

geophysics

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FALL 2019



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MINES DEPARTMENT of GEOPHYSICS

Fall 2019

Colorado School of Mines
Department of Geophysics
Newsletter

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*Cover Page: Geophysics Students at
Field Camp in Pagosa Springs,
Colorado.*

Welcome from The Department Head

You may be surprised to see my name underwriting this letter, but that will only be until you understand what led us here. After all, we have completed a Department Head search just a couple of years ago. We in Geophysics knew very well that we have done a fantastic job by recruiting my immediate predecessor, Dr. John Bradford, to lead the Department of Geophysics, but it turns out that the top Mines Administration also took notice of his outstanding leadership potential. To nobody's surprise, John was recently appointed as Vice Provost for Global Initiatives and Dean of the Earth Resources and Environmental Programs (EREP). While we lose a leader, we gain a leader, and we look forward to working with John to further develop, diversify and strengthen our own educational program. I serve as Interim Department Head and we have already launched a search for a new Head which we hope to complete before the end of the current academic year.

We are currently in the middle of the announced transition to a new undergraduate curriculum designed to blend our traditional strengths with modern aspects of applied geophysics science and technology. This new curriculum puts greater emphasis on developing computational skills with a course sequence spanning our entire undergraduate program. It also emphasizes fundamental skills by strengthening math and science requirements, and by embracing data analytics and machine learning as core competencies. The new curriculum also gives students greater flexibility in tuning their education to their own interests and career goals through a broader set of electives. The transition began last year and we are on track to complete it at the end of the 2019-2020 academic year.

During the upcoming academic year we will also launch several MSc programs with emphases on Computational, Humanitarian and Hydrological Geophysics. These new programs respond to feedback from multiple constituencies and to the broader spectrum of our students' interests and goals. They also increase our opportunities to operate in closer coordination with complementary units at Mines and multiple organizations elsewhere, and thus increase the vitality and greatly expand the scope of our MSc program.

This year we are also thrilled to welcome two new scientist-educators to our geophysics family. Dr. Matthew Siegfried joined us in Spring 2019 after completing yet another successful field season in Antarctica. Matt's interests in glaciology and remote sensing create new and exciting teaching and research opportunities in our department.

Dr. Ge Jin joined us in Fall 2019 from a dynamic and productive career in the industry. His interests and experience with fiber optic technology expands the expertise available in the department and strengthens our reservoir-oriented teaching and research. Dr. Manika Prasad also joined the department in fall 2019 from her prior appointment on the Petroleum Engineering Mines faculty. Manika has been a great friend of the department for many years, and her arrival simply formalizes her close and long established involvement with Geophysics research and education.

As we welcome new faculty, we also say farewell to our colleague Whitney Trainor-Guitton. She will leave the department at the end of 2019 to pursue new career opportunities in France. During her presence at Mines, Whitney has been a key contributor to our ambitious plans to revamp geophysics research and education, both graduate and undergraduate. Her perspective as active faculty as well as a former undergraduate student at Mines was invaluable in designing a curriculum that serves the long-term interests of our constituents. On behalf of all of us on the Geophysics faculty, I would like to thank Whitney for being a great friend and colleague, and for her contribution to the program. We wish her well on the new career path and hope to continue cooperation with her in the future.

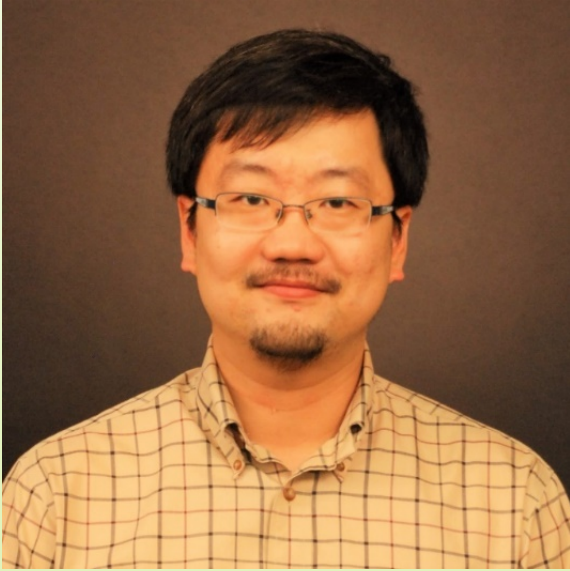
Finally, I would like to say a few words about the fantastic Geophysics staff. As my predecessors at the department helm have noted multiple times, we went through enormous changes in the past few years. It is to a great extent due to Michelle Szobody and Debra Marrufo that we managed this transition professionally and efficiently. It is also due to them that our department avoided significant administrative disruption during our nomadic years outside of the Green Center, to which we have recently returned.

