Now 30: Consortium sponsors

The Center for Wave Phenomena is very pleased to announce that four new companies joined the Consortium Project on Seismic Inverse Methods for Complex Structures in 2011, bringing the total number of sponsors to 30.

The new sponsors are (in alphabetical order): **Instituto Mexicano del Petróleo (IMP)**, **PDVSA Intevep**, **Repsol** and **Transform Software**. CWP thanks all consortium members for their ongoing support of our work!
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While generally focused on the task of subsurface imaging for exploration and production of hydrocarbons, the Center for Wave Phenomena is a culturally diverse group of people, with a diverse set of research interests. This diversity strengthens our research program. It ensures that our students and visitors experience both the freedom to choose research problems that suit them best and the responsibility to choose problems that are relevant to our sponsors. Financial support from and collaboration with those many sponsors makes this experience possible.

We look forward to you joining us.

Dave Hale, Ph.D.
Director
Center for Wave Phenomena
Colorado School of Mines
dhale@mines.edu
Roel Snieder to receive SEG Honorary Membership

By Ken Larner, CSM University Professor Emeritus

Eleven years ago, Roel Snieder could barely spell the word “exploration,” and this year he so appropriately is receiving the Society of Exploration Geophysicists (SEG)’s Honorary Membership Award.

In their SEG citation, Kees Wapanaar and Jerry Schuster state that Roel “is one of the most well balanced and highest achieving scientists that we have ever had the pleasure of knowing.” Sven Treitel goes further and writes, “it is Roel’s tendency to present the strong as well as the weaker side of an emerging technology that renders his work so valuable to the working geophysicist.” Roel’s recognition is not only for his highly innovative research, but also for his humanity - his dedication to make this world a better place on many fronts: scholarship, teaching, community and family. Roel aims to teach, in his words, “from the heart.”

Save the date! 2012 CWP Project Review Meeting

The 2012 annual meeting of the Consortium Project on Seismic Inverse Methods for Complex Structures will be held from May 14-17, 2012 at the Beaver Run Resort and Conference Center in Breckenridge, Colorado.

The Center for Wave Phenomena looks forward to welcoming representatives from our sponsor organizations and government agencies. CWP would like to thank all consortium sponsor companies and government agencies for their continuing support of our research work.

CWP will send meeting reminders for this meeting. Please contact CWP Program Assistant Pam Kraus at pkraus@mines.edu or by phone at 303.384.2178 if you have any questions or require additional information.
CWP announced in 2010 a strategic decision to expand significantly our High Performance Computing resources and to give computing a higher profile in our research and educational program. We decided to commit significant financial resources to acquire compute nodes on the Colorado School of Mines cluster called “mio,” which is administered by the Golden Energy Computing Organization (GECO). During CWP’s initial five-year commitment, we expect to continue and expand this program commensurate to our needs for HPC resources. We also continue in our efforts to encourage and support our students in strengthening their parallel scientific computing skills.

We are pleased to report that we have already implemented the first phase of this program. Last year, we acquired 192 compute cores on the aforementioned cluster. This year, we will continue with a second phase in which we plan to acquire at least as many cores as we did in the preceding year. Several CWP researchers are already taking advantage of this resource to support diverse projects, such as: wavefield modeling, imaging and tomography, wide-azimuth angle-domain imaging and wavefield-based micro-earthquake monitoring. More CWP projects, with growing student involvement, are being planned.

We gratefully acknowledge the consortium sponsors for their help and encouragement of our efforts. CWP looks forward to sharing our research results facilitated by this new computing resource with our sponsors in the near future.
Paul Sava was tenured and promoted to Associate Professor of Geophysics at the Colorado School of Mines. His position as an Associate Professor begins in the Fall 2011 semester. Prior to his new position, Paul was an Assistant Professor of Geophysics from 2006 to 2011.

Ilya Tsvankin and his longtime collaborator, Vladimir Grechka of Shell, have authored a new book called *Seismology of Azimuthally Anisotropic Media and Seismic Fracture Characterization*. The book presents a systematic analysis of seismic signatures for azimuthally anisotropic media and describes anisotropic inversion/processing methods for wide-azimuth reflection data and VSP (vertical seismic profiling) surveys. The main focus is on kinematic parameter-estimation techniques operating with P-waves as well as with the combination of PP and PS (mode-converted) data. The part devoted to prestack amplitudes includes azimuthal AVO (amplitude variation with offset) analysis and a concise treatment of attenuation coefficients, which are highly sensitive to the presence of anisotropy. Discussion of fracture characterization is based on modern effective media theories and illustrates both the potential and limitations of seismic methods. Field-data examples highlight the improvements achieved by accounting for anisotropy in seismic processing, imaging, and fracture detection. The book is published by the Society of Exploration Geophysicists (SEG) as part of the “Geophysical References Series” and is available as an eBook or in print edition from the SEG Digital Library at [http://library.seg.org/ebooks/seg/geophysical_references_series/177e](http://library.seg.org/ebooks/seg/geophysical_references_series/177e).

