geophysics

REVEALING THE DYNAMICS OF EARTH

FALL 2018

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MINES DEPARTMENT of GEOPHYSICS

Fall 2018

Coloradoo School of Mines
Department of Geophysics
Newsletter

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Cover Page: (L-R) Students Tori Doven, Kristen Marberry, and Mark Jeska, and Geophysics Post-Doctoral Fellow Adam Mangel conducting field work at Mount St. Helens, Washington State.

CONTENTS

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Welcome from Dr. John Bradford

It has been an exciting year! The Reimagine Geophysics project is well underway. As a result, a new undergraduate curriculum was approved last year and launched for 2018/2019. This new curriculum finds a balance between a traditional methods focused geophysics education with a core of computation courses that provide students a solid foundation in programming, processing, modeling, and machine learning. We believe that this approach will help our students be more adaptable and well prepared for the geophysical challenges of the 21st century.

This year we will place emphasis on revamping our Master of Science programs. We are planning to launch a new non-thesis Master's degree with an area of emphasis in Computational Geophysics that will nicely complement our undergraduate program. Additionally, we are working across department's to introduce two new interdisciplinary MSc tracks. One is Hydrogeophysics in collaboration with the Hydrologic Science and Engineering program and the other is Humanitarian Geophysics in collaboration with Humanitarian Engineering. We are excited about expanding the scope of the department's offerings through these collaborative efforts.

With 75% turnover of the faculty since 2015, the department has gone through some tumultuous times. I am happy to report that we have weathered these challenges and are as strong as ever. We owe a great deal of gratitude to Roel Sneider for leading the department through the transition, and to all of the faculty and staff for pulling together to work as a team. Last year, the department made some fantastic hires, and the trend continues this year with one new faculty member, Matthew Siegfried. Dr. Siegfried will join in early 2019, and is introduced in this newsletter. We are currently searching for a new hire focused on petroleum geophysics at which will bring us back to full strength. The energy and enthusiasm of both the new and more senior faculty has truly revitalized the department and we are entering an exciting new era.

Dr. John Bradford

jbradford@mines.edu

Dr. John Bradford
Department Head

Geophysics Department Vision

Geophysics at Mines is a globally recognized leader in research and education focused on society's major challenges related to earth, energy, environment, and sustainability. Our unique programs integrate theory, field methods, data processing, and interpretation. We are revolutionary in undergraduate and graduate education with an emphasis on high performance computing, data analytics, and machine learning to improve understanding of Earth's complexity. Our department maintains a portfolio of degree programs that are attractive and socially relevant. Geophysics at Mines reflects the demographics of our society and is a leader in expanding diversity in the geosciences.

Welcome to Geophysics

Dr. Matthew Siegfried

Dr. Matthew Siegfried is a glaciologist who uses satellite remote sensing techniques in combination with field-based and airborne geophysical methods to understand physical processes of Earth's glaciers and ice sheets. His research interests include the role of dynamic subglacial hydrology, interactions between ice, ocean, and solid earth, adapting field geophysical methods for ice-sheet applications, and independent validation of remotely sensed observations. Matt has completed field work on three continents including seven expeditions to Antarctica, conducting experiments ranging from geochemical sampling of hydrothermal systems to ground-based and airborne geophysical surveying of an Antarctic ice stream. He is a member of NASA's Operation IceBridge Science Team, the IRIS/UNAVCO Polar Networks Science Committee, and the American Meteorological Society's Committee on Polar Meteorology and Oceanography, and participates in Science Definition Team activities for the ICESat-2 mission, NASA's next-generation satellite laser altimetry mission that is set for launch in mid-September 2018. Matt received his Bachelor of Arts and Master of Science degrees in Earth Sciences from Dartmouth College. After completing his PhD at Scripps Institution of Oceanography's Institute of Geophysics and Planetary Physics, Matt was a postdoctoral researcher in the Scripps Glaciology Group at Scripps Institution of Oceanography and the Thompson Postdoctoral Fellow in the Department of Geophysics at Stanford University.

