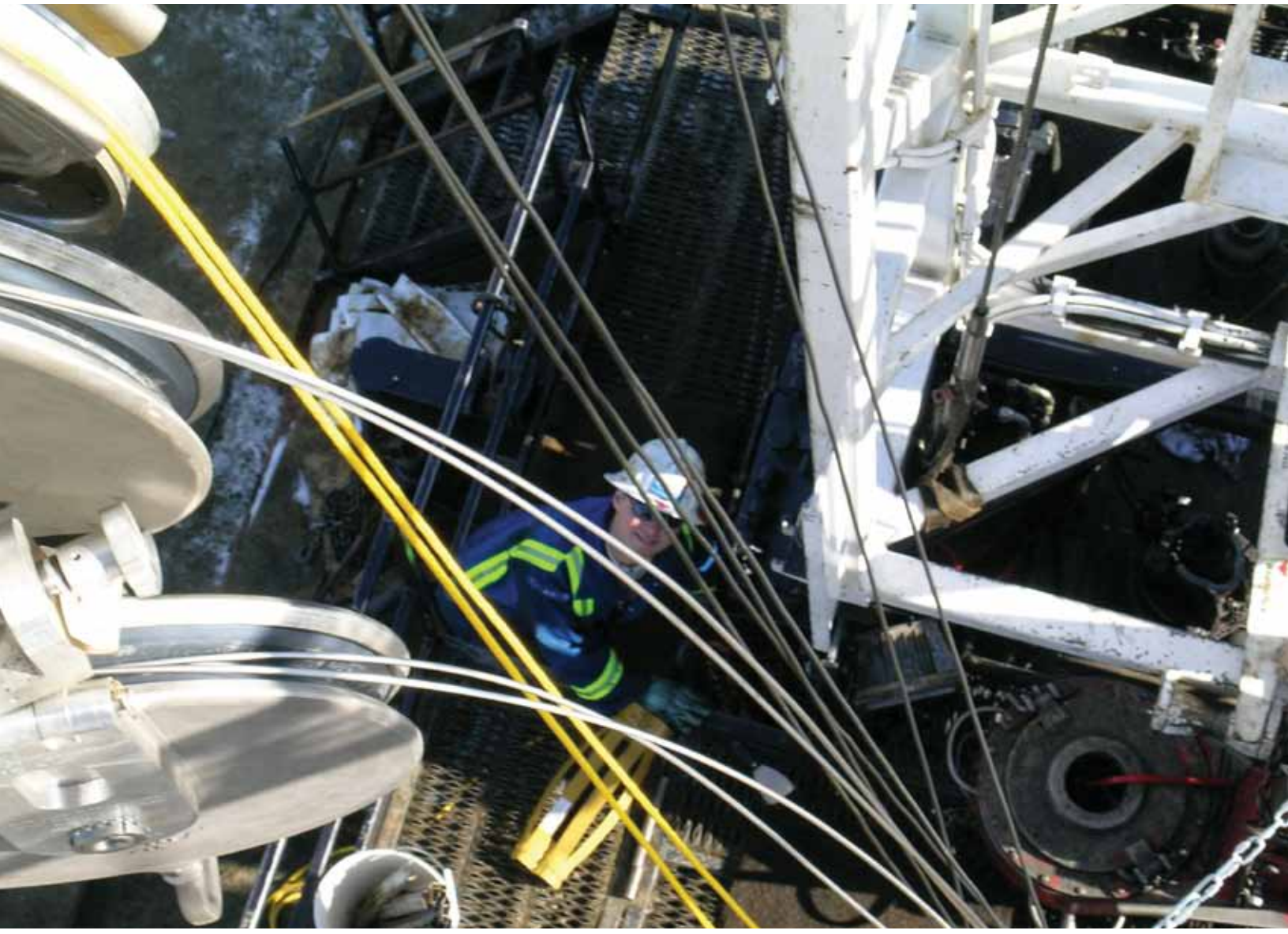
A Consortium Proposal by the

Allied Geophysical Laboratories

Full-wave Seismic Exploration for Reservoir Lithologies and Fluids

From Lab to Oilfield



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Allied
Geophysical
Laboratories

A Proposal Submitted to a Consortium of Companies by the

Allied Geophysical Laboratories (AGL) University of Houston

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Annual sponsor contribution $45, 000

