FastTIMES

Volume 27, Number 4, 2025

Geo Hazards

CONTENTS

Environmental and Engineering Geophysical Society

Calendar of Events

Call for SAGEEP 2026 Abstracts
https://www.eegs.org/sageep-2026-abstract-submission
Deadline to submit: Dec. 19, 2025

UAVs and Drones in the Geosciences
https://seg.org/calendar_events/uavs-and-drones-in-the-geosciences/
1–4 December 2025
Virtual only

Groundwater Week 2025
https://groundwaterweek.com/
9–11 December 2025
New Orleans, Louisiana, USA

American Geophysical Union (AGU) 2025
https://www.agu.org/annual-meeting/
15–19 December 2025
New Orleans, Louisiana, USA

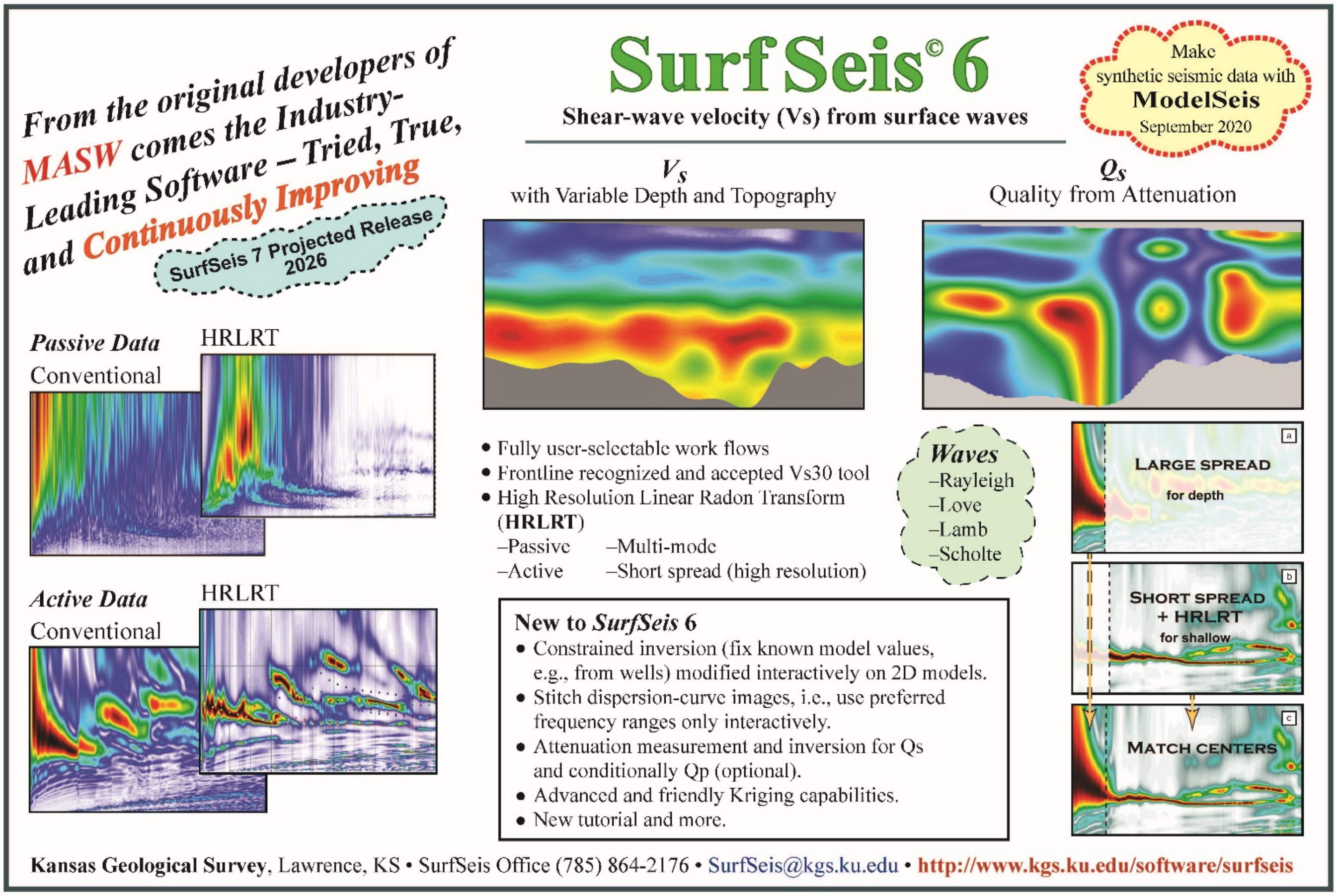
8th International Workshop on Rock Physics
https://www.8iwrp.auckland.ac.nz/
23-27 February 2026
Auckland, New Zealand

GeoTHERM Expo & Congress
https://www.geotherm-offenburg.de/en
26-27 February 2026
Offenburg, Germany

SAGEEP 2026
https://www.eegs.org/sageep-2026
March 15-19, 2026
Pittsburgh, Pennsylvania USA
Wyndham Grand Pittsburgh Downtown

European Geosciences Union (EGU) General Assembly 2026
https://www.egu26.eu/
3–8 May 2026
Vienna, Austria & Online

SEG-AGU Hydrogeophysics Workshop
https://seg.org/calendar_events/seg-agu-hydrogeophysics-workshop/
20–22 July 2026
Boise, Idaho, USA



CONSULTANTS, CONTRACTORS AND GEOPHYSICAL TECHNOLOGY PROVIDERS:

Are you reaching out….but not connecting?

Advertising in *FastTIMES* can help you reach potential users or customers….and make those connections!

GAINS is returning in January 2026!

Geophysical Applications In Near Surface

VIRTUAL COURSE

GAINS

- GAINS is a virtual training course designed for those looking for an introduction or refresher on practical applications in environmental & engineering geophysics
- Expand your knowledge & your network!
- Thursdays from 2-4pm (Mountain Time)
- Recordings will be available to registrants!

9 Weeks of Virtual Courses & a Panel at SAGEEP 2026:

Date	Module Topic	Subject Matter Expert(s)
Jan 15	Geophysical applications: history & survey essentials	Cathy Skokan, Colorado School of Mines & the EEGS Education Committee
Jan 22	Dams, levees, and embankments	Trever Ensele, Prospect Geophysics
Jan 29	Ground-penetrating radar in the Arctic	Esther Babcock, Ph.D., Logic Geophysics and Analytics LLC
Feb 5	Hydrostratigraphic characterization, contaminant monitoring	Judy Robinson, Ph.D., & James St. Clair, Ph.D., Pacific Northwest National Laboratory
Feb 12	Borehole applications and case histories	Lia Martinez, Mount Sopris Instruments & Darin Pendergraft GEOVision
Feb 19	Voids, karst, and sinkhole mapping/detection	Jacob Sheehan & Mia Painter, Schnabel Engineering
Feb 26	Marine & coastal applications	Richard Graham, Sirius Group Geo Consulting
Mar 5	Archeogeophysics and forensic geophysics	Blair Schneider, Ph.D., Kansas Geological Survey
Mar 12	Geophysics for the Pennsylvania PG exam	Kate McKinley, PGp, PG, THG Geophysics Ltd.
Mar 18	*Luncheon & GAINS SME Panel*	*Wednesday SAGEEP 2026 Luncheon in Pittsburgh, PA*

GAINS is open to all EEGS Members!

Renew your membership today & encourage your colleagues to join.

Visit eegs.org/GAINS or contact staff@eegs.org for more information

Thank you for signing up! -EEGS Education Committee


SAGEEP
Symposium on the Application of Geophysics to Engineering and Environmental Problems
March 15-19, 2026
Wyndham Grand Downtown
Technical Chair Laura Sherrod invites you to submit topics for Sessions you'd like to see at SAGEEP 2026! Send suggestions to staff@EEGS.org!
submit an abstract
Pittsburgh Pennsylvania USA
Short Courses
Student Events
Special Sessions
Keynote Speaker
Outdoor Demonstrations
Oral/Poster Presentations
Luncheons
Ice Breaker
Case Studies
Student Events
Networking Events
Conference Evening
WWW.EEGS.org/SAGEEP2026

SAGEEP 2026

Watch for updates at
www.EEGS.org/SAGEEP-2026

The Conferences

SAGEEP is internationally recognized as the leading conference on the practical application of near surface geophysics. Since 1988, the symposium has featured nearly 300 oral and poster presentations, educational short courses and workshops, a commercial exhibition and field trips. This in-person SAGEEP once again brings together geoscientists from all over the world.

The Technical Program

The Technical Program typically features 300 oral and poster presentations. SAGEEP 2026 will be a source of the latest research and case studies. Fred Day-Lewis, VP SAGEEP, will be assembling his planning team who are are developing an impressive Technical Program, featuring several special sessions and invited speakers.

Host City - Pittsburgh

Pittsburgh is surrounded by hills and rivers and features scenic topography. The Monongahela, Allegheny and Ohio rivers come together in downtown Pittsburgh. Known as the "City of Bridges", Pittsburgh's over 446 bridges connect the city's various neighborhoods and provide stunning views of the skyline.

SAGEEP 2026's host city is home to notable institutions like the Carnegie Mellon University (CMU), University of Pittsburgh Medical Center, and the University of Pittsburgh. Pittsburgh attracts leading companies and research institutions in fields such as robotics, artificial intelligence, and advanced manufacturing. The city's commitment to innovation and entrepreneurship has positioned it as a global leader in cutting-edge technologies.

The Exhibits/Exhibitors

Over 10,000 square feet will be devoted to exhibitors bringing the latest in hardware, software, and services. Attendees will be watching for the EEGS Foundation Auction where valuable and sometimes historic items will be available for bids. Posters, a valuable component of the technical program, will be viewable in the Exhibit Hall.

Sponsor/Support Opportunities

Sponsoring the conference, a Special Session or a social event is an effective and economic way to increase visibility for your organization or services. SAGEEP meetings attract a targeted audience of geophysicists from multiple disciplines.

Exhibits Manager I Micki Allen I Marac Enterprises I mickiallen@marac.com

Environmental and Engineering Geophysical Society

President's Message

Dale Rucker, President

Certerra Subsurface Imaging

drucker@hgiworld.com

This issue of FastTIMES showcases how near-surface geophysics directly serves communities and infrastructure. You'll find a self-guided tour of active growth faults in Harris County that connects decades of mapping and geophysics to real-world impacts on homes and roads, a concise case study from Oroville Dam where GPR, refraction, and borehole logging supported urgent spillway safety decisions, and front-yard-scale investigations in Austin that link pavement distress to karst and subsurface complexity. Each contribution underscores our core strength, i.e., using practical, accessible methods to make invisible problems visible.

As we celebrate this work, we also pause to acknowledge the passing of our colleague Brian Herridge, a dedicated near-surface geophysicist whose seismic expertise and ingenuity strengthened this community. Though I did not know Brian personally, it is clear from those who did that his genius inspired a generation of near-surface professionals.

Finally, FastTIMES remains a platform for your projects, technologies, and services. There are excellent opportunities to advertise to a focused audience that lives and breathes environmental and engineering geophysics. At the same time, we need your very best technical work submitted to JEEG, including rigorous case histories, new methods, and quantitative assessments. If you have a strong project in FastTIMES form, consider developing it into a full JEEG manuscript. Together through membership, contributions, sponsorship, and publication, we keep this community visible, relevant, and technically sharp.

— Dale Rucker, President, EEGS

Editorial

FastTIMES Editor-in-Chief
Mehrez Elwaseif, PhD, PGp
Jacobs

Over the past two years, serving as editor of the FT magazine has been deeply rewarding. Each issue reflected innovation and impact, making the role both professionally rewarding and personally inspiring in shaping meaningful narratives. I wish continued success for FT publication and every achievement for the next editor.
Sincerely,

Mehrez Elwaseif
Editor-in-Chief, *FastTIMES*

New Editor-in-Chief

Cian B. Dawson joins EEGS as the incoming 2026 *FastTIMES* Editor in Chief. Cian brings a passion for science communication, hydrogeophysics, and fair and open science to his new role.

"I'm excited to continue my collaborations with near-surface geophysics colleagues by promoting and sharing our community's dynamic work through timely and relevant news and information in *FastTIMES*," said Cian.

With experience in government, environmental consulting, NGOs, and environmental litigation, Cian has been developing science communication, training, and community events for scientists for almost 35 years. As a hydrologist at the U.S. Geological Survey (USGS) for 23 years, Cian worked on borehole, surface, waterborne, and airborne hydrogeophysical surveys at study sites across the US; Cian's research evolved to focus on development and testing of new drone-based sensors and their integration into hydrologic and geophysical studies. At USGS and more recently at Berkeley National Lab, his work also focused on developing and promoting community building and information sharing among scientists. In 2022, Cian, along with colleagues from the (former) USGS Hydrogeophysics Branch, was recognized with the American Geophysical Union (AGU) Edward A. Flinn III Award for training and outreach in service to the hydrogeophysics professional community. Cian also received the 2023 USGS Community for Data Integration Leadership and Innovation Award for leadership and vision through USGS data communities of practice.

Cian shared, "I have such fond memories of my first-ever geophysics professional conference presentation at SAGEEP during grad school and how welcoming the SAGEEP/EEGS community was. I look forward to representing that same welcoming community in *FastTIMES* by highlighting our community's diverse range of scientific applications, sectors, demographics, career levels, and geographies."

Planning for *FastTIMES* in 2026 is well underway, so please keep an eye out for calls for contributions to share your work! Reach out to Cian (pronounced (KEEˈ in/) at any time with suggestions for future issue themes at cian@cbdawson.com.

Figure: Preparing to test prototype payload for particle image velocimetry on the Sacramento River, California. Credit: Massimo Vespignani/NASA

Call for Submissions: March 2026 *FastTIMES*

FastTIMES, the near-surface geophysical magazine of the Environmental and Engineering Geophysical Society (EEGS), invites technical article submissions for a March 2026 special edition focused on *Fiber Optic Distributed Sensing: Recent Advancements & Future Directions*. This issue of the magazine will feature applications of fiber-optic distributed sensing methods and tools to environmental and engineering applications. Short articles will focus on:

- Examples of use of fiber optic distributed sensing (e.g., distributed acoustic sensing, distributed temperature sensing) to characterize or monitor the near-surface for environmental or engineering studies.
- Integration of fiber-optic distributed sensing surveys into multi-method geophysical studies.
- Recent advancements that have enabled current work.
- Future directions, including gaps and needs for development of tools, software, training, or other resources.

If you are interested in submitting a short paper to this edition or have further questions, please contact Cian Dawson, *FastTIMES* Editor in Chief, at cian@cbdawson.com

Submission Timeline

Deadline for abstracts: Friday, January 9, 2026
Notifications of abstract acceptance: Friday, January 16, 2026
Submission of the full and final manuscript: Friday, February 13, 2026
Publication date of the issue: March 2026

Paper Structure and Submission Guidelines

EEGS recommends potential authors review recent issues of *FastTIMES* at https://www.eegs.org/latest-issue for examples of the typical technical article style.

Audience

FastTIMES technical articles provide a timely overview of a geophysical topic, application, method, or issue to a broad science and engineering audience who may be interested in applying the information to their work. Most readers will not be detailed subject matter experts on your specific topic. The audience for the technical articles is geoscience professionals, including EEGS members, research scientists and engineers, policy makers, program managers, resource managers, and related science and technical professionals. *FastTIMES* is distributed to EEGS members, offered to several associated professional societies within and outside the geophysics community, and available online through the EEGS website.

Length

FastTIMES technical articles typically do not exceed four to six pages. Manuscripts can be longer or shorter, but the intent is for the manuscript to be read by a general geoscience audience. Please include at least 2 high-quality figures and/or photos that add value to the manuscript.

Manuscript File Format

Manuscripts should be submitted as a Microsoft Word file (.docx) with text, figures, and tables included in the document (single column, font Times Roman 11 pt). Individual image files should also be provided separately from the document.

- The standard FastTIMES technical article structure is:
    - (1) Title; (2) Author(s)' first name(s) and last name(s); (3) Affiliation for each author; (4) Email address for each author; (5) Abstract; (6) Introduction; (7) Data; (8) Methods; (9) Results and Discussion; (10) Conclusions; (11) List of References; and (12) Author Biographies.
- Include the complete text of any table captions in the document.
- Images:
    - All figures should be embedded in the Word file at the appropriate location relative to the text.

  - In addition to embedding any images in the Word document, please provide each image as a separate file, with a clear, human-readable file name.
    - All image files must be a raster format, such as jpg, png, or tiff formats.
    - Images should be at least 1800 pixels in both dimensions with a minimum resolution of 300 pixels per inch (120 pixels per cm).
  - In the Word document, include a caption for each figure or photo.
    - Assign each figure a number in the order they are referenced in text (e.g., Figure 1, Figure 2, etc.)
    - Any images for which the authors do not hold copyright ownership must include credit and affirmation of permission to use by the copyright holder. EEGS may re-use the figures in FastTIMES, on the EEGS website, on social media, and/or in other organizational print or digital materials.
  - At this time, FastTIMES does not accept animated gifs or videos.
- You may send a PDF version of your manuscript in addition to the Word file and the separate image files. A PDF cannot be submitted in lieu of the Word file.

Citations & References

For citations and references, please follow this format:
Smith, A. B., Collins, R. A., and Simpkins, T. V., 2008, Amazing and incredible results from time-domain EM: FastTIMES, v. 12, no. 3, p. 55-67. https://doi.org/10.9999/0000000.

References such as this one should be cited in the manuscript text as Smith and others, 2008.

Fees

There is no charge for publishing articles in *FastTIMES*. However, voluntary contributions to EEGS are welcome. If you choose to contribute here, please indicate that your contribution is intended to support *FastTIMES*.

