geophysics

Colorado School of Mines

Spring 2010

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From the Department Head

Special Milestones

Hearty greetings from Golden, Colorado! We are pleased this newsletter has found its way into your hands. We know you will enjoy reading about the diverse activities of our alumni, faculty, staff and students – everything from field to lab to classroom, research to education, summer internships to study abroad and travel, planet Earth to other planetary exploration. Summer field camp has grown and gone international with the participation of Imperial College as well as Boise State University. Geothermal energy is back in vogue, and the geophysics field camp is contributing to its resurgence.

We are celebrating several milestones this year. The Center for Wave Phenomena (CWP) has entered its 26th year. The Reservoir Characterization Project (RCP) celebrates its 25th year. And our research in gravity, magnetic, electrical and EM methods celebrated its 10th anniversary. Meanwhile, a brand new kid on the research block is the SmartGeo program, one of many interdisciplinary collaborations involving faculty members from Geophysics.

Our student enrollment is 150, evenly divided between undergraduate and graduate students. Almost half our undergraduates are women. 50% of our grad students and 15% of our undergrads are international students from a nice assortment of countries.

As always – but particularly in these financial times – we are especially grateful for continued support from alumni, industry sponsors, and various agencies that is essential to our maintaining programs of excellence.

A heartfelt, THANK YOU!

Terry

On the cover

The 2009 CSM Field Camp site – Chalk Cliffs, Chaffee County, Colorado.

Department Head Blindsided

Subterfuge in Geophysics Department Results in Grand Celebration

The head of a university department would like to think that he (or she) is in charge and has a handle on activity within his area of responsibility. Terry Young shares this expectation. However, upon the occasion of his 10th anniversary as department head of the CSM Department of Geophysics (January 2010), Terry had absolutely no clue of what was brewing around him.

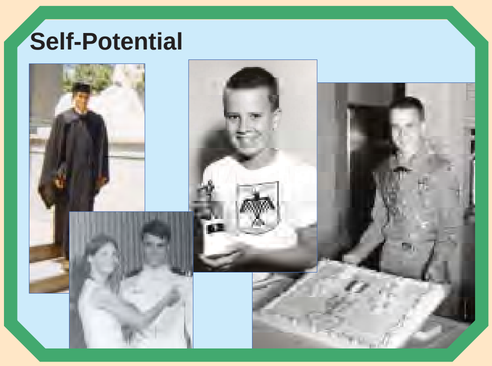
Terry was looking forward that afternoon to hearing the weekly guest Heiland Lecture speaker, Bill Scoggins, President of CSM, and he was pleased to find a larger-than-normal audience when he entered the lecture hall and took his seat in the front. Prof. Roel Snieder, as host to Dr. Scoggins, made the introductions. Dr. Scoggins then stepped to the podium and began his slide presentation, "Sustainability of Human Resources."

When the lights dimmed, the hall filled with the 1970's music of Crosby, Stills, Nash and Young "Teach Your Children Well" (a favorite of Terry's) and the slide read "Terry Young, This is your Life in Geophysics." From there, the astonished (and blushing) Terry sat through a humorous pictorial review of his life story.

The audience – composed of faculty, students, staff, administrative personnel and personal friends – had long plotted this event (with collaboration from Terry's wife, Nadine, of course). Based on those who noticed – with satisfaction – Terry's discomfiture, the surprise was deemed a success!

Following the slide show, representatives of the faculty and students offered verbal tributes and shared anecdotes, sincerely noting our communal appreciation for the leader, teacher, mentor and friend that Terry is to all in the Department. The undergraduates, expressed this especially well and their statement is reprinted on this page.

Terry Young (center) and Roel Snieder (right) welcome Heiland speaker, CSM President Bill Scoggins.



Sample slide from the presentation "Terry Young: This is the Geophysics of Your Life."

Ascii Art photo generated by undergrad Brent Putman and presented to Terry.

Congratulations and thank you,Terry Young!

Undergraduates Speak Their Hearts

– presented by Sarah Devriese and Ashley Fish

On behalf of the undergraduates, I would like to offer our personal thanks to Dr. Young for his selfless commitment to our department for the past ten years. The closeness of this department is unparalleled because of your exemplary leadership, bubbly spirit, and endless warm hospitality. Something we will forever treasure is the unique grace and style you add to everything you pursue. You always seem to add a bit of panache, not only as the department head, but also as a professor. The precision and flair of your teaching not only makes class enjoyable, but extremely effective. Your excellence in teaching spreads throughout the department, making the geophysics program one of the best options at Mines but also a world-recognized department.

The collection of courses provided by this department prepares us for a fruitful and rewarding career. Your knowledge of this field benefits us by offering interesting and challenging classes. Nowhere will we receive an education this well rounded or this practical and your leadership in the department accounts for so much of the experience. Your leadership inspires us to take on extracurriculars and to go beyond expectations. We strive outside the classroom because of what you have taught us.

We arrive here so young, wanting a college education; but we leave this department with the fundamentals of geophysics, the capability to formulate solutions, and the confidence to act. No doubt, as future graduates of this department, we will have the skill and confidence to attack any problem that comes our way. For this, we are extremely grateful.

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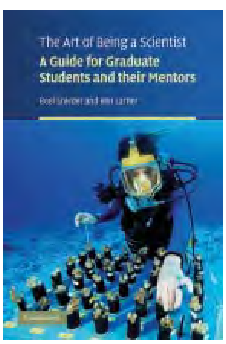
Steve Hill SEG President

CSM Geophysics Adjunct Professor Steve Hill accepted the gavel as president of the Society of Geophysicists (SEG) during the 2009 annual meeting in Houston. A long-time volunteer to the SEG in several capacities, Steve explains his loyalty to SEG, "As a transplant astrophysicist, I owe our Society a great debt. The Society courses, presentations and the publications were invaluable for converting myself into an "applied geophysicist…My willingness to serve on many of the SEG committees, and now as President, certainly does not stem from debt alone. My willingness also arises from the great fellowship with truly wonderful individuals."

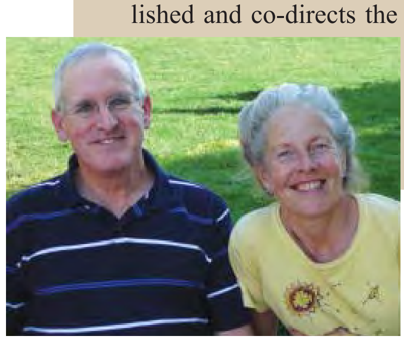
Now Available: *The Art of Being a Scientist*



The book *The Art of Being a Scientist*, co-authored by Roel Snieder and Ken Larner is now available from Cambridge University Press. Hundreds of students at CSM have taken this course taught by Roel, and their feedback consistently indicates how useful the material in this book has been to them. More information and a sample curriculum of the course, can be seen at: http://inside.mines.edu/~rsnieder/Art_of_Science.html.

Walt Lynn Tries His Hand at Teaching

The Department welcomed Walt Lynn, Lynn Inc. as an adjunct associate professor during the 2009 fall semester. Walt drew on his years of experience as a geophysicist to fill in for Steve Hill, currently SEG President, to teach Advanced Seismic Methods. Walt and his wife, Heloise, are shown here during the Welcome Barbeque.



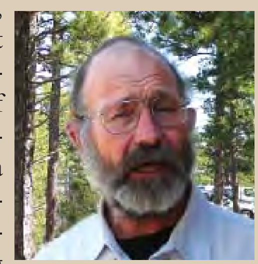
André Revil Appointed Editor

André Revil, Mines associate professor of geophysics, recently was appointed by the American Geophysical Union as editor of the Journal of Geophysical Research—Solid Earth.

The journal focuses on the physics and chemistry of the solid Earth and the liquid core of the Earth, geomagnetism, paleomagnetism, marine geology/geophysics, chemistry and physics of minerals, rocks, volcanology, seismology, geodesy, gravity, and tectonophysics.

Photo: Thomas Cooper, lightboximages.com.

Mike Batzle Selected as 2010 SEG Honorary Lecturer



Prof. Mike Batzle has been selected as the 2010 SEG Honorary Lecturer for the North America region. His lecture is titled, "It's the Fluids That Count." At CSM, Mike Batzle holds the Baker Hughes Distinguished Chair of Petrophysics and Borehole Geophysics. Mike's laboratory has a wide range of equipment to measure seismic and acoustic properties of rocks and fluids, including low-frequency and low-amplitude velocity, attenuation, and modulus measurements. He was awarded the Kauffman Gold Medal by the Society of Exploration Geophysicists for his research with Zhijing Wang on fluid properties. He established and co-directs the Rock Physics Laboratory (affectionately known as "The Center for Rock Abuse") at CSM.

A Dynamic Research Project

Becoming a BIONIC Professor

– Gary Ohloeft, Professor –

Between late January and early June 2009, I became a bionic professor of Geophysics.

After fighting Parkinson's Disease for 14 years and the accumulating side effects of the medicines, I decided to have a Deep Brain Stimulator (DBS) installed. The Neurological Movement Disorders Group at the University of Colorado Anshutz Center installed electrode strings into my brain, roughly behind each eye, into the subthalamic nucleus, with wires down the back of my head and neck to a pulse generator in my chest.


Gary and Kathy Ohloeft

Because I teach and perform electromagnetic geophysics, I felt compelled first to investigate potential electromagnetic interference with the device. Information was hard to find, so I started measuring. At home, we eliminated wireless phones and dimmer switches, rearranged the furniture and moved devices with motors (appliances) to minimize the possibility of currents being induced in the wiring about to be put into my head. At school, a partly shielded teaching lab was built in the basement of the Green Center. My daughter lined my cowboy hat with nickel mesh to give me a shielded hat.

I taught the doctors a lot about interference and how the DBS physics worked. It has several modes of operation, which they let me program, and I advised them on how to run the wires to minimize external coupling. This all resulted in a paper I was invited to give to the EMR Policy Institute Scientific Conference on Electromagnetic Impacts on Human Health and again in Norway at the International EMF Conference on Electromagnetic Interference with Medical Implants.

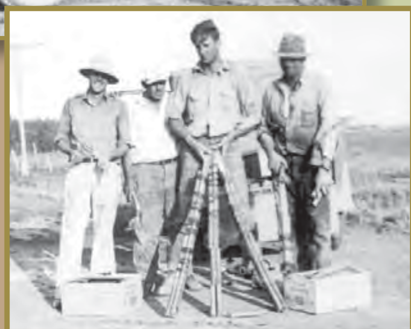
This came full circle back to geophysics when the people attempting to recommend exposure standards were unaware of the Earth's natural electrical and magnetic fields. I added a discussion of that and introduced them to the geophysical literature.

I also discovered that they programmed the device without any knowledge of the physics and assumed it did what it was told without confirming measurements. I distrusted that and built an attachment that plugs into my iPhone to verify it was operating correctly. Once, it was turned off in a retail store by the theft detection system because both devices were at the same pulse repetition frequency, 185 Hz. I set mine a little lower and explained to the doctors why this happened and why 180 Hz was also bad (a 60 Hz power line harmonic). The doctors had warned me this might happen but didn't know why.

In the Spring semester of 2009, I was on medical leave, but managed to teach several GP210 labs until an infection took out the pulse generator (removed in late April and replaced in early June). While teaching electromagnetics again during Fall 2009, I noticed no interference from the geophysical instruments. The DBS is currently set so that I talk too fast and need to break old movement patterns and habits (I'm learning how to write and walk again). I'm completely off the medicines with side effects, and if something new comes along, the doctors say the operation is reversible. This is the definition of "a new lease on life".

Dr. Ohloeft has been a professor of geophysics at Mines since 1994. His areas of research interest include petrophysics, borehole geophysics, environmental and geotechnical geophysics, planetary geophysics, electrical and electromagnetic methods.

