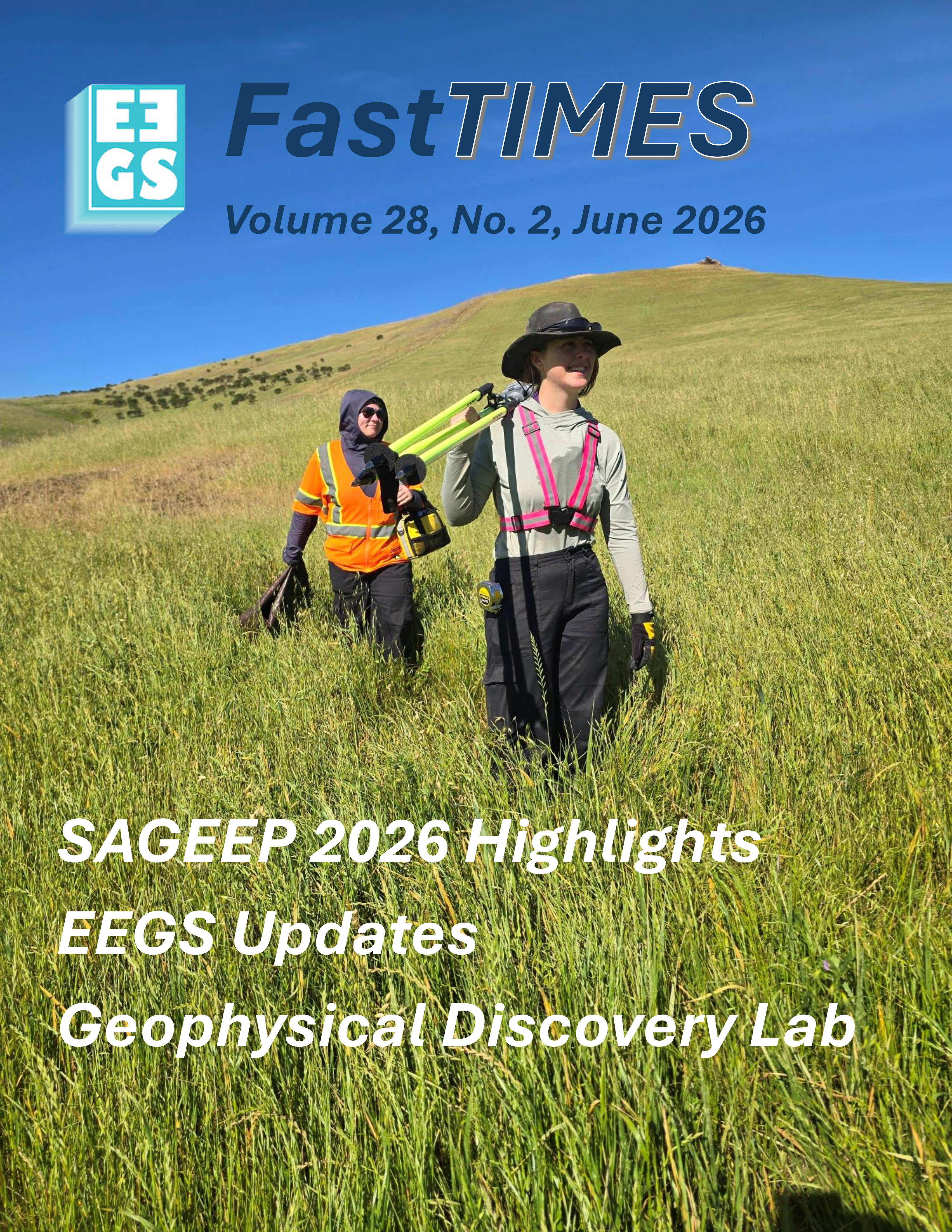
FastTIMES

Volume 28, No. 2, June 2026



SAGEEP 2026 Highlights

EEGS Updates

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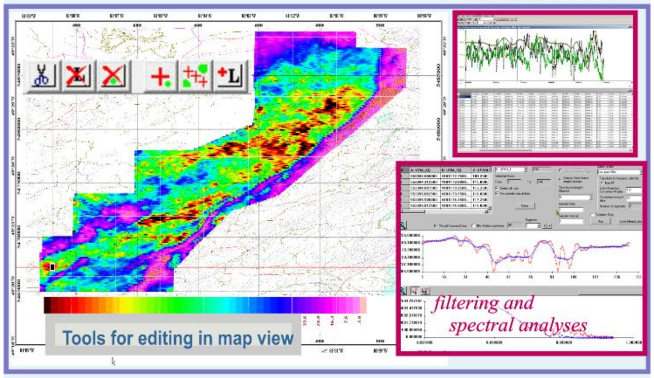
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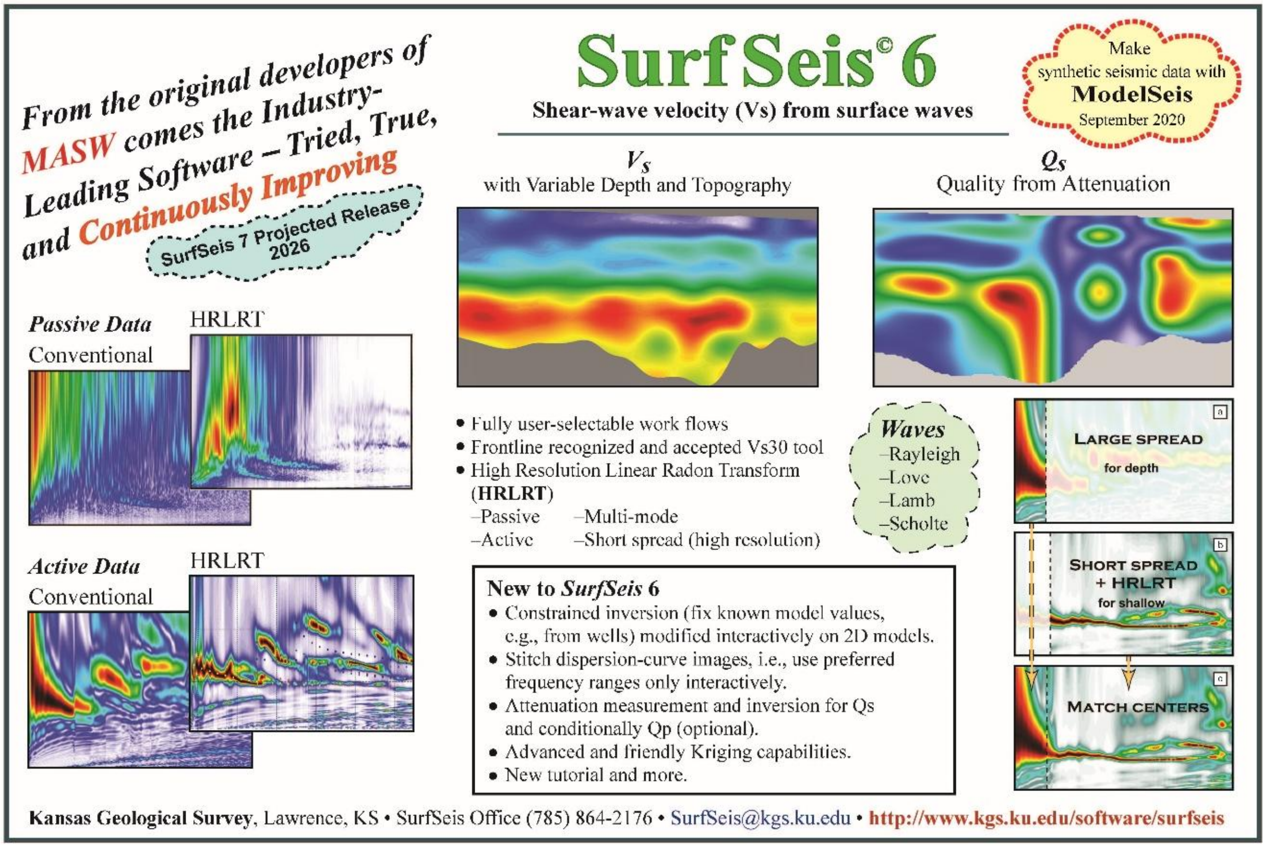
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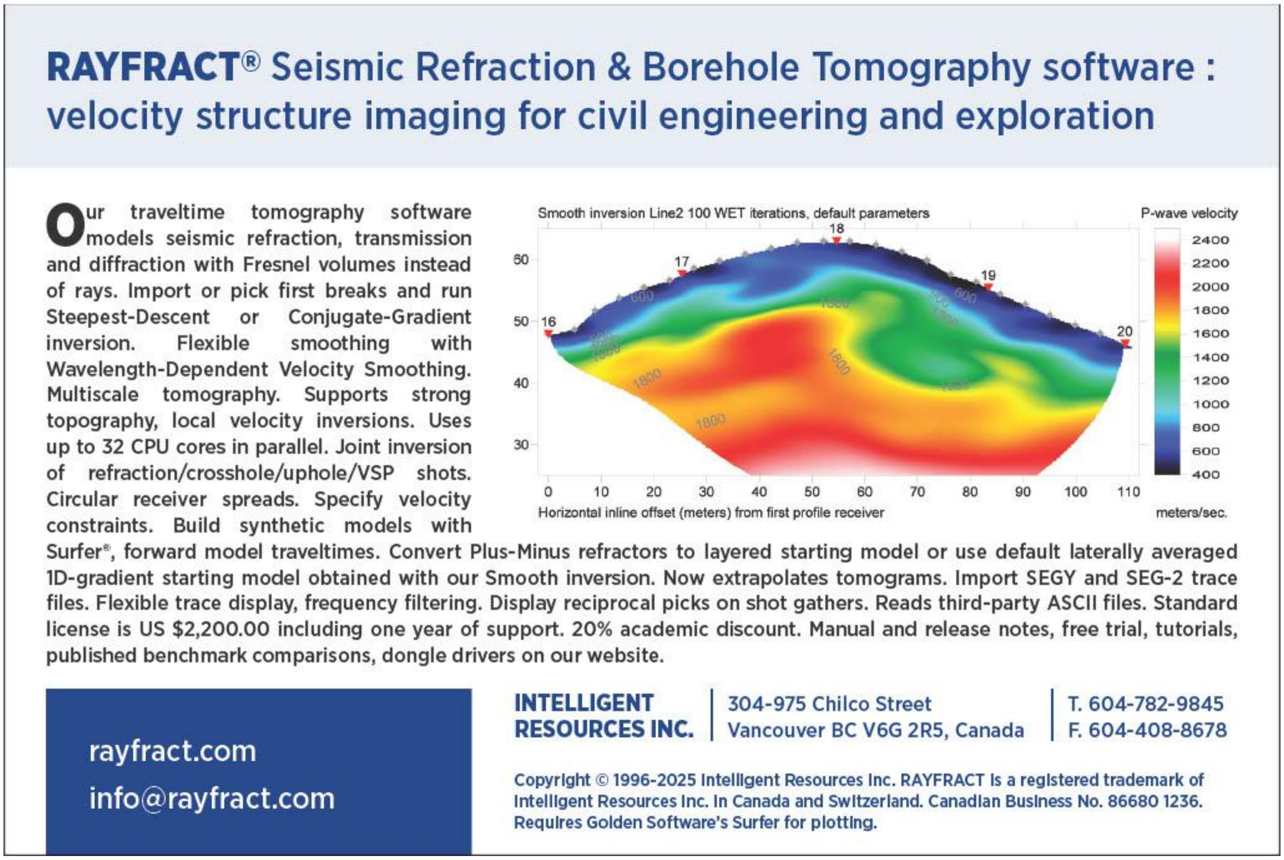
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EEGS President

Jacob Sheehan
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As I take over as EEGS president, I can't help reflecting on how much this organization has shaped my career. My very first experience giving a technical talk was as a last-minute fill-in for a cancellation at an early 2000s SAGEEP. I know the talk wasn't great, but the audience was kind, asked questions I could answer, and helped me feel that I might actually belong in the geophysical industry.

Based on my conversations with students at the most recent SAGEEP in Pittsburgh, that experience is not unique. EEGS and SAGEEP continue to welcome new people into our industry, and to me that alone means we are doing something right. That welcoming culture isn't a reflection of EEGS leadership—it's a reflection of our members.

My job as president will be easier than it could have been thanks to the amazing work of those who came before me. I'd especially like to recognize Janet Simms and Dale Rucker, our two most recent past presidents. Both went above and beyond to ensure that EEGS is in the strongest position it has been in for years, which makes it possible for me to focus on growing the organization.

I hope everyone who attended SAGEEP 2026 enjoyed it as much as I did. A successful conference doesn't just happen—it takes an extraordinary amount of work from a dedicated team of volunteers. This year's effort was led by a trio of "generals": Fred Day-Lewis (VP–SAGEEP), Laura Sherrod (Technical Chair), and Peter Hutchinson (General Chair). Each of these roles is akin to taking on a new part-time job, and they all did that job amazingly well.

My goal for the next year is to support the people who make EEGS work when I can—and to get out of their way when I can't. I'm excited to see what comes next from the Education Committee after its successful second GAINS season and the excellent student event at SAGEEP. Finally, I'm also looking forward to what's next for *FastTIMES* under the direction of Cian Dawson, who has taken on the Editor-in-Chief role with a long list of great ideas for the publication's future.

Sincerely,

Jacob Sheehan
EEGS President

Editorial

Cian Dawson
Editor-in-Chief, FastTIMES

Welcome & Update

Welcome to the June 2026 issue of *FastTIMES*, the EEGS near-surface geophysics news magazine! This issue reflects the contributions and efforts of dozens of community volunteers.

SAGEEP 2026 Highlights

Building on the excitement of SAGEEP 2026, the main articles feature highlights from Pittsburgh. The three SAGEEP 2026 featured speakers – Jon Nyquist, Kris Carter, and William Harbert – share thought-provoking articles following up on their talks. Several session chairs also contributed overviews of hot topics, themes, and trends from their sessions. The meeting was bursting with educational and student programs, as highlighted by the GAINS subject matter expert panel recap and the perspective piece from the Dickinson College EEGS Student Chapter. And, be sure to explore the SAGEEP photos throughout this issue!

Topical Columns

We are continuing some of the recurring topical columns introduced in the March 2026 *FastTIMES*, and introducing some new ones, too! Hear from Jacob Sheehan as he steps into his new role as EEGS President. The new *Collaboration Corner* column launching this month features an introduction to the Geophysical Discovery Lab at Colorado School of Mines. We also are continuing our community calendar of near-surface geophysics events, as well as the photo gallery featuring scientists from around our community.

This issue also includes a technical article from Portaz and others on imaging CO_2 migration using crosswell P-wave tomography. (The article was inadvertently omitted from the December 2025 issue.)

Environmental
and Engineering
Geophysical Society

Submit Community News & Notes!

Do you enjoy reading your alumni magazine class notes? Then you might be excited to hear that we will be adding a section to feature your recent professional news and notes! Announcements could include job promotions, job changes, awards, retirement, relocations, etc. Submit notes through our online form. News for the September issue is due by July 24, 2026.

September Issue

Inspired by the related session at SAGEEP 2026, the September 2026 issue of *FastTIMES* will focus on *Geologic Insight in Near-Surface Geophysical Interpretation*. Visit the EEGS website for details about submitting to the next issue, including deadlines and guidelines.

Cian Dawson
Editor-in-Chief, *FastTIMES*
cian@cbdawson.com

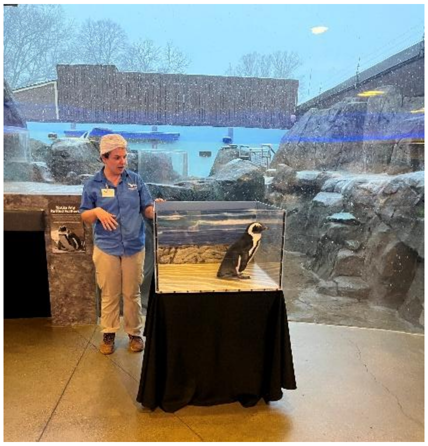


Photo: SAGEEP attendees mingled with the birds at the Student Event at the Pittsburgh National Aviary. Credit: Jacob Sheehan

Collaboration Corner

Collaboration Corner is a new recurring FastTIMES column highlighting a collaborative initiative or resource of interest to the larger near-surface geophysics community.

Geophysical Discovery Lab at Colorado School of Mines: A hands-on test site for research, education, and training

Richard Krahenbuhl, Colorado School of Mines – Geophysics

Figure 1: Map and photos from the Geophysical Discovery Lab at Colorado School of Mines.

History & Overview of Mines GDL

From 2016 – 2018, the Colorado School of Mines designed, negotiated, redesigned, funded, and constructed a massive, one-of-a-kind outdoor geophysical research and education laboratory beneath Kafadar Common on Mines Campus. The field site is called the Geophysical Discovery Lab (GDL) and it was created such that the collection of subsurface targets, physical properties, and sensors reproduce, as best as possible, a broad collection of geophysical problems and data related to civil infrastructure, humanitarian, geology, tunnel detection, natural hazards, archaeology and historical preservation (Figure 1). With this laboratory the CSM students, faculty, and visitors from off campus can train in a compact and controlled environment where the targets are accurately defined and the data contains a collection of both isolated and interfering anomalies. Additionally, the physical properties and geometries of the targets have been carefully selected to provide a combination of strong and weak anomalies for each of our various geophysical instrumentation in gravity, magnetics, electrical, electromagnetics, seismic, and borehole methods. This outdoor laboratory remains one of the most ambitious open-source projects undertaken by the Department of Geophysics at CSM, contributing to its never-ending commitment of keeping Mines at the forefront of geophysical education, research, training, and community partnership.

Features within the GDL

The Geophysical Discovery Lab contains a combination of known and secret targets, including:

- Archaeology walls - three connected segments
- Cemetery with new- and old-world coffins, and shallow clandestine graves
- UXO grid with UXOs and ISOs
- Dipping cement slab/foundation: 20’ wide, 30’ long, by 1’ thick, dipping from a 2’ to 7.2’ deep
- Sand-bed with manhole cover
- 80’ dipping gas line
- 20’ interfering gas lines
- Large ‘M’ with eight segments: Iron, cement, clay, wood, rock, aluminum, PVC with air, and PVC with salt water
- DAS/DTS grid
- Boreholes: open hole; metal cased; twin PVC-cased boreholes with ERT & DAS cables
- Utility tunnel: running along the edge of GDL, valuable for micro-gravity surveys
- 7 secret items: Two named so far, a keg & a time-capsule, but locations not revealed

Reference information and access to the Geophysical Discovery Lab

The Geophysical Discovery Lab is available most days of the year to anyone within and outside the Mines community, with prior approval required for non-CSM users. CSM activities such as field labs, research and outdoor university events have priority. Individuals from outside the CSM community can reach out to the Geophysics Department at Mines for assistance in accessing the GDL.

- **GDL Web-page**: https://people.mines.edu/rkrahenb/geophysical-discovery-lab/
- **GDL Expanded Abstract**: Krahenbuhl, R.A., B. Passerella, H. Flamme*, G. Crookston*, D. Sirota*, 2018, Developing a large underground geophysical education laboratory at Colorado School of Mines. 88th Ann. Internat. Mtg, Soc. Expl. Geophys., Expanded Abstracts. https://doi.org/10.1190/segam2018-2998344.1
- **GDL Access**: Email the CSM Geophysics Department (geophysics@mines.edu)

GDL Partners in Crime

Proper acknowledgements for funding and development of the GDL are listed on the GDL website. The following individuals from CSM (current and past) deserve recognition for their invaluable parts in making GDL a reality: Yaoguo Li; Hanna Flamme; Glenna Crookston; Brian Passarella; Dana Sirota; Whitney Trainor-Guitton

Author: *Richard Krahenbuhl (rkrahenb@mines.edu) is a research professor in the Geophysics Department at Colorado School of Mines. Dr. Krahenbuhl has a long history in undergraduate and graduate education and research with broad interests ranging from energy exploration and monitoring, near-surface, humanitarian, hazards, civil, and archaeological geophysics. He has served previously in the role of VP Committees and currently serves as VP Pre-elect SAGEEP on the EEGS Board of Directors.*

Learning Lab

Learning Lab is a new recurring FastTIMES column focused on EEGS professional development resources, as well as providing updates from the EEGS Education Committee

An Undergraduate Perspective on SAGEEP

Reflection by Anna Aaron and Dickinson College EEGS Student Chapter

Dickinson EEGS attendees left to right: Kevin Diaz '27, Emma Keane '27, Mahika Vikram '28, Vice President Anna Aaron '28, President Kate Wilcox '26, Professor Jorden Hayes. Not Pictured: PJ Ruggiero '28.

