Summer of Applied Geophysical Experience (SAGE)
SEG Foundation, Projects of Merit
Field Camp Report – SAGE 2010

Lawrence W. Braile, PI
Professor, Purdue University
SAGE Co-Director

June 20, 2011

1. Introduction (SAGE 2010):

A. The SAGE Program: SAGE is a unique program of education and research in geophysical field methods for undergraduate and graduate students from any university and for selected professionals. The core program is held for four weeks each summer in New Mexico and for an additional week in the following academic year at San Diego State University for U.S. undergraduates supported by NSF. Each year approximately 26-30 students participate in SAGE after being selected from a wide range of large and small colleges and universities. Most students are from U.S. institutions; however, every year several students attend from foreign universities or institutions. The program teaches digital acquisition, theory and methods of exploration geophysics, and team-based interpretation of results using computer modeling. Techniques taught are seismic reflection and refraction, potential field methods (gravity and magnetics), electrical and electromagnetic methods, and high resolution GPS surveying. Geophysical field applications include extensional tectonics, basin analysis, environmental remediation, archeology, and hydrogeology. All SAGE students present final results in oral and written form following SEG guidelines. Five SAGE 2010 students, two former SAGE REU (NSF-supported Research Experience for Undergraduates) students, one graduate student and six SAGE faculty were co-authors on poster presentations at the 2010 San Francisco AGU meeting. Five of these students were also supported by the NSF REU funds to attend these professional meetings and present the posters, thus contributing to the students' professional development. In addition, an abstract (three SAGE REU student authors, one SAGE graduate student author and two SAGE faculty authors) based on SAGE 2010 research has been submitted for presentation at the 2011 SEG meeting.

SAGE 2010 took place in Santa Fe, New Mexico from June 16 through July 11. Twenty-six students attended the geophysics field camp. The 26 students came from 22 different schools in the U.S., Ireland, and New Zealand (15 different US schools for the 17 REU students). Nineteen students (including 2 TAs who are former SAGE REUs) were supported by the NSF REU (Research Experiences for Undergraduate) program. Additionally, there were 9 graduate students and 6 high school and college students from local New Mexico tribes who attended a portion of SAGE 2010. All SAGE students were involved with every phase of the hands-on collection, analysis, and interpretation of all geophysical data. They completed the SAGE program by presenting a research paper orally and in written form following the style used for the SEG annual meeting and extended abstracts, respectively. Fourteen of the REU students attended a week-long, follow-up workshop in San Diego in January 2011 where they continued SAGE data analysis at a more advanced level.

Near-surface geophysical measurements (ground penetrating radar, hand-held electromagnetics, hammer refraction seismics, and magnetics) were employed during the summer at an archeological site on the abandoned San Marcos Pueblo. This was followed by groundwater/structural basin studies on the Cochiti and Santo Domingo Pueblos. These studies utilized global positioning surveying, gravity, magnetics, vibroseis refraction and reflection seismics, transient electromagnetics, and magnetotellurics.

Eleven professional visitors attended SAGE 2010. These visitors presented lectures, furnished equipment and software, and described current industry trends and job opportunities. The visitors represented mining geophysics and equipment manufacturing/contractors (Zonge Engineering and Research, Sensors and Software, URS Corporation, and Green Engineering), the oil industry (Chevron, ExxonMobil and ConocoPhillips), and government organizations (Los Alamos National Laboratory and U.S. Geological Survey). Geophysical equipment was loaned to SAGE by Geometrics, Geonics, and Sensors and Software. ION Geophysical Corporation (now INOVA) provided the vibroseis source and multichannel seismic recording system.

2. Project Participants - 2010:

- Senior Personnel:

Lawrence W. Braile (SAGE Co-Director), Professor, Dept of Earth & Atmospheric Sciences, 550 Stadium Mall Drive, Purdue University, West Lafayette, IN 47907-2051, braile@purdue.edu

Scott Baldridge (SAGE Co-Director), Los Alamos National Laboratory, EES-11, MS-D462, Los Alamos, NM 87545, sbaldridge@lanl.gov

Shawn Biehler, Professor Emeritus, UCR, 171 E. Blaine Street, Riverside, CA 92507, biehler@ucr.edu

John F. Ferguson, Professor, Geoscience Program, University of Texas at Dallas, Box 688, FO2.1, Richardson, TX, 75080, ferguson@utdallas.edu

George Jiracek, Professor, Dept. of Geological Sciences, San Diego State University, 5500 Campanile Drive , San Diego, CA 92182-1020, jiracek@moho.sdsu.edu

Louise Pellerin, Green Engineering, 2215 Curtis Street, Berkeley, CA 94702, pellerin@ak.net

Derrick Hasterok, Post-Doc, UCSD, La Jolla, CA 92093, dhasterok@gmail.com

- Other Senior Personnel (participating during part of the SAGE program)

Gary Geernaert, IGPP Director, Los Alamos National Laboratory; Aviva Sussman, Los Alamos National Laboratory; Darcy McPhee, U; S, Geological Survey; Paul Bedrosian, U; S, Geological Survey; Cathy Snelson, National Center for Nuclear Security (NCNS).

- ## SAGE 2010 Students

SAGE 2010 Students Name / Phone	7/4/2010 Address	Institution	Email	Gen-der	UGS/ Grad	Citizen-ship	BS/BA Date	Updated Status
BLOSS, Ben (720) 951-1660	613 1/2 North St. Boulder, CO 80304	U. of Colorado	benjamin.bloss@colorado.edu	M	UGS/ REU	U.S.	May, 2011	BS May, 2011, Geophysicist, USGS
CHANG, Jason (415) 218-8376	95 Sugar Hill Dr., Hillsborough, CA 94010	U. Cal. Berkeley	chang.jasonp@gmail.com	M	UGS/ REU	U.S.	May, 2010	Grad. School, Fall 2011, Stanford Univ.
CHRISMAN, Bobby (269) 760-9814	Dept. Geol. Sci., Natural Sci., East Lansing, MI 48824	Michigan State U.	bbchrisman@gmail.com	M	UGS/ REU	U.S.	May, 2011	Applied to Grad School
FABIAN, Amanda (609) 575-1356	1400 Greene St., USC Box 80312, Columbia, SC 29225	U of South Carolina	amanda.fabian27@gmail.com	F	UGS/ REU	U.S.	May, 2011	Grad. School, Fall 2011, Wash. U., St. Louis
HARDWICK, Christian	Geol. & Geophys. 115 S. 1460 E. Salt Lake City, Utah 84112	U. of Utah	backcountryice@gmail.com	M	UGS/ REU	U.S.	Aug., 2010	Grad. School, Fall 2010, Univ. of Utah
LINDSEY, Nathaniel (315) 729-9889	CPN Box 273614 Rochester, NY 14627	U. of Rochester	nathaniel.j.lindsey@gmail.com	M	UGS/ REU	U.S.	May, 2011	Applied to Grad School
MARTIN, Christopher (619) 694-7254	Dept. Geol. Sci., SDSU 5500 Campanile Dr. San Diego, CA 92182	San Diego State U.	martin64@rohan.sdsu.edu	M	UGS/ REU	U.S.	Dec., 2010	Applied to Grad School
MURILLO, Israel (209) 585-6495	One University Circle Turlock CA 95382	Cal. State U., Stanislaus	ellmurillo@yahoo.com	M	UGS/ REU	U.S.	Dec., 2011	Completing BS degree
NEDORUB, Olga (941) 421-6186	3339 Handy Rd #116 U. of S Florida, Tampa, FL 33618	U. South Florida	onedorub@mail.usf.edu	F	UGS/ REU	PR - U.S. Russian	Dec., 2010	Grad. School, Spring, 2011, Univ. of S. Carolina
NOWICKI, Anna (616) 250-0810	Dept. Geol. Sci., Natural Sci., East Lansing, MI 48824	Michigan State U.	nowick28@msu.edu	F	UGS/ REU	U.S.	May, 2011	Grad. School, Fall 2011, Indiana Univ.
PHRAMPUS, Benjamin (254) 710-2361	Dept. Geol., Baylor U., One Bear Pl. #97354 Waco, TX 76798	Baylor U.	ben_phrampus@baylor.edu	M	UGS/ REU	U.S.	May, 2011	Applied to Grad School
STRADER, Anne (301) 417-1568	P.O. Box 15 Braddock Hts., MD 21714	Bucknell U.	astrader@ucla.edu	F	UGS/ REU	U.S.	May, 2010	Grad School, Fall 2010, UCLA
TALLAKSEN, Kate (304) 292-3625	Dept. Phys., Hodges Hall, Morgantown, WV 26506	W. Virginia U.	ktallaks@mix.wvu.edu	F	UGS/ REU	U.S.	May, 2012	Senior year, Physics, B.S. exp., May 2012
THOMAS, Trevor (213) 880-2696	2646 Menlo Ave. Los Angeles, CA 90007	U. Southern California	twthomas@usc.edu	M	UGS/ REU	U.S.	Dec., 2010	B.S. Dec., 2010, Grad. School, Fall, 2011, U. Wis.
TURSACK, Emily (610) 457-7985	69 Brown St., Box 4115 Providence, RI 02912	Brown U.	emily_tursack@brown.edu	F	UGS/ REU	U.S.	May, 2011	Applied to Grad School
WILLIS, Hobart (435) 722-7383	115 S 1460 East, Sutton Bldg., Salt Lake City 84112	U. of Utah	hobie.willis@gmail.com	M	UGS/ REU	U.S.	May, 2011	Applied to Grad School
ZIMINSKY, Mark (914) 645-3051	75 Park Dr. Mt. Kisco, NY 10549	Binghamton U.	mzimins1@gmail.com	M	UGS/ REU	U.S.	Aug., 2010	Geophysicist, Zonge International
BROWNING, Joel Matt (214) 909-0053	Geosciences, F021 800 W. Campbell Rd. Richardson, TX 75080	U. of Texas Dallas	jmb080100@utdallas.edu	M	Grad	U.S.		Continuing Grad. Program
KHOZA, David 353-0-87-412-0607	5 Merrion Square Dublin, Ireland	DIAS	davidkhoza@cp.dias.ie	M	Grad	South Africa		Continuing Grad. Program

