SAGE 2012 Geophysics Highlights

Introduction: SAGE 2012 was the 30th year of the SAGE program. Thirty students (23 NSF/REU undergraduate students, 5 graduate students, one international undergraduate student, and one professional) participated in SAGE 2012 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 western edge of the Española basin and the Caja del Rio area of the Española basin northwest of Santa Fe) provided significant new seismic refraction and reflection, electromagnetic, ground penetrating radar, magnetic and gravity data. The geophysical work in the Caja del Rio area was a new geothermal initiative at SAGE partially supported by a DOE grant. 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 2012 also included three days of geology field trips, one day of seismic basin analysis (a short course presented by Orla McLaughlin and Robert Bielinski of ExxonMobil) and five days of data processing, modeling, interpretation, and written and oral report preparation. There were also several evening talks presented by visiting industry professionals. 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 2012 data. Highlights of some of the SAGE 2012 data and interpretations are shown below.

CMP Seismic Reflection Profile: Common Midpoint (CMP) seismic reflection data were collected along a NW-SE profile (Figures 1 and 2) on the Cerros del Rio plateau in the Española basin in the Rio Grande rift of New Mexico. The data were collected using a vibroseis source (vibroseis truck provided by Dawson Geophysical and INOVA) with an 8-80 Hz sweep at Vibrator Points (VPs) 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.

Nine SAGE 2012 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 REU students attending the SAGE one-week follow-up workshop held in San Diego (San Diego State University) in January, 2012. Seismic reflection data quality in SAGE 2012 was lower than in previous years due to near surface condition – a very low velocity, dry surface layer of unconsolidated sediments that reduced source and geophone coupling, and shallow, thin layers of volcanic rocks that scattered much of the seismic energy. We were able to image an intermediate depth (~1.4 s two-way travel time) basin fill layer (interpreted to be the Espinaso formation) and to recognize a small-offset fault that crossed the profile. Our plans for SAGE 2013 are to work in an area just to the east of the Caja del Rio where the young volcanics are not present and where seismic reflection data are expected to be of much higher quality.

A seismic reflection record section in our field area, from SAGE and industry data, are shown in Figure 1. In addition to the standard CMP stack record section, Figure 1 includes a perspective view (fence diagram) of the seismic data that aids in visualizing the 3-D configuration of the reflectors and correlations of reflectors where the profiles cross. The most prominent feature of this area of the Espanola basin is the deepening of the basin to the north and west. The thickness of basin fill is about 3 km in the northwest part of our study area. These results are also consistent with modeling of gravity data discussed in sections below.

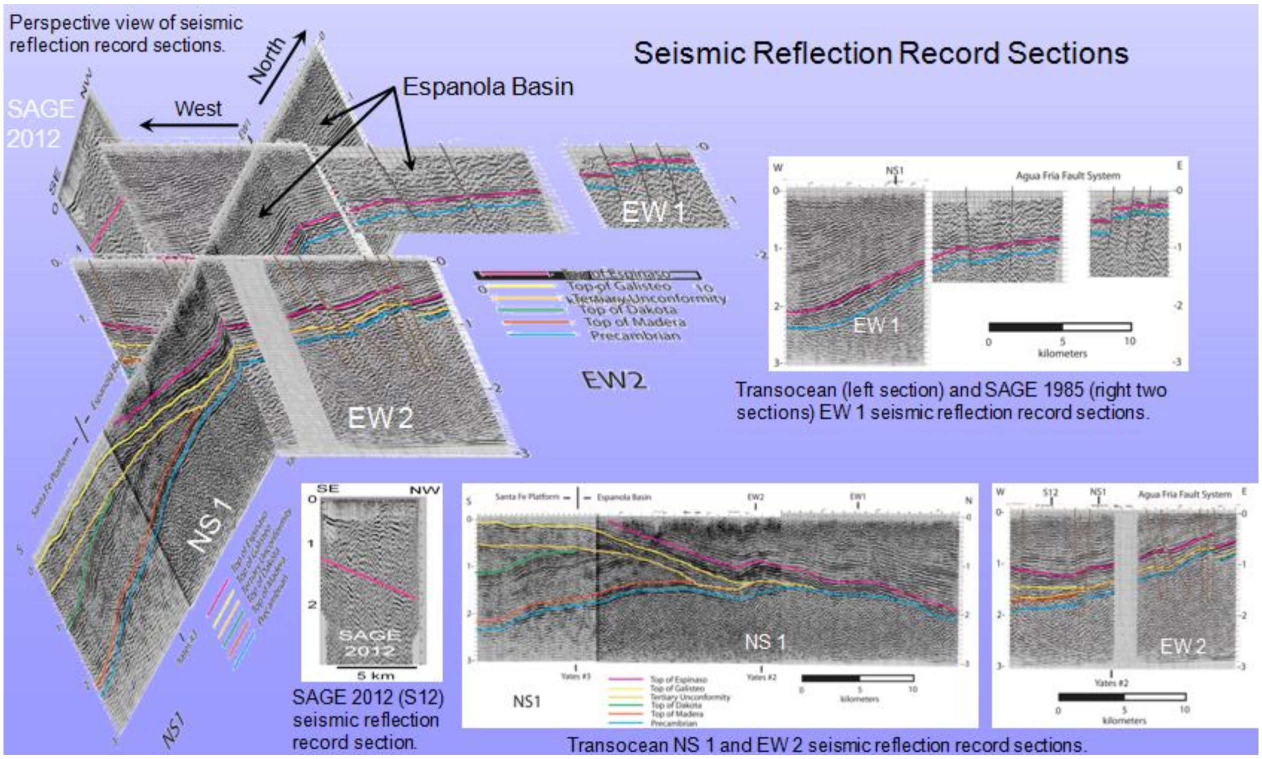

Figure 1. Seismic reflection record sections in the Caja del Rio and Española basin area west of Santa Fe, NM (from Braile et al., 2012). Locations are shown on Figure 2.

