Overview of the

Allied Geophysical Laboratories

Full-wave Seismic Exploration for Reservoir Lithologies and Fluids

From Lab to Oilfield

UNIVERSITY of HOUSTON

Allied Geophysical Laboratories

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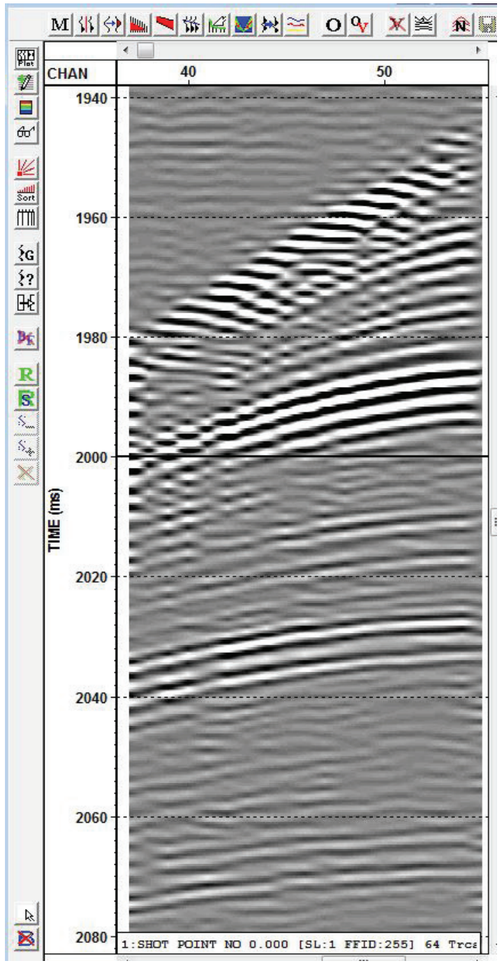
Overview of the

Allied Geophysical Laboratories (AGL) University of Houston



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UNIVERSITY of HOUSTON
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Allied Geophysical Laboratories

Summary

This overview describes the people, research projects, and educational efforts of the Allied Geophysical Laboratories (AGL) at the University of Houston. We invite potential sponsors of AGL to support and guide our quest to enhance the science of geophysics, develop aspiring scientists, and contribute to economic prosperity. Our geophisical work is based on a number of data acquisition and analysis projects directed at improved imaging and analysis of subsurface reservoirs. Research is driven by ideas and data. Novel concepts about acquisition, wave propagation, and imaging in increasingly realistic media are developed and tested via lab and field experiments. Existing advanced data sets, especially full-wave 3D seismic surveys, are analyzed to provide improved description of reservoir rocks and fluids. Graduate student education is a key component of this effort.

Laboratory experiments

We are undertaking a number of ultrasonic physical modeling experiments using our robotic surveying facility. These include 3D VSP geometries, fracture zone traverses, rugose scattering, ocean-bottom node simulations, and measurements through various anisotropic media. We are investigating anisotropic and time-lapse imaging concepts in porous fluid-saturated media under controlled lab conditions, including direct imaging of hydrocarbon movement and production through permeable models.
We have been pioneering new model building with laser-etching and 3-D printing.

Field surveys and tests

AGL's field seismic capability has expanded with GPS, well logging, VSP, and full-wave surface seismic systems, allowing us to conduct a variety of surveys and tests. We are particularly interested in unconventional resource rocks: shales, and other low-porosity, low- permeability reservoirs.
In addition, we have two field sites developed for research and teaching:
The UH Coastal Field Station is 30 miles south of Houston and is beside a producing oilfield. The Yellowstone Bighorn site in Montana is a structurally complex region also proximal to oil production. In these and other areas, we are evaluating and comparing planted geophones and land-streamers, analog and digital sensors, and microphones as auxiliary sensors, and unmanned aerial vehicles (UAVs) with seismic sensors. Our goal is continued development of the technology and methods related to the full seismic wavefield recorded with multicomponent sensors in both land and marine settings. With sponsor collaboration and counsel, we are undertaking a problem-driven field program addressing fundamental issues of data acquisition, subsurface imaging, and analysis.