McMULLEN, Melissa (734) 904-8486	Earth and Atmos. Sciences 550 Stadium Mall Dr. West Lafayette, IN 47907	Purdue U.	mmcmulle@purdue.edu	F	Grad	U.S.		Continuing Grad. Program
PERA, Amanda (408) 439-3603	37196 Talbert Terrace Fremont, CA 94536	San Jose State Univ.	amandaapera@gmail.com	F	Grad	U.S.		Continuing Grad. Program
REMPE, Daniella (512) 653-6726	269 C McCone Berkeley, CA 94720-4767	U. of Cal. Berkeley	daniella.rempe@berkeley.edu	F	Grad	U.S.		Continuing Grad. Program
SUWANNASRI, Krongrath (512) 965-4414	Geological Sciences 1 University Station Austin, TX 78712-0254	U. of Texas	krongrath@yahoo.com	M	Grad	Thai-land		Continuing Grad. Program
THAPALIA, Anita (713) 835-8056	Geological Sciences 500 N. University Ave. El Paso, TX 79968	U. of Texas El Paso	athapalia@miners.utep.edu	F	Grad	Nepal		Continuing Grad. Program
UNGLERT, Katharina 64-21-1748910	SGEES, Victoria University P.O. Box 600 Wellington, New Zealand	Victoria U. Wellington	kathiunglert@gmail.com	F	Grad	Germa n		Continuing Grad. Program
VALDES, Jessidee (305) 467-1556	Geosciences, F021 800 W. Campbell Rd. Richardson, TX 75080	U. of Texas Dallas	jxv080020@utdallas.edu	F	Grad	U.S.		Continuing Grad. Program

3. <u>Organizational Partners</u> (SAGE 2010):

SAGE and the REU students benefit greatly from the program's organizational partners, including industry partners who support the program financially and with in-kind contributions such as providing equipment or software, and attending and giving talks at SAGE and interacting with students. The organizational partners also play a major role in providing career information, contacts and networking for the REU students. The organizational partners in 2010 were: the institutions of the senior personnel; IGPP, Los Alamos National Laboratory; U S Department of Energy; Society of Exploration Geophysicists; U S Geological Survey; Green Engineering; INOVA Geophysical; Chevron; ExxonMobil; Geometrics; Zonge Engineering; Sensors and Software; URS Corporation; Archaeological Conservancy; Cochiti Pueblo; Santo Domingo Pueblo; Parallel Geosciences; Geonics, Geosoft, and Geosystem Software.

4. <u>SAGE 2010 Accomplishments and Findings</u>:

Some research highlights of results from SAGE 2010 are provided here:

SAGE 2010 Geophysics Highlights

Introduction: SAGE 2010 was the 28th year of the SAGE program. Twenty-six students (17 undergraduate and 9 graduate students) participated in SAGE 2010 in the Rio Grande rift area of New Mexico. Geophysical field work (2 days of near-surface geophysics at an archeological site and 5 days of basin-scale geophysics near the eastern edge of the Santo Domingo basin) provided significant new seismic refraction and reflection, electromagnetic, ground penetrating radar, magnetic and gravity data. All students gained experience with the theory and principles of applied geophysical techniques and with all of the geophysics field equipment and methods as well as surveying for accurate gravity station locations using differential GPS. SAGE 2010 also included three days of geology field trips, one day of seismic basin analysis (a short course presented by Orla McLaughlin and Ben Sanderson of ExxonMobil) and five days of data processing, modeling, interpretation, and written and oral report preparation. The last two days of the program were devoted to student presentations of their research results. Each student selected at least one geophysical technique and data set for a research project. The students were also organized into teams (each of the five teams included the various geophysical methods) and presented their individual and integrated interpretations of the SAGE 2010 data.

Highlights of some of the SAGE 2010 data and interpretations are shown below (and online at http://web.ics.purdue.edu/~braile/sage/SAGE2010Highlights.pdf).

CMP Seismic Reflection Profile: Common Midpoint (CMP) seismic reflection data were collected along an approximately east-west profile (Figure 1) near the eastern boundary of the Santo Domingo basin in the Rio Grande rift of New Mexico. The data were collected using a vibroseis source (vibroseis truck provided by INOVA) with an 8-80 Hz sweep at Vibrator Points (VP) spaced at 20 m along the profile. The recording equipment consisted of eighty 10 Hz, 3-component geophones connected by cables and digital telemetry along a communications cable to a recording truck. Data were recorded on an ARAM (division of INOVA) digital recording system. The profile began just west of the La Bajada fault (Figure 1) and refraction and near-vertical and wide-angle reflection data were recorded by vibrating into the active array in both directions.

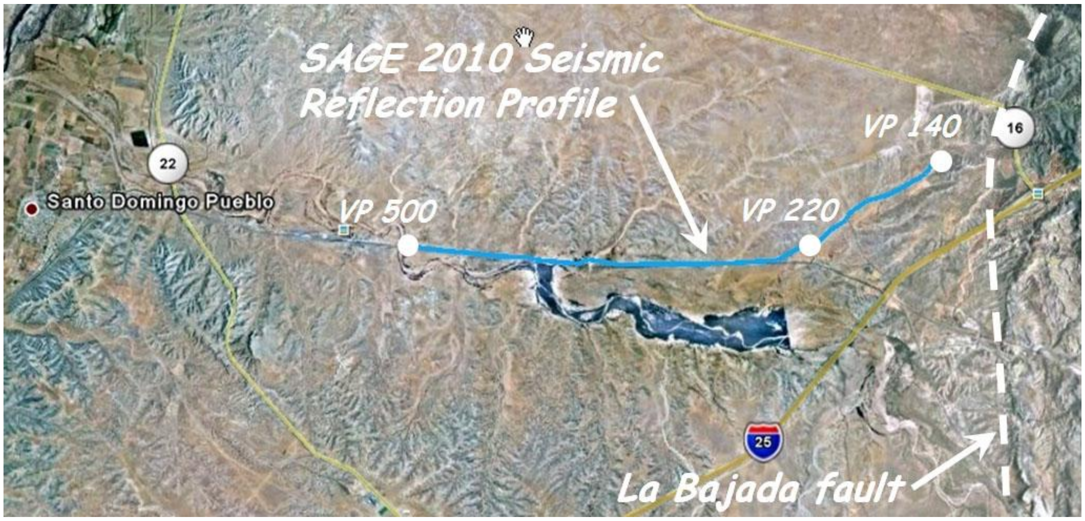

Figure 1. Map of SAGE 2010 field area showing the location of the seismic reflection and refraction profile.

Nine SAGE 2010 students focused on seismic data for processing and interpretation. CMP reflection processing was performed using the SPW (Seismic Processing Workshop, Parallel Geosciences) processing software. The processing included assigning geometry, merging shot gathers, trace kills, notch and bandpass filtering, deconvolution, velocity analysis, CMP sorting, muting, NMO correction and CMP stacking. Reprocessing with improved velocity models was also accomplished by students attending the SAGE one-week follow-up workshop held in San Diego (San Diego State University) in January, 2011. The reprocessed record section is shown in Figure 2. Reflections from a thick section of east-dipping sedimentary layers are well-imaged the section. Wide-angle data collection and recording with VPs both east and west of the active 80-channel array allowed the imaging of reflections from the La Bajada fault plane indicated by the steep, west-dipping reflections on the eastern part of the record section. This section is not migrated; however, our preliminary analysis of migration of this fault plane reflection and taking into account that our profile (near the eastern end) is not perpendicular to the fault, indicates that the true dip of the fault is close to 60 degrees. Another observation from the reflection record section is that the shallow sedimentary layers dip into the fault and thicken toward the fault, indicating that the fault was active during the time of deposition of these units. We have recorded other reflection profiles over the La Bajada fault and also have some industry record sections that cross this fault, so we now have a very good understanding of this fault which has up to 3000 meters of throw. During SAGE 2011, we will work to the west of the 2010 profile and expect to cross the San Francisco fault that also shows a down to the west offset and deepening of the Santo Domingo basin to the west. This conclusion is supported by the updated SAGE gravity map discussed below.

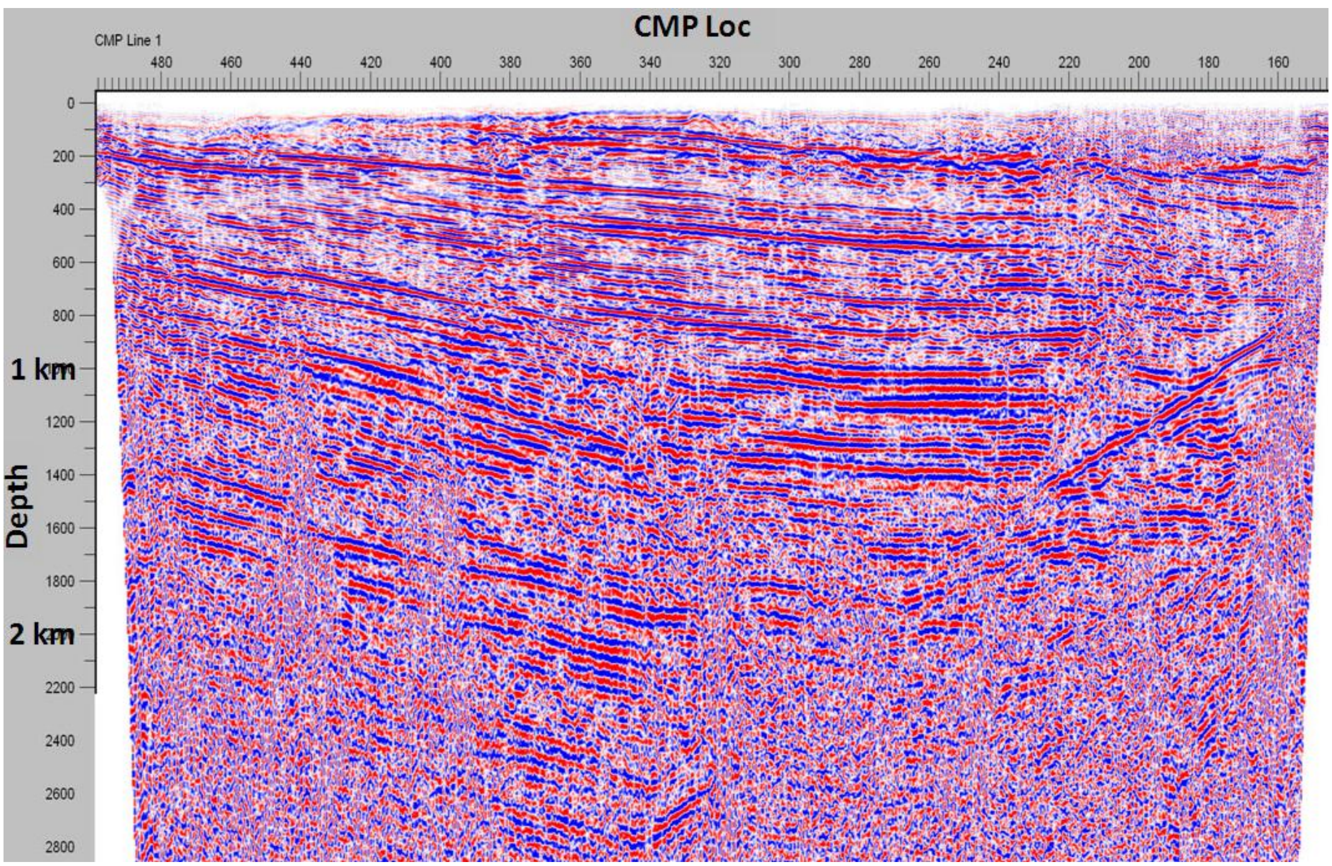

Figure 2. SAGE 2010 west-to-east CMP processed and stacked seismic reflection record section. Seismic data were recorded at a 20 m group interval from a vibroseis source with a sweep of 8-80 Hz. Seismogams plotted as a function of depth (conversion from two-way-time using derived velocity model).