Roel Snieder was recognized recently with the 2011 Colorado School of Mines Excellence in Research Award. Following a competitive nomination and selection process, the CSM Offices of the Provost and the Vice President of Research and Technology Transfer jointly presented this prestigious award during the academic year to recognize active CSM research faculty members for their outstanding research accomplishments. Snieder’s selection was made on the basis of the significance and quality of his research and creative achievements, including: establishment of a thriving research program, support of student research efforts, outstanding research accomplishments that received national and/or international recognition, as well as enhancing the reputation of CSM through his research.

CWP welcomes Shingo Sean Ishida as its new Communications Specialist. Shingo joined the CWP in April 2011, following his previous position as a Health Communications Specialist at the Colorado State Department of Health and Environment. Read more about Shingo under “Greek symbols and late nights” on page 24 in this newsletter.

Pawan Dewangan, Ph.D., a 2005 CWP geophysics graduate, was awarded the prestigious Indian National Science Academy (INSA) Young Scientist Award for 2011. He was recognized in the Earth Science category for the significant contribution to the analysis and modeling of geophysical and geological observations. He was one of only three scientists who were presented with the Young Scientist Award. Pawan is currently a scientist at the National Institute of Oceanography in Goa, India (see his CWP Alumni article elsewhere in this newsletter). He also serves as the associate editor of the *Journal of Earth Science* (*JESS*) published by the Indian Academy of Sciences. His previous distinctions include his selection as the Young Associate of Indian Academy of Sciences in Bangalore, India in 2009. Congratulations, Pawan!
Continuing a tradition of excellence in geophysics research

By Shingo Sean Ishida

The 2011 annual meeting of the Consortium Project on Seismic Inverse Methods for Complex Structures ("project review meeting") was held on the Colorado School of Mines campus from May 15-18, 2011. The Center for Wave Phenomena welcomed 100-plus representatives from sponsor companies, government agencies and other organizations supporting CWP.

The meeting began on a casual and welcoming note, as CWP hosted an evening reception and social event for meeting attendees. The reception was the perfect setting for CWP research leaders, students and staff to extend a warm welcome to all. They all caught up with familiar sponsor representatives and met new ones, especially those who were attending the meeting for their first time.

Presentations by CWP research leaders and students focused on five key subject areas: seismic imaging, velocity estimation, interferometry, seismic anisotropy and image processing/interpretation. Each presentation was succeeded by a question-and-answer session that allowed meeting attendees to ask in-depth questions.

In addition, John Stockwell, CWP research associate, gave an update on CWP resources, including Seismic Unix (SU) and Roel Snieder presented an overview of the Center for Professional Education at CSM.

Meeting attendees also enjoyed guest presentations by John Washbourne from Chevron ("Tools every geophysicist should know") and Joe Dellinger from BP America ("Passive imaging at Valhall using 4C OBC data"). Both guest speakers provided attendees with very insightful (and simultaneously entertaining) presentations on interesting topics and allowed ample time and opportunity for questions and discussion.

The project review meeting concluded with the CWP Business Meeting and Technical Discussion, which addressed administrative issues at CWP, including the transfer of the director position from Roel Snieder to Dave Hale as of June 1, 2011.

CWP would like to thank all consortium sponsor companies and government agencies for their continuing support of our research work. We look forward to seeing everyone at the 2012 annual project review meeting!

Left to right: Dave Hale, Jon Sheiman of Shell, CSM University Emeritus Professor Ken Larner and his wife Nancy

Guest presenter Joe Dellinger captures the attention of (left to right): Filippo Broggini, Mamoru Takanashi, Nori Nakata (back to camera), Huub Douma of IonGeo/GX Technology and Chinaemerem Kanu

Left to right: Hongbo Zhou of Statoil, Paul Sava and Christof Stork of Halliburton/Landmark
CWP at 2011 EAGE Annual Meeting

CWP faculty Paul Sava and students Jeff Godwin and Mamoru Takanashi represented CWP at the 2011 EAGE meeting in Vienna, Austria, May 23-26, 2011. Mamoru and Jeff share their observations and experiences from this year’s meeting.

By Mamoru Takanashi

Many people regard Vienna as one of the most gorgeous cities in Europe. The city was the residence of the Imperial court for six centuries. Vienna now plays a key role on the world energy stage, as it is home to the headquarters of OPEC (Organization of Petroleum Exporting Countries) and IAEA (International Atomic Energy Agency). Our attendance at the 2011 EAGE meeting was the perfect opportunity to not only meet with top geophysicists from over the world, but to broaden our insights into world energy issues and challenges.