It is a true privilege and a great responsibility to work with the dedicated and ambitious Geophysics students, faculty and staff. I hope that this newsletter will give you a glimpse into our professional lives, and motivate you to join in our collective knowledge voyage.

Paul Sava

Welcome to Geophysics!

We are pleased to welcome
Dr. Ge Jin and Dr. Manika Prasad
to the Geophysics Faculty



Dr. Ge Jin

Dr. Ge Jin is a research geophysicist with interests in seismic imaging and interpretation, machine learning, and fiber-optic sensing applications in the oil and gas industry. He obtained his PhD in Geophysics from Columbia University, and dual BSc degrees in Geophysics and Computer Science from Peking University

Dr. Jin joined ConocoPhillips as a research geophysicist in late 2014. His past work covers many cross-functional research projects at the company. With his strong surface-wave imaging background from his Ph.D. work, he developed methods utilizing ground roll energy to image near-surface structure. He also worked on 4D seismic processing and interpretation projects, including time-shift estimation improvement, rock-physics modeling, and 4D machine-learning interpretation.

Dr. Jin's fiber-optic research has led to major breakthroughs by uncovering the rich information hidden in the extra-low-frequency band of the DAS signal. His work has produced practical algorithms that utilize fiber-optic data for production logging, hydraulic fracture detection, well production interference evaluation, and microseismic monitoring.

Dr. Jin will join the Reservoir Characterization Project where he will conduct research on fiber-optic sensing, machine learning, and seismic imaging technologies.

Dr. Manika Prasad is the director of the Center for Rock Abuse and until recently served on the Petroleum Engineering faculty at Mines. She directs two industry consortia, the OCLASSH consortium on the physics and mechanics of reservoir shales as well the DHI/Fluids consortium on rock physics of reservoir rocks and fluids. A large part of Manika's work is on multi-physics investigations of sediments and rock materials for Carbon Capture, Utilization, and Storage and for resource development. She works on multi scale imaging of rocks as well as man-made and biologic materials.

Dr. Prasad currently serves as Second Vice President of the Society of Exploration Geophysicists. She is a 2017 recipient of the Virgil Kauffman Gold Medal for her extensive experimental work in rock physics, and has been recognized by SEG as Outstanding Educator (2015) and Distinguished Lecturer (2012). She is the 2019 SEG Distinguished Instructor of a Short Course on Rock Physics.



Dr. Manika Prasad

Global & Computational Seismology

The Global & Computational Seismology Group, led by Geophysics Professor Ebru Bozdag, focuses on investigating Earth's and planetary interiors by analyzing and modeling seismic waves, primarily generated by passive sources such as earthquakes.

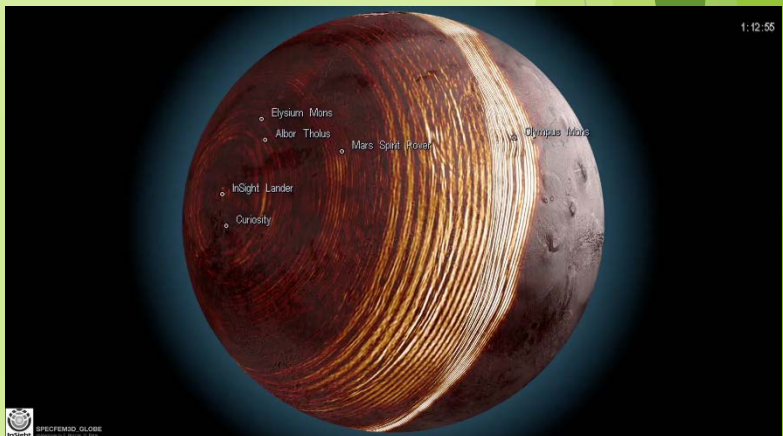
The NASA InSight mission launched on May 5, 2018 from Vandenberg Air Force Base on the coast of California, and successfully landed in the Elysium Planitia, the second largest volcanic region on Mars surface, on November 2, 2018 after a 300-million-mile journey. The mission which Ebru and others have led is the first to gather geophysical measurements from surface-installed instruments to explore the internal structure and dynamics of a solar system object other than the Earth or Moon. Studying Mars' interior and its dynamics will also help us understand the formation of the Earth and how our planet, together with our solar system, has evolved over time.

