UT-AUSTIN EDGER FORUM

INTRODUCTION AND OVERVIEW

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The University of Texas at Austin

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

WELCOME TO THE 2017 HOUSTON MEETING

- Welcome everyone!
- We very much appreciate ongoing support from sponsors. Without it, we would not be able to support graduate students who work on relevant industry-related problems and projects.
- We thank our sponsors and potential sponsors in attendance remotely or in person.
- We thank BP for allowing us to arrange the meeting here.

Agenda

- Brief introduction of EDGER forum (Sen)
- Overview of current research (Sen)
- Machine learning (Sen)
- Overview of current and future research (Spikes)
- Q&A
- Lunch

EDGER

The UT-Austin EDGER Forum is a consortium of petroleum producing and service companies focused on educating graduate students and conducting research on development and application of geophysical methods to support exploration and development of petroleum reserves.

The Forum also coordinates education and technology transfer among producing and service companies and academia.

Research Direction

Pushing the limits of seismic resolution

The research focus of the EDGER Forum is advancement of quantitative seismic interpretation. This involves development of advanced techniques for high resolution estimates of reservoir properties by integrating disparate datasets observed at multiple scales. The scope of research encompasses three major themes:

1. **Development of new techniques for seismic imaging and inversion**
2. **Application of *Machine Learning* in seismic inversion and reservoir characterization**
3. **Development of new rock physics models and adaptation of existing rock physics models to a particular field under investigation**
4. **Integration of seismic inversion and rock physics models using novel statistical approaches and validation with field datasets**

EDGER RESEARCH

- Prospectus:
  - http://www.jsg.utexas.edu/edger/prospectus/
- Recent Publications:
  - http://www.jsg.utexas.edu/edger/publications/

EDGER RESEARCH

- We have put much effort into these areas.
- The FORUM has a dedicated focus to continue in these topics and expand upon them.
- We have a collaborator, **Nicola Tisato**, who provides considerable experience and expertise in laboratory measurements of seismic velocity and attenuation at low and high frequencies.
- Our work also involves significant interaction with sedimentary and structural geologists, petroleum and civil engineers, mathematicians, and other geophysicists.

EDGER-RELATED TEACHING

- Mrinal Sen
  - Inverse theory
  - Wave propagation in heterogeneous media (Seismology III)
  - Seismic imaging
- Kyle Spikes
  - Rock physics
  - Seismic exploration (Seismology I)
  - Quantitative seismic interpretation
- Nicola Tisato
  - Geophysics for geoscience majors
  - Geophysical measurements and modeling
- FORUM
  - 5-day short course: Seismic inversion and rock physics
- SEG Continuing Education short course
  - 2-day short course: Full waveform inversion (Sen)

RECENT GRADUATES

- Anthony Barone, MS – UT Austin
  - *AVAZ in orthorhombic media – application to Hayensville Shale*
- Jennifer Beam, BS – Texas State (seeking teaching degree)
  - *Quantitative comparison of inclusion and excess-compliance models*
- Barry Borgman, MS – Schlumberger
  - *Characterization of the Cana-Woodford Shale Using Fractal-Based Stochastic Inversion*
- Qi Ren, PhD – Google
  - *Anisotropic Seismic Characterization of the Eagle Ford Shale: Rock Physics Modeling, Stochastic Seismic Inversion, and Geostatistics*
- AJ Yanke, MS – Statoil
  - *Application of Isotropic Inversion to Orthorhombic Media*
- Han Liu, PhD – BP
  - *3D simulation of seismic wave propagation in fractured media using an integral method accommodating irregular geometries* (will join BP)

SOON-TO-BE GRADUATES

- Elliot Dahl, PhD – December 2017
  - *Local and global fluid effects on sonic wave modes*
- Debanjan Datta, PhD – December 2017
  - *Global full waveform inversion*

INCOMING STUDENTS

- Wei Xie, PhD – Fall 2017
  - *MS, University of Alberta, 2014*
  - *CGG, Calgary, 2014–2017*
- Michael McCann, MS– Fall 2017
  - *BS, Purdue University, 2017*
- Son Phan, PhD– Spring 2018
  - *BS, Tulsa; MS-UT Austin 2011*

Software developed by students

- Basis pursuit inversion (BPI)
- Greedy annealed importance sampling (GAIS)
- Rock physics modeling for unconventional reservoirs
- Bayesian rock physics analysis
- Integral method for modeling seismic wave propagation in a fractured medium