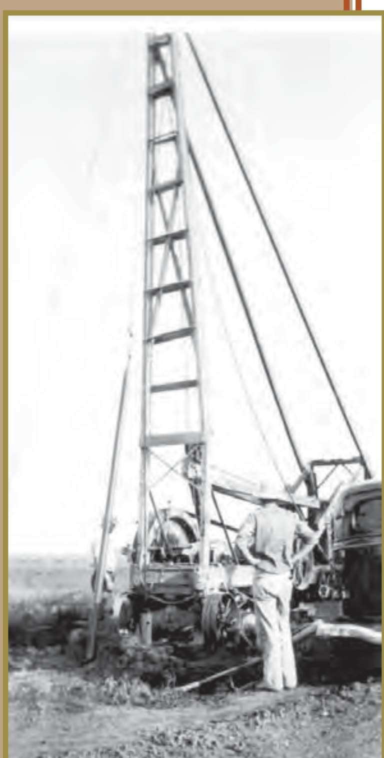
Below are excerpts from a letter written by Norman J. Christie, Mines alumnus, Class of 1935, Geol.Eng. Mr. Christie was a close friend and classmate of John Hollister who became head of the Department of Geophysics in 1949. This letter, written in 1976 to A. Easton Wren, PhD, an internationally recognized geophysicist, describes Mr. Christie's career. Below is the portion describing his first experience as a new Mines graduate working in the field in Canada. This letter and photos are shared by his son, Kevin Christie, VP Exploration, NuVista Energy Ltd. (The color photos are of the CSM 2009 Field Camp, Chaffee County, Colorado, and offer a comparison of work in the field, past and present.)



Field Work Then and Now: 75 Years of Progress

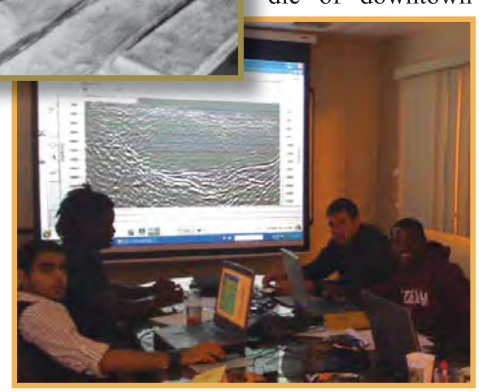
My own career began in Lethbridge in early June 1935 following my graduation from the Colorado School of Mines. Heiland Research Corporation had been awarded a summer contract by Imperial Oil to conduct reflection correlation shooting on CPR land around Lethbridge. Professor Carl Heiland, who set up the Geophysical Department at MINES in 1926 (the first to be organized in North America) was the President of Heiland Research at that time and John C. Hollister (later head of the Geophysical Research Department at MINES) was Vice President. Professor Heiland had to leave for Poland prior to the end of the school term in order to start up a crew there and I was offered employment as a computer* on the Canadian crew by John Hollister.

The crew was housed in the living quarters of a former bank building that had been closed during the depression and we maintained our offices and living room on the second floor and ate and slept on the third floor. The only part of the main floor that was used was the bank vault where we stored our dynamite at the start of the project. This arrangement was very short lived as the R.C.M.P. soon became aware that we had several tons of dynamite stored in the middle of downtown



Top-Bottom: Recording Truck, Heiland Geophysical, Lethbridge, AB, 1935. Preparing 50 lb. dynamite charge. The Shot Hole Drilling Rig.

Upper Right: Norman J. Christie, United Geophysical, Whittler, CA, 1938. No computers to help out!



*In this context, "computer" refers to a person who computes corrections for geophysical data; not a machine.

Lethbridge and ordered us to cease and desist. As a result we were obliged to use the storage facilities of Black Hardware Co. (now Explosives Limited) and since this entailed a considerable drive out of town twice a day we thought we were being imposed upon in view of the convenient set up we had previously enjoyed.

To return to the seismic crew operations — a description of the equipment and techniques follows:

DRILLS

1. A small cable tool drill comprising of a wooden tripod that could be dismantled and carried on a pickup truck — power driving.

2. A hand-powered auger — type that was clamped on the back of a pickup. Rotary action was achieved by a device similar to a meat grinder.

3. Fence post augers manually operated by anyone on the crew who wasn't busy at the time. Used for weathering corrections on the spread which was offset from the shot points.

4. One water tanker used by the cable tool unit and for tamping the charges loaded in the shot hole.

RECORDER

A six-channel unit built by Heiland Research with white lines on dark paper. One geophone per trace and 100 foot trace interval. The spread was about a mile away for the shot point so a mile of telephone line was required for communications, time break and up-hole transmission between the shooter and recorder. The normal technique was to drill a shot hole about every two miles and record in four directions with about a mile offset. This gave a correlation point about every mile.

Weathering corrections were achieved by hand auger drilling a shallow hole about a hundred feet from each end of the spread and recording first breaks with a light charge of dynamite. The spread distance was usually sufficient to achieve penetration to the upper sediments and a Blondeau curved path calculation was employed for corrections to datum. This technique was first published in the 1931 AIME bulletin on geophysics since the SEG had no official publication at that time.

Unfortunately, the quality of the data must be classed as very poor to fair and there were numerous occasions when there were no reflections to which we could apply the sophisticated (at that time) weathering corrections. To the best of my knowledge there have been no oil or gas discoveries resulting from this survey.

Field work concluded about the middle of August 1935 at which time I moved to Calgary and stayed with the van der Linden's while we completed the interpretation of the survey.

In early September, I was a member of the unemployed and hitched a ride to Denver with Ray Paterson who was on leave of absence from the Gas Company in order to obtain his Master of Science Degree at Mines. From Denver, I was offered free transportation to Houston by Paul Lewis who was returning from vacation to his job as a geophysicist with Humble. A canvas of job opportunities in Houston, Dallas, Tulsa and Bartlesville proved fruitless and I was obliged to return to my parents' home in Winnipeg to await replies to the number of applications I had filed on my tour of the southern states.

The shooting truck!

No women on this 1935 crew. Highland Research Corporation "Crew" — near Lethbridge, Alberta, 1935. L-R: Oscar Miller, Bull Cook; Randy Langlois, Observer; John Hollister, VP, Heiland Research Group; Jack Coke, Assist Observer; Leon Gaetz, Jug hustler & Rodman; Jack Kingston, Shooter; Norman Christie, Computer & Assist Shooter; Bob Brownie, Jug Hustler & Assist Surveyor.

Three Universities Collaborate for the 2009 Geophysics Field Camp

Merging three programs for the 2009 CSM Geophysics Field Camp resulted in an historically large group of participants.

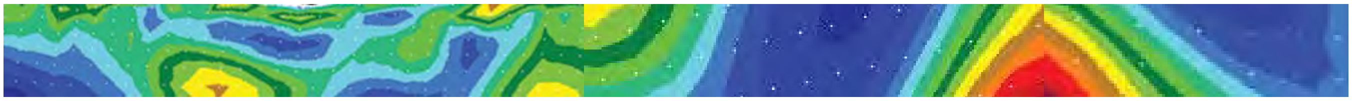
The 2009 CSM Geophysics Field Camp held in Chaffee County, Colorado and headed by Profs. Mike Batzle and André Revil, certainly was similar to those of preceding years—with one significant difference. The CSM ranks were joined this year by groups from Boise State University (returning) led by Profs. Kasper van Wijk and Lee Liberty, as well as (for the first time) the Petroleum Geophysics MSc class from the Royal School of Mines at Imperial College London, led by Prof. Helmut Jakubowicz. The composite group consisted of 50 students from 12 countries; 25 faculty, staff and volunteers; and six personnel from industry. Needless to say, the logistics of conducting this field camp were considerably magnified from those of the past.

The curriculum, activities and culture of the 2009 Field Camp have been documented by the Imperial College students in an article published in The Leading Edge (March 2010). Excerpts are reprinted here. A complete report on the projects of the Field Camp, are found at http://geophysics.mines.edu/GEO-Field-Camp.

Field Camp from an Imperial Viewpoint

There were multiple goals for this field camp. First for us the students to gain geophysical data acquisition and processing experience by studying the geothermal resources of the Upper Arkansas Valley, and second, to give the local residents an assessment and an understanding of the potential geothermal resources they have in their area. In addition to these academic goals, our class also had other plans for the visit to America. We had just finished our exams, and were all ready for a fun-filled break in the USA.

(continued on page 32)



Undergrad Field Camp Defines Grad Project

– Kyle Richards, Graduate Student

Kyle Richards

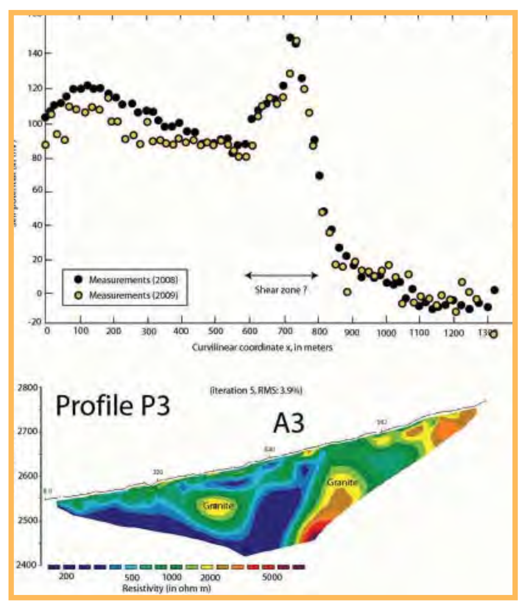
The 2009 Geophysics Field Camp, a required experience for the undergraduate students, was to be my initiation into the Colorado School of Mines geophysics world. The location, as in previous years, was in Chaffee County, at the base of Mt. Princeton, one of Colorado's 14,000 foot peaks. I was a new graduate student working under André Revil, and fellow grad student Allan Haas and I were "volunteered" to assist Dr. Revil in his search for the transitional fault system that powered the creation of the Chalk Cliffs and the hot springs that abound in the area.

After arriving at Deer Valley Camp, which would be our home for two weeks, the work began immediately, unloading the equipment and scouting what would be the first survey in the large debris-flow gulley that sluiced down the Chalk Cliffs. Over the course of the camp, we would become very familiar with the gullies that characterize the cliffs.

The next day began a routine that would last for two solid weeks; an early rise followed by 10 to 12 hours of hard work. The location was amazing. Imagine an "office" that includes the mighty Chalk Cliffs and Mt. Princeton towering overhead, with Chalk Creek meandering below. The goal of locating the fault would be achieved by laying several long lines of cable for the resistivity surveys along the Chalk Cliffs and in the "Field of Pain" where the shallow seismic survey was being done. Self potential measurements would also be done to help track down the elusive fault. The work was demanding but rewarding, working with great teams of undergrads, whose hard work and enthusiasm added to the experience. Our labor was always followed by magnificent meals at Deer Valley Camp and occasional trips to Buena Vista to visit the Green Parrot.

Our hard work at field camp proved to be a success. The resistivity profiles and self potential data showed an anomaly that corresponded with a fault and upwelling geothermal waters that run along the face of the Chalk Cliffs. That mission accomplished, now the work continues. The finding of the fault raises as many questions as it answers. Answering these questions by applying geophysics and flow and transport modeling will be my PhD research. This means a lot of long hours, brainstorming ideas, arguing over those ideas, and, as luck would have it, more trips to Mt. Princeton.

Professor André Revil stands in a flow gulley of the Chalk Cliffs.



The fault.

Warren B. Hamilton

– Distinguished Senior Scientist –

HOW THE EARTH WORKS, AND DOES NOT WORK

"The acceptance of any proposition by an individual who is not familiar with the observational data on which it is based and the logic by which it is derived is an act of pure faith and a return to authoritarianism"

M. King Hubbert, 1963

Comprehension of present and past geodynamics is obstructed by obsolete assumptions, perhaps reasonable when proposed but dogmatized by repetition and now vigorously defended with the claim, antithetical to science, that they are immune to test because products of hypothetical processes are whatever is observed or imagined wherever those processes are postulated to operate.

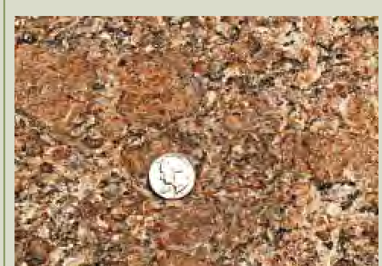
Many crippling misconceptions come from the false 1950s assumption that Earth accreted slowly and is gradually heating. Although abundant evidence now proves hot, fast accretion and very early separation of core, dependent derivative conjectures (lower silicate mantle is still unfractionated; upper mantle slowly depletes as continents grow; convection of the entire mantle drives plates, which subduct into deep mantle as plumes rise from it) still dominate mainline geodynamics. Many datasets—cosmologic, mineral-physics, petrologic, chemical, and isotopic; thermodynamic, seismologic including viable tomography; actualistic plate interactions—are satisfied by the diametrically opposed concepts that modern plates are driven by density inversions produced by top-down cooling of oceanic asthenosphere to lithosphere and are self-organized, and that their circulation is limited to the upper mantle above the 650-km discontinuity.