Author's Submission checklist:

- I am submitting an original technical article or historical/anecdotal article that is of interest to near-surface geophysicists and end-users of near-surface geophysical products.
- My paper is not intended as a commercial advertisement of a particular product or company, and does not endorse or recommend products or services.
- All listed co-authors have reviewed and provided individual written approval of the final draft for publication.
- I am enclosing a readable Microsoft Word file with text and inserted figures at their location where I want them in the published version.
- I am also attaching my figures as image files named 'Figure1.jpg' to 'FigureN.jpg'
- My manuscript structure is: (1) Title; (2) Author(s)' first name(s) and last name(s); (3) Affiliation for each author; (4) Email address for each author; (5) Abstract; (6) Introduction; (7) Data; (8) Methods; (9) Results and Discussion; (10) Conclusions; and (11) List of References.
- I am sending short bios and pictures of myself and each of my co-authors (please name picture files with the person's first and last names).
- I have the appropriate copyright permissions to use any images that were not created by the author(s).
- I have double-checked the above list and verified the Editor's email address.

Brian Herridge Memorial

Doug Crice

Brian Herridge passed away on October 18, 2025 while fishing on Lake of the Woods. The lake was cold and

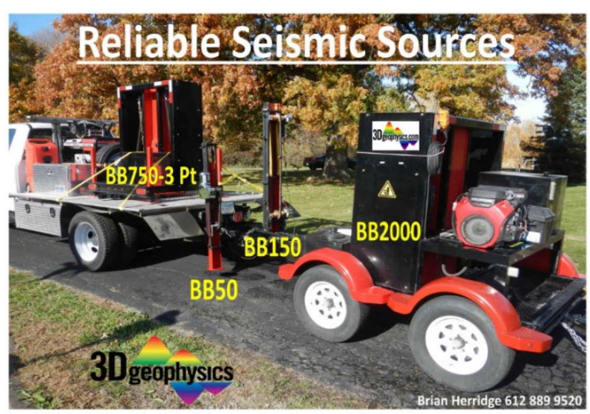
windy, like Minnesota lakes get this time of the year, and swells were reported at 5 to 7 feet. One swamped the boat as he was pulling up the stern anchor and the boat sank quickly. His companion survived for 20 minutes in the cold water before being rescued.

In the geophysical community, Brian was a larger-than-life figure, known to many of you, especially those of us who have been around for a while. I first met him over 40 years ago when he was a salesman for Bison Instruments and I competed with him at Nimbus Instruments. He was a striking, suspender-clad presence around the SEG convention floor with his flamboyant personality. As a competitor, he could sell circles around me.

While at Bison, he invented the in-hole shotgun, which he called the "Buffalo Gun". The more prudent folks at Bison recognized the potential liability and made him absolve all association with it. Sue Pullan wrote the definitive paper describing how to assemble one.

Brian had other talents, like welding for example, and if he had an idea he would go out to his shop and put it together. He built a seismic energy source which used a giant rubber band to accelerate a weight. Playing on the rubber band, he named it "the elastic wave generator". Of course, his elastic wave generator evolved into many variations of the "accelerated weight drop" that you see today.

His interest in sources continued to this day and he built an assortment of more powerful versions, including one pictured here with a 2000-pound mass. Brian believed



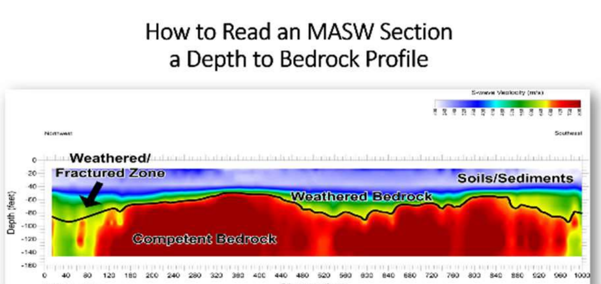
correctly that bigger energy sources collected deeper and lower frequency MASW data.

Brian got his degree in Geology from The College of St. John's in 1978 and went to work as a soil technician. Bill Kwasny says Brian caught on to everything they taught him, from testing soil in the field and in the laboratory, to running the pressuremeter. One of his valuable abilities was that he could fix any broken piece of equipment out in the field with some bubblegum and a bobby pin!

He spent some time on drill rigs and SPT hammers, so he knew the problems in the earth and methods. He learned geophysics at the University of Minnesota under Hal Moony, the godfather of engineering geophysics. He went into private consulting after his days at Bison and developed skills in all aspects of near surface geophysics. As a consultant, Brian was successful, partially because of his skill in selling geophysics.

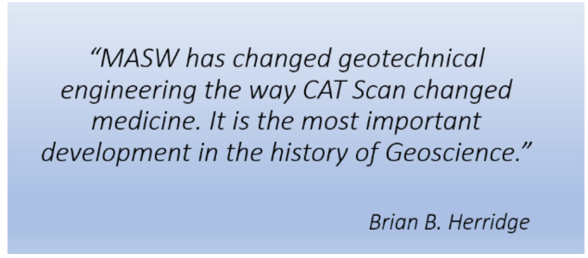
Brian started his consulting in seismic, including 3D surveys for near surface applications—hence the name of his company, 3D geophysics. As his business grew, he became expert in other methods: GPR, EM, Magnetics, Resistivity and of course his recent passion—MASW.

He was a creative genius and became both famous and notorious in the geophysical community. On occasion he would invent something that didn't quite work, like when he convinced the Navy he could image DNAPL's with reflection seismic. He never gave papers and stopped attending the conferences, which was certainly a loss to the younger generation of geophysicists, but he stayed in touch with his contemporaries. I spoke to him at length the day before he went fishing. We talked about a presentation I was giving on MASW to the local

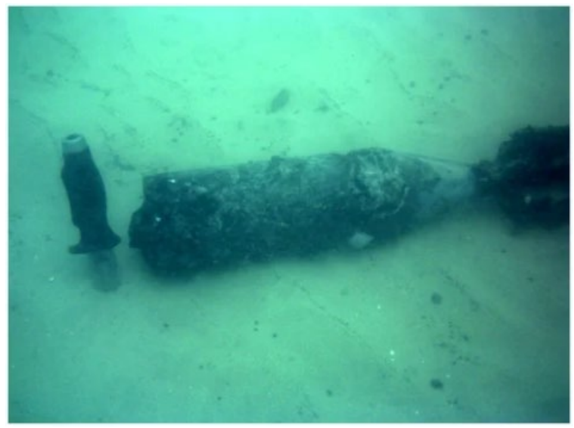


chapter of the AEG, using slides from some of his surveys. It was the heart of my talk and went well—geologists love case histories.

I even included a quote from him as the last slide in the



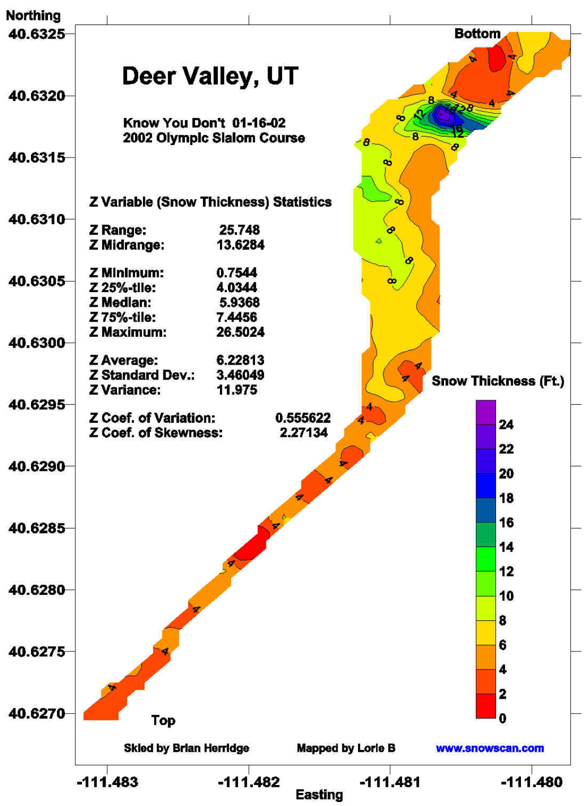
show, pasted in before I knew of his passing. I wasn't able to keep up with every creative thing Brian did. I just got little snippets of information, like when he taught the Navy how to find UXO in the water.



Brian was an avid skier. He recognized how much it cost to make artificial snow and he set out with Sensors & Software Inc. to help solve the problem. Brian took a GPR system, integrated it with GPS and mounted it on a snow grooming machine. The same system was also turned into a hand-held unit that could be used while

skiing. He took these results and created snow depth maps of the resort. These maps could be used to focus snow making efforts, making the process more cost effective.

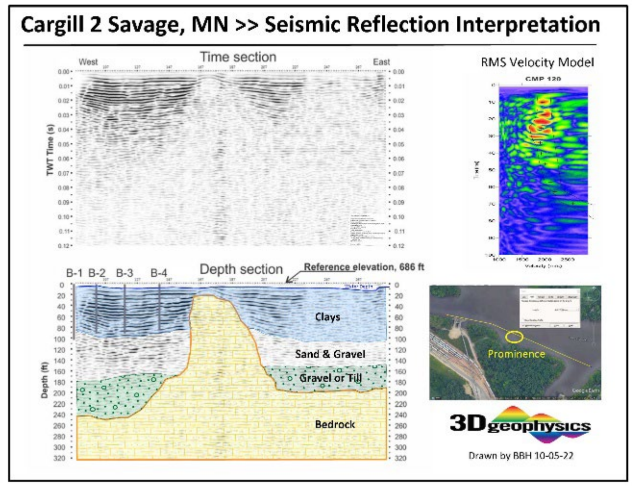
Brian sold this solution to ski resorts throughout Europe and North America. He worked non-stop, demonstrating the groomer system through the night and the handheld system through the day. In the process he created maps for resorts and helped with the snow making efforts for the 2002 Salt Lake City Olympics.



Brian instrumented a boat to conduct all kinds of marine surveys including imaging, seismic and EM. It had a Starlink receiver used for precise RTK navigation. It was

a strange-looking contraption that no doubt attracted attention from fishermen and tugboats.

He invented a seismic source that vibrated the aluminum bottom for high resolution marine surveys. It was a step up from his method of banging on the bottom of the boat with a hammer. Andre Pugin had just processed some data from it. Here is some marine data from the Mississippi River, with Brian's interpretation of Andre's processed section. The results were confirmed by the drill holes.



I get little notes from people who had experienced Brian Herridge. They all share my sense of loss: personal, to the geophysical community at large, and even to science. Above all, he liked to have fun, and it infected the people around him. He will be missed.

The Active Faults of Harris County: A Self-Paced Field Guide

Mustafa Saribudak

Environmental Geophysics Associates

Email: mbudak@pdq.net

Introduction

Over 70% of HGS members live in Harris County, and many of those members are interested to learn more about the geology of the area. It is easy to see how geologic processes shape the landscape of Harris County after episodic events such as hurricanes or flooding, but other geologic processes such as faulting and subsidence are subtly at work over geologic timescales. This guide focuses on the surface and subsurface expression of selected well-documented faults in the Houston area to provide geologic context for the processes that shape our community. This reference focuses on four faults in the greater Houston area: 1) Long Point, 2) Eureka-Heights, 3) Hockley, and 4) Willow Creek.

The geophysical data presented in this guide were gathered in the early 2000s by first author, Mustafa Saribudak, and have been published by Saribudak and Nieuwenhuise (2006), Saribudak (2011 and 2012), and Saribudak et al. (2018). Recently, major highway construction projects have obscured or remediated (e.g., asphalt patches) surface expression at some fault locations. But, upon close inspection, subtle fault deformation is visibly expressed as cracks or scarps.

This guide is intended to be a self-paced study, and the locations listed below are intended to be easily accessible, making this an activity to share with small groups. Driving directions and GPS coordinates of each fault are provided. Note that participants should always wear a high-visibility safety vest and only park in designated parking lots. Parking along highways is not a safe choice.

Structural Setting of Harris County

Sheets (1971) documented faults in Harris County associated with salt tectonic movement and regional-scale growth faults associated with formation of the Gulf of Mexico. Growth faults are characterized by increasing displacement with depth. Because displacement on growth faults occurs contemporaneously with sedimentary deposition, the downthrown side of the fault typically contains a thicker sedimentary package. Growth fault geometries can form hydrocarbon traps (Shelton, 1984, Ewing, 1983).

In the late 1970s, the United States Geological Survey (USGS) launched an extensive study of faults in Houston (Verbeek and Clanton, 1978; Verbeek et al., 1979; O'Neill and Van Siclen, 1984; Clanton and Verbeek, 1981). Based on detailed analysis of well logs and seismic data, Verbeek et al. (1979) documented an extensive fault network along the upper Texas Gulf Coast, including numerous faults in the Houston area at depths of 3,200-13,000 ft.

Some of the deep-seated faults in Harris County penetrate depths shallower than 3000 ft (McClelland Engineers (1966), and dozens of faults have surface expressions. Verbeek and Clanton (1978) used aerial photographs to identify and map the surface expressions of faults. More recently, researchers from University of Houston, such as Engelkemeir and Khan (2008) and Khan et al. (2013) have used light detection and ranging (LiDar) to map the surface expression of faults in the greater Houston area. Active faults in this region are typically not discrete ruptures. Rather, they are expressed as zones of intensely sheared ground that is tens of feet wide.

Some of the faults have been recently reactivated by petroleum production (Sheets, 1979) or groundwater withdrawal (Holzer and Gabyrsch, 1984). Fault movement is reported to be 0.2 - 0.8 inches per year (Shaw and Lanning-Rush, 2005). Norman (2005) identified some locations where displacement is more than one inch (3 cm) per year. Today, active faults are the source of damage to pavements, utilities, homes, businesses, and other manmade structures (Figure 1).

Engelkemeir and Khan (2008) report over 300 active faults in the Houston area, but the most recent USGS mapping project compiled by Shaw and Lanning-Rush (2005) identifies 150 active faults, including approximately 30 named faults (Figure 2).

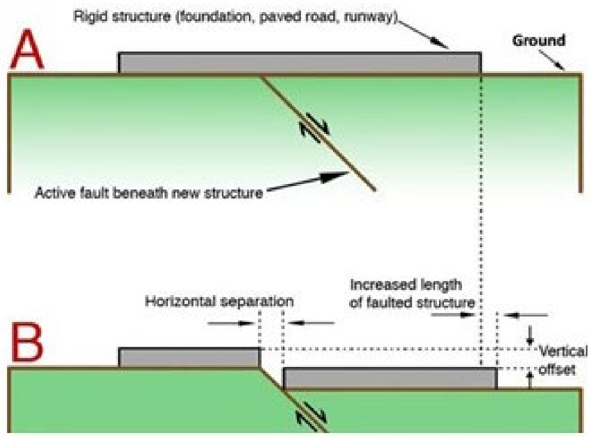


Figure 1. A). An active growth fault beneath a foundation and B) the fault movement results in horizontal and vertical separations, and is the source of damage to homes, businesses utilities, and pavements.

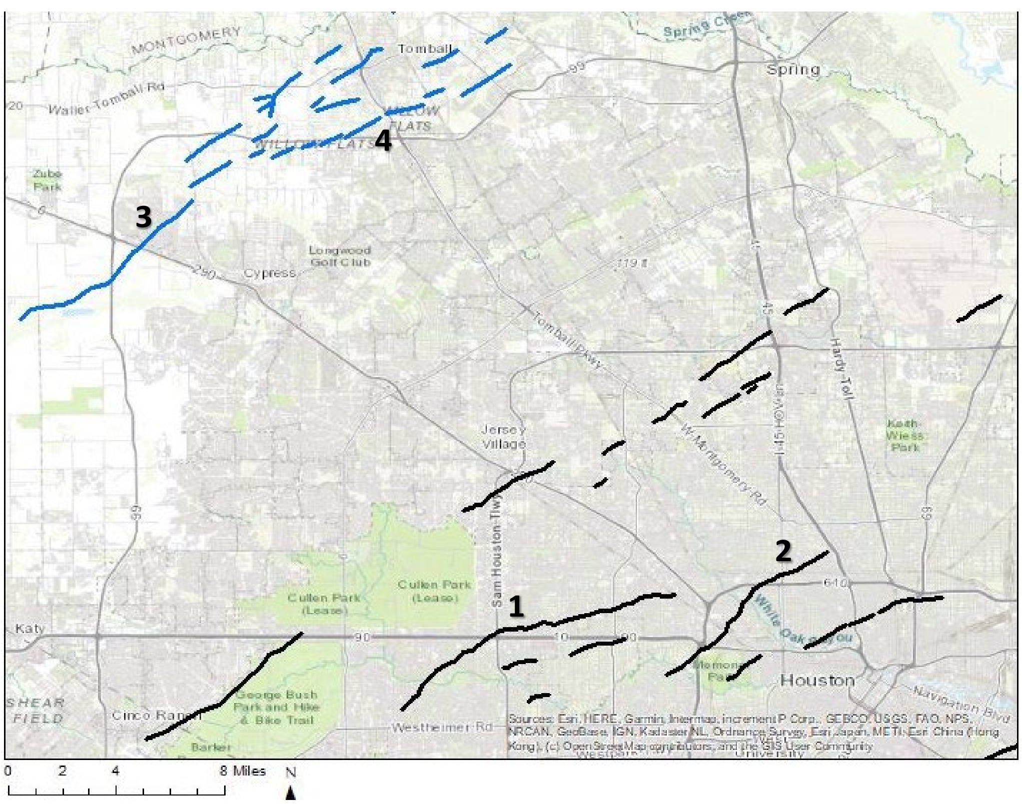


Figure 2. Map of well-documented faults in Harris County, based on Dhaw and Lanning-Rush (2005) and Engelkemeir and Khan (2008). The guidebook focuses on four faults: 1) Long Point, 2) Eureka Heights, 3) Hockley, and 4) Willow Creek.

Surficial Stratigraphy in Harris County

The coastal plain of the Gulf of Mexico is underlain by a thick sequence of largely unconsolidated, lenticular deposits of clays, silts and sands formed in shallow water and marsh-dominated depositional environments. Three Pleistocene-age formations crop out at the surface in Harris County. In ascending order, these are the Willis, Lissie, and Beaumont formations. The Willis is primarily composed of clays with lesser amounts of silts and sands; the Lissie formation contains sands with fewer silts and clays, and the Beaumont contains finer clays with silt (Moore and Wermund, 1993).