Dissemination of Results

Participants in the Forum are invited to attend the Annual Research Symposium each spring, which focuses on research results. Members are welcome to provide input of specific industry research and/or educational needs. Results will also be shared with sponsors through personal on-site visits, preprints of research papers, compilations of educational activities and results, and research computer codes from individual projects. For more information, please contact:

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UT-AUSTIN EDGER FORUM

MRINAL K. SEN Research Group

THE UNIVERSITY OF TEXAS AT AUSTIN
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Group Members

- Mrinal K. Sen, Professor
- Dr. Doug Foster, Senior Research Scientist
- Dr. Zeyu Zhao, post-doctoral fellow
- Dr. Piyoosh Jaisaval (Adrien Arnulf and Mrinal Sen – co-supervisors)
- Bei Pan (new post-doc from China joining 9/1/17)
- Debanjan Datta

Student Members

1. Han Liu (co-supervision with Kyle Spikes), PhD student, DGS (EDGER)
2. Debanjan Datta*, PhD student, DGS (EDGER/Hess)
3. Anthony Barone, PhD student, DGS (fellowship/TA)
4. Badr A. Alulaiw, PhD student, DGS (Aramco sponsored)
5. Reetam Biswas, PhD student, DGS (EDGER/BP/NSF)
6. Janaki Vamaraju, PhD student, DGS (NSF)
7. Hala Alqatari, MS student, DGS(Aramco sponsored)
8. Pedro Alejandro, MS student, DGS (PEMEX sponsored)

9. M. Chauhan (co-supervision with Prof. Maurizio Fedi) , PhD student University of Naples Federico, Italy)
10. P. K. Mishra (co-supervisor), PhD student (Indian Institute of Technology, Kharagpur, India)

* Recipient of SEG scholarship

Funding

- Spectral AVO and density inversion: BP (PI: Sen and Foster)
- FWI using VFSA: Hess (PI: Sen)
- Joint inversion of seismic and CSEM data: Total (PI: Arnulf and Sen)
- Big data challenges – subsurface fracture characterization: NSF (Wheeler and Sen)
- 3D FWI and uncertainty estimation: Total (Sen and Arnulf)
- EDGER (Sen and Spikes)

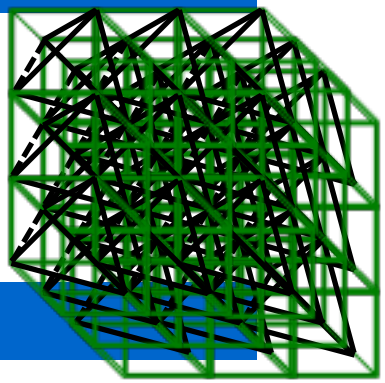
Integral formulation of elastic wave equation

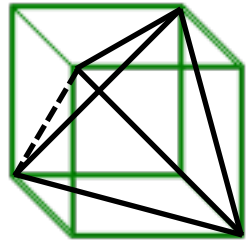
Han Liu

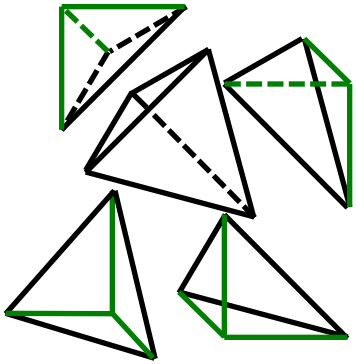
Elastic wave equation:

$$\rho \frac{\partial^2 u_i}{\partial t^2} = \frac{\partial \tau_{ij}}{\partial x_j}.$$

Mesh for arb







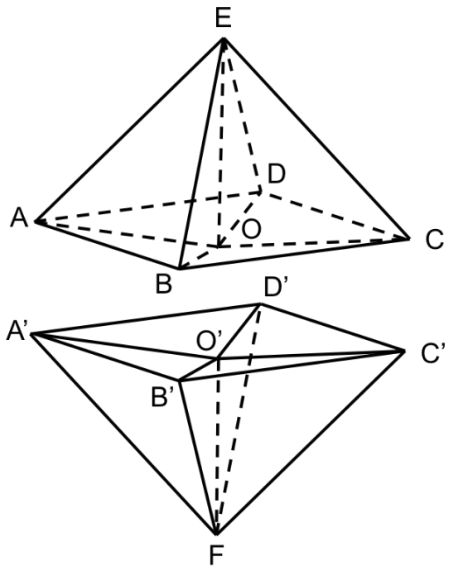
In the absence of fractures:

$$\iiint_V \rho \frac{\partial^2 u_i}{\partial t^2} dV = \oiint_S \left(\sum_{j=1}^{3} \tau_{ij} n_j \right) ds \approx \sum_{l=1}^{m} \sum_{j=1}^{3} \tau_{ij}^{l} (c_j^P)_l$$