This spring, members of our newly formed student chapter of the Environmental and Engineering Geophysical Society (EEGS) accompanied Professor and Chair of the Geoscience Department Jorden Hayes to a small, industry-specific conference: the 2026 Symposium for the Application of Geophysics to Engineering and Environmental Problems (SAGEEP). Our group was composed of a variety of class years and majors who found ourselves particularly invested in an Environmental Geophysics course this semester. As a multidisciplinary group of undergraduate students, we came into this experience with a broad range of goals, and we each left having gained something we never would have expected.

As undergraduates, we were challenged in many ways throughout the conference. Personally, I felt challenged while asking questions in front of a room of experts, wrapping my brain around fascinating but new and technical information, and rethinking how I communicate my aspirations to people outside of my field. However, SAGEEP's close knit atmosphere allowed us to have engaging discussions with members of the industry and academia. As PJ remarked, "many were genuinely interested and wanted to help connect me with people in a field I'm interested in." Similarly, as I was evidently nervous for an interview that I ended up taking in the hallway, a fellow attendee offered helpful advice, and the call resulted in an internship offer. We were met with overwhelming support from people who wanted to help students interested in geophysics.

For Kate, a standout memory from the conference was the Dinner with the Dinosaurs at the Carnegie Museum of Natural History: “Connections formed with professionals and undergraduate peers broadened my view of what careers are possible within geophysics and gave me confidence in my own educational path.” Even for those already taking the path towards a career in geosciences, this was a great chance to center fun and exploration while learning a lot.

To make this possible, we founded a Student Chapter of EEGS at Dickinson and sought funding through Dickinson’s Career Development Grant. This would not have been possible without the support of Professor Hayes. It was not something I envisioned for myself in this academic year, but this was such a unique and worthwhile endeavor. I hope our reflections might inspire you to take a chance and embrace the fun of exploring an unfamiliar topic. But all the above can be summarized in what Kevin expressed in just a few words, “I learned a lot and am more optimistic about the future.”

We had fun exploring the Carnegie Museum of Natural History at the Dining With The Dinosaurs Event: pictured left to right: back row: our new friend the stegosaurus! front row: Vice President Anna Aaron ‘28, President Kate Wilcox ‘26, Mahika Vikram ‘28, Kevin Diaz ‘27, Emma Keane ‘27, Not Pictured: Professor Jorden Hayes.

To learn more about forming a student chapter of EEGS or to connect with student chapters in your area, visit https://www.eegs.org/student-chapters

Near-Surface Geophysics Community Calendar

21st International Conference on Ground Penetrating Radar (GPR2026)
https://gpr2026.org/
23–26 June 2026

2026 Teaching Near-surface Geophysics to Undergraduates from Intro to Majors
https://www.earthscope.org/event/2026-teaching-near-surface-geophysics-to-undergraduates-from-intro-to-majors/
7–9 July 2026

SEG-AGU Hydrogeophysics Workshop
https://seg.org/calendar_events/seg-aguhydrogeophysics-workshop/
20–22 July 2026

CTEMPs DAS–DTS Reno–Tahoe Workshop 2026
https://ctemps.org/announcement/ctemps-das-dts-reno%E2%80%93tahoe-workshop-2026
10–14 August 2026

International Meeting for Applied Geoscience and Energy (IMAGE)
https://www.imageevent.org/
17–20 August 2026

2026 SEG 2nd Workshop on Fiber Optics Sensing
https://seg.org/calendar_events/2026-seg-2nd-workshop-on-fiber-optics-sensing/
10–12 September 2026

Association of Environmental & Engineering Geologists (AEG) Annual Meeting
https://www.aegannualmeeting.org/
13–19 September 2026

Near Surface Geoscience 26
https://eagensg.org/
20–24 September 2026

Meeting the Challenges of Groundwater in Fractured Rock Conference
https://www.ngwa.org/detail/event/2026/09/21/default-calendar/26sep5017
21–22 September 2026

Highway Geology Symposium
https://highwaygeologysymposium.org/
28 September – 1 October 2026

2026 SEG Summit on Drone Geophysics
https://seg.org/events/events-calendar/
26–29 October 2026

Optical Seismology and the Next Era in Seismic Sensing
https://topical.seismosoc.org/
13–16 October 2026

American Geophysical Union 2026 (AGU26)
https://www.agu.org/annual-meeting
7–11 December 2026

Postcards from the Field

Postcards from the Field is a recurring FastTIMES feature sharing photos from recent near-surface geophysics work. Community members are invited to submit your photos for future consideration.

Crew setting up capacitively coupled resistivity survey in the Arctic. Credit: Esther Babcock

Measuring ice thickness to validate radar data. Credit: Esther Babcock

High school students collect ground-penetrating radar with University of Hawaiʻi. Credit: L.Gallant

Student operates ground penetrating radar to image volcanic stratigraphy. Credit: L. Gallant

Scientists prepare Advanced Geophysical Classification (AGC) surveys in California. Credit: Jenn Weller

SAGEEP 2026 Photos

From top left: SAGEEP 2026 general session; mine tour. Second row: Sina Saneiyan receives the Geonics Early Career Award from Ryan North; incoming EEGS President Jacob Sheehan receives the honorary gavel from the past president Dale Rucker. Third row: student event at the Pittsburgh National Aviary; exhibit hall.

SAGEEP 2026

SAGEEP Updates

Peter Hutchinson, PhD, PG, THG Geophysics, Ltd.

The 2026 SAGEEP conference is “in the bank," as they say. The results are better than expected since Pittsburgh has never before hosted the SAGEEP conference. Three hundred and forty-two scientists, faculty and students registered, making it one of the largest SAGEEP conferences in several years. The conference was paired with the Pittsburgh Geological Society (PGS) Student Poster Night. Remarkably, eighty-four students registered for the conference.

I was appointed General Chair (GC) for the conference possibly because we are local to the conference and my company has had a presence at the conference for years. Unfortunately, I have never been a GC for any conference; however, my position as Vice President of the PGS provided some experience organizing meetings and finding venues within the Pittsburgh area.

The initial GC task is to organize the Conference Committee and find people to help with the four main tasks: organizing the papers, preparing the Student Night, developing courses, and arranging for a field trip. Dr. Fred Day-Lewis VP SAGEEP was an invaluable source of information for organizing the conference. Specifically, Dr. Day-Lewis directed me to Dr. Laura Sherrod (Kutztown University) to pull the technical sessions together as Technical Program Chair; Harry Wagner, Short Course Chair to solicit and organize the courses; and Dr. Sarah Morton Ranney, Student Event Chair with Paul Schwering and Miriam Johnston. My job was to organize a field trip.

Another aspect of the GC is soliciting donations. Pittsburgh has many professional organizations and companies willing to contribute to the conference. Due to our efforts, the Committee collected over $24,000 in donations to help pay for student events, student attendance and other events.

The first day of the conference consisted of five short courses, organized by Harry Wagner. The courses consisted of TEM Tools, Well Logging, ERT/IP, and GPR Theory. An MASW course was also scheduled but the instructor had transportation issues and the course was unfortunately cancelled. All courses were filled to capacity and well received by students and professionals.

The conference meeting opened on Monday, March 16, 2026, with Keynote speaker Dr. Jonathan Nyquist, Temple University, opining on the current state of geology regarding student enrollment in colleges and the misuse of AI by college students. His analysis showed that high schools do little to encourage students to pursue geology; consequently, college enrollment is down and college programs are being dropped. His Keynote speech was followed by Keynote speaker Kristin Carter, Assistant State Geologist, Pennsylvania Geological Survey. Ms. Carter provided an interesting history of the Pennsylvania Geological Survey from its origins in the early 1800s to today. After a break, the morning session concluded with “Milestones in Near Surface Geophysics: A Tribute to Pete Haeni,” chaired by William Doll.

After lunch three concurrent sessions began: Application of Geophysics to Archaeology (chaired by Kate McKinley); Geophysical Methods (chaired by Dr. Rob Jacobs); and Milestones in Near Surface Geophysics (chaired by Dr. William Doll).

The late afternoon began with the opening of the Exhibit Hall and Icebreaker. Twenty-four vendors (including three professional societies, PGS, ASCE-Geo-Institute and PCPG) brought their wares to the Exhibit Hall. Following the Icebreaker was Student Event Night at the Pittsburgh National Aviary, called “Geophysics is for the Birds.” It was refreshing to see students, professionals and professors mixing in the various activities that the

Aviary had for us. Two memorable activities included feeding live mealworms by hand to the birds in one room and being entertained by a penguin in another room.

Tuesday's morning sessions included MASW Resolution Issues/case histories (chaired by Jacob Sheehan); Drone-based Geophysics (chaired by Dr. Yuxin Wu and Dr. Piyoosh Jaysaval); Milestones in Geophysics (chaired by William Doll); Applications of Geophysics in Fractured Rocks (chaired by Dr. Jorden Hayes); Munitions Response (chaired by Jeffery Leberfinger); and Mobile Geophysical Surveying (chaired by Dr. Larisa Golovko). Milestones introduced a number of interesting papers. One specific paper in this session included a novel idea of using muon radiography in near surface geophysics.

Luncheon Keynote speaker Dr. William Harbert, Professor of Geophysics at the University of Pittsburgh, provided a thought-provoking talk on "Deep Learning, Machine Learning & AI as they impact the Geosciences." This inspiring and in-depth talk was attended by many students and professionals.

The sessions promptly resumed after lunch with a continuation of the Drone Based Geophysics session. Concurrent sessions also included Geophysical Exploration and Characterization for Critical Minerals and Mining (chaired by Patrick Brindle) and HVSR (chaired by Tyler Norris). Following the last session, there was an in-house equipment demonstration where the twenty-one exhibitors displayed their equipment for all to see and try.

The Tuesday's events concluded with dinner at the Carnegie Museum of Natural History that we designated as "Dining with the Dinosaurs." The Carnegie has a world famous collection of dinosaurs and Mesozoic biota on display. Dinner was adjacent to the Hall of North American Wildlife and overlooked the dinosaur display. This unusual setting allowed professionals, teachers and students to interface against this exotic yet relaxing backdrop.

Wednesday's morning sessions included Applications of AI to Geophysics (chaired by Thomas Urban); Humanitarian Geophysics (chaired by Paul Bauman); New Geophysical Instruments and Technologies (chaired by Amber Onufer); Geophysical Guidance for Undergrounding & Horizontal Direct Drilling Applications (chaired by Matt Toland); and Environmental Geophysics (chaired by Dale Rucker). Although this author couldn't attend all the session offerings, the papers in the Applications of AI to Geophysics session were very compelling and inspired geophysicists to exploit AI's power.

The Educational Committee organized a GAINS discussion panel after lunch. The panel was moderated by Paul Schwering and included Jacob Sheehan, Sage Wagner, Dr. Kennedy Doro, Dr. Jorden Hayes, Dr. Richard Krahenbuhl. The sessions following the GAINS discussion panel included Induced Polarization/Spectral Induced Polarization (chaired by Dr. Lee Slater); Using Geologic Insight in Geophysical Interpretation (chaired by Dr. Adam Mangel); and Geophysics Education and Workforce Development (chaired by Dr. Kyle Fredrick and Gina Pope).

The Wrap-Up Reception & Poster Session promptly followed the afternoon sessions. The Pittsburgh Geological Society hosted its annual Student Poster Night at the Exhibit Hall, which also included all the geophysical posters submitted to the conference. It was a memorable experience to see students opining about their work to professionals and potential employers.

Finally, Thursday's field trip was to the Tour-Ed Mine, an educational one-half mile tour through a former coal mine. Although the mine did not officially open until late May, a significant EEGS financial offering to the mine museum convinced the docent, Robert Black, to open the mine for us. Twenty-five students, teachers and professionals loaded into a coal car and explored how mining was done from the late eighteenth century to modern times. All in attendance had a great time and really enjoyed the experience considering the operator provided us all with T-shirts that memorialized our attendance and EEGS provided lunch.

As the General Chair, I would do it again now that I know where the issues reside. There were pitfalls and stresses at various times but the Organizing Committee helped me power through the issues. I would again like to thank the entire Committee, especially Fred Day-Lewis, Laura Sherrod, Harry Wagner, Paul Schwering, Miriam Johnston, Sarah Morton Ranney, and the crew at WMR including Jayma File and Jackie Jacoby. Special thanks goes to Amber Onufer for helping Micki Allen bring in the exhibitors.

Photo: Dr. Laura Sherrod, SAGEEP 2026 Technical Chair, and Peter Hutchinson, General Chair of SAGEEP 2026, celebrate a successful meeting.

Author: Peter Hutchinson (pjh@thggeophysics.com), Ph.D., PG, is President and Principal Scientist at THG Geophysics and Vice President of the Pittsburgh Geological Society. Pete was the General Chair of SAGEEP 2026.

From Rock Hammers to Python Notebooks: *A SWOT Analysis of Geoscience Education Today*

Dr. Jonathan E. Nyquist, Week's Chair of Environmental Geology, Temple University, Philadelphia

I'll warn you upfront: I'm a cheerful pessimist. I tend to see the glass as two-thirds empty. But the reason I like SWOT analyses is that they force us to think about how we fill the glass.

After nearly thirty years in geoscience education—as a faculty member at Temple University, as department undergraduate advisor, graduate advisor, department chair, and eventually as Director of General Education—I've seen our field from just about every angle. What follows is my reckoning with where geoscience education stands today – the threats we face, the weaknesses we must own, and the strengths and opportunities that too often go unacknowledged.

The Threats We Cannot Ignore

Federal research funding is declining. A decade ago, roughly one-third of proposals submitted to NSF's Geosciences Directorate were funded. Today that figure is closer to one-quarter, and the number of universities receiving NSF support has declined as well (NSF, 2026). For early-career scientists trying to establish research programs before tenure review, the pressure is intense.

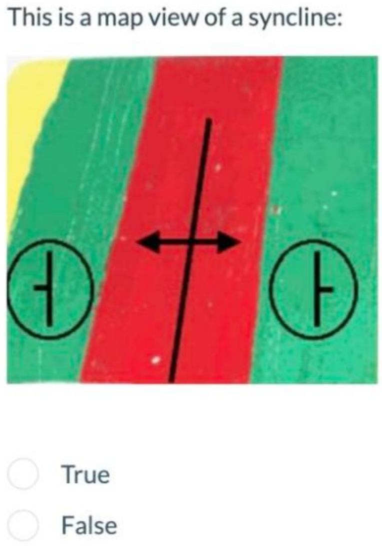
The situation is compounded by politics around climate science. A colleague of mine recently received a call from her NSF program officer saying the agency was interested in funding her stormwater research, but only if she removed any mention of climate change from the proposal. The science was fine. The context was not. Given that roughly one-third of geoscience faculty now work on climate-related topics, this creates significant anxiety across the profession.

Meanwhile, tenure itself is under siege. Since the 1970s, U.S. higher education has shifted from a predominantly tenure-track workforce to one in which roughly two thirds of instructional staff are contingent faculty (part-time or non-tenure-track) (Colby, 2025). Eliminating tenure would be a serious mistake: it would discourage talented scientists from entering academia, accelerate faculty turnover, and make it nearly impossible to sustain long-term research programs. Science moves slowly. Building a laboratory, developing a research program, conducting experiments, and publishing results takes years. Those kinds of projects are tough to pursue if faculty are working only on short-term contracts.

And then there are the students. Right around the COVID period, something shifted in the math preparation of incoming students. At my institution, Temple University, the share of freshmen science majors requiring at least one preparatory math course before beginning calculus has risen from roughly 10 percent to over 40 percent. I call it the Math Mountain—and for many students, it is steep enough to redirect them away from STEM entirely.

Finally, there is artificial intelligence. Over the course of my career, I have watched several technological changes reshape higher education. I lived through the rise of the World Wide Web, when students largely abandoned the library and started searching everything on Google. Then came the smartphone and social media, when students began watching TikTok videos and texting during class. But AI is different. AI threatens our ability to train geoscientists to think for themselves.

This isn't an abstract worry. Researchers call it cognitive off-loading: outsourcing the thinking itself (Lodge and Lobel, 2026). Struggling through an assignment is where learning actually happens. Remove the struggle and you remove the learning, leaving graduates unprepared for real-world problem-solving. To demonstrate how easily students can bypass this struggle, I solicited homework and quiz questions from my colleagues on subjects spanning Temple's geoscience curriculum, including physical geology, geochemistry, hydrogeology, sedimentology and glaciology. AI solved them all better than the typical student. One faculty colleague tried using diagram-based quiz questions to thwart AI, confident that visual reasoning would be beyond its ability. It wasn't. The AI answered correctly and explained its reasoning. That experiment was conducted over a year ago. The models have only improved since. With the advent of agentic AI, students may soon have access to software that can log into their course website and complete all coursework automatically (Guyla, 2026).



This is a map view of a syncline:

○ True

○ False

False. In map view, a syncline would have beds dipping toward the trough with the youngest rocks in the center. Here the symbol shows beds dipping away from the central red unit (and the red unit is likely the oldest), which is characteristic of an anticline, not a syncline.

Figure 1. AI had no difficulty answering diagram-based quiz questions.

The most proposed solution is AI-detection software. Several companies are now selling tools that claim to detect AI-generated writing using AI itself. The problem is that these detectors are not very reliable. One recent study found that detection accuracy was only about 40 percent, even when students made no attempt to evade the detector. When students were even slightly careful in using AI to write an assignment, detection accuracy dropped to just over 20 percent (Perkins and others 2024). And there's another issue. If you accuse a student of academic misconduct and you're wrong, the situation can escalate quickly—sometimes even into legal disputes.

The Weaknesses We Must Own

Geoscience education is being squeezed from two directions. Undergraduate enrollment in geoscience majors is falling. After a partial recovery in the 2000s, numbers peaked around 2015 and have been declining since. At Temple, our total number of majors has dropped steadily since 2020, and the ratio of environmental science majors to geology majors has shifted from roughly 1 to 1 in 2013, to 4 t0 1 in 2026. We now offer several upper-level geology courses only every other year.

Declining investment in university education has increased reliance on contingent faculty (AAUP, 2024). As states have pulled back funding, universities like Temple have filled the gap by cutting instructional costs, which in practice means replacing tenure-track faculty with part-timers. When your continued employment hinges on student evaluations, there is pressure to ease up on rigor: lighter workloads, gentler grading. The result is that the median grade at Temple, and at most colleges, is now an A. When nearly everyone gets top marks, grades stop meaning much, and employers lose one of the few signals they had for distinguishing strong candidates from weak ones.

The Strengths We Underestimate

Geoscience has been interdisciplinary since long before interdisciplinary science became fashionable. We routinely collaborate with engineers, chemists, physicists, biologists, and computer scientists. In my own department we have a nanogeochemist and an ecohydrologist—fields that didn't even exist when I was in graduate school.

Our field also sits at the center of society's most urgent challenges—climate adaptation, the energy transition, water security. Students today are looking for meaningful work. Geoscience offers it in abundance. The employment outlook is strong, retirements are creating openings for the next generation, and the work geoscientists do is unlikely to be replaced by AI any time soon.

Geoscience departments are small, collaborative, and friendly in ways that enormous biology or computer science programs cannot match. Undergraduates get to know graduate students and faculty alike. One student, quoted in the Journal of Geoscience Education, put it simply: 'You have a different breed of people in the geosciences. They're very intelligent and capable of doing important research, but they can still have a beer on the weekend and play in the dirt.' (Stokes and others, 2015)

The explosion of Earth observation data is another reason for optimism. The shift has been dramatic even within a single career. When I began doing field geophysics, instruments required handwritten readings at every measurement point. Today they sync via Bluetooth. At a larger scale, the Landsat 8 and 9 satellites collect roughly a terabyte of data daily. What this means in practice is that students can now do planetary-scale science as undergraduates, working with datasets that would have been unimaginable a generation ago.