History of Near Surface Geophysical Work Across Growth Faults

Common methods to identify faults include aerial photographs and field mapping, and subsurface borehole data on both the down and upthrown sides of the faults (Elsbury et al., 1980). In addition, geophysical methods may be used to define faults. A pioneering resistivity study was performed over some of the Houston faults by Kreitler and McKalips in 1978. They used a resistivity meter with four electrodes, and manually crossed several fault locations using a Wenner array. Their results mostly identified anomalous resistivity values that correlated with the locations of the faults.

Building on the work of Krietler and McKalips (1978), Saribudak and Nieuwenhuise (2006) used a multi-electrode resistivity meter and other geophysical methods (conductivity, magnetic, gravity and GPR) to map the Willow Creek fault. Engelkemeir and Khan (2008) published seismic and GPR work over the Long Point fault, which is one of the most active faults of the Houston area. Additional resistivity surveys were conducted over the Long Point, Katy-Hockley, Tomball, and Pearland faults, and results were published in Saribudak (2011). During the following year, integrated geophysical results (resistivity and GPR) were published in Saribudak (2012) for the Hockley fault. Khan et al., (2013) published geophysical results (seismic, gravity and GPR) over the Hockley fault along with airborne LiDar data. More recently. Saribudak et al., (2018) published new geophysical data and discussed the deformation mechanism of the Hockley fault.

Stop 1: Long Point Fault

Location: Coordinates of the fault location are 29° 47.515', 95° 32.064', which falls in the vicinity of the intersection of Moorehead Drive and Westview Drive in the West part of Houston. The fault is located in the northeast part of the intersection of Sam Houston Tollway Road (Beltway 8) and Interstate Highway 10 (I-10) (Figure 2).

Driving directions: The easiest way to reach the Long Point fault is to take Westview Road from I-10 and drive to the East until reaching the intersection of Moorehead Drive and Westview Drive. Then, proceed North along Moorehead Drive at the intersection. The fault is located about 140 feet from this intersection. There is a three-foot fault scarp that is highly visible and hard to miss.

Geologic overview: The Long Point Fault extends approximately 11 miles to the West-southwest from US 290, through the Beltway/I-10 Interchange, and close to Eldridge Parkway in West Houston (Figure 2). It is a typical Gulf Coast growth fault that slips slowly about 0.25 - 1 inch per year. The fault strikes through many neighborhoods and is responsible for deformation of residential and commercial buildings. The location of the resistivity profile that was collected across the Long Point fault is shown in Figures 3 and 4.

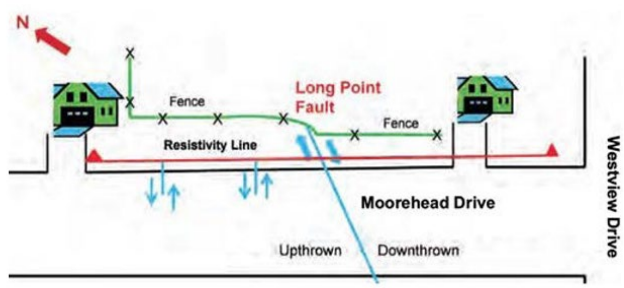


Figure 3. Schematic map of Long Point fault at Moorehead Drive. The fault location is about 140 feet from the intersection of Moorehead and Westview Drives. Note the deformation on the fence line and the presence of two small faults in the upthrown part of the Long Point fault. The position of a resistivity profile is shown with a red line. There are houses in this neighborhood that have had continuous foundation repairs since 1970s up to now due to the creeping fault movement.

Figure 4. Picture showing coordinates of the Long Point fault scarp on the road and the location of resistivity profile. The view is to the north.

The resistivity data collected along Moorehead Drive is shown in Figure 5. A fence-line break and the driveway of a nearby house are reference markers. The fault juxtaposes low resistivity soil layers (clay as displayed by the blue) against moderately resistive units (sand as displayed by green color) thus creating an anomaly. The Long Point fault location observed at the site is superimposed on the resistivity imaging data, which shows south-dipping clay layers on the South part of the fault trace. The northwest part of this anomaly is limited by a high resistivity layer shown by the red color.

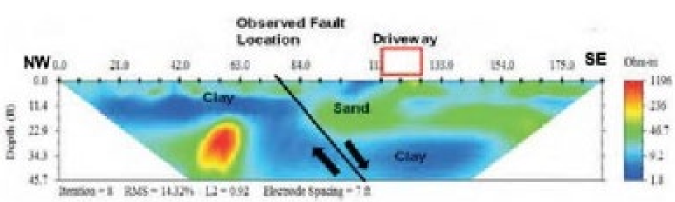


Figure 5. Resistivity imaging data taken along Moorehead Drive across the Long Point fault. Note the fault offset in the southeast direction which juxtaposes the sand and clay layers.

The resistivity anomaly can be caused by any change in the soil properties, such as change in moisture, clay content, and porosity ratio across the fault. In general, in the absence of tectonic activity, the soil layers should present horizontal layers. In the case of a growth fault, the different soil layers are juxtaposed across the fault, which creates a visible resistivity anomaly.

Ground Penetrating Radar (GPR) surveys were performed across the fault (Figure 6). The 400-MHz antenna was used with a cart system to collect GPR data. The ability of a GPR system to work successfully depends upon two electrical properties of the subsurface, electrical conductivity and relative dielectric constant. The value of dielectric constant ranges between 1 (for air) and 81 (for water). The dielectric constant for sandy soils, depending on its moisture content, varies 6 to 20. However, the dielectric constant of clay is much higher than sandy soil and ranges between 10 and 40. For this reason, the presence of clay absorbs the electromagnetic signals of GPR and limits its exploration depth.

Figure 6. GPR survey.

The GPR data is shown in Figure 7. The GPR data is displayed in a black-white amplitude format. The high amplitude values are shown by the white color, which are mostly caused by the presence of rebar in the subsurface and the underlying clay. Rebar

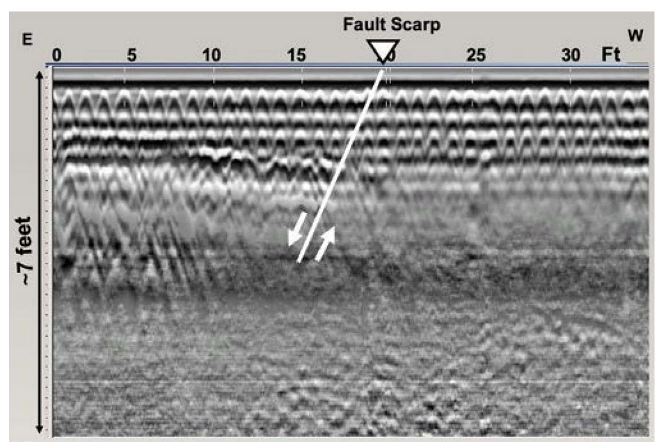


Figure 7. The GPR data across the Long Point fault. The deformation caused by the fault is visible between 7 and 25 feet. Hyperbolic anomalies are due to rebar reflections.

was likely placed within the pavement to minimize the effect of faulting across the road. Despite the heavy presence of rebar and high conductivity soil layer (high dielectric constant) the GPR profile clearly indicates the downthrown section of the fault.

The surface expression of the Long Point fault has generally remained consistent since the photos were taken. The prominent fault scarp is visible despite repairs. Some of the houses in the downthrown side of the fault have been repaired intermittently. Trip takers are encouraged to observe the extension of the fault along Westview Drive, to the East of the intersection of Westview and Moorehead Drives. The fault scarp is also visible at this location.

Stop 2: Eureka Heights Fault

Location: Coordinates of the fault location are 29° 48.914', 95° 25.036', which is near the intersection of West 31st Street and Dunsmere Road. The fault strikes northeast to southwest and crosses the NW section of N Loop W Freeway, I-10, and Highway 290. The fault tips out before Interstate 45 (Figure 2).

Driving Direction: The easiest way to reach the fault location is to take the N. Durham exit from N. Loop W Freeway, and drive until reaching West 34th Street. Turn to the West (to your left) on West 34th Street and drive about 400 feet to the West. Then, turn South (left) on Randal Street. After driving about 800 feet, turn West (right) onto West 31st Street. Drive approximately 900 feet on West 31st Street until arriving at the intersection of Dunsmere Road.

Geologic overview: The fault crosses West 31st Street and Dunsmere Road (Figure 8). Fault deformation is expressed as cracks on West 31st street that extend 75 feet across the intersection. The fault is about seven miles long. It crossesmany residential places and commercial buildings.

Resistivity and GPR were conducted along the North edge of West 31st Street (Figures 8 and 9). Collecting these data were challenging due to the location of utilities, and insufficient contact between electrodes and fill material in driveways (see Figure 8). However, the resistivity data indicates a significant fault anomaly (Figure 10). In Figure 10, the blue color is interpreted to represent clay lithology and the shape of the blue anomaly is interpreted to represent fault offset.

A GPR survey was also conducted across the fault to map the subsurface deformation. The GPR data shown in Figure 11 is interpreted to represent a fault zone between stations 10 and 37 feet. The fault location marked on the data coincides with the location of fault scarp observed on ground.

Figure 8. Site map showing the approximate location of the Eureka fault crossing West 31st Street and Dunsmere Road. Fault deformation is highly visible on the asphaltic pavement of West 31 Street. The yellow line indicates the location of geophysical profiles.

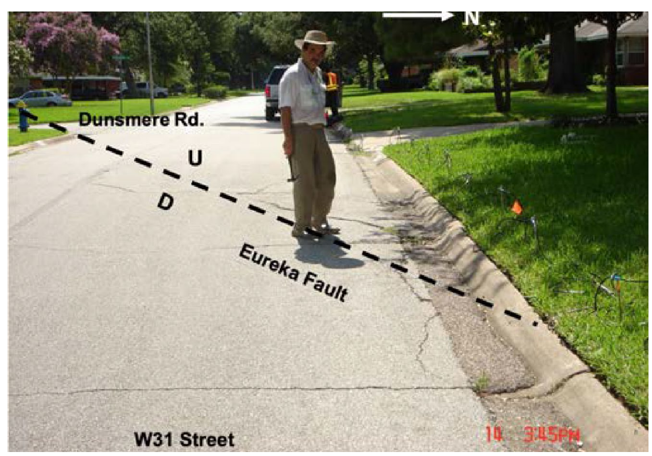


Figure 9. Picture showing the approximate fault location during the collection of the resistivity data in 2008.

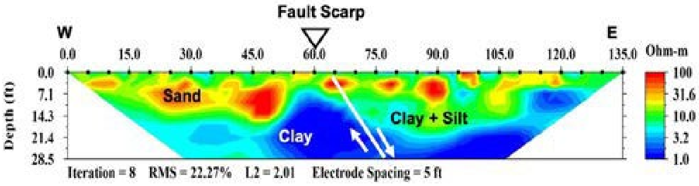


Figure 10. Resistivity data collected along West 31st Street across the Eureka fault. Note the fault offset in the East direction which juxtaposes the interpreted sand and clay layers.

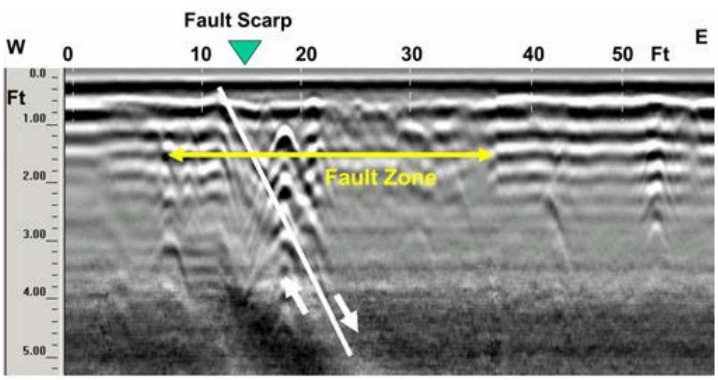


Figure 11. GPR data across the Eureka fault. The deformation caused by the fault is visible between stations at 10 and 37 feet. Hyperbolic anomalies are due to utility lines.

Stop 3: Hockley Fault System

Location: There are two fault locations (A and B) to visit at this site. Coordinates of Location A are 29° 56.617’, 95°45.241’. Coordinates for Location B are 29° 57.581, 95° 45.283’. The Hockley fault system crosses Highway 290 near the location of the Premium Outlet Shopping Center.

Driving directions: The easiest way to locate the Hockley fault is to drive West on Highway 290 from the Houston area and exit at Fairfield Falls Way. Proceed on the westbound feeder road until you reach Fairfield Falls Way.

Geologic overview: The fault A is evidenced by zones of intensely sheared and cracked ground at this location. The Hockley Fault system continues as a discrete rupture across Highway 290. The uneven highway surface, most obvious in East-bound lanes, is caused by the movement of the fault (Figures 12 and 13).

The second fault location (B) is located across from the highway on the East-bound feeder road (Figure 13). The Location of B does not align with the strike of Location A; it is shifted approximately 130 feet to the West. There is a discrete rupture of the feeder road. There are smaller cracks in the vicinity of this fault indicating that the deformation is diffusive.

Visits during April and August 2010 to the Hockley fault site provide additional evidence in the rate of fault deformation (Figure 14). Small cracks in the pavement over the main fault trace photographed in April 2010 and had extended and widened significantly by August 2010. Note that the cracks in Figure 14 have been filled with asphalt. A site visit to the Hockley fault in 2022 showed that cracks were covered with an asphaltic patch.

Figure 12. Photo showing the location of Hockley fault (Location A) at the intersection of westbound feeder road and Fairfield Falls, where the Premium Outlets shopping mall is located. The fault is evidenced by the cracks across the feeder road. These cracks are regularly fixed and are sometimes covered with asphalt patches. Look for deformation to the foundation of the store visible in the background. The fault crosses the West and the East-bound lanes of Highway 290. The yellow line indicates the location of the resistivity profile.

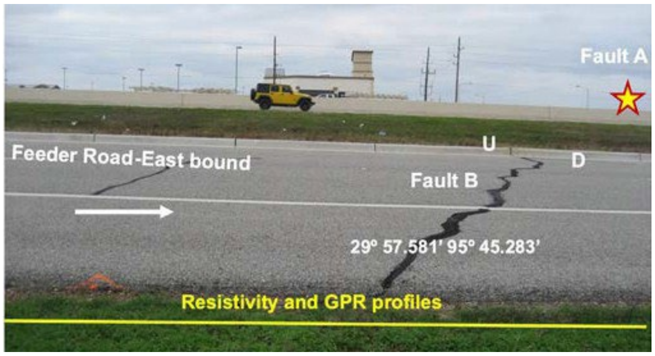


Figure 13. Photo showing the location of Fault B on the East-bound feeder road. Note that the fault is expressed as a discrete, linear rupture, which has been filled with asphalt. Resistivity and GPR data are collected along the yellow line.

Figure 14. Recent pictures of Hockley fault at Highway 290 Frontage and Fairfield Falls Way roads: (a) taken in April 2010 and (b) taken in August 2010. Note the development of the tiny cracks in (a) into significant cracks in (b).

Fieldwork for geophysical surveys was conducted in 2004 and 2005, before the shopping mall was constructed and before the expansion of Highway 290. There was a grass-covered median between the East- and West-bound lanes of the Highway (Figure 15) where more geophysical data were collected. For simplicity, only two geophysical profiles (L1 and L2) are discussed in this work.

The resistivity data collected along L1 is provided in Figure 16. A major fault anomaly is located at a station of 440 feet. The fault dips to the southeast but there is no rupture visible in sandy and clayey layers at the surface.

The resistivity data collected along Line 2 (L2) is given in Figure 17, which is interpreted to shows a fault anomaly across the discrete rupture observed in Figure 13. The fault juxtaposes high-resistivity sand and low-resistivity sand and clay layers.

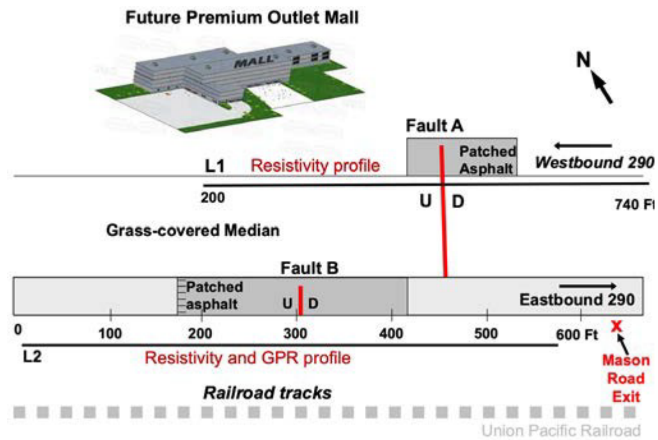


Figure 15. Schematic map of the Hockley fault at Highway 290 and Fairfield Village during 2004 and 2005. The shopping mall was not yet built, and Highway 290 had a grass-covered median between the East and West bounds. Locations of resistivity profiles (L1 and L2) are shown with a red color. GPR data were also collected along Line 2 (L2) on the feeder road of eastbound. Not to scale.

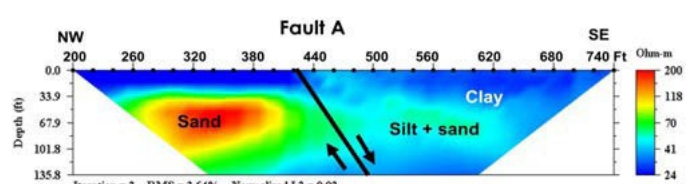


Figure 16. Resistivity data collected along profile L1 located in the northern section of the grass-covered median in the year 2005. The fault occurs where the scarp is observed on the ground.

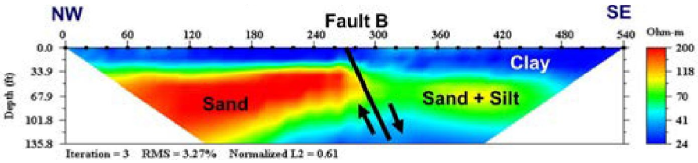


Figure 17. Resistivity data collected along profile L2 on the southern section of the East-bound feeder road. The fault anomaly is located where the scarp is located and is well-correlated with the resistivity data.

A GPR survey was also conducted along Line 2 (L2) at the southern edge of the East-bound feeder road. The 400-MHz GPR data is displayed in a color-amplitude format, and a color assigned to a specific positive or negative value of the recorded signal (Figure 18). The GPR data shows a significant anomaly at station 302 feet. The data are interpreted to show juxtaposition and offset of sedimentary layers down to the southeast.