Incorporating fractures:

$$\iiint_V \rho \frac{\partial^2 u_i}{\partial t^2} dV = \oiint_S \left(\sum_{j=1}^{3} \tau_{ij} n_j \right) ds \approx \sum_{l=1}^{m} \sum_{j=1}^{3} \tau_{ij}^{l} (c_j^P)_l + \iint_\Omega \sum_{j=1}^{3} \tau_{ij} n_j ds,$$

Weak formulation of the 3D elastic momentum equations including the Linear Slip model

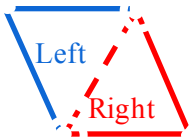


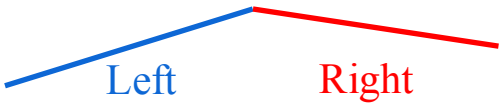
Upper surface

$$M_P \left(\partial^2 u_i / \partial t^2\right)_P = \sum_{l=1}^{m} \sum_{j=1}^{3} \tau_{ij}^{l} \left(c_j^P\right)_l + \sum_{k=1}^{3} \left[\sum_{j=1}^{3} \frac{\bar{T}_{jk} \bar{T}_{ij}}{\left(Z_{jj}\right)_P} \right] G_P \left(\Delta U_k\right)_P .$$

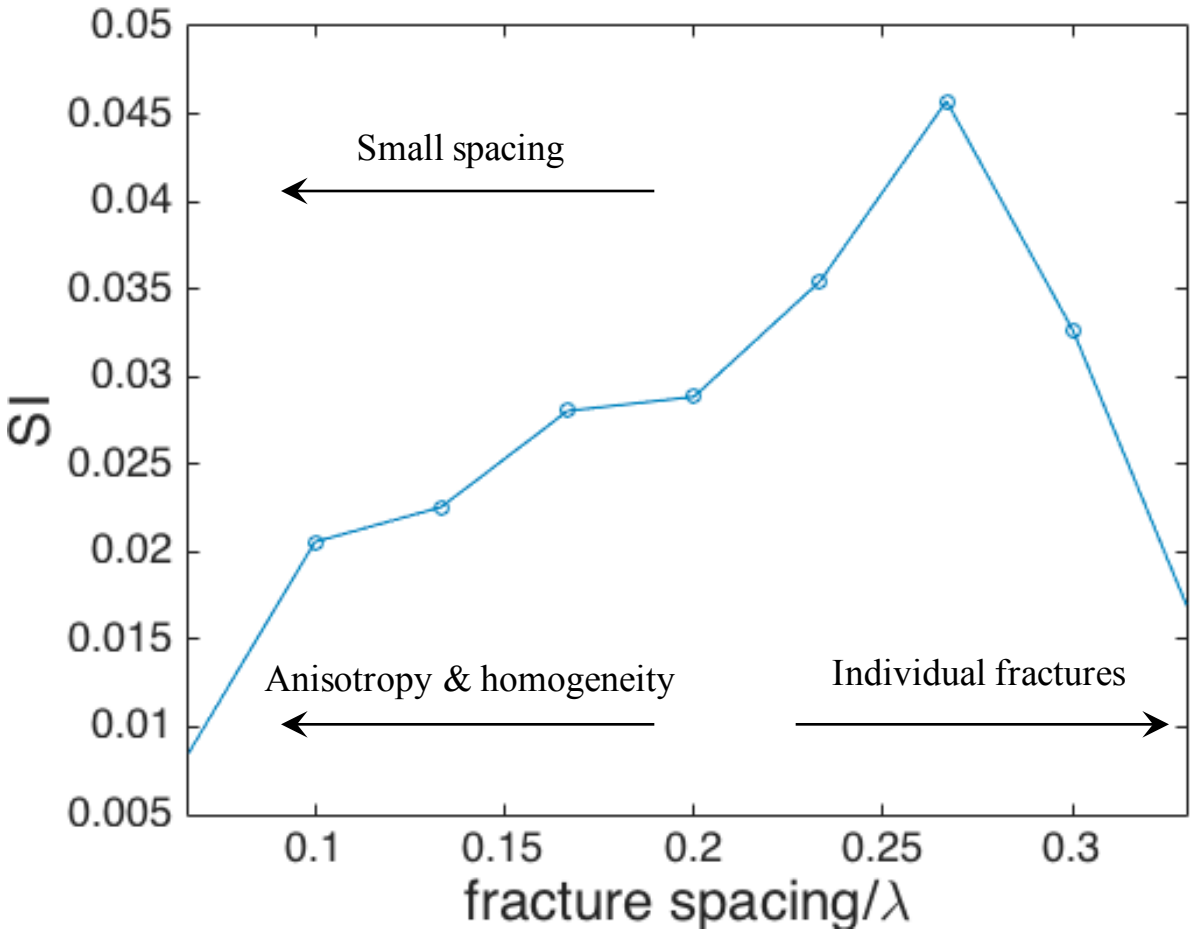
Lower surface

$$M_{P'} \left(\partial^2 u_i / \partial t^2\right)_{P'} = \sum_{l=1}^{m'} \sum_{j=1}^{3} \tau_{ij}^{l} \left(c_j^{P'}\right)_l - \sum_{k=1}^{3} \left[\sum_{j=1}^{3} \frac{\bar{T}_{jk} \bar{T}_{ij}}{\left(Z_{jj}\right)_P} \right] G_P \left(\Delta U_k\right)_P ,$$