The Phanerozoic and late Neoproterozoic clearly were plate-tectonic, for their tracts contain abundant indicators of subduction, including widespread accretionary-wedge melanges, ophiolites, blueschists, and oceanic and continental magmatic arcs. Older Precambrian terrains lack all of these indicators, yet faith in extreme uniformitarianism leads most Precambrian specialists to force ancient complexes into non-actualistic plate-tectonic models. Although their rock types and assemblages mostly lack modern analogues, the complexes are popularly assumed to record primarily aggregated island arcs. Voluminous datasets accord better with very early separation of most of Earth's potential crustal material into a thick global mafic protocrust, which was subsequently recycled (as, by mantle heating consequent on delamination and sinking of densified components) to generate most Archean igneous rocks. Paleoproterozoic orogens differ greatly from both Archean and modern ones and are dominantly ensialic, not ensimatic. Crust has shrunk by delamination and, later, subduction, and upper mantle has been re-enriched—both opposite to conventional wisdom.

PDF downloads of recent major papers addressing these topics are available on my website www.mines.edu/~whamilto. Further reports are in progress

Archean "greenstone belt" sediments, ~3.3 Ga, lie unconformably upon 3.4-3.7 Ga granite, and are overlain higher in the section by mafic and ultramafic lavas; Mullins Gap, Pilbara Craton, Western Australia. Only older continental crust has ever been seen in depositional contact beneath Archean volcanic sections, which nevertheless are conventionally assigned oceanic origins.

Lower-crustal Archean Acasta Gneiss, Slave Craton, northwest Canada. Igneous zircons in this outcrop have ages from 3.6 to 3.9 Ga; nearby outcrops, 2.7 to 4.1 Ga. Archean granite-and-greenstone upper crust was deformed passively atop long-flowing and magmatically-augmented lower crust, not by arc accretion.



Granite rich in K-spar, age 1.7 Ga, northwest Arizona. Paleoproterozoic terrains commonly have bimodal igneous rocks, both intrusive and extrusive rocks being both basaltic and potassic-silicic, and contain much reworked Archean rock and also terrigenous clastic sediments. The complexes are conventionally explained as accreted island arcs; but modern arcs are unimodal and mostly mafic, and almost wholly lack potassic-silicic and terrigenous-clastic rocks.

The Reservoir Characterization Project Hits 25 Years

The Reservoir Characterization Project (RCP) turns 25 years old in 2010. It all began in August, 1985, when Marshall Martin and Tom Davis made an industry proposal to begin a fractured reservoir characterization study at Silo Field, Wyoming. Marshall was a PhD candidate at the time and the initial study proposed was a 2-D multicomponent seismic line to see if natural fractures in the Niobrara Chalk could be detected. Claude Vuillermoz of CGG helped with the founding of the consortium by supporting the seismic data acquisition and processing. Thirteen companies sponsored the two-year study culminating in Marshall's PhD dissertation and the delivery of a paper on the study at the 1986 SEG meeting in a landmark session on multicomponent seismology and seismic anisotropy.

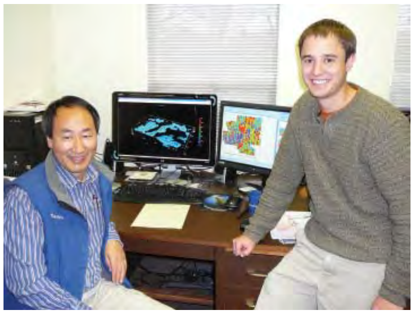
Following the success of Phase I a Phase II was proposed in 1987 which lead to the first-ever 3-D multicomponent survey involving three source and receiver components. Memorable was the blizzard of 1987 during which time we acquired the four square-mile survey over the heart of Silo Field. Approximately 6000 geophones were left in the ground from late December through early February as they were covered by six-feet snow drifts and were frozen into the ground. Needless to say the coupling was ideal and the resulting data were excellent. The data were acquired and processed by CGG. Claude convinced CGG to front the cost of a third of the survey. We were able to subsequently reimburse CGG for the cost as our membership grew during the course of the two-year phase. The data were the subject of Catherine Lewis' PhD thesis. Toward the close of Phase II Bob Benson came onboard to help direct RCP. His commitment to the Project still endures and is a huge factor in why RCP has not only survived, but continues to grow and flourish.

Fast forward to 2010 and RCP's Phase XIII, which involves time-lapse, multicomponent seismic data studies at Postle Field, Oklahoma and Delhi Field, Louisiana. From the first 3-D study at Silo involving 480 channels of recording equipment we are now using over 10,000 channels. The seismic surveys haven't gotten bigger, but the data density has increased significantly, thus enhancing the definition of reservoir response changes associated with the injection of carbon dioxide for enhanced recovery. Approximately 20 students are involved and 30-plus sponsors support RCP from around the world. What a difference 25 years makes and what a difference RCP has made during those 25 years.

– Tom Davis, Professor

10 Years of Research in Gravity, Magnetic, Electrical, and Electromagnetic Methods

– Yaoguo Li , Richard Krahenbuhl, and Misac Nabighian
Center for Gravity, Electrical, and Magnetic Studies (CGEM)



Professor Yaoguo Li and student Mike Mitchell.

10 years CELEBRATE! 5 years Anniversary CONGRATULATIONS!

2009 marked two notable anniversaries in the Department of Geophysics at CSM. The first was the 10-year anniversary of the Gravity & Magnetics Research Consortium (GMRC). The second is the five-year anniversary of the Center for Gravity, Electrical & Magnetic Studies (CGEM). As we celebrate these anniversaries, we look back and smile at our journey, which started with a small and focused research consortium, and eventually expanded into a much larger research center with a wide range of topics in geophysical methods and applications. The journey has been an exciting, rewarding, and productive one; and it continues today.

GMRC was founded in April, 1999 with strong support from the Department and in collaboration with petroleum companies. The goals were to re-establish at Mines a research group specialized in gravity and magnetic methods. Following extensive preparatory work by Drs. Misac Nabighian, Tom LaFehr, Hengren Xia, Tim Niebauer, and the new hire Yaoguo Li, we launched GMRC with four sponsors (Chevron, Marathon Oil, Total, and Bell Geospace) and with donations from Dr. Tom LaFehr and Newmont. Soon after, the late Dr. Richard Hansen became the Scientific Advisor to the GMRC. The first graduate students in GMRC were Julio Lyrio and Richard Krahenbuhl.

By May of 2000, GMRC had its first annual meeting on the CSM campus. The earlier GMRC projects were rather specific and focused on processing and interpretation of gravity gradiometry data. Within a short time, however, our research activities grew to a broad range of topics in gravity, magnetic, electrical, and electromagnetic methods. We have organized workshops on application of wavelets in potential fields and on automated depth estimation techniques. The wavelet workshop attracted live participants in Houston and participants through web broadcast in different cities around the world. Since then, we have had continuous presence and recognition for high-quality presentations at scientific conferences. To this day, the industry consortium GMRC remains the backbone of our group with its energy exploration research and funding.

The growth of the group and broadening of our research interests over the first five years led to the formation of the Center for Gravity, Electrical, & Magnetic Studies (CGEM). The group went through a period of creative naming, and we ultimately settled on CGEM with the help of Dr. Terry Young. The upload of the first CGEM webpage constructed by Richard Krahenbuhl and Sarah Shearer in July, 2004 marked the formal launch of CGEM.

While growing the research in petroleum and mineral exploration under GMRC, CGEM researchers also successfully expanded into a wide range of research in unexploded ordnance (UXO) detection and discrimination, hydrogeophysics, surface nuclear magnetic resonance (sNMR), hydrogeophysics, geothermal exploration, and archaeological geophysics.

Many exciting events and projects have happened within the scope of CGEM. Richard Krahenbuhl and Kris Davis each received the Best Student Paper Awards at consecutive SEG annual meetings in 2004 and 2005, respectively. Yaoguo Li and Alan Herring from EDCON organized a workshop on 4-D gravity monitoring of aquifer

(continued on next page)

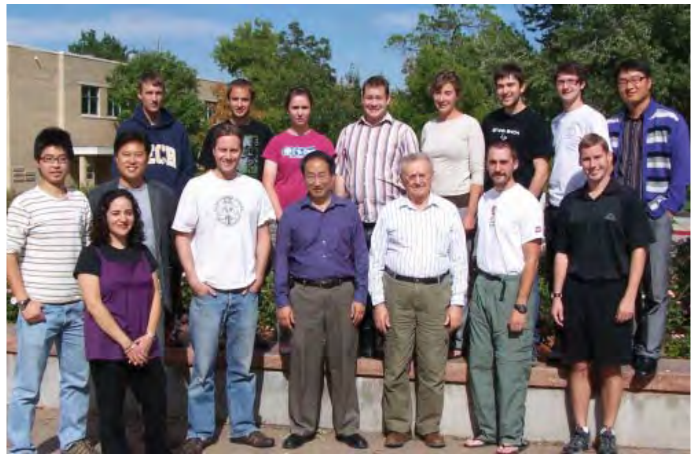
GMRC early students and alumni: left, Helen Li; center, Rich Krahenbuhl (now GP assistant professor); and right, Julio Lyrio.

GMRC + CGEM = 10 Years of Research

(continued from previous page)

and petroleum reservoirs, which led to the publication of a Special Section on 4-D gravity in GEOPHYSICS in 2008. We have carried out nine major UXO research projects funded by the Strategic Envrionmental Research and Development Program (SERDP) and US Army Engineer Research and Development Center (ERDC). One of these projects, MM-1414 'Improving UXO detection and discrimination in magnetic environments', received the distinguished Project of the Year Award from SERDP in 2007. We have also returned to mining geophysics with several research projects on gold, iron, and uranium exploration. In a recent development, we started a long-term collaboration with researchers in China on the geohazards in the Three Gorges Dam area.

Today, CGEM is a cohesive research group with three faculty members, nine full-time students, three undergraduate research assistants, and three visiting scholars. The center provides a collegial and nurturing environment through mutual support among its members. Everyone from faculty to students takes an active role with their own initiatives, while contributing positively to the group. All are dedicated to advancing the state of art of gravity, magnetic, electrical, and electromagnetic methods and their applications in petroleum, mining, archaeological, humanitarian, and hydrogeologic problems.


The CGEM 2009-2010 research group.

As we celebrate the 10-year anniversary of GMRC and 5-year anniversary of CGEM, we would like to thank our past and present sponsors: Anadarko, Bell Geospace, BGP, BP, Chevron, ConocoPhillips, GEDEX, KORES, Marathon, Newmont, Shell, Total, and Vale; and to thank our collaborating researchers from the Gary's Kids Group, RCP, CWP, UBC-GIF, Sky Research Inc., China University of Geosciences, New Mexico Institute of Mining and Technology, Michigan State University, and the United States Geological Survey.

Use of sNMR Advances Research

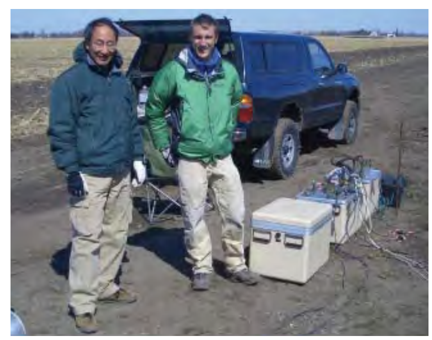
– Trevor Irons, Graduate Student

An increasing number of problems in geophysics deal with locating and characterizing water. Ideally a geophysical method would be able to directly detect the presence of this water as well as how mobile it is. However, existing methods indirectly look for signatures of water, such as electrical conductivity. Making quantitative estimates of water content and hydraulic conductivity using these measurements is difficult.

A relatively new geophysical technique, surface nuclear magnetic resonance (sNMR), promises to revolutionize geophysical water problems. Using the same physical principles of medical MRI scans, sNMR directly excites and measures the response of hydrogen atoms present in water. The measurement is sensitive not only to the amount of water that is present, but also measures parameters proportional to the mobility of the water. As hydrocarbons also have a large content of hydrogen protons, the oil industry has used these same principals with great success in borehole applications.

Being a relatively new field, lots of questions remain to be answered. Members of CGEM have been working for several years to answer these questions and are excited about the prospects. The method has an excellent track record for water exploration, but robust and reliable inversions are still needed. The method is complicated by the fact that it relies on principles of magnetics, electromagnetics, and quantum physics.

In cooperation with the United States Army Corps of Engineers Research and Development Center (ERDC) and the United States Geological Survey (USGS), we are working on advancing the field. The USGS is interested in applying sNMR data to regional groundwater models while ERDC wants to apply sNMR to civil engineering applications, such as assessing the integrity of dams and levees.