Debra Marrufo joined Geophysics in June as Administrative Assistant III. She has been at Mines since June of 2015 coming from Petroleum Engineering. She enjoys spending time with her six grandchildren and traveling to her ranch in Durango, Mexico.

Debra Marrufo

Global & Computational Seismology Group

The Global & Computational Seismology Group, led by Ebru Bozdag, focuses on investigating Earth's and planetary interiors by analysing and modelling seismic waves, primarily generated by passive sources such as earthquakes. Explaining the source of seismic waveforms, either by forward modelling or seismic tomography, is essential for understanding the thermochemical structure, geodynamics and related surface tectonic processes, such as the origin of hotspots & volcanos, the forces behind plate motions and quakes. Understanding the dynamics of our own planet and the others also help us interpret their origin, together with our solar system, and how they have been evolving over time. Higher-resolution seismic models are also important for accurately locating seismic sources, detect nuclear explosions and are required from an engineering point of view to assess seismic hazard in earthquake-prone regions. The group uses 3D numerical seismic wave simulations to improve seismic images of Earth's interior based on "adjoint tomography", a full-waveform inversion technique.

After the publication of the first-generation global adjoint tomography model GLAD-M15 (Bozdag et al. 2016),
in collaboration with Princeton, Marseille and King Abdullah University Science & Technology, the group uses Oak Ridge National Laboratory's supercomputer Titan and its successor Summit to construct the next-generation global adjoint models with an ultimate goal to perform full-waveform inversion of the entire planet including Earth's core. Apart from addressing seismological problems, at the global scale the group has recently received funding from the nuclear monitoring program of the Air Force Research Laboratory to develop techniques for combining multiple datasets in full-waveform inversion (i.e., waveforms and ISC data) and construct improved seismic models of the Middle East. The group also works on planetary seismology studies as part of the Mars InSight mission and is recently selected to the InSight Participating Scientist Program to investigate Mars interior based on 3D seismic wave simulations and observed data from the single broad-band seismometer to be deployed on Mars surface early 2019

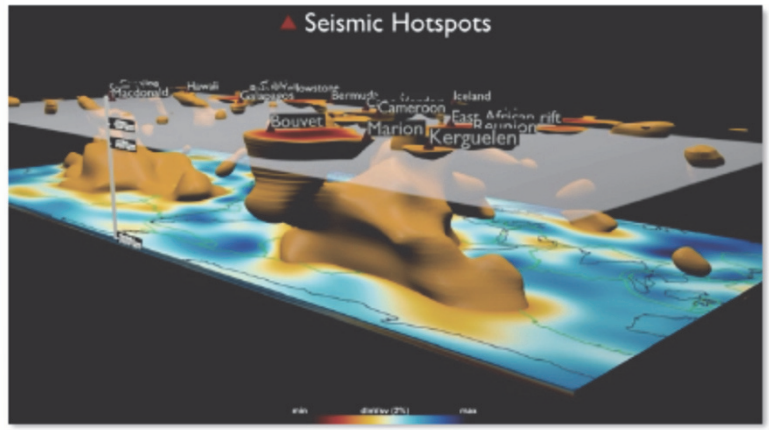


Figure 1: A snapshot of the 3D contour movie of negative shear-wavespeed perturbations of GLAD-M15 (Bozdag et al. 2016) showing major plumes/hotspots in mantle. The bottom layer is core-mantle boundary at ~2900. The movie by David Pugmire from ORNL (https://www.olcf.ornl.gov/2017/03/28/a-seismic-mapping-milestone/).

