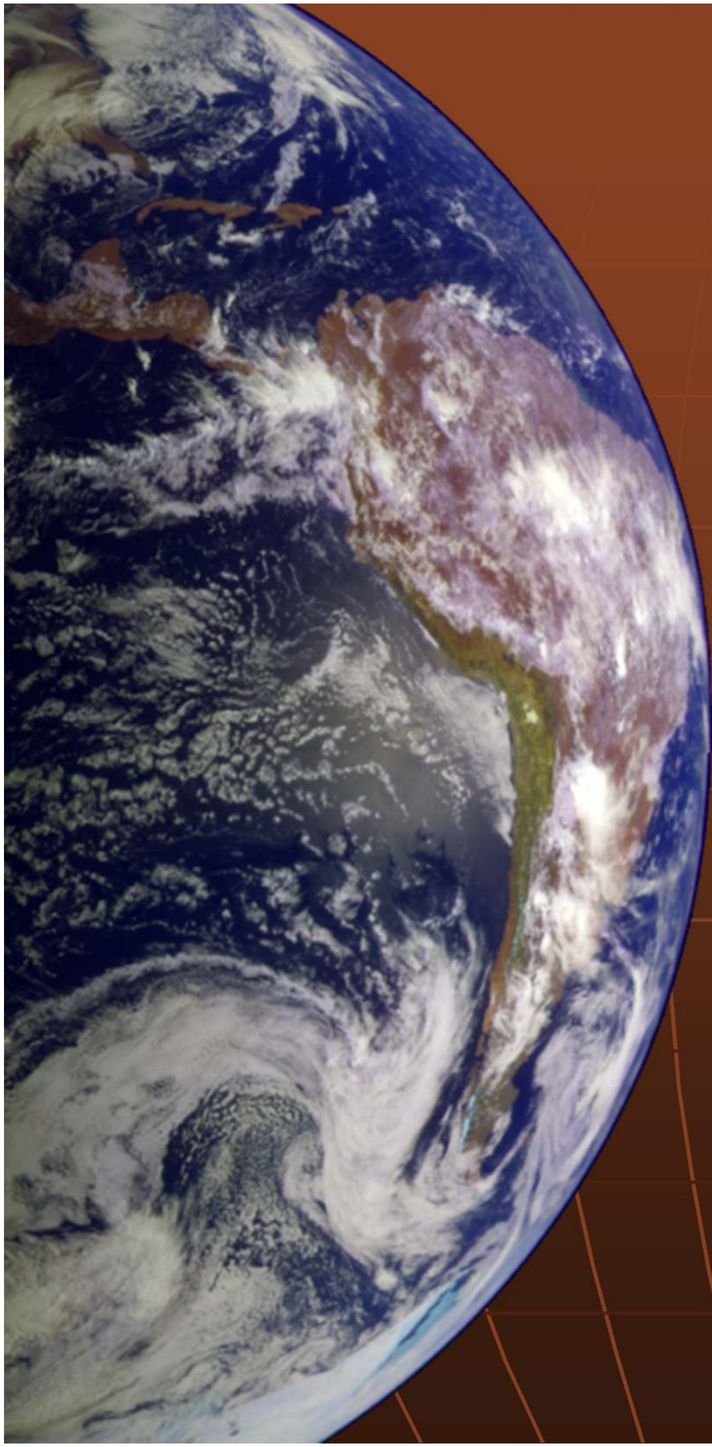


Accuracy Required in Seismic Modeling to detect Production-induced Time-lapse Signatures

Presented by

Alireza Shahin

Geophysicist, BP & Recent PhD Graduate

Supervised by

Paul Stoffa and Robert Tatham

Institute for Geophysics
Jackson School of Geosciences
University of Texas at Austin

Date: February 28th , 2011

Contents

Contents

Applications of seismic time-lapse analysis

- Identifications of flood fronts, preferential pathways, thief zones, and flow barriers, i.e. seals, by-passed pay and infill target definition.
- Estimation of saturation change, discrimination of saturation and pressure changes from changes in seismic attributes
- Updating of the reservoir flow model in order to have realistic reservoir production forecasts.

Contents

- Motivation
- Constructing a petro- elastic reservoir model
- Optimal dynamic rock-fluid physics template (update)
- Accuracy required in seismic modeling to detect time-lapse signals
-
- Contributions (publications)
- Recommendation and future work
- Acknowledgement

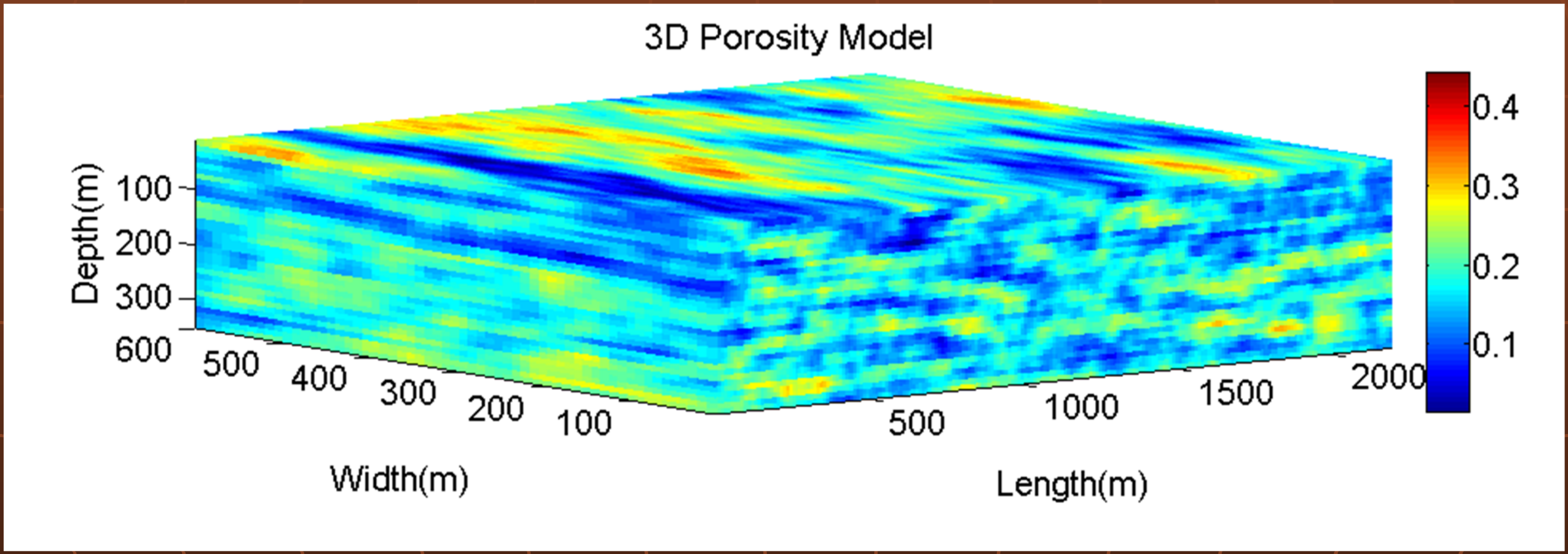
Constructing a petro- elastic reservoir model

- Geological reservoir model
- Petrophysics model
- Reservoir simulation
- Rock physics modeling

Geological reservoir model

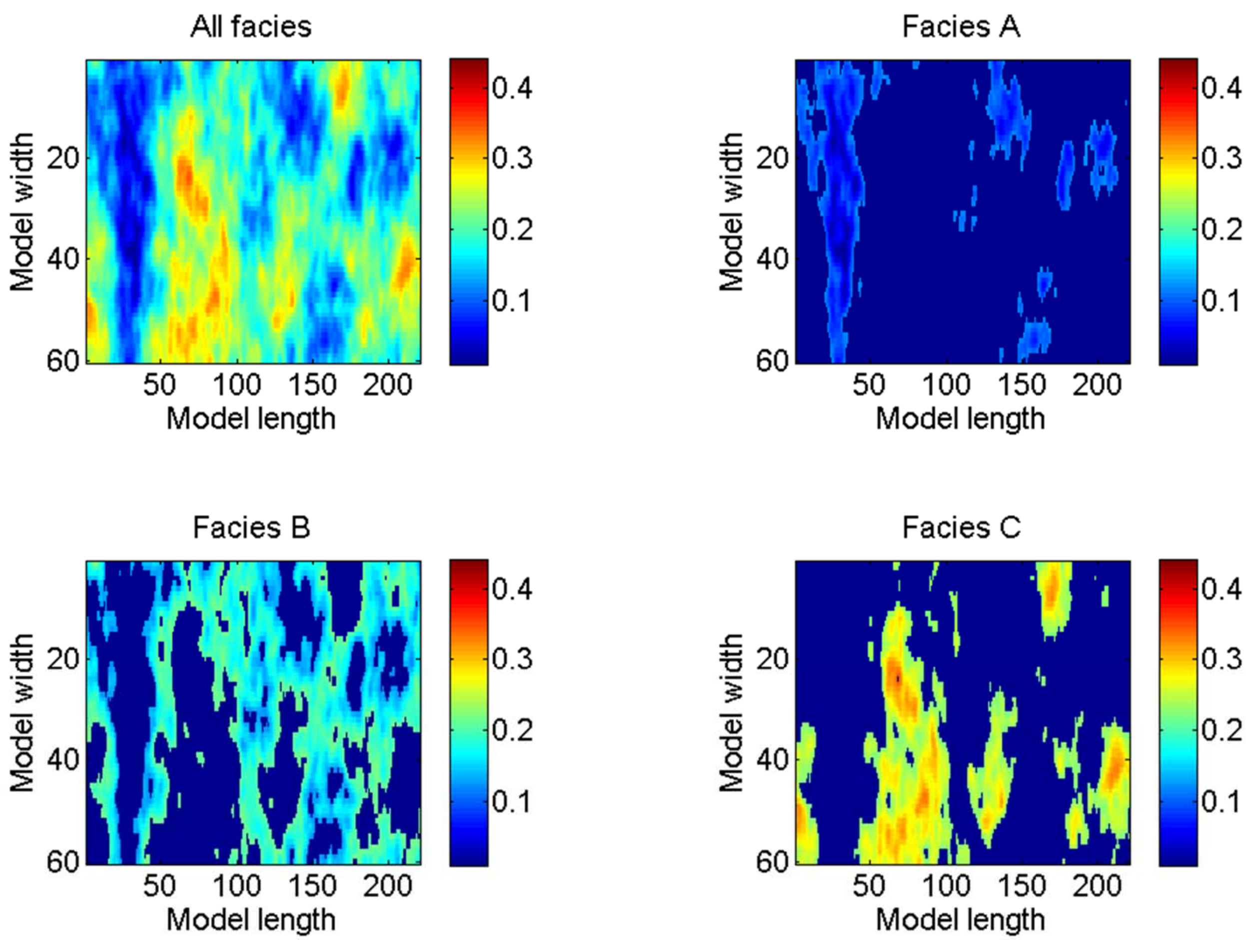
- A stacked sand-rich strandplain reservoir architecture has been considered in this study to simulate a realistic geological framework.
- Strandplains are mainly marine-dominated depositional systems generated by seaward accretion of successive, parallel beach ridges welded onto the subaerial coastal mainlands.
- They are inherently progradational features and present on wave-dominated microtidal coasts (Tyler and Ambrose 1986; Galloway and Hobday 1996).

3D effective porosity model



A large geostatistical model widely used in research on upgridding and upscaling approaches (Christie and Blunt, 2001)

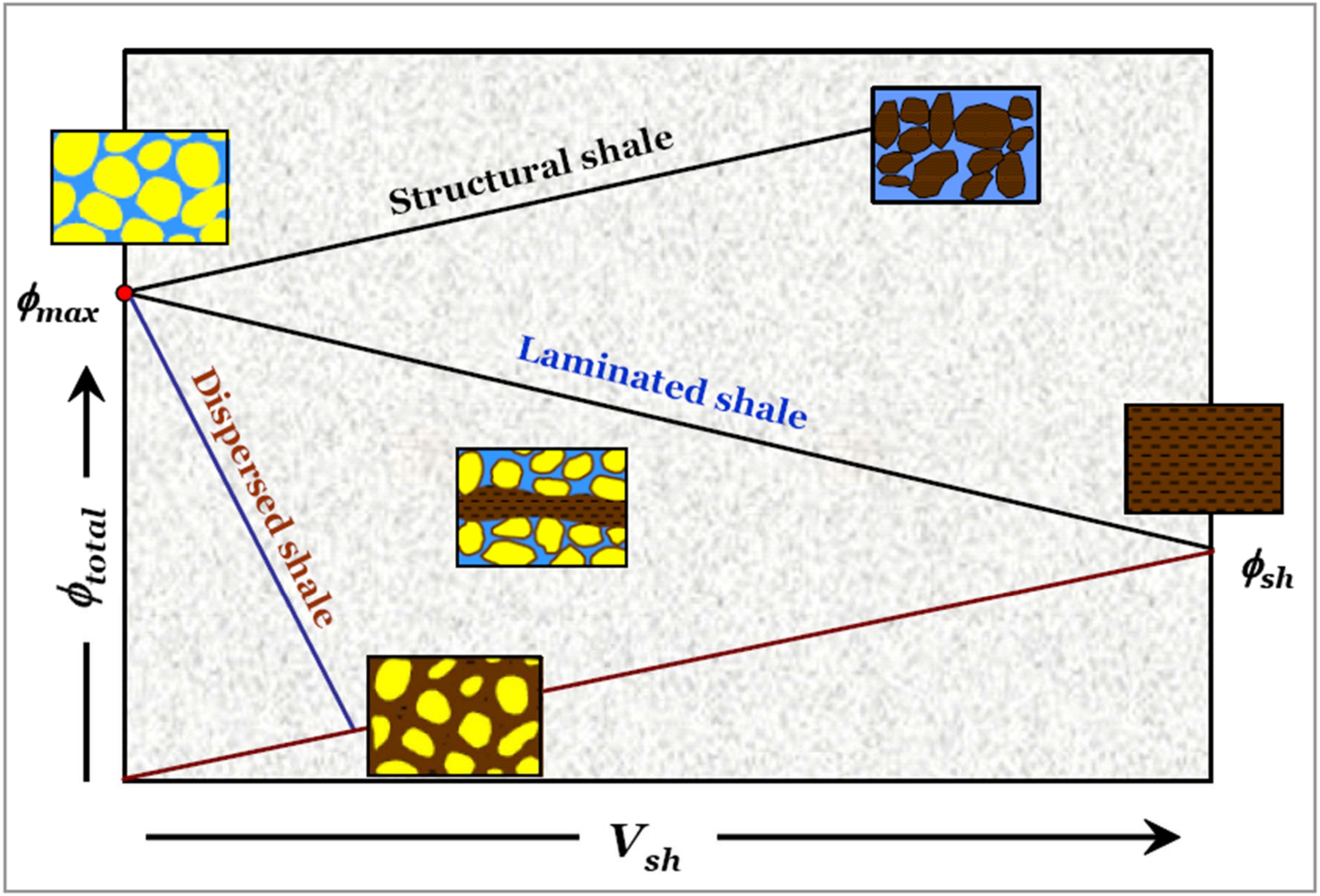
Facies distribution in effective porosity domain
Map view



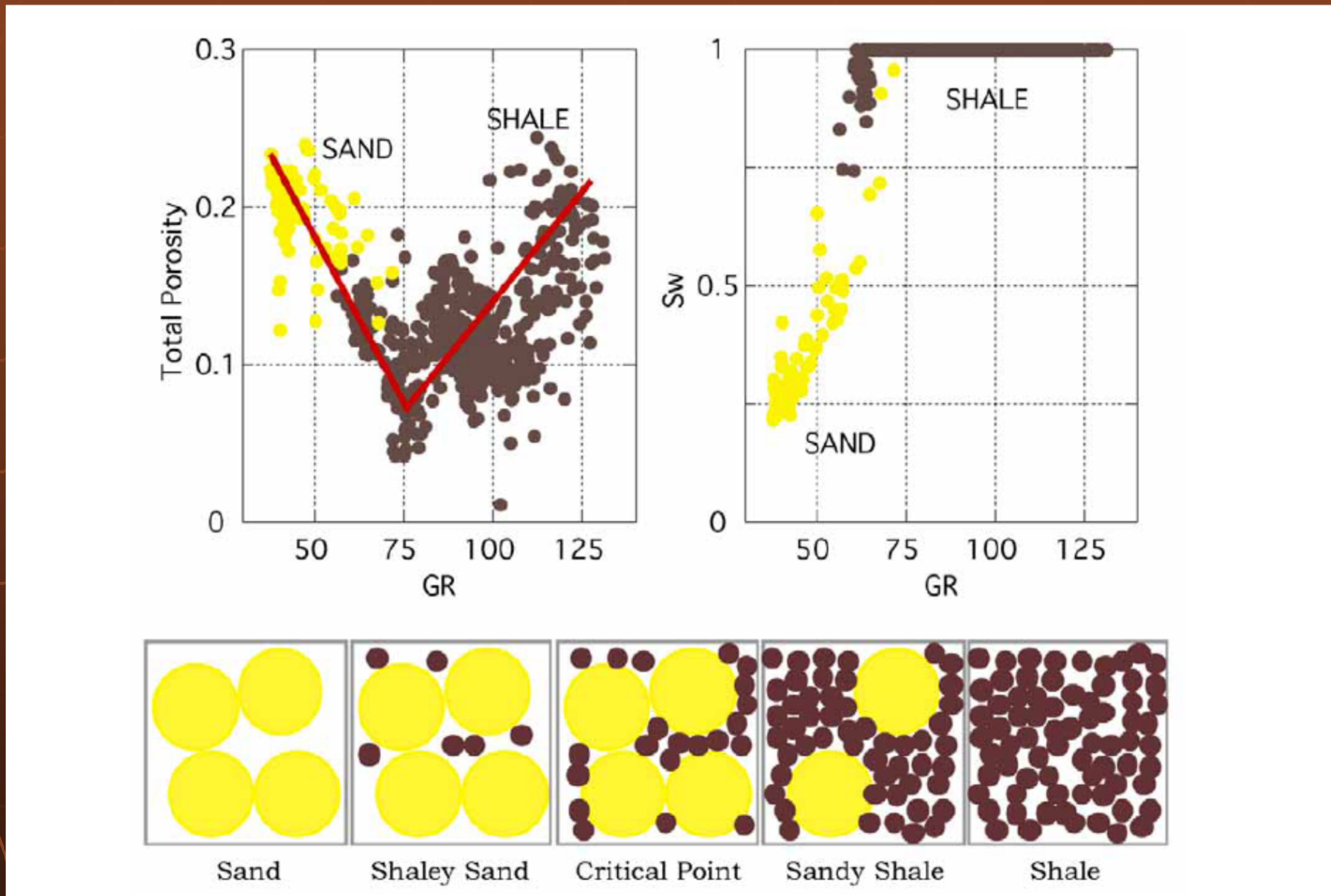
Petrophysics model

- The effective porosity model is first adopted (Christie and Blunt, 2001) and modified to meet the objectives of this research .
- Shale content and total porosity models are then computed assuming a dispersed clay distribution (Thomas and Stieber 1975; Marion et al. 1992).
- Permeabilities are calculated based on the extension of the dispersed clay model to permeability (Revil and Cathles 1999). Permeability fields depend on porosity, shale content, grain size distribution, and the degree of cementation ; subsequently facies A, B, and C are assigned different trends in permeability-shale content and permeability-porosity domains based on their grain sizes.
- An experimental correlation (Uden et al. 2004) between water saturation and shale content is combined with the dual water model (Best 1980; Dewan, 1983; Clavier, 1984) to compute clay bound water, effective water saturation , total water saturation, and oil saturation.
- Initial reservoir pore pressure is simulated assuming a linear hydrostatic gradient from the top to the bottom of the reservoir.