Trevor and Prof. Yaoguo Li collecting data.

Interest in the method is rapidly growing around the globe. We presented our work at the SEG Beijing conference in 2009 as well as the 4th International Magnetic Resonance Sounding Workshop in Grenoble, France. We are very pleased that with the help of the CSM Technology Fee, the school of Mines will be able to purchase a sNMR instrument in 2010.

At the Center for Wave Phenomena

– Roel Snieder, Professor

The Center for Wave Phenomena (CWP) has entered its 26th year. Here is a short summary of our status after a quarter of a century.

The four faculty members of the Center (Dave Hale, Paul Sava, Roel Snieder and Ilya Tsvankin) are very active in the geophysical community. They each publish, on average, five articles per year in international peer-reviewed journals. Along with CWP university emeritus professors Norm Bleistein and Ken Larner, they continue to collaborate with colleagues in industry and universities, and disseminate their expertise by traveling and offering short courses on a variety of topics, including imaging (Paul Sava), anisotropy (Ilya Tsvankin), Gaussian beams (Norm Bleistein) and The Art of Science (Roel Snieder).

The Center continues to attract (and enjoys hosting) long-term visitors. We most recently have had guests from Statoil, Sinopec, and Delft University of Technology, each for more than six months.

Despite the economic downturn, in 2009 CWP expanded its base of sponsors of the CWP consortium. The Center also received federal funding from government sources, including the National Science Foundation and the U.S. Department of Energy. In addition, CWP is supported financially by some companies for targeted research projects, which are usually carried out in a collaborative fashion.

Educating the students of today and the professionals of tomorrow is central to the mission of CWP. Complementing their graduate research studies, writing consultant Diane Witters, works with CWP students to improve their writing skills, through one-on-one tutoring sessions and writing workshops. Diane closely coordinates her efforts with CWP faculty. In addition to helping students advance their writing skills, she assists international students to transition from the work culture in their home country to the professional style more common in the United States.

Research assistant John Stockwell continues to offer his “Mathematics for Geophysicists Math Clinic” where students receive a-la-carte training in areas of mathematics that they feel need strengthening.

Roel Snieder offers the course “The Art of Science,” which is aimed at helping graduate students develop effective research habits. In addition, he is teaching a new course “Introduction to Research Ethics” to graduate students from all departments at CSM.

With 25 successful years behind us, we at CWP are well positioned and eager to tackle the next 25.

Clockwise: PhD grad Jyoti Behura with advisor Ilya Tsvankin and CWP friends; Statoil summer intern Tony Yang sports Nordic cap; Paul Sava and CWP alumnus Tariq Alkhalifah in Egypt for EAGE meeting; CWP students Jia Yan and Yongxia Liu at The Alamo during SEG annual meeting; CWP faculty, students, and visitors, Fall 2009.

Recharging the Batteries

– Ilya Tsvankin, Professor

Sabbatical leave provides faculty with a unique opportunity to "recharge the batteries," explore new research directions, and initiate collaborative projects. The sabbatical that I took in the spring 2009 semester was my first since joining CSM in 1992. I began it in Golden working on a new book and then spent two months in Europe doing joint research with Prof. Serge Shapiro at the Free University of Berlin, Germany, and visiting other research groups.

The book that I am writing in cooperation with Vladimir Grechka of Shell (a former post-doc and research professor at Mines) is devoted to seismology of azimuthally anisotropic media and application of seismic methods to characterization and monitoring of fractured reservoirs. It is a sequel to my monograph, "Seismic signatures and analysis of reflection data in anisotropic media," which has been in high demand since its publication in 2001 as both a textbook and a reference volume used by applied seismologists. The new book is scheduled to be published by the Society of Exploration Geophysicists in 2011.

Prof. Shapiro's research consortium "PHASE" (Physics and Application of Seismic Emission) investigates the physics of fluid-induced microseismicity and develops a seismicity-based approach to reservoir characterization. Our collaboration was focused primarily on stress-induced elastic anisotropy and its application in time-lapse seismic for compacting reservoirs.

A pressure drop inside a reservoir caused by production of hydrocarbons generates an excess stress field throughout the medium, which changes the velocities of seismic waves. These velocity perturbations can be used to reconstruct the spatial distribution of stress and, potentially, to identify reservoir compartments and estimate the pressure change in them. The work on this project, which also involves my Ph.D. student Steven Smith, is ongoing.

In addition, I gave a three-day course on seismic anisotropy and a series of seminars about my recent research for faculty and students of the Free University. My family enjoyed the vibrant cultural life in Berlin and took advantage of the hospitality of our hosts to sightsee in other cities.

One of my side trips from Berlin was to the office of Petroleum Geo-Services in Oslo, Norway. My presentation on anisotropic velocity analysis at PGS was well attended by geophysicists from several oil and service companies based in Oslo. I also continued collaboration with Dr. Walter Söllner of PGS (who spent his sabbatical at CSM in 2008) on multiazimuth time imaging for anisotropic media. Oslo is ranked as number two on a list of the world's greenest and "most liveable" cities, and a highlight of the trip was a boat tour of the beautiful Oslo Fjord islands.

Ilya and Olga Tsvankin (left) at the famous Sanssouc Palace in Potsdam with hosts, Prof. Serge and Ina Shapiro. *Photographer: Daniel Tsvankin*

"The Art of Science" in Japan

科学の進め方

– Roel Snieder. Professor

For the past eight years I have taught the course "The Art of Science" to CSM graduate students. This course is aimed at helping young researchers develop effective research habits.

I also offer this material as a short course and recently visited Tohoku University in Sendai, Japan. The course was attended by about 70 students and junior researchers, who were a receptive audience to my interactive lecture style. In addition to teaching, I carried out research with Prof. Haruo Sato and his co-workers.

This visit to Japan included several technical seminars, some located in Tokyo where I visited the memorial site of the 1923 Great Kanto earthquake.

Teaching this course in Japan was enlightening because it revealed the different approaches to research and teaching between cultures. Crossing such cultural bridges is important for creating a more international and accepting research culture.

Editor's Note: In December 2009, Roel presented his short course at the Australian National University, College of Physical Sciences.

Roel at the memorial site of the 1923 Great Kanto earthquake. This devastating earthquake triggered fires that caused much loss of life, and which were sufficiently intense to melt the iron in the electro-motor shown in the photo.

X-ray Vision, No place to hide

New Six-Ton Tool Yields Micron Image

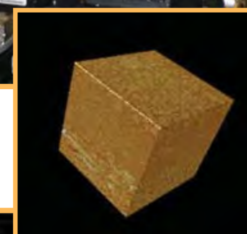
– Marisa Rydzy, Graduate Student

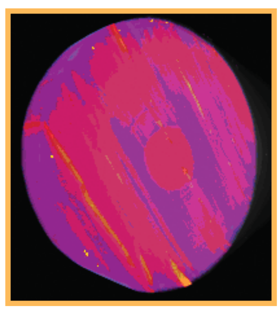
The Center for Rock Abuse, under the leadership of Prof. Mike Batzle, has become foster parent to a brand new micro X-Ray-CT scanner that was purchased by Colorado School of Mines with the help of a generous grant donated by Chevron.

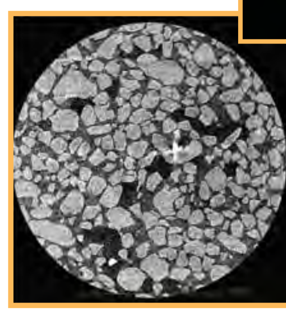
After facing some unexpected difficulties in the beginning (the six-ton device rolled off the truck – literally), the machine is now fully functional and up and running in the Green Center basement. X-Ray micro-tomography is a non-invasive imaging technique that operates in a similar fashion as a medical CAT-scanner, but can achieve much higher resolution. It generates a three-dimensional representation of a specimen's interior from two-dimensional X-ray images that are acquired while the sample rotates between X-ray source and receiver. If the sample is sufficiently small, details as small as a few microns can be resolved, whether that is in the interior of a computer chip, the hypothalamus region of a mouse brain, or the pore structure of fluid-filled sediment

In the past, heterogeneous samples, such as carbonates or hydrate-bearing sand packs, have given us rock physicists a hard time when it comes to interpreting the velocities measured in inhomogeneous rocks. Thus, one of the main applications of the new tool will be the characterization of heterogeneity in rock samples, which will make life in the Rock Abuse lab somewhat less complicated.

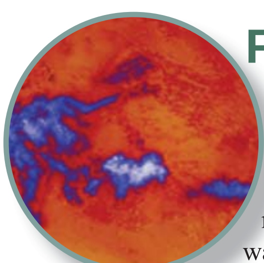
Marisa with her new research 'toy" the micro X-ray CT scanner.







Ottawa Sand & Montmorillonite Layers (above). Wet Ottawa Sand (near left). Shale (1-inch diameter) – Heavy Oil (far left).



Facing the Main Challenges in CO_2 Sequestration

– Roel Snieder and Terry Young, Professors

Concerns that emissions of CO_2 are a cause of man-made global warming have led to plans to inject CO_2 into the subsurface, a process called CO_2 Sequestration.

CSM professors Roel Snieder and Terry Young recently published a paper (*GSA TODAY*, November 2009) in which they point out the main challenges in CO_2 sequestration on a scale that makes a difference for curbing climate change. An earlier study showed that in order to make a significant difference for mitigating climate change one needs to sequester about three Gigatons of CO_2 per year. This is about the same mass as the worldwide petroleum production. Currently, CO_2 sequestration costs about $50 per ton of CO_2. Sequestering three Gigatons of CO_2 per year would cost $150 billion per year. Reducing the cost of this process is the *first challenge* that Snieder and Young identify.

Current projects inject about one Megaton of CO_2 per year. This means that one needs thousands of such sites to make a difference. Upscaling the current technology with a factor of a thousand is the *second challenge* that Snieder and Young identify.

The *third challenge* is to predict and monitor the leakage rates as small as a fraction of a percent that are needed to hold down the CO_2 for a sufficiently long time to chemically bind the CO_2 to the host rock.

Meeting these challenges is necessary for the large-scale implementation of CO_2 sequestration. Fortunately, one can reduce CO_2 emissions and energy consumption more cheaply by energy conservation and efficiency. Snieder and Young point out that the prospect of CO_2 sequestration should not prevent us from pursuing a more efficient use of energy. Their article can be downloaded from http://inside.mines.edu/~rsnieder/CCS_GSA_Today09.pdf

Image courtesy Barbara Summey, NASA Goddard Visualization Analysis Lab, based upon data processed by Takmeng Wong, CERES Science Team, NASA Langley Research Center.

Student Explores the Solar System... Without Leaving Campus!

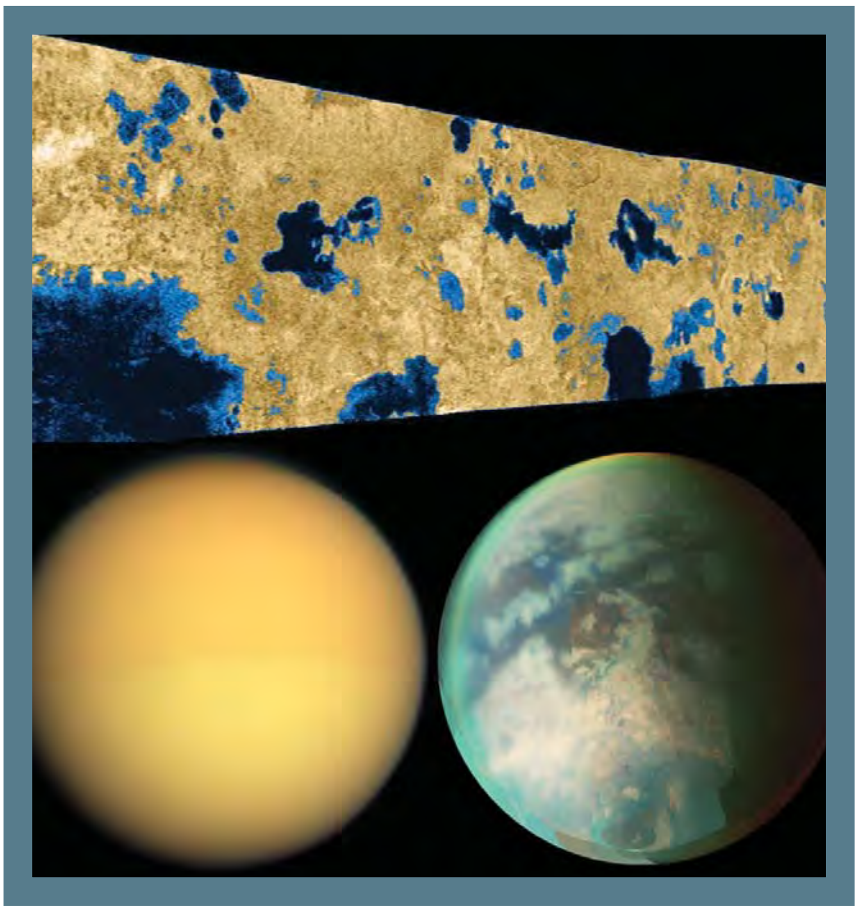
– Joyce Hoopes, GP Senior

About a year ago, I began my journey into outer space, traveling from the depths of the Martian canyon, Valles Marineris, to the hydrocarbon lakes of Saturn's icy moon Titan. The journey began in January of 2009, when I started my job as an undergraduate research assistant working for Assistant Professor Jeff Andrews-Hanna in the Geophysics Department.

