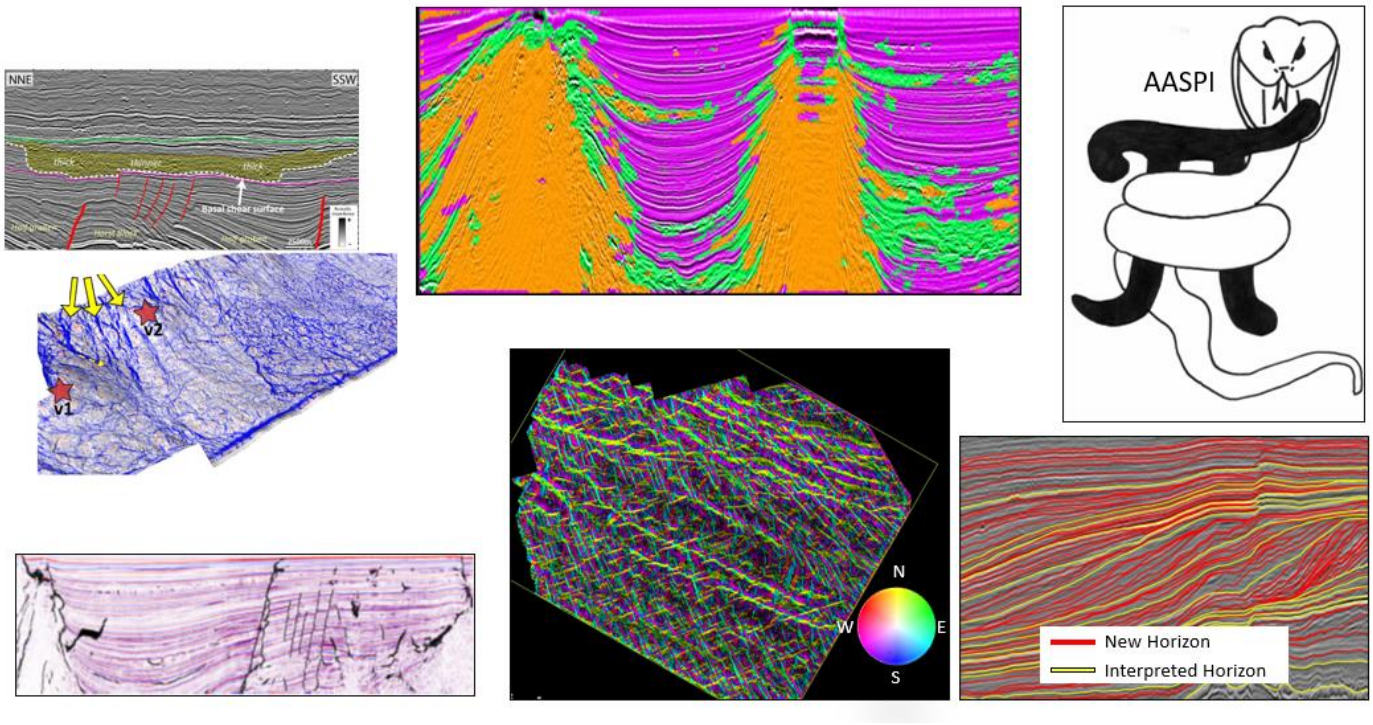

A Proposal Submitted to a
Consortium of Companies on

ATTRIBUTE-ASSISTED SEISMIC PROCESSING AND INTERPRETATION (AASPI)

Co-Principal Investigators:

Kurt J. Marfurt – The University of Oklahoma
Heather Bedle – The University of Oklahoma
Bo Zhang – The University of Alabama
Sumit Verma – The University of Texas Permian Basin
Shuvajit Bhattacharya – The University of Texas Bureau of Economic Geology
Marcilio Castro de Matos - Sismo

Sponsor contribution: $28,000/year
Contract Period: January 1, 2021 – December 31, 2021

Executive Summary

During the past three decades, seismic attributes have become a key component not only in mapping structure and stratigraphy but also in quantitative reservoir characterization. The AASPI consortium began with the development and geologic calibration of seismic attributes which currently includes volumetric estimates of coherence, curvature, aberrancy, reflector convergence, GLCM textures, amplitude gradients, and spectral components. The quality of attribute images is a direct function of the quality of the seismic data analyzed. For this reason, our work expanded into post-stack data conditioning including edge-preserving structure-oriented filtering, footprint suppression, and spectral balancing. Recently we have developed several image processing algorithms to enhance and skeletonize faults as well as quantify their vector orientation.