Clay distribution in clastic rocks

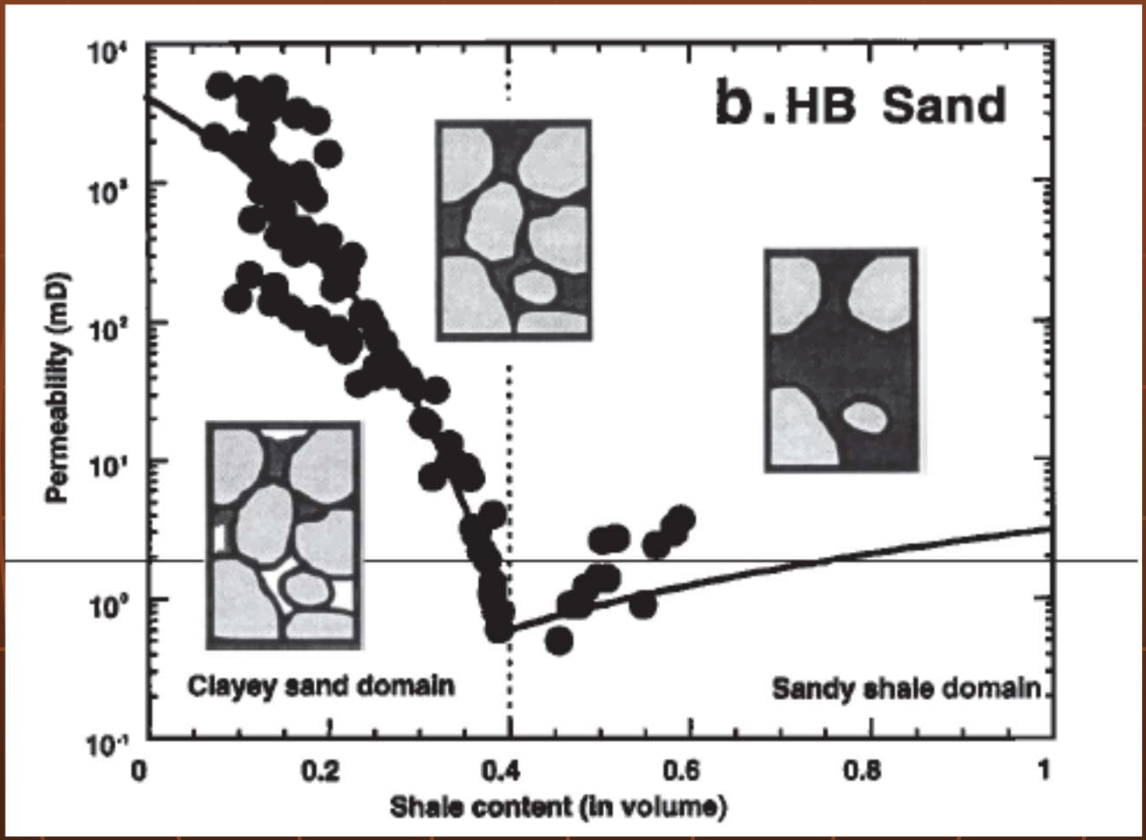


Real data example



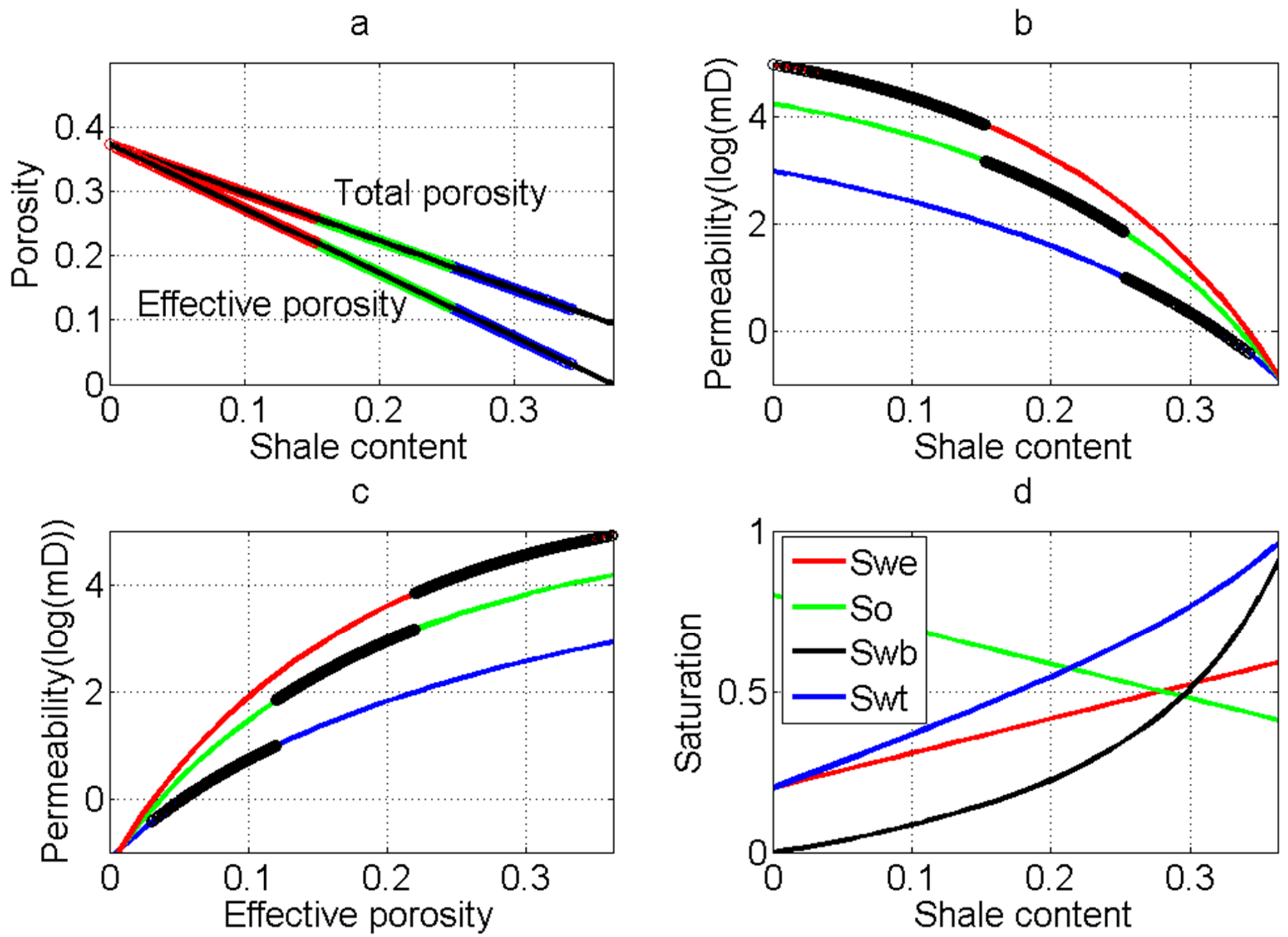
Uden et al. 2004

Real data example

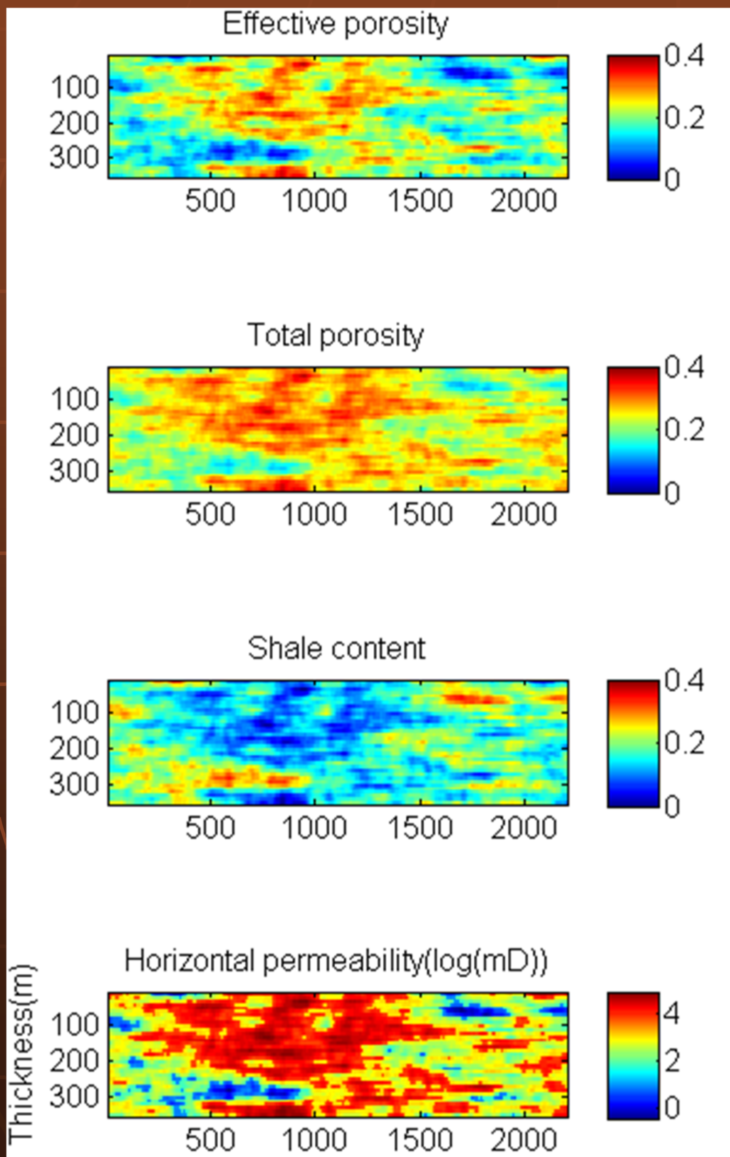


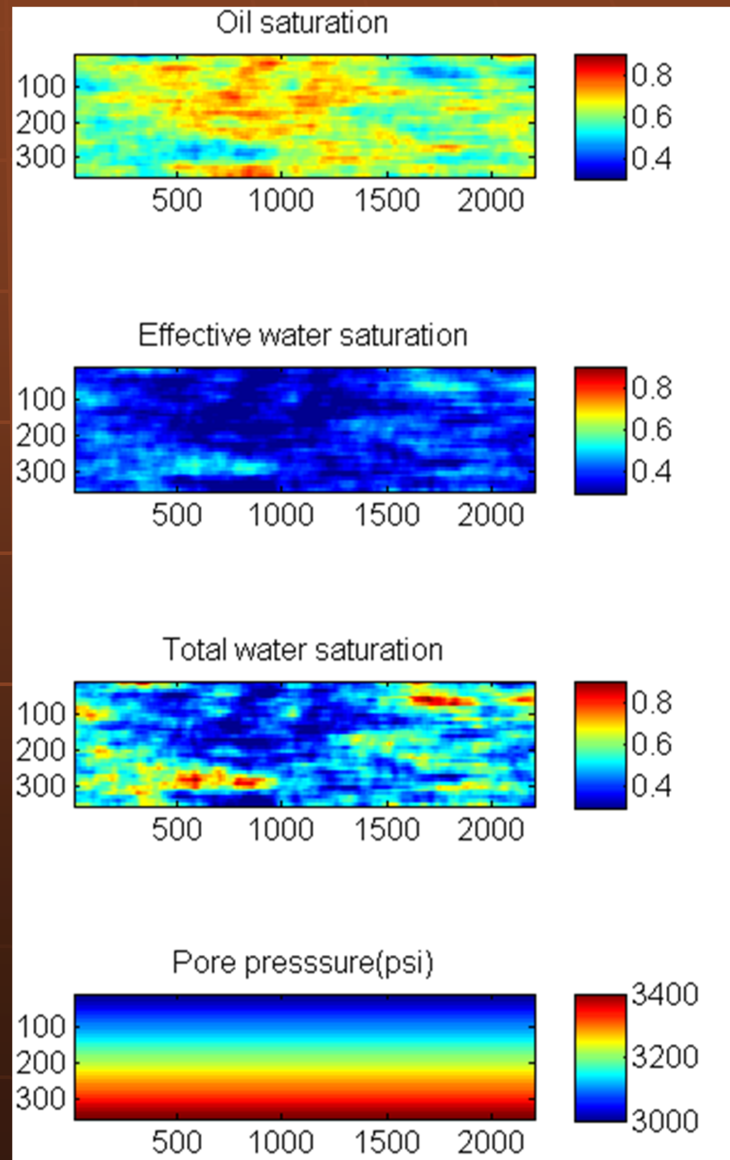
Revil and Cathles 1999

Petrophysics model



Distribution of petrophysical properties





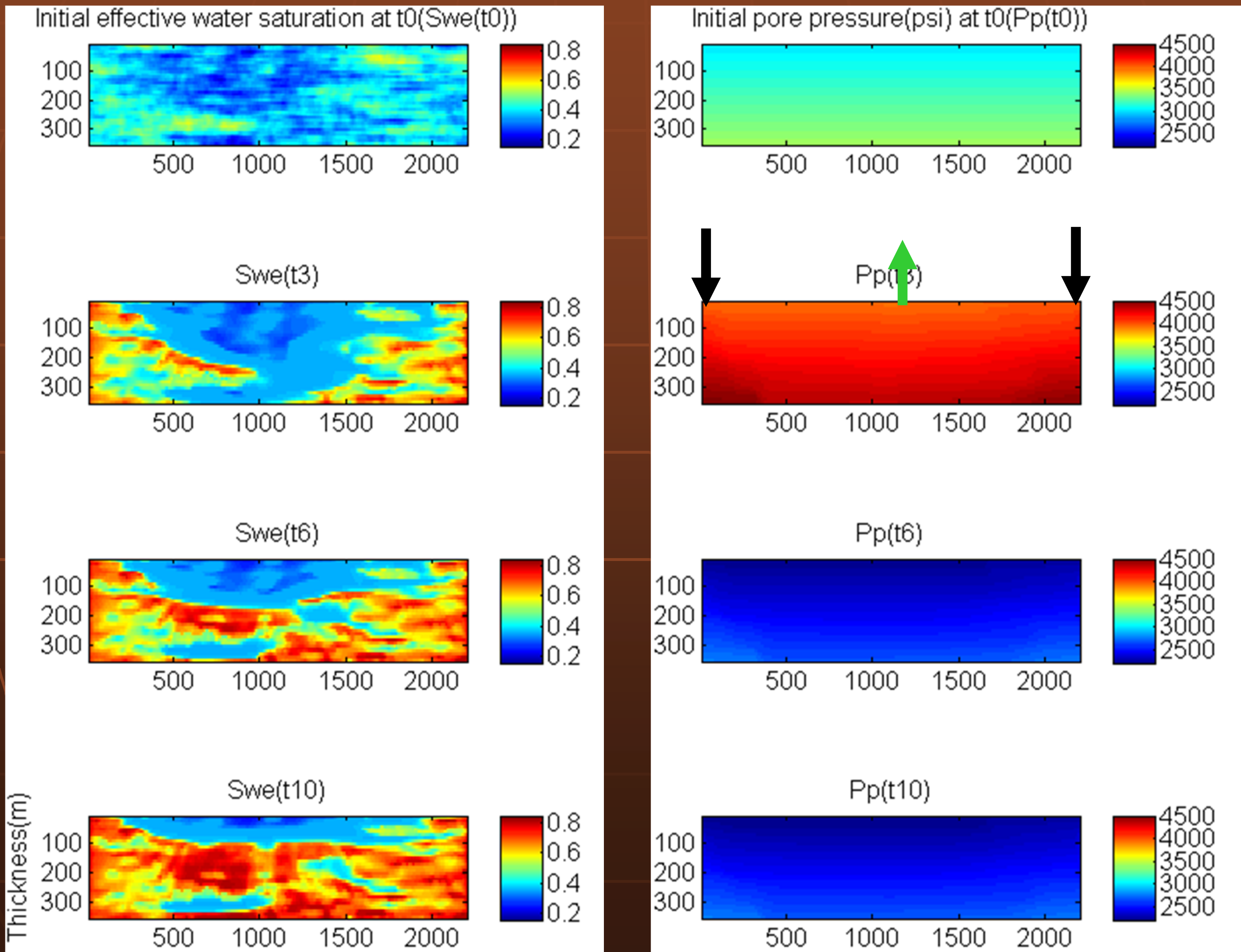
Reservoir simulation

- Fluid flow simulation combines three fundamental laws governing fluid motions in porous media.