I have helped Jeff on several projects in his research of Mars and Titan. One project involved the identification of sedimentary deposits on Mars using the Mars Orbiter Laser Altimeter (MOLA) topography data, and high-resolution images from the High Resolution Imaging Science Experiment (HiRISE).

These sedimentary deposits preserve a record of a time on Mars nearly four billion years ago, when the planet was warmer and wetter than it is today, and vast sedimentary deposits formed from the upwelling and evaporation of groundwater. I then spent some time mapping and measuring faults in the enormous Valles Marineris canyon system – a canyon more than 2000 km long, 100 km across, and 10 km deep. These canyons are still poorly understood, and this work will contribute to our understanding of the tectonic mechanism responsible for this chasm.

Thus far, my most challenging project has been to create a topographic map of Titan, through interpolation of the sparse data available from the Cassini Orbiter. I experienced the frustration of learning the tools required for the task presented to me, and the reward of accomplishing that task.



The surface of Saturn's moon Titan is hidden by clouds in visible light (bottom left), but revealed by the Cassini Visual and Infrared Mapping Spectrometer (bottom right). Radar observations reveal lakes of liquid methane and ethane in the north polar region (top).

As I continue with the Titan project, I am learning more about the analytical tools used to support research. Ultimately, this work will be used to investigate the hydrological cycle of Titan – but unlike the Earth, this hydrology involves liquid methane and ethane flowing over and through a crust of frozen water ice. My topographic interpolations helped to generate the most accurate map of the global topography to date. I was then able to use this topography to study the distribution of lakes and seas on Titan.

The experience I have gained from undergraduate research could not have been achieved in the classroom. I, like many students, am not exactly sure what I want to do with my education from Mines. However, I will always remember and cherish this experience.

Just Imagine: Painting in 3D

– Chris Engelsma, Graduate Student & Dave Hale, Professor

Decades ago, geophysicists and geologists would use colored pencils to paint seismic sections of the earth's subsurface. Those sections were displayed on paper. We would use different colors and shades to represent different geologic layers. Seismic horizons were then simply the boundaries between those colored layers.

So when painting software became widely available with personal computers in the 1980s, it became obvious that we might use this software to interpret seismic images. Digital paint has advantages. It can be applied in multiple overlays that we can easily turn off and on, and mistakes are easy to undo. Moreover, painting geology is simpler and more intuitive and direct than picking seismic horizons. Painted pixels directly represent a model of the subsurface. If we had only 2D seismic sections, we might all be interpreting them in this way.

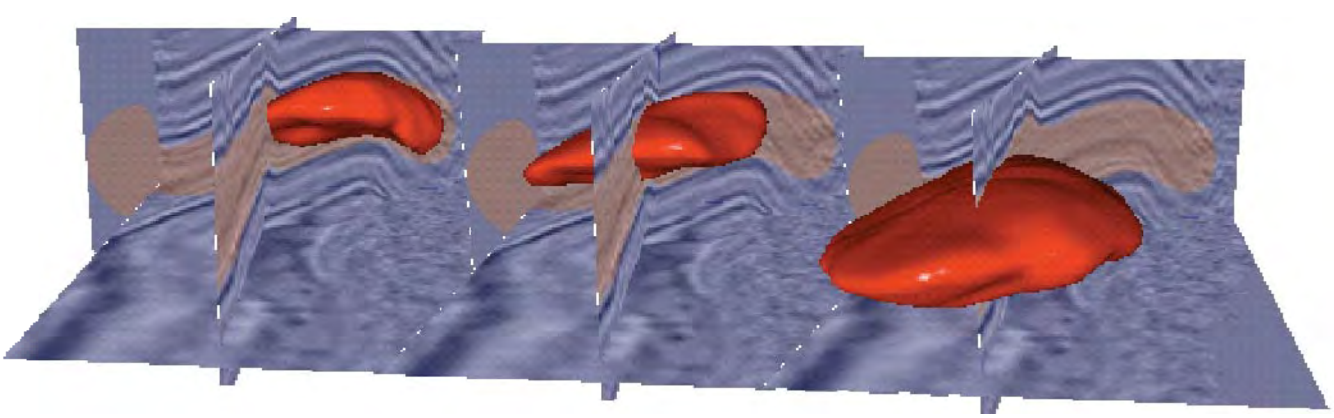
But as painting software became commonplace, so did 3D seismic images, and painting the hundreds or even thousands of 2D seismic sections in a 3D seismic image became too arduous. So today we instead pick horizons, the interfaces between geologic entities, instead of painting the geology directly.

Imagine instead that we could paint in 3D.

What does this mean? It does not mean painting with perspective on a 2D canvas. That is what artists do. They use perspective and other techniques to give the illusion of 3D. We mean something different. We want to paint voxels (3D pixels) in a 3D canvas (our subsurface model) that coincides with a 3D seismic image.

At the Colorado School of Mines we are blending geophysical image processing and interactive computer graphics to paint in 3D. The key step is to make the orientation and shape of our digital 3D paintbrush conform automatically to features apparent in 3D seismic images. Simple 3D brush shapes like spheres or cubes, analogous to circles and squares found in 2D painting software, will not do.

For as we move our paintbrush along slices of a 3D seismic image, we are actually painting voxels in a 3D subsurface model of the earth. In the example shown below, we are interactively painting all voxels inside the red 3D paintbrush. With this 3D brush, we simultaneously paint voxels in many slices of the 3D image, not only the 2D slices displayed here. While we control the maximum size of the brush, it may shrink automatically, say, near geologic faults; brush orientation and shape adapts automatically so that our painted subsurface model remains consistent with the 3D seismic image.



In *HOT* Water: Making a Case for Geothermal

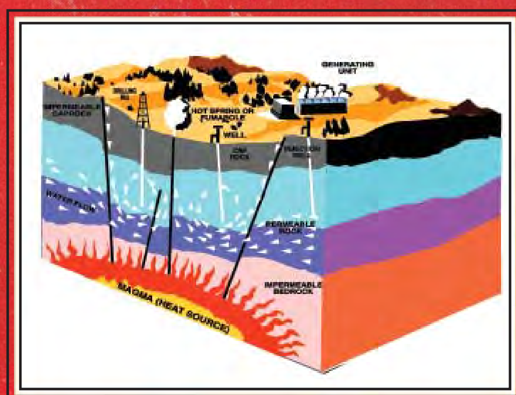
– Jeff Schoffner, Graduate Student

My involvement with geothermal began the summer after my fourth year as an undergraduate at the University of Nevada, Reno. I began working with the Navy Geothermal Program Office for the summer, collecting gravity and magnetics on a southern California military bombing range, looking for a geothermal reservoir that could potentially be used to produce power. They enjoyed my work, and offered to fund my graduate work here at Mines. I am currently working with Dr. Yaoguo Li in CGEM and using gravity, magnetics, and an airborne EM system to understand blind geothermal systems in Nevada, and where they occur.

In recent years there has been a dramatic increase in the attention to and application of renewable energy. It just makes sense. The primary sources of renewable energy are wind, solar, hydro, biofuels, and geothermal. While there are geophysical applications to all of these fields, geothermal attracts geophysicists that have experience in mineral and oil exploration. The techniques used to discover a geothermal production site draw many parallels with that of the mining sector, with the exception that the resource is deeper and —well, a fluid.

But where do you find a geothermal reservoir? There are a few options. Some of the hottest geothermal sites are located where recent volcanism has raised the thermal gradient of the earth. Other places are where the crust is thin due to tectonic activity, such as the Great Basin in Nevada, or the Salton Trough in Southern California and Mexico. These areas usually have sufficient water to flow geothermal systems, as well as the heat required to warm the water to economic temperatures.

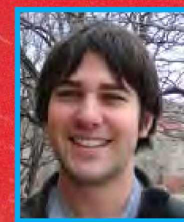
Using a geothermal site to produce energy is actually very simple. Once a reservoir is found that is relatively shallow (usually within 5 km of the surface), hosted in porous rock, and contains hot water, the reservoir is drilled



An image from wikipedia.org outlining how faulting allows fluids to migrate within the earth's crust, and where we can drill to tap into the resource.

and a pump is installed. The hot water is then brought to the surface and "flashed" to steam, which turns a turbine and produces electricity. The used colder water is then pumped back into a nearby well that will recharge the system. This makes it a renewable energy source.

Historically, exploration for production-grade geothermal sites has mimicked early exploration for oil. A surface expression of the source was discovered and then subsequently drilled. However, as we know from oil exploration, many resources have no surficial expression. In the geothermal industry, these are called blind systems.



For my research I am using gravity, magnetics, and an airborne electromagnetics system. Gravity is used to see changes in density in the subsurface. Coupled with magnetics data that measure the magnetic susceptibility, we can forward model the location of faulting. EM data is sensitive to conductivity contrasts, which can also be used to locate faulting, but has the added benefit of responding to conductive fluids. Since geothermal waters tend to have more dissolved solids and heat, they are more conductive.

Geophysics has an obvious home in the exploration for economic grade geothermal sites. The need to understand the location of hot water in porous rock at depth without any surface hints is a perfect problem for geophysics to solve.

Jeff with Wei-Chuang Huang of the Navy GPO in the Chocolate Mts Aerial Gunnery Range in Southern California.

SmartGeo Program

FirstClass REPORT

I am a member of the first class of the SmartGeo program at the Colorado School of Mines. The SmartGeo program supplies funding to research fellows through the National Science Foundation's Integrative Graduate Education and Research Traineeship (IGERT) awards. The program embodies collaborative research groups composed of CSM faculty, industry instructors, and PhD fellows from a variety of technical backgrounds.

Students in the program pursue course work within more than one department, minors in science ethics & policy, and applied research towards complex geosystems and their behaviors. After a successful first year, the SmartGeo program is gaining momentum through increased interest and support by entities such as the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, and the U. S. Geological Survey.

SmartGeo:
The first class.

Each year, the SmartGeo students and faculty will converge upon a different location for a SmartGeo retreat. The retreat is a great way to create friendships, build communication skills, and help all to learn and understand the team personality. The 2009 retreat was held at the Peaceful Valley Ranch in Lyons, Colorado, and was led by several keynote speakers. Activities included improvisation exercises for communication and team building, a managerial seminar with discussions of individual managerial styles, and a photo scavenger hunt. During the scavenger hunt, participants were given a list of themes and were required to take photos around the site that represented those themes.

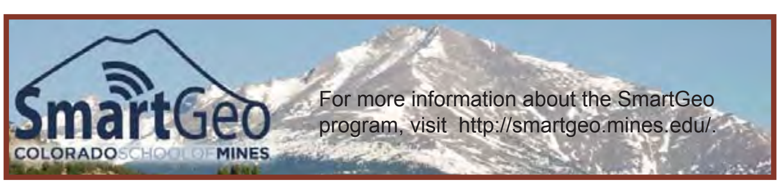
SmartGeo retreat and scavenger hunt: a demonstration of the theme "In Reverse."

The SmartGeo program is currently pursuing three collaborative research projects, and the variety of research projects will expand as future SmartGeo classes are admitted. The current applied research includes Intelligent Earth Dams and Levees (see following page), Intelligent Bioremediation, and Intelligent Geo-construction projects. Each project is heavily dependent on data acquisition systems, both wireless and wired, and on developing intelligent sensing networks that adapt to environmental changes. By doing so, the sensing networks perform their duties more effectively and efficiently on a real-time basis.

– Scott Ikard
Graduate Student

I am working on the Intelligent Earth Dams and Levees project with three other PhD fellows: Minal Parekh, Dept. of Engineering (Geotechnical); Ben Lowry, Dept. of Geology and Geological Engineering; and Kerri Stone, Dept. of Mathematics and Computer Sciences.