The lander's geophysical payload includes a very broad band seismometer to listen to the seismic activity on Mars. To better characterize and interpret seismic signals recorded by the single seismometer deployed to Mars, we run numerical seismic wave simulations using a global 3D wave propagation solver, SPECFEM3D_GLOBE (Komatitsch & Tromp 2002). The simulations have been initiated by implementing a 1D reference model for Mars, followed by superimposing topography and crustal thickness variations to analyze the distinct crustal dichotomy between the southern and northern hemispheres specifically on surface waves as on Earth. Attenuation ellipticity, rotation and gravity (Cowling approximation) are all taken into account during simulations. All Mars models will be soon integrated into the SPECFEM3D_GLOBE package available through Computational Infrastructure for Geodynamics.

Because every wiggle from Mars is invaluable, these 3D wave simulations, both at regional and global scales, are complementary to other modelling techniques to reveal Mars' mysteries. Future steps consist of implementing a set of crustal models as well as 3D mantle models derived from thermal evolution simulations and Mars' seismic sources - marsquakes, meteorite impacts, etc. Adjusting and refining these models based on observed seismic waveforms from InSight will add to our understanding of the Mars interior.



Exact size of the InSight lander with the seismometer and the heat probe in front (JPL-Caltech)



3D seismic wave simulations on Mars. Martian topography and the crustal thickness variations are superimposed on top of a 1D reference Mars model.

Geoscientists Without Borders

Since 2018, four CSM geophysics faculty (Shragge, Krahenbuhl, Bradford, and Swidinsky) have been working with Geoscientists Without Borders (GWB) through a grant for a two-year humanitarian geophysics project to develop “Low-cost Geophysical Instrumentation for Groundwater Management in West Africa.” Throughout the year, an MSc student (Dana Sirota) and a team of undergraduate students (Brett Bernstein, Gavin Wilson, and Cullen Young) built low-cost DC-resistivity and seismic node systems which were tested on the CSM campus. The systems were designed to be simple to build and use in hydrogeophysical projects in Benin and throughout West Africa.

This June, the team of students and faculty traveled to Benin to work with University d’Abomey-Calavi (UAC) running a workshop in building and using low-cost instrumentation for resistivity and seismic surveys. Students at UAC built instruments in teams and conducted surveys with both the low-cost instruments and comparable commercial equipment from both CSM and UAC in a field-camp-style investigation of the northern *Godomey wellfield* which supplies water to several nearby cities. The data from all the instruments will be analyzed to help constrain the geology and hydrology of the wellfield based on the geophysical data and drilling logs.

The resistivity instrument designs will be further improved over the next year as part of a master’s thesis project, expanding to a system with multichannel capabilities. The system will be designed with an emphasis on being low-cost, easy to use, and simple to build with parts that are easily accessible in West Africa. The improved designs will be tested both at CSM and UAC, with the potential to expand this project to other areas of French-speaking West Africa in next year’s field campaign.



Geophysics Professor Jeff Shragge showing participants how to read raw seismic data in the field.

Workshop participants and staff, with Geophysics Professors Jeff Shragge and Rich Krahenbuhl and Geophysics graduate students.



Subglacial Antarctic Lakes Scientific Access

From November 2018 to January 2019, Professor Matt Siegfried led a team of four, including Mines Geophysics class of 2015 alumna Chloe Gustafson, on a 60-day research expedition to Mercer and Whillans ice streams in West Antarctica. As part of this work, they collected the first 1D, 2D, and 3D magnetotelluric surveys of an ice stream, as well as the first controlled-source electromagnetic soundings of an Antarctic ice stream in many decades, aiming to characterize groundwater systems hidden beneath half a mile of glacier ice.

After completing their geophysical survey, the team traversed their camp supplies and scientific equipment via snowmobile to Mercer Subglacial Lake, the drill target for the National Science Foundation-funded Subglacial Antarctic Lakes Scientific Access (SALSA) project. Mercer Subglacial Lake was identified in 2007 as a 55 mi² body of water located beneath 3600 ft of glacier ice in West Antarctica. For just the second time ever, researchers drilled into a lake beneath the Antarctic ice sheet and directly sampled the largely unknown Antarctic subglacial environment. As part of the SALSA research program, Siegfried and Gustafson installed a fiber-optic cable through the ice column and into the 50-foot deep lake below. This cable was permanently frozen into the ice sheet, marking the initiation of the first long-term in situ subglacial observatory on the Antarctic continent.

For the next year, the Mercer Subglacial Observatory will collect daily temperature profiles of the Mercer Ice Stream ice column and the Mercer Subglacial Lake water column to help constrain variability of the subglacial environment and place into context the observations made during the short two-week window that the SALSA borehole was open for direct sampling.