- These laws are based on conservation of mass, momentum, and energy (Aziz and Settari 1976).

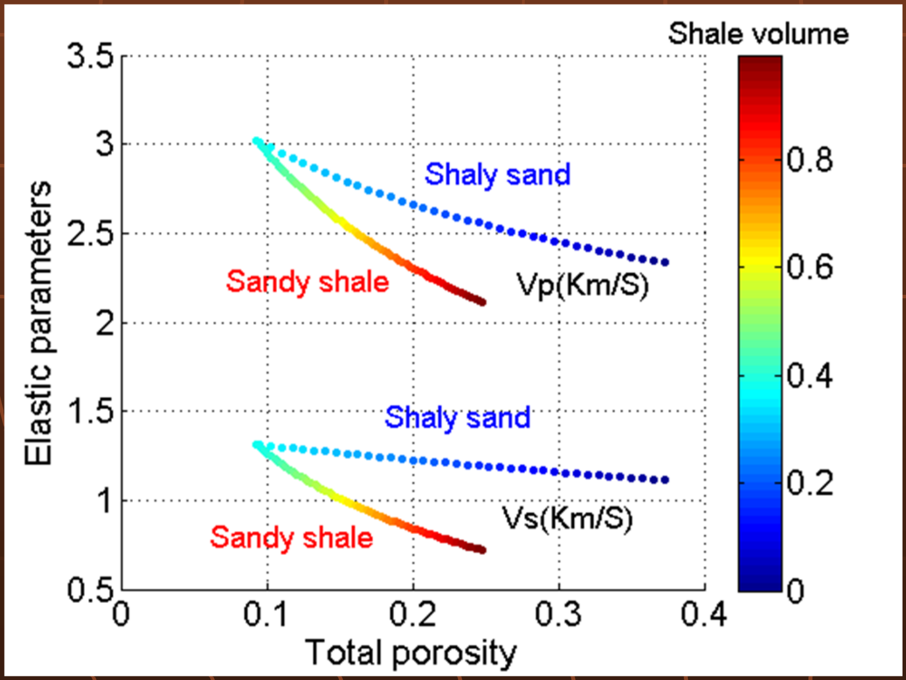
- In this research, a commercial finite difference reservoir simulator, Eclipse 100, is utilized to replicate a waterflood enhanced oil recovery on a black-oil 2D reservoir containing oil, soluble gas, and water.

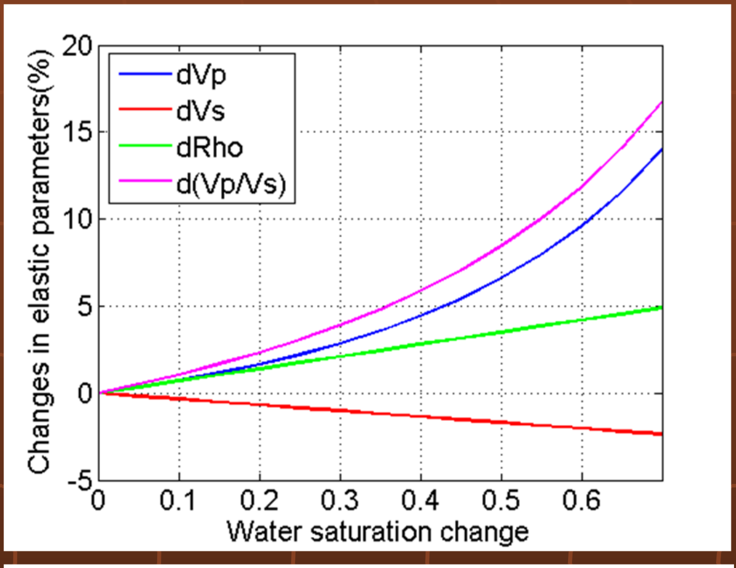
Time-dependent distributions of fluid saturation and pressure

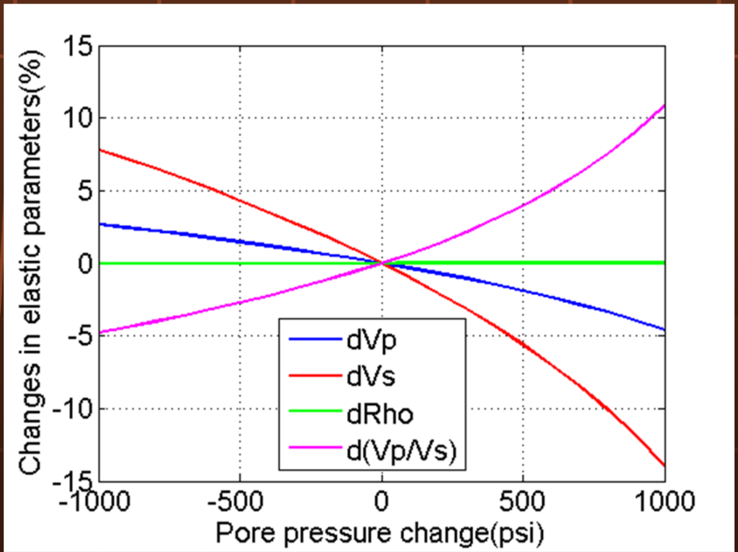


Petro-elastic model

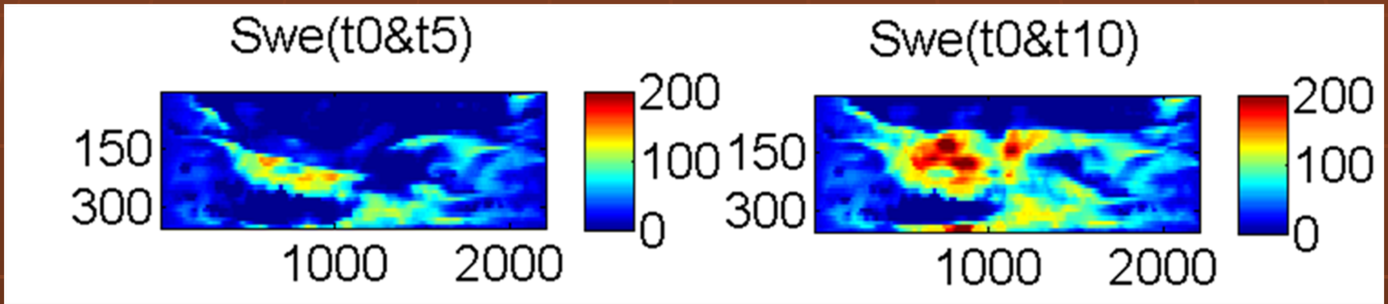
Combining Dvorkin-Gutierrez rock physics model (2002),
fluid physics model (Batzle & Wang 1992),
and using a modified Gassmann theory (Dvorkin et al. 2007),

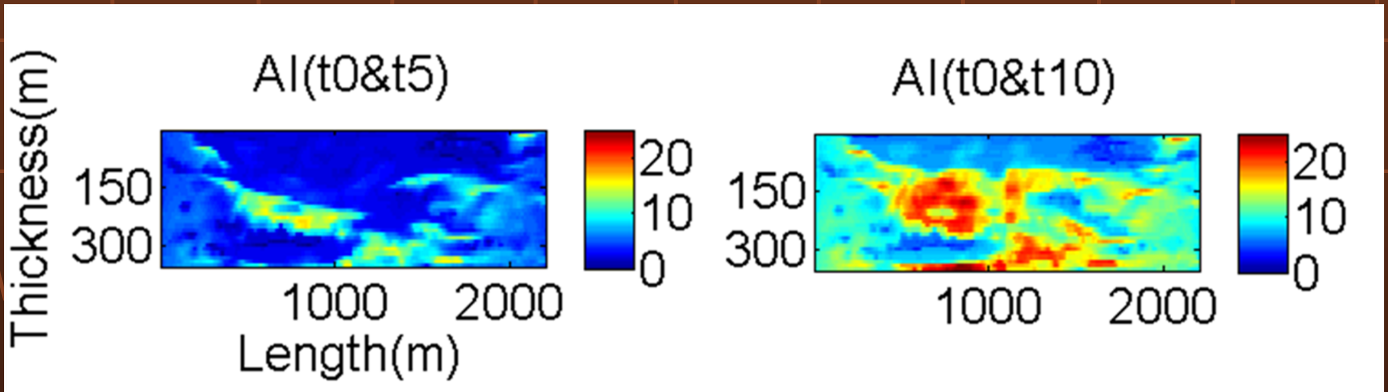






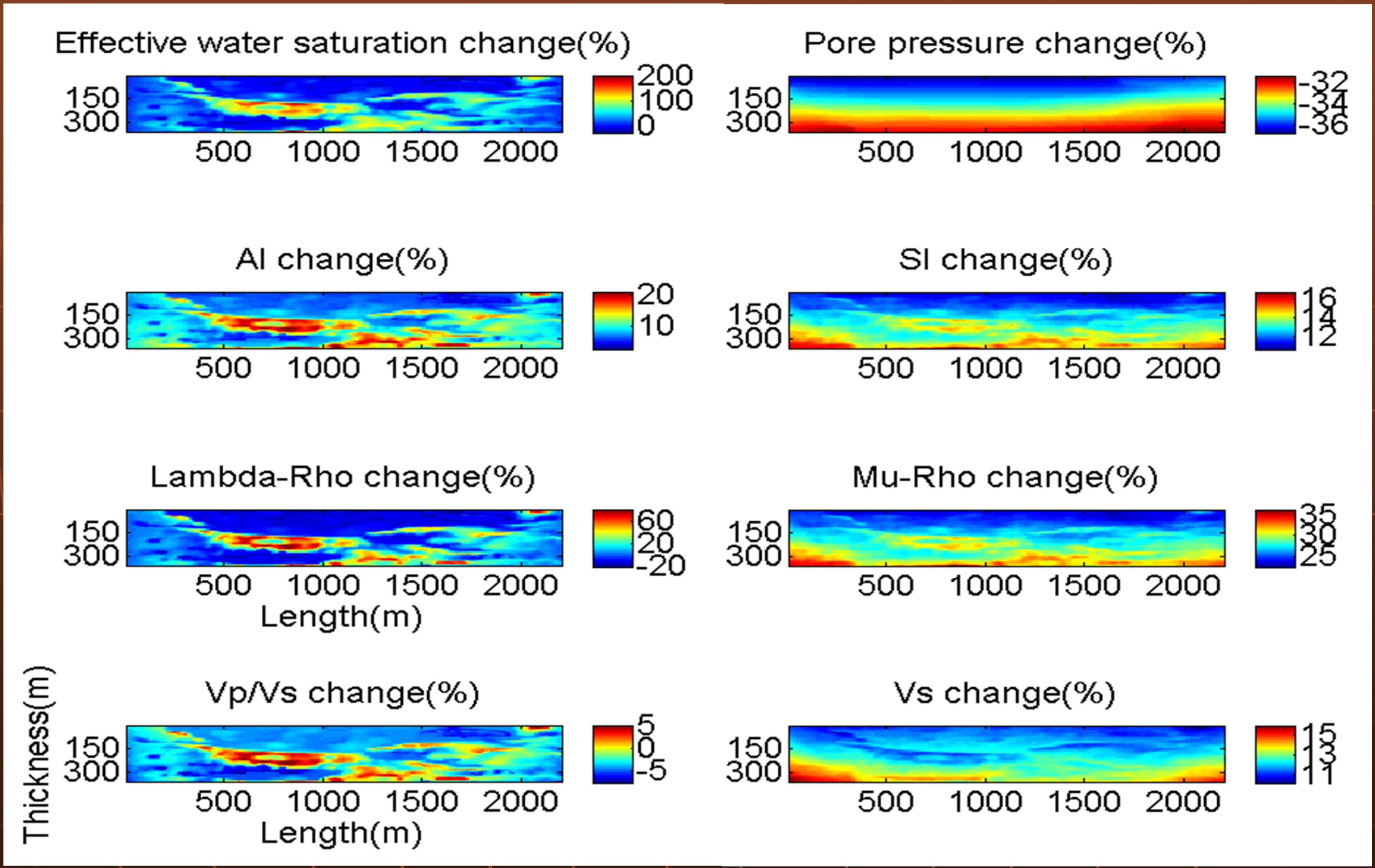
Time-lapse changes in acoustic imdedance