Summary

This proposal outlines plans for the research and educational efforts of the new 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. The proposed program will be based on a number of data acquisition and analysis projects directed at improved imaging and analysis of subsurface reservoirs. Research will be driven by ideas and data: novel concepts about acquisition, wave propagation, and imaging in increasingly realistic media will be developed and tested via lab and field experiments. Existing advanced data sets, especially full-wave 3D seismic surveys, will be 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 will investigate non-linear imaging concepts in porous fluid-saturated media under controlled lab conditions, including direct imaging of hydrocarbon movement and production through time-lapse models.

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 under development. 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. 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 propose to undertake a problem-driven field program addressing fundamental issues of data acquisition, subsurface imaging, and analysis.

Theory and processing

Analysis of field and lab data will spur development of custom algorithms while data preparation and processing will 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) with co-investigators Drs. John Castagna, Evgeni Chesnokov, Robert Wiley, and Hua-Wei Zhou are delighted to welcome distinguished colleagues Drs. Gennady Goloshubin, De-hua Han, 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 anticipate that 25 more will be supported annually. 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. The sponsorship fee is US $45,000.

Overview

Geophysical science and resource exploration begin with the acquisition of data. In the new 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 anticipate collaboration with a number of our sponsoring companies and analysis of their existing data sets. These measurements will be processed through various standard and custom algorithms and procedures, then interpreted. On the other hand, we expect to develop novel ideas about wave propagation and imaging in increasingly complex materials that will be 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 Commercialization or transfer of 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.

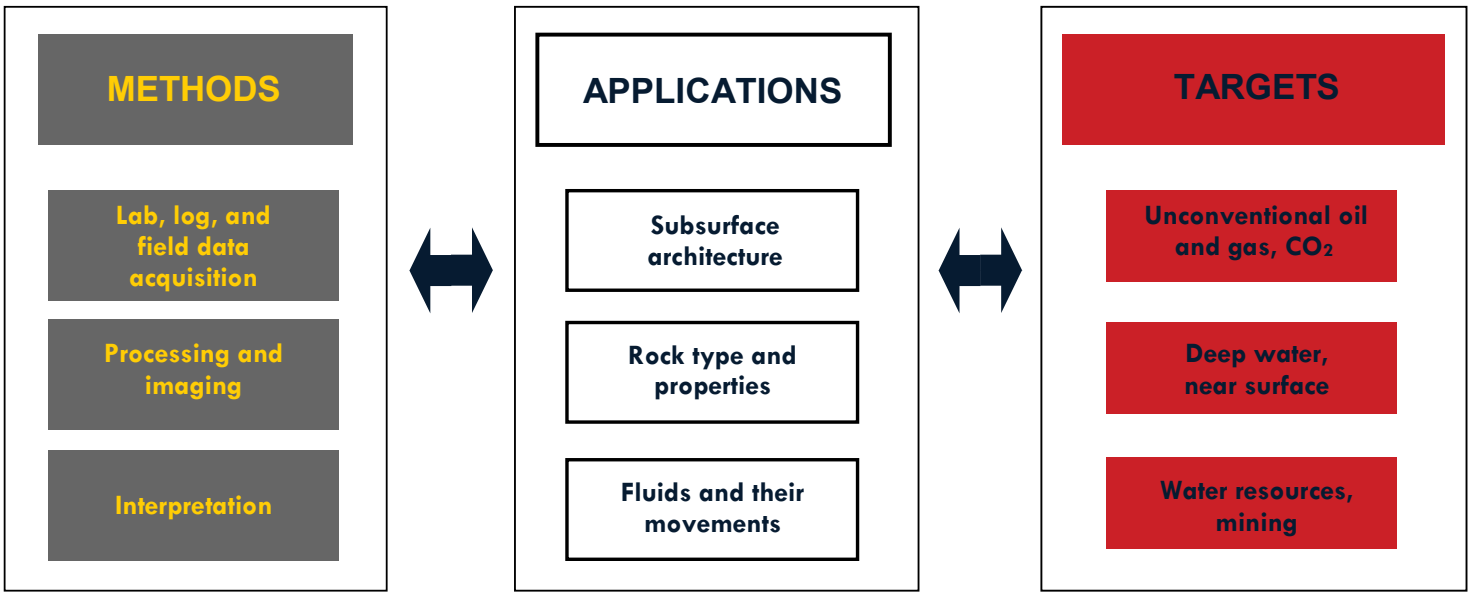

Figure 1.
Schematic overview of the elements of this proposal including methods, their applications, and specific resource targets