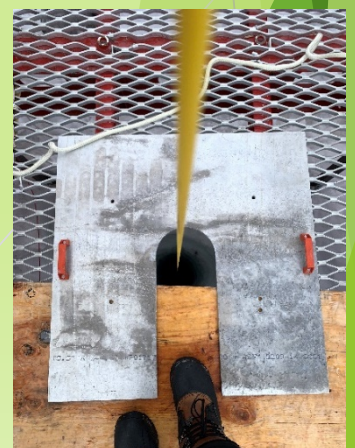


Professor Matt Siegfried tidies up at a newly installed magnetotelluric station as the weather deteriorates around the team (photo: K. Key)



View of the working deck at SALSA drill camp on Mercer Ice Stream, West Antarctica (photo: M. Siegfried)

The fiber-optic cable descends through the operations deck into the 3600 foot borehole (photo: M. Siegfried)



Geophysics Field Camp Pagosa Springs, Colorado

<http://geophysics.mines.edu/GEO-Field.camp>



Field Camp Class of 2019



The Department of Geophysics partnered with Geophysical Technology Inc., to allow our students to test wireless seismic acquisition at the 2019 Geophysics Field Camp in Pagosa Springs, Colorado. Presented with this opportunity, students deployed the GTI nodes along a conventional cabled system to compare data quality on both as well as to test ultra-dense acquired in the region from the past eight years.

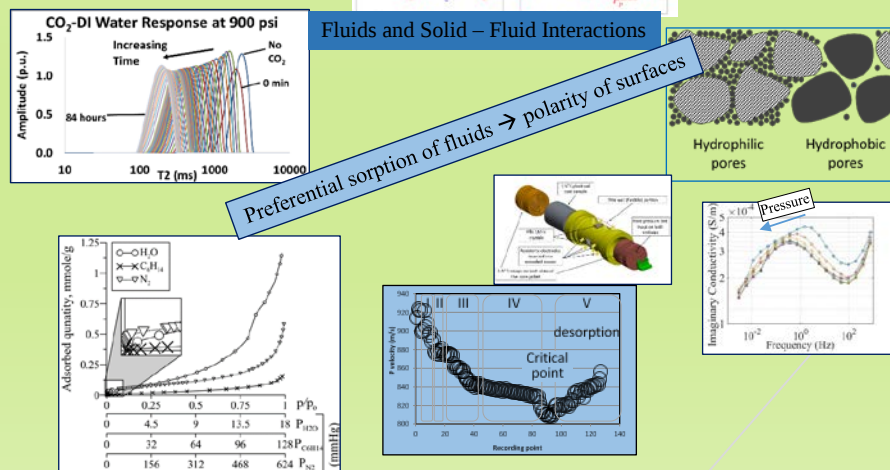
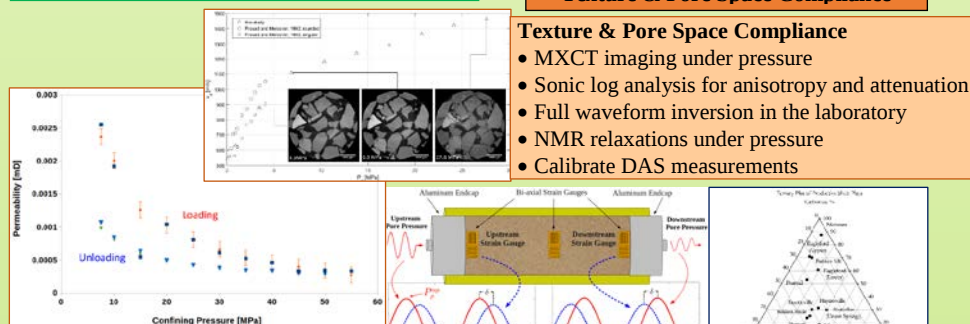
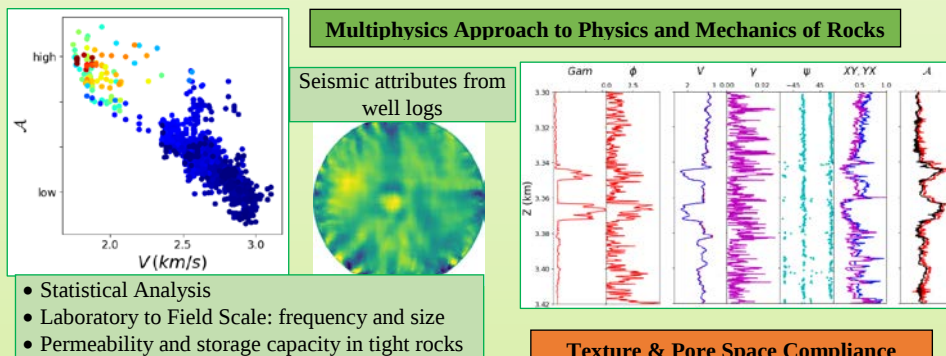
The Department is extremely grateful for the support provided for this signature student experience, including assistance from Dawson Geophysical, Sercel, GTI, Chevron, the USGS, Pagosa Verde, Halliburton, Shell, ConocoPhillips, Anadarko, and the SEG Foundation.