Gravity Data Collection and Interpretation: Over 150 gravity readings were collected during SAGE 2010. Locations of gravity stations were determined from differential GPS measurements. The 2010 data were combined with previous SAGE gravity data and stations from the U.S. Geological Survey, the Department of Defense and the New Mexico Bureau of Mines to produce the complete Bouguer anomaly contour map shown in Figure 3. Gravity modeling, with control from surface geology, sedimentary unit structure and fault offsets from seismic profiles has been very useful in determining depth to basement (at least 3 km) in the Santo Domingo basin and other areas of the Rio Grande rift in the study area.

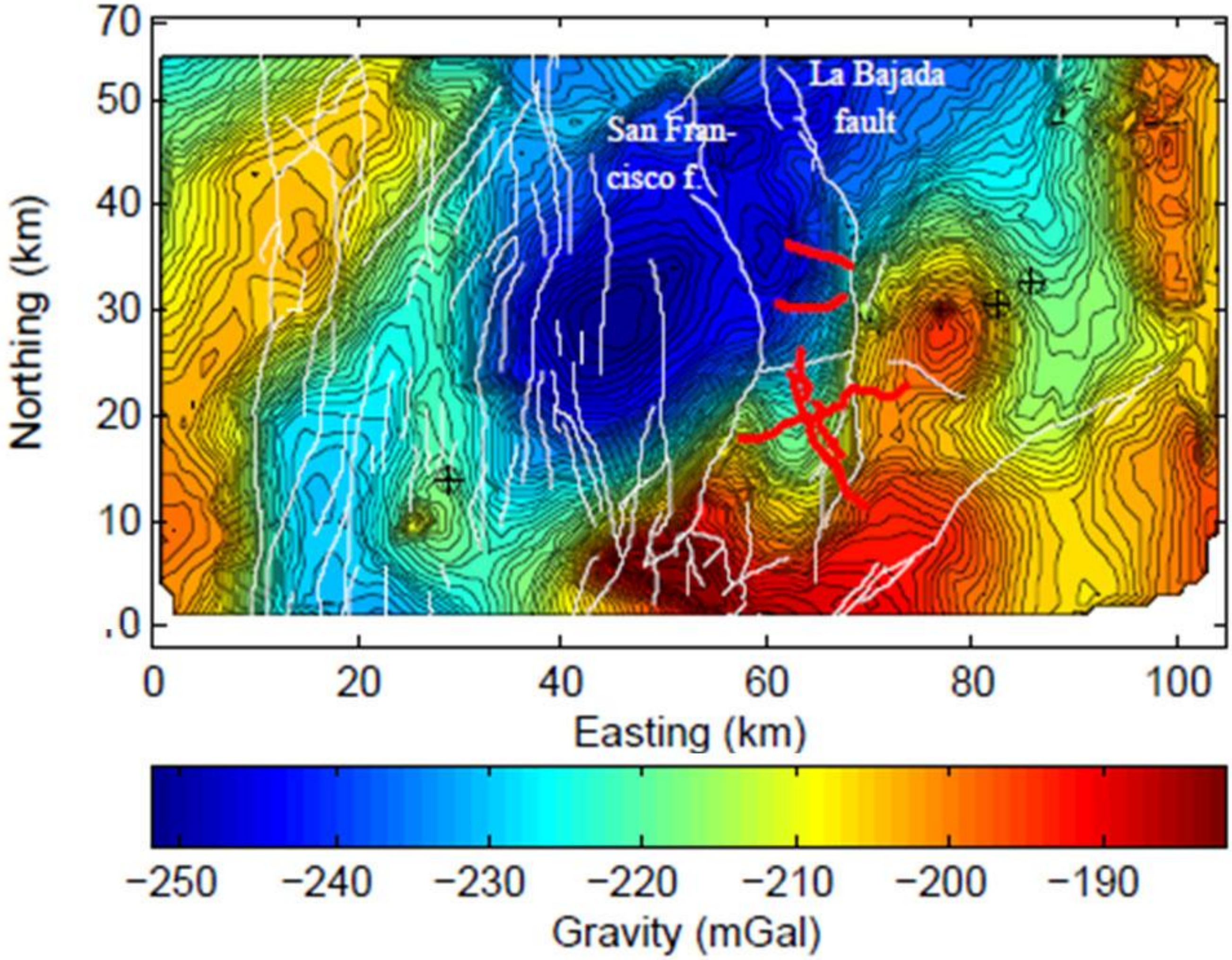

Figure 3. Complete Bouguer gravity map of the Santo Domingo basin area. Contour interval is 1 mGal. Thin white lines are faults. Bold red lines are seismic profiles. The SAGE 2010 seismic reflection profile is the second bold red line from the top.

Electromagnetic Data Collection and Interpretation: All 26 students in the SAGE class of 2010 participated in field work learning principles and operation of seismic, gravity, ground penetrating radar, and several electromagnetic (EM) techniques. Four students worked on processing and interpreting transient electromagnetic (TEM) data, and five on magnetotelluric (MT) and audiomagnetotellurics (AMT) data. TEM data were acquired along two lines to the north and south of the seismic profile, AMT data were along a profile line to the north of the seismic line, and four deep-sounding MT station were established across the larger survey area. The AMT & TEM data were generally of high quality but the profiles crossed some power lines so in addition to processing, inverting and interpreting data were analyzed for the real-world problem of distortion due to cultural noise. The TEM data were modeled (Figure 4) with two one-dimensional inversion software packages giving them the opportunity to compare various processes and results. The data were used to image stratigraphy of the top 100-200 m of the subsurface. The AMT data were processed using one and two-dimensional inversion routines to image the sediments and structure to ~500m. The TEM and AMT models were used to estimate the regional hydrogeology from resistivity models and borehole data. Several students concentrated on understanding and exploring the many parameters associated with inversion of both the TEM & AMT data, thereby quantifying their confidence in the interpreted model. One-dimensional inversion of MT data revealed information to depths of tens of kilometers, and was well correlated with the more shallow models from the AMT data. During the January workshop six students worked together to evaluate MT data, acquired in previous years at SAGE, in terms of geothermal potential in the Rio Grande Rift, and recommended sites for study in SAGE 2011.

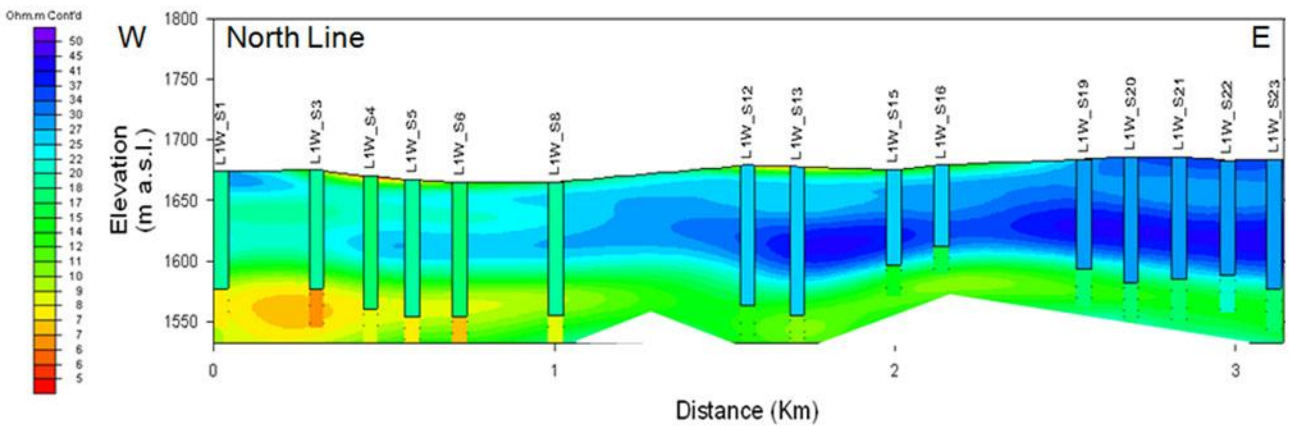

Figure 4. Two-dimensional resistivity depth section derived from TEM data showing variations in the sediments and a pronounced conductor at depth to the west, indicative of clay-rich sediments and/or briny water.

Four high-quality, broad-band (0.01 to 1000 s period range) magnetotelluric (MT) soundings (apparent resistivity versus period) were recorded in the Santo Domingo Basin during the SAGE 2010 field program. The data were interpreted by SAGE students and combined with MT data from previous SAGE programs and presented at the 2010 American Geophysical Fall Meeting in San Francisco in December 2010: Strader, A. E., C. L. Martin, T. Thomas, P. Bedrosian, L. Pellerin, and G. Jiracek, "SAGE 2010 Magnetotelluric Soundings Provide New Constraints on Rio Grande Rift Mid-Crustal Conductor."