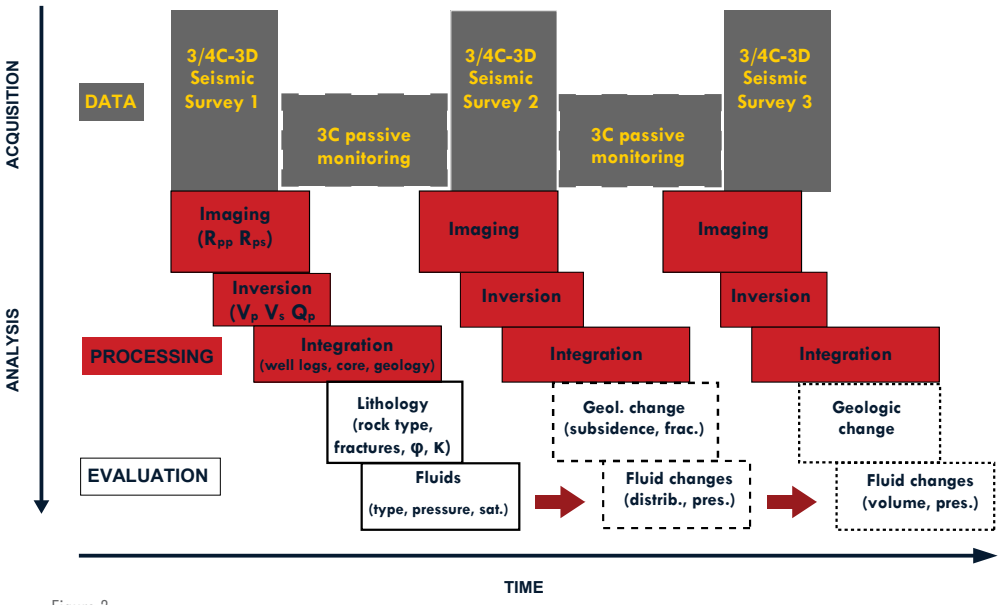

Figure 2.
Schematic diagram of full-wave seismic methodologies to assess reservoir rock and physical model properties, fluids, and their changes

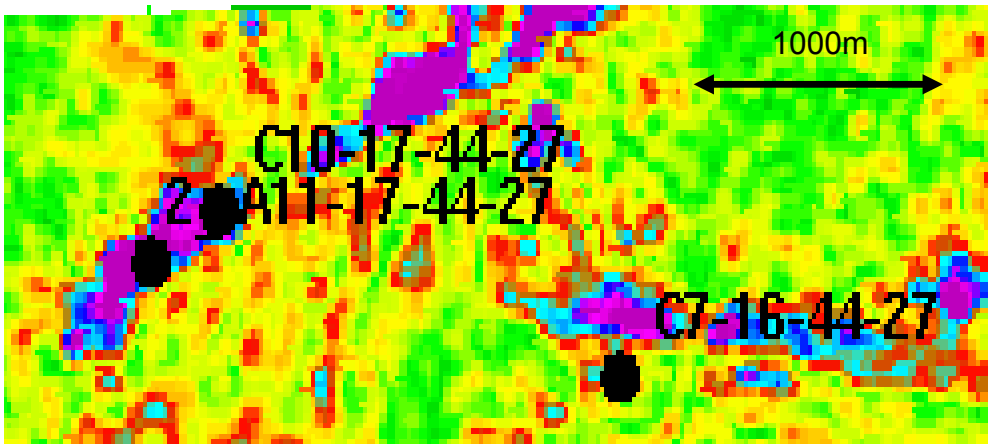

Figure 3.
Amplitude time slice from a 3C–3D seismic volume on a sand channel (Varga and Stewart, 2009, Delineating sand channels using 3C-3D seismic data, Manitou Lk. heavy oil field, Can. Soc. Expl. Geophys. Ann. Mtg.)