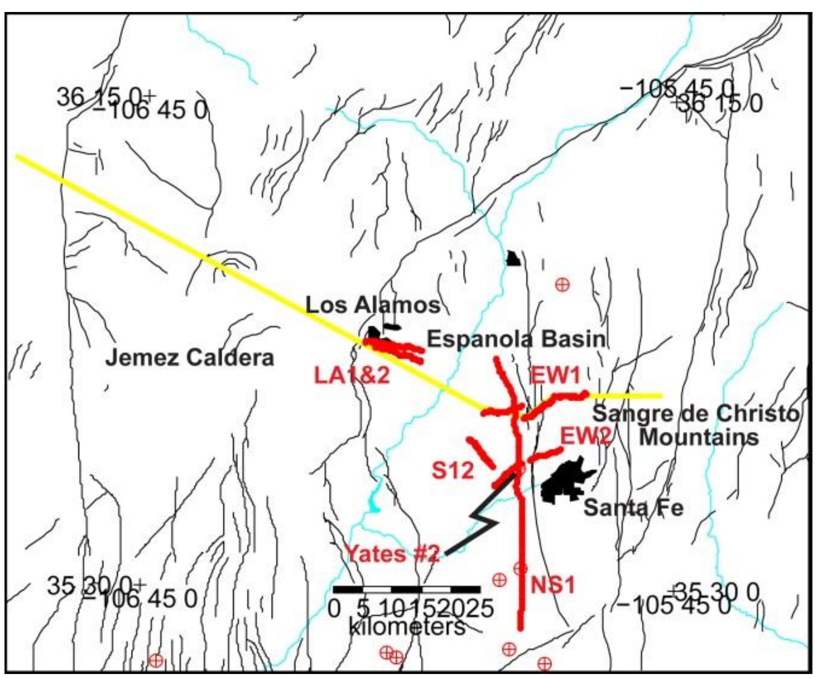

Figure 2. Fault map of the Española basin area. Red lines are seismic reflection profiles. Yellow line shows gravity model profile. Crossed circles are deep drill holes.

Gravity Data Collection and Interpretation – Caja del Rio Area: SAGE has been producing new geophysical data in the Española Basin of northern New Mexico for 30 years. We also have access to seismic reflection and borehole data from petroleum exploration in the 1970s. A wave of new geological and geophysical mapping by the NM Bureau of Geology and Mineral Resources and the US Geological Survey has also become available over the past 10 years. SAGE investigators are now seeking to integrate all of this information into a coherent tectonic model of the Española basin and its transitions with the adjacent Santo Domingo and San Luis basins. The SAGE 2012 work shown on the maps and profiles (Figures 3-5) is a good example of this integration. The majority of the gravity data incorporated into this model (Figure 5) was collected by SAGE. The east end of the model (between about 70 and 110 km) is constrained by seismic reflection data on line EW-1 (Figures 1and 2). These data include exploration data in the western 10 km and data collected by SAGE in 1985 in the eastern 15 km of EW-1. An important conclusion associated with this model is the location of the Los Alamos graben bounding fault near 75 km. Current SAGE field work (2011 and 2012) has been located in the vicinity of this profile east of the Rio Grande. These recent SAGE operations have been targeted elucidating the source of hot water detected in wells. The model is only constrained by gravity data and geologic mapping west of 80 km. A compilation of borehole data in the Jemez Volcanic Field was recently made at the SAGE 2013 REU Winter Workshop and a revised version of this model will be produced during SAGE 2013.

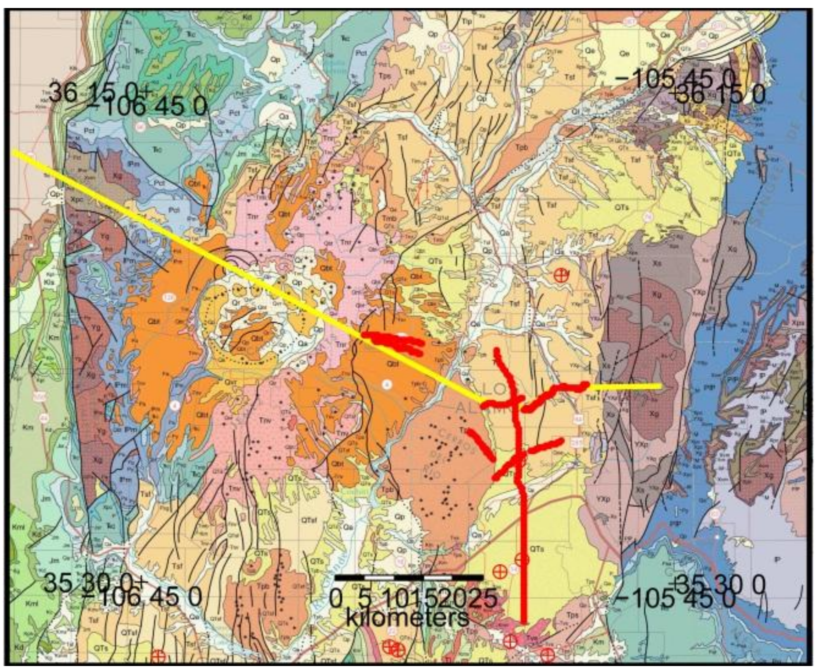

Figure 3. Geological map. Red lines are seismic profiles. Yellow line is gravity model profile. Crossed circles are deep drill holes.

