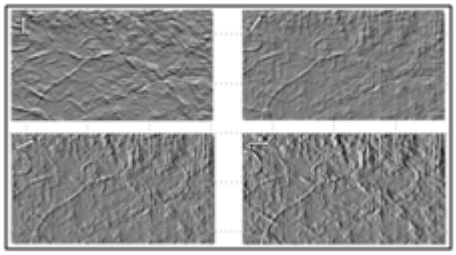
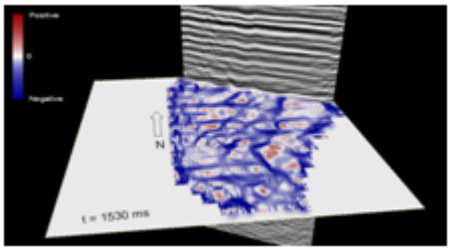
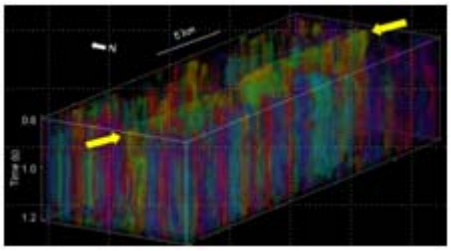
Annex A







A Proposal Submitted to a
Consortium of Companies on

ATTRIBUTE-ASSISTED SEISMIC PROCESSING AND INTERPRETATION

by

ConocoPhillips School of Geology and Geophysics
Mewbourne College of Earth and Energy
The University of Oklahoma
100 E. Boyd Street, Suite 872
Norman, OK 73019

Principle Investigator: Kurt J. Marfurt
Financial Administrator: Nancy Leonard

Sponsor contribution: **$28,000**
Contract Period: **January 1, 2009 – December 31, 2009**
Institutional Approval: **Andrea Deaton, Executive Director**
Office of Research Services
University of Oklahoma

Executive Summary

During the past decade, seismic attributes have become not only well-accepted by the interpretation community, but have also become a key component in quantitative reservoir characterization. In addition to enhancing individual faults and discontinuities, geometric attributes help interpreters map axial planes for structural analysis, relate curvature to intensity and orientation of fractures, and map lateral changes in reflectivity to detect channels below seismic resolution. During the 2009 AASPI Consortium research program, we will continue our focus on subtle stratigraphic, diagenetic, and structural features such as thin-bedded turbidites, gas shales, karsting, and fracture systems. Our research is driven by the data provided by our sponsors, such that our primary efforts will be on the calibration of these attributes over mature fields of North America (US, Canada, and Mexico) that have a combination of proprietary 3D surveys, production data, well logs, image logs, and core, within a well-understood geologic framework. We will extend our calibration to prestack data in two ways - in the selection of processing parameters and velocity model building, and in the application to offset- and azimuthally-limited volumes. We believe that a better understanding of the impact of acquisition, processing, and imaging on seismic attributes is key to quantifying the errors in reservoir characterization and hydrocarbon estimation provided by modern attribute-driven geostatistics, neural nets, and clustering technology. In addition to research reports, we provide algorithm source code to all sponsors and attribute volumes to those sponsors who provide us 3D seismic data.

A. 2009 Scope of Work

When properly calibrated to well-log and production data, high-frequency 3D seismic data play a key role in defining reservoir heterogeneity and compartmentalization. We have found that modern seismic attributes, including coherence, reflector curvature, reflector rotation, coherent energy gradients, seismic textures, and spectral decomposition, greatly improve our ability to visualize stratigraphic features that are considerably 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. Our research effort has three major 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, and (3) to calibrate features seen on seismic attributes in the context of tectonic deformation and seismic geomorphology.