While we use commercial software for prestack impedance inversion, we have developed our prestack structure-oriented filtering, azimuthal anisotropy analysis, and non-stretch NMO algorithms for prestack data conditioning and analysis. With the access of the rich data available in shale resource plays, we began to integrate microseismic, image log, 90-day production, and rate of penetration data into our analysis.

For the past four years, much of work has focused on developing, adapting, and applying alternative machine learning technologies to seismic exploration and development problems. We have deployed algorithms that use principal component analysis, independent component analysis, self-organizing mapping, generative topographic mapping, probabilistic neural networks, and support vector machines, and continue to work on random forest decision trees and Gaussian mixture models. All of these algorithms link to our new machine learning toolkit.

We provide sponsors with parallelized source code and executables that run under both Windows and Linux operating systems, as well as under batch processing systems PBS, LSF, and SLURM, where our code has run across thousands of processors. Sponsors can use this software to develop volumes for use internally, with partners, or to provide as a commercial service.

During the 2021 AASPI Consortium research program, we will continue to maintain and expanded the current suite of algorithms with an emphasis on machine learning applications for seismic facies analysis of conventional reservoirs and geomechanical facies analysis of unconventional reservoirs. We will also delve deeper into deep learning. We have deployed our initialize CNN-based fault prediction algorithm, and have prototyped facies classification algorithms based on U-net and Generative Adversarial Networks. These later algorithms are written in python and will use GPU hardware to provide efficient computation.

A. 2021 Scope of Work

When properly calibrated to well-log and production data, broadband 3D seismic data play a key role in defining reservoir heterogeneity and compartmentalization. We have found that modern seismic attributes, including coherence, reflector curvature, aberrancy, reflector rotation, reflector convergence, coherent energy gradients, seismic textures, and spectral decomposition, greatly improve our ability to visualize stratigraphic and tectonic features that are at or below the classical limits of seismic resolution. Recently, we have observed that attribute images computed on offset- and azimuth-limited volumes from North and West Texas have higher lateral resolution than those computed on full offset and azimuth volumes. We have also observed that the illumination of stratigraphic features varies with offset and azimuth. The smearing of lateral discontinuities and subsequent loss of resolution is most problematic on land surveys that are rich in azimuths and subject to heterogeneous shallow surface effects including topography, weathering zones, and stress-induced anisotropy. We have deployed both multispectral, multiazimuth, and multioffset coherence algorithms but need to better understand why they provide superior images. Our research effort has four overlapping themes: (1) to enhance our ability to map reservoir compartments and delineate fractures, (2) to use attributes to drive seismic processing work flows that will improve lateral and vertical seismic resolution, (3) to calibrate features seen on seismic attributes in the

context of tectonic deformation and seismic geomorphology, and (4) to develop prediction tools that can guide completion programs for unconventional reservoirs.

B. Target Sponsors

Our goal is to serve as a research component for independent and intermediate-sized oil and gas companies, for national oil companies dealing with imaging subtle structures in land data and shelf environments, and as a technology supplier for large oil and gas, service, and software companies that field their own seismic attribute analysis technology. For those sponsors willing to share their geologic insight and license their well control, 3D seismic data, we will apply state-of-the-art technology, specialized expertise, and most important, the time necessary to generate and evaluate emerging technologies that can influence costly drilling and completion decisions.

C. Deliverables

We believe that technology is best understood when it is applied to the sponsoring company's own data. Our deliverables will therefore include:

- Source code, executables, scripts, and graphical user interfaces for all new and previously developed algorithms. Documentation of our current software can be found under mcee.ou.edu/aaspi and can also be invoked for each application by clicking the *Help* tab. Currently available algorithms including prestack and poststack structure-oriented filtering, compensation for migration stretch, coherent energy gradients, various edge detectors, multispectral coherence, multispectral dip, spectral decomposition, volumetric structural and amplitude curvature, volumetric aberrancy, volumetric generation of rose diagrams, composite attribute display, post-migration footprint suppression, volumetric GLCM texture analysis, and the machine learning toolbox mentioned above. Sponsors may use these codes in any way they wish except software resale (which requires a separate agreement), including providing services to others and using our algorithms as prototypes for their own internal implementation.
- Copies of all AASPI thesis proposals, posters, preprints, expanded abstracts, and technical papers.
- If requested, generation of geometric attributes or data analysis (having some geological or geophysical research component to comply with OU tax exempt status) on proprietary data at time and materials cost.
- Assistance in installing and utilizing delivered software at time and materials cost.