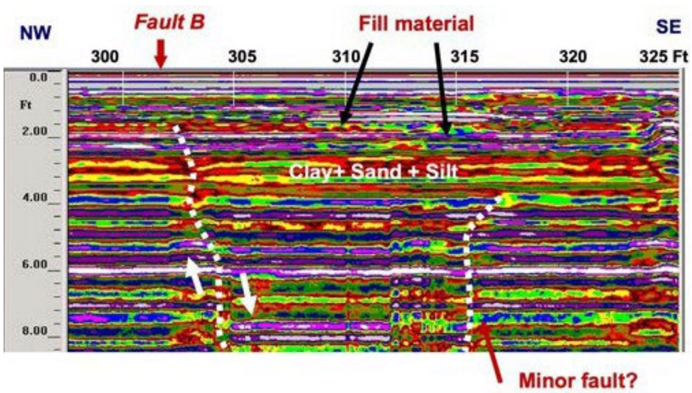


Figure 18. GPR data along profile L2. A significant GPR anomaly was observed across the fault scarp between stations 300 and 305 feet. Down-to-the-southeast drag is interpreted at depths of 6 and 8 feet below ground level. There is also a minor fault anomaly at station 315 feet. The interpreted offset of sedimentary layers at this location is in the northwest direction.

Stop 4: Willow Creek Fault

Location: Coordinates of the Willow Creek fault are 30° 3.857', 95° 37.282'. It is located on Highway 249 (Tomball Parkway) between Willow Creek and Holderrieth Road (Figure 19). The fault location is about 4,800 ft to the North of Grand Parkway (Highway 99). In 2003, a discrete rupture was visible on both bounds of the highway (Figure 20).

Figure 19. Site map showing the location of Willow Creek fault, which is located between Willow Creek and Holderrieth Road. Note that Willow Creek makes a sharp turn across the interpreted fault location. There were also asphalt patches to the south of the creek and on the bridge. It is interesting to note that the farmland to the northeast (where the farmhouse is located) is undeveloped.

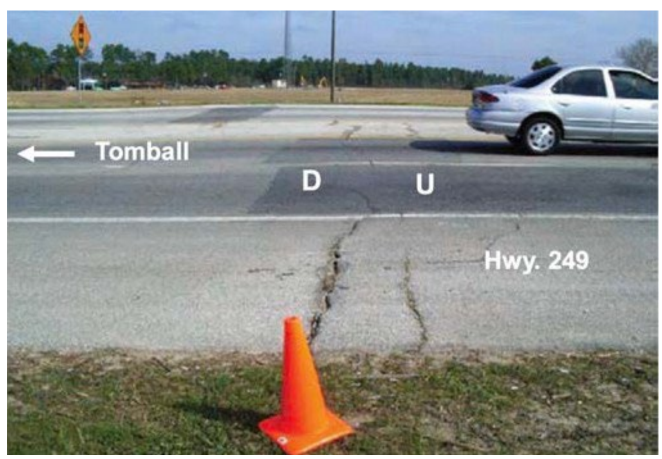


Figure 20. Picture of Willow Creek fault taken in 2003.

Driving Directions: The easiest way to drive from downtown Houston to the fault location is to take I-10 West until reaching Loop 610. At this intersection, take Loop 610 North to drive about 1.5 miles to get to Highway 290 exit. Take Highway 290 North and drive about 8 miles to reach Sam Houston Parkway (Belt 8). Then take Sam Houston Parkway (SHP) north. SHP bends to the west to meet Highway 249. At this intersection, take Highway 249 North, pass under Grand Parkway (99). Slow down to drive over the Willow Creek bridge. The fault location is about 300 feet to the North of the bridge. Immediately, there is a driveway to a farmhouse to the East, which may be a good parking location.

Geologic Overview: The Willow Creek fault is located about 300 feet north of the Willow Creek Bridge, strikes in a NE-SW direction, and dips to the north (Figure 3). This fault is antithetical to the South-dipping regional Tomball fault that is located about 3 km north. A discrete pavement break crossing both South- and North-bounds of Highway 249 clearly marks the presence of the fault (Figure 20).

When the photo in Figure 20 was taken, Highway 249 had a grass-covered median between the East- and West- bound lanes. Multiple geophysical surveys were conducted across the fault (Figure 21). Two geophysical profiles will be discussed in this study.

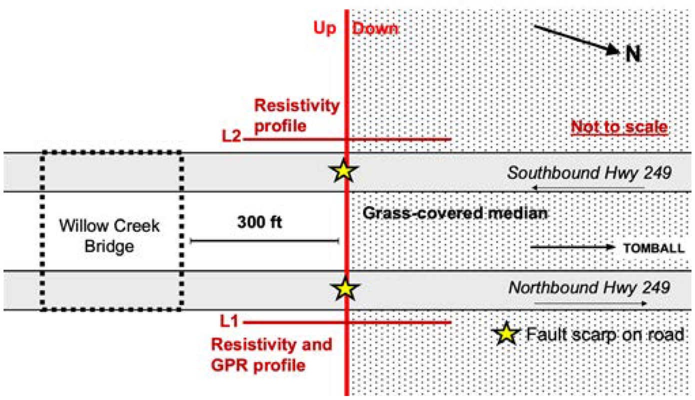


Figure 21. Schematic map of Willow Creek fault at Highway 249 during the year 2003. Highway 290 had a grass-covered median between the East- and West-bound lanes. Locations of resistivity profiles (L1 and L2) are shown with a red color. GPR data were also collected along Line 1 (L1) on the edge of northbound. Not to scale.

Two resistivity profiles across the fault are provided in Figure 22. They both indicate a sharp resistivity contrast over the fault scarp. The resistivity contrast is interpreted to be caused by the juxtaposition of high resistivity sandy and low resistivity clayey sediments.

A GPR survey profile collected across the fault scarp along profile L2 and is provided in Figure 23. The GPR data indicates discontinuous layers beneath the scarp at a depth of 2 feet that are interpreted to result from deformation. In addition, the published GPR data (Saribudak and

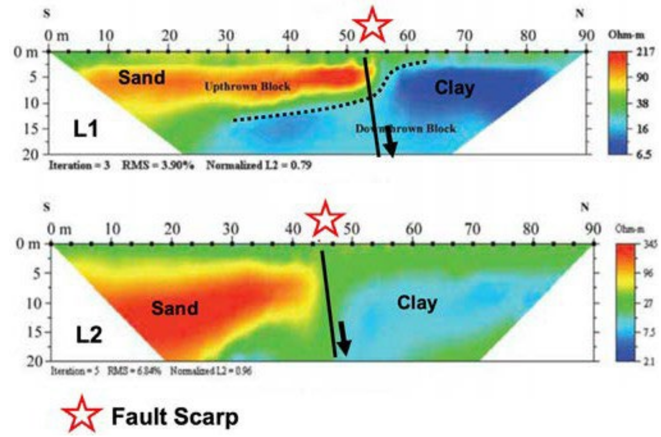


Figure 22. Resistivity data collected across the fault along profiles L1 and L2. Note that the downthrown side is to the north and juxtaposition of low-resistivity layers along the fault plane is obvious.

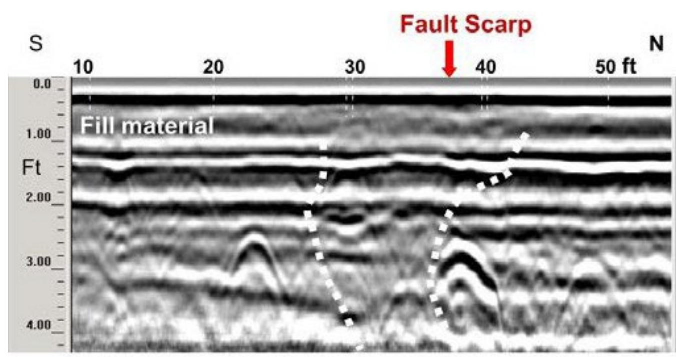


Figure 23. The GPR data across the scarp of the Willow Creek fault. The data are interpreted to show minor deformation that is less significant than observed at the Long Point, Eureka Heights or Hockley faults. However, the disruption of sedimentary layers is interpreted to be visible. Hyperbolic anomalies could be due to buried pipes.

Nieuwenhuise, 2006) detected differential subsidence and a deformation zone between the bridge and the footing of the bridge. The Willow Creek fault movement is a possible cause for this deformation.

Concluding Remarks

Active faults in Harris County are usually not discrete rupture planes, but zones of sheared ground tens of feet, which are described as fault zones as shown in this study. Geophysical methods discussed here do not provide a fault offset, except with seismic reflection. Common methods used to identify these faults, in addition to geophysical techniques, include analysis of aerial photographs and field mapping and drilling borehole data on both the down- and upthrown sides of the faults. Gamma rays electrical logging used in boreholes give the precise fault offset between the borehole locations.

It is important to know that pavement cracks and offset can be caused by subsidence of ground due to the excess withdrawal of ground water. In addition, the Beaumont Formation, which underlies a significant part of Harris County, contains swelling clays. These clays are also known as "shrink-swell soils." When wet or dry, these clays swell or shrink, respectively, which cause significant fault-like deformation to roads, houses, and utility lines.

Questions for Field Trip Participants

- Is the surface expression of the fault easy to identify? What do you see?
- Why is the surface expression of the Long Point fault easier to identify than other faults in the area?
- What are indications that this fault is connected to a deeper fault system v. restricted to the shallow surface?
- What do you think is the impact of this fault on surficial processes, e.g. runoff/drainage?
- What are other geologic processes that could have caused the apparent resistivity anomalies?
- Which fault(s) is antithetical? Why do you think this structural orientation is present? Why is it present at this location?

Safety Tips to Keep in Mind While in the Field

Note that participants should always wear a high-visibility safety vest, and only park in designated parking lots. Parking along highways is not a safe choice. They should be alert by being aware of their surroundings. A sun-protective hat and drinking water would be helpful. It is recommended that participants should be cordial and socialize with the people when they are, especially in neighborhoods.

Acknowledgment

The first author thanks geologist Richard Howe for helping correctly identify some of the fault locations. Thanks to Caroline Wachtman, P.G. for her assistance in preparing this guide for publication.

References

Clanton, S. U., and R.E. Verbeek, 1981, Photographic portraits of active faults in the Houston metropolitan area, Texas, Houston area environmental geology: Surface faulting, ground subsidence, hazard liability, edited by Etter, M.E., Houston Geological Society, p. 70-113.

Elsbury, B. R., D. C. Van Siclen, and B. P. Marshall, 1980, Engineering aspects of the Houston fault problem: ASCE Fall Meeting.

Engelkemeir, R., and S. D. Khan, 2007, Near-surface geophysical studies of Houston faults: The Leading Edge 26, p. 1004–1008, doi: 10.1190/1 .2769557.

Engelkemeir, R., and S. D. Khan, 2008, Lidar mapping of faults in Houston, Texas, USA, Geosphere 4, p. 170-182.

Ewing, T. E., 1983, Growth faults and salt tectonics in the Houston diaper province: Relative timing and exploration significance: Transactions of the 33rd Annual Meeting of the Gulf Coast Association of Geological Societies, p. 83–90.

Holzer, T.L., and R.K. Gabyrsch, 1987, Effect of waterlevel recoveries on fault creep, Houston, Texas: Ground Water, National Ground Water Association 25(4), p. 392–397, doi: 10.1111/j.1745- 6584.1987. tb02143.x.

Khan, S.D., R.R. Stewart, M. Otoum, and, L. Chang, 2013, A geophysical investigation of the active Hockley Fault System near Houston, Texas, Geophysics 78, p. 177-185.

Kreitler, C. and D. McKalips, 1978, Identification of surface faults by horizontal resistivity profiles, Texas coastal zone: Bureau of Economic Geology, Geological Circular 78–6.

McClelland Engineers, 1966, Land-surface subsidence and surface faulting (appendix C), in Turner, Collie, and Braden, Inc., A comprehensive study of Houston's municipal water system: Report to the City of Houston, 50 p.

Moore, D.W., and E. G. Wermund Jr., 1993, Quaternary geologic map of the Austin 4 × 6 degree quadrangle, United States: U. S. Geological Survey Miscellaneous Investigations Series Map I-1420 (NH-14), scale 1:1,000,000.

Norman, C., 2005, Ground subsidence and active faults in the Houston metropolitan area: Coastal subsidence, sea level and the future of the Gulf Coast: Houston Geological Society/Engineering, Science and Technology Council of Houston Conference, Field Trip Guide.

O'Neill, V.C., and D.C. Van Siclen, 1984, Activation of Gulf Coast faults by depressuring of aquifers and an engineering approach by siting structures along their traces: Bulletin of the Association of Engineering Geologists XXI(1), p. 73–87.

Saribudak, M., and B. V. Nieuwenhuise, 2006, Integrated geophysical studies over an active growth fault in Houston: The Leading Edge 25, p. 332–334. Geological Survey, Water-Resources Investigations Report 02–4022.

Saribudak, M., 2011, Geophysical mapping of the Hockley growth fault in northwest Houston, USA, and recent surface observations: The Leading Edge 30, p. 172–180, doi: 10.1190/1.3555328.

Saribudak, M., 2012, 2D Resistivity Imaging Investigation of Long Point, Katy-Hockley, Tomball and Pearland Faults Introduction 2D Resistivity Imaging Investigation of Long Point, Katy-Hockley, Tomball. FastTIMES 17(1).

Saribudak, M., M. Michal, and B.V. Nieuwenhuise, 2018, Hockley Fault Revisited: More Geophysical Data and New Evidence on the Fault Mechanism, Houston, Texas, Geophysics 83(3):1-51.

Shaw, S., and J. Lanning-Rush, 2005, Principal faults in the Houston, Texas, metropolitan area: U.S. Geological Survey Scientific Investigations Map 2874.

Sheets, M.M., 1971, Active surface faulting in the Houston area, Texas: Houston Geological Society Bulletin 13, p. 24–33.

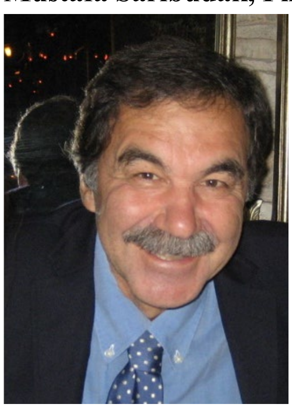
Shelton, J., 1984, Listric normal faults: An illustrated summary: Bulletin of the American Association of Petroleum Geologists 68(7), p. 801–815.

Verbeek, E.R., and U.S. Clanton, 1978, Map showing surface faults in southeastern Houston metropolitan area, Texas: U.S. Geological Survey Open-File Report 78–797, 20 p.

Verbeek, E.R., K.W. Ratzlaff, K.W., and U.S. Clanton, 1979, Faults in parts of north-central and western Houston metropolitan area, Texas: U.S. Geological Survey Miscellaneous Field Studies Map 1136, 2 plates.

Author Bio

Mustafa Saribudak, Ph.D., P.G.



Mustafa Saribudak is the principal of Environmental Geophysics Associates (EGA). He holds B.Sc. and M.Sc. (1975) in geology from the University of Istanbul and a Ph.D. (1987) from the Istanbul Technical University in Turkey. He came to the University of Houston in 1990 as a visiting geoscientist. He started working for Tierra Environmental in the Woodlands between 1991 and 1993, where he pioneered the application of geophysical methods to environmental problems. He founded EGA in 1994 to provide near-surface geophysical services for engineering, environmental, and oil and gas industries, and real estate developers. Since than he has worked on more than 400 projects.

His personal research interests have been the active growth faulting in the Houston area, major faults of the karstic Edwards Aquifer in central Texas (for example: Mt. Bonnell, Barton Springs and Haby faults); location of karstic features (caves, sinkholes, voids) across the Edwards Aquifer; location of abandoned oil and gas wells and water wells; application of geophysical methods to volcanoes. His consultancy work resulted in over 50 published papers, which provided valuable insights and quantitative data for the geophysical and geological fields.

Geophysical Investigations for the Emergency Response to the February 2017 Spillway Failure at Oroville Dam, California

William P. Owen[1], William M. Dalrymple[1], and John G. Diehl[2]

[1]California Department of Transportation, Sacramento, California
[2]GEOVision Geophysical Services Inc., Corona, California

Emails: bill.owen@dot.ca.gov, william.dalrymple@dot.ca.gov, jdiehl@geovision.com

Abstract

In February 2017, failure of the Oroville Dam Main Spillway, and near failure of the Emergency Spillway, resulted in the precautionary emergency evacuation of nearly 200,000 people downstream of the facility. Response and recovery efforts for the disaster were far-ranging and geophysical investigations were included as part of those efforts. Both state government and private consultant resources were deployed for those tasks. Ground penetrating radar, refraction tomography and borehole geophysical logging were used to assist with determining condition of the remaining Main Spillway, the variability of the bedrock weathering profile, and rock velocity at critical locations across the facility. The data assisted the facility engineering team regarding operational decisions immediately post-failure and longer term with design of the replacement structures.

Introduction

Lake Oroville is the second largest artificial reservoir in California (Figure 1). Completed in 1967, the dam at Oroville is the tallest in the United States, impounding up to 3.5 million acre-feet of water. After several years of drought, 2017 produced the second wettest winter on record in California at that time. On the morning of February 7, 2017, a significant portion of the Main Spillway failed during routine discharge of the reservoir. The resulting crisis forced the dam operators to quickly make critical and difficult decisions, where neither the risk trade-offs nor the results of those decisions could be predicted with complete confidence. The chain of events that ultimately occurred resulted in the overtopping of the Emergency Spillway for the first time in its history. This caused extensive erosion, with head-cutting migrating upstream to the base of the Emergency Spillway, jeopardizing its integrity. The risk of failure was sufficient to warrant emergency evacuation of nearly 200,000 people downstream until the crisis could be contained.