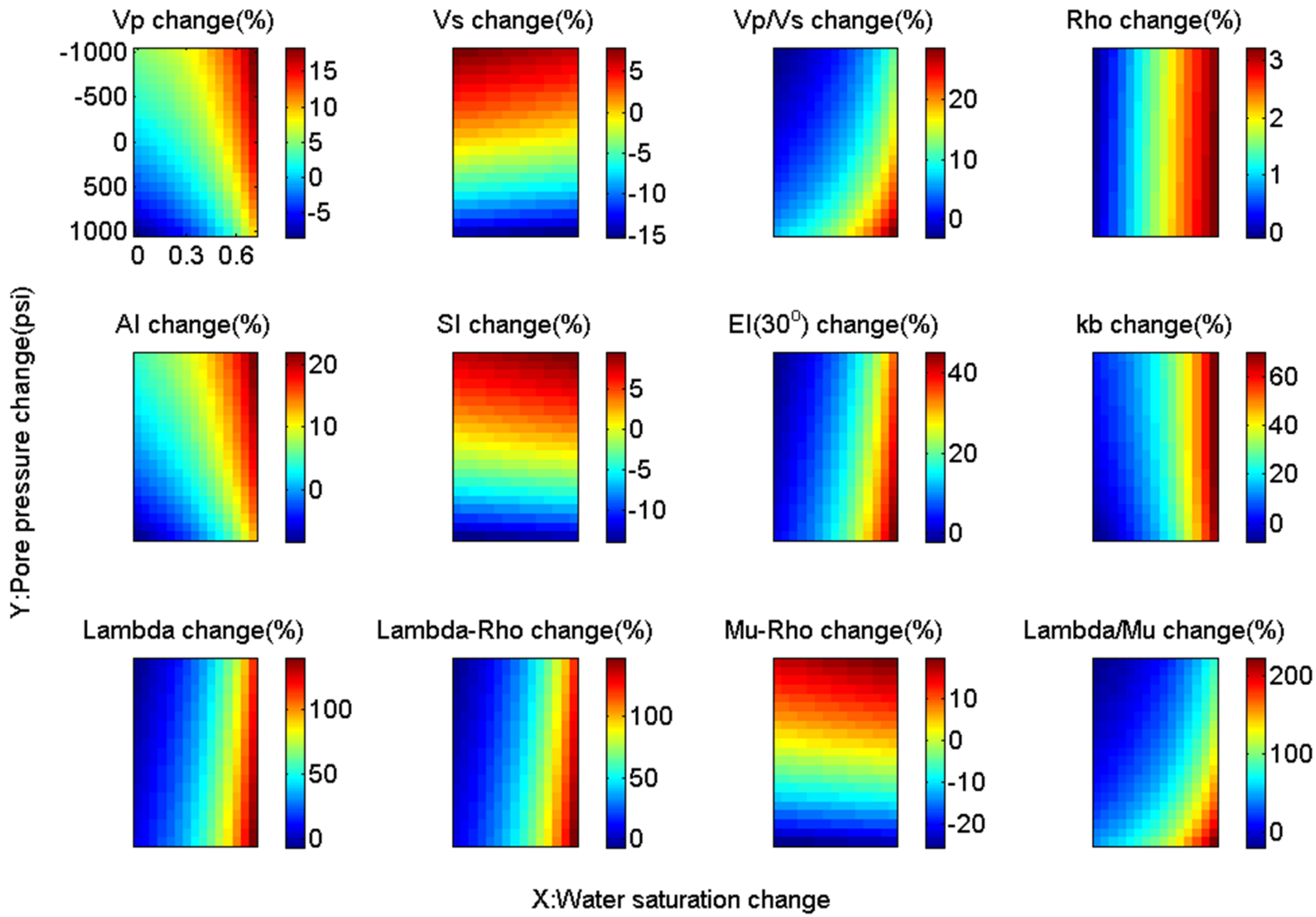


Contents

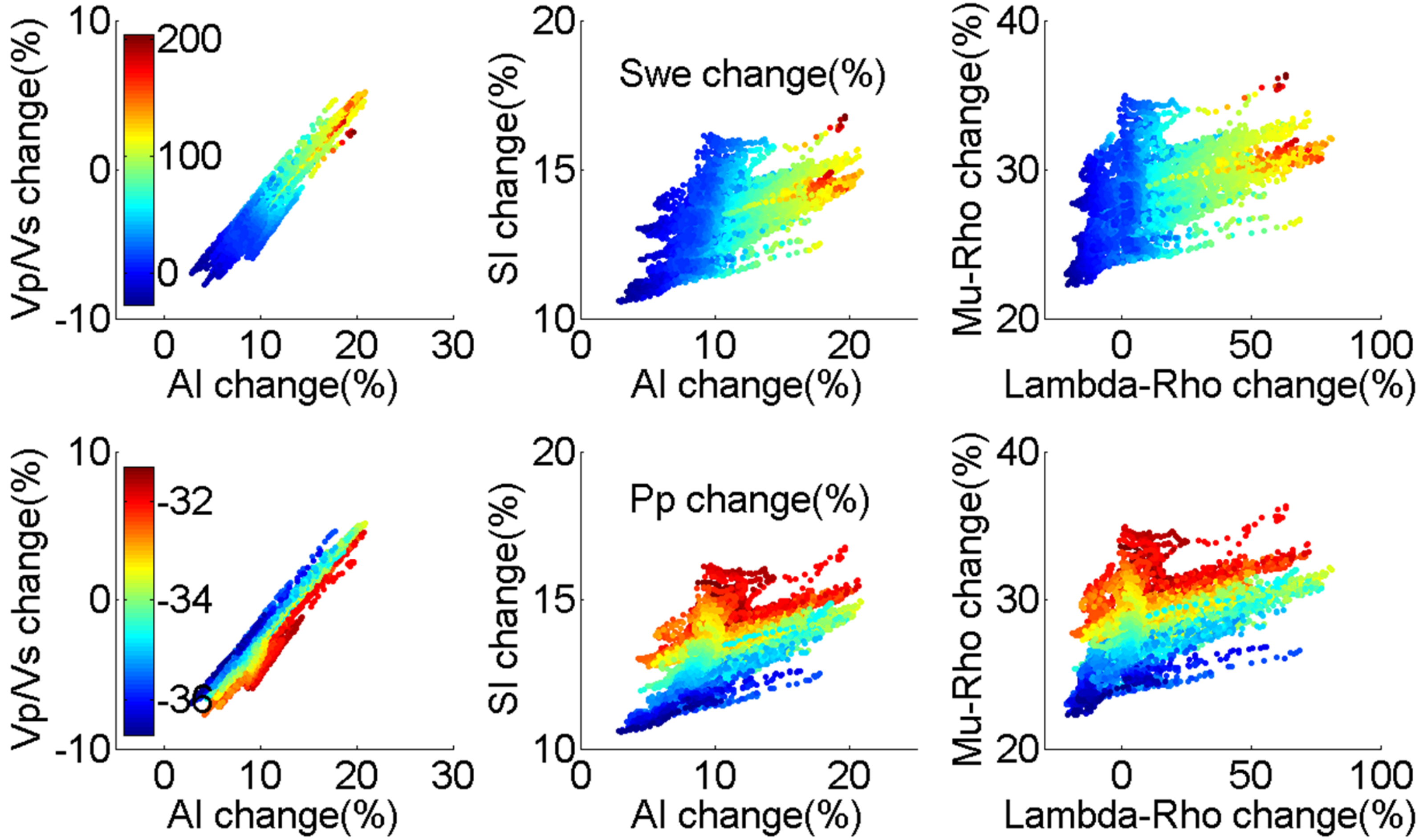
Time-lapse change in reservoir properties and associated elastic parameters



Sensitivity of elastic parameters to joint effect of pore pressure and water saturation change



Time-lapse crossplot (t5-t1)



SEG abstract presented at Denver meeting 2010

Summary of time-lapse rock-fluid physics templates

- Sensitivity analysis demonstrates that [AI vs. SI] is the most useful crossplot to quantitatively separate saturation and pressure changes.
- Saturation patterns are detectable in most of the time-lapse scenarios because of the high percentage of change in water saturation.
- Pressure patterns are also well detected in most of the time-lapse scenarios in particular when notable pressure changes exist between the base and monitor surveys.
- The percentage in pressure change is often lower than of that of the saturation change in our waterflooded reservoir. Consequently, saturation patterns are more likely to be detected than pressure patterns.
- Imperfections exist in both saturation and pressure patterns and they appear in different forms such as mix-scattering and misallocated points preventing monotonic patterns. Some factors causing this phenomenon are the interaction of saturation and pressure, diffusive nature of the pressure front, and rapid change in pressure due to the production operations.

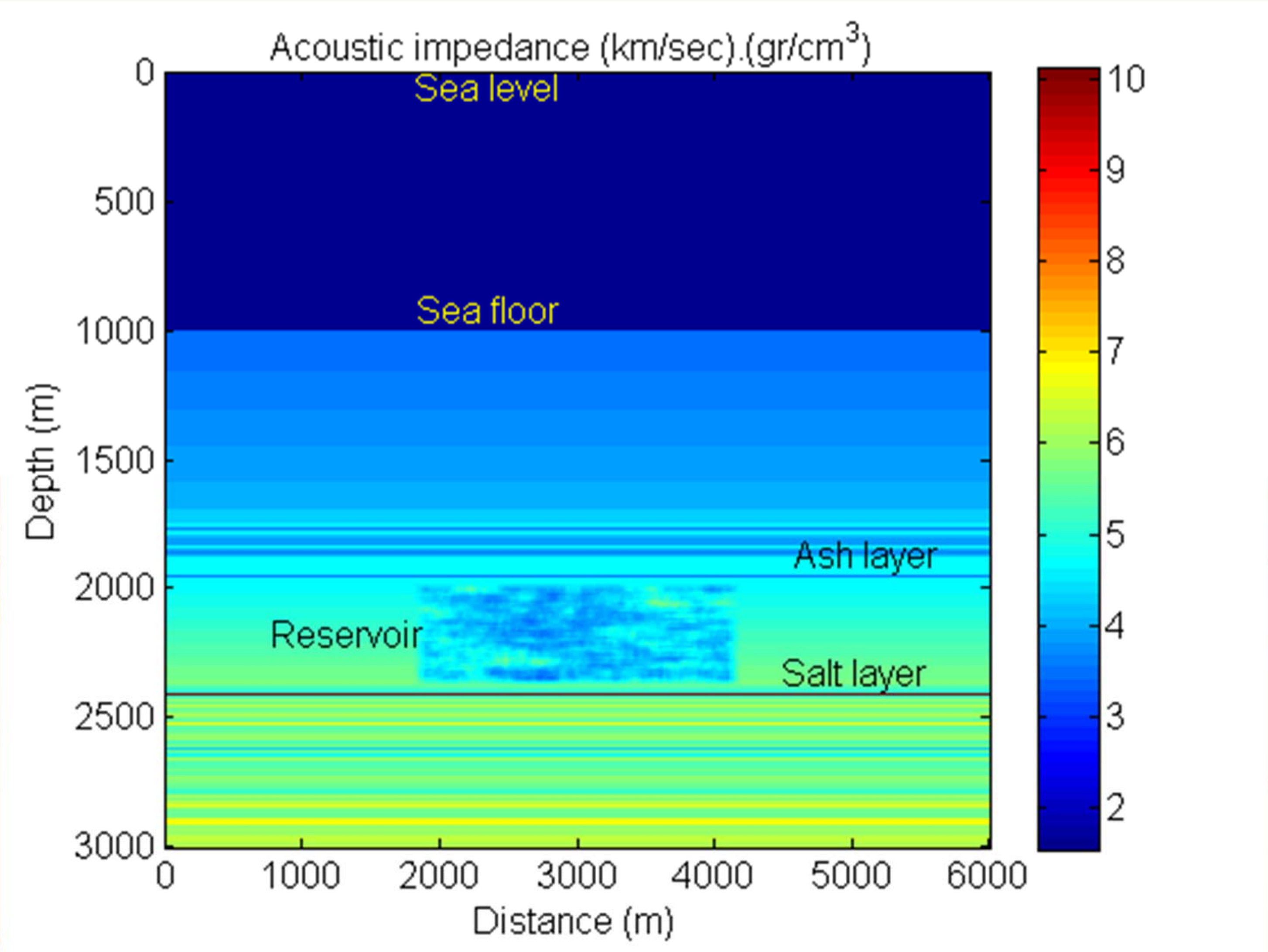
Contents

- Motivation
- Constructing a petro- elastic reservoir model
- Optimal dynamic rock-fluid physics template (update)
- **Accuracy required in seismic modeling to detect time-lapse signals**
-
- Contributions (publications)
- Recommendation and future work
- Acknowledgement

Seismic modeling algorithms

Algorithm / Characteristics	Acoustic	Elastic	Full elastic (Reflectivity)	Plane-wave Split-step Fourier	Full Elastic finite Difference (FD)
Earth Model	1D	1D	1D	1D/2D/3D	1D/2D/3D
Primaries	Yes	Yes	Yes	Yes	Yes
Internal Multiples	Optional	No	Yes	Optional	Yes
Converted waves	No	Elastic reflection coefficients	Yes	Elastic reflection coefficients	Yes
Diffraction	No	No	No	yes	Yes
Accuracy	Simplest	Simple	Perfect for 1D	Up to 25% lateral variation	Accurate
Speed	Super fast	Very fast	Fast	Average	Slow

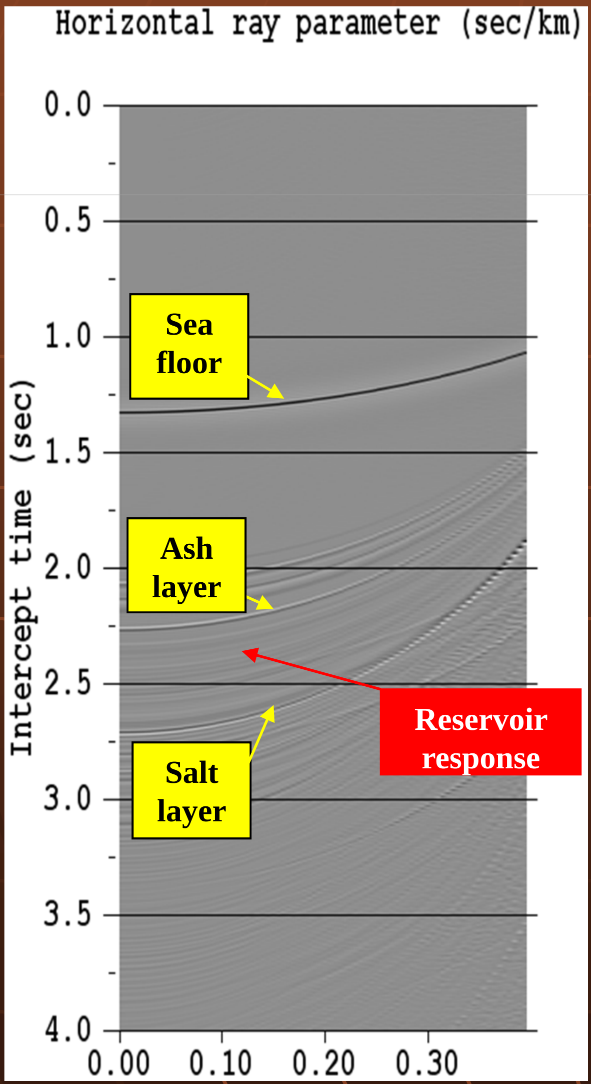
Reservoir inserted into background elastic model



1D locally seismic modeling to see the effects of :

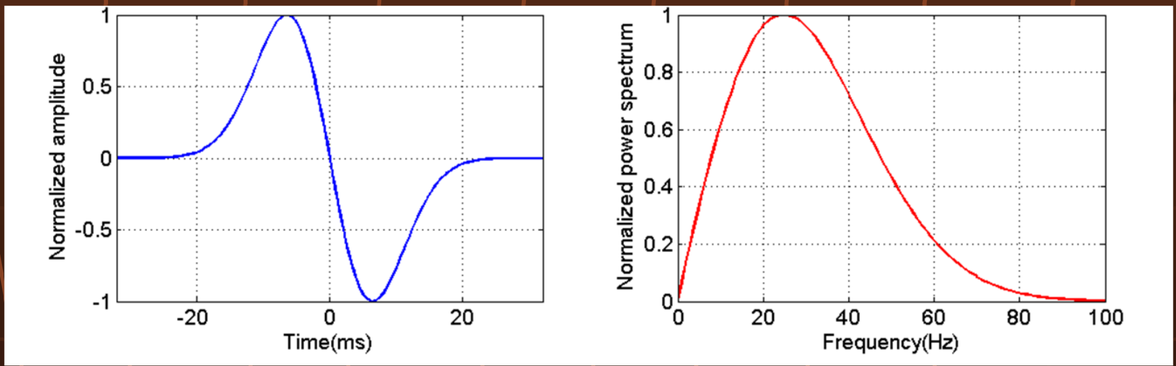
- Acoustic vs. elastic wave propagation
- Internal multiples
- Converted waves

Plane-wave response (full elastic reflectivity) of the 1D locally model in the middle of 2D reservoir for base survey (T0)



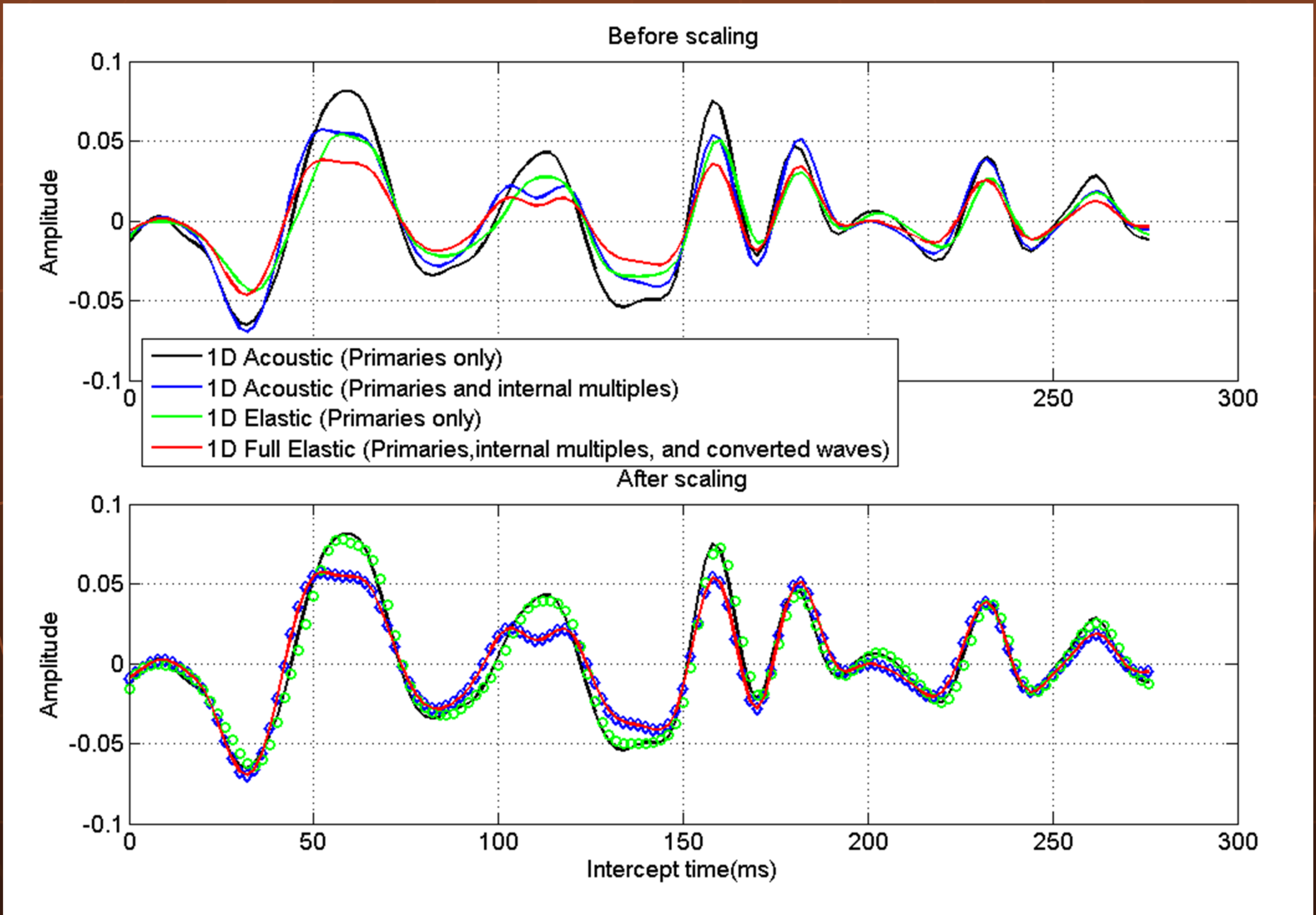
Geometry of different pre-stack traces simulated by 1D and 2D plane-wave seismic modeling techniques

	First trace	Second trace	Third trace	Forth trace
Ray parameter (sec/km)	0.0	0.10	0.20	0.30
Offset (km)	0.0	0.721	1.526	2.565
Incident angle at sea level (degree)	0.0	8.7	17.4	26.7
Incident angle at reservoir top (degree)	0.0	11.8	24.1	37.8
Intercept time (sec)	2.314	2.278	2.167	1.965
Traveltime (sec)	2.314	2.350	2.472	2.735

