Exploration and Development Geophysics Education and Research (EDGER)

The University of Texas at Austin

www.jsg.utexas.edu/edger/

Prospectus 2016

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: *Pushing the limits of seismic resolution*

In the past decade, efforts have increased to search for hydrocarbons in difficult areas and in unconventional and fractured reservoirs. This search prompted acquisition of multi-azimuth and wide-azimuth datasets and development of processing algorithms using more complete physics of wave propagation. Currently the primary focus of EDGER is on advancement in quantitative seismic interpretation (QSI). 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:

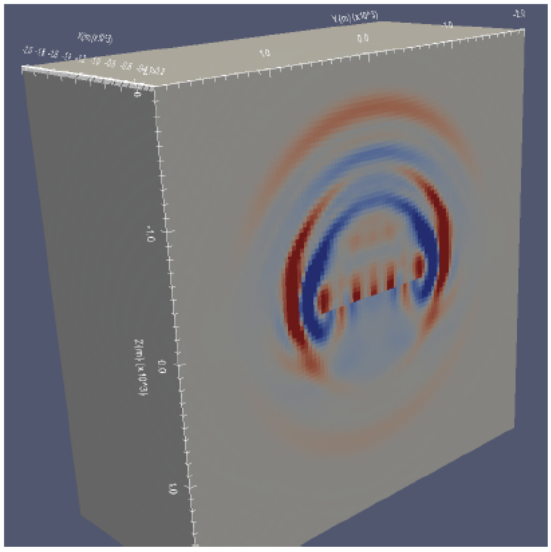
- Development of new techniques for seismic imaging and inversion
- Development of new rock physics models and adaptation of existing rock physics models to a particular field under investigation
- Integration of seismic inversion and rock physics models using novel statistical approaches and validation with field datasets.

Our imaging and inversion efforts include development of new theory and numerical algorithms for forward seismic modeling that are computationally efficient and accurate. These are used in full waveform imaging and inversion. Inversion for reservoir parameter estimation will be carried out using hybrid Markov Chain Monte Carlo methods. Effective medium models are being tested by computing the seismic responses of realistic rock models based on distributions of rock properties. We are developing new data integration techniques using geostatistical methods and Bayesian analysis.

Current and Planned Research:

1. Seismic Modeling, imaging and inversion

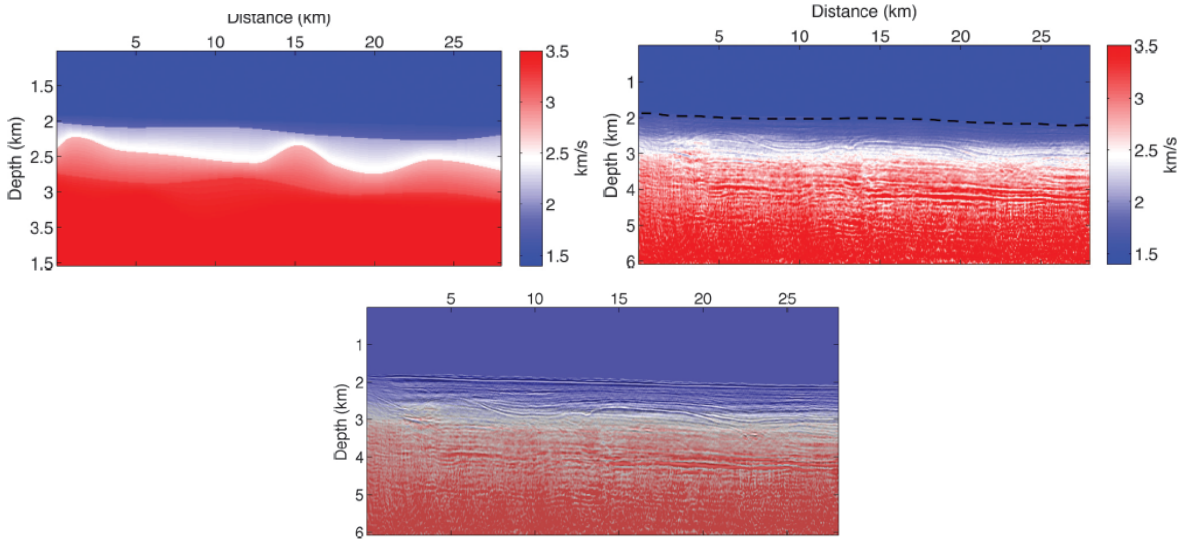
1.1 *Spectral Element (SEM) and Discontinuous Galerkin (DG) finite element methods for numerical simulation of wave propagation in 3D:* We are continuing our efforts in estimating errors in FE and FD methods. At the same time we are developing a 3D DG code that is capable of incorporating realistic fractures. We are addressing how the true microstructure of a rock affects the elastic properties, and thus, the seismic velocities. This is a developing subject through the use of digital rock physics where elastic moduli are obtained from numerical wave propagation experiments through segmented images using the discontinuous Galerkin method.