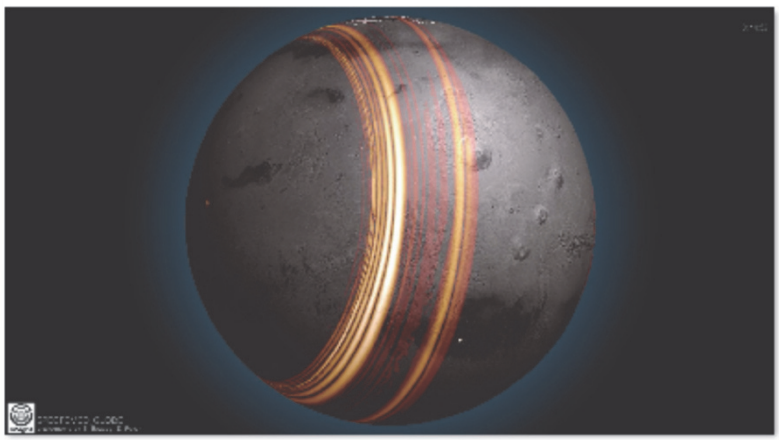


Figure 2: A snapshot of the movie of global 3D wave simulations on Mars. The simulation is performed for the model with 3D crustal thickness variations as described in Bozdag et al. (2017), The movie by Daniel Peter from KAUST.

Mount St. Helens National Volcanic Monument

Three students Kristen Marberry, MS; Tori Doven, BS; Mark Jeska, BS, and two faculty members Adam Mangel and John Bradford, of the Department of Geophysics spent two weeks at the Mount Saint Helens National Volcanic Monument. The objective of the trip was to characterize a natural dam that resulted from the debris flows of the explosive 1980 eruption. The dam is currently blocking flow from Spirit Lake into the Toutle River and represents a notable geologic hazard given the unconsolidated, heterogeneous, and unstable nature of the sediment that comprises the dam (volcanic ash and pumice).

By knowing the distribution of these materials within the dam, engineers can better develop plans for mitigation of the risk of dam failure, limiting potential loss of life and economic losses resulting from a catastrophic failure. To assist in characterizing the dam, the group collected several seismic, ground-penetrating radar, and time-domain electromagnetic surveys. Each day, the crew hiked roughly 10 miles through the rough terrain, encountered giant herds of elk, hauled nearly 800 pounds of geophysical equipment (sometimes by helicopter), and spent the nights sleeping in tents at a nearby campsite. Kristen Marberry will be working through the data over the next year and presenting the results to the stakeholders as part of her master's degree.

Humanitarian Geophysics at CSM

Broadly defined, *Humanitarian Geophysics* focuses on applying the principles of geophysics to improve the lives of disadvantaged communities and the natural environments in which they live. Over the past 10+ years, individuals working with organizations such as Geoscientists *Without* Borders (GWB) have been undertaking a number of humanitarian geophysics projects around the world on a wide range of humanitarian topics, including access to groundwater, understanding local seismic hazard, and remediation of abandoned mine sites.

During 2017-18, CSM Geophysics has undertaken two important initiatives in the area of Humanitarian Geophysics. First, in collaboration with the Engineering, Design & Society Division, which houses CSM's successful Humanitarian Engineering program, the Geophysics Department has developed and is seeking final approval for a new MSc degree in *Humanitarian Engineering and Science: Geophysics.* This new program would be the first MSc Geophysics program in the US to specifically train students for the roles that geophysicists will play in working with a wide variety of stakeholders to develop novel solutions to important geoscience-related challenges faced by human society. Graduates from the proposed program would be well equipped for employment in all levels of government, non-government organizations, industry or continuing on with research training in a related PhD program. Enrollment for the first cohort of students is expected in Fall 2019.

To help kickstart the program, four CSM Geophysics Faculty (Shragge, Krahenbuhl, Bradford and Swidinsky) recently were awarded a GWB grant for a two-year Humanitarian Geophysics project entitled "*Low-cost Geophysical Instrumentation for Groundwater Management in West Africa*". This grant will see a number of CSM Geophysics Faculty, MSc and undergraduate students working on developing, testing and validating low-cost geophysical hardware and software (largely based on Raspberry Pi technology) intended for permanent use in hydrogeophysical investigations in Benin and throughout West Africa. The project also involves running annual hydrogeophysics and instrumentation workshop at University d'Abomey-Calavi (Benin) for a network of West African geoscientists, who are interested in developing the skill set and geoscience network for locating new sources of groundwater in an era of increasing scarcity.