The high quality of the SAGE 2010 MT soundings, as illustrated in Figure 5, allowed inverse modeling that yielded the depth to a mid-crustal conductor (MC) of ~20 km and a depth to electrically resistive basement (presumably Paleozoic limestone and Precambrian granite) of ~2.2 km. Depth to low permeability basement is a an important consideration for exploitation of possible enhanced geothermal systems. The MC is likely caused by aqueous brine overlying a partial melt zone. Its depth is thought to be a proxy for the 500°C isotherm which is shallower under the Rio Grande rift compared to surrounding geologic terranes, reflecting the rift's higher geothermal potential.

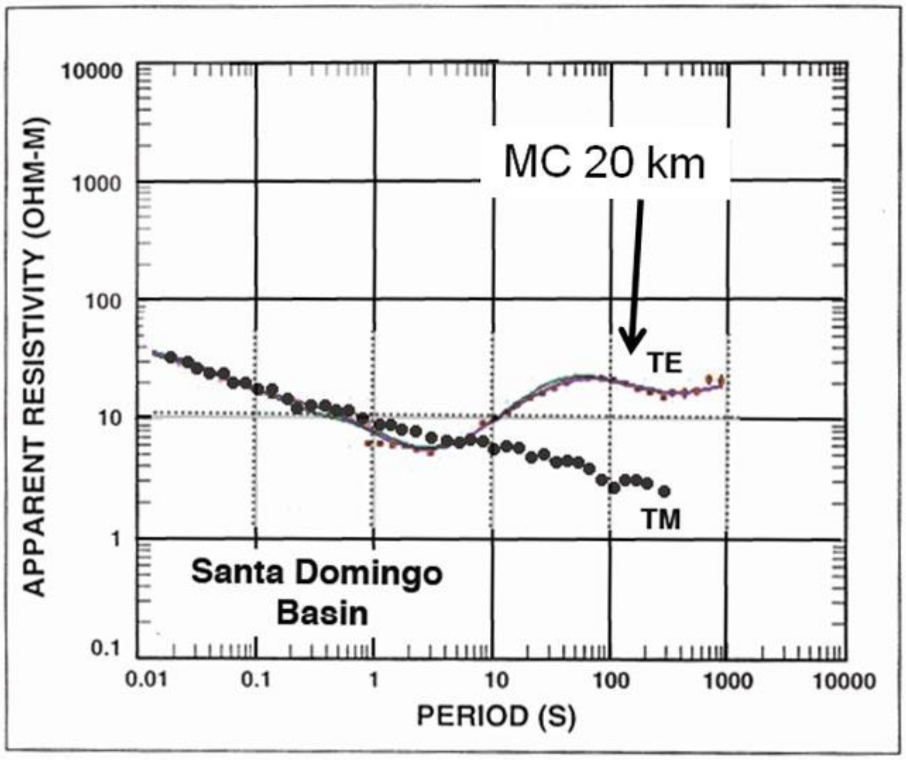

Figure 5. Magnetotelluric (MT) sounding of apparent resistivity versus period recorded during SAGE 2010 in the Santo Domingo Basin. TE and TM indicate transverse electric and transverse magnetic MT modes, respectively. Arrow indicates portion of TE sounding data where midcrustal conductor (MC) is detected at ~20 km depth.

SAGE 2010 Poster Presentations at the Fall 2010 AGU Meeting:

PDFs of the posters can be downloaded from the following links:

http://web.ics.purdue.edu/~braile/sage/SAGEAGU2010.Baldridge.et.al.pdf

http://web.ics.purdue.edu/~braile/sage/SAGEAGU2010.Strader.et.al.pdf

Additional research accomplishments and findings are included in the student report abstracts (below) and in the abstracts of recent publications presented in section 6 (below).

Contribution to Project – Abstracts of Student Reports (SAGE 2010):

The effect of parameters within the 1D Occam Model for AMT
Benjamin Bloss
Abstract:

The Occam model is a powerful tool to help interpret magnetotelluric data. By looking at each parameter individually, we can get a better grasp of the effects, as well as realize the limitations of the model. By means of using an AMT data set, collected at SAGE (Summer of Applied Geophysical Experiences) 2010, and evaluating each parameter of the inversion I was able to define a best-fit model. Every parameter has profound effects, however the model's sensitivity to depth is, perhaps, the greatest factor.

Examination of San Marcos Pueblo, NM Using GPR

Jason P. Chang

Abstract:
To locate subsurface features and artifacts at San Marcos Pueblo, NM without disturbing the archaeological site, ground penetrating radar (GPR) surveys were conducted by students and faculty at the Summer of Applied Geophysical Experience program. Two grids were surveyed: 17E4, a 21x30m block near midden 4; and 20E2, a 26.5x30m block near midden 3 and room block 15. After applying a time gain and other processing steps to the data to overcome the negative effects of clay on data quality, noteworthy features at both grids were apparent. 17E4 displays a horizontal feature in the west, a region of high amplitude response in the south, and significant scattering in the north. 20E2 displays a long, nearly-linear feature running north-south in the western part of the grid. When taking into account the positions of the grids on the site, it is possible that the northern anomaly in grid 17E4 corresponds to midden 4, while the linear anomaly in the western region of grid 20E2 corresponds to a deep fluvial channel. Unfortunately, the other anomalies, particularly those in grid 17E4, are difficult to classify. With the integration of other geophysical methods, it should be possible to better constrain what these anomalies could be.

Seismic Reflection within the Santo Domingo Basin: Velocity Analysis: Constant Velocity Stacking

Bobby Chrisman

Abstract:
A SAGE seismic reflection survey was completed to image the Santo Domingo subsurface between the La Bajada and San Francisco faults with a focus on the subsurface stratigraphy. Constant velocity stacking (CVS) was one of two velocity analyses done to covert the reflection survey into an interpretable and realistic seismic stack. CVS is a method done my human selection and trial and error steps to get corrected reflector velocities. The CVS revealed a transition in velocities from 1300 m/s to about 3000 m/s down the seismic section to a depth close to 2 km. This final processed and velocity corrected cross section along with other SAGE geophysical surveys provide evidence that within this survey line the Santa Fe has a maximum thickness of 1.1 km which lays above the Espinaso (400 m thick), the Galisteo (600 m thick), and the Mancos Shale. On the East side of the line is strong geologic feature which could be the location and dip of the possible La Bajada fault or the Tertiary unconformity. The true migrated dip is calculated to be ~54 degrees.

Effects of Density and Topography on Bouguer Anomalies in the Santo Domingo Basin

Amanda Fabian

Abstract:
Density and topography are known as direct influences on the computation of Bouguer anomalies. We collected gravity data in the Santo Domingo Basin and calculated the complete Bouguer anomalies using five different densities. These anomalies were contoured and compared to observe just how much of an effect density has on the CBA. We have determined that topography is the main input into the Bouguer calculation, and that the density plays a major role as well. It is also seen that given the location of our site in a rift zone, the expected relationship does not display implying the crust is not significantly thin.

SiTEM and SEMDI: A Brief Overview of TEM Data Processing and Inversion Software

Christian Hardwick

Abstract:
SiTEM and DEMSI software package has previously not been employed at SAGE for the processing and inverse modeling of TEM data. The strength of SiTEM and DEMSI is customizable noise filtering and built in sensitivity analysis for optimizing raw data editing and modeling. SiTEM is excellent at filtering out large noise but not so good for filtering small coherent noise patterns. A manual operator is therefore needed to initially inspect the data and make the appropriate changes to filter settings. DEMSI is comparable to WinGLink in the model comparison done in this study. It is recommended that SAGE allow SiTEM and DEMSI as an alternative to WinGLink for future works.

Near-surface Magnetic Survey of San Marcos Archaeological Site, NM (LA 98)

Nathaniel J. Lindsey

Abstract

San Marcos Pueblo in New Mexico (occupied 1300 - 1680AD) is an important archaeological site for the study of sixteenth and seventeenth century Spanish-Native interactions in the southwest. Of particular anthropological interest is the use of Spanish metallurgical techniques by natives, and possible implications of this technology on the pueblo's social order during the 140 year period of colonization. In summer 2010 students from SAGE (Summer of Applied Geophysical Experience - an award- winning geophysics field camp program sponsored by a consortium of industry, academic and government partners) utilized non-invasive, near-surface geophysical techniques to profile San Marcos Archaeological Site. Two 30 m^2 grids were surveyed using a Cesium Vapor Magnetometer made by Geonics, and processed using MATLAB and Oasis Montaj. Three types of total magnetic field anomaly are identified in the data: 1) a high-amplitude linear feature associated with a buried pueblo room block; 2) sharp magnetic dipole structures strongly correlating to metallurgical debris spread across the surface; 3) a fluvial channel oriented N-S interpreted as a tributary of the San Marcos arroyo. All magnetic data acquired at San Marcos by SAGE (2004-2010) were then merged permitting robust, regional interpretation of the metallurgical history of the area.

SAGE Magnetotelluric Data Processing and Analysis

Chris Martin

Abstract

Magnetotelluric data were collected south of Santa Fe, New Mexico on the Santa Domingo Pueblo to evaluate subsurface resistivity variations from roughly 10 m to 20 km depth. Raw data collected using remote reference techniques measured magnetotelluric impedances, which were analyzed using MATLAB and then converted into file formats suitable for interpretation with WinGLink software. Inversion models clearly showed a large resistive section beginning at a depth of about 2 km which were interpreted as thick unsaturated sediments overlying Paleozoic/Precambrian basement a total of about 18 km thick. The models revealed a deeper conductive layer possibly indicative of partial melt and/or aqueous fluid. Depths above the basement a varying conductive section were interpreted to be saturated sedimentary rocks of with decreasing resistivity with depth 300m and 1km, respectively. These data were collected as part of the SAGE 2010 program.

Magnetic analysis of San Marcos archeological site on line 17

Israel Murillo

Abstract:

The San Marcos pueblo (LA 98) is an archeological site south of Santa Fe, New Mexico that was once inhabited by the Yat'ze people and the Spaniards during the Rio Grande Classic period. The Summer of Applied Geophysical Experience (SAGE) program has been working with the cooperation of The Archeological Conservancy to do non-evasive near-surface geophysics in the area to map San Marcos pueblo to find any undocumented buried pueblo structures, metallurgical works, and to define the geological stream terrace that has provided the San Marcos pueblo inhabitants with a steady source of water. Magnetic data were recorded to specifically define the stream terrace parallel the San Marcos arroyo and south of the former Spanish mission. The data indicates that the over-burden material ranges from 3 meters to 20 meters in certain areas and matches data from previous SAGE field data.