One of the main topics discussed during the 2011 EAGE was the development of unconventional energy resources in Europe. Since big energy consumers such as Germany and Italy decided to shut down nuclear power plants despite increasing world energy demand, unconventional gas and oil are expected to be among the most important resources in the coming decades. Europe is believed to have significant potential for unconventional gas and oil, although production from unconventional reservoirs is not yet as common as in North America.

Seismic-guided characterization and the monitoring of “unconventional” tight reservoirs are the key technologies for enhancing production. We presented methods that may potentially make characterization of tight fractured reservoirs more robust and it is our hope that our work can ultimately contribute to a more stable and balanced energy supply.

By Jeff Godwin

This year, I had the pleasure of traveling to Vienna, Austria to attend the 2011 EAGE 73rd Annual Conference and Exhibition to present a talk on microseismic imaging.

At the conference, I attended a number of interesting talks in full-waveform inversion, seismic processing, advances in seismic acquisition and electrical methods. It was very exciting to see how far the field can advance in a year in some of the subfields of exploration geophysics and how the popular opinion on certain areas of research can change from year to year. As always, the EAGE conference was a great place to make connections with new peers from around the world. I was actually quite surprised to see a different crowd at this year’s conference compared to last year, which meant there were lots of new faces!

Of course, I also explored the beautiful city of Vienna during my stay. I visited some stunning sights, including: Josef’s cathedral, Schonbrunn Palace and the Imperial grounds.

I was amazed by how culturally different Austria is, when compared to other places I have previously visited in Europe. My visit to Vienna was an enriching educational experience, from both a scientific and cultural perspective.
Demand high for Grechka and Tsvankin’s Seismic Anisotropy course

Anisotropic models have become a must in seismic imaging and characterization of fractured reservoirs

Ilya Tsvankin and Vladimir Grechka continue to co-teach their SEG Continuing Education Course called "Seismic anisotropy: Basic theory and applications in exploration and reservoir characterization."

Their course is in particularly high demand worldwide nowadays because anisotropic models have become common in seismic imaging (for example, for prestack depth migration in subsalt plays) and characterization of fractured reservoirs.

After teaching the course in New Orleans during the SEG Education Week, Ilya and Vladimir made back-to-back trips to Poland and Mexico in late May and June. Geofizyka Toruń, a Polish service company, invited Ilya and Vladimir to present an expanded version of the course and conduct training in anisotropic processing methods (Geofizyka Toruń group, above and right). The interest in employing anisotropy-based methodologies in Poland is fueled by the need to develop unconventional tight fractured reservoirs, especially gas-bearing shales.

The company is based in the picturesque 800-year old Gothic town of Torun, near Gdansk (below left) famous for being the birthplace of Nicolaus Copernicus (right) and for its delicious gingerbread. Ilya and Vladimir also had a chance to practice their native Russian, which is fluently spoken by many locals and has many similarities with Polish.

Ilya and Vladimir next taught their course in Puebla, Mexico, in conjunction with Congreso Mexicano del Petroleo (Mexican Petroleum Congress). To the instructors’ surprise, the classroom at a local university was a gorgeous hall decorated in the Baroque style (bottom left and right). The course was very well received by a diverse group of geophysicists and geologists, despite the need for simultaneous translation into Spanish.
The Colorado School of Mines (CSM) educates graduate students who will lead the way in industry, government and academia. As students acquire scientific and engineering skills, it is essential that they obtain other vital skills needed to perform well on the job after graduation. These other skills may directly support science or engineering activities (for example, written or oral communication) or they may support broader aspects of professional life, such as ethics.

Roel Snieder and Tom Boyd, CSM dean of graduate studies, founded a new Center for Professional Education. This Center brings together faculty from different departments with the aim of coordinating and optimizing professional education for graduate students. The Center currently offers the following graduate courses:

- The Art of Science;
- Fundamentals of College Teaching;
- Academic Publishing;
- Professional Oral Communication;
- Advanced Science Communication; and
- Introduction to Research Ethics.

The goals of the Center are to:
- first and foremost, develop more competitive graduates for careers in industry and academia;
- act as a clearing house and promotional vehicle for formal and informal offerings in professional development;
- expand course offerings for professional education;
- develop opportunities for faculty to enhance their skills so that they may better serve the needs of students;
- develop a vibrant research program in professional education;
- use the program in professional education to attract the best international and domestic students; and
- establish a world-class presence at Mines in engineering and science professional education.

The Center for Professional Education is received very favorably at CSM. W.M. Scoggins, CSM president, states:

"The Colorado School of Mines is committed to providing students with an exemplary graduate education experience. Through our Center for Professional Education, Mines graduate students have access to a wide array of resources and services designed to complement and enhance their formal technical education."