Center for Rock Abuse

Although we are (newly) back in Geophysics, our work crosses various disciplines in earth sciences and in engineering. We are a motley group of people ...lab rats really performing experiments in the bowels, also called the garden level of Marquez Hall and Green Center. Our labs and offices are without windows, because sunlight seems to bring out the worst instincts in us, e.g., hiking, skiing, going to GCB, etc. Visit us in our new home! We are:

Faculty: Manika Prasad (does not really do anything), Jyoti Behura (tries to bring order in the chaos – but his program always crashes), Mathias Pohl (Group mama); **Technician:** Weiping Wang (Group magician for fuzzy designs). **Ph.D. scholars:** Kurt Livo and Gama Firdaus. **MS students:** Valeria Suarez, Arkhat Kalbekov, Simi Adebisola, Aun Al Ghaithan, Maitham Alabbad. **Visiting scholars:** Dawei Zhang (China University of Petroleum, Beijing) and Janet Ayorinde (Pan African University, Nigeria).

Simultaneous Measurements to assess physical controls on geophysical data



CT imaging, NMR, acoustics, complex conductivity, mechanical and dynamic stiffnesses, sorption, permeability, and storage capacity as functions of stress

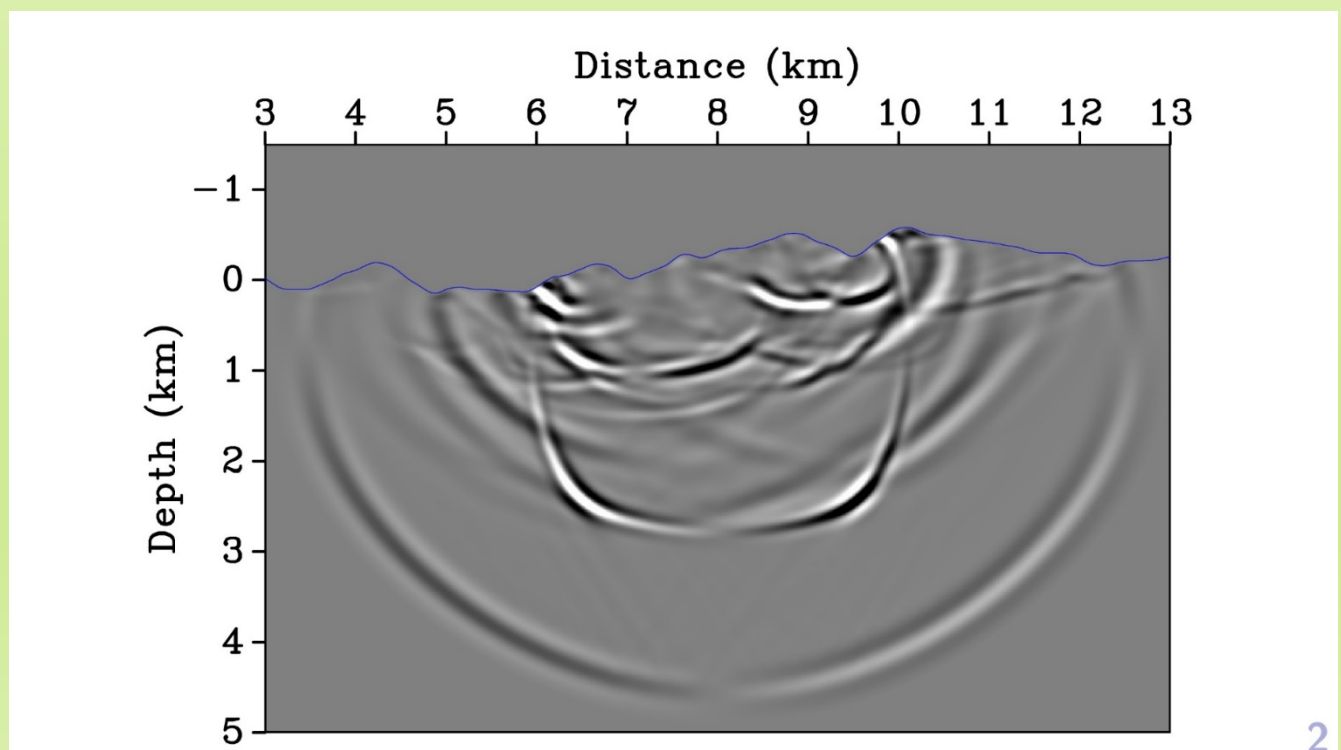
Center for Wave Phenomena

[cwp.mines.edu]