B. Target Sponsors

Our goal is to serve as a research component for independent and intermediate-sized oil and gas companies, domestic North American business units of large companies, and National Oil companies dealing with imaging subtle structures in land data and shelf environments. In exchange for geologic insight, well control, 3D seismic data, and consortium funding from

sponsor companies, we will apply state of the art technology, specialized expertise, and most important, the time necessary to generate and evaluate emerging technologies that can impact costly drilling 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:

- Generation of a full suite of geometric attributes to those sponsors who provide us with 3D seismic data. Ideally, each sponsor would provide us with a first data volume with good well control that could form the basis of publications and theses. If desired, we will process a 2nd volume that may be of more immediate exploration interest that can be held in confidence.
- Source code for all new and previous developed algorithms. Currently available algorithms including structure-oriented filtering, volumetric dip, azimuth, spectral curvature, coherent energy gradients, various edge detectors, spectral decomposition, volumetric generation of rose diagrams, composite attribute display, post-migration footprint suppression, volumetric GLCM texture analysis, and filtering of dip volumes. Sponsors may use these codes in any way they wish except software resale (which requires a separate agreement), including providing services to others.
- Copies of all AASPI thesis proposals, posters, preprints, expanded abstracts, and technical papers.
- 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.

Our R&D plan is structured about M.S. theses and Ph.D. dissertations, many of which will result in publications and software. We summarize our current plans for 2009 below:

AASPI Deliverables 2009 - Reservoir Characterization Workflows			
Task	**Researcher**	**Affiliation**	**Advisor**
Further development of tools to calibrate oil and water production to distance of wells from fault/fracture 'lineaments' seen on curvature and coherence. Preliminary callibration to Dickman Field, KS	Brad Wallet	PhD Candidate, OU	Kurt Marfurt
Analysis of multicomponent, multiazimuth data for fractures (applied to Ft Worth Basin, TX, Osage Co., OK, and Kansas surveys	future student		
Statistical analysis of GCLM textures - is there a correlation with fractures and production?	Miguel Angelo	MS Candidate, OU	Marcilio Matos Kurt Marfurt
2D wave equation modeling and migration of karsted faults, Kansas: Do we see them because of collapse features in the surface or because of velocity push-down?	Rachel Barber		Sue Nissen
Calibration of thickness, upward fining, upward coarsening, and blocky patterns seen in well logs to moments (mean, bandwidth, skewness, kurtosis) as well as non-Gaussian measures (mode, bi-modal behavior) of matched-pursuit spectral components	Kui Zhang	PhD Candidate, OU	Kurt Marfurt
Calibration of production from Morrow channels to spectral decomposition	Yoscel Suarez	PhD Candidate, OU	Kurt Marfurt
Development of workflow to compute true tuning thickness rather than vertical apparent tuning thickness listric faults and roll-over anticlines	Supratik Sarkar	PhD Candidate, OU	Roger Slatt and Kurt Marfurt
Wave equation modeling or Red Fork 'invisible channels'. Can we predict if acquiring higher frequencies, longer offsets, or converted wave data, will illuminate them?	Yoryenys del Moro; Rachel Barber	Exchange student, Simon Bolivar U.; M.S. Candidate, OU	Kurt Marfurt
Seismic expression of reservoir competance with drop in pressure - attributes and 4D seismic applied to Forties Field, North Sea	Sunday Amoyedo	PhD Candidate, OU	Roger Slatt Kurt Marfurt
Measure rock properties of chert from Osage Co., OK. Correlate to attribute and impedance inversion response	Miguel Angelo; Malleswara Yenugu	MS Candidate, OU; PhD Candidate, OU	Kurt Marfurt, Carl Sondergeld, Chandra Rai
Calibrate attribute response to coal bed methane production data (Queensland, Australia)	Jeremy Fisk	MS Candidate, OU	Kurt Marfurt
Evaluate use of S-wave vs. P-wave images in illuminating compartments within the Diamond-M component of Horseshoe Atoll, TX	Carlos Russian	MS Candidate, OU	Roger Young
Callibration of Woodford Shale Production to Attributes and AVO/Elastic Impedance	Yanxia Guo	MS Candidate, OU	Roger Young
Prototype parasequence well log classifier for shales. Calibrate to seismic?	Brad Wallet; Roderick Perez	PhD Candidates, OU	Kurt Marfurt