. Wavefield in a 3D domain with a 1 $Km \times 1\ Km$ horizontal fracture.

1.2. 3D wave propagation modeling on GPU/CPU: We are developing an algorithm for modeling seismic wave propagation in 3D by making use of parallel computation using CPU and GPU. We are able to obtain significant speed-up in computation.

1.3. Full waveform inversion using hybrid optimization methods: FWI methods are generally based on local optimization and are highly sensitive to the choice of a starting model. Our proposed hybrid methods make use of the salient features of global and local optimization methods such that the dependence on the starting model is significantly reduced. At the same time, convergence can be attained rapidly by using powerful gradient information.



Example of hybrid-FWI inversion of marine data: (a) a random starting model, (b) VFSA derived model used in gradient based FWI, (c) final velocity model.

1.3. Pre-stack reverse-time migration (RTM) in frequency-ray parameter domain: We are developing a new RTM algorithm that reduces the data volume significantly and thus will perhaps reduce the computational burden of RTM. Feasibility of least squares migration in the coupled ray-parameter domain is also being examined.

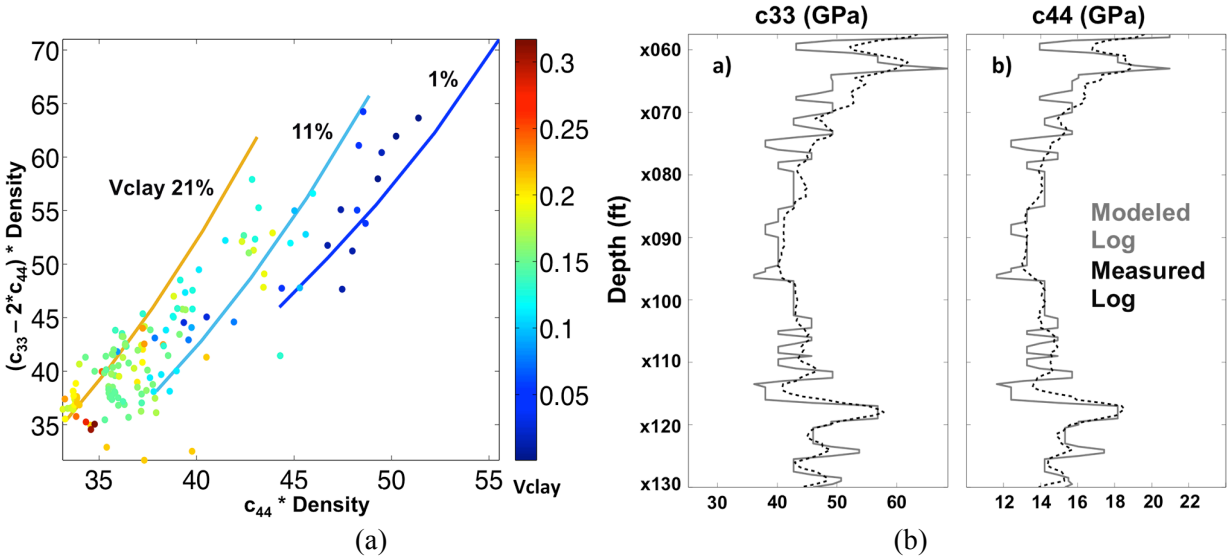
2. Seismic Inversion for reservoir characterization

2.1 Transdimensional inversion: In the past year, we developed a basis pursuit inversion (BPI) scheme and a fractal based stochastic inversion algorithm for reservoir parameter estimation. Currently we are focusing on one fundamental question: "How many layers are constrained by seismic data?" In other words, in our transdimensional inversion, the number of layer parameters is also a variable that we solve for. The optimization will be carried out using Hamiltonian Monte-Carlo approach.

2.2 Quantitative fracture characterization: Most recently we extended the AVOA method to directly estimate fracture weaknesses that can be directly related to fracture density. Our current effort is to extend this algorithm to orthorhombic media.

3. Advanced Rock Physics Modeling

3.1 Rock-physics models link rock properties and seismic responses, thus enabling a quantitative approach to seismic interpretation. For anisotropic rocks, resulting from alignment of platy clay minerals and non-spherical pores differentiate shale from conventional reservoir rocks. This high degree of anisotropy affects both the seismic response and log measurements, and should be accounted in rock-physics modeling. We investigate anisotropic rock physics modeling by using rock types and anisotropic effective medium models. The effective medium models consist of distributions of minerals, mineral moduli, pore types, and orientation functions. For conventional reservoir rocks, the modeling approaches account for compaction, diagenesis, lithology, and fluid distributions. Statistical and numerical approaches aid in describing scenarios observed in well and core data and in assessing scenarios not observed in well locations but are geologically likely.