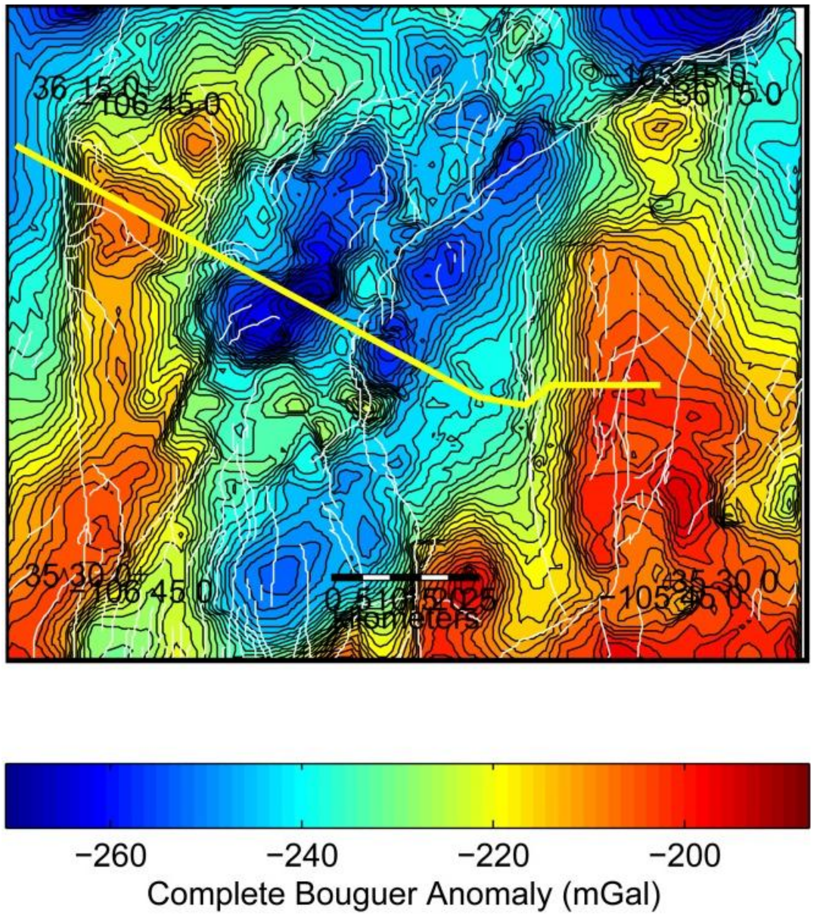

Figure 4. Complete Bouguer anomaly map of the Española basin area. Yellow line is gravity model profile.

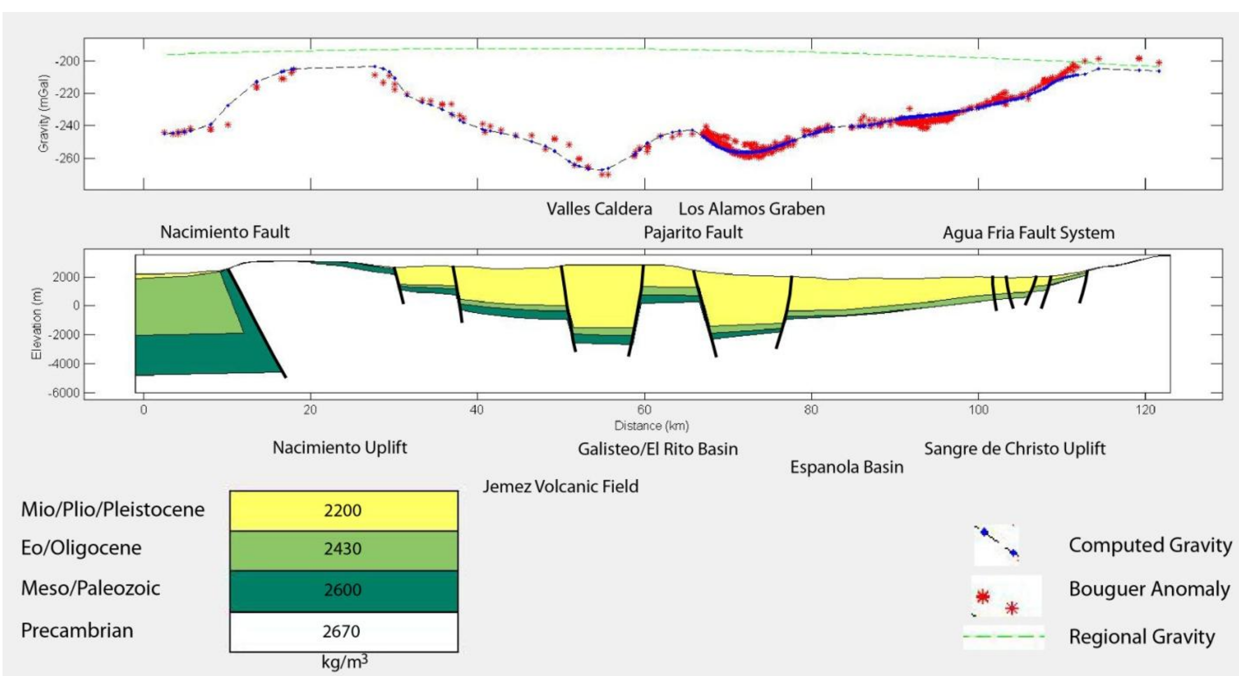

Figure 5. Gravity model along profile shown in Figure 4.

