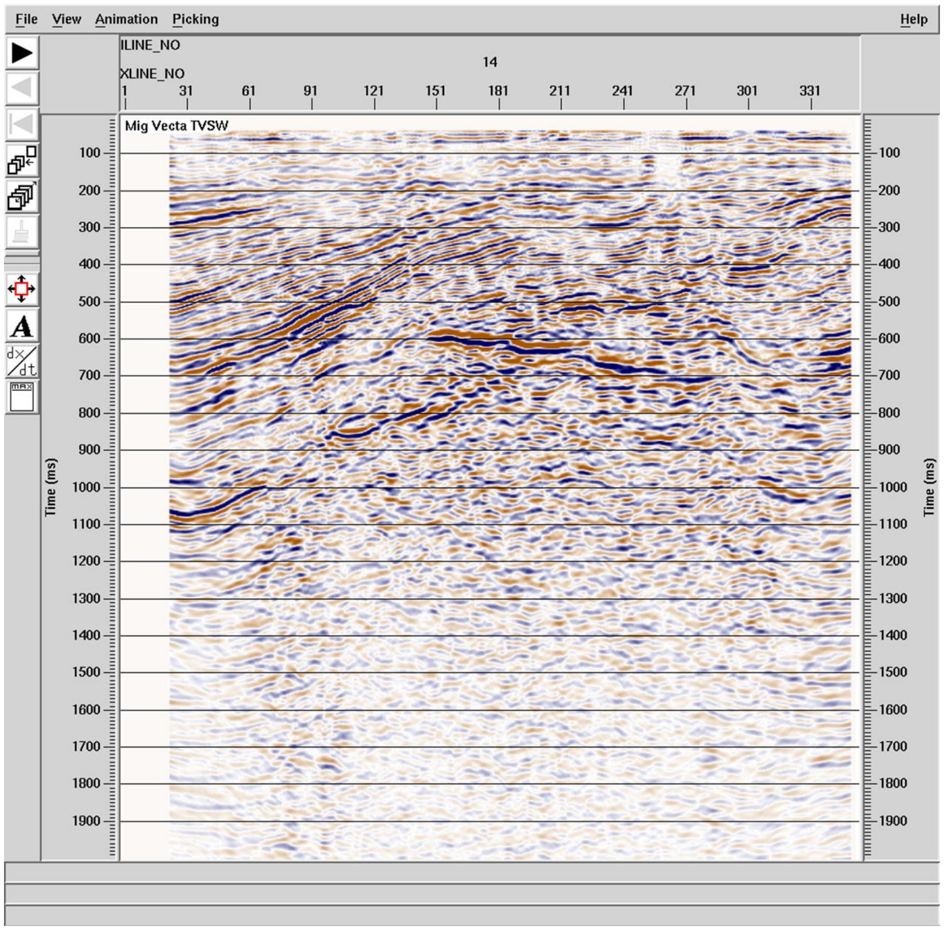
Least-squares reverse-time migration with modified TV regularization

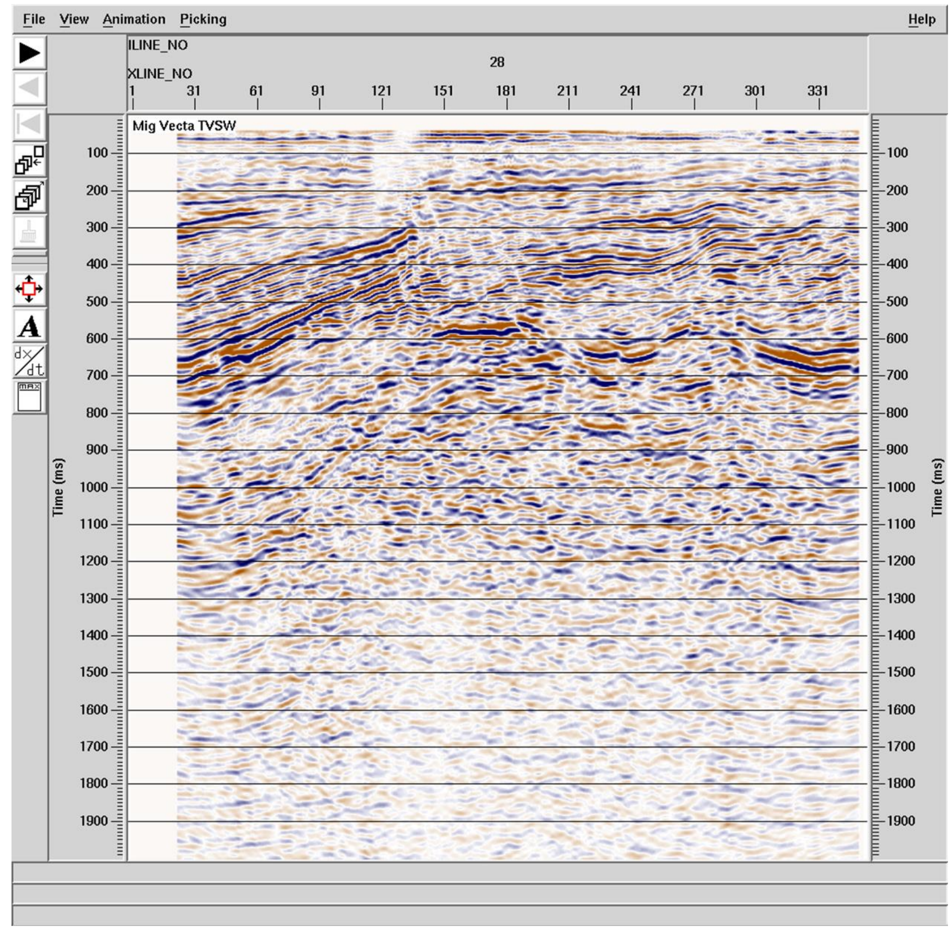
Migration with **noisy** synthetic surface seismic data for **30** shots



Processing of Soda Lake 3D surface seismic data by Vecta Oil & Gas

(Processed PP-data will be ready in April and PS-data will be ready in May, 2015)





Future Directions

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- Future plans:
  - Complete processing of Soda Lake seismic data.
  - Study practical feasibility of elastic reverse-time migration for imaging fault zones.

Milestone or Go/No-Go	Status & Expected Completion Date
Develop and validate parallel computing code for 3D reverse-time migration	Expect to meet milestones by 06/31/2015
Verify the 2D imaging capability for detecting fault zones using 2D field data	Expect to meet milestones by 09/30/2015
Obtain migration velocity models for the Soda Lake geothermal site using full-waveform inversion	Expect to meet milestones by 01/31/2016
Verify the 3D imaging capability of reverse-time migration for detecting fault zones using 3D field data	Expect to meet milestones by 06/30/2016

Mandatory Summary Slide

- Our novel elastic-waveform inversion algorithm with edge-guided regularization scheme produces high-resolution, high-fidelity subsurface velocity models for migration imaging.
- Our elastic reverse-time migration algorithms with new imaging conditions improves the computational efficiency for 3D migration.
- Our new boundary-wavefield extrapolation method significantly reduces the computer memory requirement for 3D reverse-time migration and full-waveform inversion.
- Our new least-squares reverse-time migration method with modified total-variation regularization significantly enhances the image quality for noisy and sparse data.
- We have validated all new algorithms using synthetic seismic data.