Theory and processing

Analysis of field and lab data spur the development of custom algorithms while data preparation and processing use the latest industry-standard tools. We aspire to make advancement in theory as well as data processing. Some of our topics of interest and focus include: fluid substitution effects, surface-wave and reflectivity inversion, converted-wave analysis, microseismic monitoring, anisotropic wave propagation, seismic attributes, spectral characteristics, and time-lapse phenomena.

Personnel

Professor Robert Stewart (AGL Director) and associates Drs. John Castagna, Yingcai Zheng, Evgeni Chesnokov, Robert Wiley, and Hua-Wei Zhou are delighted to welcome distinguished colleagues Drs. Gennady Goloshubin, Fred Hilterman, Aibing Li, Will Sager, and Leon Thomsen as collaborators.

Goals, deliverables, and fees

A primary goal of AGL is the education and professional development of students. Some 25 MS and PhD graduate students are currently associated wtih AGL. We aspire to support 25 more. Upon graduation, they will be ready for industrial and academic roles in geophysical acquisition, processing, interpretation, or research. Our scientific objective is to better understand and image the subsurface and thus, to enhance the discovery and recovery of resources. Deliverables from this work include ideas, lab and field data, software, reports, newsletters, courses, and presentations.

Overview

Geophysical science and resource exploration begin with the acquisition of data. In the Allied Geophysical Lab, we start many of our studies with full wavefield generation and measurement. We make measurements in three broad ways: (1) elastic wavefield computer simulation, (2) accurately scaled ultrasonic physical modeling in the lab, and (3) field acquisition over areas of resource interest. In addition, we collaborate with a number of our sponsoring companies and analysis of their existing data sets. These measurements are processed through various standard and custom algorithms and procedures, then interpreted. On the other hand, we develop novel ideas about wave propagation and imaging in increasingly complex materials that are tested with actual experiments. Thus, our work is directed toward developing better seismic imaging techniques for new resource targets.

At the university, our mandate is multicomponent or 3C: Create, Conserve and Communicate knowledge. We might add to this Commercialize or transfer our results to receiving groups for application to problems of practical interest. Our role is somewhat complementary to that of the industry. We have educational and research responsibilities, in contrast to largely economic ones. Nonetheless, much of our research is naturally targeted toward problems and areas of current economic interest (Figure 1). Exciting recent resource targets include those overlain by deep water and hydrocarbons contained in shale or low-permeability sandstone. Monitoring the hydraulic fracturing process or predicting where natural fractures occur continues to be a challenge as does following CO_2 enhanced oil recovery and sequestration.

The full-wave or multicomponent seismic method has much to offer for subsurface imaging and rock property estimation. However, full-wave seismology is more complex than simple acoustic imaging, thus grand challenges remain in improving data acquisition, developing more accurate processing methods, and interpreting the images more usefully. We advocate acquiring elastic (3C or 4C) seismic data whenever possible to advance lithologic and petrophysical aspects of reservoir assessment. Much of our ability to detect fluid movement depends on understanding the changes that a rock undergoes with fluid saturation. Thus, a major component of the project is attached to laboratory measurements on rocks and scaled models, computer simulations, and well log analysis. Acquisition and use of these richer data sets will also help students become familiar with their value and application.