We are completing a proposal for a decision support system that will detect and monitor internal erosion in embankment dam cores. This is a long-term project that will build upon several smaller, focused research projects. This project will require expertise and research in the fields of geophysics, electrical engineering, geotechnical engineering, hydrogeology, mathematics, computer science, and information systems. Geophysical applications and research include, but are not limited to self potential, DC resistivity, induced polarization, ground penetrating radar and seismology. Project members will collaboratively publish research in each of these fields.



For more information about the SmartGeo program, visit http://smartgeo.mines.edu/.

Hidden Dam Case Study:

Self Potential for Detection of Known and Unknown Seepage Pathways

– Scott Ikard, Graduate Student

I am a student in the Geophysics department pursuing a PhD in geophysical engineering under the guidance of Professor André Revil. I am a member of André's hydrogeophysics research group, and am an NSF-IGERT Fellow in the SmartGeo program (see preceding page).

With the SmartGeo program I am researching the geophysical contributions to autonomous decision support systems that are designed to continuously monitor and detect internal erosion in embankment dams. In May 2008 I assisted in a self-potential survey and seepage assessment of the Hidden Dam, Madera County, California, with the Crustal Imaging and Characterization Team of the United States Geological Survey (USGS) in Denver, Colorado. The project is ongoing through March 2010 and will culminate in a series of USGS Open File Reports documenting the findings of the research.

The Hidden Dam, shown in the photographs is a 5,700ft long, 184ft high rolled earthfill embankment located in Madera County, California, approximately sixteen miles northeast of the town of Madera, in Raymond, California. The dam is a zoned design containing a central impervious core, a select fill downstream transition zone, outer shell zones of random fill materials on the upstream and downstream slopes, a vertical chimney drain and a horizontal blanket drain that does not cover the entire downstream topography (Cedergren, 1980a).

There is a documented history of seepage problems and attempted remedial measures at the Hidden Dam. Cedergren (1980a; 1980b) provides detailed reporting of localized and distributed seepage zones, primarily on the downstream face of the right abutment (lower photograph) and extending towards the dam center line. Head gradients imposed by seasonal reservoir fluctuations force water under the foundation of the dam where it then flows upwards to intersect and accumulate on the downstream topography (Minsley et al, in press). Large-scale historical remediation measures include the deployment of a synthetic filter on the downstream topography overlain by a coarse gravel drainage apron (following the Cedergren, 1980 seepage report), and a network of pipe drains to channel collected seepage. Despite these efforts seepage is believed to be an on-going problem at the Hidden Dam.

The self-potential survey was undertaken to assess the current seepage conditions at the dam. The survey was designed to coincide with the seasonal high-pool elevation under the presumption that this would also correspond to the period when the seepage potential was maximum. Preliminary results indicate, 1) seepage and ponding are still likely on the right abutment and near the dam center line due to the presence of relatively large positive self-potential anomalies over the synthetic filter and gravel apron, 2) internal ponding within the dam may be likely over the seepage drain and may produce or contribute to internal seepage, and 3) while there are no documented seepage zones on the left abutment, a large positive self-potential anomaly discovered on the downstream slope of the left abutment, as well as visual observations of localized soil moisture may indicate that internal seepage is now occurring. Future work will include the analysis of a thirty-year long historical record of water-level measurements from piezometers and observation wells located in and around the dam, 2D steady-state and transient partially saturated flow modeling to compare with survey results, and publication of the results.

For references and further information, check out the Open File Report at http://www.usgs.gov/pubprod.

Hidden Dam, Madera County, California: This photo taken on the dam crest at the northwest right abutment looking towards the left abutment.

Hidden dam as seen from the global survey base station at the right abutment looking towards the left abutment.

A Glimpse of the Big Picture

– Yuanzhong Fan, Graduate Student

Sitting on a flight from Winnipeg to Denver, I asked myself these questions: What do geophysicists do? Is the Colorado School of Mines really as good a place to study geophysics as my professor recommended? After finishing my master's degree in physics, I started my journey in geophysics in the fall of 2006.

By taking several seismic classes and attending seminars, at the end of the first semester, I thought I had figured out what geophysicists do for a living. They try to interpret the subsurface from seismic wiggles. Later, I realized that geophysics is much more than this.

Because of the lack of a geophysics background, I started my research with Prof. Roel Snieder on a more physics-oriented topic of "interferometry for waves and diffusion." Interferometry, also referred to as the virtual source method in seismic, is a technique to retrieve the Green's function that describes the field propagation between two receivers without having a physical source at the receiver's positions. In 2006, interferometry was already a popular method in seismic. My research was to study whether it was practical to use this technique for diffusive fields such as low-frequency electromagnetic.

After realizing that Shell and Delft University of Technology were also interested in the same line of research, we started our collaboration with them. This joyful teamwork led to my overseas study in the Netherlands for three months and two successful summer internships with Shell.

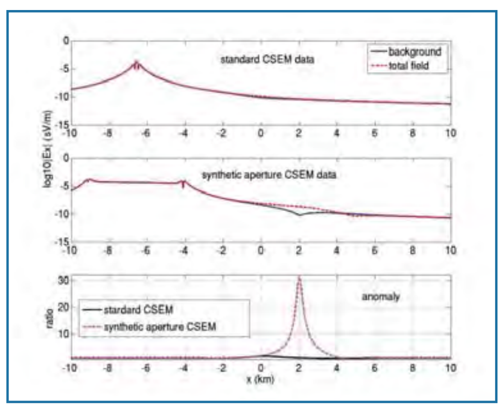
During my stay in Delft, I worked with Evert Slob, Kees Wapenaar and their geophysics students. Aside from my study, I really enjoyed the living and traveling in Europe with my wife Jing. She still misses the bread and cheese from the C1000 store in Delft, French fries in Brussels, and crêpes from the streets of Paris.

In the summer of 2008, I had my first internship with Shell, Houston. The EM group I worked with was awesome. They allowed me to work on my school project because they were interested to see progress in this area. At the end of the internship, we learned that interferometry can be applied to CSEM data, but only with an unrealistically dense receiver array. After I came back to school, we developed the concept of the synthetic aperture to solve this dense sampling issue.

We also realized that the synthetic aperture for CSEM itself was an attractive research topic. Consequently, my second internship with Shell was to apply the concept of the synthetic aperture to CSEM. The synthetic study shows that the magnitude of the anomaly in CSEM data can be increased from 20% to a factor of 30 by using the proper synthetic aperture. The real data example also shows significant improvement in finding an anomaly. Besides allowing me to progress in my research, the two internships helped me to see the big picture of the energy industry and to build my network with many people working in this industry.

For me, geophysics is an exciting career field. There are still a lot of unknowns: what will be my next research topic? Where will I live in the next five years? Where am I going to travel and who am I going to work with? But this is exactly what attracts me: surprises and adventures. I thank the Department of Geophysics at the Colorado School of Mines for preparing me to be a qualified geophysicist in my continuing journey.

Fan and Jing in Delft, the Netherlands



Top panel: the background (solid) and total (dashed) inline Ex field from a standard CSEM survey; Middle panel: the background (solid) and total (dashed) inline Ex field from a synthetic aperture whose field is steered toward the target; Bottom panel: The anomaly (ratio of the total and the background field) from the standard CSEM and the synthetic aperture CSEM.

ConocoPhillips team celebrates 2nd place ping pong victory.

Experience in Cooperation

– Xiaoxiang Wang, Graduate Student

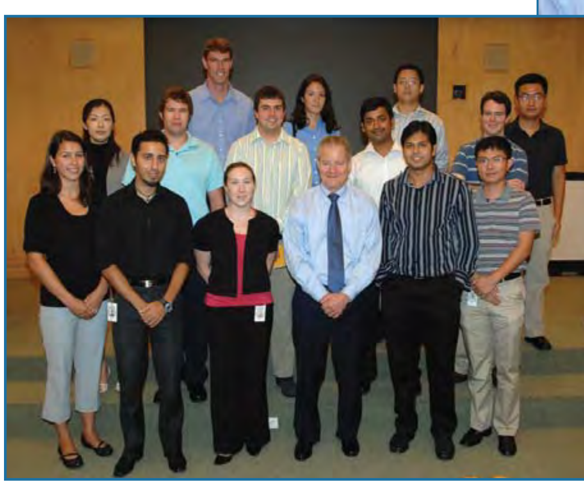
Cheering voices and applause, combined with disappointed sighs, could be heard from the entertainment room of CGGVeritas, one of the premier geophysical service companies. There was a friendly but vigorous ping-pong game going on between CGGVeritas and ConocoPhillips, who often collaborate with each other as vendor and customer. But on that day, collaboration was replaced by competition as four teams from each company battled for a prize trophy. I played for one of the ConocoPhillips teams as a new company intern, winning in the first round and losing in the second with my partner in doubles. In the end, our four-man team finished second in the field of eight teams. No wonder that I laughed so heartily when holding the trophy—it was the biggest award I have ever won as a long-time ping-pong player.

To be honest, I doubted if it was a good idea to leave colorful Colorado in the summer for hot, humid Houston. But after I arrived at ConocoPhillips, my doubts were immediately dispelled. The company headquarters where I worked looked like a park with several interconnected buildings, some standing on a man-made lake. Also, an expansive gym with a swimming pool and even a small soccer field offers employees various sports and fitness options.

I joined the Seismic Technology Team led by Dr. Phil Anno, who had received his PhD from our department and the Center for Wave Phenomena. My mentor, Dr. Brian Macy, and other geophysicists helped me define the research topic, which was closely related to my Ph.D. thesis on ray-based postmigration tomography in TTI (transversely isotropic with a tilted symmetry axis) media. It looked like smooth sailing from the beginning, but a lot of problems emerged along the way. Fortunately, I received help from experts in different fields, from seismic imaging to reservoir simulation, and successfully completed my project on time.

Yiaoxiang is greeted by ConocoPhillips CEO James Mulva.

During my internship, ConocoPhillips also offered many opportunities for interns from different departments to interact with each other and learn from specialists in other areas. For example, there was a "lunch-and-learn" event every Tuesday with an expert from each department discussing their daily work, management style, and future plans. One of these events was hosted by the CEO of ConocoPhillips, Mr. James Mulva, who presented a wonderful talk about the company's operations and priorities, and gave his advice regarding the development of young professionals.



Among ConocoPhillips interns of 2009 were CSM geophysics students Xiaoxiang Wang (back row, far right), Colin Melvin (middle row far right), Yong Ma (front row, far right), and Agni Das (not pictured).

So many impressions of my summer internship pop into my mind as I type these words, but it is impossible to describe all the details in this brief article. I cannot end without mentioning that I really miss the authentic traditional Chinese food available in Houston, which remains a scarce commodity in the Golden/Denver area.

In Thailand

A Multi-Cultural Field Camp

– Michael Mitchell, GP Senior

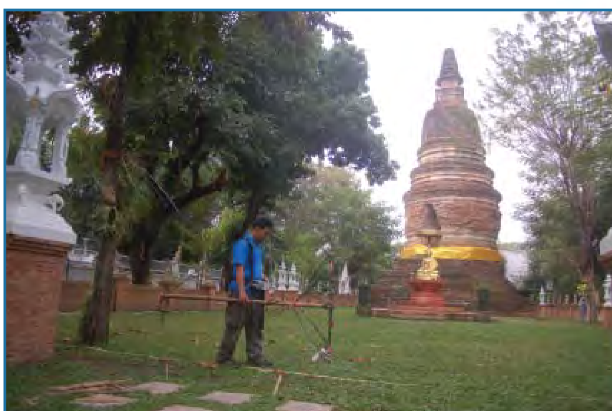
During the winter break, fellow students Roxy Frary, Joyce Hoopes, and I travelled to northern Thailand as teaching assistants for a geophysical field camp funded by the SEG Geoscientists Without Borders program. Though the program was organized by Boise State University, CSM's strong partnership with BSU enabled the department to send us along as well.

The main temple of the ancient town of Wiang Kum Kam, which is still occupied by monks.

The primary goal of this project was to provide geophysics students from the South Pacific, who might not otherwise have this type of valuable field experience, with the opportunity to learn how to collect, process, and interpret a wide variety of geophysical datasets.