Photo courtesy of Thomas Blum

Geophysical Investigation of the Geothermal System (Field Camp) in Pagosa Springs, Colorado

Class of 2018
http://geophysics.mines.edu/GEO-Field.camp

Setting Gravity Meter

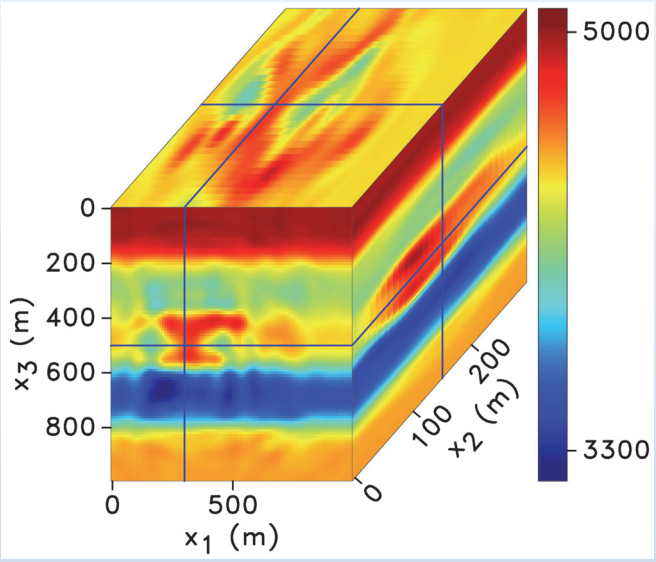
Field Camp

Geology Mapping

Dr. Bob Reynolds, Denver Museum of Nature & Science

Center for Wave Phenomena

Inverted VTI Model



The current CWP research portfolio includes wavefield imaging and tomography, waveform inversion and wave-equation velocity analysis for anisotropic media, modeling of 3D acoustic/elastic wave propagation, seismic interferometry and Marchenko imaging, novel acquisition methods using robotics and distributed acoustic sensing (DAS), and quantification of uncertainty in seismic inversion. The figure illustrates a project on anisotropic waveform inversion (WI) of borehole microseismic data. WI, which is extensively used in reflection seismology, can provide improved velocity models and event locations for microseismic surveys and, therefore, help monitor hydraulic fractures. We have developed a 3D elastic WI algorithm for VTI (transversely isotropic with a vertical symmetry axis) media designed to estimate the velocity field along with the source parameters from multicomponent microseismic data

Reservoir Characterization Project

Fiber Optic Research Program

Distributed fiber optic sensing is a promising technology for many borehole geophysics applications in the oil and gas industry. Using a laser interrogator at the surface, real-time measurements of acoustic, temperature, and strain signals can be acquired continuously along a fiber optic cable in the borehole with low risk. The Fiber Optic Research Program in RCP is conducting laboratory tests and developing software tools to interpret the copious amount of data produced by fiber optic sensing. Currently, a laser interrogator is being used to measure acoustic properties of fluid flow in an experiment on the CSM campus. It is planned to upgrade the experiment to a full-scale horizontal borehole drilled in Edgar Mine. Field data from hydraulic fracturing operations in the Eagle Ford Shale and Permian Basin are also being analyzed for many different applications including time-lapse vertical seismic profiling surveys, microseismic monitoring, and completion and production monitoring.