A Call to Action: Opportunities

So where does this leave us and what can the professional community do? EEGS has always stood at the intersection of industry and education, and right now higher education needs that connection more than ever. There are concrete ways to help.

The American Geosciences Institute reports that only about five percent of community colleges have dedicated geoscience programs, yet roughly half a million students transfer from community colleges to four-year institutions every year. If you can teach a course at your local community college, that is an enormous contribution. If that feels like too large a commitment, consider offering to give a departmental seminar. Last semester, my department invited a geotechnical consultant to discuss work done for the Philadelphia airport runway expansion. The students were riveted.

Wherever possible, employers should create internship opportunities. Students who intern frequently end up employed by the organizations that hosted them. Industry professionals can also serve on departmental advisory boards—most universities conduct external program reviews every six or seven years, and employer perspectives are invaluable in shaping curriculum.

As for AI: the answer is not to ban it, but to teach students to use it wisely. I tell my data science students that Python code probably looks like ancient Greek to them right now—and that they should not rely on AI-generated code until they can actually read it themselves. The goal is to use AI to accelerate things you already understand, not to replace the understanding. If employers can emphasize that problem solving skills are needed beyond AI – the message will break through.

Yes, the glass is two-thirds empty. But geoscience has the people, the problems, and the purpose to fill it.

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Author: Jonathan Nyquist (jonathan.nyquist@temple.edu) gave a SAGEEP 2026 keynote talk, "From Rock Hammers to Python Notebooks." Jon is a Professor of Geophysics at Temple University. A long-time EEGS member, Jon has also previously served as editor-in-chief of JEEG, and as president and past-president of EEGS.

The Pennsylvania Geological Survey: An Historical Tale of Four Surveys

Kristin Carter, Pennsylvania Geological Survey

The Pennsylvania Geological Survey has evolved over time, from the First Survey's early reconnaissance of our state's geologic resources in the early to mid-1800s to the Fourth Survey's 21st Century approach to preparing and delivering geologic data and products. Pennsylvania was the ninth state in the U.S. to pass legislation for a geologic survey, and one of four established in 1836 (alongside Georgia, Maine and New York).

Henry Darwin Rogers was the State Geologist of the **First Geological Survey (1836 – 1842)**, which conducted a geological and mineralogical survey of the Commonwealth; performed detailed mapping that set the geologic framework for all the other states along the Appalachian mountains; and pioneered the study of the form and arrangement of rock layers (i.e., structural geology) and correlation of rock units (i.e., stratigraphy) across the Commonwealth.

J. Peter Lesley was the State Geologist of the **Second Geological Survey (1874 – 1889)**, which was formed in response to accelerated industrial growth and discovery of oil in the Commonwealth. The Second Survey enjoyed the benefit of more staff and more time to evaluate stratigraphy, characterize resources and prepare geologic products, including nearly 120 atlases and volumes and >25,000 pages of printed matter. As the Second Survey completed and published geologic maps for each of Pennsylvania's 67 counties, it became the first to publish a geologic map for the entire state of Pennsylvania (Figure 1). In addition, the Second Survey established much of the lithostratigraphy and stratigraphic nomenclature that the geologic community continues to use today.

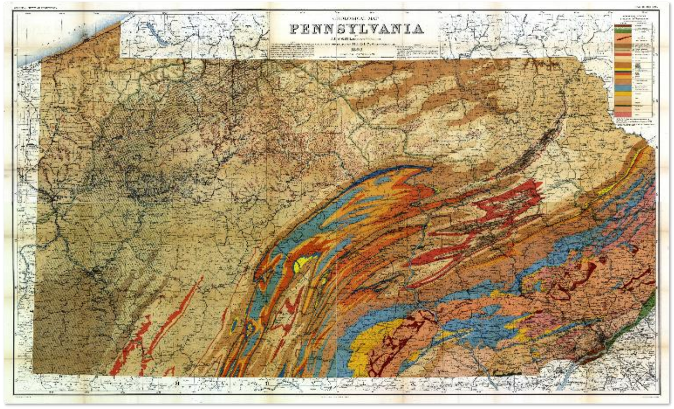

Figure 1. Geologic map of Pennsylvania (Lesley, 1893).

One of the Second Survey's geologists, John F. Carll, is regarded as the world's first petroleum geologist and first petroleum engineer. He published North America's first geologic structure maps (Venango Group sandstones in the Pleasantville area of northwestern Pennsylvania); invented 'the rack,' a series of wall-mounted shelves used to hold small bottles of drill cuttings collected at well sites and that could be moved independently to match up similar looking samples, thereby correlating oil sands from well to well (Figure 2); and invented the strip log, a graphic representation of rocks penetrated in a well bore combined with a description of the lithology, mineralogy, fossils and any other characteristics of note printed alongside.

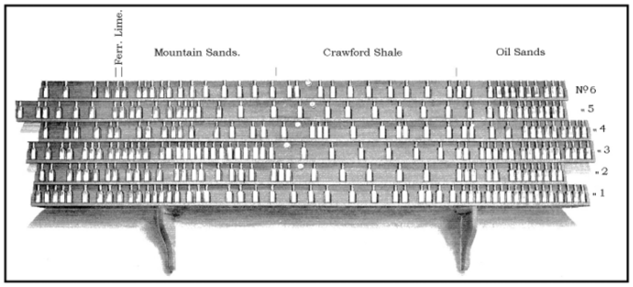

Figure 2. Carll's 'rack' for correlating oil sands from well to well (Harper, 2002, simplified from Carll, 1880).

Both Lesley and Carll can be considered visionaries in that they gained insight from previous Survey reconnaissance work and appreciated the utility of oil drilling activity as it could be applied to subsurface geology and lithostratigraphy, all for the purpose of improving their geologic work and products.

Richard Hice was the State Geologist of the **Third Geological Survey (1899 – 1914)**, established as a commission of three unpaid citizens to confer and accept cooperation with the United States Geological Survey. This formal collaboration focused on preparing statistics to quantify the state's mineral resources, as well as the publication of many topographic and geologic maps prepared at a scale of 1:62,500 (15-minute quadrangles). The Third Survey' s geologic work focused mainly on western Pennsylvania's oil, coal and gas resources, and it was the first to map the Broad Top Coal Field in Huntingdon and Bedford counties, south-central Pennsylvania. This same field was remapped to refine correlations and structural characteristics by Fourth Survey geologists in 2025.

George Ashley was the first State Geologist of the **Fourth Geological Survey (1919 – present)**, which was commissioned to "undertake, conduct, and maintain…a thorough and extended survey of the State for the purpose of elucidating the geology and topography of the State." The State legislature charged the Survey with performing mapping and chemical analysis of mineral resources, energy resources, clays, soils and fertilizers; mapping and characterization of rock formations that would be useful for highway construction; and putting its information and products in a form convenient for use and reference.

The Fourth Survey's immediate focus was on coal, limestone and natural gas, based on public need and industry activity at the time. In 1919, a miner's strike underscored the need to locate alternative coal resources. The state's highway department needed road material for its work in northwestern Pennsylvania, and the McKeesport Field was discovered in Allegheny County, southwestern Pennsylvania, producing significant amounts of natural gas.

The Fourth Survey realized that dissemination of information was just as important as gathering it. The first map it published was the Oil and Gas Fields of Pennsylvania in 1922. This was a 72-page report with five plates. The Fourth Survey also initiated its cooperative program with the U.S. Geological Survey in 1923 to explore groundwater resources, a collaboration that resulted in six regional reports and a statewide report over the subsequent 18 years.

The drilling, completion and production activity associated with Pennsylvania's oil and gas industry has remained a focus of the Fourth Survey's subsurface geologists from the early 20th Century when shallow conventional drilling efforts established the Pennsylvania oilfield, to the mid-20th Century when shallow and deep conventional oil and gas were being developed across the western half of the Commonwealth, to the late 20th Century when unconventional tight sands and coalbed methane were developed for gas, to the 21st Century where unconventional shale gas development from organic-rich rocks like the Marcellus and Utica account for the majority of Pennsylvania's annual drilling and production activity.

Having been in existence for more than a century, the Fourth Survey has benefited from the work and inspiration of many talented geologists with interests in field work, resource characterization, education and outreach. The Fourth Survey began to offer an annual Pennsylvania Field Conference in 1930. Even today, this educational opportunity for practicing geologists draws participants from far and wide.

Over the past several decades, the Fourth Survey established several new types of publications, including *Pennsylvania Geology* magazine, 13 Educational Series publications, and multiple geologic park guides. Today, our data, maps and other publications are available digitally using Pennsylvania GEOlogic Data Exploration (PaGEODE; Figure 3; https://gis.dcnr.pa.gov/pageode/).

PaGEODE

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Author: Kristin M. Carter, PG, CPG, krcarter@pa.gov, serves as Assistant State Geologist of the Pennsylvania Geological Survey and manages its Geologic Resources Division from the Survey's Pittsburgh office. Kristin is a member of the American Association of Petroleum Geologists, Pittsburgh Geological Society, Pittsburgh Association of Petroleum Geologists, Potential Gas Committee, the Petroleum History Institute, and the Friends of Drake Well, Inc.

How Far We Have Come: Milestones in Near Surface Geophysics

William Doll (Collier Geophysics) and Laura Sherrod (Kutztown University).

The Milestones in Near Surface Geophysics sessions at SAGEEP 2026 provided an opportunity to look back on how much our profession has advanced over the past quarter century. Before the 1990s, many of the methods that we use today had been developed for mining or petroleum exploration but were not as widely used for environmental and engineering applications. Since that time, many new methods have been developed, and the mining and petroleum exploration techniques have been refined for application to the near surface. The Milestone talks were contained in three sessions and consisted of fourteen invited presentations. The recent advances with ML and AI were cited by several speakers as key factors that will likely lead to the next Milestones!

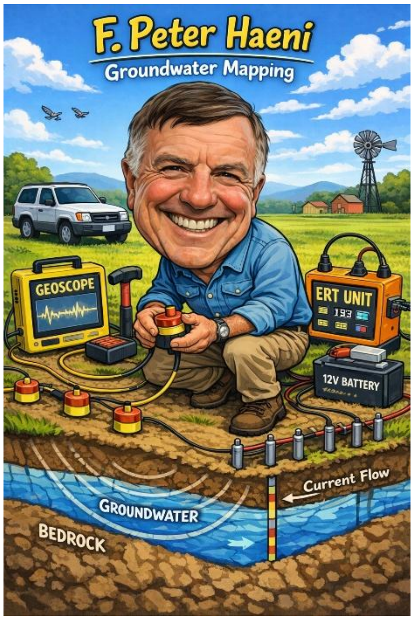
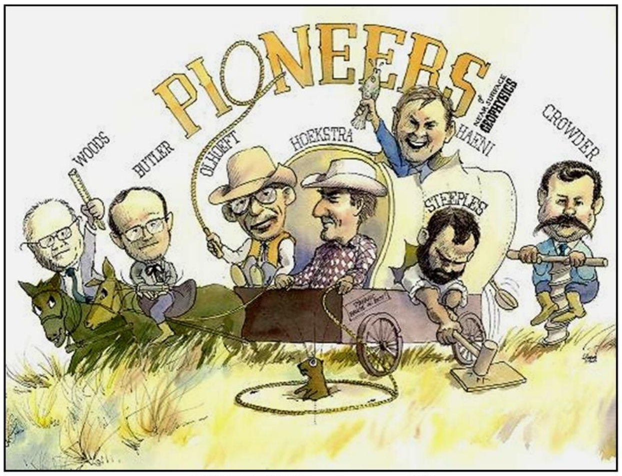


Figure 1. Pete Haeni Image produced using ChatGPT

Introduction; Haeni Tribute: Fred Day-Lewis, PNNL

The session honored our friend and colleague Pete Haeni, who was instrumental in guiding and defining many of those advances. Pete led the USGS hydrogeophysics group, based in Storrs CT for many years, and applied the full complement of technologies that were available during his career to addressing groundwater problems. In an introductory presentation on Pete's career, presented by Fred Day-Lewis, we learned that his field work covered 49 of the 50 states (all except West Virginia!) and many nations. Every day in the field was an opportunity to teach and train the field crew! Pete was truly a Pioneer of Near Surface Geophysics, as indicated in the attached figure from SAGEEP 2007! (Figure 2)



SAGEEP 2007 – Denver, CO

Figure 2. SAGEEP 2007 graphic of Pioneers of Near Surface Geophysics

Gradual and Punctuated Evolution of Technologies Affecting Near-Surface Geophysics Over the Last Three Decades: Jeff Paine, BEG, University of Texas

As an introduction to the Milestone sessions, Jeff Paine summarized many of the opportunities that his younger colleagues have missed in methods for acquiring and processing near surface data! He talked about how communications and conference presentations have changed over the years as well as positioning methods, power supplies, data storage, and field operations (display and flexibility). Some of the transitions have been gradual, while others have been punctuated! These themes were echoed by speakers in subsequent presentations in the sessions.

The History and Future of GPR: Innovation, Expansion, and Overselling: Jan Francke, Geolitix Inc

Jan provided an entertaining summary of the evolution of GPR and the problems that result from many charlatans who infer that it can solve *any* problem, when actually GPR can only solve *almost any* problem!

Where am I? 45 years of collecting data around the world...and trying to get back to the same location years later, Bob Selfridge, USACE-Huntsville.

Bob Selfridge summarized his experience with positioning systems he has used and tested in 50 years of near surface geophysics. Over the years, we have progressed from civil survey-based point measurements to acoustic positioning systems (USRADS) to RTK GPS systems and now, even more advanced systems that can usually work under canopy and sometimes provide <2cm precision in both horizontal and vertical components. Bob's experience has largely been focused on ordnance surveys, where positioning is particularly critical.

Mobile Transient Electromagnetics: When Near-Surface TEM Became a Big-Data Method, Eric Johnson, BGC

The new mobile time-domain EM systems are among the most exciting developments in near-surface geophysics of the last 5-10 years. Eric provided a summary of how these systems are used. Because they yield immense datasets, they now require specialized processing and analysis approaches, while they are capable of providing significantly better maps for addressing a wide range of problems with greater reliability than previous EM systems in a time-efficient manner.

The H/V Method: Story, Glory and Pitfalls, Silvia Castellaro, University of Bologna, Italy

The H/V (Horizontal to Vertical Spectral Ratio or "HVSR") method has been around for decades, but has recently been shown to be a useful tool to support interpretation of other data sets and to extend profiles to the third dimension. Sylvia provided a summary of the origins of the method in seismic station parameter determinations, and extension to more applications She wrapped up her presentation with a summary of her current work in using AI to improve the quality and reliability of H/V measurements.

MASW: Two Decades of Use and Evolution, Choon Park, Park Seismic LLC

Choon focused on the historical development of MASW with several examples based on his experience over the years. He discussed efficient data acquisition methods, multi-mode analysis and full mode / full waveform inversion.

Milestones in Seismic Refraction, Jacob Sheehan, Schnabel Engineering

Jacob shared his experience with seismic refraction and refraction tomography (SRT) over the years. He began by discussing conventional methods including Palmer's GRM method. He then discussed his experience with synthetic and field data representing cavities/voids. The field data seemed to indicate that SRT could detect voids while models indicated the opposite. Why? He then discussed the 3D SRT and synthetic model workshop and results from SAGEEP 2012 (Zelt et al., JEEG 2013), and some recent developments from Colin Zelt (Rice University) that indicated more advanced capabilities that can extract more information from seismic refraction data.

Recent Advances in the Direct-Current Electrical Resistivity Method, Dale Rucker, Certerra Subsurface Imaging

Dale provided a detailed historical account of electrical resistivity and how it has arrived at its current state. The advances have involved both hardware and computational advances.

Figure 3. Dale Rucker's slide on Troubleshooting

Muon Radiography Applications in Industry and Geophysics, Tancredi Botto, Muon Vision

For the physicist in our profession, muon radiography is one of the most interesting of methods that have been developed in the past quarter century. It was featured in the December 2016 issue of *FastTIMES*, but is still more familiar in the mining industry than in near-surface applications. Dr. Botto provided a nice synopsis of the physics of muon radiography which led to some interesting discussion regarding downhole measurements and application to the near-surface.

Unlocking Insights to Subsurface Processes and Remediation with Spectral Induced Polarization, Jon Thomle, PNNL

Complex resistivity methods and Spectral IP have been used for distinguishing insulating from electron conducting minerals and for contaminant detection for many years. The study of spectral IP is very much an integration of geophysics with geochemistry. Jon Thomle summarized laboratory studies that are now being used to support soil and groundwater remediation at the DOE Hanford site in Washington.

Repurposing Petroleum Seismic Reflection Surveys for Groundwater Studies, John Jansen, Collier Geophysics

There is a large volume of seismic reflection data that were acquired in the 80s by the petroleum industry in an effort to identify previously unknown reserves. For the most part, these projects were not effective in identifying exploitable reserves. However, they provided a library of raw data that has been maintained over the years and can now be reprocessed to provide critical information related to groundwater resources with relatively little expense. John discussed projects where these data have been used to help define aquifers and/or aquicludes, and have helped to keep Boomers actively employed, as they hold an understanding of how the data were acquired and how they can be appropriately reprocessed.

Evolution of the Application of Airborne Electromagnetics to Characterize the Subsurface over the Last 25 years, Ted Asch, AquaGeo Frameworks

Another technology that has evolved over the years to become valuable for groundwater surveys are airborne electromagnetic surveys. Newer airborne systems have more bandwidth than predecessors and can provide greater detail at depths relevant to groundwater. Improved calibration has allowed better correlation with paleochannels or other aquifers that can be exploited for groundwater. Newer data can be merged with older data to provide more reliable maps. These maps need to be provided in terms that are useful to the client, and this requires greater interpretation and analysis by trained geophysicists.

Advances in Borehole Logging Hardware and Software over the Past Three Decades, John Stowell

John provided a nice summary of how near-surface logging was developed, and the limitations of some of the earlier tools. Over the years, hardware developments have allowed greater precision, smaller electronics have enabled more advanced tools to be adapted to near-surface boreholes, and demand has grown for incorporating borehole measurements in the project workflow.

Overall, the Milestones sessions provided a reminder of how far we have come in a generation of developments in near surface geophysics as well as some encouraging thoughts on where we might go looking forward.

Authors: William Doll (william@colliergeophysics.com) chaired the SAGEEP 2026, "Milestones in Near Surface Geophysics." Bill is a Senior Geophysicist with Collier Geophysics, former EEGS President, and served as General Chair for SAGEEP 2011 (Charleston) and SAGEEP 2017 (Nashville). Laura Sherrod (sherrod@kutztown.edu) is a former EEGS President, and was Technical Chair of SAGEEP 2026. Laura is a Professor at Kutztown University of Pennsylvania, where she teaches geophysics and hydrology.

Beyond Anomalies and Against Assumptions: Geologic Insight and Geophysical Interpretation

Adam R. Mangel, Haley & Aldrich, Inc.

The session "*Using Geologic Insight in Geophysical Interpretation*," held at SAGEEP 2026 in Pittsburgh, brought together a set of presentations that collectively made a clear point: geophysics is most effective when it is grounded in geologic understanding rather than treated as a standalone imaging tool. Across environmental, engineering, geomorphic, permafrost, and mineral exploration settings, the presenters showed that interpretation improves when geophysical data are framed by depositional history, weathering processes, hydrogeologic behavior, and direct subsurface observations.

A central theme was that geology does more than provide background context. It should actively shape how we design surveys, constrain inversions, and judge the plausibility of competing interpretations. One presentation addressed this idea directly by showing how knowledge of critical zone structure can guide regularization choices in inversion, leading to models that better reflect the layered nature of regolith, fractured bedrock, and fresh bedrock. That message resonated across the session. Whether the problem involved karst hazards, buried channels, groundwater exchange, or permafrost structure, the best interpretations came from combining geophysical response with an explicit geologic process model.