Importance of Predictive Deconvolution filtering in seismic data interpretation, Santo Domingo Basin, NM

Olga I. Nedorub

Abstract:

7.2 km of seismic reflection data were collected during SAGE 2010 program in the Hagan Embayment, Santo Domingo Basin (SDB), NM. Analysis and interpretation was done in steps involving preprocessing, F-K filtering, Deconvolution, Muting, Velocity analysis, NMO correction, Stacking, and Migration. A Predictive Deconvolution filter was applied in order to remove reverberation. This step proved to be a powerful step in removing multiples along the first arrival without disturbing the reflections. Final cross-section profile was built based on values determined by velocity analysis. Interpretation was based on geologic characteristics of the strata forming the SDB. Correlation with well-defined previous interpretations of seismic lines in the area was conducted, and estimated velocities for corresponding formations were taken into consideration. The thicknesses of the formations were the following: Santa Fe Group – 400 - 650 m; Espinaso Fm – 300 - 500 m; Galisteo Fm – 300 - 400 m. The La Bajada Fault was imaged. True dip was estimated to be 50 degrees. The surface location for the LBF was predicted to be 740 m to the east of the first station along the seismic line.

Seismic Refraction in the San Marcos Pueblo, NM

Anna Nowicki

Abstract:

The San Marcos Pueblo Archeological Site is located on the western side of the Galisteo Basin, near Sante Fe, New Mexico. Evidence of human occupation at this site dates from the end of the thirteenth century until approximately 1680. The people of the San Marcos Pueblo settled in this area because of it's unique hydrological abilities. After surveying a 192.5 meter long line within the archeological site using seismic refraction, data were used to create a forward model within the software program Geomod. This model was interpreted using previously published seismic refraction work from this area. Because the modeled water table is incised by a tributary to the San Marcos Arroyo the Ancha Formation basically outcrops into the arroyo located on the Southwest end of the seismic line, allowing water to flow easily from the saturated Ancha layer. This indicates that springs would theoretically flow into and along this arroyo, giving the people of the San Marcos Pueblo a unique source of water, located within a typically dry desert area. Results show that the Ancha Formation is approximately 8 to 12 meters thick in this area, while the water table can be modeled at a level approximately 8 to 10 meters beneath the surface. This level coincides with the measured water level of the nearby well (1816 meters elevation), supporting the forward seismic refraction model created in this study.

Seismic Reflection Processing in the Santo Domingo Basin Hyperbolic Picks for Velocity Analysis

Benjamin Phrampus

Abstract:

This survey located on the southern edge of the Santo Domingo Pueblo land in the Santo Domingo Basin is aimed to characterize and understand the Rio Grande Rift as a whole. SAGE utilized eight 80 channel geophone receivers along a 7.2 km stretch of road in order to image the subsurface. Multiple preprocessing and processing steps were taken to refine the result, including the hyperbolic pick velocity analysis method. With the implementation of this method multiple stratigraphic structures were mapped from the La Bajada Fault down to the Galisteo Sandstone.

Magnetotelluric Interpretation of Santo Domingo Basin Stratigraphy

Anne Strader

Abstract:

The Santo Domingo Basin magnetotelluric (MT) field site, located between the northern ends of the San Francisco Fault and the La Bajada Fault, extends 8 km and consists of four linearly aligned stations trending northeast-southwest. Long-period MT data were collected in order to detect hydrologic and geologic layers within a 100 m-25 km depth range. Using WinGLink, MT data from three stations were inverted to produce 1D models, detecting five layers. The surface layer is 300 m deep and has a resistivity of 40 Ωm, in accordance with observed Cenozoic sandy alluvium basin fill at the field site. The underlying conductive layer is 1.7 km thick and has a 5 Ωm resistivity. Previous studies, which have resulted in similar resistivities for this layer, indicate that the high conductivity is caused by clay, deposited from the Mesozoic to Cenozoic eras, rather than a saturated aquifer with high ion concentrations. A split in the TE and TM mode resistivities indicates a lateral discontinuity possibly caused by a fault or unconformity. Below the conductive clay layer, an 18 km-thick 100 Ωm layer is interpreted to contain 1-2 km of Paleozoic sandstone that overlies Precambrian basement rock. A mid-crustal conductor is detected at 20 km depth, but unlike previous data, current data indicate that the conductor is confined by an underlying resistive layer. The conductor is constrained by a conductance range of 1000-1700 S, with an assumed thickness of 600 m-1.5 km. Mid-crustal conductor resistivities range from 0.5- 2Ωm, which supports a fractional porosity of 0.01 and a fluid resistivity of 0.01 Ωm. Whether this layer is caused by partial melt or ion-rich fluid largely depends on geologic composition; a geothermal gradient of 30°C/km yields a temperature of ~618°C, sufficient to melt felsic material.

The Physics of Boundary Charges

Katharine Tallaksen

Abstract:

After long period magnetotellurics data were collected, a split was observed. This split was analyzed using Maxwell's equations and their boundary conditions. The split is due to the discontinuity in the normal electric field and surface charges at a boundary between two media of different resistivities. A forward model was created using WinGLink; this model was created using two media of differing resistivites. When analyzed, this model produced a similar split.

Hydrological Interpretation of the Santo Domingo Basin using Audio-Magnetotellurics

Trevor Thomas

Abstract:

The 2010 SAGE session set out to characterize the subsurface of the Santo Domingo Basin portion of the Rio Grande Rift's Espanola Basin, southwest of Santa Fe, New Mexico. AMT data were taken along a West-East transect bounded on either side by the San Francisco and Labajada faults and running approximately perpendicular to the general geologic strike of the area. The transect includes 12 stations spaced at approximately every 300m with a total transect length of 3300m. Stations 3 and 10 received unusable data and were not used for data processing, and the data for station 4 is unrecoverable. Data from the remaining 8 stations was processed using Geosystem's WinGlink™ software. WinGlink's D+ smoothing algorithm was used to fit a curve to the raw data. D+ smoothed curves were then used to compute 2D inversions of the transect dataset. Using these models and several other constraints, the aquifer under the area is characterized, and an interpretation of the water quality therein is approximated. Good aquifer material was found underneath the study site, and the theoretical water salinity was found to be too high for general consumption.

Transient Electromagnetic Survey in the Santo Domingo Pueblo, New Mexico

Emily Tursack

Abstract:

Transient electromagnetic (TEM) data collected in the Santo Domingo Pueblo, New Mexico were processed using inverse and forward modeling techniques to produce a resolved one dimensional resistivity model for the subsurface at the TEM survey locations. The model was then compared to local well logs and lithological data for interpretation and understanding of the shallow depth geology. We determined that a relatively resistive, clay-rich sand layer of resistivity 30 Ωm is atop a conductive, water-rich clay layer of resistivity 15 Ωm. The resistive layer is not present in the southwestern portion of the survey suggesting a possible fault. Future studies should consider the more complex geology of the region for a more accurate interpretation.

S.E.I.S.M.O. – Seismic rEfraction In Santa doMingO basin

Hobie Willis

Abstract:

SAGE 2010 students conducted a seismic survey in the southern Santa Domingo basin in order to determine the subsurface structure. Seismic refraction was employed to create a velocity model of the shallow subsurface. Data acquisition took place over the course of four days using eight arrays of 80 geophones each. Ten refraction shots were made using a Vibroseis truck from ION Corp. Each shot was recorded on a seismogram that was processed to enhance the refracted first arrivals. In addition to reducing noise in each seismogram, geometry was added to the seismic records by assigning UTM coordinates to each source and receiver. Using the known offset between each source-receiver pair, and the time between to the first arrival, travel time curves were created in SeisImager®. Velocities of the subsurface were estimated from the change in slope of these travel time curves. An initial velocity model was created in SeisImager® to visually image the subsurface. This simple 2D layer-cake model was then enhanced using a tomographic inversion method. Refraction paths, and corresponding travel times, were iteratively calculated from receivers to sources, and compared to the measured travel times. The misfit between the calculated model and the observed travel times was given by the RMS value in milliseconds. The final model was created using a total model depth of 1500 meters with the top of the lowest layer again set at 1000 m. The velocity gradient spanned from 600m/s to 3000m/s over 12 layers. Seven iterations were computed with 2 nodes per cell and two smoothing passes of .3 smoothing weight each. The RMS value for this model was 20.9ms. The most notable feature in this model was a large body of material approximately 800 meters thick with a velocity ranging from 1800m/s to 2200m/s. This body is believed to a geologic formation comprised of different sedimentary layers known as the Santa Fe group.

TEM: The importance of diligent masking

Mark Ziminsky

Abstract:

Using WinGLink and EMMA, TEM data from the Santo Domingo Pueblo near Santa Fe, NM was processed to model the resistivity of near surface sediments. A preliminary model was created that was discontinuous along the profile. Simply by being more selective in the beginning of processing, by masking outliers before merging the soundings, the gaps in the preliminary model were filled in creating a coherent continuous model which roughly delineates the surface of the water table along the profile.

Gravity Analysis of the Southern Hagan Embayment

Matt Browning

Abstract:

The Hagan Embayment is a syncline structure that lies between the La Bajada and San Francisco faults in northern New Mexico. Gravity measurements have been made throughout the southern region of this structure and into the Albuquerque Basin; a number of which follow an older Trans-Ocean seismic line which has been previously interpreted. A south-north 2-D gravity line has been previously used to produce a model, and will, along with the Trans-Ocean line interpretation, provide constraint for a west-east 2-D gravity model. The Hagan Embayment basin fill is known to consist of several sedimentation groups, and this gravity model will distinguish between the Santa Fe group and the Espinaso/Galisteo layers. This choice of modeling is based primarily on the density contrast from the basement of these layers, and omits the stratigraphically lower layers that have a very low density contrast with the basement. This 2-layer, 2-D model captures the location of the La Bajada and San Francisco faults, and also provides details on the depths of the Santa Fe group and Espinaso/Galisteo layers. The model also extends into the Albuquerque Basin, and while relatively few gravity stations are available for data there, provides a rough initial look at this basin's structure.