Geophysical Surveys in the Caja del Rio Geothermal Area: The SAGE program was expanded in 2011 to include geothermal assessment by taking advantage of its location in Rio Grande rift and additional short-term funding from the National Renewable Energy Lab (NREL/DOE). This expansion addressed the national call for more renewable energy and new career opportunities for students. The initial effort was followed by a proposal in September of 2011 to the NSF and the DOE to enhance the SAGE program to include a geothermal component. The proposal was funded and the enhancement implemented by SAGE in 2012. A field site near Santa Fe, New Mexico was selected after SAGE students reviewed 28 years of SAGE geophysical results and other available geological, geohydrologic, geophysical, and geochemical data. The site is ~25 km northwest of Santa Fe, New Mexico in the Caja del Rio volcanic field. Here, 1.14-2.8 Ma volcanism has been mapped from 50 exposed vents and high temperatures recently have been reported (Manning, 2009) in deep water wells. These findings along with high $^3He/^4He$ ratios in groundwater (Manning, 2009) and numerous, rift-related faults may expose a high-temperature magmatic/mantle component in the groundwater.

Magnetotelluric data and results: Students during the 2012 SAGE program applied phase tensor (Jiracek et al., 2012) analysis to 8 magnetotelluric (MT) soundings (Figure 6) aimed at understanding the occurrence of anomalously high vertical and horizontal temperature gradients located approximately 25 km NW of Santa Fe, New Mexico. Four of the MT soundings were recorded by SAGE 2012 students. Plots of phase tensor ellipses allowed unique, distortion-free visualization of the dimensionality and directions of major geoelectric variations. Analysis of the plots as functions of frequency and location revealed a nearly one-dimensional (1-D) upper conductive, Española Basin sedimentary section. Variations in the orientations of the principal axes of phase tensor ellipses exposed an overall, deeper three-dimensional (3-D) geoelectric structure in the region. However, two sequential frequency bands revealed dominantly two-dimensional (2-D) regional features over much of the ~16 km long profile (Figure 6). They were identified as trends in the approximately 3 km-deep resistive basement and a midcrustal conductor at about 15 km depth, each with differing geoelectric strike directions. MT data from the upper 1-D/2-D (basin/basement) section permitted non 3-D analysis with results agreeing with drill hole, seismic, and gravity data. Figure 7 presents the geoelectric section stitched together from 1-D inversions of the MT data. Here, the basin/basement depth of ~3 km agrees very well with the independent gravity density model (Figure 8) obtained during SAGE 2012.

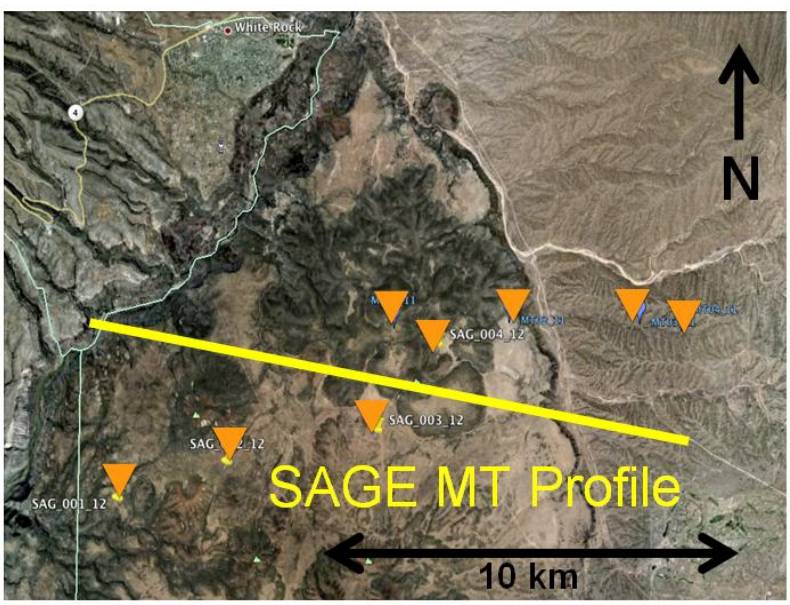

Figure 6. Location of MT sites and modeling profile in SAGE 2012 north-central New Mexico study area.