Another strong theme was the distinction between identifying anomalies and understanding what those anomalies mean. Several case studies showed that high-quality geophysical data alone do not guarantee a correct interpretation. In complex settings, the same geophysical signature may support more than one geologic explanation. The session repeatedly emphasized that interpretation improves when anomalies are evaluated against site history, geomorphology, drilling results, groundwater observations, and lithologic information. This was especially evident in studies of suspected subsurface voids and instability. In West Texas, apparent "void" conditions encountered during drilling were better explained as buried paleo-river channel deposits rather than open karstic cavities. In east Texas, integrated electrical resistivity imaging, multi-channel ground-penetrating radar, frequency-domain electromagnetic induction, and borings supported a similar conclusion: surface evidence and groundwater discharge had raised concern about pseudokarst beneath a highway, but the combined data suggested that erosion, runoff, saturation, and variable cementation were more credible explanations than large subsurface voids. Together, these studies highlighted an important practical lesson for engineering and environmental work: geophysical interpretation should test alternative geologic hypotheses, not simply confirm the most alarming one.

The session also showed the value of multi-method integration. A recurring pattern in the presentations was that no single method was sufficient in heterogeneous subsurface conditions. Electrical methods helped delineate conductivity contrasts tied to saturation, clay content, and karst development. Ground-penetrating radar resolved shallow structure and stratigraphic detail where conditions allowed. Electromagnetic methods provided rapid reconnaissance over broader areas. LiDAR, sediment cores, borings, and direct observations supplied the ground truth needed to interpret geophysical signatures with confidence. This integrated approach was not presented as a luxury. It was presented as a practical necessity in settings where lithologic variability, groundwater conditions, and geomorphic overprinting complicate interpretation.

The environmental and hydrogeologic applications in the session reinforced that point. One case study showed how geophysical evidence, coupled with borehole data, challenged an established conceptual site model at a remediated river-adjacent site. Distributed temperature sensing indicated that groundwater was still discharging to the river, despite a prior model that treated underlying bedrock as a relatively impermeable boundary. The significance of that example extended beyond the site itself. It illustrated how geophysics can play a strategic role in updating conceptual site models, identifying where remediation assumptions may be incomplete, and guiding follow-up investigation and monitoring. More broadly, the presentation underscored that conceptual site models should remain testable and revisable. When geophysical data contradict a long-standing interpretation, the right response is not to discount the new data, but to reexamine the geologic assumptions behind the model.

Several presentations also demonstrated that geologic insight helps define the scale at which a method can answer a question. Some studies focused on near-surface engineering hazards, where the goal was to separate voids from saturated sediment, distinguish shallow resistive units from deeper conductive materials, or map subsurface variability beneath infrastructure corridors. Others addressed larger stratigraphic and landscape questions. The Delmarva Peninsula work used ground-penetrating radar and sediment cores to reconstruct paleosols, buried forests, estuarine deposits, and long-term paleoenvironmental change over multiple glacial-interglacial cycles. The permafrost tunnel study used controlled tunnel geometry and known cryostratigraphy to compare antenna frequencies and evaluate how depth of penetration and resolution affect the imaging of active layer thickness, ice wedges, and internal frozen-ground structure. A separate presentation showed how rapid, spatially continuous soil-thickness estimation can improve geophysical interpretation by providing a physically informed framework for shallow subsurface variability across complex terrain. Although these applications differed in scale and objective, they shared the same underlying principle: geophysics becomes more useful when it is tied to a realistic model of how the subsurface formed and evolved.

The session further suggested that geologic insight is valuable not only after data collection, but before and during it. Survey design, line placement, frequency selection, inversion strategy, and the choice of complementary methods all benefit from an initial understanding of site geology and process setting. In other words, interpretation is not a final step layered onto an otherwise generic workflow. It begins at project conception. This idea is especially important for practitioners working in complex environmental and engineering settings, where budgets and access may limit the number of methods that can be deployed. The session examples showed that a modest but well-targeted program, informed by a strong geologic framework, can be more effective than a broader but less focused data collection effort.

Taken together, the presentations pointed to a broader maturation in near-surface geophysics. The field continues to advance technically, but the session made clear that the greatest gains may come from improving how we integrate method, geology, and decision-making. The goal is not simply to produce better images. The goal is to produce interpretations that are (hydro)geologically defensible, useful to project teams, and appropriate for the decisions at hand. For a broad technical audience, that may be the most important takeaway from the session: geophysical interpretation is strongest when it moves beyond pattern recognition and becomes an exercise in geologic, hydrogeologic, or geochemical reasoning.

Author: Adam R. Mangel (AMangel@haleyaldrich.com), a hydrogeologist and geophysicist, chaired the SAGEEP 2026 session "Using Geologic Insight in Geophysical Interpretation." Adam is a senior technical specialist at Haley & Aldrich, Inc.

GAINS Luncheon & Capstone Panel

Paul Schwering; Sarah Morton Ranney; Miriam Johnston; Trever Ensele

The EEGS Education Committee hosted the "capstone" of the 2026 Geophysical Applications in Near Surface (GAINS) program. Since 2024, the GAINS program has featured Subject Matter Experts from the private and public sectors throughout their virtual training program. This capstone brought together university faculty and practicing geophysicists for its first in-person discussion of the past, present, and future of geophysics education, as well as workforce development challenges and opportunities. The panel was moderated by Paul Schwering, EEGS Education Committee Chair, and the luncheon was generously sponsored by IRIS Instruments and Colorado School of Mines. The panel conversation was lively and thoughtful, and concluded after a Q&A session in which attendees were encouraged to interact directly with the panelists! While there were many great moments during the session, the following quotes from each panelist particularly stood out.

The SAGEEP 2026 GAINS Subject Matter Expert panel, from left to right: Jacob Sheehan, Dr. Kennedy Doro, Dr. Jorden Hayes, Dr. Richard Krahenbuhl, and Sage Wagner. Not shown: Paul Schwering (moderator).

On applied/field training opportunities for students: "When we do have an opportunity to go out in the field or when it's time to do a lab or field camp, the students really latch on to that and to apply everything that they've been doing out in the field. …Understanding the problem, understanding what you need to do to understand that problem and working in teams… teamwork is really an important part that we try to bring together within them as well." ~ Dr. Richard Krahenbuhl

An undergraduate student asked the panelists "what is it that motivates you and makes you excited about geophysics in the day-to-day?"

"My passion is to solve environmental problems…if you find your passion as the technology is evolving, you will be evolving with the technology." ~ Dr. Kennedy Doro

"I go to work every day because I never know what's going to happen that day. No two days are going to look alike, and you never know what new challenges will come. That makes it fun!" ~ Jacob Sheehan

"As I'm carrying heavy equipment… to help essentially protect the integrity of [a] dam, I think a lot about the people who actually built the dam… I felt inspired to be a part of that. …ultimately being able to make a difference in the world to some degree, that's really what I get out of this job." ~Sage Wagner

On training students with the integration of artificial intelligence: "It's placing more demand on me now to really train my students to… spot problems with the [AI] processing and improve on them because an agentic AI mode or machine learning mode can easily do the basic processing." ~ Dr. Kennedy Doro

Reflecting on GAINS: "Where GAINS comes from, for instance, is to operate at that intersection between what you can learn, say, in schooling, and what you can learn on the job." ~ Jacob Sheehan

On cultivating student attitudes/enthusiasm for applied geophysics: "I think this is a really big opportunity for near-surface geophysics in particular… students are very motivated and it's a good recruitment and retention tool to think about why what we're doing matters…And communicating that I think really does motivate students and gives them a disposition that…there's meaning behind this work that we do. And that kind of disposition, I think, is really valuable." ~ Dr. Jorden Hayes

The EEGS Education Committee is grateful to the panelists, luncheon attendees, EEGS staff and volunteers, and the EEGS members supporting the GAINS virtual training program. GAINS is a member benefit for the EEGS Community and we look forward to hosting GAINS again in early 2027.

Authors: The EEGS Education Committee, with our thanks to the SAGEEP Planning Committee for the support and coordination that made this event possible and successful!

Support EEGS - Support the Future

In 1988, a group of geophysicists organized a meeting that would focus on near surface geophysics and named it the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP). Four years later, it was apparent an organization was needed to assure SAGEEP's longevity and to offer other resources. In 1992, the Environmental and Engineering Geophysical Society (EEGS) was formed and incorporated as a not for profit organization.

The geophysics community still needs SAGEEP and EEGS... and we need your support.

Making Your Contribution

You or your corporation can support EEGS and its programs by donating online now. If you are **in the United States**, Support EEGS and your receipt will contain the charitable contribution information needed for federal tax return purposes.

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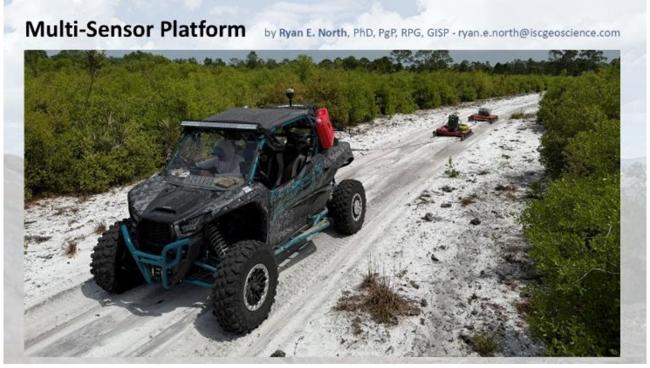
Mobile Geophysical Surveying: From High-Speed Mapping to Collaborative Soil Intelligence

Larisa Golovko, PhD

The "Mobile Geophysical Surveying" session at SAGEEP 2026 in Pittsburgh marked a significant shift in our community's focus. We moved beyond simply discussing "how fast" we can collect data to "how well" we can integrate it into broader environmental and agronomic frameworks. The session featured a diverse range of scales, from 20,000-acre geologic mapping to high-precision levee seepage analysis and 4D carbon monitoring.

The session opened with large-scale applications. **Ryan North (ISC Geoscience)** demonstrated the logistical feat of mapping 20,000 acres in Florida using a multi-sensor suite (TEM, GPR, and radiometrics), highlighting the "data deluge" challenges inherent in mobile surveys. This was complemented by **Zach Marazza (THG Geophysics)**, who showcased the economic efficiency of multi-dipole TCM for karst risk assessment on solar farm sites proving that mobile methods are now the "gold standard" for budget-sensitive, large-parcel developments.


Multi-Sensor Platform

by Ryan E. North, PhD, PgP, RPG, GISP - ryan.e.north@iscgeoscience.com

Technical innovation was a major highlight. **Joseph Capriotti (LSU)** introduced a novel level-set joint inversion using the ADAM optimizer, typically found in machine learning. His work on CO2 injection monitoring showed that mobile data can be processed with linear time complexity, a necessity for real-time applications. Similarly, **David Gomez (Terracon/LSU)** presented the efficacy of the backpack-mounted "Loupe" TEM system for levee characterization, bridging the gap between traditional geotechnical borings and high-resolution spatial data.

The Soil3D Movement and Community Response

The presentation of the **Soil3D** framework sparked a particularly engaging Q&A. One attendee, Geoff Pettifer (Terra Entheos Geoscience Pty. Ltd.), asked a pivotal question: *"Is this project commercial or government-sponsored?"* The response defined the spirit of the session: Soil3D is a **grassroots movement**. The goal is to build momentum for a collaborative ecosystem where we move away from proprietary "data silos" toward a shared "Near-Surface Data Exchange (NSDX)". By using a **Feature Vector** approach, derived soil properties like clay content and moisture rather than raw, secret inversion math the entire community can benefit from a self-correcting global database without compromising individual IP.

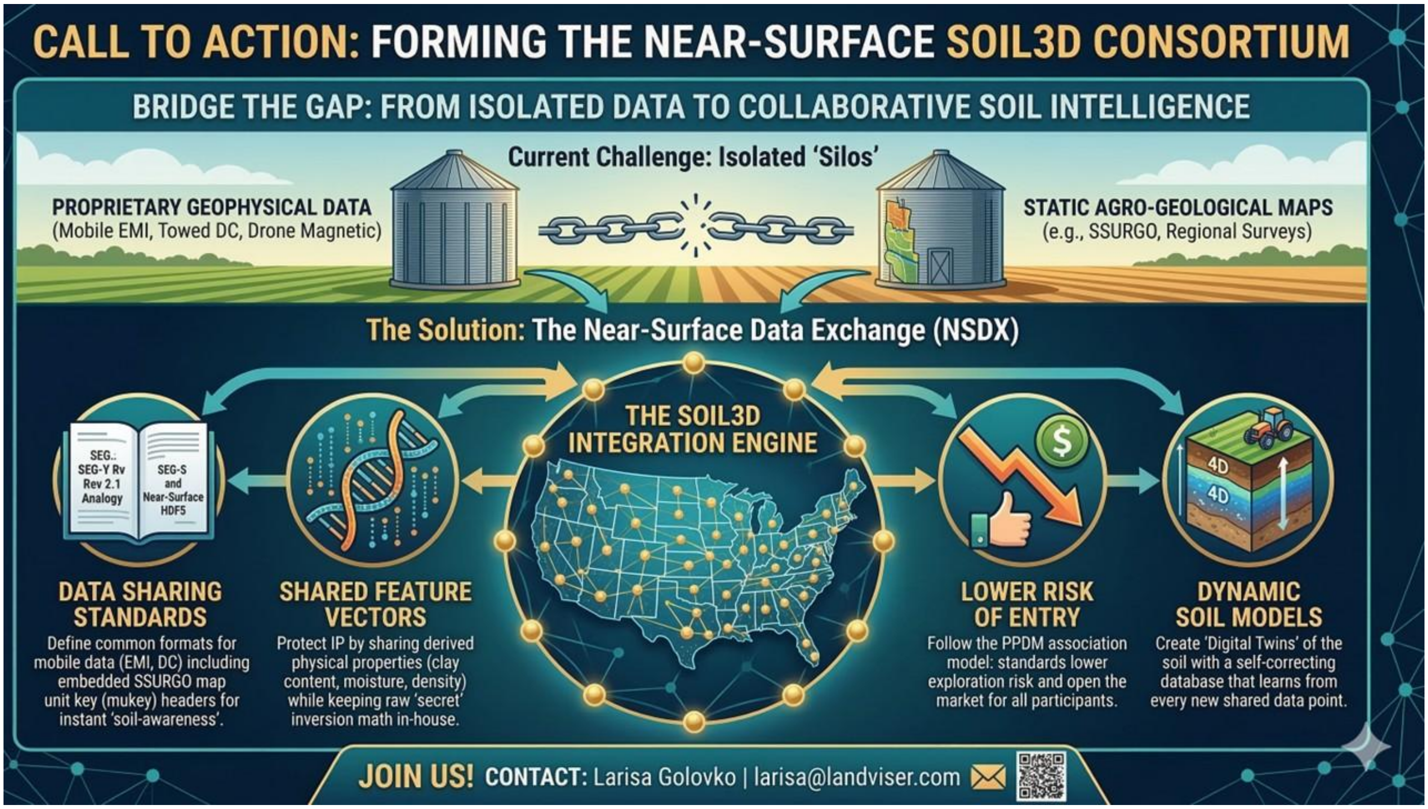
Inspiring the Next Generation

Perhaps the most rewarding feedback came from the students in the audience. Several commented even during "Dining with Dinosaurs" social event later Tuesday that the session was "refreshing" because it highlighted **interdisciplinary professional opportunities**. It demonstrated that a career in geophysics today isn't just about rocks and oil; it's about soil health, climate resilience, and precision agriculture. The integration of geophysical sensors with USDA

SSURGO databases and NASA weather feeds showed that our field is becoming the "bridge" between hard physics and sustainable land management.

The session concluded with a clear call to action: our industry needs a standardized "Near-Surface HDF5" format — analogous to the deep geophysics SEG-Y Rev 2.1 — that embeds soil-specific metadata like the SSURGO map unit key (mukey) into geophysical headers.

Author: Larisa Golovko is the CEO of Landviser LLC and GeoTools LLC. She served as the Session Chair for Mobile Geophysical Surveying at SAGEEP 2026. For more information on the Soil3D grassroots movement, contact her at larisa@geotoolsusa.com.



CALL TO ACTION: FORMING THE NEAR-SURFACE SOIL3D CONSORTIUM

BRIDGE THE GAP: FROM ISOLATED DATA TO COLLABORATIVE SOIL INTELLIGENCE

Current Challenge: Isolated 'Silos'

PROPRIETARY GEOPHYSICAL DATA (Mobile EMI, Towed DC, Drone Magnetic)

STATIC AGRO-GEOLOGICAL MAPS (e.g., SSURGO, Regional Surveys)

The Solution: The Near-Surface Data Exchange (NSDX)

THE SOIL3D INTEGRATION ENGINE

DATA SHARING STANDARDS
Define common formats for mobile data (EMI, DC) including embedded SSURGO map unit key (mukey) headers for instant 'soil-awareness'.

SHARED FEATURE VECTORS
Protect IP by sharing derived physical properties (clay content, moisture, density) while keeping raw 'secret' inversion math in-house.

LOWER RISK OF ENTRY
Follow the PPDM association model: standards lower exploration risk and open the market for all participants.

DYNAMIC SOIL MODELS
Create 'Digital Twins' of the soil with a self-correcting database that learns from every new shared data point.

JOIN US! CONTACT: Larisa Golovko | larisa@landviser.com

Geophysics in the Pursuit of Critical Minerals

Patrick Brindle, Chief Operating Officer, NeoMag

Beginning in May 2018, the United States established a list of 35 minerals and commodities defined broadly as critical minerals. From early 2026, the U.S. Geological Survey has expanded this list to 60 materials, including battery materials such as lithium, cobalt, manganese, copper, nickel and graphite as well as rare earth elements including neodymium, praseodymium, dysprosium, terbium, and yttrium.

Following the announcement of broad tariffs by the U.S. Government in April 2025, China responded with targeted export restrictions on seven heavy rare earth elements, exposing weaknesses in Western supply chains reliant on a single source for these metals which are indispensable for modern life.

Significant effort is being undertaken in the U.S. today to define potential resources of critical minerals from unconventional sources, whether from low concentration lithium brines, which could be recovered by direct lithium extraction (DLE), or as rare earth co-products recovered from re-processed tailings from coal or polymetallic mining operations.

During this important session we heard presentations which covered a number of perspectives and techniques for identifying potential critical mineral resources. Our presenters delivered information along two broad themes: 1) how to use remote sensing techniques, such as large scale low altitude radiometric and mag surveys, to identify potential critical mineral targets; and 2) extraction of valuable data from expensive exploration drill holes to create cost effective solutions for evaluating resource potential. Additionally, re-examination of historical drill core and exploration data sets for critical mineral resources potential was also examined.

Presenters touched on two (2) large scale efforts being undertaken by the U.S. Government to characterize the country's endowment of critical minerals. These efforts include the USGS Earth Mapping Resource Initiative

(Earth MRI) and the Department of Energy's Carbon-Ore, Rare Earth and Critical Minerals (CORE-CM) Initiative. During question and answer we discussed whether specific Mineral Resource and Mineral Reserve estimates and their associated resource models could be tested against the large data sets being developed under these two programs using generative AI to enhance data set interpretation for the identification of drill targets.

While all techniques presented have application in the field of exploration geology, none are full substitutes for traditional 'boot and hammer' prospecting and exploration drilling. That said, geophysics tools can make time consuming and expensive exploration programs more targeted and efficient.

As a session chair without a background in geophysics or geology (my background is mineral processing), I found all of the presentations fascinating. I believe it would benefit the conference in general to see additional sessions focused on the intersection of geophysics with exploration geology and mining, and I look forward to attending future Society conferences.

Author: Patrick (brindle@neo-mag.com) is the Chief Operating Officer of NeoMag, a U.S. company focused on the development of a mine-to-magnet supply chain for U.S. based manufacturing of permanent rare earth magnets. Patrick has spent the last eight of his 25+ year career focused on development of critical minerals for western economies with focus on lithium and rare earths.