SAGE 2010: 2D gravity modelling across the La bajada and San Francisco faults, New Mexico

David Khoza

Abstract:

As part of the hugely successful Summer of Applied Geophysical Experience (SAGE) program, different types of geophysical datasets were collected across the Santo Domingo Basin in Santa Fe, New Mexico, in an effort to characterize the regional geology. This work focuses particularly on the two-dimensional (2D) modelling and interpretation of gravity features evident in the basin. In addition we present a 2D gravity model of an east-west EW) profile across the La Bajada and San Francisco faults, which off-sets the basin-fill sediment stratigraphy of the Santo Domingo basin. The resulting 2D forward are consistent with the known stratigraphy of the area and the approximate location and geometry of the La Bajada and San Francisco faults. The depth-to-basement maps produced show elevated depths west of the La Bajada fault coinciding with the Cerrillos uplift segment of the Rio Grande rift. The Santo Domingo basin rests on a reduced basement level suggesting the rift fill sediments up 3.5 km thickness.

Exploring the Topographic and Structural Features of the Santo Domingo Accommodation Basin

Melissa McMullen

Abstract:

Rift structures are extraordinarily complex features and the Rio Grande rift is no exception. Similar to the East African rift, there are side-stepping basins separated by zones of accommodation. As part of the Summer of Applied Geophysics (SAGE), gravity measurements were made within one of these basins to better understand how deformation was accommodated. From the complete Bouguer anomaly maps and with the help of a forward model cross section to understand the subsurface, several correlations between lithology, topography and anomaly were made. Differences in displacement suggested by both the geology and the subsurface cross section along the La Bajada and the San Francisco faults, indicated that deformation may be accommodated by shifting movement progressively basinward.

Seismic Reflection Survey of the Santa Domingo Basin, New Mexico

Amanda A. Pera

Abstract:

A seismic reflection survey was conducted in the Santo Domingo Basin, within the Rio Grande Rift, New Mexico, during the SAGE 2010 field session. Data were collected over a five day period and then processed using Seismic Processing Workshop software. The focus of this study is to better constrain the subsurface structure and stratification of the Santo Domingo Basin. Final imaging of the data reveals the contact between the westward dipping La Bajada fault and eastward dipping basin sediments at a depth of approximately 1000 m on the east side of the seismic profile. Observed stratigraphic units in contact with the La Bajada fault include the Mancos, Galisteo, Espinaso and Santa Fe Group.

**Geologic controls on groundwater movement in the Ancha Formation:
San Marcos Pueblo, New Mexico**

Daniella Rempe

Abstract:

Geophysical methods can provide information about the distribution of sediments within a basin and are useful for predicting the distribution, movement and quantity of groundwater resources. Seismic refraction was used to map hydrostratigraphy at the San Marcos Pueblo, an archaeological site in central New Mexico with known groundwater discharge areas. Refraction results indicated that the basal contact of the Ancha Formation, the local aquifer material, is the Galisteo Formation rather than the previously mapped Espinaso Formation. The pyroclastic volcanic deposits from the Espinaso Formation are locally absent and were likely eroded during the Miocene and Pliocene creating a conduit for Ancha deposition. This narrow band of porous, hydraulically conductive material is connected to the greater Ancha Formation that blankets the Santa Fe embayment and provides a reliable water source at the San Marcos Pueblo site validating their decision to settle the area. The hydrostratigraphic section obtained through analysis of seismic refraction travel times revealed the depth and distribution of the water table within the Ancha formation. Examination of local wells and water levels corroborated with this analysis. Refraction results also provided P-wave velocity estimates for the various hydrostratigraphic units allowing for an estimated porosity of 0.4 for the Ancha Formation.

Evaluating the Effectiveness of F-K Filtering for SAGE 2010 Reflection Seismic Data

Krongrath Suwannasri

Abstract:

Most land seismic records contain unwanted signals such as surface waves which make seismic reflection processing difficult. This is also true with SAGE 2010 seismic data. This study intends to reduce surface wave energies and enhance reflected wave signals by using a F-K filter. At the same time, it also evaluates the effectiveness of F-K filtering for this data set. After applying F-K filtering to the data set, I characterize results into 3 categories: improved, moderately improved, and poor category. The distribution among the three categories is about 20%: 30%:50%. I found that the amount of aliasing and coherence of seismic data have an important role in controlling the success of F-K filtering in this data set. The F-K filtering is capable in enhancing reflection waves and suppressing surface waves in only few shot records. However, in terms of the whole SAGE 2010 seismic data, the f-k filtering is not very effective. In the end, I suggest other types of filtering for SAGE 2010 seismic data due to time and computational constraints.

Application of Transient Electromagnetic (TEM) Survey to Delineate Shallow Subsurface Geology of Santo Domingo Pueblo, NM

Anita Thapalia

Abstract:

Summer of Applied Geophysical Experience (SAGE) 2010 conducted fieldwork in the northern section of the Rio Grande Rift zone in the Santo Domingo Basin near Santa Fe, NM. In order to integrate data processing from different methods, I utilized Time domain electromagnetic (TEM) method to image shallow subsurface resistivity of the basin. The shallow subsurface geology is correlated with TEM data from 1 D inversion models. Forward model is used to check the sensitivity of the 1-D inversion models. The conductive layer around 80 to 100 m depth is observed which is overlain by the resistive layer. Geologically this conductive layer consists of clay rich sand or water saturated clay rich sediments from Ancha Formation of Santa Fe Group. TEM technique is vital to understand the geology and depositional environment of shallow subsurface. TEM methods have been implied to delineate the aquifer boundaries and depth of water table in the subsurface.

Investigating the effects of inversion parameters on 2D modelling of AMT data

Kathi Unglert

Abstract:

The Rio Grande Rift and particularly the Santo Domingo Basin were investigated with seismic refraction and reflection, electromagnetic and magnetic methods as well as with gravity and ground penetrating radar by the students and faculty of the Summer of Applied Geophysics 2010. Main aims were to map the subsurface structure in the area on and around the La Majada Mesa in terms of fault and aquifer location. This report focuses on the application of audio frequency magnetotellurics along a 3.2 km profile on the La Majada Mesa, in particular on the effect of different parameters on 2D inversion of frequency domain resistivity functions. We find that using smooth curves fitted to the actual data points for the inversion results in smoother models and lower misfit of predicted and observed data (RMS). Increasing the number of iterations from 10 to 40 can decrease the RMS by up to ~4%. An increase in number of frequencies per decade from 5 to 20 yields a decrease in RMS by 15%. Using the gradient as

roughness measure instead of the Laplacian gives rougher models but lowers the misfit. Furthermore, raising the smoothing parameter yields an increase in RMS and shows a more complex relationship to roughness that has to be further investigated. We develop a set of final inversion parameters appropriate for this dataset. From this model, we infer resistive material in the western part of the profile, a resistive layer in the uppermost 100 m in the centre (topsoils and relatively unconsolidated sands and gravels) and one or two deeper conductive structures to the centre and the East (most likely water saturated clay).

Using Tail Muting for Seismic Reflection Processing in the Santo Domingo Basin and its effecting in the Interpretation

Jessidee Valdes

Abstract:
SAGE (Summer of Applied Geophysical Experience) conducted a geophysical study in the Santo Domingo Basin, including Gravity, Magnetotelluric (MT), Time-Domain Electromagnetic (TEM), Audiomagnetotelluric method (AMT) and Seismic data collection. A vibroseis truck source was used to produce the reflections and refractions gathered by the geophone array. This seismic line produced almost a 7.2 km seismic profile. In the processing phase of the seismic data, the application of a mute proved to be a great tool to remove a large portion of the surface waves in the data set. Once the surface wave noise was discarded, it was possible to see the reflection points of La Bajada Fault. Since the seismic study was not conducted directly on top of the fault, it was a great surprise and intrigue to see the reflections of the fault in the seismic profile, as well as to approximate the apparent dip of the fault and where it would be seen on the surface. Moreover, with some additional cross referencing information it was possible to interpret and decide on the possible depositional layers. Thusly, muting proved to be a great processing step that allowed for the reflections to exuberate themselves for a better interpretation of the data set.

5. Training and Development:

A. SAGE Program - 2010:

a. The primary goal of SAGE is to actively involve students in all phases of exciting, applied geophysics using modern field equipment and computer processing/interpretation tools. The time-frame used to attain this goal begins with lecturing followed by data collection in the field, data assessment/processing, and modeling/interpretation. This sequence is guided by geophysicists who are proven researchers and teachers. Students work with faculty, teaching assistants, and industry experts in a variety of geophysical surveys such as seismic reflection, seismic refraction, gravity, magnetics, and electromagnetics.

b. SAGE enables undergraduate and graduate students from both large and small schools (and some professionals) to share the excitement of hands-on, modern, field geophysical research and learning.

c. SAGE begins by first building on the student backgrounds so that they understand the basic scientific principles involved when applying geophysics to geologic problems.

d. There are interactive discussions on the objectives of the field research, the geophysical techniques to be applied and the rationale, and how the data will be collected. The central activity of SAGE is the collection and interpretation of geophysical field data.

e. After data collection, all students are guided by SAGE faculty, teaching assistants, and SAGE adjunct scientists to engage in computer processing and modeling to support a focused research topic. These topics address testable hypotheses that can be resolved with the help of computer analysis of the data that the students have collected themselves at SAGE. A two-level team approach has proven to be a very effective learning and research strategy. Students are organized into: (1) "technique teams" in which they concentrate on an individual geophysical method, e.g., seismic reflection, seismic refraction, gravity, transient electromagnetics, or magnetotellurics; and (2) "integration teams," in which a student representing each technique joins others to integrate their collective results. All students complete SAGE by orally presenting their focused research results to the entire group and by writing a scientific report. Written reports (expanded abstracts) follow the style used in *Geophysics;* oral presentations are patterned after the format of the SEG annual meeting.

f. The basic chronology followed by students during the main summer SAGE program is outlined by the following:

1. REU students only arrive 3 days early for lectures on the scientific method as applied to geophysical research, basic geophysical principles and their relations to physical properties, and for an introduction to digital geophysical analysis. A field trip connects geophysics to geology.
2. An orientation and discussion of first aid and health hazards of northern New Mexico. Ultimate expectations of each student are clearly described.
3. Lectures on the specific geology of field areas and geophysical techniques to be used which includes research objectives and experimental design. There is a geologic field trip to study areas.
4. Geophysical field measurements at (1) a shallow environmental or archeological site and (2) in basin-scale research area with deep hydrological and structural objectives.
5. Selection of focused research topics by all students. Faculty encourage students to select something that they are unfamiliar with, i.e., to learn something new.
6. Computer processing, modeling, and interpretation of collected data addressing the student's focused research topic and the integration of all geophysics.
7. Completion of focused research study and integration with all techniques. Presentation of talk and submission of written report.
8. A one-week workshop 6 months later, usually in January, to revisit SAGE research objectives with advanced effort (REU students only).