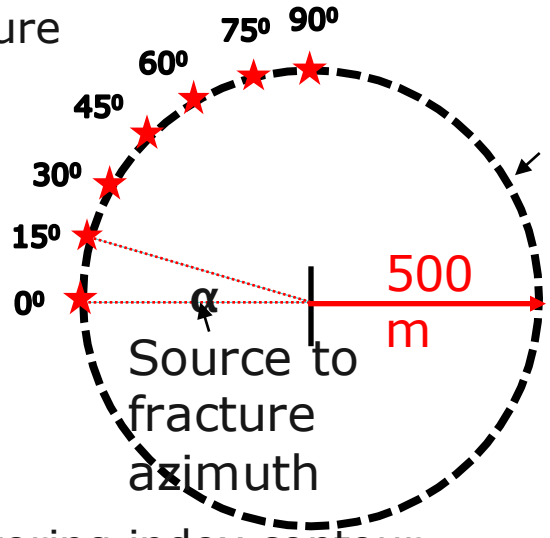


Correlation with Fracture Spacing



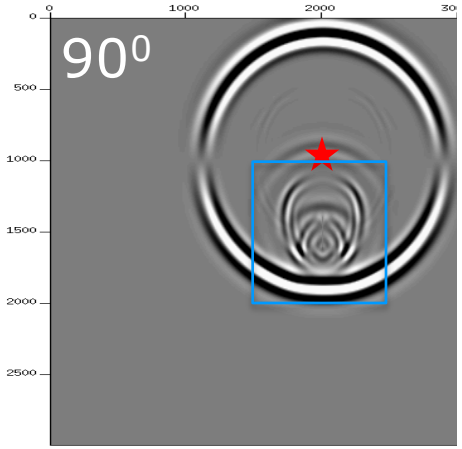
Han Liu

1. Fracture models

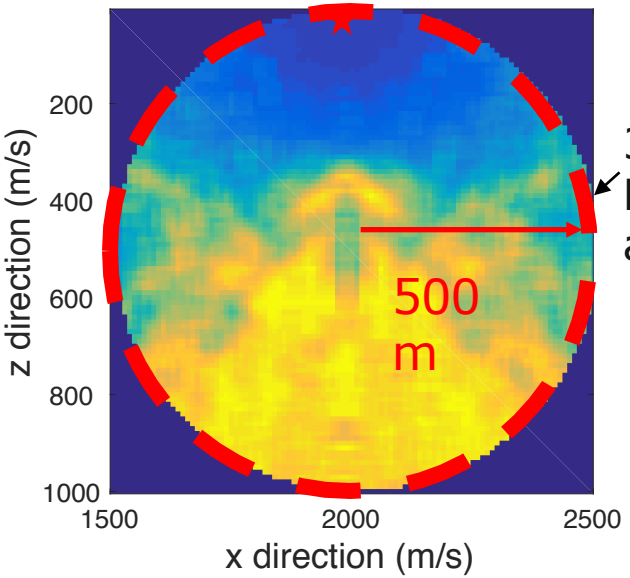


360⁰ Receiver azimuth

2. Wavefield

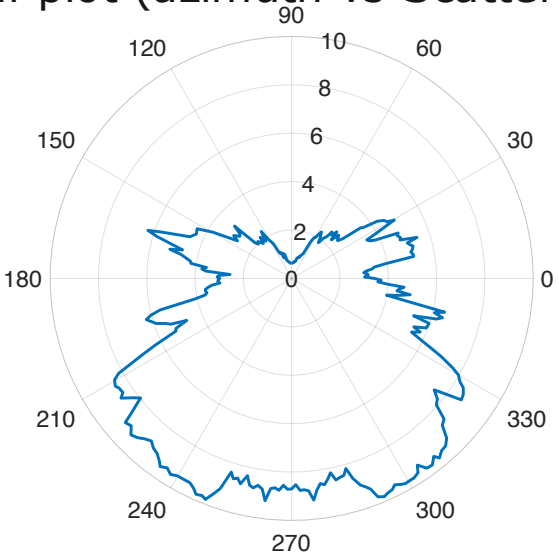


3. Scattering index contour



360⁰ Receiver azimuth

4. Polar plot (azimuth vs Scattering index)



Anthony Barone

Hybrid Born-Rytov Method Basic Theory

A "family" of approximations that span between the Born and Rytov approximations (Marks, 2006):

$$Born: \quad u = u_0 + \Delta u = u_0(1 + \phi)$$

$$Rytov: \quad u = u_0 e^{\phi} \leftrightarrow \phi = \ln\frac{u}{u_0}$$

u = Total Wavefield

u_0 = Reference Wavefield

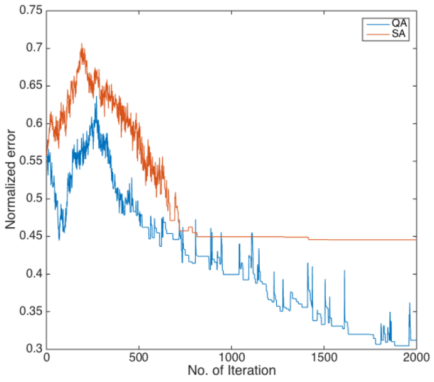
Δu = Wavefield Pertubation
$(\Delta u = u - u_0)$