Machine Learning, Deep Learning, and Applications to Shallow Geophysics for Civil Engineering and UXO Identification

William Harbert, Department of Geology and Environmental Science, University of Pittsburgh, Pittsburgh, PA., 15260

This article provides a brief historical overview of machine learning and deep learning, followed by a discussion of how these techniques are applied in shallow geophysics for civil-engineering site investigation and in the detection and discrimination of unexploded ordnance (UXO). In this paper, I also present a comparative methodology for binary classification on a tabular dataset of ten numerical features that I have found useful. A baseline of three neural architectures—a feedforward neural network (FNN), a one-dimensional convolutional network (1D CNN), and a long short-term memory network (LSTM)—is extended into a unified pipeline of fourteen approaches. The pipeline incorporates additional architectures (gated recurrent units, bidirectional LSTM, residual networks, transformer encoders), self-supervised representation learning via autoencoder pretraining, deep ensembles, stacked generalization with a logistic meta-learner, mean-field variational Bayesian neural networks, the tabular-specific TabNet architecture, gradient-boosted decision trees (XGBoost), and post-hoc isotonic probability calibration with F1-optimal threshold selection. To mitigate the modest size of the training set, we generate one thousand additional training rows using per-class Gaussian kernel density estimation in the standardized feature space. Hyperparameters for nine of the methods are optimized automatically via multivariate Tree-structured Parzen Estimator search with median-based pruning, and tuned configurations are propagated into compound methods (deep ensemble members, stacking base learners, and the calibration demonstration). Predictive uncertainty is treated as a first-class output, quantified through Monte Carlo dropout, ensemble disagreement, or posterior sampling, depending on the model class. All approaches are evaluated on the same held-out test set using accuracy, precision, recall, F1 score, area under the receiver operating characteristic curve, and average prediction uncertainty. This manuscript is related to an invited presentation given at the recent 2026 SAGEEP meeting recently held in Pittsburgh, Pennsylvania.

A Brief History of Machine Learning

Machine learning (ML) emerged from the convergence of three threads: mathematical models of biological neurons, statistical pattern recognition, and computer science. The earliest formal model of neural computation was given by McCulloch and Pitts (1943), who showed that networks of binary threshold units could compute any logical function. Declassification of work on information systems based analysis relevant to cryptography were also essential components (Shannon, 1945; Shannon, 1949). Alan Turing's 1950 essay on machine intelligence framed the broader question of whether machines could learn from experience (Turing, 1950). The term "machine learning" itself is generally attributed to Samuel, whose checkers-playing program of 1959 used reinforcement of potential move evaluations against game outcomes (Samuel, 1959). Charting the ML world champion in various games, checkers, chess, go, and various video games, can be used as a metric in the development of Machine Learning. Another example is the labyrinth navigating mechanical mouse, “Theseus” described in Shannon (1951).

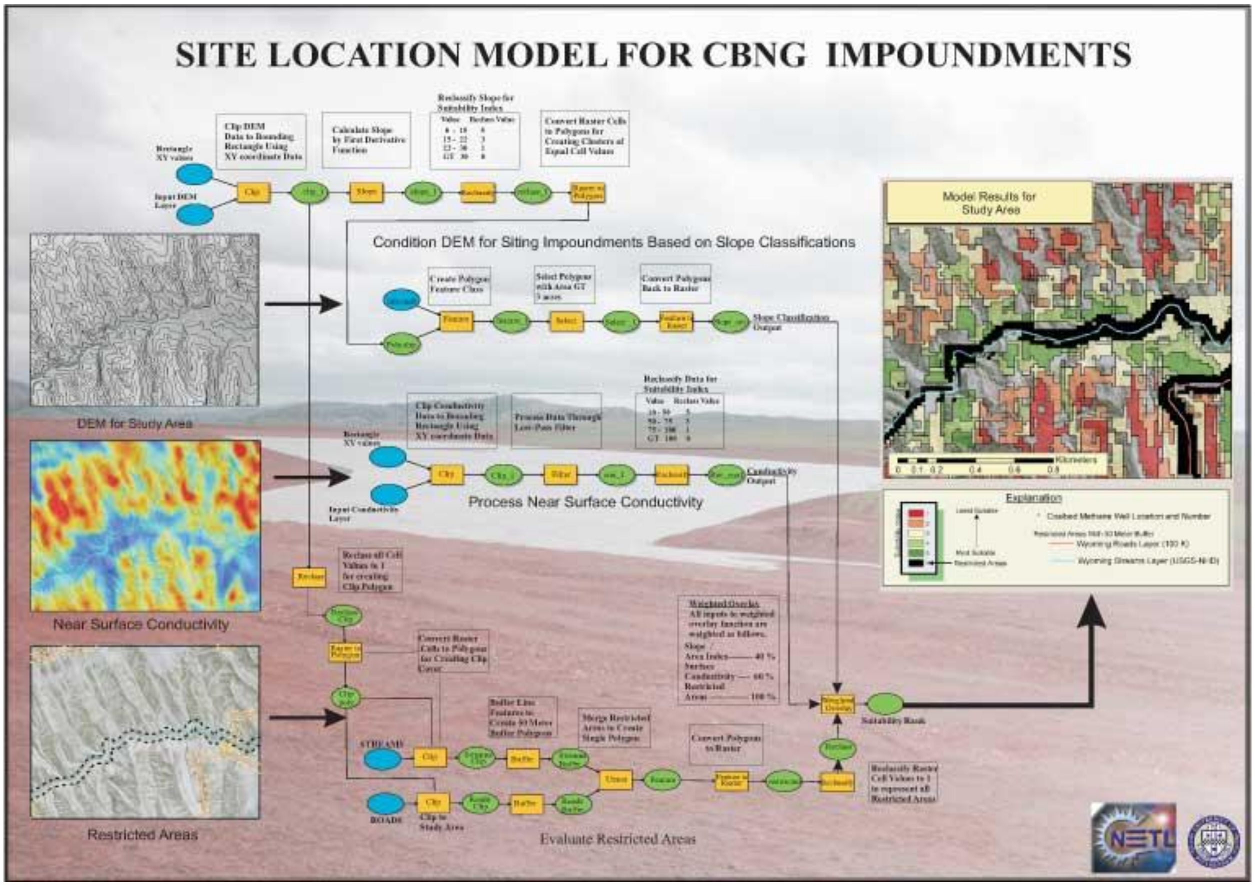


Figure 1: An expert system model combining digital elevation model (DEM) and helicopter electromagnetic (HEM) near surface apparent conductivity from Lipinski and others, 2008 and Sams and others, 2007). These older expert systems-based approaches are being replaced by Deep Learning methods.

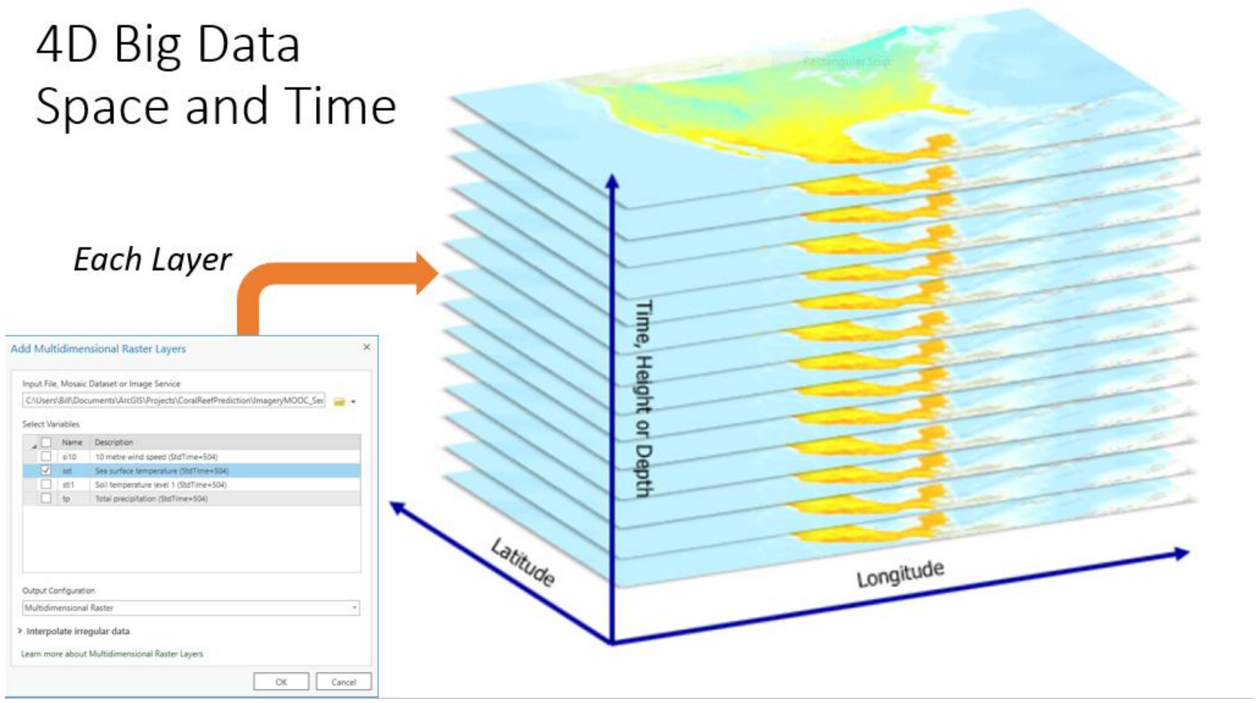
The Perceptron of Rosenblatt (1958), introduced in 1958, was the first trainable single-layer linear classifier and inspired widespread early interest in neural computation. It was complementary by the ADALINE work of Widrow and Hoff (1960), which introduced the least-mean-squares update rule that remains the basis of online linear regression. Enthusiasm cooled in 1969 when Minsky and Papert (1969) proved that single-layer perceptrons could not represent functions such as exclusive-or, contributing to the first "AI winter" of the 1970s during which funding and academic interest in connectionist approaches contracted sharply.

The 1980s saw a revival. Hopfield introduced energy-based associative memory networks (1982). Rumelhart, Hinton, and Williams popularized the backpropagation algorithm for training multi-layer networks (1986); the algorithm itself had been independently derived several times before, but the 1986 paper made it accessible and reproducible. LeCun and colleagues then demonstrated convolutional networks for handwritten digit recognition (1989), laying the groundwork for what would become the modern computer vision pipeline. The simultaneous and continuing revolution in computer systems, array processing specialized hardware components and ultimately the graphical processing unit (GPU) intersected with these techniques resulted in significant economic opportunities for those working on computers applied to a variety of image and real-time data analysis problems.

The 1990s and early 2000s were dominated by statistical learning theory. Cortes and Vapnik (1995) introduced support vector machines, which combined a strong geometric formulation with kernel-based nonlinearity and were widely regarded, for nearly a decade, as the default classifier for tabular and small-image problems. Breiman's random forests (Breiman, 2001) showed that bagged ensembles of decision trees could match or exceed neural networks on a wide range of tabular tasks and remain a strong baseline today. Hochreiter and Schmidhuber's long short-term memory (LSTM) recurrent unit (Hochreiter and Schmidhuber, 1997) solved the vanishing-gradient problem in sequence models and enabled the practical training of deep recurrent networks.

The Deep Learning Revolution

The phrase "deep learning" entered widespread use following the 2006 work of Hinton, Osindero, and Teh (2006) on layer-wise pretraining of deep belief networks, which showed that very deep networks could be trained successfully if initialized appropriately. The decisive empirical breakthrough came in 2012, when Krizhevsky, Sutskever, and Hinton's (2012) deep convolutional network reduced the top-five error rate on the ImageNet classification benchmark by roughly ten percentage points relative to the prior state of the art. This result was made possible not only by algorithmic improvements (rectified linear unit activations and dropout regularization in particular) but by the use of graphics processing units to accelerate the matrix operations underlying network training. The combination of larger labeled datasets, better regularization, and dense parallel hardware proved decisive.



Input File, Mosaic Dataset or Image Service: C:\Users\Bill\Documents\ArcGIS\Projects\CoralReefPrediction\ImageryMOOC_Se

Select Variables

	Name	Description
☐	si10	10 metre wind speed (StdTime=504)
☑	sst	Sea surface temperature (StdTime=504)
☐	stl1	Soil temperature level 1 (StdTime=504)
☐	tp	Total precipitation (StdTime=504)

Output Configuration: Multidimensional Raster

› Interpolate irregular data

Learn more about Multidimensional Raster Layers

Figure 2: The Big Data and Big I/O (Input/Output) Revolutions enable the Deep Learning Revolution. Shown below is a multi-decadal high-resolution dataset of monthly parameters. Understanding and analyzing such massive time-space cubes requires Deep Learning. In my experience, advanced undergraduate homework assignments in Advanced GIS and Computer Methods type courses routinely match or exceed 2010-2020 Master thesis levels of analysis and interpretations.

The decade following the 2012 result saw rapid architectural innovation. Goodfellow's generative adversarial networks (Goodfellow and others, 2014) established a new paradigm for generative modeling by training a generator and discriminator network in opposition. These insights and colleagues' residual networks (He and others, 2016) enabled successful training of networks hundreds of layers deep through skip connections that preserve gradient flow. Vaswani's transformer (Vaswani and others, 2017) replaced recurrence with self-attention and now dominates not only natural language processing but increasingly image, audio, and tabular tasks as well. A comprehensive synthesis of the field is given by LeCun, Bengio, and

Hinton (2015), and a textbook treatment by Goodfellow, Bengio, and Courville (2016).

Two characteristics distinguish deep learning from earlier machine learning approaches. First, learned representations: rather than engineering features by hand and applying a relatively simple classifier, deep networks learn the feature hierarchy and the classifier jointly from raw or lightly preprocessed data. Second, scale: deep learning performance has tracked closely with the amount of training data, the number of model parameters, and the compute budget allocated to training, in a manner that has not been observed for classical methods. These two properties have made deep learning particularly transformative for problem settings in which good features are difficult to engineer manually and labeled data are abundant or can be generated synthetically. Table 1 lists some methods used by the author and tuning considerations; Table 2 shows some strengths and weaknesses of each method.

Table 1. Methods evaluated, grouped by category, with their hyperparameter tuning regime.

Method	Category	Tuning regime
Feedforward NN (FNN)	Neural — feedforward	Optuna, 15 trials
Residual FNN	Neural — feedforward	Optuna, 15 trials
1D CNN	Neural — convolutional	Optuna, 15 trials
LSTM	Neural — recurrent	Optuna, 15 trials
GRU	Neural — recurrent	Optuna, 15 trials
BiLSTM	Neural — recurrent	Optuna, 15 trials
Transformer encoder	Neural — attention	Optuna, 15 trials
Pretrained FNN (autoencoder)	Self-supervised + supervised	Fixed defaults
Deep Ensemble (FNN × 5)	Ensemble of NNs	Inherits tuned FNN params
Stacking (FNN + ResNet + GRU)	Meta-learner blend	Inherits tuned base params
Bayesian NN (variational)	Bayesian deep learning	Fixed architecture
TabNet	Tabular-specific NN	Optuna, 10 trials
XGBoost	Gradient-boosted trees	Optuna, 30 trials
FNN + Calibration + Threshold	Post-processing wrapper	Inherits tuned FNN params

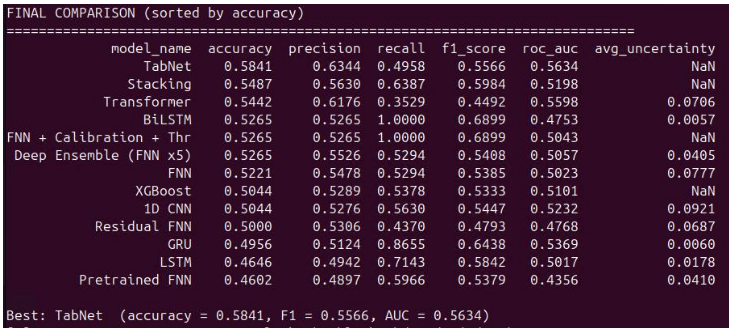
Table 2. Strengths and weaknesses of each method evaluated.

Method	Strengths	Weaknesses
Feedforward NN (FNN)	Simple and fast to train; flexible nonlinear function approximator; well-understood baseline; benefits substantially from hyperparameter tuning and from synthetic augmentation.	No structural inductive bias; can overfit on small data; performance on tabular problems is often matched by simpler tree-based methods.
Residual FNN	Skip connections ease optimization of deeper networks; additional depth without vanishing gradients; modestly more expressive than a plain FNN.	Extra parameters relative to a plain FNN provide diminishing returns on shallow tabular tasks; benefit on a 10-feature input is typically small.
1D CNN	Captures local patterns between adjacent features through parameter sharing; reduces effective parameter count relative to a fully connected network of comparable receptive field.	Assumes feature ordering carries meaning, which is generally false for tabular data; locality bias is wasted unless features are deliberately ordered.
LSTM	Strong inductive bias for ordered sequences; gating mechanism handles long-range dependencies; mature, widely studied.	Sequence assumption is misaligned with unordered tabular features; comparatively slow to train; many parameters relative to the signal available.

GRU	Comparable performance to LSTM with fewer parameters and faster training; simpler internal state.	Same fundamental misalignment with non-sequential tabular data; limited gain over a well-tuned FNN on this problem class.
BiLSTM	Doubled representational capacity through forward and backward passes; sees full context at every position.	Twice the parameters of an LSTM; directionality is meaningless on permutation-invariant tabular features.
Transformer encoder	Self-attention models pairwise feature interactions explicitly; permutation-invariant when no positional encoding is used (well suited to tabular data); modern, actively researched architecture.	Data-hungry relative to simpler models; many hyperparameters; can underperform tree-based methods on small datasets despite additional capacity.
Pretrained FNN (autoencoder)	Learns representations from features alone; useful when labeled data are scarce relative to unlabeled data; can yield smoother decision boundaries through latent regularization.	Latent space is optimized for reconstruction, not classification, and may discard discriminative information; two-stage training adds engineering complexity; gains diminish when labels are abundant.
Deep Ensemble	Strong empirical accuracy and well-calibrated uncertainty through ensemble disagreement; trivially parallel; benefits compound when members use tuned hyperparameters.	Linear cost increase in both training and inference with ensemble size; no formal Bayesian interpretation despite uncertainty behavior; storage requirements scale with member count.
Stacking	Combines diverse base learners through a learned meta-mapping; can exceed the best single learner when base models make different kinds of errors; modular and extensible.	Pipeline complexity higher than single-model approaches; risk of meta-level overfitting if the validation strategy is naive; full out-of-fold stacking would require additional training cost.
Bayesian NN (variational)	Principled posterior over weights; provides epistemic uncertainty directly; sampling from the posterior produces a richer uncertainty distribution than dropout-based approximations.	Variational ELBO can be unstable to optimize; mean-field factorization underestimates posterior correlations; requires the tensorflow-probability dependency; slower training than deterministic networks.
TabNet	Designed specifically for tabular data; sequential attention mechanism provides feature-selection inductive bias and a degree of interpretability; differentiable end-to-end.	More hyperparameters than gradient-boosted trees; PyTorch dependency adds complexity in a TensorFlow-centric pipeline; frequently does not exceed XGBoost on small tabular datasets.
XGBoost	Strong performance on small-to-medium tabular data; fast training and inference; handles missing values and unscaled features natively; mature, well-tested implementation.	Native uncertainty quantification is limited (typically requires auxiliary methods such as quantile regression or bagging); trees-based models can be sensitive to extrapolation outside the training distribution; integration with deep methods is less natural.
FNN + Calibration + Threshold	Improves probability calibration without retraining the base model; allows the operating point to be matched to the downstream objective (here, F1); cheap and modular.	Requires a held-out calibration set, reducing data available for training; isotonic regression can overfit on very small calibration sets; F1-optimal

		threshold may not transfer if class balance shifts at deployment.

Creating very high noise synthetic test cases is something I believe is important to check the tools being used for analysis. Figure 3 shows a typical output example, in addition to these attributes ROC curves are completed for each method and saved for comparison. An example of applying Deep Learning to GPR B-scan data can be found in Hongyuan and others, 2024.