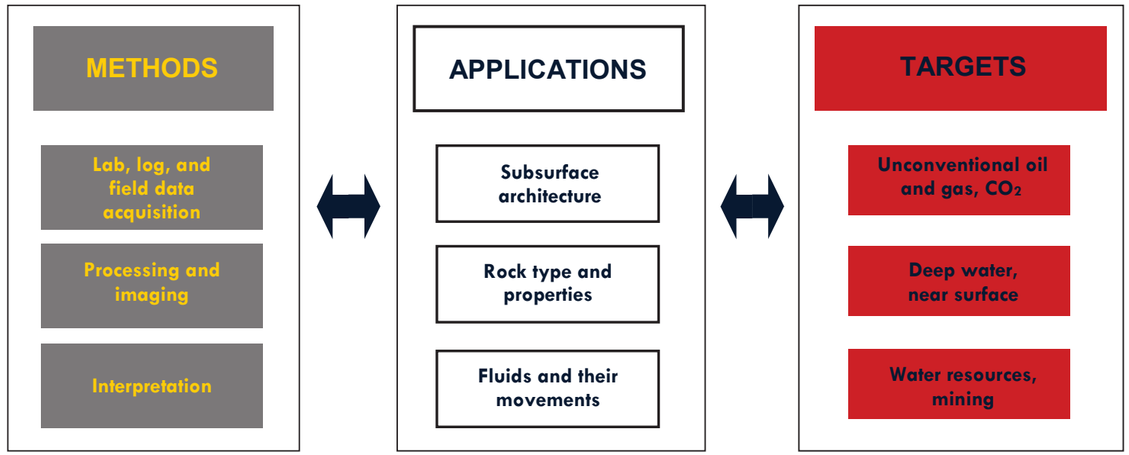

Figure 1.
Schematic overview of the elements of this proposal including methods, their applications, and specific resource targets

The Allied Geophysical Lab

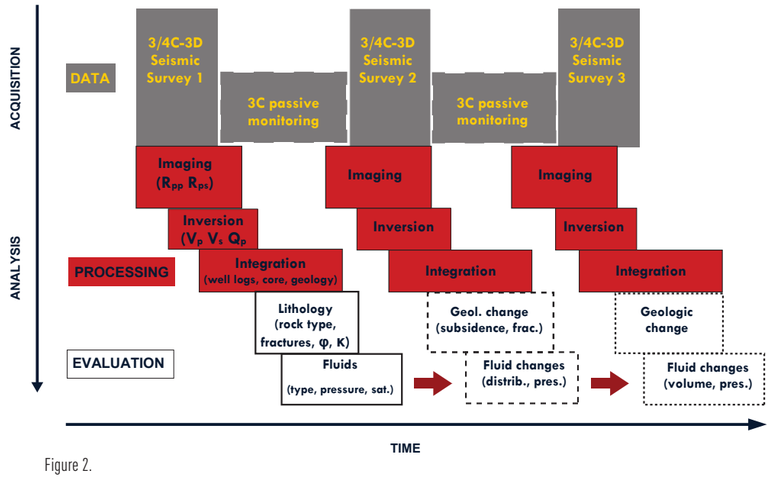

Figure 2.
Schematic diagram of full-wave seismic methodologies to assess reservoir rock and physical model properties, fluids, and their changes

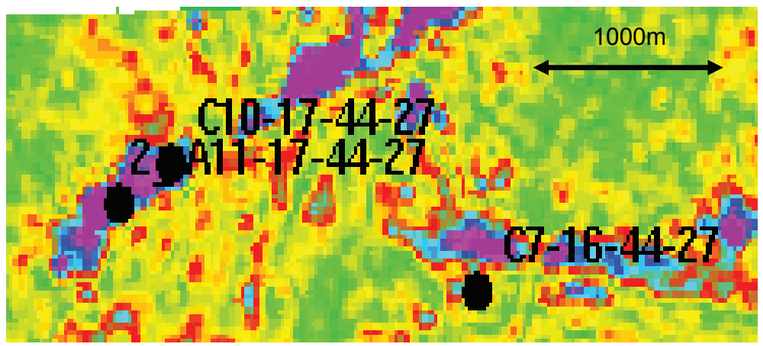

Figure 3.
Amplitude time slice from a 3C–3D seismic volume on a sand channel (Varga and Stewart, 2009, Delineating sand channels using 3C-3D seismic data, Manitou Lk. heavy oil field, Can. Soc. Expl. Geophys. Ann. Mtg.)

Going beyond the lab and logs, seismic methodology for subsurface imaging and monitoring is often divided into three broad categories: data acquisition, processing, and interpretation. As we believe that all three categories are intimately and inextricably connected, we conduct research in all three areas. Seismic data are often first collected for exploration purposes, but then possibly repeated for reservoir development and management (Figure 2). Initially, the data are processed into a reflection image (to provide a band-limited subsurface architecture – see Figure 3) then, with supporting information, they may be analyzed further into pictures of estimated lithology and other properties. Integrating these images with follow-on survey results leads to indicators of geologic and fluid change. To this end, we will undertake time-lapse, full-wave experiments in the lab and field.