ϕ = Phase Term

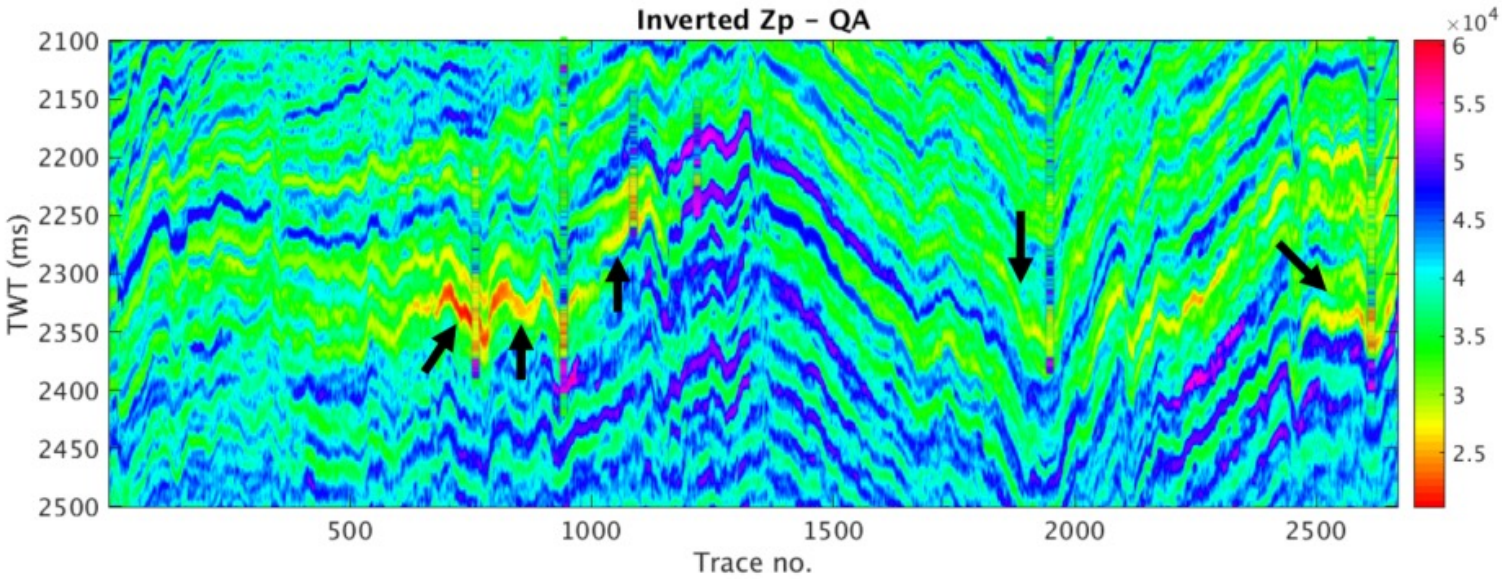
$$\phi_{Born} = \frac{\Delta u}{u_0}$$

$$\phi_{Rytov} = \ln\frac{\Delta u}{u_0}$$

Badr Alulaiw



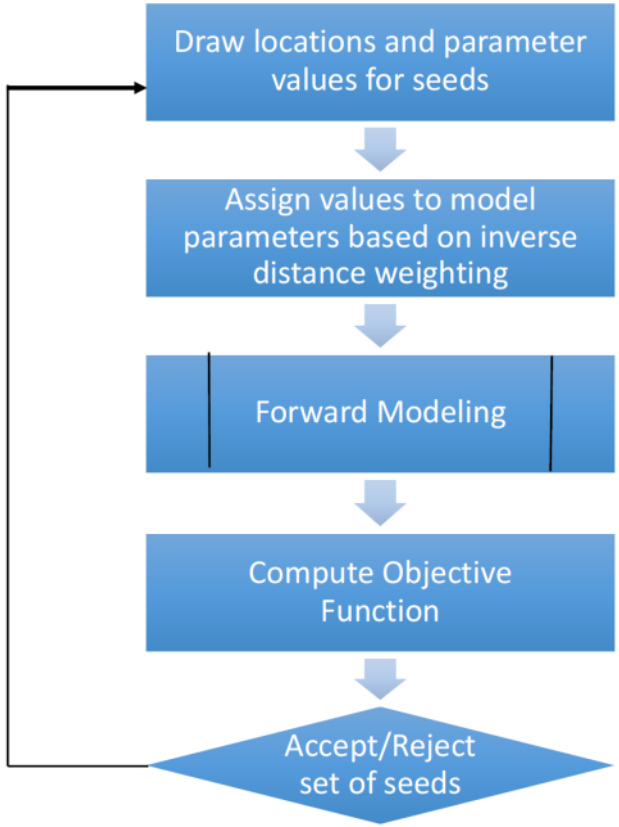
Stochastic inversion by quantum annealing



Badr Alulaiw

Inversion of 3D seismic data for fracture parameters and porosity

- **u=Gm**
- **m**: model vector.
  - Δ_N
  - Δ_T
  - Pore porosity.
- G: physics of wave propagation.



Debanjan Datta