RCP Flow Loop

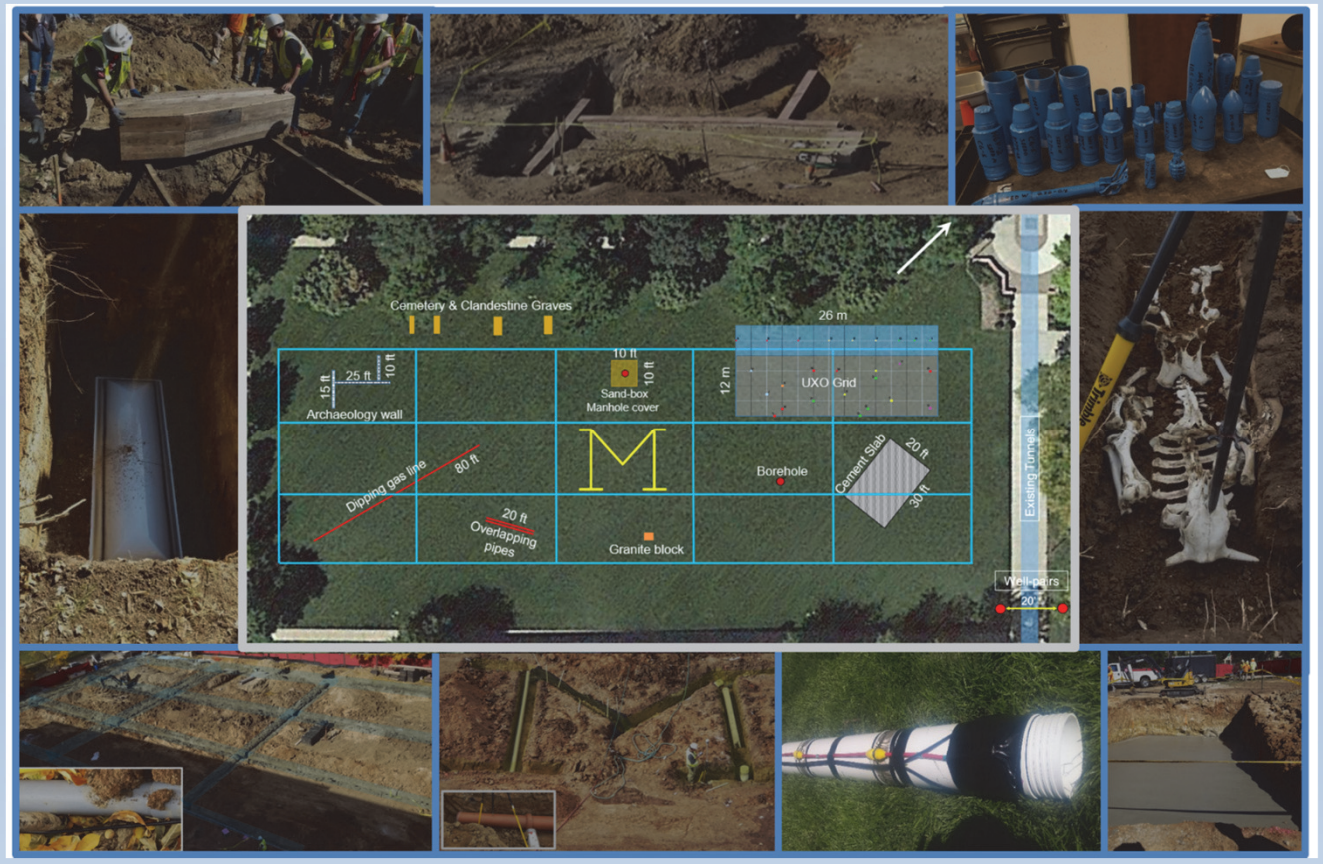
Kafadar Geophysics' Large Outdoor Underground Geophysical Laboratory

We are excited to announce the completion of a massive, outdoor, underground geophysical laboratory for research and education in the heart of Mines campus. This two year initiative began in 2016 with the demolition of Meyer Hall on campus and the subsequent construction of the new CoorsTek Center for Applied Science and Engineering in its place.

Coincident with the construction, a large grassy field, Kafadar Common, was stripped and established as a staging area in front of the Department of Geophysics and the future CoorsTek building. At the time, we proposed and were granted a one-time window of opportunity, between the completion of CoorsTek and the rebuild of Kafadar Commons, to construct a large, one of a kind underground laboratory complete with distributed sensors, boreholes, and numerous targets of varying physical properties, geometries, depths, and levels of overlap/interference.