Our R&D plan is structured about M.S. theses and Ph.D. dissertations, many of which will result in publications and software. Our accomplishments for 2020 are attached as Annex B. We summarize our plans for 2021 on the next page:

Poststack Attribute and Image Processing Software Development				
Task	**Program name**	**Researcher**	**Position**	**Target**
Compare seismic bandwidth measured by spectral decomposition to that provided by instantaneous bandwidth	spec_cwt, spec_cmp, spec_maximum_entropy	Kurt Marfurt	Faculty	May-21
Replace spectral slope calculation with a version of the Holder exponent	spec_cwt, spec_cmp, spec_maximum_entropy	Kurt Marfurt; Bin Lyu	Faculty, Collaborator	May-20
Write program to extract fault plane "objects" from fault_skeletonization output	fault_object_extraction	Jose Pedro Mora	M.S. Candidate, Geophysics	Aug-20
Release Taeger-Kaiser Energy algorithm in AASPI software	taiger_kaiser_energy	Marcilio Matos	Sismo	Mar-21
Modified S-transform and application	s_transform	Marcilio Matos	Sismo	Nov-21
Mount Nvidia card on Linux box and evaluate performance	all CNN algorithms	collaboration with OU supercomputer system	External Collaborator	Mar-21
Evaluate basis pursuit algorithms to improve seismic resolution	bp_bandwidth_extension	Yichuan Wang	Staff research scientist	Nov-21
Modify aaspi i/o to allow the use of OpenVDS	aaspi_io libraries	Thang Ha, David Lubo	Ph.D. Candidates, Geophysics	May-21
Generate 3D visualization capabilities using OpenVDS input	py_vista and vtk	David Lubo	Ph.D. Candidates, Geophysics	May-21
Rework multispectral construct of structure-oriented filtering algorithms to be consistent with those of multispectral coherence in similarity3d	sof3d	Kurt Marfurt	Faculty	May-21
Convert MatLab sparse pulse decomposition Q estimation algorithm to f90 or python running under MPI	Q_sparse_pulse	Yichuan Wang	Staff research scientist	Jun-21
Prototype multiattribute Laplacian of coherent energy	similarity3d	Kurt Marfurt	Faculty	Mar-21
Seismic sequence boundary attribute (Convert MatLab code to python)	sequence_boundary	Bo Zhang	Faculty	May-21
Compare attributes generated on time- vs depth-migrated data volumes	multiple codes	Ahmet Murat Alyaz	M.S. Candidate, Geophysics	Dec-21

Simulating manual procedure of generating fault surfaces	structural_modelling	Bo Zhang	Faculty	Mar-21

Machine Learning Software Development				
Task	**Program name**	**Researcher**	**Position**	**Target**
Modify aaspi_plot to allow display of corresponding vector on selected classified voxel	aaspi_plot	Thang Ha	Ph.D. Candidates, Geophysics	May-21
Modify and rework random forest decision tree program into machine learning toolbox	rfdt3d	David Lubo	Ph.D. Candidate, Geophysics	Mar-21
Modify and rework proximal support vector machine program into machine learning toolbox	psvm3d	David Lubo, Thang Ha	Ph.D. Candidates, Geophysics	May-21
Modify and rework self-organizing mapping machine program into machine learning toolbox	som3d	Kurt Marfurt, David Lubo, Thang Ha	Faculty	Mar-21
Modify and rework generative topographic mapping machine program into machine learning toolbox	gtm3d	Kurt Marfurt, David Lubo, Thang Ha	Faculty	Mar-21
Rework som_waveform_classification to allow multiple input volumes (e.g. ZP and ZS)	som_waveform_classification	Kurt Marfurt, David Lubo, Thang Ha	Faculty	Mar-21
Rework python i/o and memory management template to allow CNN 3D window algorithms to run on large data volumes	cnn_fault_identification	Thang Ha	Ph.D. Candidate, Geophysics	Mar-21
Implement multilinear feed forward neural networks; compare with psvm3d, gtm3d, som3d, and pnn3d	mlfn3d	David Lubo	Ph.D. Candidate, Geophysics	Jun-21
Machine Learning interpretability using SHAP values	shap	David Lubo	Ph.D. Candidate, Geophysics	Jun-21
Develop new CNN-based fault identification training that better represents data quality	cnn_fault_identification	Bo Zhang	Faculty	Mar-21
Well log facies classification	python codes	Saurabh Sinha	Ph.D. Candidate, Geophysics	Aug-21
Prototype an autoencoder classification algorithm	autoencode3d	Thang Ha	Ph.D. Candidate, Geophysics	Nov-21