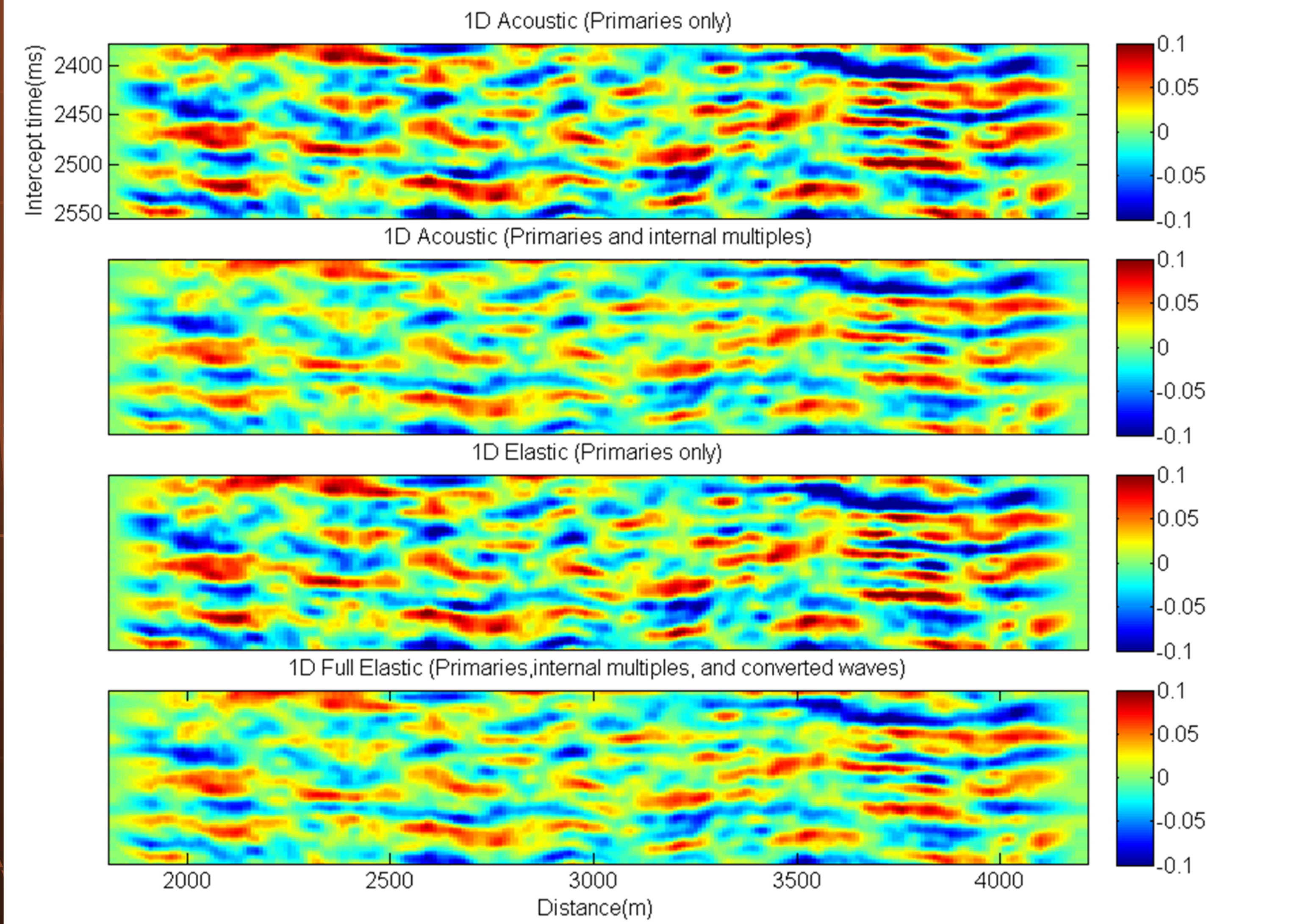


Normalized derivative of a Gaussian wavelet with a peak frequency of 35 Hz

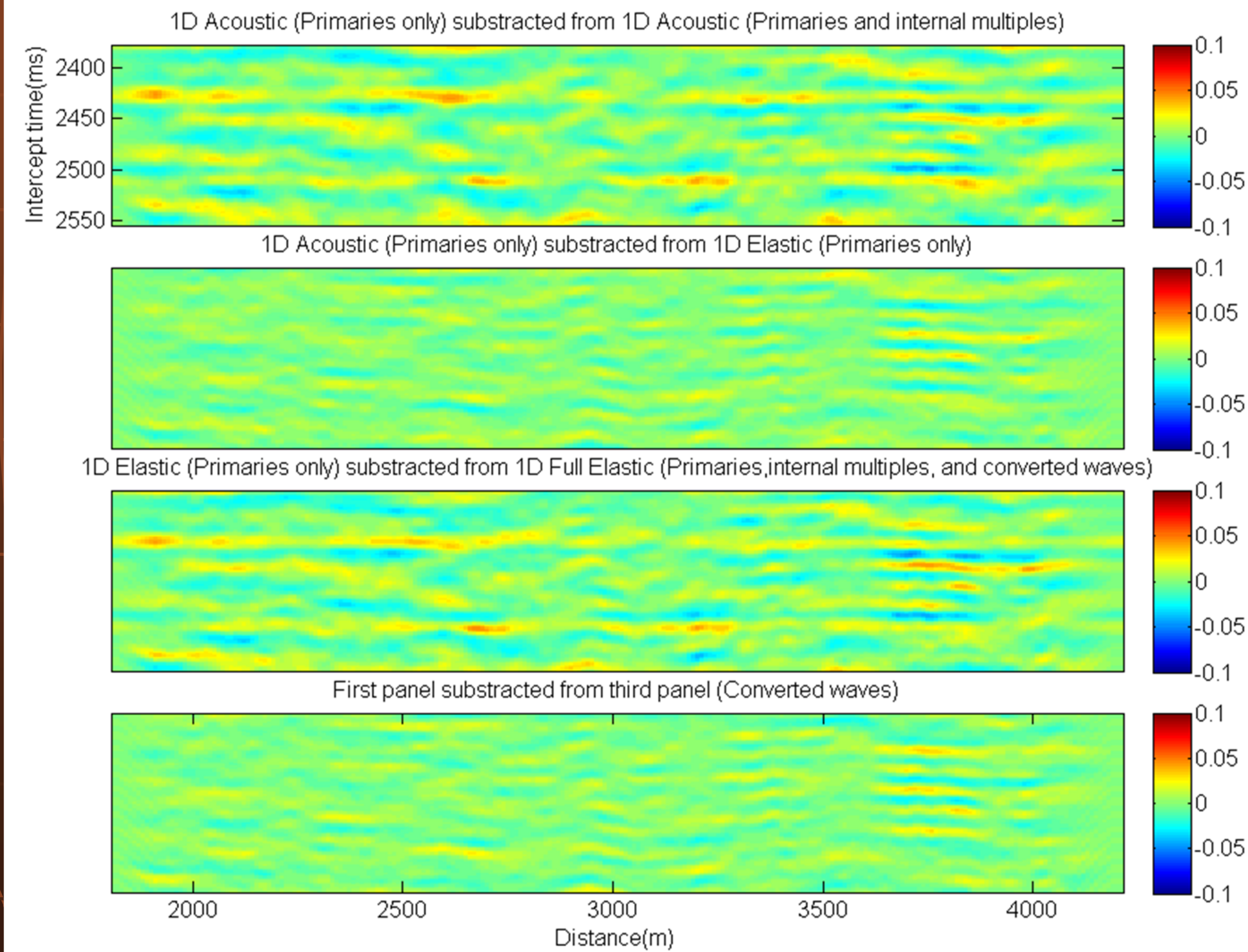
The scaling scheme used to tune 1D plane-wave seismic data computed from various algorithms



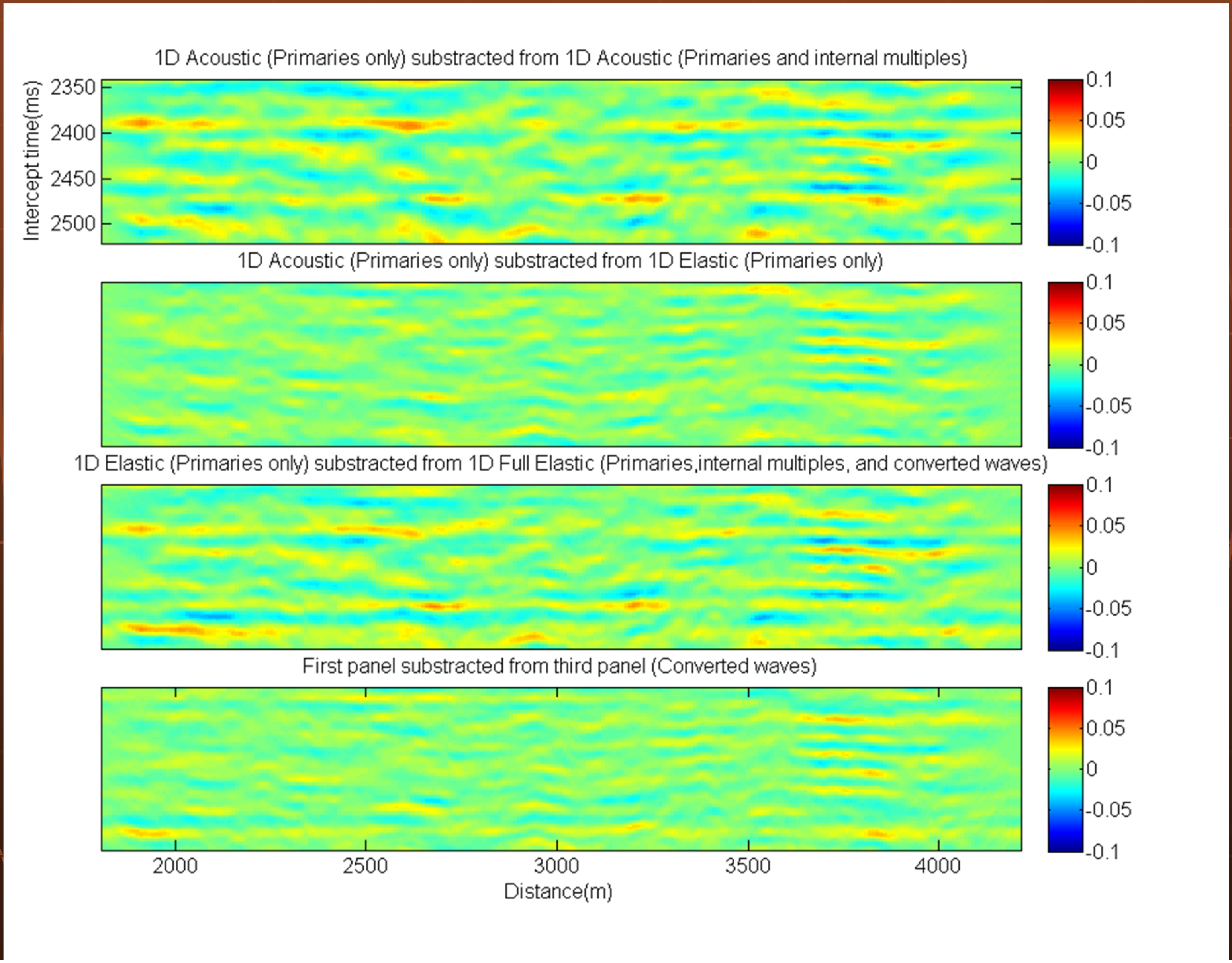
1D plane-wave responses of the base survey (T0) at ray parameter (p=0 sec/km) computed by different seismic modeling methods



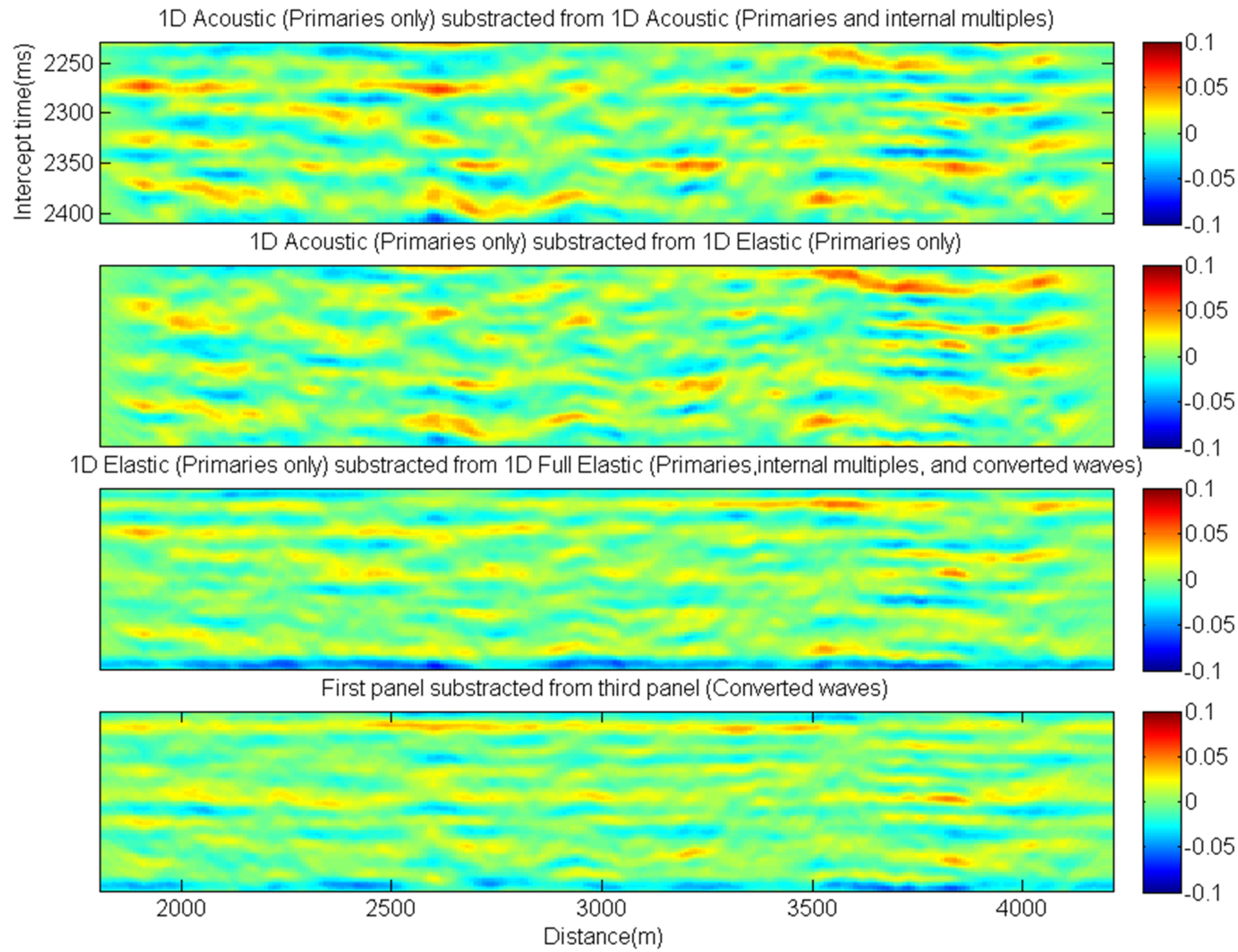
Residuals of 1D plane-wave responses of the base survey (T0) at ray parameter (p=0 sec/km) computed by different seismic modeling methods



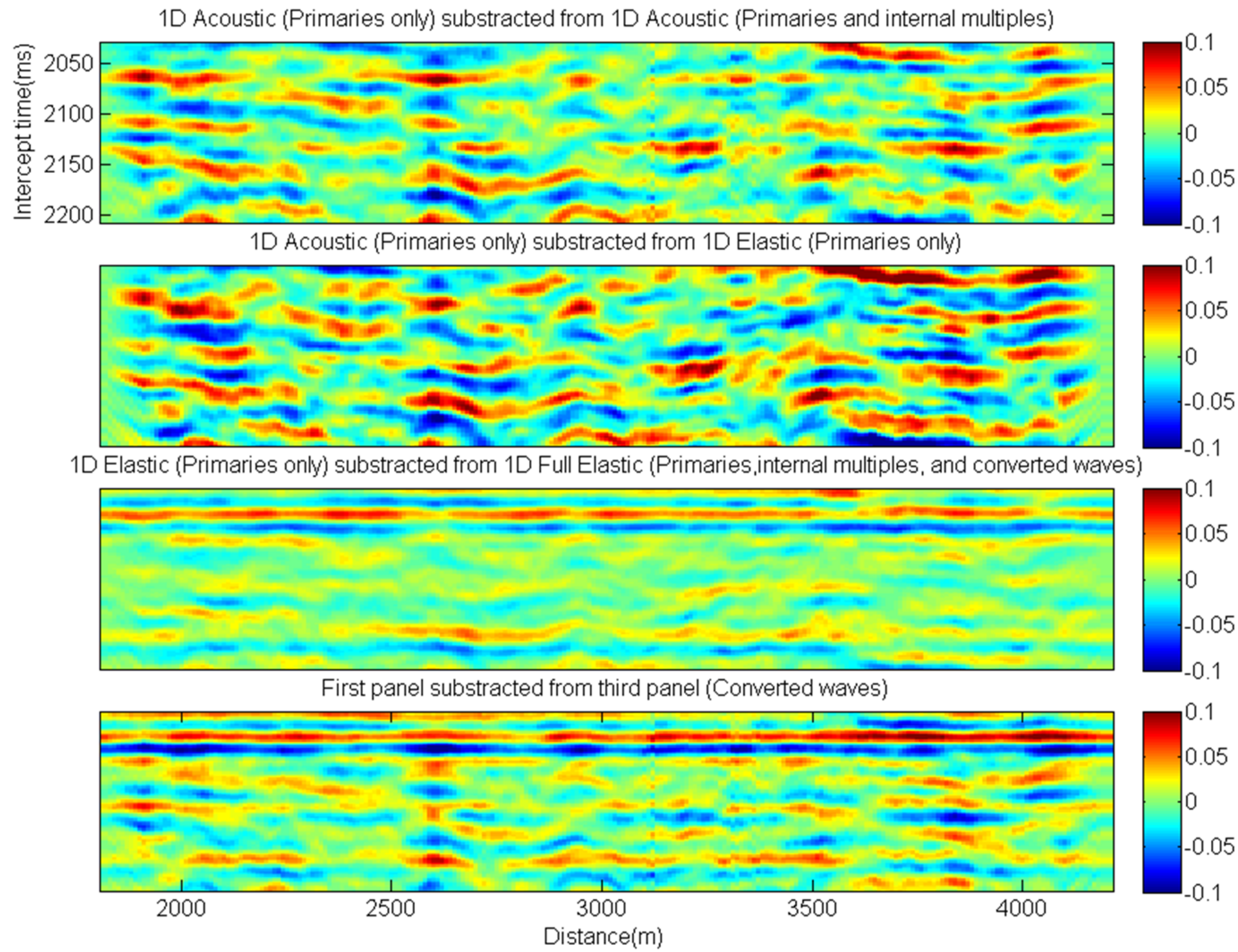
Residuals of 1D plane-wave responses of the base survey (T0) at ray parameter (p=0.1 sec/km) computed by different seismic modeling methods