During the first week of the field camp we collected different datasets including gravity, magnetics, GPR, DC resistivity, electromagnetics, reflection and refraction seismic, surface wave analysis, and passive seismic. The hope was to be able to use this plethora of data to help characterize the basin in which the city of Chiang Mai sits, assess the seismic hazards associated with a number of sites throughout the city, investigate the possibility of groundwater contamination from an old landfill, and search for the buried walls of ancient temples at Wiang Kum Kam and Wat Pan Sao. During the second week, we helped guide the data processing, interpretation, and report writing process.

Geoscientists Without Borders
Society of Exploration Geophysicists
Founding Supporter Schlumberger



Data gathering and survey work.

This was an amazingly rewarding and enriching experience for the three of us. It is not every day that you have the opportunity to work with 42 other geophysicists representing 7 countries and 13 different institutions. We would like to thank the Geophysics Department for their financial support and belief in our abilities.

It is experiences such as these that truly provide students the opportunity to grow. Additional thanks to the SEG Geoscientists Without Borders program and our friends and colleagues at Boise State for enabling this project to progress from a mere idea to fruition.

The final report, presentation, and photos are posted at http://cgiss.boisestate.edu/gwb, under the "GWB Field Camp 2010" link.

INVITATION to VENEZUELA

– Alejandra Maldonado Pena
Graduate Student

Every December, my family plans a trip to our vacation house in the west side of Venezuela, where the Andes Mountains delight us with the most beautiful natural scenarios. Specifically, we go to a small town called Timotes, in Mérida state. Our house is part of a community that decided to form a cooperative to grow produce, which is sold to help support the surrounding communities. Our family decided to grow roses! So you can imagine how wonderful the house and its surroundings smell… In the house, we enjoy being together as a family; we have time for relaxing, playing lots of games, reading, taking long walks in the mountains, admiring nature and especially, eating lots of good Venezuelan food!

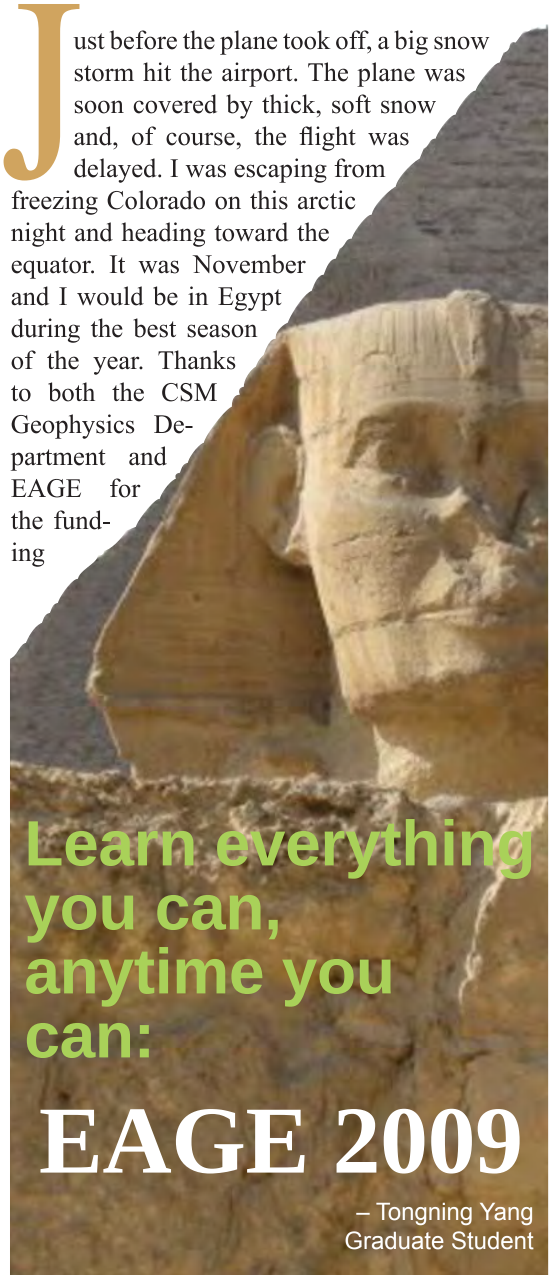
Graduate student Alejandra at her family's vacation home and rose garden in Timotes, Mérida, Venezuela.

We also enjoy being part of the traditions of the town. In Timotes, one of the most important events of the year is the San Benito (St. Benedict) festival, which is a religious tradition celebrated in all the western region of the country. On December 29, the citizens of Timotes wake up very early to prepare their costumes and their dances. They organize themselves in comparsas, which are groups of dancers that perform their dances for hours on the streets, followed by musicians (violins or drums), making a tribute to the Saint. Generally, the dancers are dressed in a traditional white dress (called liqui-liqui) from which they hang ribbons of different colors. Each ribbon represents a promise that they have made to San Benito during their life. It is very amazing to see some dancers doing their performance for hours on their bare feet!

Dancers in traditional dress during the San Benito festival.

This celebration and the beautiful landscapes of Venezuela are a unique experience of the world! I invite you all to visit and be part of the wonderful culture of Venezuela.

The Andes overlook the family property in Mérida (left), and (right) Alejandra and her family enjoy an outing during her visit.



Learn everything you can, anytime you can: EAGE 2009

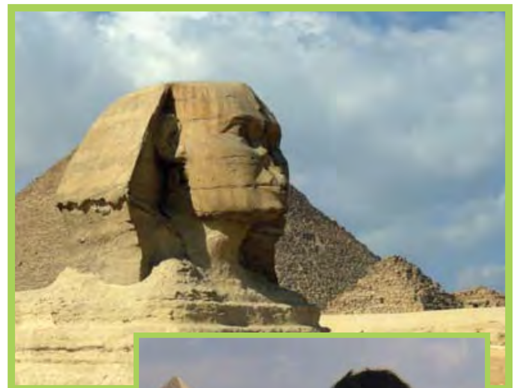
– Tongning Yang
Graduate Student

Just before the plane took off, a big snow storm hit the airport. The plane was soon covered by thick, soft snow and, of course, the flight was delayed. I was escaping from freezing Colorado on this arctic night and heading toward the equator. It was November and I would be in Egypt during the best season of the year. Thanks to both the CSM Geophysics Department and EAGE for the funding support, I was traveling to Cairo for the 2009 Subsalt Imaging Workshop.

When I arrived in Cairo, I learned the surprising fact that there were two students total in the workshop, and I was the only one who would present research work. What a lucky dog! This was indeed a precious opportunity, and I told myself that it would be a crime if I did not utilize it well. As a result, I set several goals: learn more, experience more, and think more.

Following these principles, I tried to talk to people from different companies, discuss different topics, and visit different places (rather than stay in the hotel during the whole workshop!). And when I look back on the workshop, I realize that it was very fruitful. I listened to some presentations on advanced technology in imaging, presented my latest results in velocity model building, asked questions, participated in discussions, met new and old friends, and received an internship offer. Wow!! How could I ask for more?

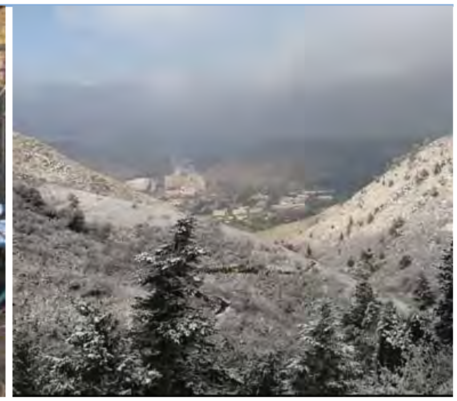
When one attends a conference, the meeting is not the whole story. For a conference in Egypt, there is one thing that can never be missed: the pyramids. Although I have seen pyramids thousands of times on TV and in photographs and books, I was still deeply astonished when I stood in front of such a great wonder. There are rare cases that something looks better in reality than in a photograph; a pyramid is definitely one such example.



Surrounded by the desert, the pyramid was built on a square foundation formed by countless huge stone bricks. Although not every brick is identical in size, each shares the same height. I climbed on top of one brick, which was almost as high as me, so that I could view the pyramid more carefully. But seeing is not enough to enjoy the stunning beauty and elegance of the pyramid. I wanted to indulge myself by trying to imagine the history that the pyramid has witnessed. If a pyramid had emotion, I guess it must be proud of standing firm for thousands of years, or even for eternity.

CSM graduate student Tony Yang

The CSM connection reaches to far away places: Professor Paul Sava and student Tony meet up with geophysics alumni.



"What is the primary characteristic of the USA according to Polish people?", the man asked me.

"Hmmm… I don't know… maybe hamburgers and coca-cola?"

"HaHaHa," the man laughed outright. "That's ok. I associate Poland with Polish sausage, very good sausage I must admit."

Geophysics Visitor Discovers 'Golden' Experience

– Karolina Pieniazek
Visiting Scholar

It was Friday afternoon. I was sitting in the garden in front of a hotel in Golden, Colorado, and I was listening to music played live by a group of musicians. The women who had rented me a room brought me here. It was my first week in the USA. I was so unsure and nervous. How will it be here? How will I cope with everything, all alone so far away from home for so long?

At the beginning, the most strange thing for me in Golden was the empty pavements – there were hardly any pedestrians except for downtown and on campus. Another difference between Golden and my home city of Krakow is a special kindness of all the people everywhere. "How are you?" or "Hi" and a smile from people you do not know – it is a nice habit in Golden.

I received a warm welcome at school. Everybody was ready to help me. For a person at CSM for the first time the campus map is essential. Of course you can always ask somebody for directions, but this little map gave me a constant sense of security, helping me pass through those first days without being lost.

Thanks to staff and students I coped with all the required formalities at school – filling out huge amounts of paper forms in different buildings. Also thanks to them, I quickly became used to attending classes and all the RCP group activities. I enjoyed the academics and was absorbing knowledge like a sponge.

At CSM you can feel like you are in many parts of the world all at the same time. While walking in the corridors you can see faces of students from many countries. This international mixture is the most visible during International Day, which is a campus event held each year. At this event, you can try traditional food from many countries, watch dance performances, and see traditional clothes. If you want to meet people and learn foreign habits, you can attend an international conversation group, which takes you around the world.

Karolina Pieniazek was a three-month visiting scholar with the Reservoir Characterization Project during fall 2009. She is an employee of the Oil and Gas Institute, Krakow, Poland.

Another thing that I especially remember occurred as I was walking along one of Golden's streets when suddenly a young deer appeared in front of me. I was not so surprised only because I had heard that deer are frequent guests of the inhabitants of Golden. They like coming into gardens and looking into windows. It was also very nice to meet birds (woodpeckers, bullfinches) during my solo hiking on nearby Lookout Mountain and surroundings. I felt really happy to be so close to nature.

Of course I missed my family and friends. I appreciated the ability to talk with and see them via internet. I used my free time to ask how they are and to tell them about what is new with me. I also described Golden to them.

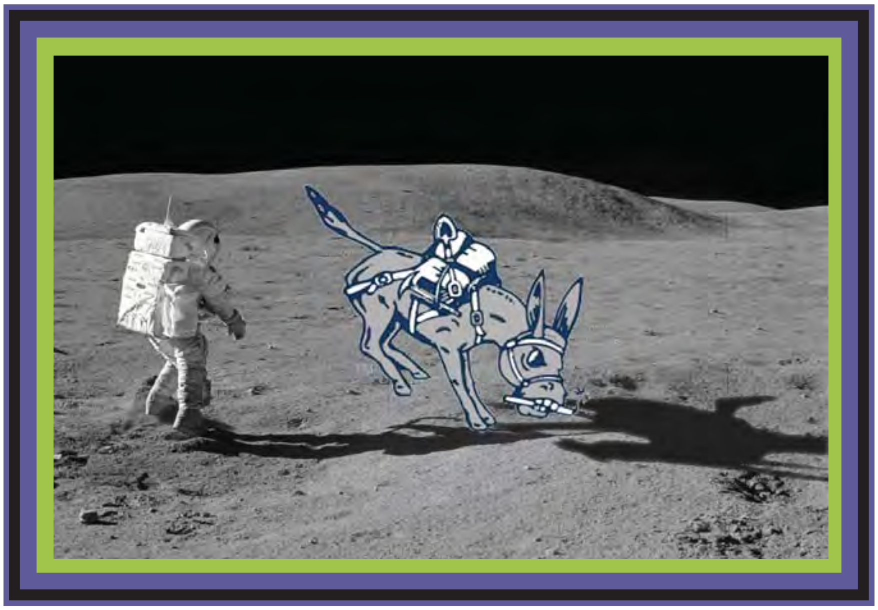
Finally, it turned out three months in the USA passed very quickly. I liked the house where I was living, and I was among friendly people in a nice small town. I have a lot of good recollections.