The initial designs for the laboratory and subsequent discussions with the university began on June 1, 2016. On June 1, 2018, two years to the date, the laboratory reached completion with the placement of the final two items – a pair of boreholes, lined with specialized geophysical sensors, and straddling the underground tunnels at the east end of Kafadar.

To design the field site, we consulted with interested faculty, negotiated regularly with the CSM Architect and Executive Director of Capital Planning and Design, and sought the practical expertise of colleagues and alumni from the United States Geological Survey, the Army Corps of Engineers, Sandia National Labs, Pacific Northwest National Lab, and Necro-Search (yes, that's real!). Oh, and the FBI. The targets were ultimately selected to represent, as best as possible, sources related to civil infrastructure, archaeology, forensics, historical preservation, humanitarian geophysics, geology, and natural hazards.



GMRC Research

This is the 20th year of the Gravity and Magnetics Research Consortium (GMRC) and 15th year since the establishment of the Center of Gravity, Electrical, and Magnetic Studies (CGEM), which is an academic research group in the Department of Geophysics. We specialize in the processing, inversion, and interpretation of gravity, magnetic, and electromagnetic data in oil and gas exploration and production as well as mineral exploration. GMRC forms the anchoring research program within CGEM, and we also have a variety of independent research projects funded by industry and government agencies.

One primary expertise area of CGEM is the development of generalized inversion methods in support of quantitative interpretation, focusing first on inversions of individual data sets and lately on joint inversions of multiple geophysical and geological data sets to recover 3D distributions of physical properties in the subsurface. Recent examples of such research endeavors include the solution of the discrete-valued inverse problem using a fuzzy c-means clustering approach, inversion of magnetic data to recover full magnetization distribution and its application in geology differentiation, joint inversion gravity and gradiometry data, inversions for anisotropic electrical conductivity and magnetic susceptibility, coupled inversion of time-lapse geophysical data and production data for static and dynamic reservoir properties.

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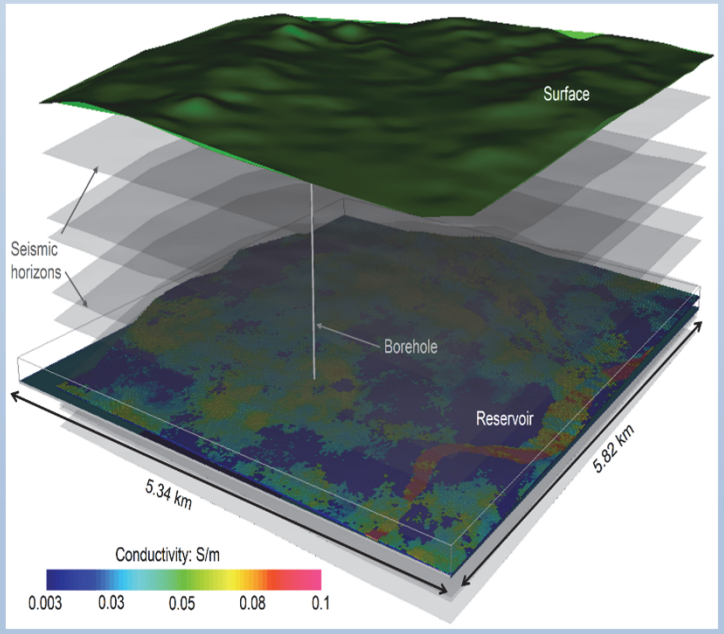
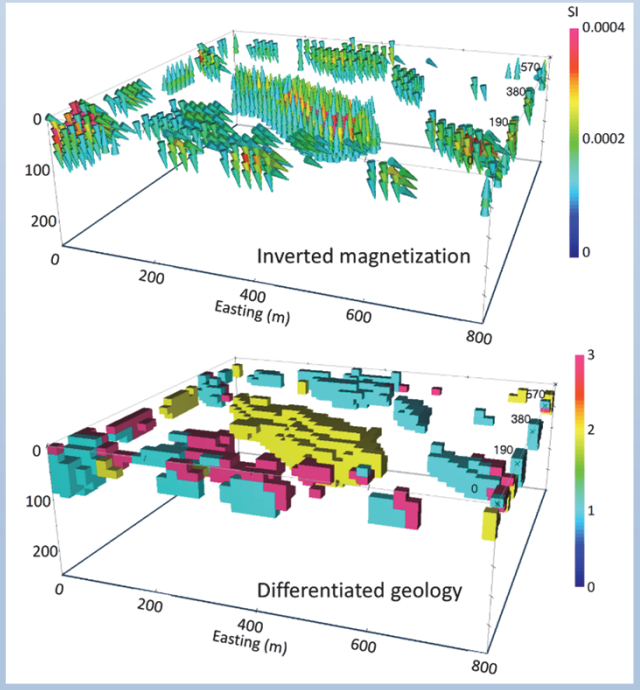