Most of the methodology that we are developing for imaging hydrocarbon reservoirs can be applied to making images of greenhouse or waste gases injected into the subsurface. We seek to find improved ways of understanding gas emplacement and containment. Detecting and mapping water and its flows may be amenable to similar seismic methodologies. In fact, sophisticated seismic analysis has found significant application in the mining industry, especially as related to faults and aquifer flows.

Allied Geophysical Laboratories

The original Allied Geophysical Lab came to life under the tutelage of Dr. Fred Hilterman some 40 years ago. It was founded by associating disparate exploration-related projects: physical modeling, well log analysis, seismic data processing, and interpretation. In the following years, AGL made outstanding contributions to exploration geophysics while educating generations of students. We are returning to some of the AGL's geophysical roots, but with energetic new growth. The new AGL is focusing on experimental geophysics and associated theory, data assessment, and application. We carefully collect and thoroughlyanalyze a wide variety of geophysical data, from the lab to field scale. The Department of Earth and Atmospheric Sciences at the University of Houston has expanded its geophysical capabilities with the recent hiring of two geophysics professors: Yingcai Zheng and Will Sager. Further geophysicist hiring is underway. Dr. Stewart in the Director of AGL and Drs. Castagna, Chesnokov, Wiley, Zheng, and Zhou are associates. Other collaborators include Drs. Gennady Goloshubin, Fred Hilterman, Aibing Li, Will Sager, and Leon Thomsen. These individuals and their students bring a wealth of experience and expertise to AGL efforts.As part of a presidential initiative, the University of Houston is hiring more geoscience faculty in the coming months. We anticipate that some will undertake joint projects with AGL personnel.

Research Personnel and Expertise

The AGL group of experienced and enthusiastic geophysicists is uniquely suited to the challenge of lab-to-field experimentation, analysis, and application. They are committed to working together as a team and advancing the field of exploration geophysics. Their backgrounds and general areas of expertise are outlined below.

Investigator	General expertise
 **Robert Stewart** PhD, Massachusetts Institute of Technology Chevron, ARCO, Veritas, University of Calgary	Borehole geophysics (well logging, VSP, crosswell analysis), multicomponent seismic methods, unmanned aerial vehicles (UAVs)
 **John Castagna** PhD, University of Texas at Austin ARCO, Fusion Geophysical	Rock properties, seismic attributes, AVO
 **Yingcai Zheng** PhD, University of California Santa Cruz Postdoc, Masachusetts Institute of Technology	Global Seismology, and Seismic Wave Inversion
 **Robert Wiley** PhD, Colorado School of Mines Marathon Oil	Physical modeling, instrumentation, shallow seismic analysis
 **Fred Hilterman** PhD, Colorado School of Mines Geophysical Development Corp., Mobil	AVO, seismic processing, petrophysic
 **Leon Thomsen** PhD, Columbia University Amoco, BP, Delta Geophysics	Anisotropy, seismic processing, EM analysis
 **Hua-Wei Zhou** PhD, California Institute of Technology	Tomography, microseismic, migration
 **William Sager** Ph.D., Marine Geophysics, University of Hawaii, Hawaii Institute of Geophysics, Texas A&M University	Marine geophysics, Plate tectonics, Paleomagnetism
 **Gennady Goloshubin** PhD, Institute of Solid Earth, Moscow Western Siberian Institute	Seismic exploration, reservoir analysis, permeability prediction
 **Aibing Li** PhD, Brown University Woods Hole Institute	Seismic tomography, inversion, crustal structure
 **Evgeni Chesnokov** PhD, Moscow State University University College of London, University of Oklahoma	Theoretical seismology, anisotropy, fracture monitoring

Current Resources and Work

AGL operates a fully equipped ultrasonic modeling tank (2m x 4m x 1.5m) with acoustic and elastic measurement capability. The lab recording system has been upgraded to have a 60-channel simultaneous capability. New amplifiers and recorders are under Labview control.