The emergency response to the failure was far-ranging, and although geophysical surveys were only a small part of the total effort, the information from those surveys was important to key decisions in the repairs for the damaged structures. Both state and contract resources were employed to acquire condition data on the surviving portion of the Main Spillway, and contract services were deployed to acquire seismic tomography, borehole televiewer and downhole velocity data in support of the foundation repair for the Emergency Spillway. Time-critical deadlines for information required rapid turnaround of the geophysical data as it was collected. Many users of that data were not regular consumers of geophysics. That, combined with the need for rapid dissemination, focused data presentation on graphic and visual representations that could quickly convey the most important pieces of information needed to assist the engineers and geologists responsible for making time-critical decisions.

.

Figure 1. Lake Oroville Dam and Reservoir, circa 2015 (before spillway failure). Outflows from the reservoir are controlled from the three locations: 1) power plant, 2) Main Spillway, and 3) Emergency Spillway.

Prologue

2017 was the second wettest winter on record in California. Heavy January rains in the Oroville drainage basin were causing the reservoir to quickly rise. Under normal operations, this was a manageable situation, and spillway releases at that time were well within design limits. That changed on the morning of February 7, when shortly after 10:00 AM, employees reported a substantial disturbance in water flow at the lower half of the spillway (Figure 2). The trunnion gates were closed by 12:25 pm, and inspection revealed that a significant portion of the spillway slab had washed away, forming a large erosion hole where the slab sections were now missing. As inspections continued, lake waters continued to rise. The damaged Main Spillway had to be reopened, but outflows were reduced to minimize further damage. Operators knew further damage was certain, but the extent could not be predicted, and further erosion of the foundation rock and loss of additional slab sections occurred during this period. By that time, the majority of discharge flow was no longer confined to the spillway and was now channelized to the southeast, causing rapid and severe erosion of soil and rock south of the spillway (Figure 3).

Figure 2. The Main Spillway at time of first damage (A), February 7. and (B) shortly after shutdown showing initial damage.

Figure 3. Views of the Main Spillway (A) during post-failure managed emergency discharge in February 2017, and (B) shortly after shutdown for emergency repairs in March 2017. Note the extreme erosional damage from flow channelization at the right (southeast) side of the image.

Figure 4. Views at the Emergency Spillway (A) during overtopping on February 11, (B) downstream view from the crest during peak flows, showing washout of the access road (arrow indicates relative location), (C) post-flow, near the former access road, showing extent of downstream erosion and channelization (Photo by author; note the human inspector in the background (circled for scale).

By February 10, reservoir inflows exceeded the established combined discharge capacities of the power plant and the crippled Main Spillway. On February 11, the Emergency Spillway at Oroville was activated for the first time in its history. Although erosion was anticipated downstream of the Emergency Spillway, the extent could not be fully predicted. The uncontrolled discharge caused erosion and channelization as it flowed down the unprotected natural terrain, with head-cutting regressing upstream rapidly toward the base of the spillway (Figure 4). This threatened the stability of the Emergency Spillway structure itself, so at 3:44 pm on February 12, an evacuation order was issued for about 188,000 downstream residents. Although reservoir drawdown ultimately succeeded and the evacuation order was lifted on February 14, the area remained under an evacuation warning for an additional five weeks. On February 27, the spillway gates were

closed and on-site investigations and recovery actions commenced. During that time, investigations and remedial actions were interrupted occasionally for Main Spillway releases to manage the reservoir.
spillway.

Geophysics Efforts

State government geophysicists and private consultants were used to acquire geophysical data during the recovery efforts. State resources were limited to the Main Spillway, consultant efforts were broader in scope and included the Main and Emergency spillways and adjacent areas. We limit our discussion to the state efforts at the Main Spillway and the consultant work on the Emergency Spillway.

Main Spillway

Under Mutual Aid agreements established and administered by the Governor's Office and the California Office of Emergency Services, all agencies of the state must provide emergency management personnel and technical specialists to support disaster operations. On March 2, 2017, the Office of Emergency Services requested assistance from the Geophysics and Geology Branch at the California Department of Transportation (Caltrans). A Caltrans crew arrived on site the same day to perform ground penetrating radar (GPR) investigations on the remaining portion of the undamaged Main Spillway. Over the course of eight days, Caltrans personnel acquired a linear equivalent of 27.2 miles of GPR data in support of the repair efforts.

Investigation goals for the Caltrans GPR work required us to: 1) evaluate the location and distribution of the drainage gallery beneath the undamaged portion of the spillway, 2) provide estimates of concrete thickness within the undamaged spillway, 3) identify any potential voids at the base of concrete within the undamaged spillway, and if possible, 4) identify the distribution of any rock discontinuities beneath the undamaged

Our work was complicated by the nature of the emergency response. Due to the extremely short response time frame, the investigation plan had to be developed literally overnight. We didn't know how much time we had to complete work. Reservoir levels were not yet stable and emergency evacuation of the spillway could occur at a moment's notice. If that happened, all equipment would be abandoned. We also had to share space with other crews who were frantically racing to make repairs ahead of planned spillway reactivation, which required work staging to accommodate changing priorities.

Initial information available for investigation planning were:

1. Minimum design concrete thickness was 15 inches,
2. Concrete reinforcement was a single layer of #5 rebar on a 12"x12" grid,
3. The spillway slabs were secured by rock anchors embedded five feet into rock and spaced at roughly ten-foot intervals (Figure 5),
4. 4'x4' reinforcing mesh was embedded within the concrete, about 4 inches above rock surface and placed at the base of each rock anchor,
5. At the base of concrete, a sub-drain gallery of 6-inch vitreous clay pipe (VCP; the same material used in clay pots) with gravel filter was arranged in a herringbone pattern spaced at about 25-foot intervals (Figure 5). Drainage relied on passive gravity flow, so pipe elevation decreased from the center of the spillway toward collector pipes outside the Main Spillway.

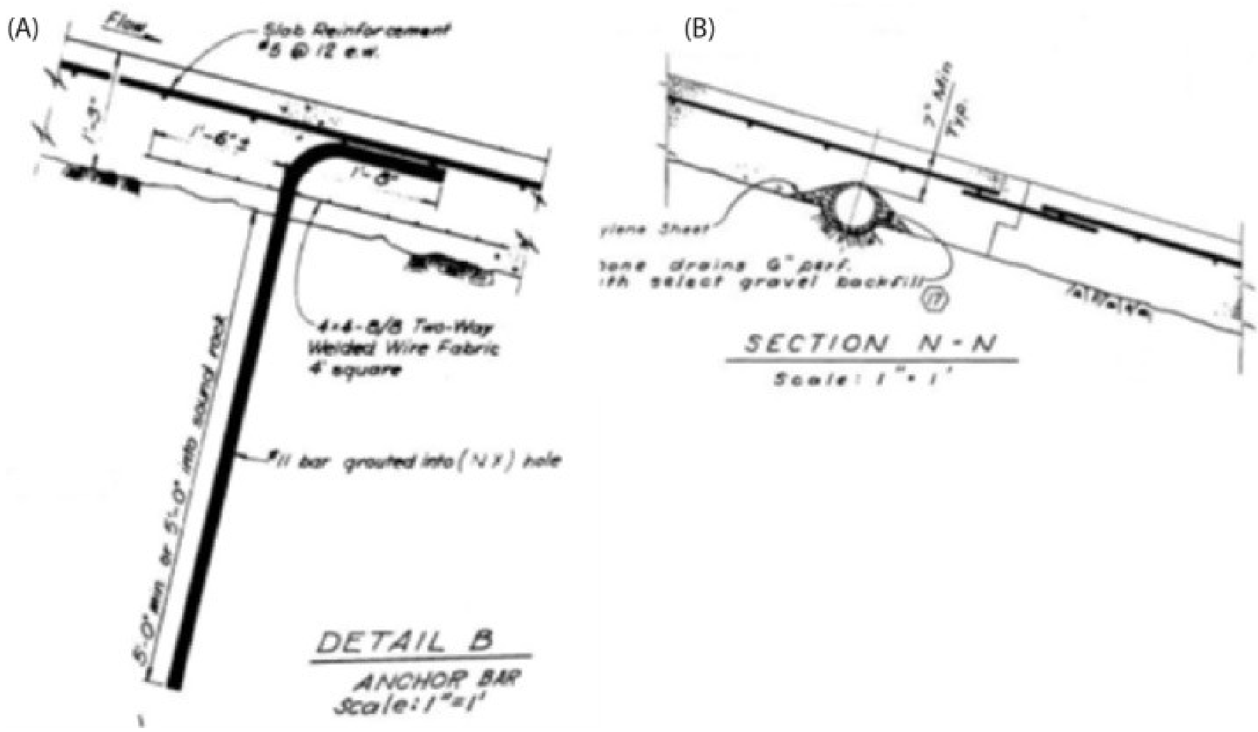


Figure 5. Construction details for the concrete slab, anchors and subdrains for the Main Spillway. (A) Anchor details showing welded wire mesh fabric above top of rock. (B) Cross-section showing vitreous clay pipe (VCP) drain with gravel filter pack at the base of concrete. From DWR (1965).

The spillway foundation is located within the Smartville Ophiolite Complex (Cole and McJunkin, 1978; Saucedo and Wagner, 1992). Rock here consists of steeply-dipping, foliated, metamorphosed volcaniclastics, pillow basalts, breccia, and diabase dikes and sills. Rock is blue-grey on fresh surfaces, grading to dark brown where weathered. It is very hard where fresh but is strongly foliated and exhibits steeply dipping tight to open joints. The thickness of the weathering profile is quite variable, on the order of 10-100 feet. The dielectric properties of the Oroville bedrock proved to be very advantageous for GPR acquisition. With a 500 MHz transducer, depth of investigation was at least 6 feet, with reflections from 8 feet or greater observed at many locations. We observed reflections from joints or fractures in the underlying rock. Many of those reflections were good enough to measure joint attitudes.

We generated multiple maps with different data views of the entire undamaged spillway section.

We used Google Earth 2016 aerial imagery for the base map. Those images were pre-failure and were the best available at that time. Using Google Earth imagery for base maps provided a common file format with easily understood visual references. “Rubber-sheeting” of the imagery was accurate to about six inches, more than sufficient for data presentation. Image resolution was good enough to recover project stationing from visible concrete joints and known landmarks.

The subdrains were conspicuous on the GPR profiles (Figure 6), and the herringbone pattern of the drains and gravel filter were readily visible in plan view (Figure 7A). These features are artificially induced voids, so they gave us some idea of how a void beyond the drains should appear. We also observed reflections from the lower reinforcing mesh (Figure 7A), and ringing off the vertical rebar of the rock anchors was seen at most locations (Figure 6).

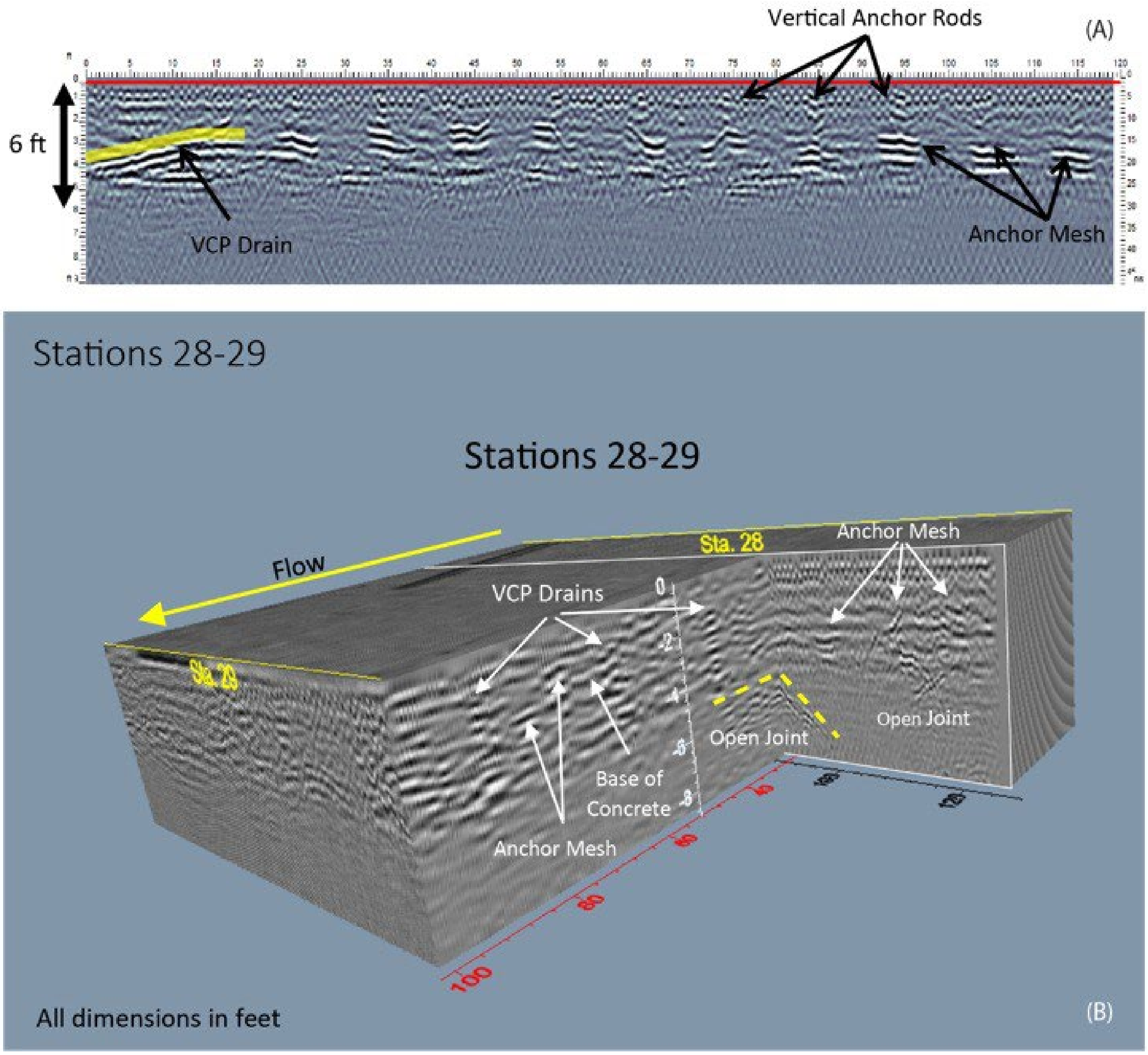


Figure 6. GPR data views in the vicinity of Station 28-29. (A) Profile view. (B) 3D cutaway view (composite from successive 2D profiles). Examples of interpreted features labeled as shown. Note lack of consistent reflection from base of concrete. VCP drains and anchor mesh served as proxies for estimating concrete thickness. From Owen and Mallah (2017).

Conspicuously absent in the data was any consistent reflection from the base of the concrete. We simply did not find any strong evidence of voids or delamination between the base of concrete and the top of rock along the remaining spillway, with the exception of an area in the vicinity of Station 26 (Figure 7D). That observation was consistent with an area of "significant clay fines" at the top of the rock surface noted during construction, and confirmed during demolition of the spillway during replacement the following year (IFT, 2018). Figure 7D includes the extent of clay fines observed during spillway demolition overlaid on the GPR interpretations. Figure 8B includes a photo taken of that exposed rock surface during demolition.

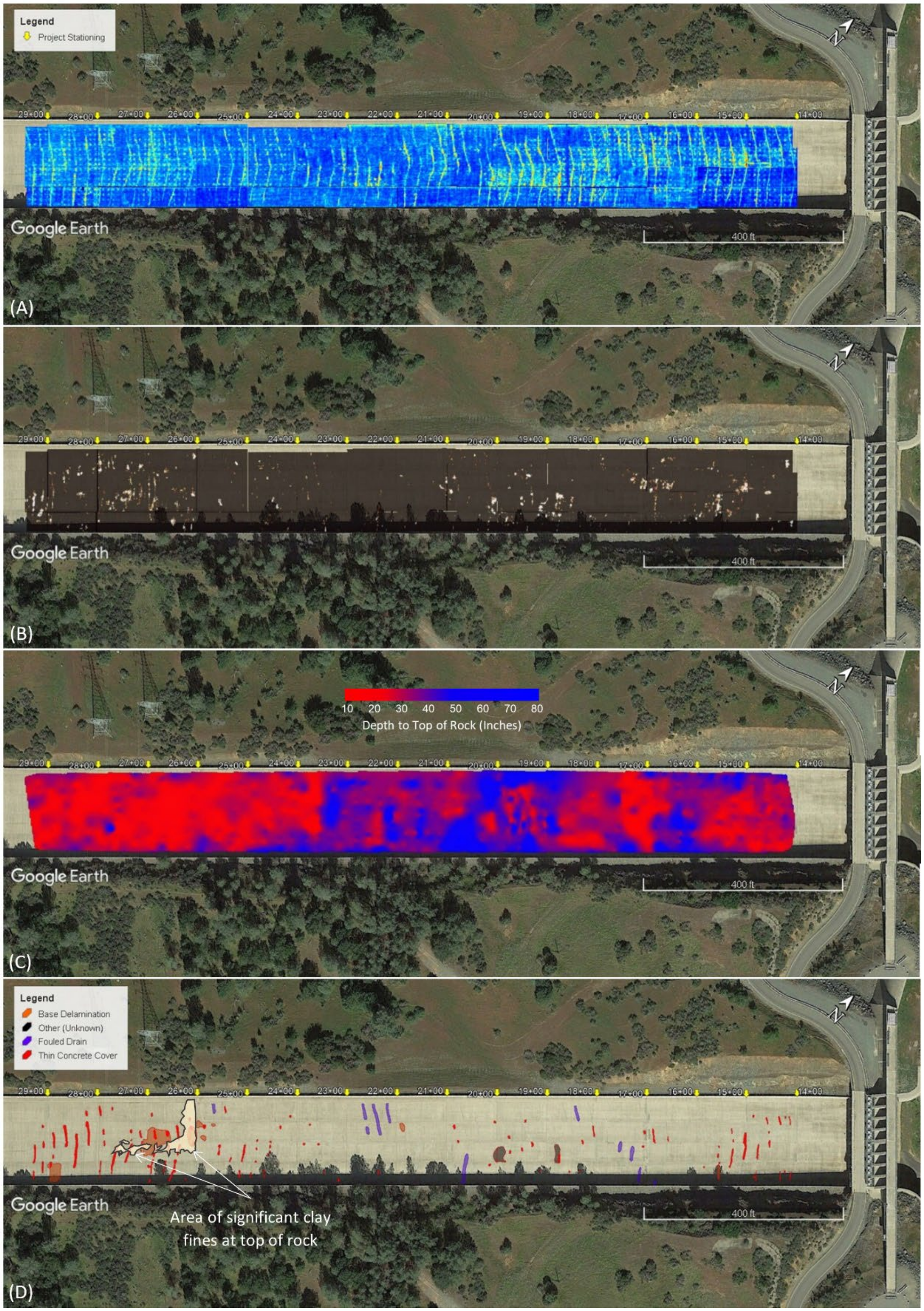


Figure 7. Plan View GPR maps produced for the Main Spillway. (A) Distribution of VCP drains and anchor mesh mats. (B). Discontinuities in bedrock below concrete. (C) Concrete thickness estimates. (D) Interpreted defects. Yellow arrows indicate project stationing. From Owen and Mallah (2017). See text for additional discussion.