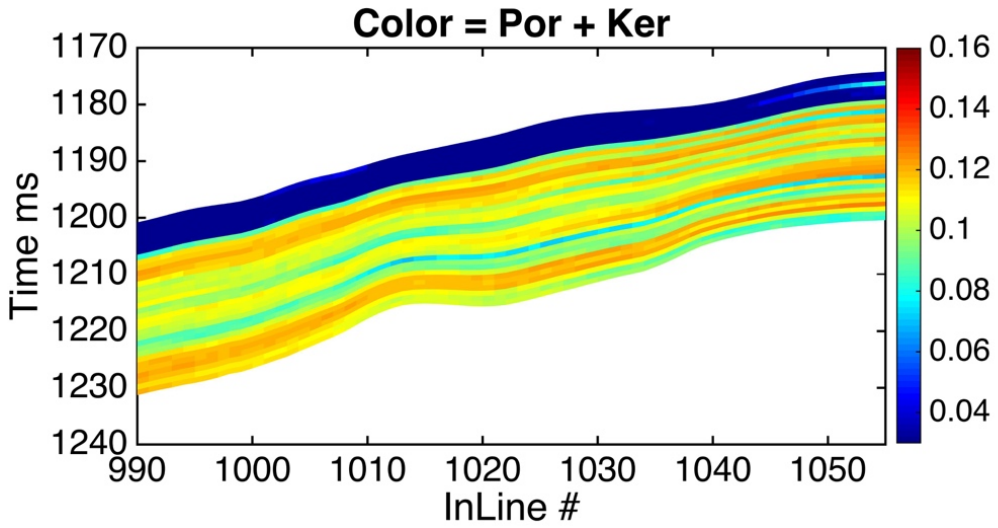


Modeled anisotropic stiffness components lines compared to well log measurements from an anisotropic interval. Color is the volume of clay (a). (b) Comparison of modeled and measured stiffness logs where the model comes from statistical sampling from the plot in (a).

3.2 *Quantitative Seismic Interpretation*: *Integration of rock physics modeling and seismic inversion*

Our recent applications of rock physics and seismic inversion for reservoir characterization have been in the areas of conventional and unconventional reservoirs and for CO2 injection for EOR and storage. In each case, the heterogeneity of the reservoirs must be accounted as well as pertinent geologic factors such

as cementation or geophysical factors such as anisotropy. Our seismic-scale estimates are derived through rigorous rock-physics modeling done at the well log and core scale scales and validated at test wells. This integrated approach also provides uncertainty estimates at every step of the forward and inverse problems.



Geostatistically guided kerogen plus porosity realization. A thin bed, anisotropic inversion routine coupled to geostatistical simulations and an anisotropic rock physics model resulted in high-resolution estimates of rock properties.

Research Team

Dr. Mrinal K. Sen, Co-principal Investigator

Mrinal K. Sen is a professor and holder of Jackson chair in Applied Seismology with joint appointment at the institute for Geophysics and the Department of Geological Sciences. His research interests include seismic wave propagation and inverse theory. He has co-authored two books on geophysical inversion. His group has been engaged in developing new techniques for seismic modeling and inversion including data integration for subsurface model building.

Dr. Kyle T. Spikes, Co-principal Investigator

Kyle T. Spikes is an associate professor in the Department of Geological Sciences with a focus in rock physics. His interests primarily involve the integration of geologic information with quantitative tools for seismic reservoir and basin characterization. This area of research includes both forward and inverse problems that combine rock physics, stochastic geologic modeling, and seismic-attribute analysis.

Dr. Robert H. Tatham, EDGER forum advisor

Robert Tatham is Professor Emeritus at the Jackson School of Geosciences and the founder of the EDGER Forum. He has been actively involved in all aspects of geophysical methods applied to petroleum problems for over 45 years. His research activities have included seismology applied to exploration, development and production of hydrocarbons. Recent activities have expanded these efforts to include characterization of the most productive parts of resource shales.

Thomas E. Hess

Mr. Hess provides crucial technical support for the EDGER Forum's research efforts as Seismic Applications Software Manager. He oversees seismic data sets from our sponsors and supports graduate students, faculty and researchers for the Exploration Geophysics program in the Dept. of Geological Sciences as well as for the UT Institute for Geophysics.