Integrated electrical conductivity model constructed for use in a time-lapse charged wellbore casing controlled-source electromagnetic (CWC-CSEM) study of CO2 storage project. The model combines information from 3D seismic images, borehole logs, surface EM surveys, and reservoir simulations and forms the basis for imaging CO2 migration using time-lapse EM data being acquired at the site. (Krahenbuhl et al., 2018)



Top panels show the magnetization vector recovered from inversion of total-field magnetic data using a fuzzy c-means clustering approach. The model captures the influence of remanent magnetization and enables one to perform geology differentiation. Lower panel shows the differentiated geological units consisting of three different categories. (Li and Sun, 2016)

Misac Nabighian

The applied geophysics community has lost a pioneer, an extraordinary scientist, a great teacher and mentor, and an extraordinary human being. Dr. Misac Nabighian passed away on August 8, 2018. He is best known as a leading theoretician in electromagnetic and potential-field geophysics. He was known for his teaching, mentoring, and extraordinary care for his students, friends, and colleagues. He held leading research positions at Newmont, and held academic appointments at the universities of Berkeley, Columbia, Toronto, Arizona, and Colorado School of Mines.

Nabighian was born in Bucharest, Romania. He received his B.S. degree in geophysics from the Polytechnic Institute of Petrol and Gas in 1954. He became in 1957 the assistant to Professor Sabba Stefanescu, a leading theoreticians of his generation. They wrote the first theoretical paper on the magnetometric resistivity method, and won the Theoretical Value and Elegance Prize awarded by the Romanian Academy of Sciences for a paper on an analytic solution for the spiraling magnetic field lines about two inclined long current lines.

Nabighian immigrated to the United States in 1962. He married Aida Eghiaian in 1966. He obtained his doctorate in geophysics from the Columbia University in 1967, and joined Newmont in the same year. After retiring from Newmont in 1997, he joined the Department of Geophysics at Mines as a Distinguished Senior Scientist, where he taught and pursued research. Nabighian retired from Mines in 2017.

At Newmont, he developed many novel theoretical concepts and techniques to interpret gravity, magnetic, DC resistivity, induced polarization, time-domain electromagnetic, borehole, and radiometric data. His work on the Hilbert transform led to the development of the Analytic Signal technique to quantitatively interpret potential-field data both in 2D (1972, 1974) and 3D (1984). Another important paper "Quasistatic transient response of a conducting half-space: An approximate representation" (1979) provided insight into the behavior of transient EM fields diffusing into the earth. The impact of this paper has been tremendous. In 1984 he served as the editor of a special issue of GEOPHYICS devoted to time-domain electromagnetics and in 1990 he edited and contributed to the two SEG volumes "Electromagnetic Methods in Applied Geophysics", which are still two of the best-selling books published by SEG.

At CSM, Nabighian taught courses on applied geophysics and presented many special tutorials on time-domain EM methods and complex analyses. He co-authored many papers, one of which entitled “Unification of Werner and Euler deconvolutions in 3D via the generalized Hilbert Transform," established a solid theoretical basis for the method of Extended Euler Deconvolution.