AASPI Deliverables 2009 - Seismic Geomorphology			
Task	**Researcher**	**Affiliation**	**Supervisor**
Volumetric attribute mapping of basement faulting, Osage County, OK	Bunmi Elebiju	PhD Candidate, OU	Randy Keller; Kurt Marfurt
Correlation of large scale (basin sized) fault and fracture systems seen on gravity and magnetics to local faults seen in the basement on attributes applied to seismic surveys - Ft Worth Basin, Texas. Interpretation within the Ouachita orogeny framework	Bunmi Elebiju	PhD Candidate, OU	Randy Keller; Kurt Marfurt
Calibrate curvature and coherence images on vertical and time slices to structural deformation - Mesozoic section of Chincontepec Basin survey	Ha Mai	PhD Candidates, OU	Kurt Marfurt
Evaluation of geometric attributes to map shallow fluvial deltaic fan systems on the Gulf of Mexico shelf	Felipe Lozano	PhD Candidate, UH	Kurt Marfurt
Evaluation of volumetric attributes to map turbidites and mass transport complexes in a salt minibasin: Gulf of Mexico, USA	Supratik Sarkar	PhD Candidate, OU	Kurt Marfurt; Roger Slatt
Application of Schlumberger 'ant-tracking' algorithms to mapping axial planes on volumetric curvature	Roderick Perez; Ha Mai	PhD Candidates, OU	Kurt Marfurt
Expression of amalgamated channels or complex reefs using both the magnitude and phase components of wavelet-based spectral decomposition	future student		
Evaluate use of volumetric curvature and volumetric rose diagrams to map subtle reef features within the Diamond-M area of the Horseshoe Atoll, TX	Carlos Russian; Ha Mai	MS Candidate, OU; PhD Candidate, OU	Roger Young
Attribute expression of Cretaceous faults and folds in a transpressional terrain, Chincontepec Basin, Mexico	Ha Mai		Kurt Marfurt
Evaluation and modification of volumetric attributes to map fractured basement oil reservoirs - Cuu Long Basin, Vietnam	Ha Mai	PhD Candidate, OU	Kurt Marfurt
Map attribute expression of shallow volcanic intrusive and extrusive features and their effect on data quality - application to Chicontepec and China	Victor Pena; Supratik Sarkar; Kui Zhang; Zhonghong Wan	MS Candidate, OU; PhD Candidates, OU; visiting scholar, BGP	

AASPI Deliverables 2009 - Algorithm Development			
Task	**Researcher**	**Affiliation**	**Supervisor**
Implement 'texture attributes' computed along reflector dip/azimuth (Imitation of work by West et al., Gao, Chopra, etc.). How do these measures compliment/correlate to 'geometric attributes'?	Miguel Angelo	MS Candidate, OU	Marcilio Matos; Kurt Marfurt
Prototype 2D self-origanizing maps (SOM) algorithms and display clusters against a 2D HS color bar. (Matlab application)	Marcilio Matos	Research Scientist, OU	
Develop phase-unwrapping strategies amenable to 4D phase volumes computed by spectral decomposition	Marcilio Matos; Kui Zhang	Research Scientist, OU; PhD candidate, OU	Kurt Marfurt
Develop prototype unconformity attribute based on discontinuities in unwrapped spectral decomposition phase	Marcilio Matos	Research Scientist, OU	Kurt Marfurt
Prototype Generative Topological Maps (GTM) algorithms and display clusters against a 2D HS color bar. Compare to SOM. (Matlab application)	Brad Wallet; Tim Kwiatkowski	PhD Candidate, OU; Research Scientist, OU	Kurt Marfurt
Improvement of attributes to better image listric and reverse faults (fault planes having significant dip).	Kurt Marfurt	Professor, OU	Kurt Marfurt
Multicomponent polarization filter migration that rotates components based on S-wave travel path rather than source receiver azimuth	Kui Zhang	PhD Candidate, OU	Kurt Marfurt
Migration-driven residual azimuthal anisotropy analysis based on Perez' algorithm for better delineation of fractures	Kui Zhang	PhD Candidate, OU	Kurt Marfurt
Suppression of acquisition footprint on volumetric dip calculations	Oswaldo Davogustto	MS Candidate, OU	Kurt Marfurt
Modification of attribute algorithms to better image angular unconformities	Kurt Marfurt	Professor, OU	Kurt Marfurt
Maintenance and continued/improved documentation of attribute software already deployed	Kurt Marfurt	Professor, OU	Kurt Marfurt
Improved structure-oriented filtering by reworking current geometric attribute computation into a flow with steps of: 1) dip/azimuth estimation, 2) user-controlled edge-reserving nonlinear dip/azimuth filtering, followed by 3) edge-preserving mean, median, alpha-trimmed mean, and principal component filtering along dip/azimuth	Kurt Marfurt	Professor, OU	Kurt Marfurt
Estimate Q from unwrapped spectral phases	Marcilio Matos	Research Scientist, OU	
Suppression of coherent seismic noise using constrained least-squares migration	Marion King	MS Candidate, UH	Kurt Marfurt
Attribute-assisted acquisition footprint suppression using *kx-ky* time slice matched filters	Kurt Marfurt	Professor, OU	Kurt Marfurt
Development of direction amplitude gradients and directional (Euler) curvature	Ha Mai	PhD Candidate, OU	Kurt Marfurt
Development of structural rose diagrams amenable to interpretation within commercial software	Ha Mai	PhD Candidate, OU	Kurt Marfurt
Develop GUIs for rose diagram generation	Ha Mai	PhD Candidate, OU	Kurt Marfurt
Develop GUIs for footprint suppression workflows	Ha Mai	PhD Candidate, OU	Kurt Marfurt