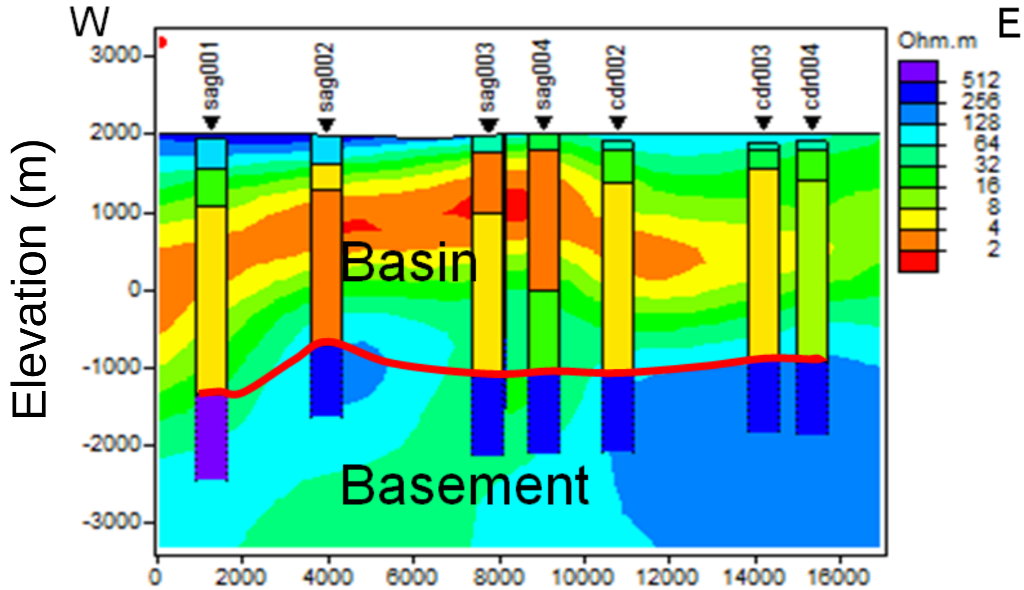

Figure 7. MT geoelectric section derived from stitched together 1-D inversions showing ~ 3 km deep basin/basement contact. Horizontal scale is distance in meters.

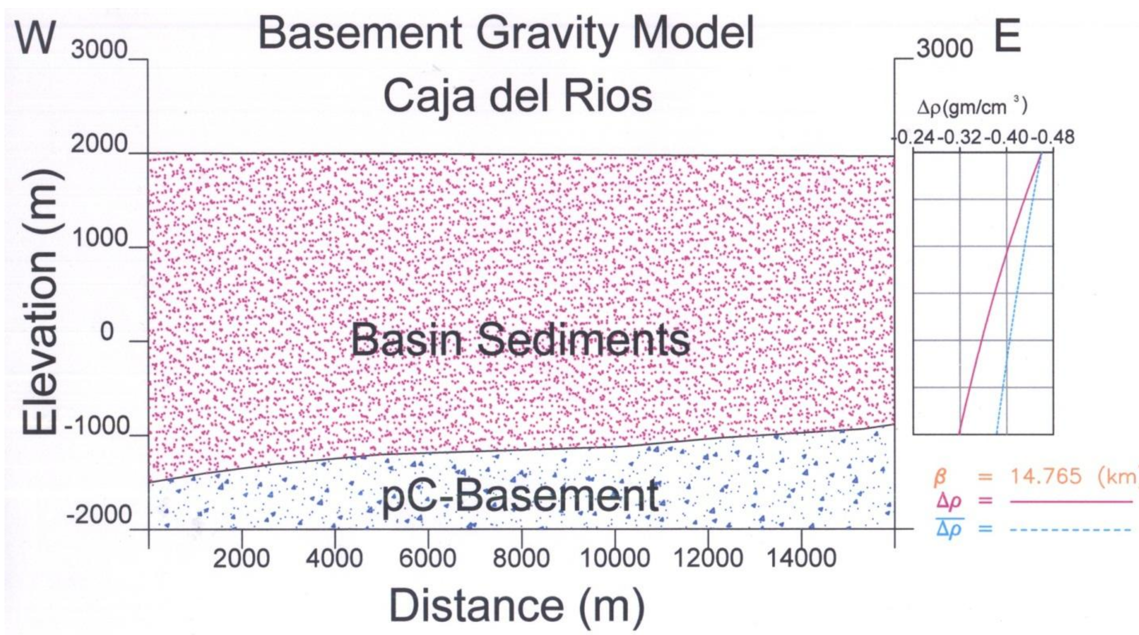

Figure 8. Basin/basement density model derived from 2-D inversion of SAGE gravity data assuming a hyperbolic change of density with basin depth.

Mapping the edge of the Cerros del Rio volcanic field, New Mexico: The Cerros del Rio volcanic field located west of Santa Fe, New Mexico spans the southwestern part of the Espanola Basin with the Rio Grande to the west. Underlying the volcanics are the Santa Fe Group sediments, which contain the Ancha Formation, an important aquifer in the region. High temperature gradients in water wells reveal a potential geothermal prospect. In 2012 the Summer of Applied Geophysical Experience (SAGE) program acquired transient electromagnetic (TEM), audiomagnetotelluric (AMT), gravity and ground magnetic data to determine the buried eastern margin of the volcanic field and underlying structure (Figure 9).