Mount Nvidia card on Linux box and evaluate performance	all CNN algorithms	Collaboration with OU supercomputer system	External Collaborator	Mar-21
LSTM + RNN for missing well log prediction	LSTM_LOGS	Saurabh Sinha	Ph.D. Candidate, Geophysics	Aug-21
Implement the convolutional LSTM (RNN) model for 3D seismic facies classification	LSTM_facies	Miao Tian	Ph.D. Candidate, Geophysics	Jun-21
Modify code for aaspi_io	rnn3d	Thang Ha	Ph.D. Candidate	Apr-21
Bayesian RNN for facies classification	rnn3d	Miao Tian, Sumit Verma	Ph.D. Candidate, Geophysics; Faculty	Jun-21
Facies classification using generative adversarial networks	gan3d	Alex Vera	Ph.D. Candidate	May-21
Building acoustic impedance model for seismic inversion using CNN	cnn_impedance_inversion	Yitao Pu	Ph.D. Candidate, Geophysics	Dec-21
Simulating the procedure of manual seismic structural interpretation (converting MATLAB code to Python) to develop training data	aaspi_horizon_interpretation, aaspi_fault_interpretation	Bo Zhang	Faculty	Aug-20
Create training library for fusilinid CNN classification using microCT scans	cnn_image_classification	Carl Buist	Ph.D. Candidate, Geophysics	Dec-21

Attribute Calibration using Geological Control and Geologic Principles			
Task	**Researcher**	**Position**	**Target**
Evaluate multispectral amplitude gradients response to lateral changes in thin beds (channels, levees, fans, …)	Karelia La Marca	Ph.D. Candidate, Geophysics	Jun-21
Better define the spectral response of gas hydrates, including Q estimation	Roberto Clairmont	M.S. Candidate, Geophysics	May-21
Build on November 2020 special issues of INTERPRETATION journal that provides a library of Funny Looking Things seen on seismic data	Heather Bedle, Sumit Verma, Shuvajit Bhattacharya	Faculty wearing SEG/AAPG hats	Dec-21
Record poststack data conditioning tutorial	Kurt Marfurt	Faculty	Mar-21
Seismic data conditioning and reprocessing for permafrost bearing deltaic setting	Sumit Verma, Shuvajit Bhattacharya	Faculty	Dec-21
Record aberrancy tutorial	Sumit Verma, Shuvajit Bhattacharya	Faculty	Mar-21
Construct improved CNN data base for listric and other faults that provide poor coherence images	Zach Williams	B.S. Candidate, Geophysics	Dec-21
Evaluate AASPI PNN for fault classification	Jose Pedro Mora	M.S. Candidate	May-21
Evaluate AASPI PNN for well log classification	David Lubo	Ph.D. Candidate	May-21
Automated well log analysis using machine learning - Applications to the Midland Basin	Sumit Verma, Khaled Chowdury, Shuvajit Bhattacharya, Rob Hissong, and Miao Tian	Faculty and grad students	Nov-21
Evaluate geometric attributes for fault characterization, offshore Brazil	Edimar Perico	M.S. Candidate	May-21

Attribute Calibration using Engineering Control			
Task	**Researcher**	**Affiliation**	**Target**
Correlate production data to proximity to faults	Swetal Patel	Alumnus	May-21
Correlate production data to geomechanical stacking pattern	Swetal Patel	Alumnus	May-21
Extract brittle/ductile supervision data using microseismic event location	Swetal Patel	Alumnus	May-21
A comparison of machine learning and deep learning for reservoir properties prediction	Bo Zhang	Faculty	Dec-21
Use SOM, GTM, and PNN to evaluate Pinnacle reef characterization with core and production control	Carl Buist, Clayton Silver	Ph.D. and M.S. Candidates, Geophysics	Aug-21

Prestack Data Conditioning and Imaging Algorithm Development			
Task	**Researcher**	**Affiliation**	**Target**
Thin bed thickness estimation based on angle-dependent tuning spectra	future student?		
Tuning frequency vs. azimuth analysis	future student?		
Q or other scattering measures as a function of azimuth for detection of natural or induced fractures and/or horizontal stress field	Yichuan Wang	Research Staff	Jul-21
Evaluate using CNN to predict lithology or rock types predicted from triple combo logs from migrated gathers in the absence of P- and S- wave logs	David Lubo and Berk Caf, Alex Vera	Ph.D. Candidates, Geophysics	Jul-21
Seismic denoising using generative adversarial networks	Alex Vera	Ph.D. Candidate	Sep-21

Research Staff

Kurt Marfurt, Ph.D.