Figure 8. Results from destructive testing acquired during emergency response at the Main Spillway. (A) Thin concrete cover above a VCP drain in the vicinity of Station 26 (note lack of gravel filter blanket). (B) Sand and silt deposits above the bedrock surface in the vicinity of Station 26. (C) Results of video inspection of VCP drains at Station 22. From IFT (2018)., Appendix D and Appendix I.

The ability to observe reflections several feet into rock allowed us to collect some information on the rock discontinuities immediately beneath the spillway. It was even possible to get attitudes from many of the rock features observed on the profiles.

Although the rock discontinuities were a low-priority target for our investigation, we could produce a rapid, qualitative assessment of the distribution of observed discontinuities by plotting high-contrast images of the rock reflections, creating a composite image of reflections from the rock joints and fractures beneath the spillway slab (Figure 7B). Although it doesn't provide orientation data for the discontinuities, we believed that the distribution of the observable features could assist with identification of probable shear zones or other regions of potential rock instability that might affect any preservation plans for the remaining spillway.

The lack of consistent reflection from the base of concrete complicated any effort to measure concrete thickness. However, with the information we had at hand regarding the placement of the base mesh at the rock anchors and the construction of the VCP drains, we could attempt to use those details as a proxy for the actual top of rock. Using depth estimates derived from the VCP drains and the anchor mesh, we produced a contour map of concrete thickness for the undamaged spillway (Figure 7C). Though we didn't expect high accuracy with this approach, the GPR depth estimates nonetheless were useful in developing a general picture for concrete thickness distribution across the spillway, and yielded some interesting trends. We noted a zone of increased thickness approximately within the area between Station 19 and Station 23+50.

That conclusion is supported by comparison of average concrete core thicknesses recovered during the emergency work (IFT, 2018, p. D-20). That information generally agrees with what we observe on the GPR data.

Caltrans' final work product for this investigation was the summary interpretation of potentially significant anomalies (Figure 7D). Our interpretations centered on three general categories: regions of anomalously thin concrete, suspected fouled drains, and potential voids or delaminations between the base of the concrete and the top of rock.

Results indicated that most of the anomalously thin concrete cover is clustered below Station 24, where cores and GPR data indicate concrete is thinnest overall (Figure 8A). Corroboration of our most significant finding is that no voids were discovered beneath the spillway slab during destructive testing, consistent with what we saw on the GPR data. At Station 26, inspection of the rock surface where we identified a potential delaminated zone revealed a layer of fine-grained sand and silt between the slab and the top of rock (Figure 8B), confirming lack of bonding between concrete and bedrock at that location. Video inspection of the VCP drains at Station 22 revealed drain fouling at one location near the area where we interpreted potential fouling, but no significant sediment buildup in the drains was noted at the locations that we identified (Figure 8D).

Emergency Spillway

At the Emergency Spillway, a secant (cutoff) wall and concrete splashpad were to be constructed at the spillway base to attenuate flow energy and mitigate future headcutting in the event of activation. GEOVision Geophysical Services was contracted to provide geophysical support for the design of that repair.

P-wave seismic refraction was chosen to delineate depth to competent bedrock and provide seismic velocities for qualitative evaluation of rock hardness.

Line placement was completed "on-the-fly", and final locations were dictated by on-site conditions at the time of data collection. P-wave seismic refraction was acquired along 20 profiles, each with 1 to 4 overlapping spreads of 48 geophones. Geophone spacing ranged from 4.5 to 10 ft and total line lengths were 211.5 to 1,125 ft. A 20-lb. sledgehammer or a truck-mounted 240-lb. accelerated weight drop (AWD) were used as the seismic sources. All lines were collected outside of the damaged spillway (Figure 9).

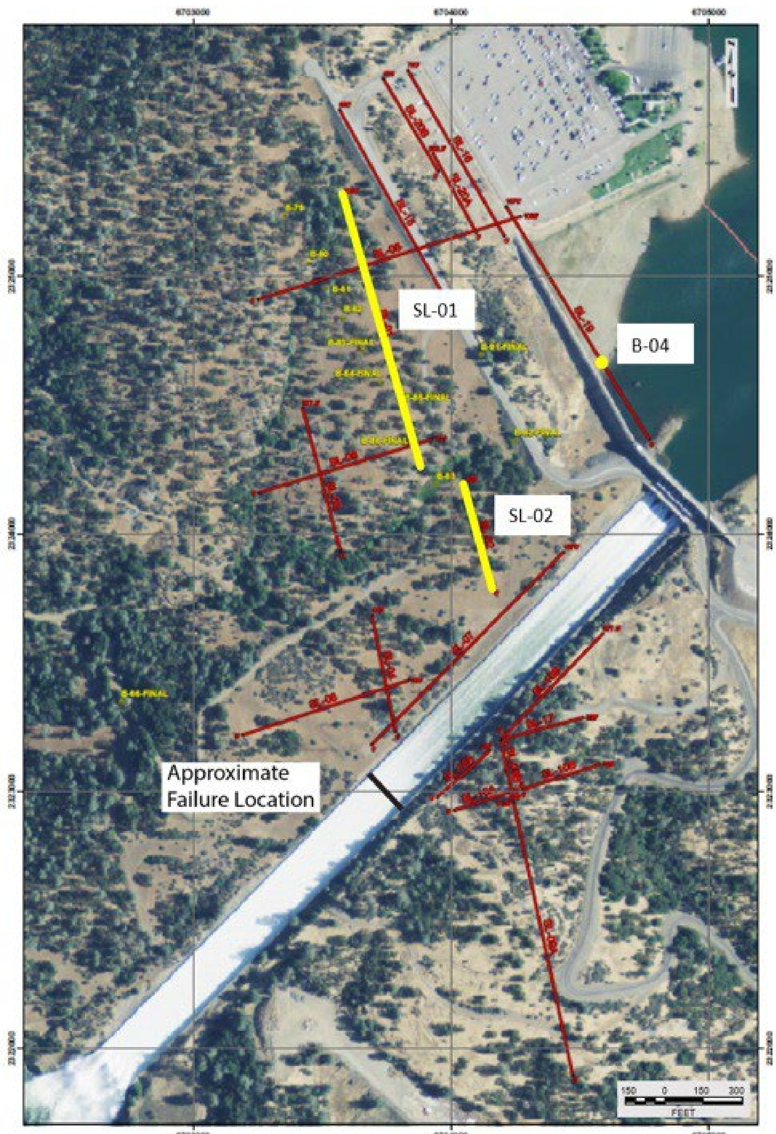


Figure 9. Locations of P-wave seismic refraction profiles and borehole geophysical logs. Highlighted locations (in yellow) shown in Figures 10-12. From Dalrymple (2017).

All profiles were processed using both unconstrained and constrained starting models using a local inversion tomography program. Unconstrained models were generated from 1D velocity profiles, and the constrained models were generated from time-term velocity sections. Both initial models were converted to 20-layer models and run for a minimum of 30 iterations. From the preliminary assessments of the subsurface conditions at the dam, it was expected that the geology consisted of variable weathered rock over competent rock. Tomography modeling was chosen for processing to allow for the variable weathering profiles to be more accurately rendered. Layer-based starting models were used to constrain initial conditions to preserve subsurface layering, if present. In all cases, the unconstrained models and the constrained models were similar, confirming that velocity contrasts at the project site are derived from the observed deep and variable rock weathering, rather than well-defined bedding. The processed tomography models provided sections that showed the highly variable weathering profile as it transitions to more competent rock across the site. All P-wave velocity profiles showed similar results with variations in weathering thickness. An example time-term tomography section is shown as Figure 10.

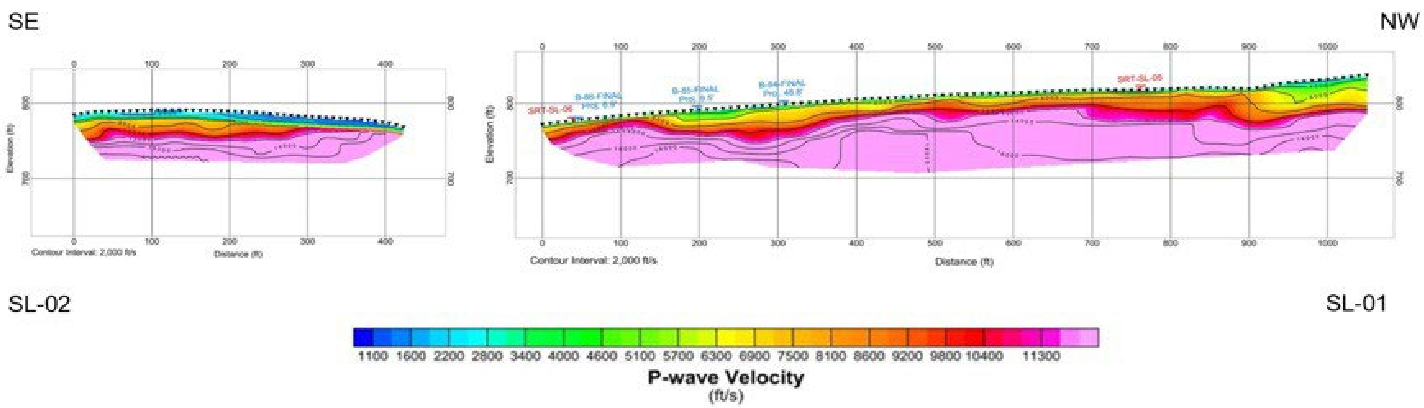


Figure 10. SRT-SL-01 and -02: Time-Term P-wave seismic tomography model, near the secant wall. Locations shown in Figure 9. View oriented looking downslope. Note that the weathered rock is thicker toward the northwest, with competent rock approaching the surface near the center and southeast of SL-01 and the northwest end of SL-02. From Dalrymple (2017).

Available geophysical and borehole logs from B-23, B-36, and B-81 were used to estimate the comparable velocity contours of the weathered rock and competent rock in the tomography models. Velocities of weathered rock were assumed to be in the range of about 5,000 ft/s to 7,000 ft/s and competent rock is assumed to be in the range of 9,000 to 11,000 ft/s. However, due to the gradational nature of the velocities of weathered and competent rock, alternate interpretations of the assumed velocity ranges are possible. Although no seismic lines were collected within the spillway, it was expected that the variable nature of the weathered section would have continued underneath the spillway, at least prior to construction.

Borehole geophysical logs were acquired at 95 locations across the project site. Boreholes were logged using a combination of Acoustic and Optical Televiewer and 3-Arm Mechanical Caliper logs. In situ velocity data were acquired at seven of the locations using a PS Suspension probe. Borehole logs were acquired as the drilling completed at each hole, and up to 10 drill rigs were simultaneously operated on site. That created a fast-paced, and dynamic geophysical logging schedule. To meet the demanding schedule, a logging crew remained on 24-hour standby at the site for approximately two months.

Interpretation of televiewer features was aided using core logs and other geophysical logs where available. Generally, televiewer feature interpretations aided by core data are more accurate than those derived from televiewer images alone. An example of an Acoustic Televiewer log with feature picks is provided as Figure 11.

PS Suspension logging provided depth and velocity correlations to observed geologic conditions and other geophysical observations. An example PS Suspension log is provided as Figure 12. In the examples presented here, both the televiewer and PS log were from the same borehole located at the Emergency Spillway and coincident with a nearby seismic refraction line.

Instances like this allowed for more detailed comparison and correlation between the geophysical observations and geologic logs.

The borehole geophysical logging, along with the seismic refraction surveys, provided rock depth, correlated rock types, and general conditions surrounding the spillway. Borehole logs that were in close proximity to the seismic refraction data showed good agreement, revealing a highly variable, weathered, and fractured rock profile throughout the site.

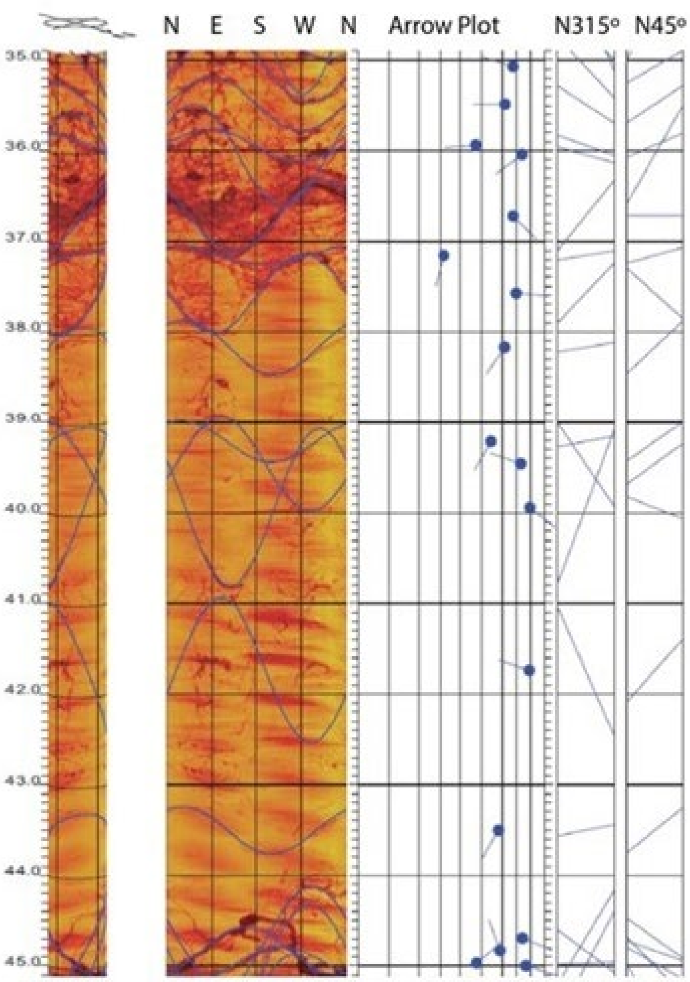


Figure 11. Borehole B-04, acoustic televiewer, 35 to 45 ft depth range. From Diehl (2018).

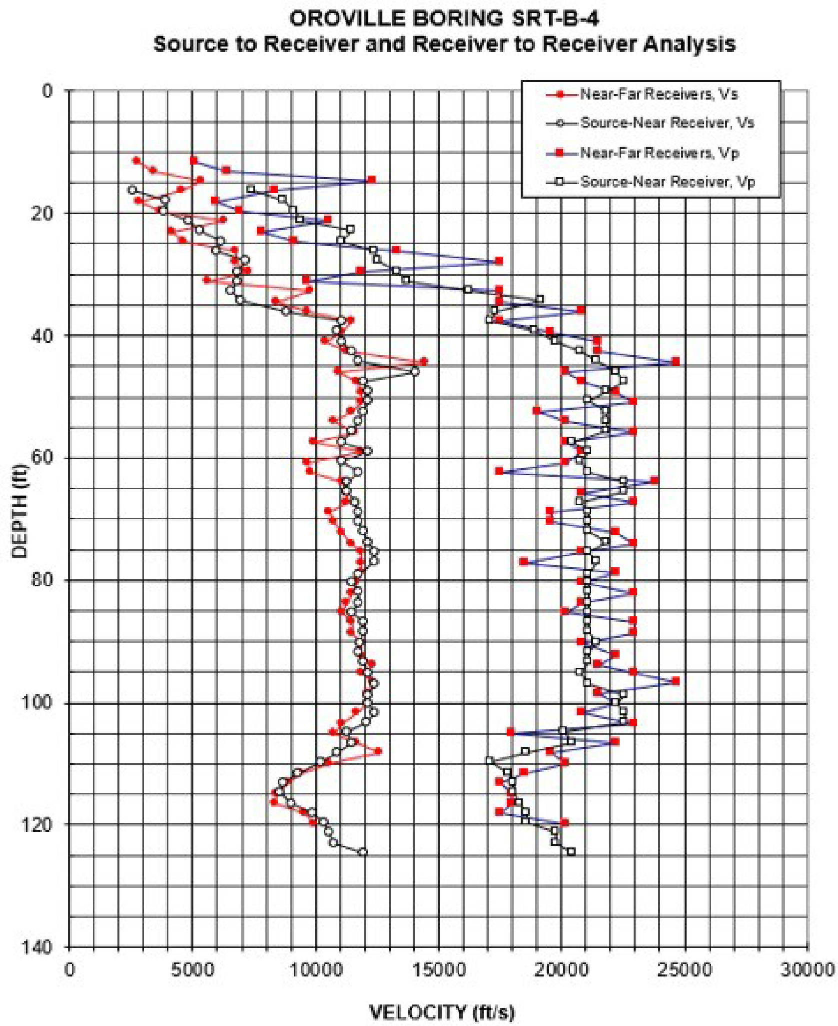


Figure 12. Borehole B-04, PS suspension log. Location shown in Figure 9. From Diehl (2018).

Conclusion

Safety is a long game, and no one can become complacent where it involves ensuring the integrity of the nation's civil infrastructure. So, how did geophysics contribute to understanding the spillway incident? The contributions can be summarized in four key points:

1. It provided a better understanding of the as-built service condition of the spillway, including concrete thickness, drain placement, and anchor placement.
2. It provided a better understanding of the variability of rock discontinuities at the Main Spillway and the Emergency Spillway.
3. It provided data to assist with the design of both the Main Spillway and Emergency Spillway repair.
4. It illustrated the important benefit of detailed, non-destructive testing for supplementing standard inspections and destructive testing for evaluating the characteristics and conditions of the spillways and their foundations.