The Center for Wave Phenomena (CWP) had another strong year, producing cutting-edge research results, expanding its sponsorship base, and further diversifying its research portfolio. CWP is led by three full-time faculty in the Geophysics Department (Paul Sava, Jeff Shragge, and Ilya Tsvankin) and former GP faculty member Roel Snieder, who is currently responsible for professional development education at Mines. The faculty are putting emphasis on adding new research directions, which are rapidly becoming relevant in applied geophysics, while maintaining the traditional strengths of CWP in imaging and inversion of seismic data. Among the new CWP projects are acquisition methods that use robotics and distributed acoustic sensing (DAS), seismic applications of machine learning, and quantification of uncertainty in seismic imaging/inversion. The group continues to work on elastic wavefield tomography, full-waveform inversion and wave-equation velocity analysis for anisotropic media, efficient modeling of 3D acoustic/elastic wave propagation, seismic interferometry, and Marchenko imaging.

Over the previous year, CSM has upgraded the HPC facilities through the introduction of the 3000-core Wendian computer cluster. CWP has been an "Early Adopter" of this computing facility and has participated in user testing. As part of this HPC procurement, CWP acquired 20 V100 NVIDIA GPU cards that are integrated into the Wendian HPC platform. These GPU cards are being used by CWP as hardware accelerators for advanced seismic modeling, imaging, and inversion codes, as well as for our growing machine learning research activities.

The figure illustrates a new approach to solving the anisotropic viscoelastic wave equation for irregular geometries including rough topography. PhD student Tugrul Konuk and his advisor Jeff Shragge have developed a tensorial formalism that involves coordinate mapping between the irregular physical domain and a regular computational grid on which numerical solutions can be calculated at a relatively low cost. This methodology provides an efficient tool for viscoelastic modeling, imaging, and inversion of seismic data in complex computational domains.



Reservoir Characterization Project

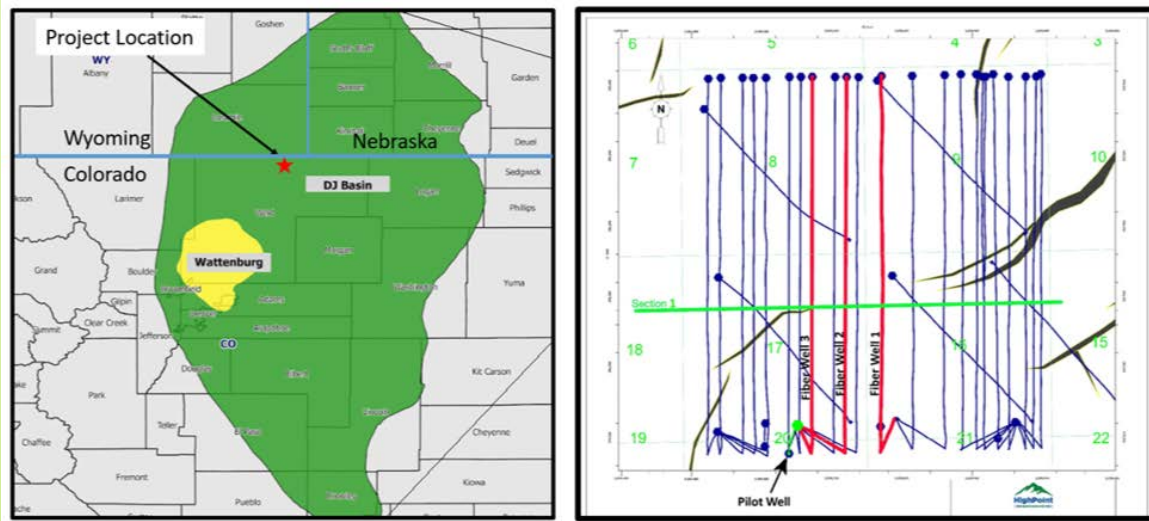
[rcp.mines.edu]

RCP is a premier group working on fiber optics technology for characterizing fracture heights by stage, optimal completion parameters, and understanding how to generate production logs along horizontal multi-stage wells during well life with small and large scale lab and field experiments.

We are also pushing the envelope in optimal randomized seismic acquisition for application to reservoir characterization in unconventional. RCP is using machine learning to improve seismic and engineering methods. In addition to land studies, RCP is working on two offshore time-lapse converted-wave (C-wave) projects to improve reservoir characterization in the North Sea and Brazil.

We continue to work on interstage DAS VSP for understanding hydraulic fracturing properties in the Permian basin with Apache using brand new technology DAS data with a substantially improved signal-to-noise ratio.