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 will 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 New Allied Geophysical Lab

The original Allied Geophysical Lab came to life under the tutelage of Dr. Fred Hilterman some 30 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 plan to carefully collect and thoroughly analyze a wide variety of geophysical data, from the lab to field scale. The Department of Earth and Atmospheric Sciences at the University of Houston is broadly expanding its geophysical capabilities with the recent hiring of two geophysics professors: Hua-Wei Zhou and Will Sager. Dr. Stewart was appointed as Director of AGL and Drs. Castagna, Chesnokov, Wiley, and Zhou are co-investigators. Collaborators include Drs. Gennady Goloshubin, De-hua Han, 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 is hiring three 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
	**John Castagna** PhD, University of Texas at Austin ARCO, Fusion Geophysical	Rock properties, seismic attributes, AVO
	**Evgeni Chesnokov** PhD, Moscow State University University College of London, University of Oklahoma	Theoretical seismology, anisotropy, fracture monitoring
	**Gennady Goloshubin** PhD, Institute of Solid Earth, Moscow Western Siberian Institute	Seismic exploration, reservoir analysis, permeability prediction
	**De-hua Han** PhD, Stanford University Unocal, HARC	Laboratory rock properties, seismic monitoring
	**Fred Hilterman** PhD, Colorado School of Mines Geophysical Development Corp., Mobil	AVO, seismic processing, petrophysics
	**Aibing Li** PhD, Brown University Woods Hole Institute	Seismic tomography, inversion, crustal structure
	**Leon Thomsen** PhD, Columbia University Amoco, BP, Delta Geophysics	Anisotropy, seismic processing, EM analysis
	**Robert Wiley** PhD, Colorado School of Mines Marathon Oil	Physical modeling, instrumentation, shallow seismic analysis

Current Resources and Work

AGL operates a fully equipped ultrasonic modeling tank (2m x 4m x 1.5m) with acoustic and elastic measurement capability. Dr. Robert Wiley is currently conducting a 3D VSP survey in the Vinton Dome model (Figure 4) simulating a wide-azimuth field experiment. 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 will be made available to sponsors. In addition, there are several dozen industry seismic data sets currently available for processing and interpretation.

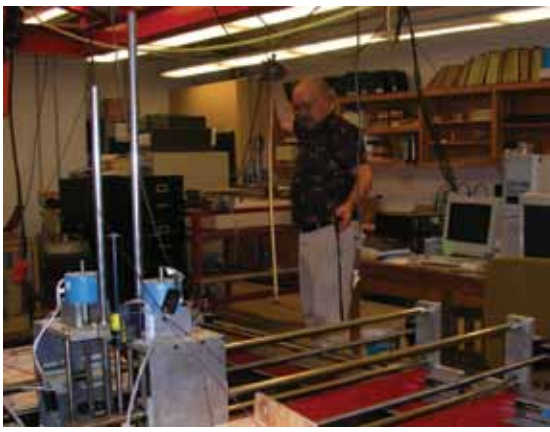

Figure 4.
Physical modeling facility at AGL with Dr. Wiley configuring the Vinton Dome 3D VSP model

The University of Houston manages the Yellowstone Bighorn Research Association (YBRA) Geoscience Field Camp near Red Lodge, Montana (Figure 5). We have conducted the 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. We return to YBRA annually in August.

A little closer to UH, we are developing 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 (Figure 6). This key site is being used to test equipment, acquire repeat surveys, and conduct field schools. We recently drilled two wells for VSP and logging tests, as well as monitoring experiments.

Figure 5.
Classroom at the YBRA field site
(photo by Mike Murphy)

AGL has a 200-channel Geometrics seismic recording system as well as a 300-channel I/O system. We use the PEG accelerated weight drop source and an IVI T15000 vibrator. We have a number of vertical and 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.