The geophysical information provided additional confidence that allowed DWR engineers to determine that the remaining undamaged portion of the Main Spillway could be kept temporarily in service with high probability of success. The results also allowed DWR to proceed with immediate, initial construction and material removal in the Emergency Spillway area to prepare for final construction and repairs.

Epilogue

DWR contractors began rebuilding the Main and Emergency spillways in May 2017. Emergency repairs on the Main Spillway were completed in November 2017 to allow controlled discharges as needed to maintain safe reservoir levels. In 2018, the secant cutoff wall and splashpad were completed at the Emergency Spillway to mitigate future headcutting and erosion in the event of activation. By 2019, reconstruction of the Main Spillway to current design standards was completed (Figure 13). Grading of the eroded areas was completed in 2020. Revegetation of the damaged areas is ongoing.

Figure 13. Oroville Dam Main Spillway and Emergency Spillway in 2020, after completion of reconstruction efforts.

Disclaimer

The California Department of Water Resources (DWR) did not participate in this article. All opinions presented herein are those of the authors. All supporting information presented herein is public-domain and available for independent review. Unless otherwise noted, all photos herein are reproduced courtesy of DWR and are available on their website at https://water.ca.gov/Programs/State-Water-Project/SWP-Facilities/Oroville/Oroville-Spillways.

References

Cole KA, McJunkin RD, 1978, Geology of the Lake Oroville area, Butte County, California: DWR Geological Maps, B 203-78.

Dalrymple WM, 2017, GEOVision report, Oroville Dam seismic refraction survey 17125-01: Report prepared for the California Department of Water Resources, DOE – Project Geology, Oroville Spillway Restoration Team, GEOVision Geophysical Services, Inc., 06/16/2017, 61 pages.

Diehl JG, 2018, GEOVision Report, Oroville Dam borehole geophysics 17101-01 rev 3: Report prepared for the California Department of Water Resources, DOE – Project Geology, Oroville Spillway Restoration Team, GEOVision Geophysical Services, Inc., 03/13/2018, 1568 pages.

DWR, 1965, Oroville dam spillway, chute drainage system: California Department Water Resources, Division, Spec. No. 65-09, Drawings A-3B9-1 through A3B9-4, Sheets 47-50.

IFT, 2018, Independent Forensic Team report, Oroville Dam spillway incident: Association of State Dam Safety Officials, Independent Forensic Team Report, January 5, 2018, https://damsafety.org/sites/default/files/files/Independent%20Forensic%20Team%20Report%20Final%2001-05-18.pdf.

Owen W, and Mallah M, 2017, Mutual aid report, Oroville Dam spillway GPR investigation: Report prepared for the California Department of Water Resources Division of Operations and Maintenance, California Department of Transportation, Sacramento.

Saucedo GJ and Wagner DL (eds), 1992, Geologic map of the Chico quadrangle, California, 1:250,000: California Division Mines Geology Regional Map Series, Map No. 7A.

Author Bios

William Owen, PGP, CEG, PG
Bill Owen is a Professional Geophysicist and chief of the Geophysics and Geology Branch for the California Department of Transportation in Sacramento. He has over 30 years of experience managing and conducting engineering geophysical investigations for highway infrastructure throughout the state. He has also participated in numerous research projects and federal outreach efforts demonstrating the efficacy of geophysical methods for transportation and engineering problems.

William Dalrymple, PGP
William Dalrymple is a Professional Geophysicist with the Geophysics and Geology Branch at the California Department of Transportation. He has 20 years of experience, conducting geophysical projects for highways, dams, mine sites, nuclear and chemical plants, and environmental sites worldwide. His current focus is on performing seismic, electrical, electromagnetic, and GPR investigations for transportation projects throughout California.

John Diehl, PE
John Diehl received his BSCE in 1976 from California State Polytechnic Institute of Pomona. His Masters in Engineering was received in 1977 from UCLA, where he also attended to receive his MBA in 1988. With two partners, he founded GEOVision in 1995, which nearly 30 years later is one of the most respected geophysical consulting firms in the United States. Over the course of his career, he has authored or co-authored over 30 publications, focusing primarily on geophysical instrumentation and geophysical testing. He is a lifetime member of ASCE and is a Professional Engineer in the state of California.

Front Yard Geophysics in Northern Austin: Location of a Significant Karst Anomaly in Austin Chalk, Travis County Texas

Mustafa Saribudak

Environmental Geophysics Associates

Email: mbudak@pdg.net

Introduction

Unusual road cracks and several road patches exist on a circle road located north of Austin. A Google map of the area shows the peculiar geometry of the cracks and some of the asphalt patches. The first question that comes to mind is what is causing the cracks and the second is if their existence I ins some way related to the road patches.

A chat with a neighbor indicated that the cracks have been there as long as she remembers (~20years), and the patches on the road were due to the "sinkhole repairs." The last repair, according to the neighbor, was approximately done two years ago. This circle road and its vicinity is located in the geological formation of the Austin Chalk.

Geology

The Austin Chalk is an upper Cretaceous geologic formation in the Coast region of the United States. It is named after type section outcrops near Austin, Texas. The Austin Chalk consists of recrystallized, fossiliferous, interbedded chalks and marls. The Austin Chalk crops out in a wide belt almost through the center of the city of Austin, extending from south of Onion Creek all the way past Pflugerville. Interstate Highway 35 is constructed on the high ground that represents the Austin Chalk escarpment. The study area is shown in Figure 1 with a red/yellow star on the geologic map of Austin.

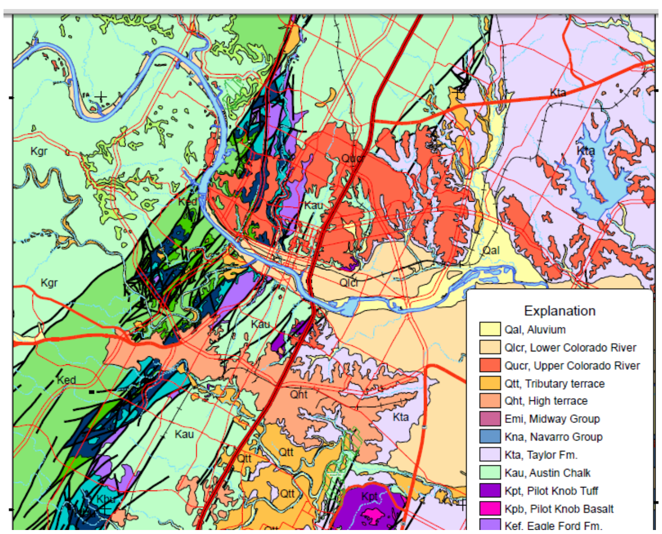


Figure 1. Geology map of the Austin area showing the study area in the Austin Chalk.

Geophysical Surveys—Field Survey Design

To determine what is causing the cracks and/or to understand the extent of the sinkhole(s), resistivity, natural potential (NP) and ground penetrating radar (GPR) surveys were performed at the study area.

First, as a reconnaissance work, I collected NP data along both sides of the front yards of the houses encircling the road (blue lines in Figure 2). The station spacing was 10 feet, but where anomalous NP values were observed the data were collected with a tighter spacing of 5 feet. The total number of NP data points was 58. I collected the NP data after a rain shower in the vicinity of the site. The NP values were tied to a near-by base station and corrected for diurnal variations. The NP unit is measured in millivolt (mV). The rule of thumb in NP interpretation is that sinkholes generate a negative anomaly whereas an air-filled cave forms a positive NP anomaly.

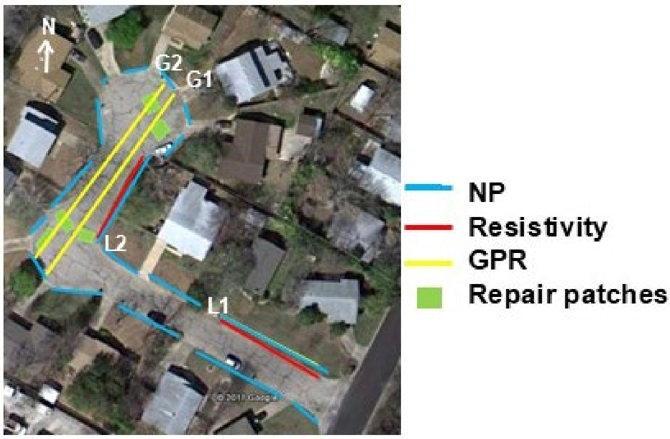


Figure 2. Site map showing locations of geophysical surveys.

Secondly, I performed GPR surveys along the road crossing the asphalt patches on the road. North-south GPR profiles G1and G2 are shown with a yellow colored line in Figure 2. Note that I did run a few E-W GPR lines on the road; however, they did not indicate any significant anomalies. For this reason, I will not discuss the results from the E-W profiles. Lengths of both GPR profiles were 200 feet. The depth of exploration with the GPR survey was about 8 feet.

Finally, based on the NP results, I chose two resistivity locations and collected resistivity data along the lines L1 and L2. These profiles are shown with a red colored line in Figure 2. The location of the profile L1 was chosen along NP values that did not show any anomalies, whereas the location of the profile L2 showed extremely significant NP values. Although I wanted to collect two more resistivity profiles across some negative NP anomalies, it was not possible logistically due to moving traffic in and out of the drive ways.

Interpretation of NP Data

All the NP data collected along the front yards of the houses across the study area are plotted on a site map and shown in Figure 3. The NP data points are shown with a red/yellow circle and the NP values are shown with white numbers. The NP map indicates zero and/or background values in the southeastern part of the site. Negative values appear to show further west on either side of the front yards. However, a very significant positive NP anomaly (~115mV) is observed on the eastern flank of a front yard where the street makes a turn to the north.

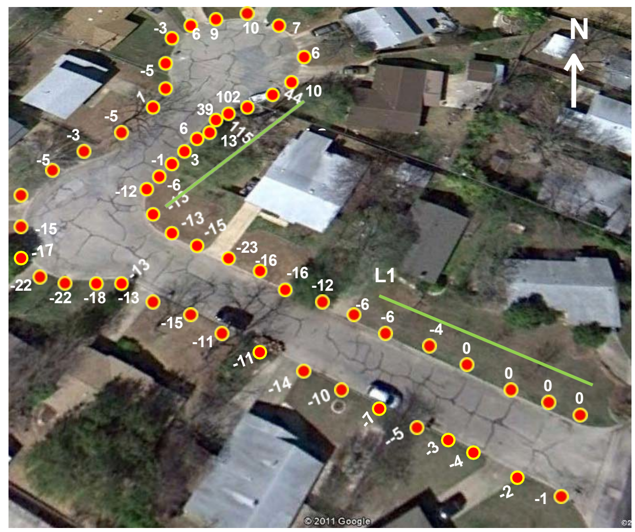


Figure 3. Location of NP stations.

Interpretation of Resistivity and NP Data

The resistivity imaging and NP data taken along line L1 are shown in Figure 4. The resistivity profile indicates horizontal layers of resistivity ranging between 20 and 200 Ohm-meter, which correspond to marl and limestone units, respectively. The NP data also show no significant anomalies along the profile.

The resistivity imaging and NP data taken along profile L2 are given in Figure 5. The resistivity data show a significant subsidence between stations 20 and 50 feet. The resistivity layers range between 7 and 180 Ohm-meter, which may be indicative of clay and weathered limestone. The NP data also indicate a quite significant NP anomaly (positive) over the resistivity anomaly.

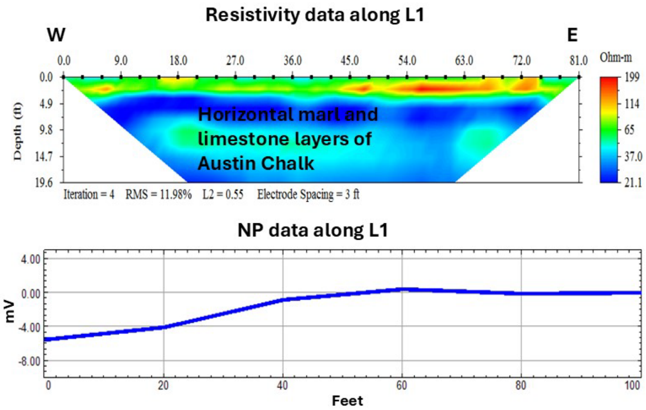


Figure 4. Resistivity inversion (top) and NP (bottom) results for line L1.

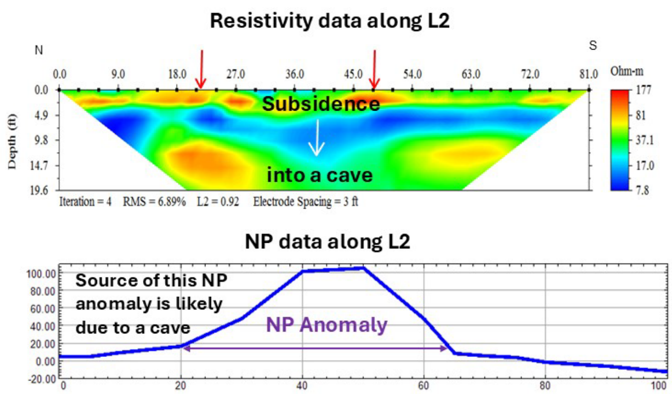


Figure 5. Resistivity inversion (top) and NP (bottom) results for line L2.

Interpretation of GPR Data

Two GPR profiles (G1 and G2) were processed and interpreted (Figure 6). The first pair of the profiles (Figure 6a and b) are chosen between stations zero (0) and 25 feet where both data sets indicate subsiding subsurface soil layers. Locations of these subsidence anomalies are correlative with the locations of the repair patches in the northern part of the site.

The second pair of the GPR profiles (Figure 6c and d) are chosen between stations 175 and 200 feet where both data sets indicate subsiding subsurface soil layers. Locations of these subsidence GPR anomalies are correlative with the locations of the repair patches in the southern part of the site.

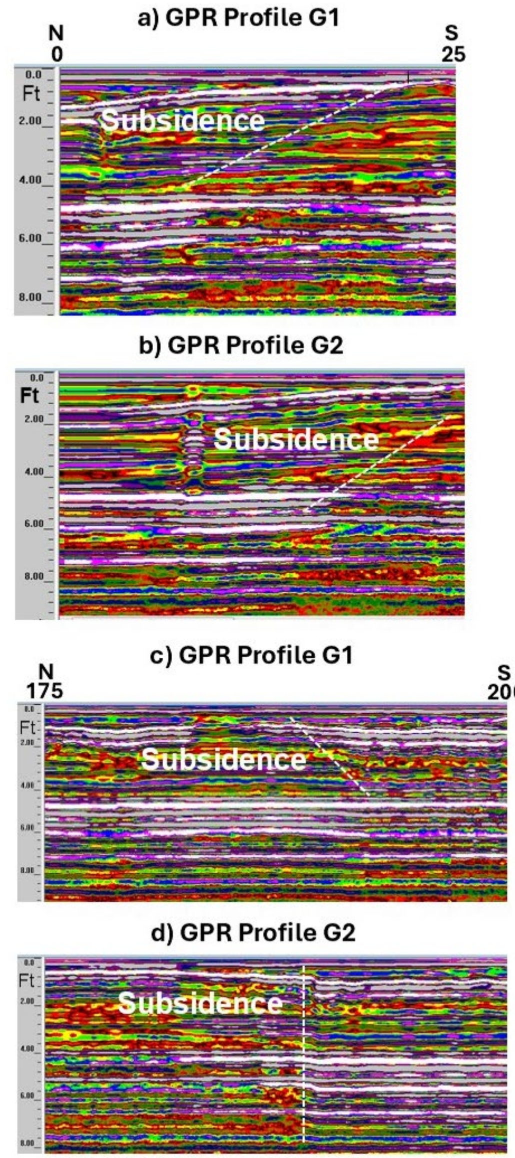


Figure 6. GPR profiles G1 and G2. a) Distance 0 to 25 ft. b) Distance 175 to 200 ft.

Conclusions

Areas of negative NP (yellow-dashed line), positive NP (white-dashed line) are approximately defined on a site map below. The significant high NP anomaly location and resistivity anomaly indicating subsidence are also shown with a green circle on the eastern part of the circled road. Locations of GPR anomalies are shown with blue lines and their subsidence directions with white arrows in Figure

7. The presence of all these geophysical anomalies indicate subsidence, sinkholes, and caves in the subsurface. Their tectonic interactions could be responsible for the peculiar geometry of the surface fractures that are present at the site.

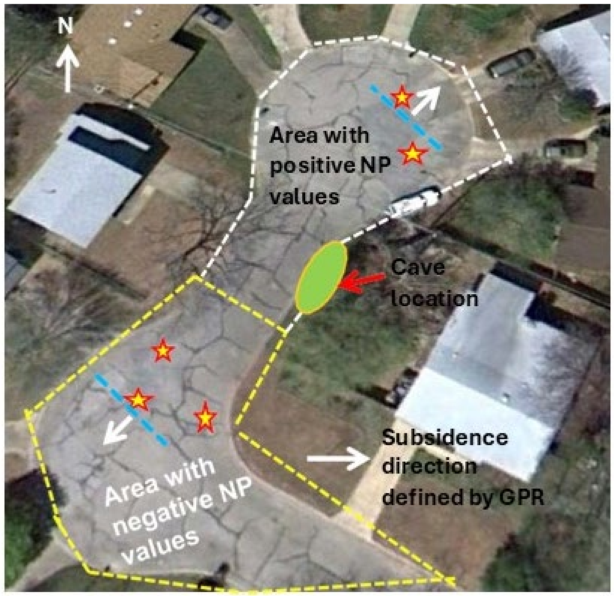
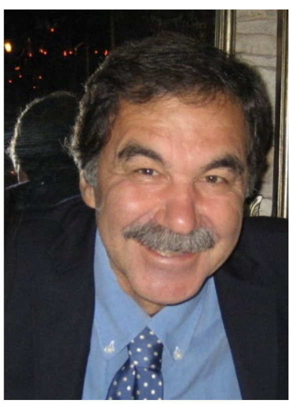


Figure 7. Locations of positive and negative NP values.

.