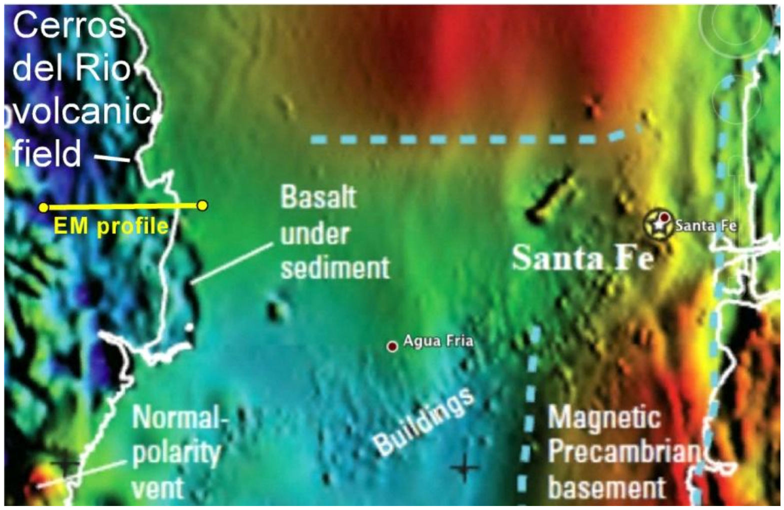

Figure 9. The roughly EW 5-km long transect was sited from USGS aeromagnetic data (Grauch et al., 2009) to cross the boundary of the Cerros del Rio volcanic field.

TEM data were collected at ten stations, at 200-400 m spacing along the transect, employing an in-loop configuration, a square 100 m x 100 m transmitter loop and both a Zonge receiver coil and a 5 m square receiver loop. The-5 m loop allowed for the recovery of early-time data that was saturated when using the Zonge coil. AMT data were acquired at eight stations, at 400-500 m spacing, using the Geometric Stratagem system recording from 92 kHz to 10 Hz; a horizontal magnetic dipole transmitter was used to augment low signal strength at around 1 kHz. Gravity data along the profile were acquired using CG-3 and CG-5 Scintrex gravimeters with a station interval >250 m. Magnetic data were acquired with a Geometrics Cesium vapor G-858 magnetometer for about 3500 m along the profile at a 0.5 second sampling rate.

Two volcanic flows interbedded with Ancha Formation and overlying Santa Fe Group sediments were identified in both the TEM and AMT models (Figure 10). High surface resistivity zones (>300 ohm-m) with depths ranging from ~100 to 300 m define the volcanic flows and correspond to high densities (2.3 to 2.55 g/cm3), while low resistivity zones (<30 ohm-m) correspond to lower densities (~2.1 g/cm3). High spatial-frequency magnetic variations are a possible indication of different volcanic flows that are characterized by normal or reverse remnant magnetization. The upper flow (normally polarized) is inferred to extend beyond the study area and, therefore, past the end of the Cerros del Rio volcanic field boundary defined by USGS aeromagnetic data.

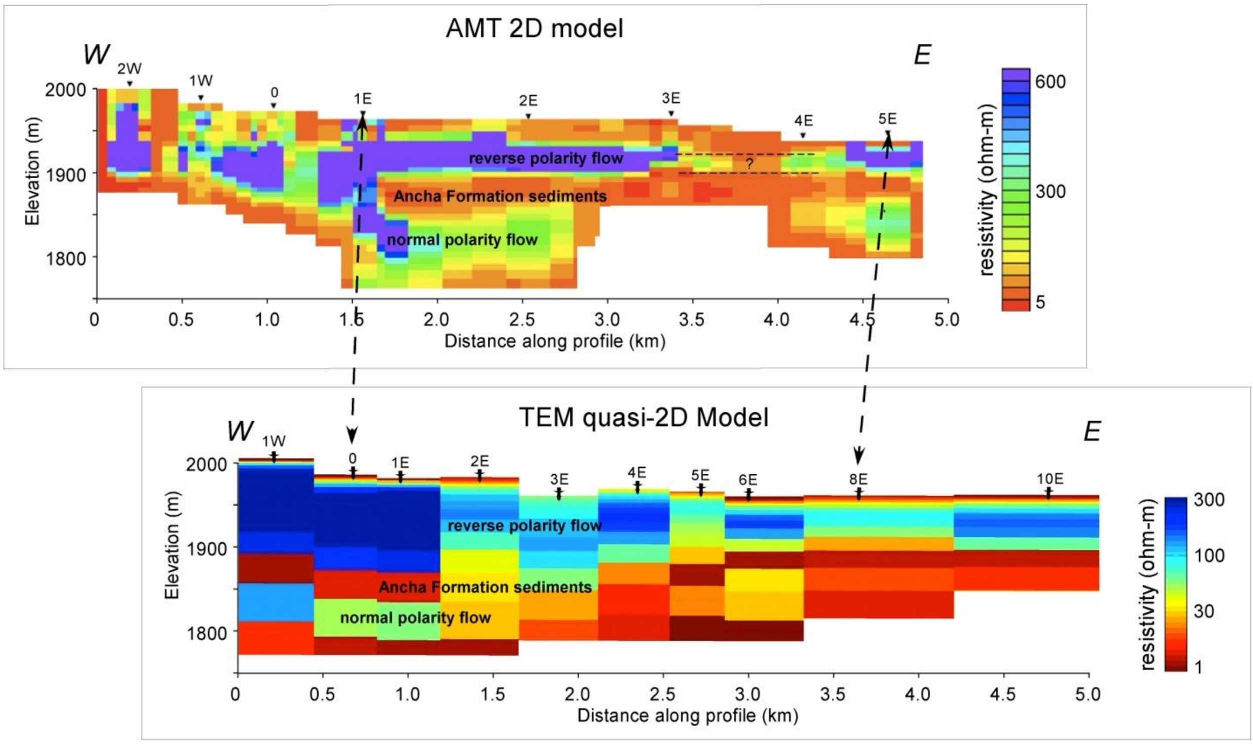

Figure 10. AMT data were processed with 0.9, 0.7 and 0.5 coherencies; 0.5 was found to produce the highest quality apparent resistivity and phase curves were used in a 2-D inversion. Twenty layer-earth (or 1D) models were fit to the TEM data at each station and stitched together along the profile to create a pseudo 2D cross-section.