B . Outreach Activities - SAGE 2010: Besides the traditional SAGE students, the NSF funds have allowed the inclusion of Native American high school and college students at SAGE while field work is on their tribal lands. The Native American students are typically freshmen or sophomores in college and are studying engineering or other technical fields. Although they usually do not have geoscience background, our 7-day program, including field trips to classic northern New Mexico geology sites and participation in some of the geophysical field work, provides an excellent inroduction to relevant Earth science topics and illustrates some practical applications of geophysical explorations (faulting, development of the current landscape, stratigraphy, ground water resources, etc.). They are selected by their tribes and they present the results of their experience to their families and the elders at the end of the SAGE program. They receive a stipend and lunch during their days of participation. An additional success already of this initiative has been a student from the Cochiti Pueblo, Joe Grimley, who is now attending Colorado College and majoring in geophysics. The Native American students that participated in SAGE in 2010 were: Desiree Aguilar, Gabrielle Bird and Rose Chavez from the Santo Domingo Pueblo, and Joe Grimley, Cameron Quintana and Arielle Quintana from the Cochiti Pueblo.

6. <u>Publications and Products</u> (SAGE 2010):

- Abstracts of Poster Presentations at Fall, 2010 AGU:

SAGE 2010 Magnetotelluric Soundings Provide New Constraints on Rio Grande Rift Mid-Crustal Conductor *A. E. Strader[1]; C. L. Martin[5]; T. Thomas[2]; P. A. Bedrosian[4]; L. Pellerin[3]; G. R. Jiracek[5]* 1. Earth and Space Sciences, UCLA, Los Angeles, CA, United States. 2. Department of Earth Sciences, University of Southern California, Los Angeles, CA, United States. 3. Green Engineering, Inc, Berkeley, CA, United States. 4. US Geological Survey, Denver, CO, United States. 5. Department of Geological Sciences, San Diego State University, San Diego, CA, United States.

Since the inception of the Summer of Applied Geophysical Experience (SAGE) program in 1983, long-period magnetotelluric (MT) soundings have imaged a pronounced mid-crustal conductor at 10-20 km depth within the central Rio Grande rift. Wideband MT soundings (0.01 to over 1000 s period) collected in 2010 extended the detection of this feature to nearly 100 km length along the rift axis in the vicinity of Santa Fe, New Mexico. The conductive anomaly is clearly defined in the longest periods of the mode identified as the transverse electric (TE) in the recently acquired MT data. The spatially-limited 2010 soundings in the Santo Domingo Basin do not allow two-dimensional (2-D) inversions; however, one-dimensional (1-D) inversion of TE mode measurements in conductive rift basins can yield good depth estimates of deep conductive layers as has been shown by 2-D rift MT modeling. Such 1-D inversions of the 2010 MT soundings yield ~20 km depth to the top of the mid-crustal conductor, 5-10 km deeper than 90 km to the north if 3-D effects are negligible. Estimated conductance of the Santo Domingo basin conductor is 2000 S with resistivities in the range of 2-10 ohm-m. An interpretation of the ubiquitous, mid-crustal conductor in the Rio Grande rift is interconnected, saline, aqueous fluid trapped in the ductile crust below the ~10 km-deep seismogenic zone after fluid release and upward ascent from an upwarped mantle.

Seismic Investigations of an Accommodation zone in the Northern Rio Grande Rift, New Mexico, USA *W. S. Baldridge[1]; J. Valdes[3]; O. Nedorub[2]; B. Phrampus[4]; L. W. Braile[5]; J. F. Ferguson[3]; M. C. Benage[6]; M. Litherland[7]* 1. Earth and Environmental Sciences Division, Los Alamos National Laboratory, Los Alamos, NM, United States. 2. Department of Geology, University of South Florida, Tampa, FL, United States. 3. Geoscience Program, University of Texas at Dallas, Richardson, TX, United States. 4. Department of Geology, Baylor University, Waco, TX, United States. 5. Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN, United States. 6. Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, United States. 7. Department of Geophysics, Stanford University, Stanford, CA, United States.

Seismic reflection and refraction data acquired in the Rio Grande rift near Santa Fe, New Mexico, in 2009 and 2010 by the SAGE (Summer of Applied Geophysical Experience) program imaged the La Bajada fault (LBF) and strata offset across the associated, perpendicular Budagher fault (BF). The LBF is a major basin-bounding normal fault, offset down to the west; the smaller BF is an extensional fault that breaks the hanging wall ramp of the LBF. We chose this area because it is in a structurally complex region of the rift, comprising a small sub-basin and plunging relay ramps, where north-trending, en echelon basin-bounding faults (including the LBF) transfer crustal extension laterally between the larger Española (to north) and Albuquerque rift basins. Our data help determine the precise location and geometry of the poorly exposed LBF, which, near the survey location, offsets the rift margin vertically about 3,000 m. When integrated with industry reflection data and other SAGE seismic, gravity, and magnetotelluric surveys, we are able to map differences in offset and extension laterally (especially southward) along the fault. We interpret only about 200 m of normal offset across the BF. Our continuing work helps define multiple structural elements, partly buried by syn-rift basin-filling sedimentary rocks, of a complex intra-rift accommodation zone. We are also able to discriminate pre-Eocene (Laramide) from post-Miocene (rift) structures. Our data help determine the amount of vertical offset of pre-rift strata across structural elements of the accommodation zone, and depth and geometry of basin fill. A goal is to infer the kinematic development of this margin of the rift, linkages among faults, growth history, and possible pre-rift structural controls. This information will be potentially useful for evaluation of resources, including oil and/or gas in pre-rift strata and ground water in Late Miocene to Holocene rift-filling units.

- Invited Presentation at SERC Workshop:

Braile, L. W., *Field Geophysics at SAGE: Strategies for Effective Education* (invited paper; http://serc.carleton.edu/files/NAGTWorkshops/field/workshop10/field_geophysics_sage_strategi.v2.ppt), Teaching Geoscience in the Field in the 21st Century, Workshop, Montana State University, Bozeman, MT, August, 2010.

- Submitted Paper (accepted) from SAGE 2010 for Presentation at the 2011 SEG Meeting:

Hydrogeophysics and the Settlement of San Marcos Pueblo, NM: Investigations by the SAGE Geophysical Field Course
John Ferguson, University of Texas, Dallas, Daniella Rempe, University of California, Berkeley, Anna Nowicki, Michigan State University, Kate Talaksen, W. Virginia University, Nathaniel Lindsey, University of Rochester, Jason Chang, University of California, and Louise Pellerin, Green Engineering*

- Web/Internet Site (SAGE 2010):

The SAGE website can be accessed at: http://www.sage.lanl.gov/. The website contains extensive information about SAGE including links to some SAGE student presentations.

We have also produced a web page (http://www-rohan.sdsu.edu/~jiracek/DAGSAW/) on Digital Analysis of Geophysical Signals and Waves that utilizes SAGE data and is a learning resource for the signal and wave concepts that we use in SAGE. The site is used by SAGE students and faculty during SAGE and is an openly available resource for other students and educators.

- Other Specific Products and Contributions (SAGE 2010):

An extensive set of SAGE research data is archive by the SAGE faculty. These data have been used for several research publications and student theses. We have also developed extensive notes and software related to geophysical techniques that we use during the SAGE program. Some of these materials are being made available to students and others on the Internet. Examples of some of the data and analysis for SAGE 2010 is included in Section 4, above.

SAGE 2010 - SAGE provides a significant field geophysics experience for undergraduate and graduate students. Universities and colleges have relied on SAGE for some of their field or research course requirements for their students. SAGE often provides the first geophysics experience to many students, especially those from small schools. In the last five years we have had 82 REU students from over 40 different campuses. Smaller schools such as Centenary College, Carleton College, Milsaps College, Illinois State University, Bloomsburg University, Centre College, Hastings College, University of South Florida, California State University-Stanislaus, College of William and Mary, Wheaton College, Mesa State College, Winona State University, SUNY-Fredonia, Appalachian State University, Shippensburg University, and Swarthmore College usually have no (or limited) geophysics program so students from these schools get their first exposure to geophysics at SAGE.

Industry has been highly supportive of SAGE, partly because they value SAGE students and have hired many of our former students. SAGE REU students also have a very high (~75%) rate of enrollment in graduate school. Many of the students who do not go on to graduate school are employed in their geosciences discipline. As shown by the Table in section 1, 13 of the 17 2010 REU students are now in grad school (or are expected to enter grad school in the Fall semester of 2011). Two of the 2010 REU students are now employed in the geophysical industry, and two students will complete their senior year in 2011-2012. A significant number of former SAGE students have obtained PhD degrees and hold positions in academia or with the US Geological Survey or national laboratories.

- Student Evaluations of SAGE (SAGE 2010):

We use a two-page questionnaire to obtain evaluations of the SAGE program from the students. Some of the questions request feedback on specific aspects of the program and we have used the results to improve SAGE over the years. The questionnaire can be completed anonymously, but most students include names. For 2010, there were 26 student (17 REU students and 9 graduate students) evaluations (all of the students). Some evaluation results and comments are included below:

Question 5b. To what extent did you meet your goals?

“To a great extent. I’ve met awesome people, both students and faculty, and I learned so much.”
“Exceeded – the crash course in near-surface.”
“Almost fully met. Would have liked to be a part of processing all methods.”
“I got them done.”
“Exceeded.”
“Absolutely.”
“I learned more than what I expected.”
“I learned a lot about field methods, general theory, data processing was lacking.”
“Fully!”
“Fairly highly. I still enjoy geophysics.”
“I met them all!!!”
“I have a much clearer understanding of MT and electromagnetic methods in general.”
“Very well.”
“Completely.”

“Above and beyond.”
“Beyond expectations!”
“Completely.”
“Mostly, although data processing and modeling is still an area that needs further work.”
“Met my goals. I learned about seismic processing to the extent I wanted to.”
“I wish I had worked on a different geophysical method for my project.”