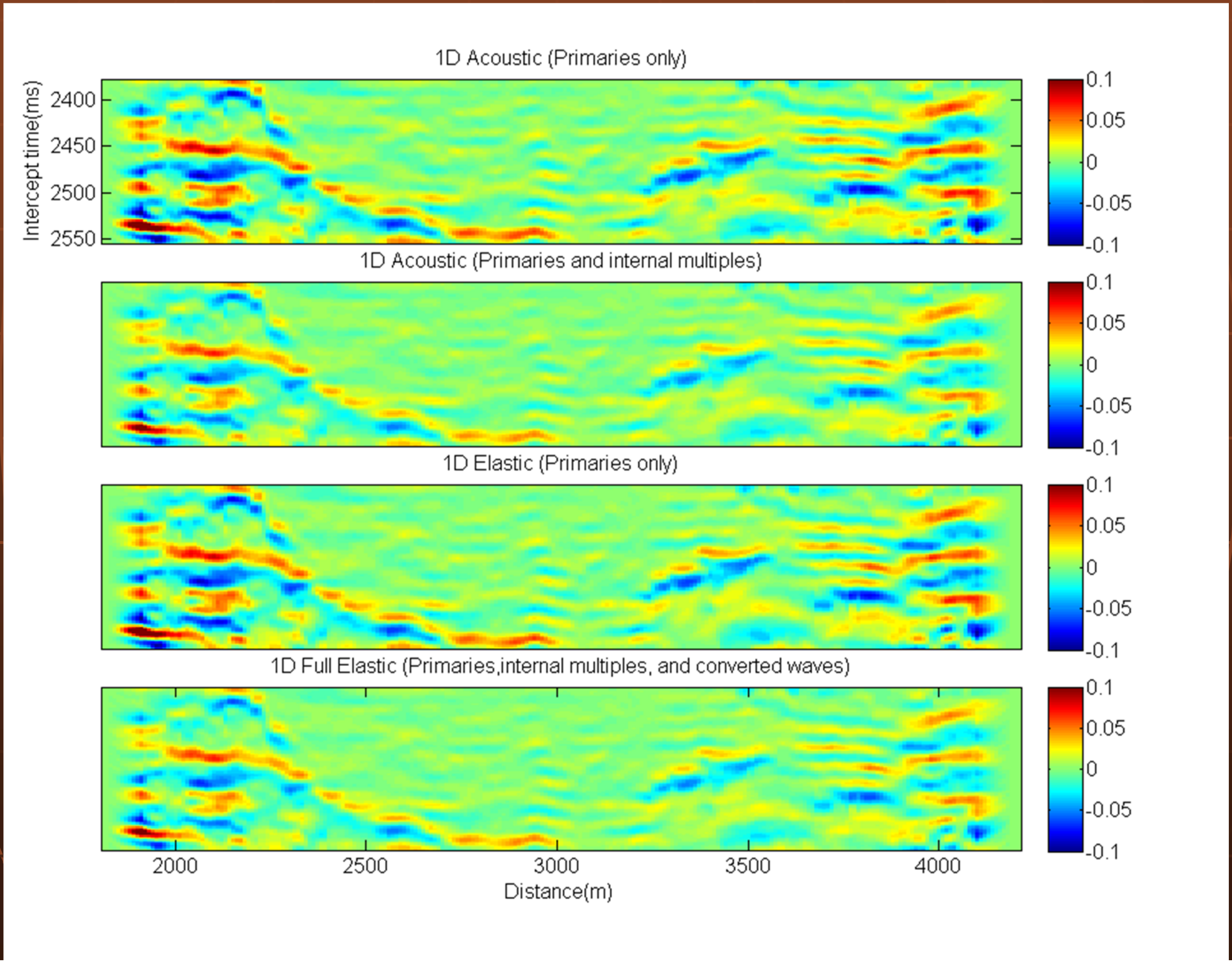
Residuals of 1D plane-wave responses of the base survey (T0) at ray parameter (p=0.2 sec/km) computed by different seismic modeling methods



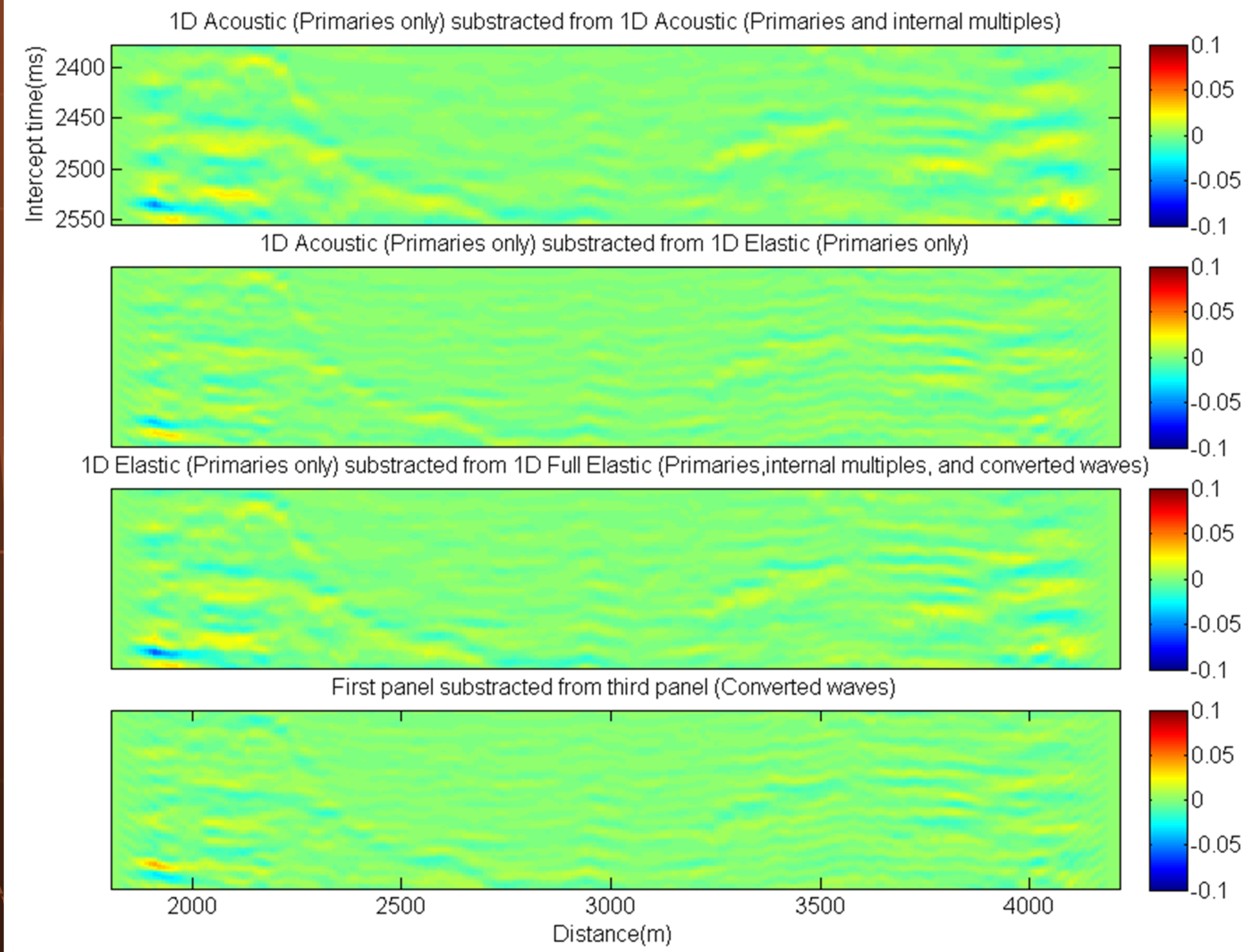
Residuals of 1D plane-wave responses of the base survey (T0) at ray parameter (p=0.3 sec/km) computed by different seismic modeling methods



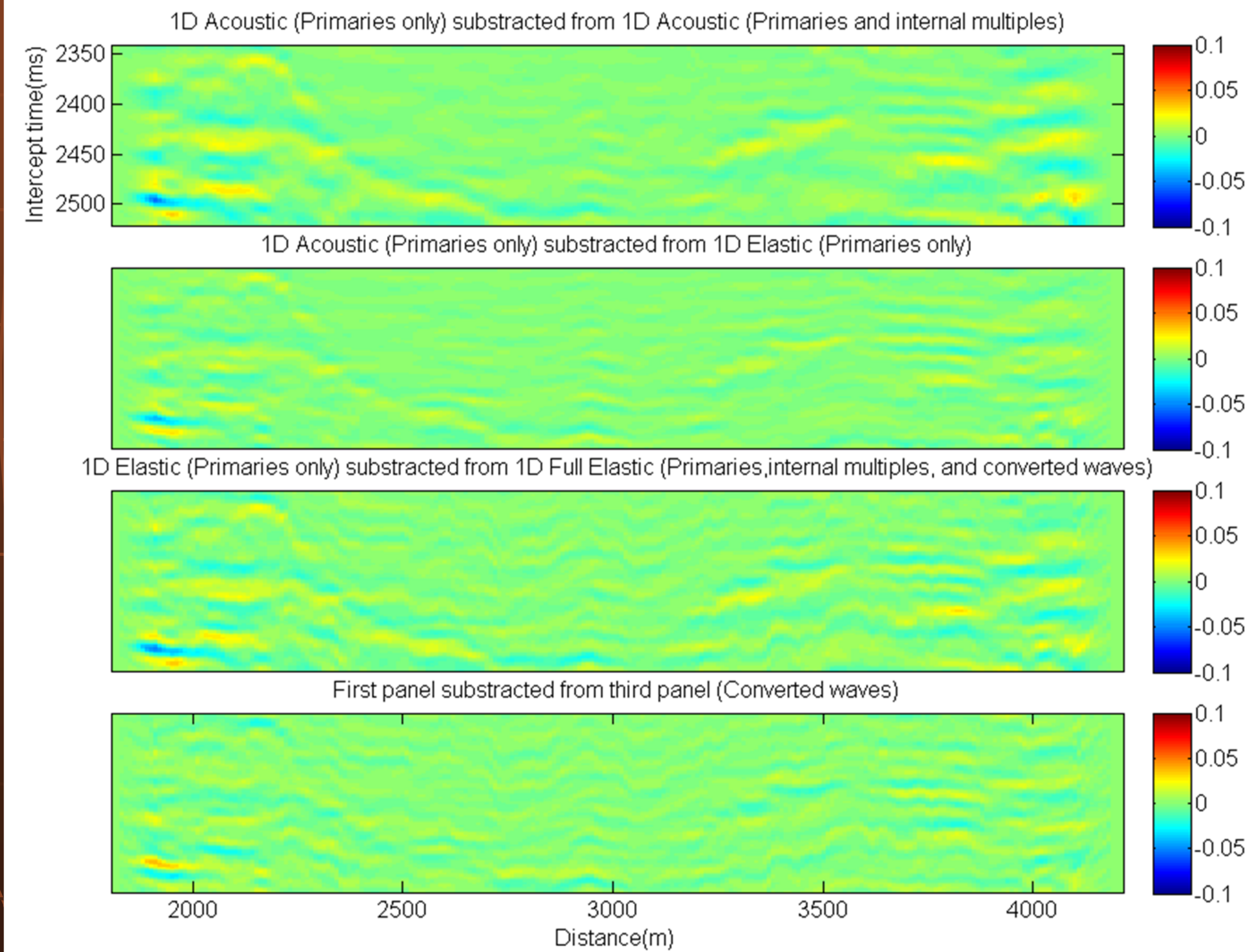
1D plane-wave responses of the time-lapse (T5-T0) at ray parameter (p=0 sec/km) computed by different seismic modeling methods



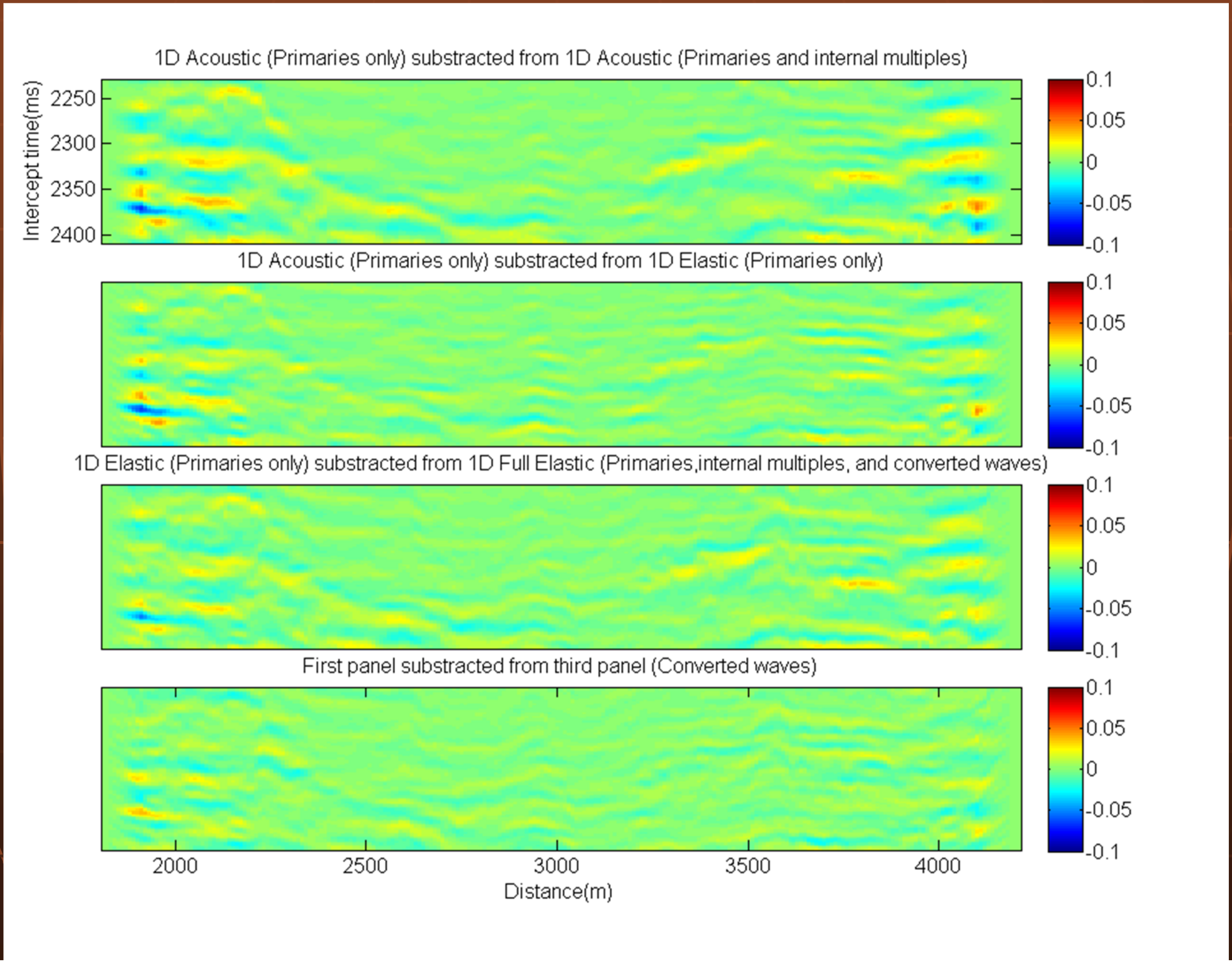
The residuals of 1D plane-wave responses of the time-lapse (T5-T0) at ray parameter (p=0 sec/km) computed by different seismic modeling methods