Kurt Marfurt is a geophysicist with 40 years' experience in seismic attribute analysis, algorithm development, data processing, and interpretation. During his 18 years at Amoco, he played a role in developing both coherence and spectral decomposition algorithms and lead Amoco's attribute calibration team. After Amoco, Kurt served eight years furthering this effort as director of the University of Houston's Allied Geophysical Lab, after which he joined OU in 2007.

Heather Bedle, Ph.D.

Heather Bedle is a geophysicist brings us a background in petrophysics, time-lapse seismic, and prestack inversion gained from her previous work at Chevron. Heather and her students have been working on projects in multi-attribute analysis and a variety of machine learning methods to improve imaging our geologic applications to seismic geomorphology, gas hydrate analysis, clastic and carbonate depositional settings.

Marcilio Matos, Ph.D.

Marcilio Matos is a geophysicist with a Ph.D. in Electrical Engineering and was a visiting scholar with AASPI during the time period January 2008-December 2009. Marcilio has expertise in digital signal processing, spectral decomposition and self-organizing maps. In 2010, Marcilio returned to Brazil where he continues collaborating with us in algorithm development and calibration.

Bo Zhang, Ph.D.

Bo Zhang is a geophysicist teaching at the University of Alabama, and developed several of the AASPI prestack data conditioning algorithms, including non-stretch NMO and high-resolution velocity analysis. Bo and his students have deployed several interactive algorithms for seismic geochronostratigraphy within the MatLab framework and are currently converting them to python for tighter integration with our other algorithms. He is also constructing the training data necessary to expand our CNN fault prediction algorithm to more difficult listric and reverse faults.

Sumit Verma, Ph.D.

Sumit Verma is a geophysicist teaching at the University of Texas, Permian Basin, and developed several of the data processing algorithms in AASPI. He has also developed workflows to correlate TOC measured in core to logs and thence from logs to 3D seismic attributes. Working in Midland, TX, Sumit and his students are particularly interested in applying supervised learning technology to correlate (normalized) volumes of proppant, breakdown pressure, and 90 days production to seismic attribute volumes to 3D geometric and geomechanical attributes. He is also constructing supervised facies classification tools with RNN and other algorithms.

Shujavit Bhattacharya, Ph.D.

Shuvajit Bhattacharya is a researcher at the Bureau of Economic Geology, the University of Texas at Austin. He is an applied geophysicist/petrophysicist by background. He is primarily interested in extracting and integrating fundamental rock and fluid properties across multiple scales of resolution (well log and seismic). His expertise is in 3D seismic attribute-assisted interpretation, detailed petrophysical modeling, and machine learning. Recently, he has used conventional machine learning and deep learning algorithms to analyze the distribution of multi-phase fault networks and submarine landslides. Prior to joining BEG, he worked with the University of Alaska Anchorage, Battelle, and other organizations in different roles, such as an assistant professor and petroleum geoscientist. He completed multiple projects for resources exploration, carbon sequestration, and induced seismicity in the US, Australia, South Africa, and India.

Resources

The bulk of the work will be conducted within OU's Crustal Imaging Facility (CIF) with computationally intensive work being done at the Oklahoma Supercomputing Center (OSCER). Through the generosity of commercial software vendors and service companies, CIF has onsite installations of state-of-the-art software products in seismic interpretation, processing, imaging, modeling, visualization, reservoir calibration, and reservoir simulation which exceeds that available to employees at many independent oil companies. Through close collaboration with oil and service companies, we have been able to obtain licenses 3D seismic, core, wireline, image log, microseismic, and production data, with a particular emphasis on resource plays, that allow us to both test and calibrate our new developments in seismic attributes.

Project Coordination and Oversight

The six co-PIs will coordinate the overall effort with the distributed across the five different institutions.