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FINAL COMPARISON (sorted by accuracy)
==============================================================================
             model_name  accuracy  precision  recall  f1_score  roc_auc  avg_uncertainty
                 TabNet    0.5841     0.6344  0.4958    0.5566   0.5634              NaN
               Stacking    0.5487     0.5630  0.6387    0.5984   0.5198              NaN
            Transformer    0.5442     0.6176  0.3529    0.4492   0.5598           0.0706
                 BiLSTM    0.5265     0.5265  1.0000    0.6899   0.4753           0.0057
FNN + Calibration + Thr    0.5265     0.5265  1.0000    0.6899   0.5043              NaN
 Deep Ensemble (FNN x5)    0.5265     0.5526  0.5294    0.5408   0.5057           0.0405
                    FNN    0.5221     0.5478  0.5294    0.5385   0.5023           0.0777
                XGBoost    0.5044     0.5289  0.5378    0.5333   0.5101              NaN
                 1D CNN    0.5044     0.5276  0.5630    0.5447   0.5232           0.0921
           Residual FNN    0.5000     0.5306  0.4370    0.4793   0.4768           0.0687
                    GRU    0.4956     0.5124  0.8655    0.6438   0.5369           0.0060
                   LSTM    0.4646     0.4942  0.7143    0.5842   0.5017           0.0178
         Pretrained FNN    0.4602     0.4897  0.5966    0.5379   0.4356           0.0410