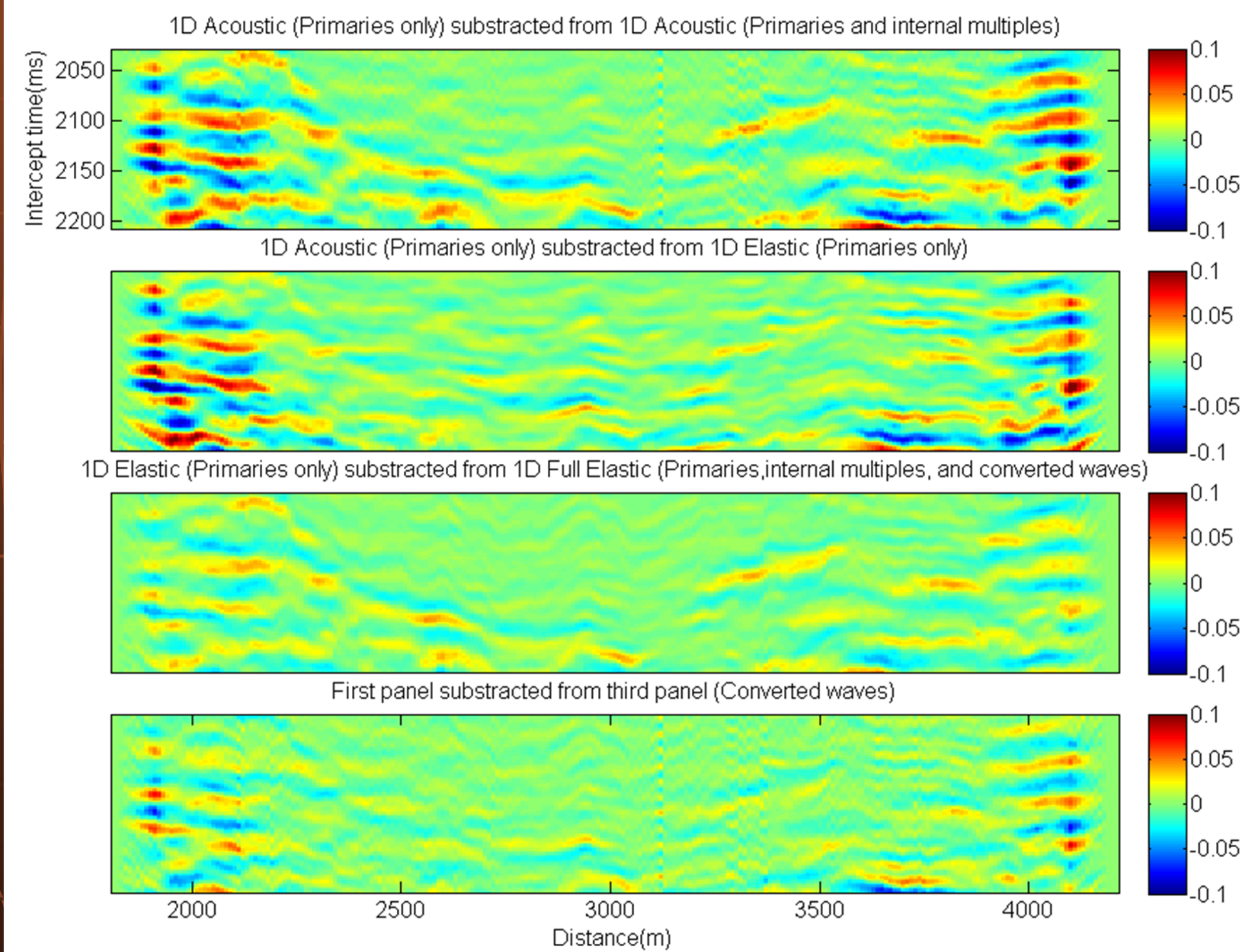
The residuals of 1D plane-wave responses of the time-lapse (T5-T0) at ray parameter (p=0.1 sec/km) computed by different seismic modeling methods



The residuals of 1D plane-wave responses of the time-lapse (T5-T0) at ray parameter (p=0.2 sec/km) computed by different seismic modeling methods



The residuals of 1D plane-wave responses of the time-lapse (T5-T0) at ray parameter (p=0.3 sec/km) computed by different seismic modeling methods

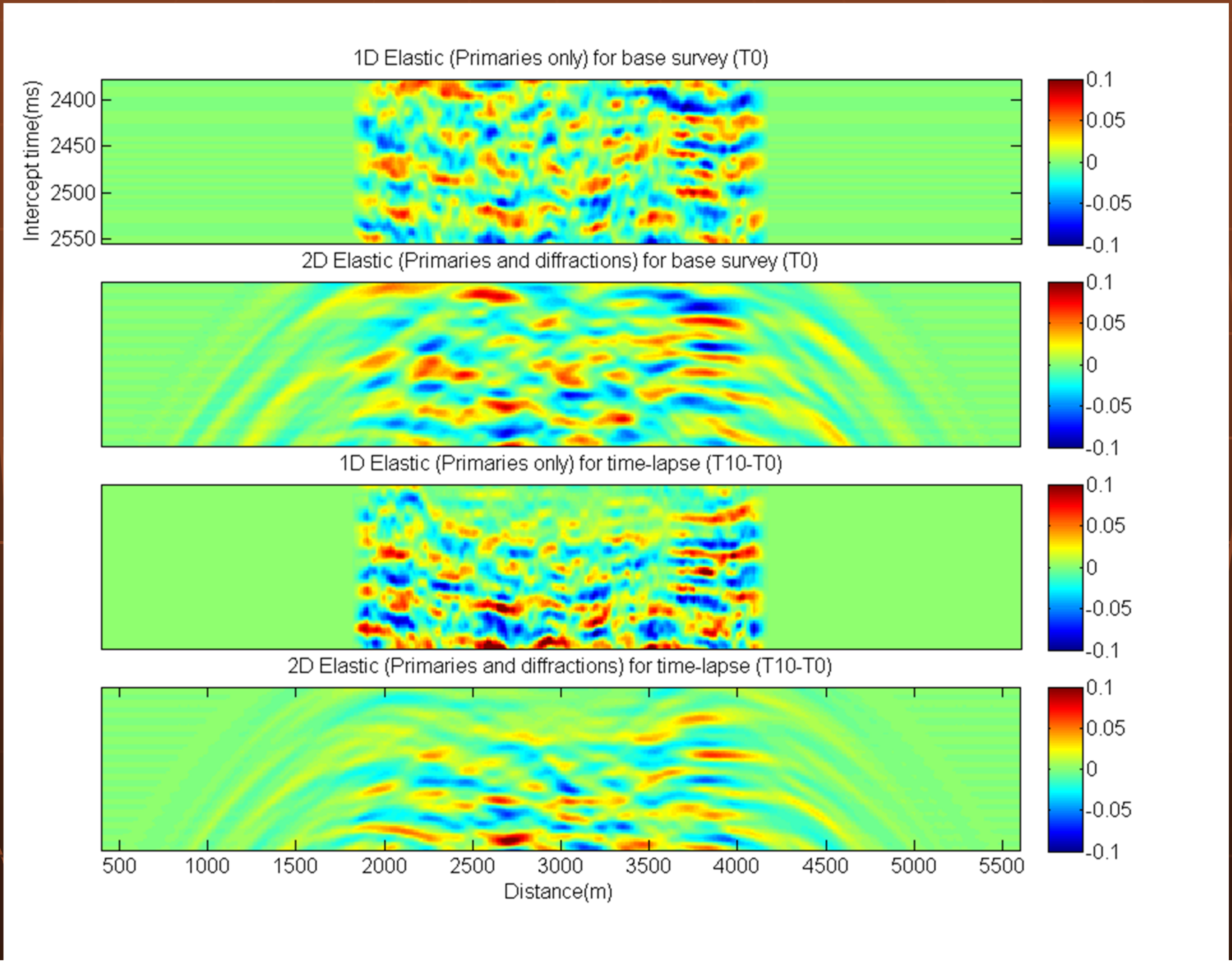


2D plane-wave seismic modeling to see the effects of :

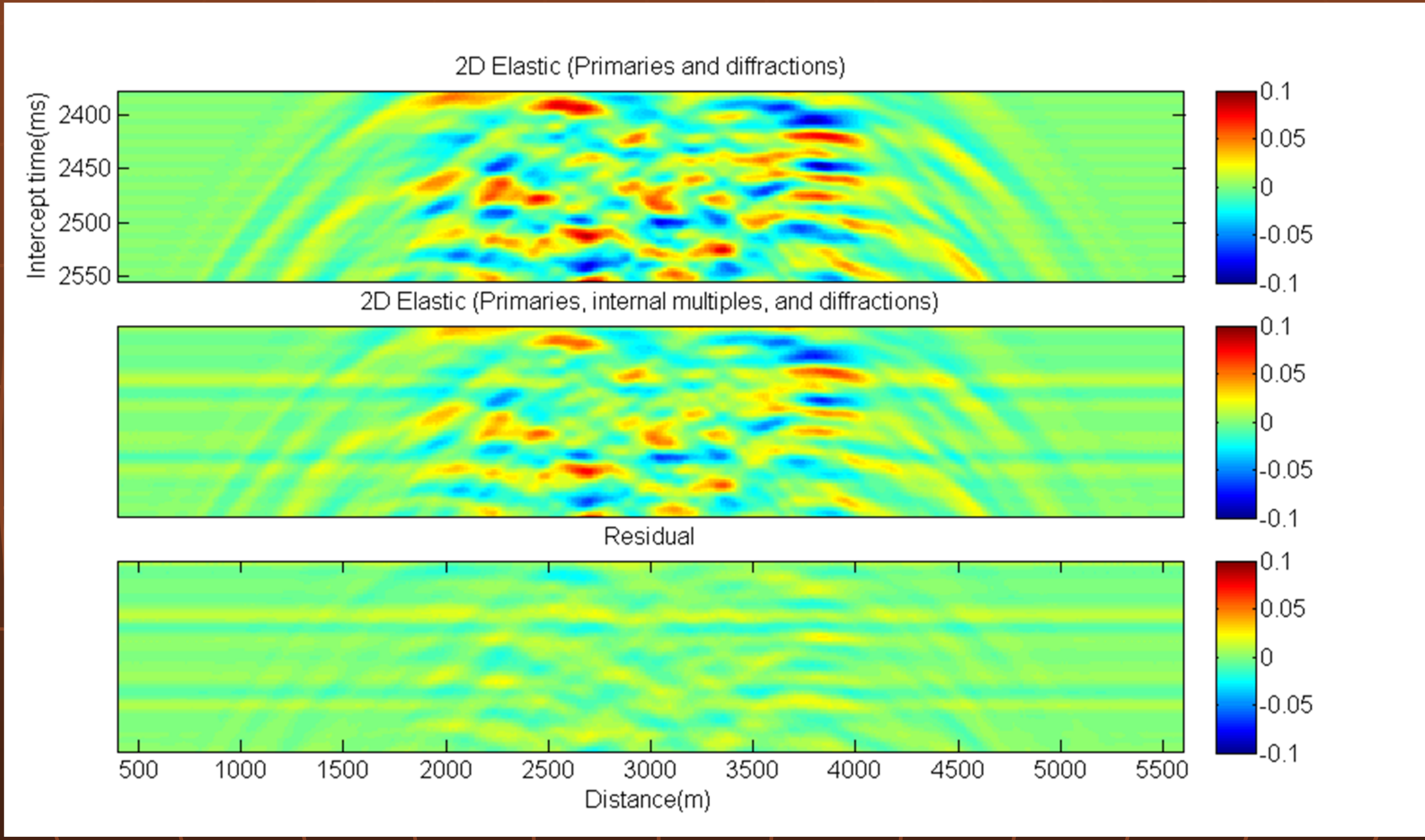
1D vs. 2D elastic wave propagation

2D Internal multiples

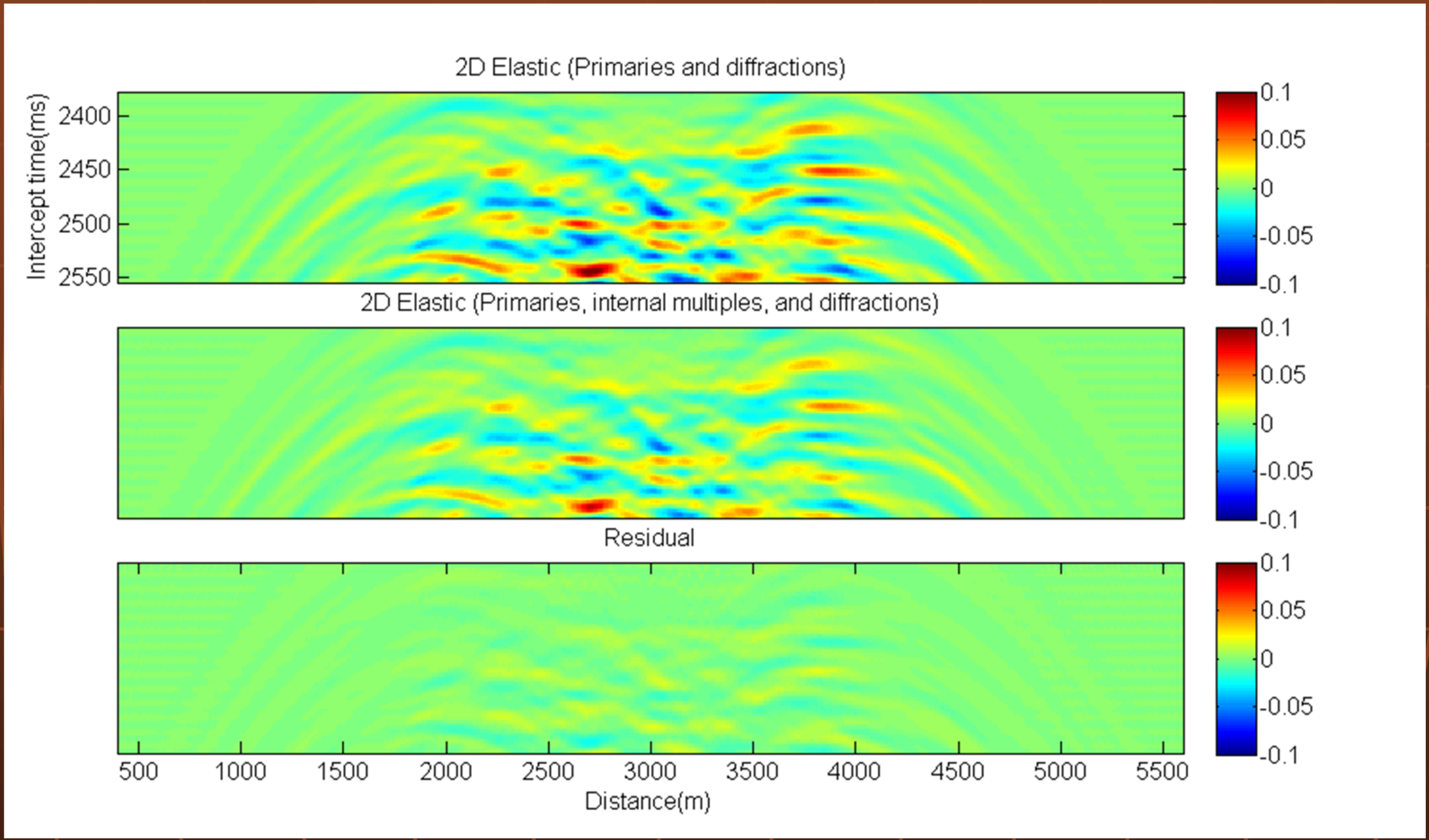
Plane-wave responses for base survey (T0) and time-lapse (T10-T0) at p= 0 sec/km, to compare 1D modeling 2D plane-wave modeling (SFPW algorithm)



2D Plane-wave responses for base survey (T0), at p= 0 sec/km, with and without internal multiples



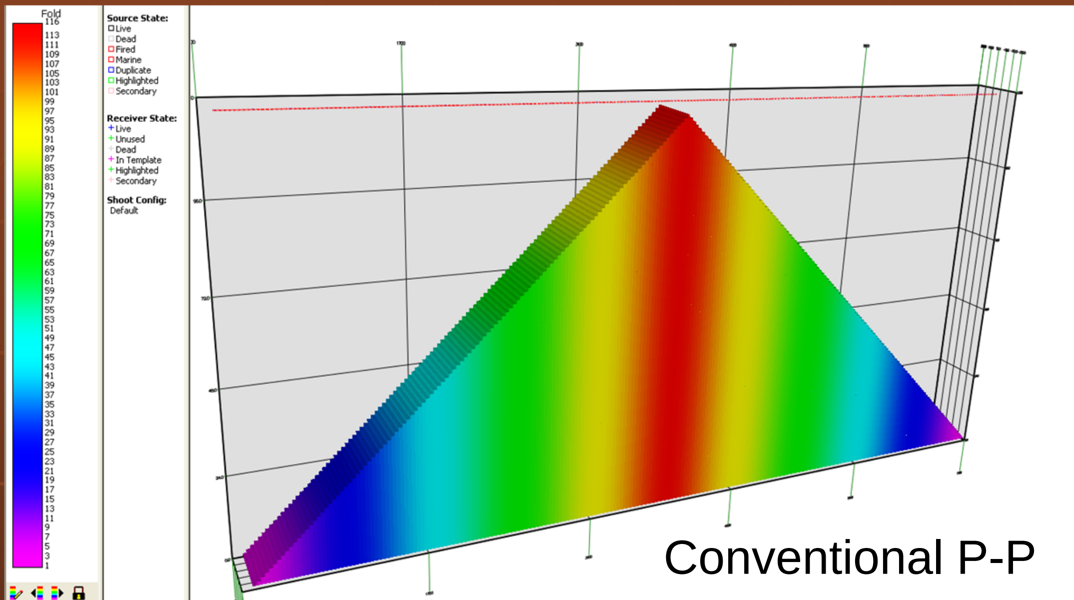
Plane-wave responses for time-lapse (T10-T0) at p= 0 sec/km, with and without internal multiples