Area of Special Interest

Reaching for the Stars

– Jeff Andrews-Hanna, Assistant Professor

"Houston, we have a problem."



Astronaut Charlie Duke encounters Blaster the Burro at the Apollo 16 landing site on the Descartes Highlands.

Since it's establishment in 1874, the Colorado School of Mines has continued to grow and diversify the many opportunities it offers to students. In the early years of the school, students could choose to study in the departments of drafting, physics, metallurgy, chemistry, and mining. Students can now choose from 17 majors and an even greater number of minors and areas of special interest, many of which could not have been anticipated by the school's founders, but all of which contribute to our mission of educating students in fields related to the earth, energy, and the environment.

Now I am happy to announce yet another program to expand the educational opportunities available to Mines students: an Area of Special Interest (ASI) in Space and Planetary Science and Engineering (SPSE). SPSE brings together classes from five departments and programs across campus in the areas of astronomy, planetary science, and space engineering. The new program is the result of both the hard work of a number of faculty on campus, and the enthusiasm of the students.

Students taking part in this new ASI have interests ranging from astronomy, to planetary science, to aerospace engineering. Course options for students in this ASI include: Planetary EPICS Design II (EPICS 251), which provides hands-on design experience; Solar System Exploration (EGGN 498), which covers a wide range of topics related to space exploration; Planetary Geology (GEOL 411), covering the geology of the planets; and Introduction to Astronomy and Astrophysics (PHGN 324).

The Geophysics Department features prominently in this new program, contributing two classes: Satellite Remote Sensing of the Earth and Planets (GPGN 470), and Planetary Geophysics (GPGN 498).

The program now offers only an ASI; however, looking to the future, we anticipate increasing the course offerings and perhaps adding a minor.

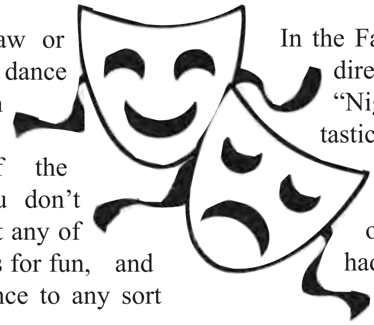
Despite the fact that the program was just approved in November of 2009, a number of students in the Class of 2010 intend to graduate this spring with credit for the ASI (including geophysics students Joyce Hoopes and Gordon Johnson). This cross-departmental program will also serve to draw students from other departments into geophysics classes, and encourage geophysics students to venture outside the department and broaden their education.

The planetary and space sciences have long been a part of both the Geophysics Department and the university. This Area of Special Interest is simply a means of organizing the various courses that have been teaching CSM students about science and engineering beyond the Earth. A number of CSM researchers from various departments have been working at the forefront of space and planetary science and engineering under the umbrella of the Center for Space Resources. Both undergraduate and graduate students from CSM and the Geophysics Department have gone on to careers in these fields. If you would be willing to share your story to inspire the Mines students of today to reach for the stars, please send it to the SPSE program director at jcahanna@mines.edu.

A GEEK AND PROUD OF IT!

– Roxanna Frary
GP Senior

When most people think of geeks, they think of those who are intelligent, quirky, and introverted, à la Sheldon in television's "Big Bang Theory." This is especially true at schools like ours. But when I think of geeks, I think of the theatre geeks with whom I spend nearly every Sunday from 1-4 pm. That's our scheduled rehearsal time, whether we're doing one of the two fall straight plays, or the huge production of the spring musical. These are the people I think of when someone says "geek."



Mines Little Theatre (MLT) has been such a huge blessing in my life the past four years. Hard-working students like us need some sort of creative outlet. Some people pick music and join the orchestra or choir, some people write, some take photos, some draw or paint. I act, sing, and dance with a whole bunch of other students here at Mines. And one of the best parts is that you don't have to be very good at any of those things. We do this for fun, and many of us cannot dance to any sort of rhythm, or carry a tune in a bucket. But we somehow manage to put on two straight plays every fall, and a musical every spring, and we actually get people to come see them.

Roxy (right) performing in "Best Little Whorehouse in Texas."

I have been a part of a production every fall and spring since I started at Mines. These include "6 Rms Riv Vu," "The Boyfriend," "Curious Savage," and "The Best Little Whorehouse in Texas."

In the Fall of 2009, I made my directorial debut with "Night Watch." I had a fantastic cast, and the majority of them were inexperienced in the ways of MLT. They actually had their lines memorized by the deadline! (This rarely happens in other MLT productions.) The show was performed two nights in November to 150 spectators. It was a huge success, and many of the people who came to see it are my friends, classmates, and professors in the Geophysics department. I am grateful to them all for their support last fall, and over the past few years.

It is for you that we put these productions together every semester. The encouragement we get from the faculty and students on campus really help give us a reason to come to rehearsal every Sunday.

Talented Student Tied to String Theory

GP senior Renee Francese is just one of our multiply talented students who is not only serious about academics, but also exercises the "right" side of her brain.

Renee Francese

Renee is a violist with "The String Theory Quartet," which was formed at CSM in the fall of 2007. The common thread among the quartet members when they met was that they were all physics students in some form. Jeff Miller, (violin) had already earned his B.S. in engineering physics and was working towards a M.S. in mechanical engineering; Renee (viola) was a geophysics major; Michael Bratton (cello) was a physics major; and Kendall Aubertot (violin) was an undeclared freshman, but was considering a major in engineering physics (now a computer science major).

Their early repertoire included Dvorak's "American" quartet, Schubert's "Death and the Maiden" quartet, and a cute little book of classical favorites. They were invited to play at school functions, weddings, engagements, and various gigs and chamber recitals throughout Denver and the front range.

Each also plays in the Jefferson Symphony Orchestra and the Evergreen Chamber Orchestra (ECO) under Dr. William Morse. Spring 2010 Renee had the honor of performing as soloist with the ECO, playing the Concerto for Viola and Orchestra in D by F.A. Hoffmeister.

The String Theory Quartet: (l-r) Jeff Miller, Kendall Aubertot, Renee Francese and Michael Bratton.

Geophysics Graduates
Spring 2009

Bachelor of Science
(Geophysical Engineering)

Raied Ibrahim Al Sadan
Hamad Algenaim
Abdulrahman Mohammad Alrugaib
Michael Chad Baillie
Jeremy Ambrose Brown
Diego Thomas Castaneda
Nathaniel James Cockrell
Dylan Mark Connell
Thomas Andrew Cullison
Arianne M. Dean
Christopher Andrew Engelsma
Jeffrey Allen Godwin
Elise Marie Goggin
Derek Carlton Grimm
Faisal Hakeem
Brian Douglas Hart
Jesse Brandon Havens
Tyson Craig Jesser
Rebecca Lyn Johnson
Christopher John Lang
Cericia D. Martinez
Tracy Elizabeth McEvoy
Shawn K. Meier
Samuel Thomas Nilsson
Ryan David Paynter
David Christopher Wilson

Master of Science
(Geophyics)

Merrick H. Johnston

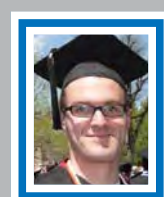
Doctor of Philosophy
(Geophysics)

Ludmila Adam
Arpita Pal Bathija
Matthew S. Casey
Rodrigo F. Fuck

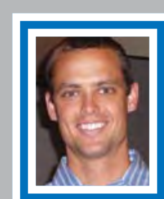
PhD graduates: Matthew, Arpita, Ludmila and Rodrigo.

BS graduates: (back l-r) Faisal, Jeff, Chris E., Dylan, Tom, Nathaniel, Diego; (front l-r) Raied, Arianne, Elise, Jeremy, Chad , and Hamad.

Shawn

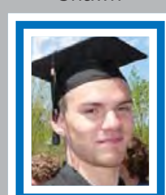


David



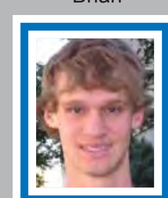
Brian

Rebecca

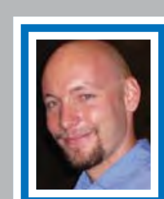


Jesse

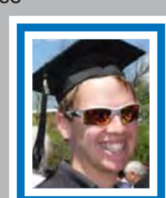
Tracy



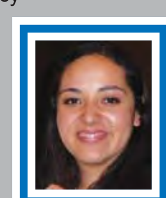
Derek



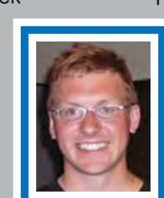
Tyson



Chris L.



Cericia



Samuel

Not pictured: Abdulrahman Alrugaib, Ryan Paynter and Merrick Johnston.

Geophysics Graduates
Fall 2009

Jyoti

Karoline and Iris

Mohammed, Alicia and Alex

Gary, Kristen and Shannon

Standing left to right: Alicia Hotovec, Iris Tomlinson, Karoline Bohlen, and Kristen Schmidt. Kneeling left to right: Jyoti Behura and Alex Araman. Not pictured: Julio Lyrio, Mark Wiley and Ran Xuan.

Bachelor of Science
(Geophysical Engineering)

Karoline Jean Bohlen
Iris Wood Tomlinson

Master of Science
(Geophyics)

Alexandre William Araman
Alicia Jean Hotovec
Mark Lyle Wiley
Ran Xuan

Master of Science
(Hydrology)

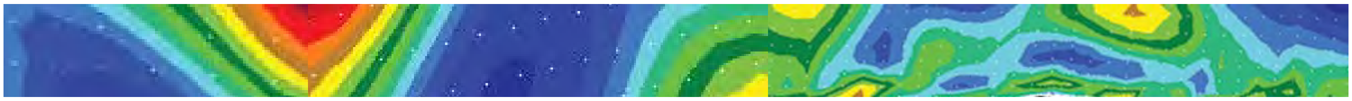
Kristen Raye Schmidt

Professional Masters
(Petroleum Reservoir Systems)

Mohammed Al-Najjar
Shannon Marie Rensberger
Gary Dayton Scherer

Doctor of Philosophy
(Geophysics)

Jyoti Behura
Julio Cesar Lyrio



Field Camp 2009

(continued from page 8)

The area of interest for our geophysical surveys is part of the Upper Arkansas Basin and it is characterized by unusually high heat flow in the subsurface. There are geothermal hot springs present throughout the area. Currently, the geothermal resources are being used commercially in resorts and by local residents as a hot water supply. In one case, in the San Luis Valley, there is also an alligator farm that uses the hot water to harvest tropical fish and alligators. With President Obama's recent mandate for renewable energy to provide 20% of the United States energy supply by 2025, there is increased interest in this area becoming a hub for geothermal energy production.

The geophysical data collected from our field session will be integral in providing an assessment of future geothermal resources for Colorado. DC Resistivity, Self Potential, Gravity, Magnetics, Electromagnetics, 2D and 3D seismic surveys were among the data collected on our two weeks of data acquisition at Chaffee County. We then spent two weeks [on the CSM campus] processing and interpreting the collected data.

One of the key requirements before geophysical data acquisition could begin was to understand the geology of the Upper Arkansas Basin. Led by "Dr. Bob" Raynolds of the Denver Museum of Nature and Science, we went on geologic excursions at the start of the field session. One of the key results of the field work was producing a geologic west-east cross section of the basin based on field observations. During field data acquisition, a 9.6 km 2D deep seismic line was acquired in the same trajectory as our cross section. When this seismic line was processed and interpreted, the initial predicted geologic section fit well with the interpretation of the seismic data.

Another main outcome of the field session was the importance of data integration. Integration of all available data: gravity, magnetic, resistivity and seismic data is fundamental to producing an accurate interpretation and understanding of geothermal activity in the local area. The field session also highlighted alternate local geothermal hot spots to focus on for future field camps.

Perhaps some of the most unforgettable field acquisitions were the DC resistivity with Dr. André Revil, which usually involved climbing the steepest hills with heavy reels of cables on our backs. We were all struggling to get used to the 7500 ft elevation at Mt Princeton, compared with almost sea level in London. Most found it quite rewarding though when great resistivity and gravity profiles were eventually produced.

For almost everyone, driving a twenty-three ton vibroseis truck was an awesome experience. Other highlights were spending a day visiting the Zapata water falls, the alligator ranch and SUN-EDISON's solar powered plant in the San Luis Valley.

It was an enlightening experience working and socializing with the Americans. They are all hard working, enthusiastic students and not to mention, outstanding leaders. All in all, the technical and personal experiences we have acquired will remain with us and be extremely useful for the rest of our careers

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