Best: TabNet  (accuracy = 0.5841, F1 = 0.5566, AUC = 0.5634)
```

Figure 3: Comparison of models for a very high noise synthetic database. In this example a total of 10 attributes were observed and analyzed.

Applications to Shallow Geophysics in Civil Engineering

Shallow geophysics encompasses non-invasive subsurface investigation methods operating in roughly the upper tens of meters of the ground: ground-penetrating radar (GPR), electromagnetic induction (EMI), magnetometry, electrical resistivity tomography, and shallow seismic refraction and reflection methods. Civil-engineering applications include subsurface utility mapping, pavement and bridge-deck condition assessment, foundation evaluation, void and sinkhole detection, karst characterization, soil and rock characterization, and pre-construction site investigation. The data are typically high-dimensional, noisy, and ambiguous: a single anomaly in a magnetic image or a hyperbolic reflector in a GPR B-scan is consistent with many possible subsurface configurations and resolving that ambiguity has traditionally relied on substantial human expertise.

Machine learning has emerged as a complement and, increasingly, a partial substitute for expert manual interpretation across these workflows. Bergen and others, 2019, survey machine learning for data-driven discovery in solid Earth geoscience, identifying signal-to-feature mapping, automated event detection, and forward-model surrogate modeling as the principal use cases. Reichstein and others, 2019, argue similarly for the integration of deep learning with process understanding in Earth-system science, emphasizing that the most successful applications combine the representational flexibility of neural networks with the prior knowledge encoded in physics-based models.

Several capabilities are particularly valuable in shallow geophysics for civil engineering. First, automated interpretation of GPR and EMI imagery: convolutional networks have been applied to GPR B-scans for automatic detection of rebar, utilities, and tunnel-boring obstructions, with throughput far exceeding manual picking. Second, multi-sensor fusion: feedforward, recurrent, and attention-based networks can integrate observations from disparate sensors (magnetic, electromagnetic, seismic) into a single predictive output, in a manner that hand-crafted decision rules cannot match. Third, regression from indirect measurements: gradient-boosted trees and feedforward networks have been applied to petrophysical and geotechnical regression from multi-sensor logs, yielding rapid estimates of properties such as soil density, moisture content, and shear-wave velocity. Fourth, uncertainty quantification: predictive variance from Monte Carlo dropout, deep ensembles, or Bayesian neural networks lets the engineer distinguish high-confidence predictions from regions where the model is extrapolating, an essential property for engineering decisions that carry physical and financial risk.

Applications to UXO Identification

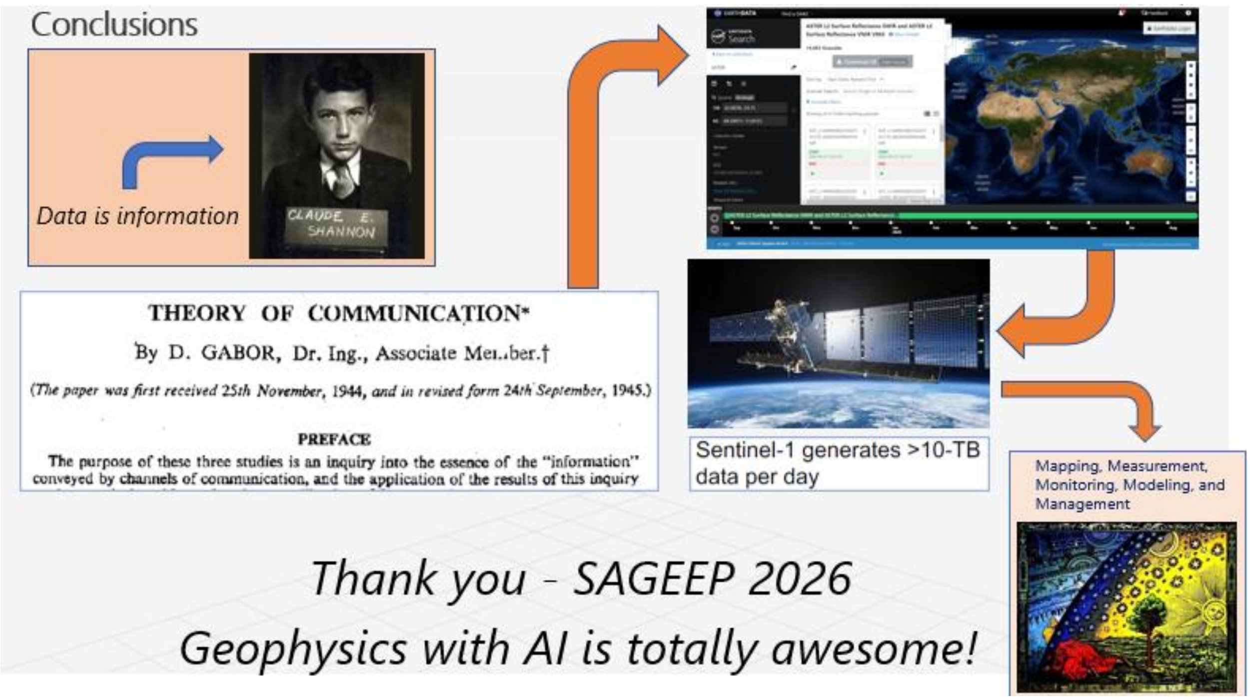
The detection and classification of buried unexploded ordnance (UXO) is a particular subdomain of shallow geophysics with acute humanitarian and economic stakes. The use of Autonomous Aerial Systems

(UAS/UAV) and Autonomous Subsea Systems (UUV/UAV) are rapidly expanding the need for real-time object identification and classification. Standard practice combines magnetometry and time-domain or frequency-domain electromagnetic induction, often with multi-component sensor arrays that recover the directional structure of the target's induced magnetic dipole. The classical workflow is to fit a physics-based forward model — typically a polarizability tensor describing the target's induced response as a function of time or frequency — to the measured signal, and then to use the fitted parameters as features for discrimination. Bell and others (2001) established the polarizability-tensor framework for EMI; Pasion and Oldenburg, 2001, introduced a discrimination algorithm based on parametric decay fits of time-domain EMI data, which became foundational for the field; and Billings (2004) developed the corresponding magnetic-discrimination methodology, with subsequent extensions to detailed library-based magnetic models (Bell and others, 2006). In their excellent abstract Heagy and others, (2024) review machine learning methods for UXO detection using EM data in marine settings.

The principal challenge in UXO remediation is not feature detection but accurate and real-time feature classification. Excavation costs dominate UXO remediation budgets, and a substantial fraction of all anomalies in a typical site are non-hazardous clutter — shrapnel, scrap metal, geological inclusions, or cultural debris. The objective is therefore to reduce the false-positive rate (the fraction of clutter targets that must be excavated) while maintaining a near-perfect true-positive rate (the fraction of UXO that are correctly identified as such). The asymmetric cost structure — missed UXO are potentially fatal, excavated clutter is merely expensive — places strong demands on classifier reliability and operating-point selection.

Machine learning contributes to this problem in several ways. First, classifiers operating on physics-derived features (the polarizability decay parameters, magnetic dipole moments, fitted depths and orientations, and goodness-of-fit metrics from the underlying inversions) have repeatedly demonstrated lower false-positive rates than threshold-based decision rules at fixed true-positive rate. Feedforward networks, gradient-boosted decision trees, support vector machines, and ensemble methods are all applicable; the choice often depends on the available training set size and on the desired interpretability. Second, deep networks operating on raw or lightly preprocessed sensor data can in principle recover discriminative information that hand-crafted features miss, although interpretability and regulatory acceptance become more difficult, and the training-set sizes typical of UXO campaigns may be insufficient to realize the full benefit.

Third — and most important for the present pipeline — calibrated predictive uncertainty quantification is particularly valuable in this domain. Overconfident misclassification of a UXO as clutter carries severe consequences; conversely, an overconfident classification of clutter as UXO drives unnecessary excavation cost. A well-calibrated uncertainty signal, obtained through Monte Carlo dropout, deep ensemble disagreement, or Bayesian posterior sampling, lets the system flag ambiguous targets for additional investigation, multi-sensor follow-up, or conservative excavation, rather than forcing a hard decision in the regime where the model is least reliable. Combining a physics-based feature extractor with a machine-learning classifier and an explicit uncertainty estimate is the structure of the pipeline described in the accompanying methodology report: ten physics-derived features per anomaly, binary discrimination of UXO from clutter, and explicit uncertainty quantification through multiple complementary mechanisms. The same pipeline structure transfers directly to the broader civil-engineering applications discussed earlier, where the inputs are different physical features but the underlying decision-theoretic problem — classify, calibrate, quantify uncertainty — are the same.



Conclusions

Data is information

THEORY OF COMMUNICATION*

By D. GABOR, Dr. Ing., Associate Member.†

(The paper was first received 25th November, 1944, and in revised form 24th September, 1945.)

PREFACE

The purpose of these three studies is an inquiry into the essence of the "information" conveyed by channels of communication, and the application of the results of this inquiry

Sentinel-1 generates >10-TB data per day

Mapping, Measurement, Monitoring, Modeling, and Management

Thank you - SAGEEP 2026

Geophysics with AI is totally awesome!

Figure 4: Big Data, Big I/O, and Deep Learning are essential elements of understanding and interpreting all observations. "Commit yourself to lifelong learning. The most valuable asset you will ever have is your mind and what you put into it." — Albert Einstein

Conclusions

We live in revolutionary times as shown in Figure 4. In my opinion, this generation, inheriting the tools, datasets, and research vectors of earlier generations, is the luckiest generation in human history. If you can imagine something, it is possible to create that workflow, hitch your dreams to the stars. My sincere thanks to SAGEEP for their excellent symposium on the application of geophysics to engineering and environmental problems held in Pittsburgh .

Acknowledgements

My sincere thanks to J. Sheehan, (EEGS President), F. Day-Lewis (EEGS Vice President), J. File (MMR) and Peter J. Hutchinson PG, SAGEEP 2026 General Chair for the opportunity to present a luncheon lecture "*Deep Learning, Machine Learning & AI as they impact the Geosciences: What is it, how it works, what you need, and why it matters (Spoiler alert: These approaches are changing the world every day).*" I am especially grateful for the wide-ranging discussions, excellent questions, and many insightful comments by those who attended. Thank you all so much.

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Author: Dr. William Harbert received his MS in Exploration Geophysics and Ph.D. in Geophysics from Stanford University. He then completed a National Research Council (NRC) post-doctoral Research Associate appointment with the United States Geological Survey in Menlo Park, California. He was also an Exchange Scientist between the US Academy of Sciences and the Academy of Sciences of the USSR (Академия Наук СССР) during the last year of this program. He was a R&D 100 Award Winner for National Risk Assessment Partnership (NRAP) Toolset, working on a United States Department of Energy National Laboratory Team. Dr. Harbert's research is related to subsurface imaging and analysis, and a rock physics-based determination of geologic units. He has also been involved with environmental geophysical technologies relevant to remote subsurface water quality and topology analysis. He and his students and collaborators actively work on the application of Deep Learning methods to seismic emissions and geophysical object detection and classification.

Technical Article

Imaging CO_2 Migration in Heterogeneous Sedimentary Deposits using Crosswell P-Wave Tomography

(1)Débora Portaz, (2)Sonja Mackens-Siemes, (2)Lutz Karl, (2)Thomas Fechner
(1) Ecole et Observatoire des Sciences de la Terre (EOST), Strasbourg, France
(2)Geotomographie GmbH, Neuwied, Germany
Email : dboraportaz@gmail.com

Abstract

Geological storage of CO_2 is a promising mitigation strategy to reduce atmospheric greenhouse gas concentrations by storing CO_2 into deep subsurface formations. However, the long-term efficiency and safety of such storage depend on a precise understanding of CO_2 migration mechanisms and potential leakage pathways. We present results from a controlled CO_2 injection experiment conducted at the Svelvik test site in Norway, monitored using crosswell seismic P-wave tomography over six days. The resulting tomograms, along with normalized and relative difference images between consecutive days, clearly reveal the displacement of gas within the formation. CO_2 accumulates beneath a clay layer at approximately 35 m depth, and a potential leakage pathway was identified, either through a discontinuity in the impermeable layer or along a borehole. A detailed analysis, combined with the calculated hydraulic permeability tomogram, indicates that the gas tends to accumulate in or below less-permeable zones and migrates preferentially through more-permeable layers. Furthermore, fluctuations in the water table appear to influence gas displacement by pushing it upward toward the impermeable layer, thereby promoting CO_2 spreading.

Introduction

Gas injection into geological formations is increasingly investigated as part of strategies for subsurface energy storage and greenhouse gas mitigation. The success of such operations depends not only on the capacity of the reservoir to host and retain the injected fluid, but also on a detailed understanding of the hydrodynamic conditions in the reservoir. Monitoring during and after injection plays a central role in updating the subsurface model, assessing reservoir integrity, and better constraining the key parameters that govern subsurface flow (Miocic and others, 2023). But above all, a robust monitoring, measurement, and verification plan is legally required to obtain and maintain a storage permit (Al Khatib and others, 2025). A wide range of geophysical monitoring tools can be employed to track gas plumes in the subsurface. Borehole-based techniques provide high-resolution insights in the near-well environment. Moreover, time-lapse imaging approaches are particularly suited for detecting changes in physical properties induced by gas saturation. The long-term monitoring of the Utsira Formation at Sleipner demonstrated the value of geophysical methods for tracking CO_2 injection and migration including seismic methods (Arts and others, 2008). Beyond traveltime tomography, full waveform inversion refines velocity models, while attenuation analyses (quality factors) offer complementary insights (Böhm and others, 2015; Zhang and others, 2012).

Seismic studies revealed characteristic signatures such as amplitude dimming and horizon pushdown, linked to plume evolution (Boait and others, 2012). Time-lapse crosswell seismic P-wave tomography further captured the spatiotemporal dynamics of the plume with high-resolution imaging (Saito and others, 2006; Böhm and others, 2015), consistently showing reduced seismic velocities due to changes in rock elasticity.

Complementary studies have examined the geomechanical effects of CO_2 injection on reservoir formations. Injection of CO_2 increases pore pressure within the reservoir, which can trigger geomechanical responses such as fault reactivation, microseismicity, and even surface uplift (Verdon and others, 2013). Increased pore pressure resulting from CO_2 injection can alter the stress state in the reservoir rock, potentially leading to shear or tensile failure. The shear stress could produce a dilatation and induce grain rearrangement, permeability change and increase in porosity. So, the uplift does not only depend on the increase in pore pressure but also on the thickness and extent of the formation and on hydro-geomechanical properties of the porous media (Teatini, 2010). A well-documented example is the In Salah CCS project, where satellite-borne SAR data revealed measurable uplifts linked to CO_2 injection. The observed uplift was associated not only with significant pore pressure increases but also with microseismic events and the reactivation of fracture networks. Time-lapse seismic monitoring has proven valuable for detecting such geomechanical changes, as it can reveal pressure variations and stress transfer within the reservoir (Chadwick and others, 2012; Hatchell and Bourne, 2005; Staples and others, 2007).

In addition, other studies have also examined the influence of external factors such as aquifer dynamics on CO_2 injections. For example, the relationship between water-level variations and S-wave velocity changes during a CO_2 injection has been explored as part of the DIGIMON project (DIGIMON, 2022). The study shows that S-waves arrival times changed as well as P-waves arrival time during the injection. It is suggested that tidal pressure may displace the injected gas and locally modify seismic responses, although larger contrasts would be needed to unambiguously confirm this effect. So, the question remains if the observed variations of S-wave velocity are due to tides or to CO_2 injection.

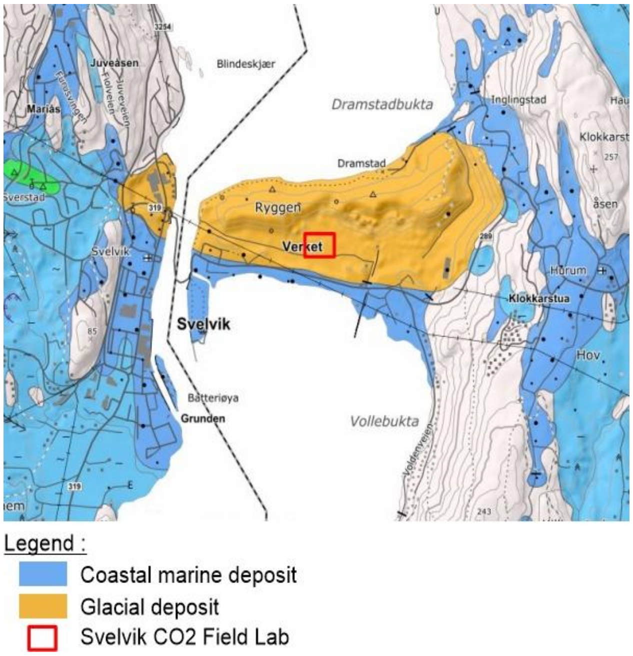
Beyond plume detection, several works have focused on the petrophysical properties of the reservoir rocks, which govern gas migration and storage potential. The Kozeny–Carman equation, for instance, relates permeability to porosity, tortuosity, and specific surface area. Since P-wave velocity correlates with porosity, subsequent studies have extended these relationships to clay content and even permeability (Marion, 1990; Becht, 2004).

Establishing robust links between monitoring data and petrophysical models is therefore essential for capturing the effects of reservoir heterogeneity, mineral composition, and aquifer connectivity on gas migration. In this context, we first analyzed time-lapse monitoring data of a CO_2 injection experiment using crosswell seismic P-wave tomography. In a second step, the seismic observations were interpreted in terms of hydrodynamic properties, with particular emphasis on permeability and the influence of water-table dynamics.

Site Description and Field Experiment

The Svelvik field laboratory has been established in the Holocene deposit of the Svelvik ridge, a peninsula formed by glacial retreat, located in the Drammensfjord, 50 km south of Oslo (Norway). The subsurface consists mainly of unconsolidated sand layers with variable clay content. This deposit is classified as a glaciofluvial–glaciomarine terminal formation, emplaced during the Ski stage of the Holocene deglaciation, when the glacier advanced to Svelvik and remained stable for an extended period. The sequence includes diamictic sediments overlain by aerial deposits that were reworked by wave and tidal processes after the glacier's retreat (Hagby and others, 2018; Bakk and others, 2012; Melø, 2011). The ridge is presently above sea level due to postglacial isostatic uplift (SINTEF, 2024). The geological map from the Norwegian Geological Survey and Sørensen (Figure 1a) confirms that glaciofluvial deposits of the Svelvik ridge are flanked by clay units on both sides. The entire structure overlies a granite bedrock at depths of 300-400 m. Two aquifers are present: an unconfined aquifer extending from the water table down to about 20 m depth, containing freshwater, and a deeper confined aquifer that may be influenced by seawater intrusion.

(a)



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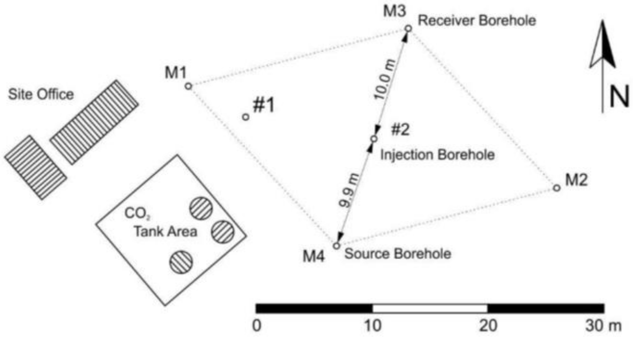


Figure 1: Description of the Svelvik Field Lab. Geological map of the region (NGU, 2025) (a) and scheme of the field lab (b).

This geological setting makes the Svelvik site particularly suitable for investigating leakage processes at shallow depths as well as for CO_2 storage studies at greater depths. Several research initiatives have already taken advantage of its unique characteristics. For instance, experiments have been carried out to investigate CO_2 leakage both at shallow and deeper levels (Dillen, 2009; Barrio, 2014). In addition, large collaborative projects have focused on CO_2 storage monitoring at the site, including the pre-ACT and DigiMon projects (Eliasson and others, 2018; SINTEF, 2024).

The Svelvik CO_2 Field Lab includes one central injection well (#2) and four monitoring wells (M1–M4), forming a rhombus around #2 (Figure 1). The injection well is screened between 64 and 65 m depth and is designed for low-overpressure CO_2 injection. Monitoring wells are PVC-cased to 100 m (SINTEF, 2024).

Field Experiment and Baseline Data Survey Results

Within the framework of the Digimon Project, a CO_2 injection experiment was conducted from 14 to 22 September 2021, with injection starting on 16 September. Crosswell seismic P-wave tomography was employed to monitor the process, during which CO_2 was injected over six days into borehole #2. CO_2 was injected at the screened interval between 64 and 65 m depth, with an overpressure of 0.1 bar and a daily rate of 8 m^3. The seismic source was placed in borehole M4, while hydrophone receivers were deployed in borehole M3. The P-wave source was fired at 1 m intervals between 30 and 77 m depth, with depth referring to the top casing. Two hydrophone strings, each containing 24 channels with 1 m spacing, were installed in borehole M3 to cover the same depth interval (Koedel and others, 2022). Initial P-wave measurements were conducted prior to the gas injection to establish a baseline. During the six days of injection, the reservoir was continuously monitored using P-waves to provide high-resolution insight into the evolving conditions. Additional seismic methods, including S-waves and Distributed Acoustic Sensing (DAS), were also applied during the experiment but are not discussed further in this paper.

The baseline survey was processed in a previous study (Figure 2) (Koedel and others, 2022). It revealed alternating layers characterized by low and high P-wave velocities. Low velocities are around 1700 m/s, while higher values reach approximately 1900 m/s and more. These ranges are typical of clay-rich and water-saturated sandy deposits. At a depth of about 35 m, a distinct high-velocity layer was observed, corresponding to the clay-rich horizon identified in previous studies (SINTEF, 2024).

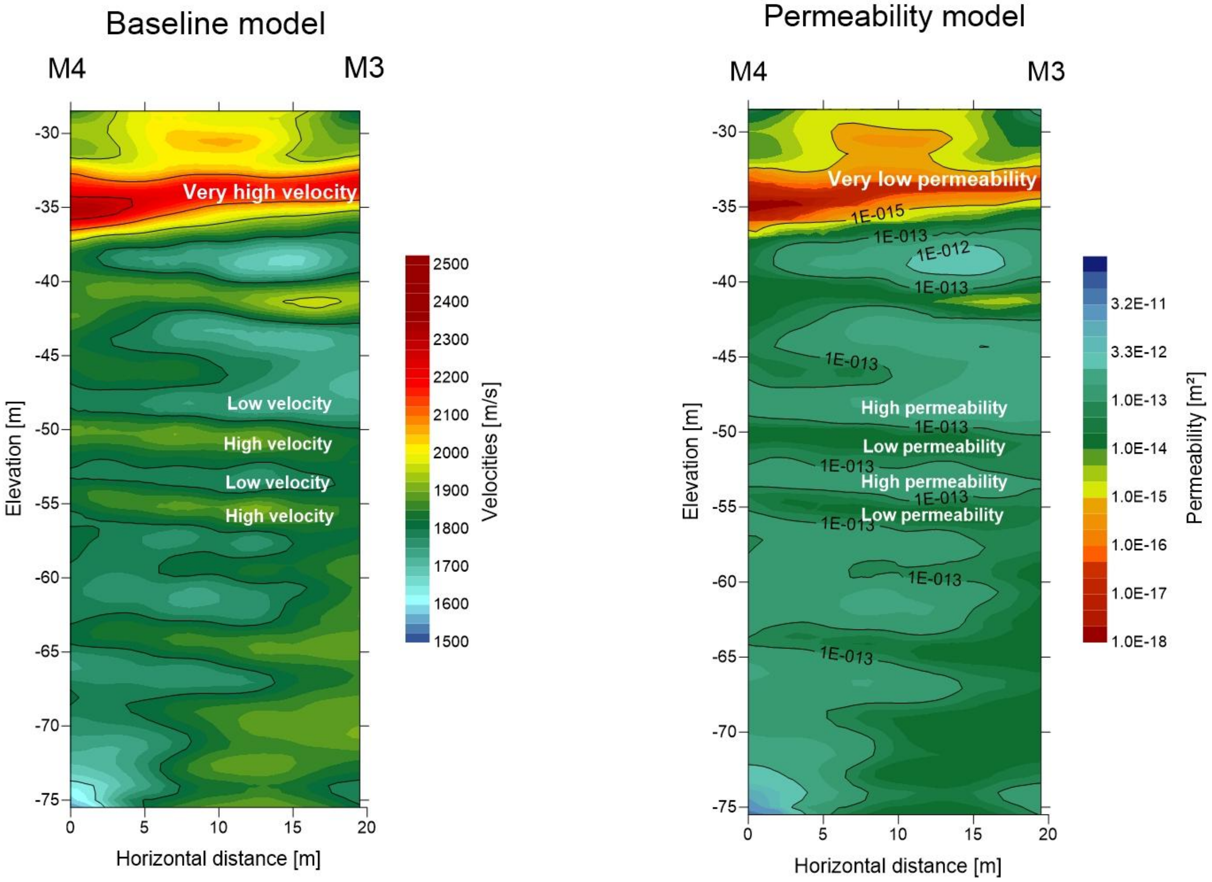


Figure 2: Baseline velocity model between boreholes M3 and M4 (left). Permeability tomogram calculated from the velocity model, thanks to literature, sonic and gamma logs in borehole #1 (right).

The relationship between clay content and seismic velocity is complex. Clay content can be inferred from natural gamma-ray logs, as the radioactive elements in many clay minerals (K, U, Th) emit gamma radiation. This results in a well-established correlation between gamma-ray intensity and clay concentration (Fricke and Schön, 1999; Howarth, 2024).

According to Marion (1990), dispersed clay in sand initially increases P-wave velocity and reduces porosity by filling pore space, as long as clay content remains below that of the sand. Once clay becomes the dominant component, both P-wave velocity decreases and porosity may increase due to the intrinsic microporosity of clays. Consequently, in clayey sands (sand-dominated with dispersed clay) clay content is generally negatively correlated with porosity, whereas in sandy clays (clay-dominated) the correlation becomes positive (see Figure 3).

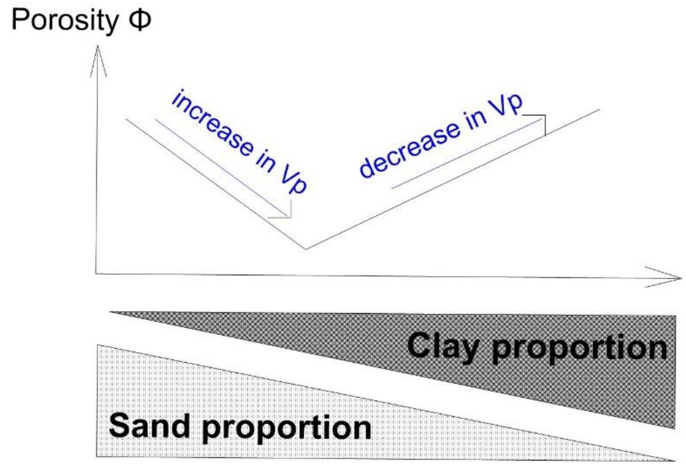


Figure 3: Relations between clay content, P-wave velocity Vp and porosity in sand and clay (after Marion, 1990).