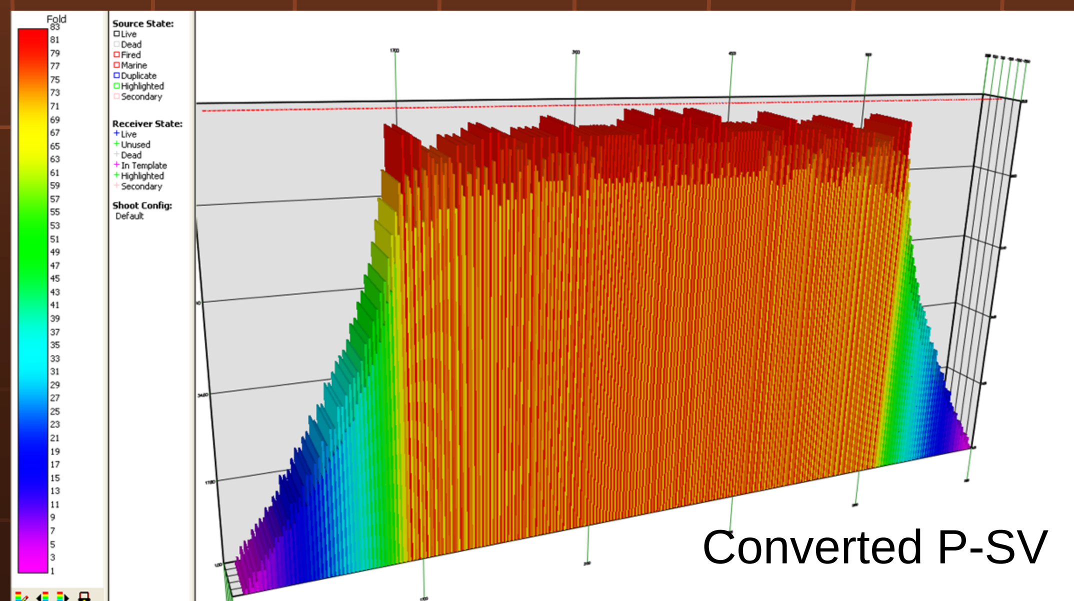
2D finite difference seismic modeling to see the effect of :

2D elastic plane-wave vs. 2D full elastic FD

Seismic Survey design

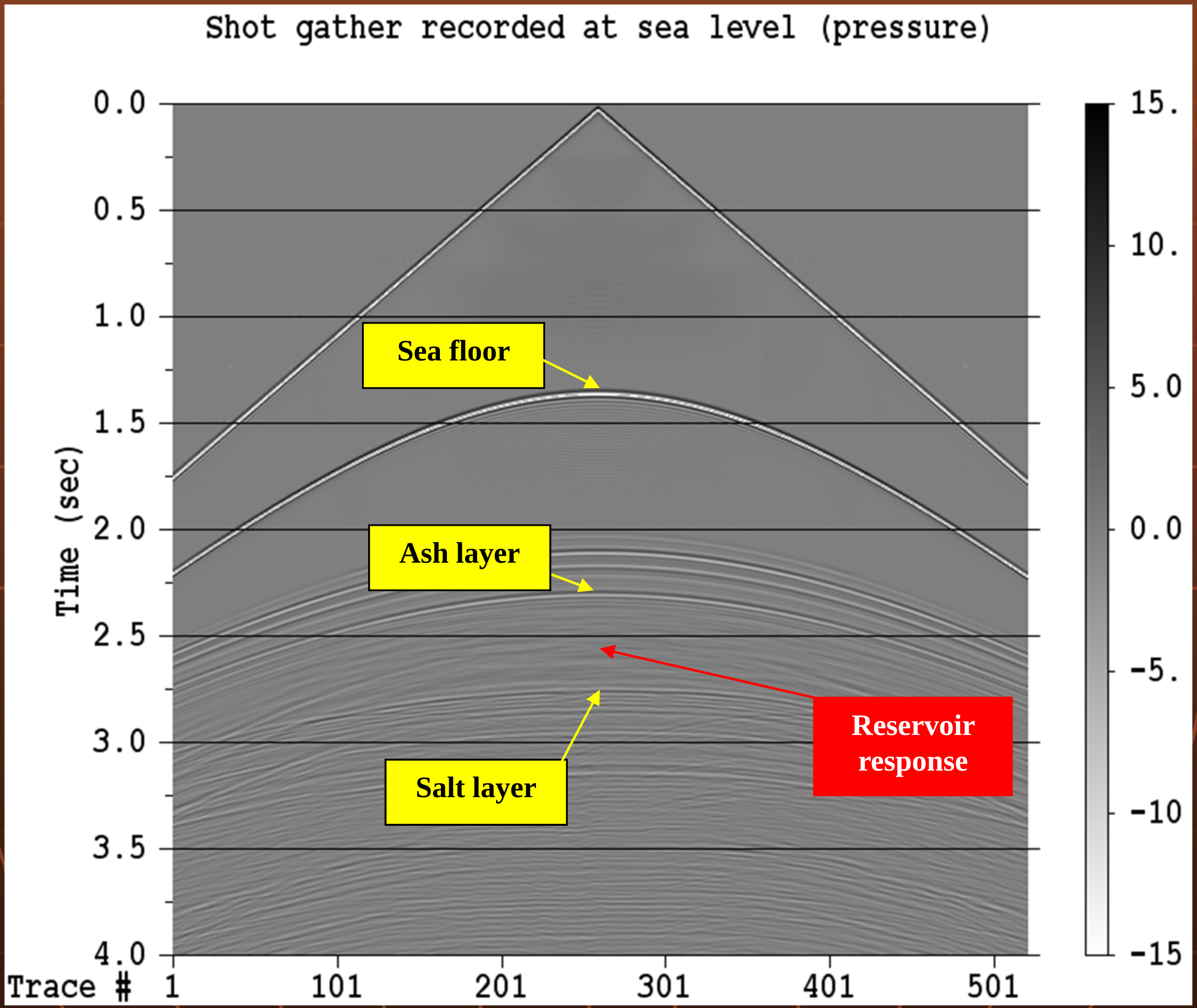


Max Fold=116
Fold range over reservoir 65-116

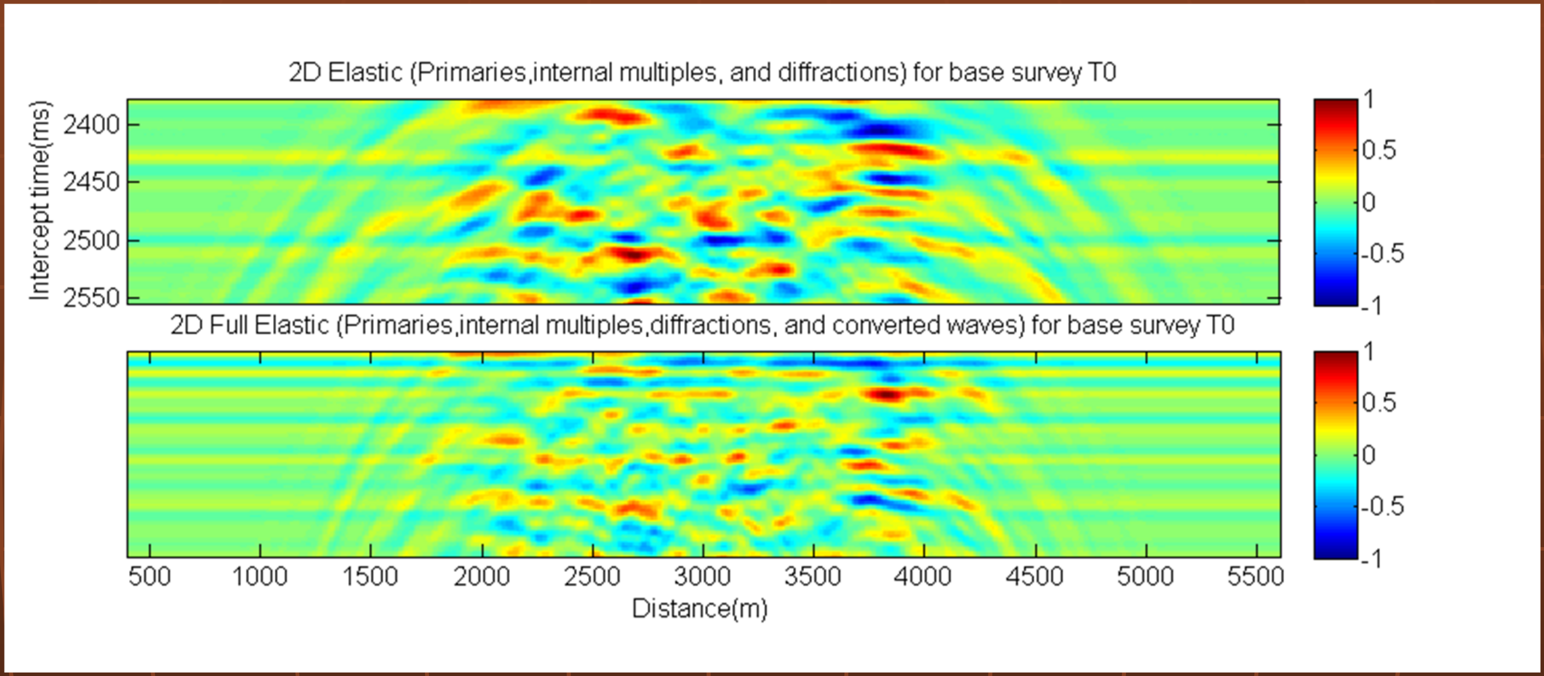


Max Fold=83
Fold range over reservoir 65-83

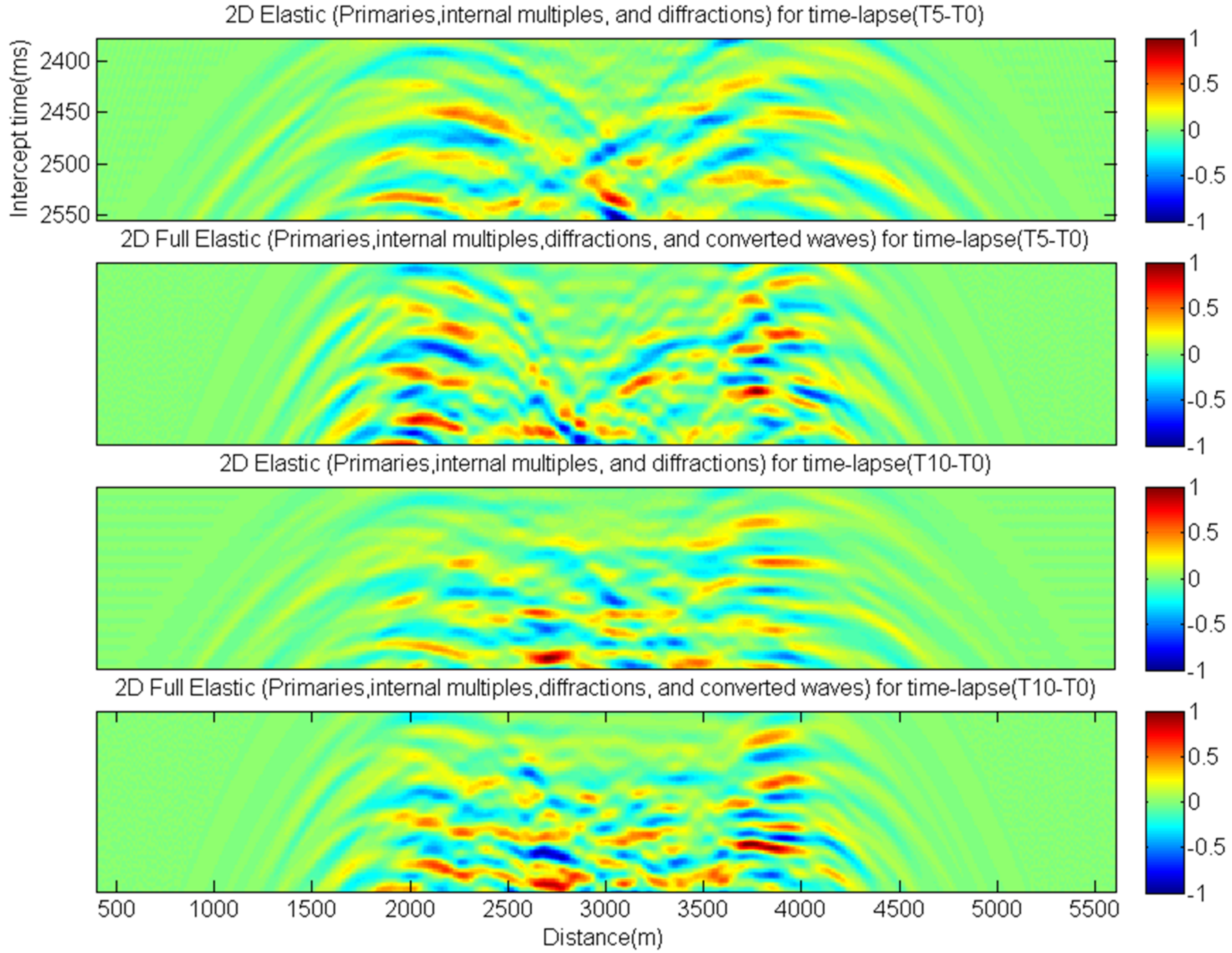
Pressure wavefield simulated by finite difference shot gather located in the middle of 2D reservoir for base survey (T0)



2D Plane-wave and Finite difference responses of the base survey (T0) at p=0.0 sec/km.



2D Plane-wave and Finite difference seismic responses at p=0.0 sec/km



Summary of time-lapse seismic modeling

- The geologically consistent petro-elastic model provided an opportunity to evaluate the effect of various seismic modeling techniques on a realistic reservoir model and investigate the corresponding time-lapse signatures.

- Our analyses demonstrated that internal multiples behind waterfront, flooded zones, partially subtract out, so they are less significant in monitoring projects than reservoir characterizations.

- We also found that for time-lapse seismic modeling, acoustic modeling of an elastic medium is a good approximation up to p=0.2 sec/km. In addition, at p=0.3 sec/km, differences between elastic and acoustic wave propagation is the most dominant effect. Here, converted waves are generated with significant amplitudes compared to primaries and internal multiples.

- We also showed that time-lapse modeling of the reservoir using SFPW approach is very fast compared to FD, 100 times faster for our case here and it is capable of handling higher frequencies than FD. It provides an accurate image of the waterflooding process comparable to FD. Consequently, it is a powerful alternative for time-lapse seismic modeling.

Contents

- Motivation
- Constructing a petro- elastic reservoir model
- Optimal dynamic rock-fluid physics template (update)
- Accuracy required in seismic modeling to detect time-lapse signals
-
- Contributions (publications)
- Recommendation and future work
- Acknowledgement

Publications and presentation

1. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Sensitivity analysis of multi-component seismic attributes to fluid content and pore pressure, presented in 78th Annual International Meeting, Society for Exploration Geophysicists (SEG), Las Vegas, Expanded Abstracts, November 2008.
2. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Multicomponent seismic time-lapse cross-plot and its applications, presented *in* 79th Annual International Meeting, Society for Exploration Geophysicists (SEG), Houston, Expanded Abstracts, November 2009.
3. **Shahin, A.**, Tatham, R., H., Stoffa, P., L., Spikes, K., T., 2010, Comprehensive petro-elastic modeling aimed at quantitative seismic reservoir characterization and monitoring, presented at SEG 80th annual meeting, Denver, Colorado.
4. **Shahin, A.**, Key, K., Stoffa, P., L., Tatham, R., 2010, Time-lapse CSEM analysis of a shaly sandstone simulated by comprehensive petro-electric modeling, presented at SEG 80th annual meeting, Denver, Colorado.
5. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Uncertainty in rock physics modeling: Impact on seismic reservoir characterization and monitoring, presented at SEG 2008 Development and production Forum, The University of Texas at Austin (July 2008).
6. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Multi-component seismic AVO/TVO analysis: sensitivity to saturation & pressure, presented at SEG 2008 Development and production Forum, The University of Texas at Austin (July 2008).
7. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., A statistical approach to quantify the detectability of dynamic reservoir properties using multi-component time-lapse seismic attributes, presented at SEG 2008 Development and production Forum, The University of Texas at Austin (July 2008).
8. **Shahin, A.**, Key, K., Stoffa, P., L., Tatham, R., Petro-electric modeling for CSEM reservoir characterization and monitoring, Geophysics (in review).
9. **Shahin, A.**, Tatham, R., H., Stoffa, P., L., Spikes, K., T., Optimal dynamic rock-fluid physics template validated by petro-elastic reservoir modeling, Geophysics (in review).
10. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Multi-component time-lapse seismic: on saturation-pressure discrimination and statistical detectability of fluid flow (in preparation, to be submitted to Journal of exploration seismology).
11. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Seif, R., Accuracy required in seismic modeling to detect production-induced time-lapse signals (in preparation, to be submitted to Journal of Geophysical International).
12. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Derivative-bases sensitivity analysis: a viable tool in reservoir geophysics (in preparation, to be submitted to Journal of exploration seismology).

Recommendations and future work

- The development of the petro-elastic model is based on the dispersed clay distribution. An extension of the current work will be the generation of a model with layered distribution of clay and then perform seismic and CSEM feasibility studies.
- Using the developed petro-elastic model, Inversion of seismic data to elastic properties or even direct inversion to petrophysical properties are the next logical steps.
- Seismic reservoir history matching will be the ultimate application of the developed petro-elastic model .
- Real data application will be the final stage of this research study.

Acknowledgment

- My supervisors, Dr. Paul Stoffa and Dr. Bob Tatham
- Dr. Kyle Spikes and Dr. Diana Sava for technical discussion of rock physics
- Dr. Roustam Seif for helping with finite difference and reflectivity codes
- Thomas Hess and Steffen Saustrup for helping with Paradigm (Focus)
- Mark Wiederspahn, Kevin Johnson, and John Gerboc for technical support
- Technical support of CGG-VERITAS (Hampson-Russell), ION-GTX(GMG), Paradigm (Focus), Fugro Jason (JGW), and Schlumberger (Eclipse).
- EDGER Forum sponsors and Jackson School of Geosciences for financial support
- Pinky Vinson, Tiger team leader, BP GOM deep water exploration

Thanks for your attention

Questions?