Current EDGER Post-Doctoral Fellows:

Kelvin Amalokwu: Spikes, 2016–2018
Zeyu Zhao: Sen, 2015–2018

Current EDGER Graduate Students:

Hala Alqatari, Advisor: Sen, Ent Fall 2016, PhD
Badr Alulaiw, Advisor: Sen, Ent Fall 2014, PhD
Anthony Barone, Advisor: Sen, Ent. Fall 2014, PhD
Reetam Biswas, Advisor: Sen Ent. Fall 2014, PhD
Elliot Dahl, Advisor: Spikes, Ent. Fall 2013, PhD
Debanjan Datta, Advisor: Sen, Ent. Fall 2013, PhD
Pedro Garza, Advisor: Sen, Fall Ent. Fall 2016
Han Liu, Advisor: Sen/Spikes, Ent. Fall 2012, PhD
David Tang, Advisor: Spikes, Ent. Fall 2014, PhD
Janaki Vamaraju, Advisor Sen, Ent. Fall 2016, PhD

EDUCATION

A principal objective of the EDGER Forum is the education of students who have expressed interest in employment in the petroleum industry. Our students commonly serve summer internships in the industry. The current enrollment of graduate students associated with the Forum is 10. Three (2 MS and 1 PhD) graduated in the last calendar year. Since 2000, nearly 40 graduate students have completed.

FORUM

One of the major benefits of participation is, perhaps, "community activities" sponsored by the Forum. Symposia and workshops have provided a platform for exchange of ideas between industry members (contractors, equipment manufacturers and producers), academics and the graduate students. Discussions of research directions by industry and academic participants have led to student and faculty research projects. The EDGER Forum is in an excellent position to facilitate communication between the various elements to encourage participation within the exploration and development geophysics community.

2016 Publications

1. Chatterjee, R., D. K. Singha, M. Ojha, M. K. Sen, and K. Sain, 2016, Porosity estimation from pre-stack seismic data in gas-hydrate bearing sediments, Krishna-Godavari basin, India: Journal of Natural Gas Science and Engineering 33, 562–572.
2. Datta, D., and M. K. Sen, 2016, Estimating a starting model for full-waveform inversion using a global optimization method: Geophysics, 81(4), R211–R223.
3. De Basabe, J. D, M. K. Sen, and M. F. Wheeler, 2016, Elastic wave propagation in fractured media using the discontinuous Galerkin method: Geophysics 81 (4), T163–T174.
4. Jiang, M., and K. T. Spikes, 2016, Rock-physics and seismic-inversion based reservoir characterization of the Haynesville Shale: Journal of Geophysics and Engineering 13 (3), 220–233.

5. Kumar, D., S. Mondal, M. J. Nandan, P. Harini, BMVS Sekhar, and M. K. Sen, 2016, Two-dimensional electrical resistivity tomography (ERT) and time-domain-induced polarization (TDIP) study in hard rock for groundwater investigation: a case study at Choutuppal Telangana, India: Arabian Journal of Geosciences 9 (5), 1–15.
6. Ma, J., X. Chen, M. K. Sen, and Y. Xue, 2016, Free-surface multiple attenuation for blended data: Geophysics 81 (3), V227–V233.
7. Naraghi, M. E., K. Spikes, and S. Srinivasan, 2016, 3-D Reconstruction of Porous Media From a 2-D Section and Comparisons of Transport and Elastic Properties: SPE Western Regional Meeting, SPE-180489.
8. Ojha, M., M. K. Sen, and K. Sain, 2016, Use of split spread configuration of marine multichannel seismic data in full waveform inversion, Krishna-Godavari basin, India: Journal of Seismic Exploration 25 (4), 359–373.
9. Pan B., M. K. Sen, and H. Gu, 2016, Joint inversion of PP and PS AVAZ data to estimate the fluid indicator in HTI medium: a case study in Western Sichuan Basin, China: Journal of Geophysics and Engineering 13(5), 690.
10. Ren, Q., and K. T. Spikes, 2016, Modeling the effects of microscale fabric complexity on the anisotropy of the Eagle Ford Shale: Interpretation 4 (2), SE17–SE29.
11. Ren, Q., M. Sen, M. E. Naraghi, S. Srinivasan, and K. T. Spikes, 2016, Geostatistics Guided Seismic Inversion of 3D seismic data in VTI media: 78th EAGE Conference and Exhibition.
12. Spikes, K. T., 2016, Statistical Rock-Property Estimates from Inverted Impedances and Rock-Physics Modeling: Offshore Technology Conference, DOI: 10.4043/26882-MS.
13. Wang, E., Y. Liu, and M. K. Sen, 2016, Effective finite-difference modelling methods with 2-D acoustic wave equation using a combination of cross and rhombus stencils: Geophysical Journal International, 206(3), 1933–1958.
14. Zhao, Z., M.K. Sen, and P. L. Stoffa, 2016, Double-plane-wave reverse time migration in the frequency domain: Geophysics 81(5), S367–S382.
15. Zhao, Z., and M. Sen, 2016, Double Plane Wave Least Squares Reverse Time Migration with Approximate Diagonal Hessian, 78th EAGE Conference and Exhibition.

Contact Information

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