Introducing Phase XVIII: Chalk Bluffs



For Phase XVIII, RCP will commence the Chalk Bluff Project with High Point Resources. The Chalk Bluff Project is a comprehensive data acquisition program to understand hydraulic fracturing and completion properties and how those impact production. High Points' data set, acquired through a horizontal well program, is unique. There will be different completions tests in different wells and different stages in each well. The red wells in the figure have fiber optics outside the casing. Also, a single vertical pilot well will be part of the data acquisition program. Our goal is to perform reservoir characterization, geological studies, and reservoir simulation through integration.

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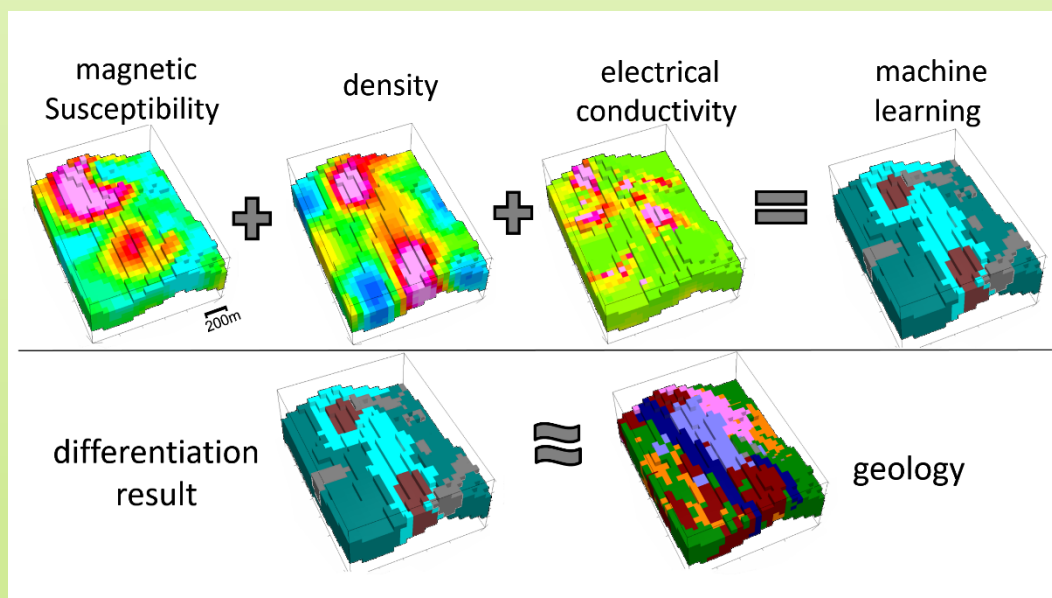
Gravity and Magnetism Research Consortium

[CGEM.mines.edu]

Center for Gravity, Electrical, and Magnetic Studies (CGEM) and its anchoring program Gravity and Magnetism Research Consortium (GMRC) have stepped into the 21st year of research in the processing, inversion, and interpretation of gravity, magnetic, and electromagnetic data. Professor Yaoguo Li continues to develop new methodologies and tools for interpreting geophysical data in oil and gas exploration and production as well as mineral exploration. We also aim to expand into a broader range of research topics by leveraging our unique expertise and emerging technologies in allied disciplines.

The first two decades of CGEM research focused on the geophysical tools, and we have now advanced to a stage of integration and focusing on the solutions of geological and reservoir problems using these tools. With the accumulated tools for inversion-based quantitative data interpretation and associated expertise, CGEM researchers have moved beyond the paradigm of obtaining a geophysical image from each geophysical data set.

Our current focus is on how to integrate geophysical data with a wide range of geoscientific data to directly image geology and subsurface processes. One major direction is the geology differentiation that integrates physical property models from inversion to distinguish and characterize different geological units. The results of this process are quasi-geology models that serve to map the 3D geology. Parallel to geology differentiation is the direction of reservoir monitoring and characterization through integration, in which CGEM is pursuing time-lapse studies using gravity and electromagnetic data coupled with 3D seismic images and reservoir simulations.



Result of geology differentiation that integrates three inverted physical property models using machine learning. The panels in the top row show (respectively) the inverted magnetic susceptibility model from total-field magnetic anomaly, density model from airborne gravity gradient tensor data, electrical conductivity from ground DC resistivity data, and the result of classification using an unsupervised machine learning algorithm. The latter is referred to as the quasi-geology model. The lower row illustrates the comparison of the 3D geology model constructed using the information from several hundred of drilled holes and the quasi-geology model from 3D individual geophysical models (Melo, 2018).