Develop GUIs for 4D spectral component QC display	Ha Mai	PhD Candidate, OU	Kurt Marfurt
Develop GUIs for 2- and 3-attribute color display	Ha Mai	PhD Candidate, OU	Kurt Marfurt
Modify principal component spectral analysis (Guo and Marfurt, 2009) algorithm to read flattened data volumes. Then release	Kurt Marfurt	Professor, OU	Kurt Marfurt
Develop prototype Petrel Ocean module that allows modulation of (a 1-, 2-, or 3-) attribute image plotted against HLS by another (potentially 4th) attribute that modulates alpha (opacity)	Brad Wallet	PhD Candidate, OU	Kurt Marfurt
Prototype Image Grand Tour (IGT) software and workflow for spectral decomposition analysis (Java)	Brad Wallet	PhD Candidate, OU	Kurt Marfurt
Evaluate alternative statistical distributions of natural fractures where part of the distribution falls below seismic resolution	Brad Wallet	PhD Candidate, OU	Kurt Marfurt

Kurt Marfurt

Kurt Marfurt is a geophysicist with 31 years experience in seismic attribute analysis, algorithm development, data processing, and interpretation. At Amoco, he played a role in developing both coherence and spectral decomposition algorithms and lead Amoco's attribute calibration team. Kurt served as director of first AGL, then CAGE, at the University of Houston. The OU AASPI effort is the current phase of this continuing work.

Tim Kwiatkowski

Tim Kwiatkowski is a geophysicist with a Ph.D. in Physics and 21 years experience in computer science, data processing, AVO, and spectral analysis. Before rejoining OU, Tim implemented software solutions at Fusion.

Marcilio Matos

Marcilio Matos is a geophysicist with a Ph.D. in Electrical Engineering who is working with AASPI as a visiting scholar during the time period January 2008-December 2009. Marcilio has expertise is digital signal processing, spectral decomposition and self-organizing maps. Marcilio is currently on leave of absence from the Brazilian Military College where he teaches and conducts research on behalf of the Brazilian petroleum industry.

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 that exceeds that available to employees at many independent oil companies. Through close collaboration with oil and service companies with OU, or through grants with the U.S. Department of Energy, we have been able to obtain licenses to several modern data sets that will allow us to both test and calibrate our new developments in seismic attributes.

Project Leverage

The bulk of this work will be through shared students with other faculty and consortia within OU. At OU, we will draw on expertise on rock physics from Chandra Rai and Carl Sondergeld's rock physics consortium, on seismic geomorphology from Roger Slatt's effort on mapping turbidites and calibrating them with outcrop and image logs, on mapping fractures from acoustic emissions with Deepak Devegowda, in addition to geophysical processing and interpretation guidance from Roger Young and Randy Keller.