The models indicate the resistive volcanics are thickest in the west and thin towards the east, with an upper and lower resistive unit in the West separated by a thin conductor. Possible explanations for the observed structure include multiple volcanic flows, fault control, and the presence of water.

San Marcos Pueblo Archaeological Site Geophysical Surveys: Over the past four years the SAGE efforts at the San Marcos Pueblo archaeological site have focused on creating detailed (0.5 m sample interval) maps of a 2.25 hectare area (about 10% of the site) using a total field magnetometer (Figure 11), EM-31 (Figure 12) and 250 MHz radar. The “El Mapo Grande” area covers four room blocks and an extensive plaza area (Figure 13). The area is underlain by Pleistocene terrace and Pliocene Ancha formation sediments. Spanish Colonial age metal smelting operations have been excavated at the points plotted near the center of the Magnetic Map. The maps are being used to identify other potential archaeological features and to constrain the geologic model of the site. There are trains of magnetic material in shallow channels eroded into the hill-slope below the room blocks. These debris plumes may be related to the smelting operations and this hypothesis is under investigation. There are also nine high resolution seismic refraction and reflection lines in the map area (only two are shown on the Index Map, Figure 13). Current and future efforts are being directed at integration of these data, which were collected over an 8 year period, and the siting of additional seismic lines in areas of particular interest.

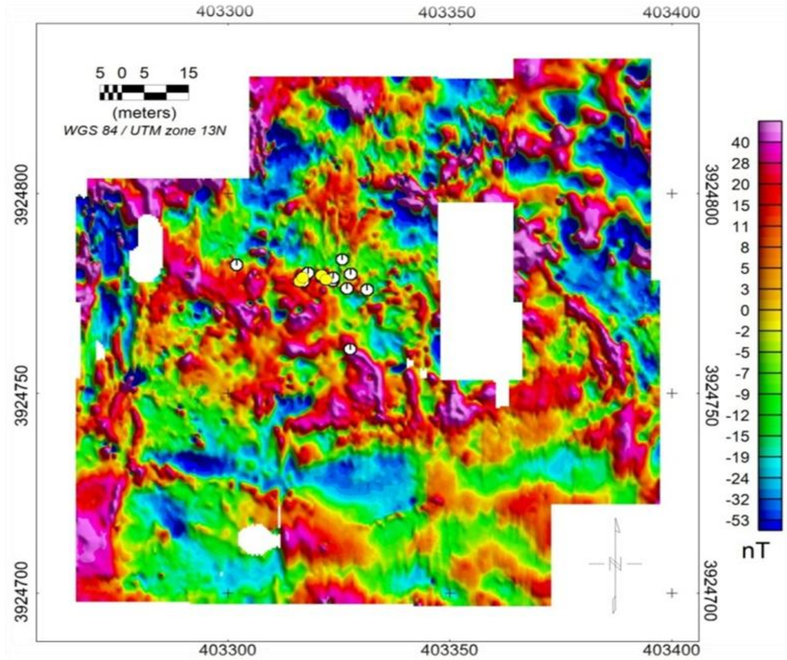

Figure 11. Residual total field magnetic anomaly map of an area (Figure 13) of the San Marcos Pueblo. Coordinates are zone 13N UTM.

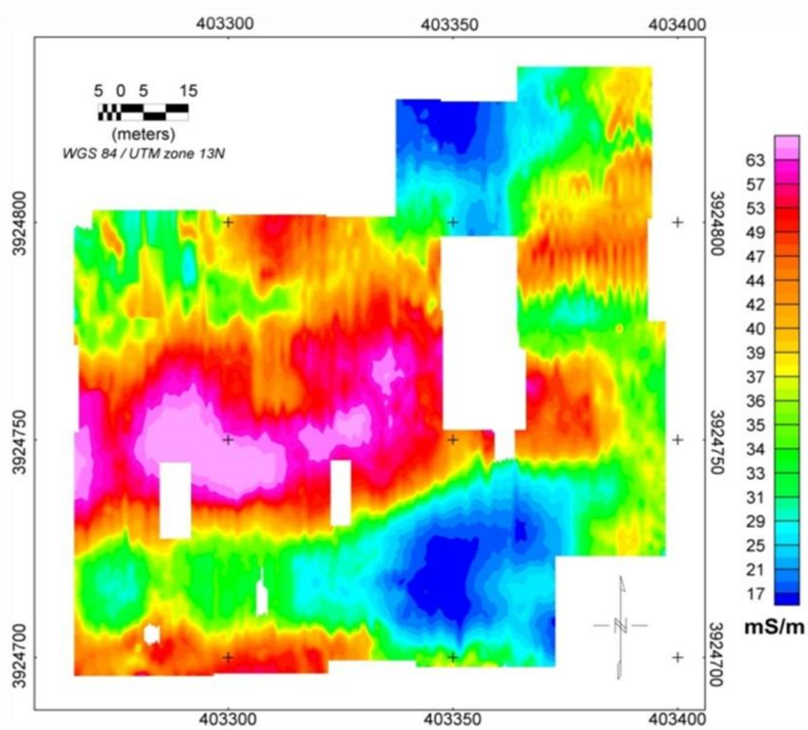

Figure 12. Conductivity anomaly map of an area (Figure 13) of the San Marcos Pueblo. Coordinates are zone 13N UTM.