We have access to the UH Texas Learning and Computation Center (TLC2). This is a first-class visualization facility for demonstrations, analysis, and development. For example, we are very interested in building tools for interactive 3D visualization of time-lapse phenomena. AGL has access to a Departmental computational network consisting of a Sun Starfire 880 server with dozens of Sun Ultra workstations augmented by a Beowolf computing cluster. Additionally, TLC2 operates a 500 CPU Titanium cluster and two 64 CPU SGI Altix clusters. We also use a wide variety of commercial software for seismic processing, imaging, visualization, interpretation, reservoir calibration, and flow simulation. AGL has a large inventory of previously shot physical and numerical modeling data sets, including the Marmousi elastic wave numerical model. These are made available to sponsors. In addition, there are several dozen industry seismic data sets currently available for processing and interpretation.

The University of Houston manages the Yellowstone Bighorn Research Association (YBRA) Geoscience Field Camp near Red Lodge, Montana. We have conducted geophysical field schools there since the summer of 2009. Students undertake experimental, hands-on acquisition of 3C seismic surveys as well as GPS, GPR, well logging, and VSP data.

A little closer to UH, we have developed a field geophysics test site (the La Marque Geophysical Observatory) on university-owned land. This facility is part of UH's Coastal Center and includes a producing oilfield. This key site is being used to test equipment, acquire repeat surveys, and conduct field schools. We recently drilled two 140m wells for VSP and logging tests, as well as monitoring experiments. We are using the site for flighing drones (unmanned aerial vehicles) and testing them that deliver seismic sensors.

AGL has a 240-channel Geometrics seismic recording system as well as 120 Geospace GSR seismic nodes. We use the PEG accelerated weight drop source and an IVI T15000 vibrator. We have a number of vertical and horizontal geophones in addition to land streamers. We also have a suite of well logging tools from Mt. Sopris as wells as VSP receivers from Geostuff. Our ground-penetrating radar equipment includes Sensors and Software's NOGGIN and Pulse EKKO systems. We use a Blastmate 4C system for vibration monitoring and a V-Meter for field testing of rock samples. In addition, we employ a Scintrex CG-5 instrument for gravity measurement. The group has recently been active undertaking sonar surveys with Edgetech and side-scan sonars.

Seismic drone system

Edge Tech sub-bottom profiling system

UH IVI T15000 vibrator

Activities and Timeline

Our goals are ambitious. Moving forward requires equipment, instruments, computers, and software. New personnel are needed to undertake research, maintain and operate equipment, as well as for administrative operations, university reporting, safety compliance, and sponsor communications. An overview of our proposed activities over the next two years is shown.

Aspect \ Time	Phase 1	Phase 2	Phase 3	Phase 4
Equipment	Vibroseis, GPR, ultrasonic upgrades	300-ch 3C seismic vibroseis; 120 land nodes	Shallow marine seismic	OBS
Facilities and software	VISTA, Petrel Kingdom, Ekos	Omega Hampson-Russell	Computer hardware upgrade	ProMax
Personnel	Application geophysicist graduate students	Administrative assistant graduate students	Post-docs graduate students	System/data geophysicists graduate students
Physical modeling	3D VSP, Crosswell Doppler sonar imaging	Microseismic, Time-lapse sand	Acoustic emission, sonar	3C-3D anisotropy fractures
Field work	Houston/local (shallow faults); Louisiana; Buoyancy NASA Nuetral Lab	Montana (deep structure); Texas crater; Utah sand	Houston/local (deeper structures)	Gulf of Mexico

Deliverables and Other Benefits

AGL aspires to make a significant impact on the science of geophysics and deliver clear benefit and advantage to our supporters. A list of deliverables and other benefits of sponsorship follows:

- All AGL-sponsored physical modeling data will be available to sponsoring organizations
- Substantial field data acquired by AGL will be available to sponsors
- All AGL-supported theses, posters, preprints, expanded abstracts, and technical papers and reports will be provided to sponsors
- Sponsor representatives will be invited to the AGL Annual Spring Meeting summarizing the year's research activities in addition to the Annual Dobrin Lecture. Each sponsor will receive the AGL Annual Report
- Each sponsor will receive periodic communication about AGL personnel, activities, and research
- Sponsors will have a voice on the AGL Industrial Advisory Board to provide guidance and counsel to the Lab
- Sponsors have the opportunity to become familiar with students (prospective staff) and their work