Question 5d. What were the major highlights for you at SAGE?

“Making contacts. Being exposed to new material.”
“Field work and just talking about science.”
“Field work, learning about processing techniques.”
“Field work.”
“Integrating different methods.”
“Lectures; community of SAGE students and faculty.”
“Field work and data processing. Field trips also a plus.”
“Field work, George and Shawn.”
“Seismic.”
“Field work! As well as making so many connections and friends☺”
“Learning a great deal in such a short time and meeting people in academics and industry.”
“Discovering subsurface layers/structures with previously unfamiliar geophysical methods.”
“Making new friends, field work.”
“Comprehensiveness, depth of material.”
“Doing the field work and working on processing/interpretations.”
“The full week of field work, and the week of data processing, very intense, but amazing.”
“Field work, especially working on the seismic line.”
“Field work and being able to use the SPW software.”
“Field work, working with faculty.”

Question 6. What are your current career interests/goals? (we asked them to circle one answer, but many circled more than one, so all of the responses are included below)

a. Oil and Gas	8 (2009)	9 (2010)
b. Mining	2	3
c. Hydrology	3	6
d. Environmental/Engineering	5	16
e. Teaching/Academia	8	6
f. Research	8	14
g. Government	8	10
h. Other	9	1 (Geothermal 4)

Question 11. How did you learn about SAGE (e.g., from you professor, from other students, searching for summer programs, the NSF web pages, etc.)?

From professor or advisor	15 (2009)	21 (2010)
From former SAGE students	5	2
NSF REU website /Internet	3	2

No answer	2	1

Question 12. How would you characterize SAGE as an educational experience?
"Priceless. I have learned more in the past month than in the past few years at university."
"Fantastic. A very productive 4 weeks and a must for any student interested in near-surface geophysics."
"Immersion into geophysical collection – processing and interpretation; hands on experience."
"Intensive experience."
"Awesome field work and top notch lecturing. An opportunity to focus and deliver valuable geophysical results while learning from the best."
"Extraordinarily beneficial! I hope more of industry recognizes this amazing program."
"It is a very good experience."
"Oh my God! The best I ever experienced!"
"Awesome!"
"I would recommend this to ANY geophysics student."
"SAGE introduced a lot of new information effectively in a short amount of time. I'd learned equivalent amounts of information over a semester."
"Very informative. A good program."
"Equivalent to more than a semester long course academically. Also learn to work as a team. Great overview of geophysics disciplines."
"The best learning/educational experience I've ever had! You have to be committed and interested in advancing in geophysics."
"An incredible immersive program, invaluable to those interested in geophysics. Simply amazing."
"Amazing."
"Total immersion program – definitely lets you know whether or not geophysics is for you."
"An exceptional educational experience."
"Very hands on."
"Very hands on experience."
"Superb – unique experience. Very grateful for all of the field, lecture and lab opportunities."
"It is rock and roll. Sometimes, I do not quite know what I am doing but it is still fun."
"Wonderful practical experience; latest technology in geophysics."
"Great on all levels (field work, data analysis, team and presenting skills); maybe a bit more involvement of students in experiment planning."
"An excellent opportunity to truly experience what geophysics is in "The Real World" not just in the classroom. It's an incredible hands on experience opportunity."

Question 14. How do you rank the overall value of SAGE?
[Very valuable] 5 4 3 2 1 [Not valuable]
Results were: Twenty-one 5's, one 4.5, three 4's, and one 3.5.

Question 15. Other comments:
"Thank you so much. I will value this month for the rest of my life."
"Thank you!"
"Thanks!"
"Excellent geophysical immersion experience."

“Thank you!”
“I had a wonderful time overall!”
“Please make sure everyone is receiving attention, especially when it comes to data processing.”
“☺”
“Thanks for an incredible month!”
“Thank you!”
“Thanks!!”
“Thanks for having me! I truly enjoyed every minute of it ☺”

- Recruitment and Demographics (SAGE 2010):

A. Recruitment: Because SAGE has been an ongoing program for many years, much of our recruiting is, effectively, by “word of mouth.” Although we advertise widely every year, many of our REU students apply to SAGE because the program was recommended to them by their advisor or another professor, or from a former SAGE student. In one of our evaluation questions for SAGE 2009, we asked how the students learned about SAGE, the results (all SAGE students; some gave more than one answer) were: from an advisor or professor, 15; from the NSF REU website or Internet, 2; from a former SAGE student, 11; no answer, 1. There are similar results for our 2010 recruitment (see results from evaluation, above). Our recruitment includes a flyer that is sent by email each year to several hundred geosciences faculty members and departments. We also have a brochure that was distributed at national meetings (GSA, AGU, SEG, SAGEEP, SACNAS) meetings. In 2009 and 2010, we also obtained a list of geosciences students who attended the SACNAS national meeting. A personal email was sent to each of these students with SAGE information attached. We also sent an email with SAGE information to the ABGG association and were listed in the Black Physics Association website in 2011. In general, we are attracting an excellent pool of students. In both 2008, 2009 and 2010 we had over 48 applicants and had to decline many qualified students – this situation was very evident in our SAGE 2010 recruiting and selection for 2011 in April, 2011. However, recruiting underrepresented minority students remains a challenge. If funds were available, we would visit selected schools with large populations of underrepresented minority students to meet with students or present a seminar on SAGE. We believe that this approach could significantly improve our recruitment of underrepresented minority students for SAGE.

B. Demographics: There were 17 REU students in SAGE 2010 including 11 males and 6 females. One of the 2011 REU students are Asian and one is Hispanic. Nineteen REU students are expected to participate in SAGE 2011. Six of these students are female (we do not have full underrepresented status data on the 2011 students at this time). The long term demographics of the SAGE program are perhaps more representative. Overall, 702 students have attended SAGE since its inception in 1983. In terms of the demographics and participation of underrepresented groups, there are good records of the undergraduates supported by the NSF’s Research Experiences for Undergraduates (REU) program since our initial NSF funding in 1990. Since then (through 2010) the REU students have numbered 300; there have been 147 underrepresented REU students (49% of the total) including 121 women, 18 Hispanics, 5 Native Americans, and 3 African Americans. Similar percentages of underrepresented graduate students attend SAGE.

7. <u>Safety Plan</u> (SAGE 2010):

During each year of SAGE, a Hazard Control Plan (HCP) for the SAGE program is prepared and submitted to our primary host and sponsor, Los Alamos National Laboratory. The HCP details the hazards that may be encountered, plans for mitigation of the hazards and emergency procedures. We also provide the SAGE students and other participants with an extensive hazards document for reference on a wide range of hazards that can be encountered in the local environment and during field work and field trips. At the beginning of the SAGE program, SAGE faculty conduct a one hour lecture/discussion session with the SAGE students in which the hazards, safety precautions and emergency procedures are covered. Additional reminders of hazards and safety procedures are included in planning discussions for each field work period and field trip.

8. <u>Acknowledgments</u> (SAGE 2010):

We are very grateful to The SEG Foundation and donors Geophysical Pursuit, Inc. and TGS-NOPEC Geophysical Company for financial support for the SEG Foundation Projects of Merit, Field Camp grant. This support has enhanced the SAGE program and helped support students who participated in SAGE 2010.

SAGE financial and in-kind support is also provided by Los Alamos National Laboratory, IGPP, the Department of Energy, the National Science Foundation REU program, the U.S. Geological Survey and the participating universities. Several petroleum and geophysical industry companies, including ExxonMobil, Chevron, INOVA, Zonge International, Green Engineering, Kinemetrics and ConocoPhillips have also provided funds and in-kind support for SAGE.

9. <u>Financial Report</u> (SAGE 2010):

The financial report for the SEG Foundations grant is shown below from Purdue University's Sponsored Programs Services (SPS). Accounting and auditing of all expenses was performed by the Purdue Department of Earth and Atmospheric Sciences business office staff under the direction of Business Manager Melissa Guinn and SPS staff.

PURDUE
UNIVERSITY

SPONSORED PROGRAM SERVICES

May 26, 2011

SEG Foundation
Attn: Projects of Merit/Field Camps
P.O. Box 702740
Tulsa, OK 74170-2740

To Whom it May Concern:

Enclosed please find the final financial statement of expenses incurred during the period of May 10, 2010 through March 31, 2011. The project is entitled "Support for SAGE (Summer of Applied Geophysical Experience) 2010." A refund check in the amount of $138.66 will be sent under a separate cover.

This project is under the direction of Dr. Lawrence W. Braile. The SEG Foundation's reference number is 10086606 and Purdue's reference number is Grant 204693.

If you have any questions or require additional information, please contact me at 765-494-6943 or by email spindnfp@purdue.edu.

Sincerely,

Allison Harris
Senior Account Manager

AKH/JES
Enc.

Young Hall ▪ 155 South Grant Street ▪ West Lafayette, IN 47907-2114 ▪ (765) 494-1055 ▪ Fax: (765) 494-1360

FINAL PROJECT FINANCIAL REPORT

Sponsor: Society Of Exploration Geophysicists
Project Name: Support for SAGE (Summer of Applied Geophysical Experience) 2010

Project Investigator: Lawrence W. Braile

Project Period: 05/01/10 - 03/31/11
Report Period: 05/01/10 - 03/31/11
Purdue Grant No.: 204693
Sponsor Award No.: 10086606

Description	Budget	Period Expenses	Accum-to-Date Expenses	Balance
Consultants	$ 6,000.00	$ 6,226.66	$ 6,226.66	$ (226.66)
Travel	6,000.00	6,590.14	6,590.14	(590.14)
Participant Support	6,000.00	3,591.96	3,591.96	2,408.04
Other Supplies & Expenses	2,203.56	3,656.14	3,656.14	(1,452.58)
Total Direct	**$ 20,203.56**	**$ 20,064.90**	**$ 20,064.90**	**$ 138.66**
Facilities & Administration	-	-	-	-
Total Sponsor Cost	**$ 20,203.56**	**$ 20,064.90**	**$ 20,064.90**	**$ 138.66**

I certify to the best of my knowledge that all expenditures reported for payments requested are for appropriate purposes and in accordance with the agreement set forth in the application and award document.

Allison Harris, Senior Account Manager – Sponsored Program Services
(765) 494-6943; spindnfp@purdue.edu

Total Expenses	$ 20,064.90
Payments Received	20,000.00
Earned Interest Income	203.56
Balance	**$ 138.66**