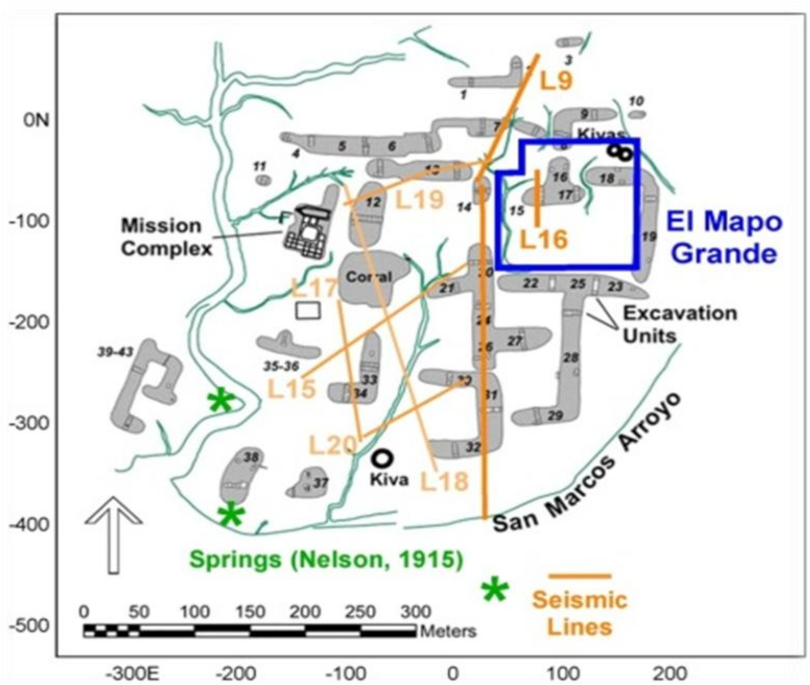

Figure 13. Site map of the San Marcos Pueblo.

SAGE Publications – 2012

Recent SAGE Publication: Baldridge, W.S., L.W. Braile, S. Biehler, G.R. Jiracek, J. Ferguson, D. Hasterok, L. Pellerin, P. Bedrosian, D.K. McPhee, and C. Snelson, SAGE at 30, *The Leading Edge*, June, 2012, p. 702-708.

Poster presented at Fall 2012 SEG meeting: *El Mapo Grande: A geophysical investigation of the San Marcos Pueblo*; C. Joiner, J. Ferguson, J. Nolan, P. Gillies, M. Litherland, G. Johnston, D. McPhee and L. Pellerin, (2012). (http://web.ics.purdue.edu/~braile/sage/JoinerSEG2012.pdf)

Poster presented at Fall 2012 AGU meeting: *Mapping the edge of the Cerros del Rio volcanic field, New Mexico: a piece of the puzzle to understanding a potential geothermal resource*; Pellerin, L., Gallegos, M., Goebel, M., Murphy, B., Smith, J., Soto, D., Swiatlowski, J., Volk, C., Welch, M., Feucht, D., Hollingshaus, B., Bedrosian, P.A., and McPhee, D.K.
(http://web.ics.purdue.edu/~braile/sage/PellerinAGU2012.pdf)

Poster presented at Fall 2012 AGU meeting: *Magnetotelluric Phase Tensor Applications to Geothermal Assessment in New Zealand and New Mexico*, George R. Jiracek, Daniel Weston Feucht, Diana Brown, Brian Castro, Jason Chang, Derek Goff, Christian Hardwick, Becky Hollingshaus, Esteban Bowles-Martinez, Jenny Nakai, Collin Wilson, Edward Alan Bertrand, Stewart Bennie, Grant Caldwell, Graham J. Hill, Erin Wallin, Paul A. Bedrosian, Derrick P. Hasterok, and Louise Pellerin.
(http://web.ics.purdue.edu/~braile/sage/JiracekAGU2012.pdf)

Poster presented at Fall 2012 AGU meeting: *Seismic and Gravity Investigations of the Caja del Rio Geothermal Area, New Mexico*, Lawrence W. Braile, Brandon Burke, Emily Butler, Christopher Harper, Jennifer Livermore, Austin McGlannan, Anne Wasik, W. Scott Baldridge, Shawn Biehler, John F. Ferguson, Darcy K. McPhee, Catherine Snelson, Aviva Sussman.
(http://web.ics.purdue.edu/~braile/sage/BraileAGU2012.pdf)

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Joiner, C., J. Ferguson, J. Nolan, P. Gillies, M. Litherland, G. Johnston, D. McPhee and L. Pellerin, (2012), El Mapo Grande: A geophysical investigation of the San Marcos Pueblo, NM, 2012, SEG Annual Meeting, Las Vegas, NV.

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