Salt model building by shape-based parameterization and global FWI

Debanjan Datta and Mrinal Sen, University of Texas at Austin; Faqi Liu and Scott Morton, Hess Corporation*

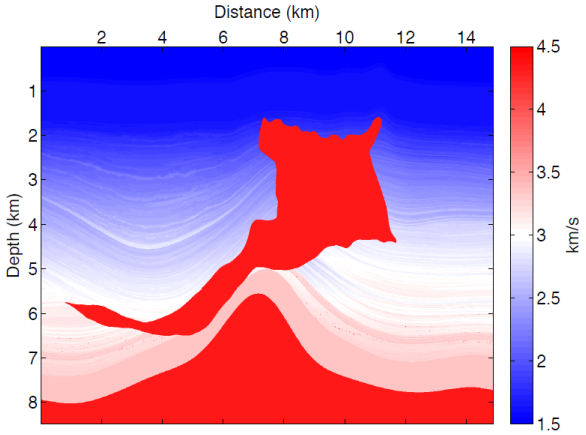


Figure 1: True model for our tests. The model is a variant of the SEG SEAM phase I model

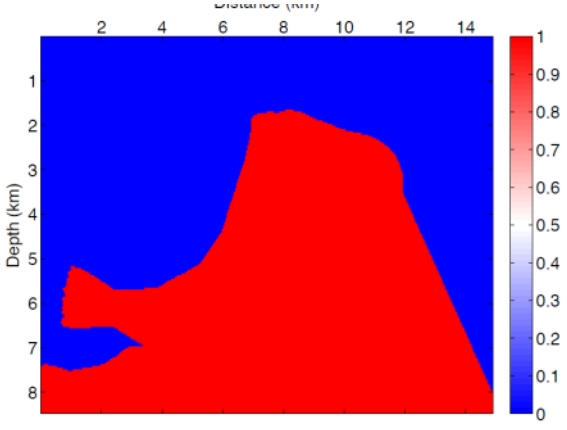


Figure 3: The total search space of the salt body used in our VFSA algorithm.