P-wave velocity is strongly controlled by porosity, which governs the bulk and shear moduli of the rock–fluid system. According to Gassmann's equations, the P-wave velocity of a saturated rock can be predicted from the bulk modulus of the mineral matrix, the dry rock frame, and the pore fluid, with porosity entering explicitly in the formulation. In addition, the relationship between velocity and porosity has been bounded by the Voigt and Reuss limits, which provide theoretical upper and lower bounds for elastic wave velocities in porous media. Both approaches confirm the general trend that velocity decreases with increasing porosity. Porosity reduction is commonly associated with sediment compaction and cementation, and may also result from clay infill within the pore space. The applicability of Gassmann's equation to gas-saturated saline aquifers has been supported by several studies, which demonstrate that the theoretical framework remains valid under such fluid–rock conditions (Singh and others, 2017; Allo and others, 2024). Moreover, porosity is directly linked to permeability through the Kozeny–Carman relation, where permeability depends on the specific surface area of the grains and the tortuosity of the pore network, both of which are controlled by grain shape, size, and arrangement.

To illustrate these relationships in our study area, we computed correlations between gamma-ray intensity and P-wave velocity, as well as between gamma-ray intensity and permeability, using well-log data from borehole #1. This analysis allowed us to indirectly link P-wave velocity to permeability. Although the computed correlations are relatively weak, their trends are consistent with published results, which supports the reliability of our findings (Junker and others, 2025).

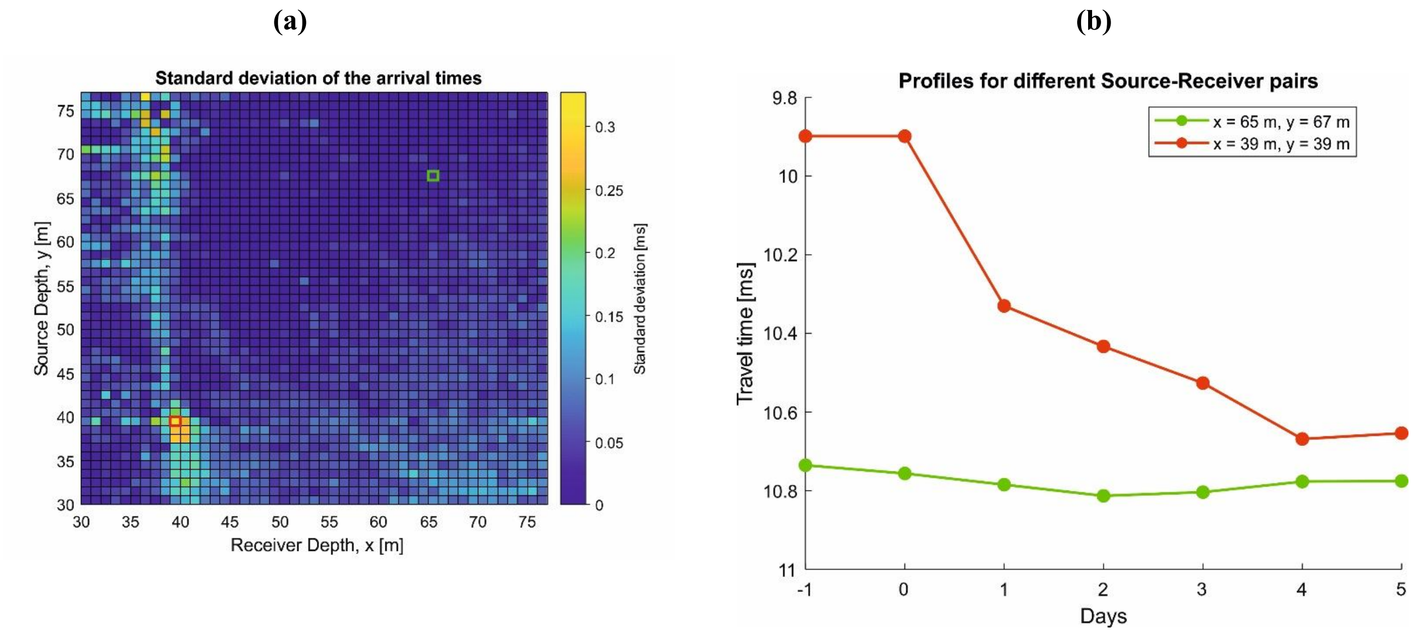
Figure 2 presents the hydraulic permeability tomogram derived from the baseline velocity model. Alternating high- and low-permeability layers can be clearly distinguished. The low-permeability intervals coincide with high-velocity zones in the baseline model, in line with previous studies. Notably, the compact, clay-rich layer at approximately 35 m depth exhibits very low permeability, consistent with its high-velocity signature. The estimated permeability values in this layer range between 10^{-18} and 10^{-16} m^2, which is typical for glacial till to clay. In contrast, the remaining permeability values in the tomogram fall within the range generally associated with sand and silt.

Processing of the Monitoring Data

The complete monitoring data set consists of the baseline data set and six daily monitoring data sets after the injection started. Each data set contains 48 shot records to 48 hydrophone receivers. To eliminate potential picking errors we re-sorted and joined the data sets, i.e., a newly assembled shot record now contains traces from baseline and monitoring data to all 48 receivers given a total of (1+6)*48 traces per shot. This procedure allowed us to carry out a quality control of the arrival times while manually picking each trace. The only restriction we applied while picking was that the arrival times of the monitoring data had to be equal or longer than the baseline picks. In fact, as P-waves move faster in water than in a gas-water mixture we only expected to see travel times which are equal or longer compared to the baseline data. So, consequently also the monitoring velocities should be equal or lower compared to those imaged in the baseline velocity model.

After completion of the travel time picking a quantitative inspection of the time changes was carried out by calculating the standard deviation for the picks for each source-receiver pair (see Figure 4). In Figure 4a low standard deviation values indicate source-receiver pairs where only small temporal changes occur whereas higher values attribute source-receiver pairs with greater variability during injection. As an example the travel time changes for a source-receiver pair with small and higher standard deviation are displayed in Figure 4b.

Tomographic inversion was carried out using the Simultaneous Iterative Reconstruction Technique (SIRT) available in the software package GeoTomCG (GeoTom, LLC, 1996). As a first modelling step the subsurface has to be divided into three-dimensional (3D) cells as a starting model with a starting velocity. The cell sizes for inversion were chosen to be 1.08 m x 1 m x 0.91 m in the X, Y, and Z directions. During the inversion procedure, seismic rays with source-receiver angles exceeding 45° were neglected. This procedure eliminates rays with steep angles, which often lead to velocity artifacts as longer rays tend to bend outside the observation plane. This limitation has also been noted by Böhm and others (2015) and Becht (2004).


(a)

(b)

Figure 4: Standard deviation map of the arrival times between baseline to day 5 (a). The red curve shows a source-receiver location with a high standard deviation, while the green curve shows the trend for a low standard deviation point (b).

Tomographic inversion was carried out to visualize absolute and relative changes. The inversion procedure to visualize absolute changes always uses the baseline velocity model as the starting model for inversion. We call this “All-to-Baseline” in the following. The “All-to-Baseline” inversion was constrained to allow only model velocity updates with velocities equal to or lower than the baseline model velocity. In this way the inversion reflected our picking procedure allowing only equal to or longer travel times of the monitoring data compared to the baseline picks. The inversion procedure to visualize relative changes uses the velocity model of the baseline model or the previous monitoring day respectively. We call this “Step-by-Step” in the following. Apart from the inversion of the “Day 0” data the velocity changes for all following data sets were not restricted. The “Day 0” data set was constrained in respect to the baseline data set as described for the “All-to-Baseline” data.

Finally, we compute and visualize the normalized difference between each model and its respective starting model, excluding the baseline where it is compared to itself. The formula is as follows:

$$\text{Normalized difference to starting model} = \frac{(day\_n\_velocity\_model - starting\_velocity\_model)}{starting\_velocity\_model} * 100$$

Thus, if the velocity is lower than in the starting model on the day in question, the normalized difference will be negative. Conversely, if the velocity is higher than in the starting model, the normalized difference will be positive.

Discussion of the Tomographic Inversion Results

The resulting tomograms for the “All-to-Baseline” inversion of the normalized differences to the baseline starting model are shown in Figure 5. The values are consistently zero or negative, indicating that tomogram velocities calculated after the injection starts are equal or lower than the baseline velocity model. Between approximately 35 and 37 m depth, a distinct zone appears where the velocity decrease becomes progressively stronger in time, changing from -1% to -8% at day 5. Changes in this region become visible shortly after the start of the injection, indicating a rapid upward movement of the CO_2. One can observe that the velocity decrease becomes more dominant in time and it seems that the CO_2 is trapped right below the high-velocity layer (the center of the high velocity layer is marked as a dashed line). The CO_2 causing the decrease in seismic velocity seems to be not homogeneously distributed. Interestingly, while the gas clearly accumulates below the clay, we also observe velocity reductions within the clay itself. This may indicate that part of the gas has actually entered the clay. But, a more plausible explanation lies in the inversion process, which discretizes the subsurface into cells that do not perfectly match geological boundaries. Consequently, some cells may partially overlap the clay, introducing a positional uncertainty of about half the cell size in the tomograms due to interpolation between inversion cells. Moreover, the tomogram pictures a 2D situation but assuming the clay layer extends in space the CO_2 forms a layer below the clay.

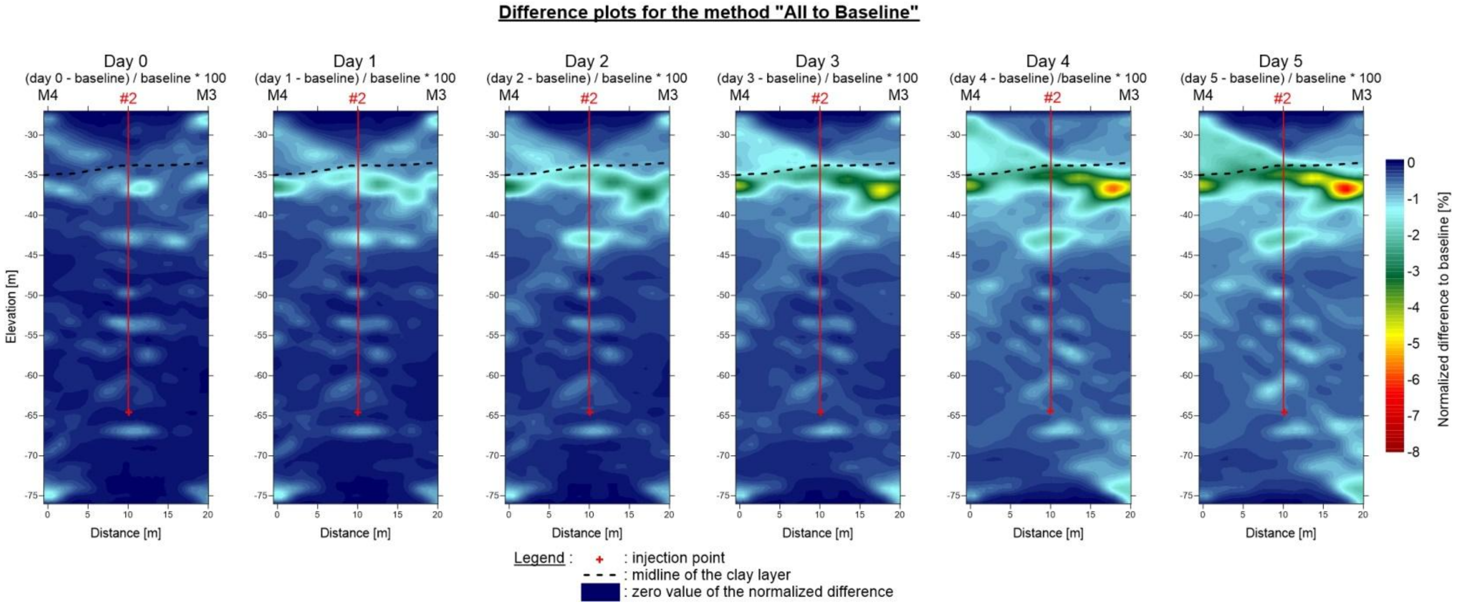


Figure 5: Evolution of the normalized difference of each day's model to the baseline model. The models have been built according to the "All to Baseline" method.

Further to the accumulation of CO_2 below the clay layer there seems to be CO_2 present above the clay layer towards borehole M4. In time a triangle-like structure is building up potentially generated by CO_2 moving upwards in the center borehole #2 or along the borehole M4 but perhaps also migrating through higher hydraulic conductive areas inside the clay layer. In fact, the clay may not be uniform across its extent, and the gas could have exploited a zone of higher permeability or a discontinuity. Since the tomograms are 2D sections, such pathways may also lie outside the imaged plane.

A third, smaller zone showing a velocity decrease between 40 and 45 m depth is building up in time originating from the injection hole #2 and a fourth area of velocity decrease appears at about 75 m depth towards M3. Outside these areas, no significant velocity decrease is observed.

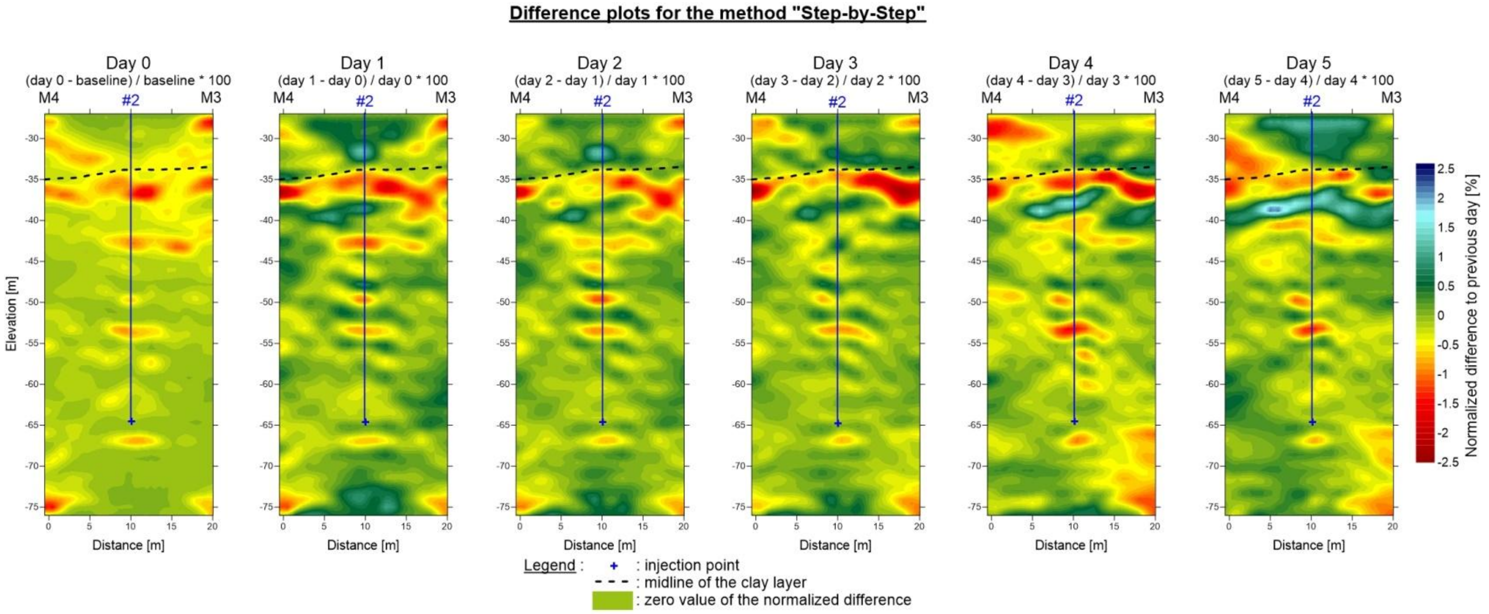


Figure 6: Evolution of the normalized difference of each day's model to the model of the previous day. The models have been built according to the "Step-by-Step" method.

Figure 6 shows the normalized differences between each tomogram generated from the "Step-by-Step" method and the velocity model of the previous day (excluding the baseline). In this case, the values alternate between increases (blue) and decreases (red) in velocity, i.e. areas where the CO_2 decumulates and areas where CO_2 accumulates. This means that, from one day to the next, velocity may increase, but it always remains lower than or equal to the baseline considering the results of the previous method.

We find the same gas accumulation beneath the clay layer as imaged through the "All-to-Baseline" models. In the same way, on day 5, the gas does not accumulate only below 35 m depth, but has also clearly spread upward, forming a triangular shape.

In addition, the same other areas as in Figure 5 where gas accumulates appear in Figure 6 at about 75 m depth next to the borehole M3 and between 40 and 45 m depth along the borehole #2. A fifth zone of gas accumulation appears between 50 and 55 m depth along the borehole #2, that we can image in the tomograms of the "All-to-Baseline" model but of lower significance. These last two areas may be due to the gas rising upwards along the borehole or finding an escape between 40 and 45 m or 50 and 55 m depth.

Next, it can be observed that the velocity changes are not constant from one day to another. For example, between days 2 and 3, there is a significant decrease in velocity between 35 and 38 m depth, more pronounced on day 3 than on day 2. This means that the displacement of the gas into the formation is not constant and homogeneous. We will discuss it in the next sections providing ideas to explain this phenomenon.

Finally, an area of velocity increase can be identified at about 40 m depth: it corresponds to the bluish layer beneath the main anomaly, which first appears on day 3 (Figure 6). This suggests that gas is "escaping" from this zone. Yet, a reason why this occurs, why it initiates specifically at that depth, and why it begins on day 3 remains unclear.

Interpretation of the Tomographic Inversion Results

The two different model approaches presented within the paper raise questions regarding the CO_2 migration paths. If the upward path is restricted by the overlying clay of low permeability, the gas may instead spread laterally along the boundary of this layer, which could explain the observed redistribution. Anyhow, if the gas injection is continuous over time there might be no reason that we image areas of CO_2 decumulation. Furthermore, gas accumulation and decumulation seem to be bound to a layer structure, a layer structure which was imaged through the P-wave seismic tomography (see figure 2, left).

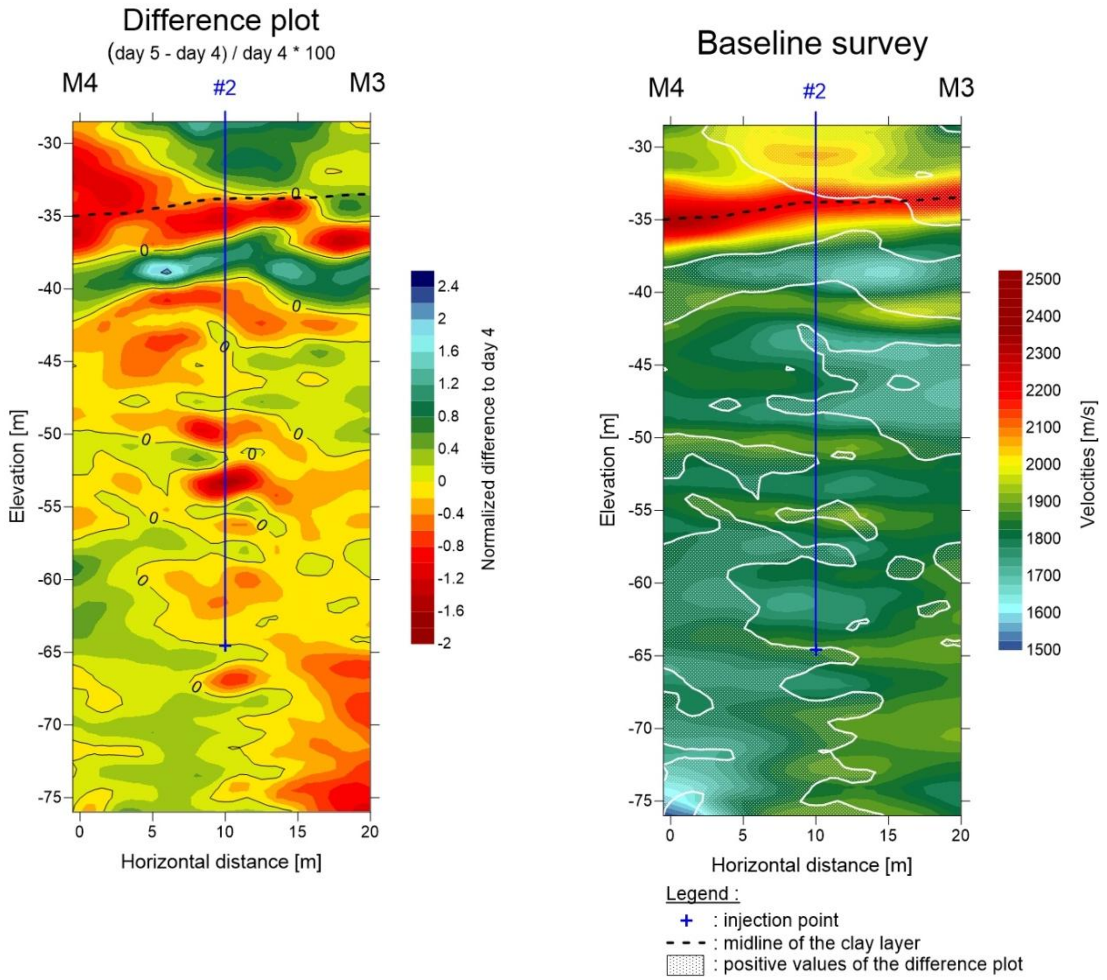


Figure 7: Model from the baseline data (right) in comparison to day 5 of the method "Step-by-Step" (left). The zero isolines from the difference plot are superimposed on the baseline survey.

In Figure 7 (left), the zero contour of the normalized differences calculated for day 5 using the method "Step-by-Step" are shown. The zero contour line divides the tomogram into areas of velocity increase (positive changes) and decrease (negative changes). Figure 7 (right) shows the baseline velocity model and the areas of positive changes overlayed. It can be observed that the changes in velocity in the baseline model coincide with changes between these zero contour lines. Upon closer inspection of these layers, we notice that positive changes predominantly occur in low velocity zones, and vice versa. According to the local site-specific correlation between seismic velocity and hydraulic conductivity the low velocity layers are related to higher permeable sediment zones which allow a higher groundwater flow. This confirms that P-wave velocity captures hydrodynamical rock properties. The permeability tomogram in Figure 2 (right) further supports this interpretation: gas accumulates in less permeable layers and spreads within more permeable ones. Notably, before day 5, gas also concentrates in a greenish zone (positive changes) beneath the clay, suggesting entrapment within a low-permeability layer of the baseline model, without penetrating the nearly impermeable overlying clay.

As mentioned earlier positive changes are related to CO_2 decumulation which point to a driving external force pushing the CO_2 out of these zones. Apart from the buoyancy force generated by CO_2 migration we believe that also changes in the local ground water flow may have an influence on CO_2 migration. Figure 8 shows the observed water level changes at the site during the experiment. It can be observed that the water level changes hourly mainly following normal tidal effects.

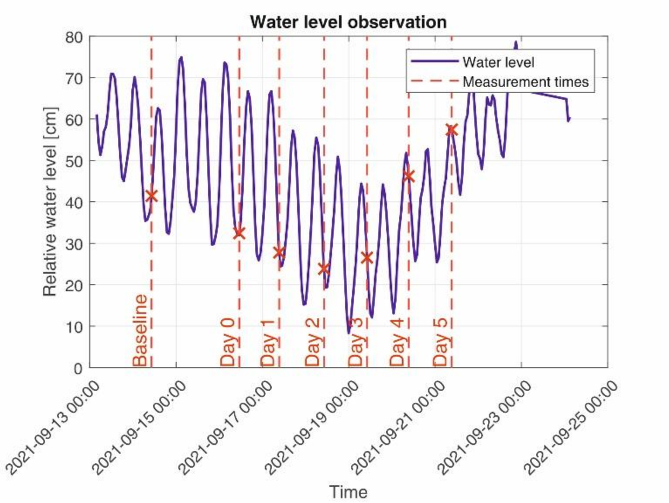


Figure 8: Temporal tide hub change and representation of the time of the measurement for P-waves measurements. The times considered are the exact date and hour of the middle of our P-wave records for each day.

Anyhow, a slowly varying, low-frequency effect can be observed, which is likely associated with influence of riptide and neap tide. The red vertical dashed lines and the red crosses indicate the time of the P-waves acquisition. If one follows the time of the seismic data acquisition the water level goes down slowly. Between day 3 and day 5, the water level rises up with an amplitude almost two times higher than between baseline and day 3. In fact, during the first five seismic measurements the water level changes only within about 15 cm whereas the water level rises during the last two seismic measurements by 20 to 30 cm. This marked rise in water level coincides with the timing of gas spreading (evidenced by velocity decreases in Figure 6 on days 4 and 5). Thus, the water table may have exerted additional pressure on the gas, forcing it to spread laterally or upwards and to escape from this layer.

Conclusion

At the end of our study, we can provide a clear time-lapse image of the gas injection conducted in 2021 at the Svelvik Field Lab. The absolute or relative normalized differences between consecutive P-wave velocity models highlight the migration of gas within the reservoir. In particular, the accumulation of gas below an impermeable layer is recognizable by a strong decrease in P-wave velocity.

Moreover, we identified a probable leakage on the last day of the experiment. This leakage may have been caused by a discontinuity or a more permeable zone within the clay layer, providing a pathway for the gas. However, we cannot rule out the possibility that the gas escaped along a borehole.

Finally, we noted that gas displacement during the experiment was not linear. We also observed an underlying area from which the gas was leaving during the last three days of the experiment. Two hydrogeological factors may explain these behaviors. First, the stratigraphic structure of the study site (characterized by alternating layers of varying permeability) likely controls the irregular migration pathways. This interpretation is supported by the observation that hydraulic permeability contrasts coincide with zones of gas accumulation or depletion. Second, we found encouraging evidence linking changes in water level to velocity variations in the tomograms. The water level rose during these days, supporting the 2022 investigation (Koedel and others, 2022), which suggested that fluctuations in the water table can drive and influence gas displacement.

Moreover, we defined the hydraulic permeability of the formation thanks to P-wave velocity and clay content, but clay is not the only factor influencing porosity. Grain size, shape, and arrangement also exert a strong control. Unfortunately, we lack detailed information on these parameters. Therefore, the nonlinear and heterogeneous displacement of the gas may still result from variations across the layers highlighted in the baseline velocity model. To improve monitoring data and their interpretation, additional geological information or a larger set of tomograms would be required to better determine the migration pathways of the gas and the lithological controls influencing its rise. As a first step, we recommend obtaining or producing a detailed geological log to identify the layers highlighted by our model. Furthermore, high-resolution density and permeability measurements of the study area would provide valuable insights into porosity and permeability contrasts and their role in gas migration.

Finally, this study is considered highly relevant to CO_2 storage monitoring, as it demonstrates that gas displacements can be effectively imaged. At the same time, other processes — such as potential leakages and hydrodynamic effects related to water-table fluctuations — must also be considered. Our results show that P-wave tomography not only captures the migration of gas, but also provides key information on these associated phenomena.

Acknowledgment

The presented work has been funded by the program Accelerating CCS Technologies (ACT) under grant ID 03EE5022B and is hereby gratefully acknowledged. We thank Martin Raphaug and Cathrine Ringstad, SINTEF, for their help and support for the fieldwork.

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Authors

Débora Portaz *(dboraportaz@gmail.com) is a geophysics student at EOST (University of Strasbourg, France), specializing in Energy. She obtained her bachelor's degree in geology in 2023 at the same institution and is currently completing a combined engineering and research master's degree in geophysics. Her final internship at Geotomographie mbH focuses on seismic tomography applied to carbon capture and storage (CCS) projects.*

Sonja Mackens-Siemes *obtained her degree in Geology from RWTH Aachen University, specializing in Ground Penetrating Radar and Geoelectrics, and received her diploma in October 2014. Since 2011, she has been employed as a geologist at Geotomographie GmbH, where her work focuses on seismic data analysis and interpretation. Her expertise includes the processing of downhole, crosshole, and seismic tomography data, as well as surface seismic data derived from refraction and MASW surveys. She is also experienced in field data acquisition and advanced seismic data processing techniques.*

Lutz Karl *received his civil engineering degree with a specialization in geotechnics from Bauhaus University Weimar in 2001. He subsequently worked at the Soil Mechanics Laboratory of Ghent University, where he obtained his Ph.D. in 2005. Since then, he has contributed to several subsurface exploration projects at Geotomographie GmbH, focusing on integrating geotechnical and geophysical methods.*

Thomas Fechner *received his university Master degree in geophysics at the TU Bergakademie Freiberg in 1992 and a Ph.D. at the University of Tuebingen in 1998. He has been managing director of Geotomographie GmbH since 1999. He has participated in numerous international projects on geophysical exploration. His main expertise is in crosshole seismic instrumentation and geotechnical parameter estimation.*

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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: $ ____________

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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

https://www.eegs.org/join-or-renew-

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
Website Advertising	Purchase Separately	
One (1) Pop-Under, scrolling marquee style ad with tag line on Home page, logo linked to Company web site	$600/yr.	Package Rates include both web site ad locations
One (1) Button sized ad, linked logo, right rail on each web page	$250/yr.	

Environmental and Engineering Geophysical Society

2026 Corporate Membership Application

Renew or Join Online 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

- ☐ Consultant
- ☐ User of Geophysical Svcs.
- ☐ Student
- ☐ Geophysical Contractor
- ☐ Equipment Manufacturer
- ☐ Software Manufacturer
- ☐ Research/Academia
- ☐ Government Agency
- ☐ Other

Interest or Focus

- ☐ Archaeology
- ☐ Engineering
- ☐ Environmental
- ☐ Geotechnical
- ☐ Geo. Infrastructure
- ☐ Groundwater
- ☐ Hazardous Waste
- ☐ Humanitarian Geo.
- ☐ Mining
- ☐ Shallow Oil & Gas
- ☐ UXO
- ☐ Aerial Geophysics
- ☐ Agriculture
- ☐ Renewable Energy
- ☐ Other

Geophysical Expertise

- ☐ Borehole Geophysical Logging
- ☐ Electrical Methods
- ☐ Electromagnetics
- ☐ Gravity
- ☐ Ground Penetrating Radar
- ☐ Magnetics
- ☐ Marine Geophysics
- ☐ Remote Sensing
- ☐ Seismic
- ☐ Other

Professional/ Scientific Societies

- ☐ AAPG
- ☐ AEG
- ☐ ASCE
- ☐ AWWA
- ☐ AGU
- ☐ EAGE
- ☐ EERI
- ☐ GeoInstitute
- ☐ GSA
- ☐ NGWA
- ☐ NSG
- ☐ SEG
- ☐ SSA
- ☐ SPWLA
- ☐ NAOC

Willing to Serve on a Committee?

- ☐ Publications
- ☐ Web Site
- ☐ Membership
- ☐ Student

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

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☐ **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.

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- 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


Fast TIMES
Volume 27.1, November 2024

UXO Geophysics

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- Synthetic Seeding: An Effective Approach to Augment Quality Control on Advanced Geophysical Classification Projects
- Electromagnetic Induction Sensing of Underwater Munitions: Detection and Classification with the UltraTEM system

Vol 27.1

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
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Geophysical Society