Figure 6.
UH minivibe and logging equipment at the La Marque Geophysical Observatory well site

Specific Research Topics

Investigator	Topics
Robert Stewart 20 students	Microphones and geophones; 3C land processing; MEMS response; surface-wave inversion; full-wave case histories; microseismic monitoring (Figure 7)
John Castagna 5 students	Spectral decomposition and AVO, rock physics
Evgeni Chesnokov 5 students	Wave propagation in anisotropic media, fracture characterization, hypocenter location
Gennady Goloshubin 2 students	Waves in porous media and 3C seismic analysis, permeability studies
De-hua Han 2 students	Seismic monitoring and rock properties
Fred Hilterman 2 students	AVO and attributes
Aibing Li 2 students	Surface-wave inversion, 3C continuous monitoring, microseismic analysis
Will Sager 2 student	Marine geophysics, potential fields, seismic interpretation
Leon Thomsen 2 students	Anisotropy and rock properties
Robert Wiley 2 students	Physical modeling: Vinton Dome 3D VSP and RVSP, anistropic fault 3C-3D
Hua-Wei Zhou 2 students	Tomography, microseismic, migration

Figure 7.
Testing true amplitude seismic response in the field to calibrate monitoring instruments

Activities and Timeline

Aspect \ Time	Phase 1	Phase 2	Phase 3	Phase 4
Equipment	200-ch seismic, GPR, ultrasonic upgrade, GPS, microphones	300-ch 3C seismic vibroseis; 120 land nodes	Shallow marine seismic	OBS
Facilities and software	VISTA, Petrel Kingdom	Transform, Focus Hampson-Russell	Computer hardware Upgrade	ProMax
Personnel	Aplication geophysicist	Administrative assistant	Post-docs	System/data geophysicists
Physical modeling	3D VSP, fracture, fault	Time-lapse sand	3C structure nonlinear	3C-3D anisotropy
Field work	Houston/local (shallow faults); Louisiana; Haiti	Montana (deep structure); Texas crater; Utah sand	Houston/local (deeper structures)	Gulf of Mexico (shallower tests)

Our goals are ambitious and moving forward will require sponsorship for the purchase of 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 is shown above.

Deliverables and Other Benefits

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

- All AGL-sponsored physical modeling data will be available to sponsoring organizations
- All 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 Graphics 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

Budget Overview

In this period, we intend to purchase a substantial amount of geophysical equipment. To date, the University of Houston has provided $1,500,000 toward this effort and will expend another $300K. We seek further contribution from the industry and various other agencies. Equipment purchases are to upgrade the existing physical modeling facility as well as provide an augmented field acquisition and data processing capability. Our first step was a portable seismic system, but we continue to work toward assembling a full industry-standard land and marine system. Other supporting equipment includes GPS, well-logging, VSP, CG-5 gravimeter, and GPR instruments.

Budget	Expenses	Revenue
Equipment, instruments, computers	$410,000	
Personnel salaries	$400,000	
Field work, travel, communication	$115,000	
University, state, federal contribution (cash)		$385,000
Industry sponsorship (cash)		$540,000
Total	$925,000	$925,000

Lab Instruments Transducers, A/D converters, controllers, lasers, software $75k
Field Equipment 100-channel seismic recorder (Geometrics/Geodes), cables and 3C geophones $85k, GPS $25k, Well Logging tools, cable, winch and truck $80k, VSP tools, cable, and recorders $20k, 120 seismic recording nodes $50k
Computers Hardware, software, and visualization $75k
Personnel Five(s) graduate students $150k, Four technical staff $250k
Field Work Survey travel $45k
Travel Conferences, meetings, courses $20k
Communication Publication costs, newsletters, seminars, meetings $50k

Total expenses - $925K

We require a number of additional staff to operate and maintain the various computer and measurement systems as well as facilitate research. We anticipate hiring four staff. They would include a geophysical technician, geophysics postdoctoral fellow, system and data manager, and an administrative assistant. We seek AGL industrial sponsors from the energy, mining, engineering and related sectors. Annual sponsorship cost is $45K. A reduced rate of $15K is available for smaller enterprises (under $5 million annual revenue). We anticipate that this support and collaboration will arise primarily from the energy industry. We also offer a limited number of Founding and Sustaining Memberships that allow more direct involvement and impact on the future of AGL and its people.

Contact director Robert Stewart for further information.

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Allied Geophysical Laboratories

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. Specifically, we will 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. 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 are developing 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 (mostly seismic) 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, and Marcellus 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 five closely associated faculty (Stewart, Thomsen, Chesnokov, Zhou, and Castagna), we have some 70 graduate students and staff attached to our applied geophysics effort. We are enthusiastic about working with our industry partners!

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