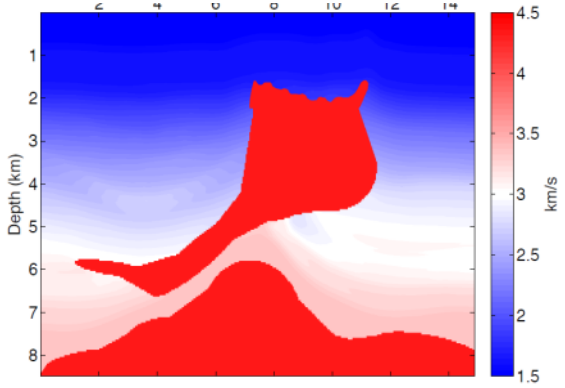


Figure 4: Model after 200 iterations of VFSA. The model resembles the true salt fairly well.

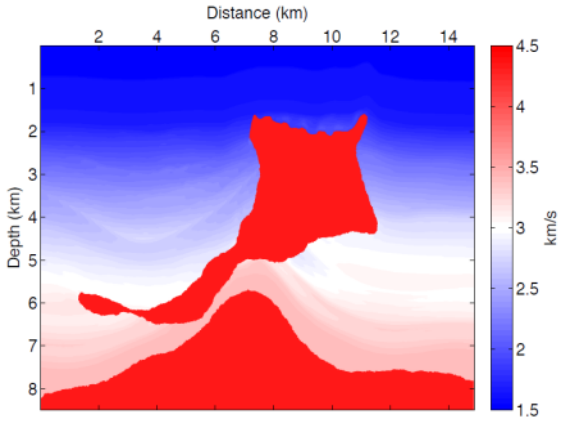


Figure 7: The final model after two runs of Partioned FWI using 4Hz and 5Hz central frequencies. The estimated salt is much closer to the true salt and the background velocity has also been updated in the correct direction.

Janaki Vamaraju

EG (CG with Constants)

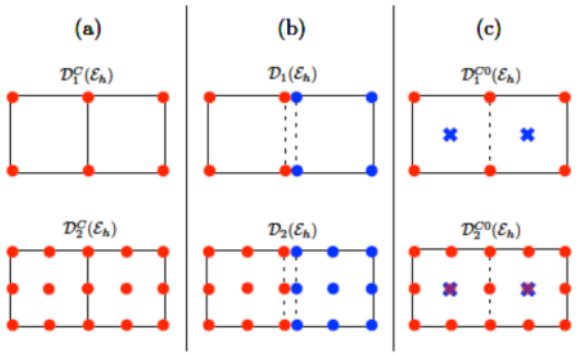
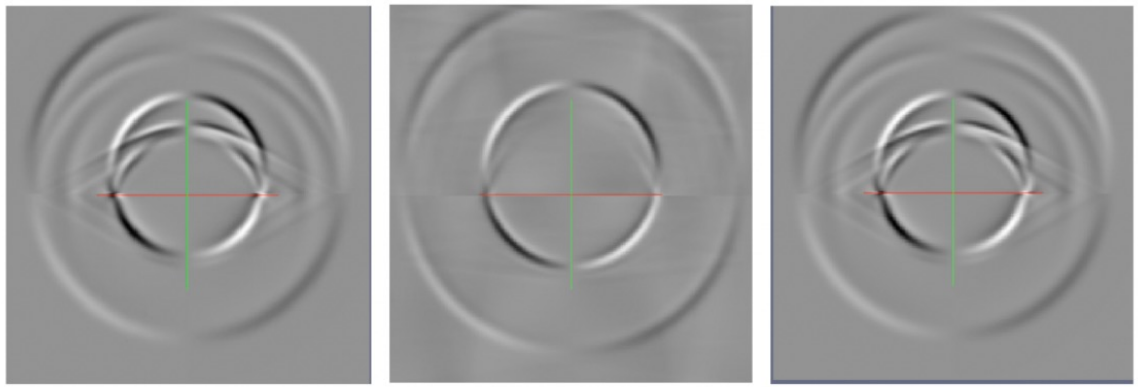


Figure 2.2: Support points for bilinear and biquadratic basis functions. (a) CG: all support points in red. (b) DG: support points for left element in red, for right element in blue. The common edge has two sets of support points - one from each element. (c) EG: support points from CG approximating space in red, piecewise constants in blue. Only the piecewise constant degree of freedom is discontinuous across the common edge.