Results

List of previous M.S and Ph.D. thesis (2013-2016)

Author(s)	Year	Title
Aziz, A.	2016	**3D ground-penetrating radar (GPR) investigations: Buried culverts, historical graves, a sandstone reservoir analog, and an impact crater**
Ruiz, F.	2016	**Rock-physics and 3C-3D seismic analysis for reservoir characterization: Marcellus shale, Pennsylvania**
Huang, L.	2016	**Estimating seismic anisotropy: Fluid substitution theory, 3D-printed inclusion models, and multi-component 3F VSP in the Bakken shale**
Omoboya, O.	2015	**Seismic anisotropy dependence on fluids, fractures, and stress: Physical modeling with Bakken and Barnett shale field cases**
Kocel, E.	2015	**3D seismic survey design: Coil shooting, multi-component (3C) receivers with gulf of Mexico and Caribbean case histories**
Du, Y.	2015	**Borehole seismic analysis: Up and downward continuation, migration velocity updating, and a Bakken shale case history**
Hyslop, C.	2015	**Imaging and inversion of reflected surface waves**
Zong, J.	2014	**Elastic properties of salt: Laboratory measurements, well-log analysis, and a seismic survey over the Hockley salt mine, Texas**
Coskun, S.	2014	**3-D seismic survey design via modeling and reverse time migration: Pierce Junction salt dome, Texas**
Akbas, O.	2013	**Microseismic monitoring: Physical modeling and source characterization**
Zhang, M.	2013	**S-wave velocity estimation using converted-wave VSP data**
Roy, S.	2013	**Near-surface characterization via seismic-wave inversion**
Turolski, A.	2013	**Near-surface geophysical imaging of complex Structures: Meteor Crater, AZ and Jemez Pueblo, NM**
Mukherjee, T.	2013	**Time-lapse scenario modeling and VSP analysis for an EOR reservoir in Oman**

The Allied Geophysical Lab (AGL) Vision

Our goal is to do excellent applied geophysical research!

We are dedicated to making significant advances in the understanding and imaging of the subsurface. We work with the resource industry and professional societies to create novel ways to discover and conscientiously recover resources while educating the next generation of geoscientists.

Scope of Work

At AGL, we emphasize the physics behind making geologic images of the subsurface. This involves three main categories: Acquisition, analysis, and interpretation of largely seismic data. A key component of our effort is to make geophysical measurements in the laboratory, computer, and field. We have one of the few physical, robotic modeling facilities in the world dedicated to making scaled surveys of structures of energy interest. We employ novel methods of laser etching, molding, and 3-D printing to create novel models of resource interest. In addition, we write and employ a number of numerical modeling codes. Furthermore, we have an excellent capability to acquire near-surface geophysical data (seismic, VSP, well logs, GPS, GPR, and gravity.) The University owns a section of land near Galveston that we have developed as a geophysical test site (the La Marque Geophysical Observatory) which includes the recently drilled 140m boreholes. UH also manages a 100-person geoscience field camp near Red Lodge, Montana for the education of students in field methods.

On the processing and analysis side, we develop algorithms related to the imaging and understanding of geophysical data. We also use many of the industry standard processing codes (Paradigm, VISTA, Petrel, Kingdom). Our particular expertise is in multicomponent seismic analysis, seismic attributes, borehole seismic, AVO, quantitative interpretation, attenuation, and anisotropy. We are involved with a number of case histories including resource targets in the Barnett, Bakken, Marcellus, and Pimienta shales. In addition, we have numerous studies relating to VSP and 3D (several 4C) seismic data sets in the Gulf of Mexico. Along with our seven close faculty (Stewart, Zheng, Wiley, Thomsen, Chesnokov, Zhou, and Castagna), we have some 40 graduate students and staff attached to our applied geophysics effort. We are enthusiastic about working with our geophysical societies and industry partners!

How to Supporrt AGL

- Consortium membership
- Confidential or open research contract
- Student fellowship
- Donations

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