He also co-authored a book on "Fundamentals of Gravity Exploration" and a chapter in Treatise of Geophysics on "Magnetic Methods of Exploration – Principles and Algorithms". In addition, he co-authored many review papers on gravity, magnetic, and electrical methods at various milestones of SEG. Nabighian was Associate Editor of GEOPHYSICS for electrical methods from 1977 to 1981. He was the first recipient of the Gerald Hohmann Award. In 1987 he was awarded Honorary Membership in SEG; in 1994 he was elected Doctor Honoris Causa from the Polytechnic Institute of Bucharest; and in 2016 he received SEG Award of Life Membership.

Nabighian was always exceptionally friendly and caring; he was truly a scholar and gentleman. He had an enormously positive impact on innumerable geophysicists. As a friend, he gave unreserved advice on life, career, and scientific research. As a scientist, he showed many of us how to achieve simplicity through mathematics, gain insight through physics, and focus on geology through geophysics.

Nabighian was a passionate traveler and food connoisseur, often recounting his travels with stories that weaved together food, culture, and nature’s beauty. His loved dark chocolate and espresso, gave a superb explanation of the Riemann surface using honey baked ham as an analogy. He will be remembered by his colleagues for his unparalleled contributions to electromagnetic and potential-field geophysics, his mathematical rigor, his love of travel and food, and his unreserved mentoring and care for others. He is survived by his wife Aida of Highlands Ranch, their son Edward of San Jose, daughter Diana of Arvada, and three grandchildren of San Jose.

FACULTY HONORS

Whitney Trainor-Guitton a Colorado School of Mines professor is part of a partnership that has been recognized for developing a computer software package to assess the environmental risk of geologic carbon dioxide storage sites. The National Risk Assessment Partnership (NRAP) Toolset was named one of the 100 most technologically significant products introduced into the marketplace in the past year by R&D Magazine. Geophysics Assistant Professor Whitney Trainor-Guitton was part of the team from Lawrence Livermore National Laboratory; other national labs in the partnership were Los Alamos, Lawrence Berkeley, Pacific Northwest and the National Energy Technology Laboratory

Brandon Dugan, Associate Professor of Geophysics and Baker Hughes Chair of Petrophysics and Borehole Geophysics, will receive the Asahiko Taira International Scientific Ocean Drilling Research Prize for 2018 from the American Geophysical Union (AGU). The Taira Prize was established in 2014 through a partnership between the AGU and the Japan Geoscience Union (JpGU). It is awarded annually in recognition of "outstanding transdisciplinary research accomplishment in ocean drilling."

Ebru Bozdag has been selected to the InSight Participating Scientist Program by the NASA with her proposal entitled "**Investigation of Mars Interior based on 3D Simulations of Seismic Wave Propagation**". Dr. Bozdag joins Mars InSight mission's science team and will be one of the scientists to investigate Mars interior by analyzing Martian seismic data with the help of 3D numerical seismic wave simulations. On May 5, 2018, Insight mission sent a geophysical lander to Mars, including a broad-band seismometer, which is scheduled to land on Mars surface on November 26, 2018. This will be the first time we will hopefully receive meaningful seismic signals from a planet other than the Earth and the Moon.

Geophysics Graduates

Geophysics Outstanding Graduating Senior
Aspen Anderson

Fall 2017

PhD Graduate Noor Wibowo receiving his
Doctoral Hood from Dr. John Bradford.

Masters Students, Thanyanat (Nat)
Akarapatima, Samara Omar, Samir Jreij, Xun Li,
and Andrew Pare

Spring 2018

(L-R) Cesar Velasquez,
Bane Sullivan, Daniel
Walker, Sean Smith
and Kent Lewis

(L-R) Aline Melo, Johanna
Jansen, Mandy Schindler,
Professor Yaoguo Li, Mitra
Azizian, Noor Wibowo,
and Paul El Khoury

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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.