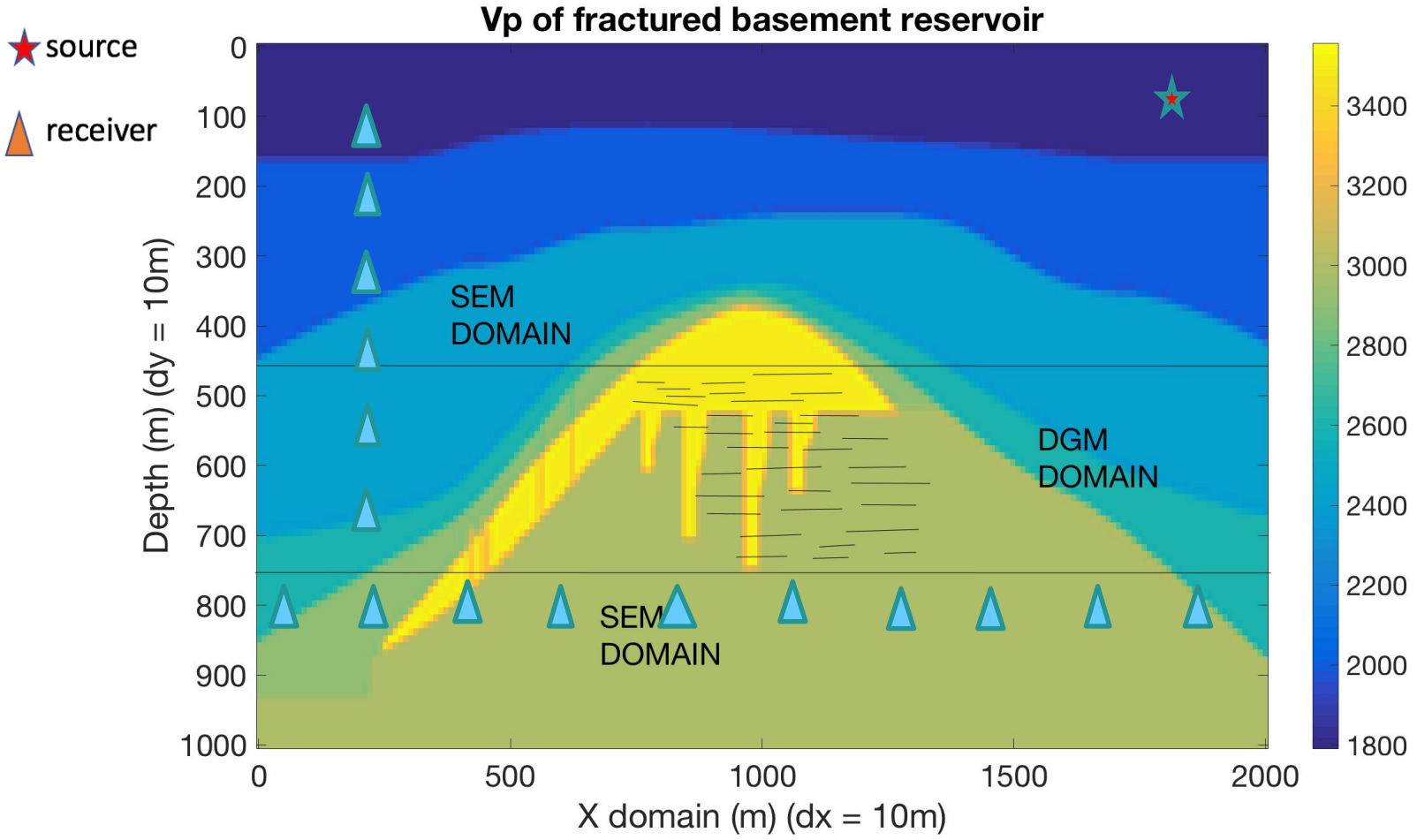
Enriched Galerkin finite element method for fracture modeling

Horizontal displacement snapshots at t = 0.3s



DGM (K = 5) EG (K = 5) EGL (K = 5)

Fractured Basement Reservoirs (Vamaraju and Sen 2017)


Vp of fractured basement reservoir
source
receiver
SEM
DOMAIN
DGM
DOMAIN
SEM
DOMAIN
Depth (m) (dy = 10m)
X domain (m) (dx = 10m)
0
100
200
300
400
500
600
700
800
900
1000
0
500
1000
1500
2000
3400
3200
3000
2800
2600
2400
2200
2000
1800


U Z
2.544e-10
1.1224e-10
-2.9974e-11
-1.7218e-10
-3.144e-10
Y
X
Z


U Z
2.535e-10
1.1905e-10
-1.5403e-11
-1.4986e-10
-2.843e-10
Y
X
Z

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