Author Bio

Mustafa Saribudak, Ph.D., P.G.



Mustafa Saribudak is the principal of Environmental Geophysics Associates (EGA). He holds B.Sc. and M.Sc. (1975) in geology from the University of Istanbul and a Ph.D. (1987) from the Istanbul Technical University in Turkey. He came to the University of Houston in 1990 as a visiting geoscientist. He started working for Tierra Environmental in the Woodlands between 1991 and 1993, where he pioneered the application of geophysical methods to environmental problems. He founded EGA in 1994 to provide near-surface geophysical services for engineering, environmental, and oil and gas industries, and real estate developers. Since than he has worked on more than 400 projects.

His personal research interests have been the active growth faulting in the Houston area, major faults of the karstic Edwards Aquifer in central Texas (for example: Mt. Bonnell, Barton Springs and Haby faults); location of karstic features (caves, sinkholes, voids) across the Edwards Aquifer; location of abandoned oil and gas wells and water wells; application of geophysical methods to volcanoes. His consultancy work resulted in over 50 published papers, which provided valuable insights and quantitative data for the geophysical and geological fields.

Environmental and Engineering Geophysical Society

2026 Individual Membership Application

Renew or Join Online at www.EEGS.org

Individual Membership Categories

EEGS is the premier organization for geophysics applied to engineering and environmental problems. Our multi-disciplinary blend of professionals from the private sector, academia, and government offers a unique opportunity to network with researchers, practitioners, and users of near-surface geophysical methods.

Memberships are for 1 calendar year and include access to the *Journal of Environmental & Engineering Geophysics (JEEG)*, proceedings archives of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), and our electronic newsletter, *FastTIMES*. Members also enjoy complimentary access to SEG's technical program expanded abstracts, as well as discounted SAGEEP registration fees, books and other educational publications. EEGS offers a variety of membership categories tailored to fit your needs. Please select (circle) your membership category and indicate your willingness to support student members below **to contribute to the growth of this important segment of EEGS' membership:**

☐ **Yes, I wish to sponsor ________ student(s) @ $20 each to be included in my membership payment.**

Individual Members

Individual memberships are for 1 calendar year (Jan. 1 through Dec. 31)

Category	All Dues USD
Individual	$150

Retired Members

Your opportunity to stay connected and support the only organization focusing on near surface geophysics. Retired memberships are for 1 calendar year (Jan. 1 through Dec. 31)

Category	
Retired (*Must be Approved by EEGS Board of Directors*)	$60

Introductory Members

If you have not been a member of EEGS before, we offer a reduced rate for new members to enjoy all the benefits of individual membership (except vote or hold office) for one year.

Category	
Introductory	$80

Lifetime Members

New! Support EEGS, receive benefits on an ongoing basis and never renew again! Members in this category enjoy all the benefits of Individual membership.

Category	
Lifetime Member	$995

Developing World Members

Those wishing to join this category of EEGS membership are invited to check the list of countries to determine qualification. Memberships are for 1 calendar year (Jan. 1 through Dec. 31)

Category	
Developing World (*List of qualifying countries next page*)	$60

Student Members

Students represent EEGS' future and we offer two Student Member types to support students. Student members enjoy all the benefits of individual membership (except to vote or hold office). Available for all students in an accredited university up to one year post-graduation. Please submit a copy of your student ID and indicate your projected date of graduation: ___ /____ (Month/Year). Students in year two beyond graduation are offered a special rate for 1 year.

Category	
Student up to 1 Year Post Graduation: Grad Date: Mo/Yr.: ___/___	$25
Student - Year Two Post Graduation	$55

Environmental and Engineering Geophysical Society

2026 Individual Membership Application

Renew or Join Online at www.EEGS.org

Membership Renewal
Developing World Category Qualification

If you reside in one of the countries listed below, you are eligible for EEGS's Developing World membership category rate of $50.00.

Afghanistan
Albania
Algeria
Angola
Armenia
Azerbaijan
Bangladesh
Belize
Benin
Bhutan
Bolivia
Burkina Faso
Burundi
Cambodia
Cameroon
Cape Verde
Central African Republic
Chad
China
Comoros
Congo, Dem. Rep.
Congo, Rep.
Djibouti
Ecuador
Egypt
El Salvador
Eritrea
Ethiopia
Gambia
Georgia
Ghana
Guatemala
Guinea-Bissau
GuyanaHaiti
Honduras
India
Indonesia
Iran
Iraq
Ivory Coast
Jordan
Kenya
Kiribati
Kosovo
Kyrgyz Republic
Lao PDR
Lesotho
Liberia
Madagascar
Malawi
Maldives
Mali
Marshall Islands
Mauritania
Micronesia
Moldova
Mongolia
Morocco
Mozambique
Myanmar
Nepal
Nicaragua
Niger
Nigeria
North Korea
Pakistan
Papua New Guinea
Paraguay
Philippines
Rwanda
Samoa
Sao Tome and Principe
Senegal
Sierra Leone
Solomon Islands
Somalia
Sri Lanka
Sudan
Suriname
Swaziland
Syria
Taiwan
Tajikistan
Tanzania
Thailand
Timor-Leste
Togo
Tonga
Tunisia
Turkmenistan
Uganda
Ukraine
Uzbekistan
Vanuatu
Vietnam
West Bank and Gaza
Yemen
Zambia
Zimbabwe

1391 Speer Boulevard | Suite #450 | Denver, CO 80204
(p) 001.1.303.531.7517 | staff@eegs.org | www.eegs.org

Environmental and Engineering Geophysical Society	Renew or Join Online at www.EEGS.org
2026 EEGS Membership Application	

CONTACT INFORMATION

Salutation	First Name	Middle Initial	Last Name

Company/Organization	Title

Street Address	City	State/Province	Zip Code	Country

Direct Phone	Mobile Phone	Fax

Email	Website

ABOUT ME: INTERESTS & EXPERTISE

In order to identify your areas of specific interests and expertise, please check all that apply:

Role	Interest or Focus	Geophysical Expertise	Professional/ Scientific Societies	Willing to Serve on a Committee?
☐ Consultant	☐ Archaeology	☐ Borehole Geophysical Logging	☐ AAPG	☐ Publications
☐ User of Geophysical Svcs.	☐ Engineering	☐ Electrical Methods	☐ AEG	☐ Web Site
☐ Student	☐ Environmental	☐ Electromagnetics	☐ ASCE	☐ Membership
☐ Geophysical Contractor	☐ Geotechnical	☐ Gravity	☐ AWWA	☐ Student
☐ Equipment Manufacturer	☐ Geo. Infrastructure	☐ Ground Penetrating Radar	☐ AGU	
☐ Software Manufacturer	☐ Groundwater	☐ Magnetics	☐ EAGE	
☐ Research/Academia	☐ Hazardous Waste	☐ Marine Geophysics	☐ EERI	
☐ Government Agency	☐ Humanitarian Geo.	☐ Remote Sensing	☐ GeoInstitute	
☐ Other	☐ Mining	☐ Seismic	☐ GSA	
	☐ Shallow Oil & Gas	☐ Other	☐ NGWA	
	☐ UXO		☐ NSG	
	☐ Aerial Geophysics		☐ SEG	
	☐ Agriculture		☐ SSA	
	☐ Renewable Energy		☐ SPWLA	
	☐ Other		☐ NAOC	

1391 Speer Boulevard | Suite #450 | Denver, CO 80204
(p) 001.1.303.531.7517 | staff@eegs.org | www.eegs.org

Environmental and Engineering Geophysical Society

2026 EEGS Membership Application

Renew or Join Online at www.EEGS.org

FOUNDATION CONTRIBUTIONS

FOUNDERS FUND

The Founders Fund has been established to support costs associated with the establishment and maintenance of the EEGS Foundation as we solicit support from larger sponsors. These will support business office expenses, necessary travel, and similar expenses. It is expected that the operating capital for the foundation will eventually be derived from outside sources, but the Founder's Fund will provide an operation budget to "jump start" the work. Donations of $50.00 or more are greatly appreciated. For additional information about the EEGS Foundation (an IRS status 501(c)(3) tax exempt public charity), visit the website at http://www.EEGSFoundation.org.

Foundation Fund Total: $ ____________

STUDENT SUPPORT ENDOWMENT

This Endowed Fund will be used to support travel and reduced membership fees so that we can attract greater involvement from our student members. Student members are the lifeblood of our society, and our support can lead to a lifetime of involvement and leadership in the near-surface geophysics community. Donations of $50.00 or more are greatly appreciated. For additional information about the EEGS Foundation (a tax exempt public charity), visit the website at http://www.EEGSFoundation.org.

Student Support Endowment Total: $ ____________

CORPORATE CONTRIBUTIONS

The EEGS Foundation is designed to solicit support from individuals and corporate entities that are not currently corporate members (as listed above). We recognize that most of our corporate members are small businesses with limited resources, and that their contributions to professional societies are distributed among several organizations. The Corporate Founder's Fund has been developed to allow our corporate members to support the establishment of the Foundation as we solicit support from new contributors.

Corporate Contribution Total: $ ____________

Foundation Total: $ ____________

PAYMENT INFORMATION

☐ Check/Money Order ☐ VISA ☐ MasterCard

☐ AmEx ☐ Discover

Subtotals

Membership: $ ____________

Student Sponsorship: $ ____________

Foundation Contributions: $ ____________

Grand Total: $ ____________

Card Number ____________ **Exp. Date** ____________ **CVV #:** ____________

Name on Card ____________

Signature ____________

Make your check or money order in US dollars payable to: EEGS. Checks from Canadian bank accounts must be drawn on banks with US affiliations (example: checks from Canadian Credit Suisse banks are payable through Credit Suisse New York, USA). Checks must be drawn on US banks.

Payments are not tax deductible as charitable contributions although they may be deductible as a business expense. Consult your tax advisor.

Return this form with payment to: EEGS, 1391 Speer Boulevard, Suite #450, Denver, CO 80204 USA

Credit card payments can be faxed to EEGS at 001.1.303.820.3844

Corporate dues payments, once paid, are non-refundable. Individual dues are non-refundable except in cases of extreme hardship and will be considered on a case-by-case basis by the EEGS Board of Directors. Requests for refunds must be submitted in writing to the EEGS business office.

QUESTIONS? CALL 001.1.303.531.7517

Environmental and Engineering Geophysical Society

2026 Corporate Membership Application

Renew or Join Online at www.EEGS.org

EEGS is the premier organization for geophysics applied to engineering and environmental problems. Our multidisciplinary blend of professionals from the private sector, academia, and government offers a unique opportunity to network with researchers, practitioners, and users of near-surface geophysical methods.

Memberships include access to the Journal of Environmental & Engineering Geophysics (JEEG), proceedings archives of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), and our electronic newsletter FastTIMES. Members also enjoy complimentary access to SEG's technical program expanded abstracts as well as discounted SAGEEP registration fees, books and other educational publications. EEGS offers a variety of membership categories tailored to fit your needs. We strive to continuously add value to all the Corporate Membership categories. For the best value, we offer the Basic + Web ad Package Website Advertising opportunities. Please select (circle) your membership category and rate. EEGS is also offering an opportunity for all EEGS members to help support student(s) at $20 each. Please indicate your willingness to contribute to support of student members below:

☐ **Yes, I wish to sponsor ______ student(s) @ $20 each to be included in my membership payment.**

Category	2026 Basic Dues Rate	2026 Basic + Web Ad Package
Corporate Student Sponsor *Includes one (1) individual membership, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES and Sponsorship of 10 student memberships*	$320	$870
Corporate Donor *Includes one (1) individual EEGS membership, one (1) full conference registration to SAGEEP, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES*	$685	$1235
Corporate Associate *Includes two (2) individual EEGS memberships, an exhibit booth and registration at SAGEEP, the ability to insert marketing materials in the SAGEEP delegate packets, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES*	$3210	$3760
Corporate Benefactor *Includes two (2) individual memberships to EEGS, two (2) exhibit booths and registrations at SAGEEP, the ability to insert marketing materials in the SAGEEP delegate packets, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES*	$4035	$4585
	Purchase Separately	
Website Advertising *One (1) Pop-Under, scrolling marquee style ad with tag line on Home page, logo linked to Company web site* *One (1) Button sized ad, linked logo, right rail on each web page*	$600/yr. $250/yr.	**Package Rates include both web site ad locations**

Environmental and Engineering Geophysical Society

2026 Corporate Membership Application

Renew or Join Online at www.EEGS.org

CONTACT INFORMATION (*Corporate Memberships are based on a Primary Member's contact information)*

Salutation | First Name | Middle Initial | Last Name

Company/Organization | Title

Street Address | City | State/Province | Zip Code | Country

Direct Phone | Mobile Phone | Fax

Email | Website

ABOUT ME: INTERESTS & EXPERTISE

In order to identify your areas of specific interests and expertise, please check all that apply:

Role	Interest or Focus	Geophysical Expertise	Professional/ Scientific Societies	Willing to Serve on a Committee?
☐ Consultant	☐ Archaeology	☐ Borehole Geophysical Logging	☐ AAPG	☐ Publications
☐ User of Geophysical Svcs.	☐ Engineering	☐ Electrical Methods	☐ AEG	☐ Web Site
☐ Student	☐ Environmental	☐ Electromagnetics	☐ ASCE	☐ Membership
☐ Geophysical Contractor	☐ Geotechnical	☐ Gravity	☐ AWWA	☐ Student
☐ Equipment Manufacturer	☐ Geo. Infrastructure	☐ Ground Penetrating Radar	☐ AGU	
☐ Software Manufacturer	☐ Groundwater	☐ Magnetics	☐ EAGE	
☐ Research/Academia	☐ Hazardous Waste	☐ Marine Geophysics	☐ EERI	
☐ Government Agency	☐ Humanitarian Geo.	☐ Remote Sensing	☐ GeoInstitute	
☐ Other	☐ Mining	☐ Seismic	☐ GSA	
	☐ Shallow Oil & Gas	☐ Other	☐ NGWA	
	☐ UXO		☐ NSG	
	☐ Aerial Geophysics		☐ SEG	
	☐ Agriculture		☐ SSA	
	☐ Renewable Energy		☐ SPWLA	
	☐ Other		☐ NAOC	

1391 Speer Boulevard | Suite #450 | Denver, CO 80204
(p) 001.1.303.531.7517 | staff@eegs.org | www.eegs.org

Environmental and Engineering Geophysical Society

2026 Corporate Membership Application

Renew or Join Online at www.EEGS.org

FOUNDATION CONTRIBUTIONS

FOUNDERS FUND

The Founders Fund has been established to support costs associated with the establishment and maintenance of the EEGS Foundation as we solicit support from larger sponsors. These will support business office expenses, necessary travel, and similar expenses. It is expected that the operating capital for the foundation will eventually be derived from outside sources, but the Founder's Fund will provide an operation budget to "jump start" the work each year. Donations of $50.00 or more are greatly appreciated. For additional information about the EEGS Foundation (an IRS status 501(c)(3) tax exempt public charity), visit the website at http://www.EEGSFoundation.org.

Foundation Fund Total: $ ________________

STUDENT SUPPORT ENDOWMENT

This Endowed Fund will be used to support travel and reduced membership fees so that we can attract greater involvement from our student members. Student members are the lifeblood of our society, and our support can lead to a lifetime of involvement and leadership in the near-surface geophysics community. Donations of $50.00 or more are greatly appreciated. For additional information about the EEGS Foundation (a tax exempt public charity), visit the website at http://www.EEGSFoundation.org.

Student Support Endowment Total: $ ________________

CORPORATE CONTRIBUTIONS

The EEGS Foundation is designed to solicit support from individuals and corporate entities that are not currently corporate members (as listed above). We recognize that most of our corporate members are small businesses with limited resources, and that their contributions to professional societies are distributed among several organizations. The Corporate Founder's Fund has been developed to allow our corporate members to support the establishment of the Foundation as we solicit support from new contributors.

Corporate Contribution: $ ________________

Foundation Total: $ ________________

PAYMENT INFORMATION

☐ Check/Money Order ☐ VISA ☐ AmEx

☐ MasterCard ☐ Discover

Subtotals

Membership: $ ________________

Total Student Sponsorship @ $20 ea. $ ________________

Foundation Contributions: $ ________________

Grand Total: $ ________________

____

Card Number **Exp. Date** **CVV #:**

____

Name on Card

____

Signature

Make your check or money order in US dollars payable to: EEGS. Checks from Canadian bank accounts must be drawn on banks with US affiliations (example: checks from Canadian Credit Suisse banks are payable through Credit Suisse New York, USA). Checks must be drawn on US banks.

Payments are not tax deductible as charitable contributions although they may be deductible as a business expense. Consult your tax advisor.

Return this form with payment to: EEGS, 1391 Speer Boulevard, Suite #450, Denver, CO 80204 USA

Credit card payments can be faxed to EEGS at 001.1.303.820.3844

Corporate dues payments, once paid, are non-refundable. Individual dues are non-refundable except in cases of extreme hardship and will be considered on a case-by-case basis by the EEGS Board of Directors. Requests for refunds must be submitted in writing to the EEGS business office.

QUESTIONS? CALL 001.1.303.531.7517

Your products, services and expertise should stand apart when you advertise

When you participate in the *FastTIMES* advertising program, yours will!

Consultants, contractors and geophysical technology providers, your potential users and customers will be viewing your ad in a news magazine published electronically by the Environmental and Engineering Geophysical Society (EEGS) where each issue features technical articles on diverse topics, news from the near-surface geophysical community, information on recent and coming events, and notices of professional opportunities.

Why *FastTIMES*?

- Widely distributed to a targeted audience of over 3500 near surface professionals
- Easy to download format allows readers to view your products and services on demand
- Features technical articles on the latest developments, case histories and applications and Special Issues on timely topics
- Advertisers can reserve ad space adjacent to articles or information related to or especially applicable to your product or service
- Trusted source – EEGS and its publications maintain a level of professionalism advertisers can trust to run cost-effective, prominently advertisements and readers value as a reliable source

How Do I Participate in *FastTIMES* Advertising Program?

To learn more about advertising in *FastTIMES*, access https://www.eegs.org/advertising-information, call 303.531.7517 or email staff@eegs.org.

Environmental and Engineering Geophysical Society