Alumni Spotlight by Chloe Gustafson

I graduated from Mines in 2015 with a B.S. in geophysical engineering, and then continued on to graduate school at the Scripps Institution of Oceanography where I received my M.S. in Earth Science. Now I am working on my Ph.D. at the Lamont-Doherty Earth Observatory. My research focuses on using electromagnetic methods to characterize submarine and subglacial groundwater systems. (Shout out to Andrei Swidinsky for sparking my interest in electromagnetic methods and to Yaoguo Li for encouraging me to apply to a Ph.D. program.)

One component of my research focuses on using marine electromagnetic methods to characterize submarine aquifer systems on the U.S. Atlantic margin. In 2015 we collected both magnetotelluric and controlled source electromagnetic data off the coasts of New Jersey and Martha's Vineyard. From jointly inverting the two electromagnetic datasets, we imaged continuous and robust low-salinity aquifers extending 90 km offshore New Jersey and Martha's Vineyard. We were able to ground-truth our electromagnetic interpretation with several pore water measurements from wells offshore New Jersey. We were also able to examine structural controls on submarine aquifer extent and geometry by combining our electrical resistivity model with depth-migrated seismic images (courtesy of Mines GP Professor Brandon Dugan); we discovered clinoform structures that control the lateral extent of offshore groundwater and may play a role in submarine groundwater discharge. We estimate that there is $\sim 2800 \text{ km}^3$ of low-salinity water between our two surveys and there is likely more low-salinity groundwater beyond the bounds of our survey; we just need to do more geophysics to find out.

I also use electromagnetic methods to image groundwater systems buried under half a mile of ice. Antarctic subglacial hydrologic systems modulate ice sheet dynamics, host microbial communities, and deliver freshwater and nutrients to the Southern Ocean. However, the total volume of water and the mechanisms by which water is stored and transported remains unknown. I spent November 2018 – January 2019 in Whillans Ice Plain, West Antarctica, conducting the first magnetotelluric survey of an active subglacial hydrologic system with Mines GP Professor Matt Siegfried in order to better understand subglacial groundwater systems. We collected a 3D magnetotelluric survey over Whillans Subglacial Lake (SLW) and two 2D magnetotelluric profiles over a grounding zone, where SLW is thought to drain into the southern ocean beneath Ross Ice Shelf. I am currently analyzing the spatial character of our MT data and running 2D and 3D inversions of the data. This research will provide the first insight into the deeper groundwater systems of West Antarctica.



Chloe Gustafson in the field in Antarctica

Geophysics Faculty Accolades



Dr. John Bradford, Professor, Dean and Vice Provost, assumed his new role, July 1st. As one of the three vice provost and deans in the Office of Academic Affairs, Bradford will be responsible for strategic initiatives related to international program enhancements and partnerships as well as managing a diverse portfolio of departments that includes Petroleum Engineering, Mining Engineering, Geology and Geological Engineering, Civil and Environmental Engineering, Geophysics, Applied Math and Statistics, and the Colorado Geological Survey.



Dr. Andrei Swidinsky, formerly Assistant Professor was one of 22 Mines faculty who was awarded tenure and promotion. Andrei was also given the Outstanding Teaching Award for a third year in a row. Andrei is currently on sabbatical in Germany for the Fall 2019 semester working on marine mineral exploration research.

Andrei serves as founder and Director of the EMREX group, where three of his students successfully completed their MS degrees in Spring 2019. Max Mifkovic defended his work on using geophysics for underground tunneling applications, and will move on to work with Chevron in Houston.

Ethan Anderson defended his research on the effects on steel infrastructure on EM surveys, and is now with Noble Energy in Houston.

Stephen Cuttler also successfully defended his work on magnetic storms and their impact on the electric power grid, and plans to work with Pagosa Verde in Pagosa Springs, Colorado.



Dr. Paul Sava, Professor, C.H. Green Chair of Exploration Geophysics, Interim Department Head

Geophysics Graduates



Geophysics Outstanding Graduating Senior, Sarah Alhumaidan, gives the student Commencement address



RCP Masters Graduate Paul Benitez



Geophysics Graduates 2019



Dr. Ivan Lim and Dr. Azar Hasanov



Geophysics undergraduate students Sam Chambers and Kaden Nostrom



THANK YOU FOR YOUR CONTINUED SUPPORT!

The Department of Geophysics is grateful for gifts and support from alumni, friends of the Department, and corporate partners. Your support helps us deliver many of the programs from which our students benefit, including graduate and undergraduate fellowships and scholarships, opportunities for students to engage in professional development activities, computing upgrades, department initiatives, and field camp. If you are interested in making a gift to the Department of Geophysics or sponsoring one of its programs, please contact us, (303-273-3935) or Sara Pond, Assistant VP and Director of Annual Giving, at (303-273-3153)