Future employers of Mines graduates will benefit from the professional training that CSM graduate students receive. We plan to make some of the courses available to industry; in fact, this is happening already with “The Art of Science,” provided as a short course at Saudi-Aramco, Shell and ExxonMobil. We see tremendous value in a partnership with industry for professional education. To discuss such a partnership in more detail, please contact Roel Snieder at rsnieder@mines.edu.
Teaching the Art of Science
Helping young researchers develop effective research habits

By Roel Snieder

In 2002, Roel Snieder started a new course called "The Art of Science." This course aims to help young researchers develop effective research habits. Graduate students traditionally learn about research by working under the supervision of an advisor, just as an apprentice would learn a trade under a master. In practice, this model either falls short in teaching students the skills needed to be an effective researcher or lead students to make mistakes that usually involve a loss of time in graduate school.

The Art of Science started out modestly with a handful of students; however, over the years the class has become so popular that about 60 graduate students per year take the class, or approximately 20 percent of all graduate students at the Colorado School of Mines. The topics covered range from the philosophical to the practical, and include: the philosophy of science, the choice of a research topic and advisor, the importance of asking questions, challenges and opportunities in research, oral and written communication, publishing a paper, time management, writing proposals, as well as the scientific career. The course notes have evolved into the book The Art of Being a Scientist that Roel authored with his co-author and CSM University Emeritus, Ken Larner. More information about this book can be found at http://inside.mines.edu/~rsnieder/Art_of_Science.html.

Roel's course consistently receives highly favorable evaluations from students. Students often express regret for not taking the course earlier because doing so would have saved them much time. A student from another university commented in the course evaluation as follows:

"I am glad I found this course early in my academic career. If only my university had required faculty members to come to your class! Thank you for putting all the things together which otherwise probably would have taken me years and many unfortunate incidents to figure out."

Apart from offering the class as a full semester course at the Colorado School of Mines, Roel and Ken offered the class as a short course at these universities: Stanford University, Tohoku University (Sendai, Japan), Delft University of Technology, Australian National University (Canberra, Australia), and King Abdullah University of Science and Technology (Jeddah, Saudi Arabia). They have also given a short course on The Art of Science in the research laboratories of Saudi Aramco (Dhahran), Shell, and ExxonMobil.
Sava invited to share his expertise at 2011 Madagascar school in China

CWP is among top contributors/users of the open-source package

CWP faculty Paul Sava participated as a co-instructor in the 2011 Madagascar School of Reproducible Computational Geophysics in Beijing, China.

Approximately 240 geophysicists from academia and industry attended this year’s school, hosted by the Institute of Geology and Geophysics of the Chinese Academy of Sciences.

Over a period of two days, the participants were introduced to the Madagascar open-source package through hands-on exercises constructed in collaboration with colleagues from the University of Texas at Austin, King Abdullah University of Science and Technology (KAUST), the University of Western Australia and Jilin University.

As stated on its website (www.ahay.org), “Madagascar provides a complete environment for organizing one’s research, from new software development to running computational experiments to publishing the experimental results in papers and reports, archiving them for future usage, and sharing them with colleagues and sponsors.” Paul Sava and his students at CWP are among the top users and contributors to this open-source package, focusing mainly on the code used for wavefield modeling and imaging.

Congratulations to 2011 CWP graduates!

Congratulations to CWP graduate students Tom Cullison and Chris Engelsma, who received their Master of Science degrees at the 137th Annual Commencement ceremony at the Colorado School of Mines on May 13, 2011.

Tom received his degree in Mathematics and Computer Sciences, while Chris’ degree is in Geophysics.

Since graduating from CWP, Tom has been employed by the Hess Corporation in Houston, Texas, while Chris is working for the Chevron Energy Technology Company, also in Houston.

Congratulations, Tom and Chris! All the best in your future endeavors!
CWP Research

NMO ellipse for a stratified medium with laterally varying velocity

By Mamoru Takanashi

Robust estimation of anisotropy parameters is one of the most important problems in velocity analysis and fracture characterization. Lateral heterogeneity (LH) on a scale smaller than spreadlength, often associated with velocity lenses (such as channels and reefs) in the overburden, can significantly distort anisotropy parameters even for gently dipping structures (Figure 1). Extending previous work by Grechka and Tsvankin, we presented a general analytic expression for the NMO ellipse in a stratified anisotropic medium with an arbitrary number of LH layers.

The distortion of the effective NMO ellipse is caused primarily by quadratic lateral variation of the vertical velocity and traveltime, and the errors typically increase with the distance between the target and an overlaying LH layer. Because of the depth dependence of the distortion, application of the generalized Dix equation can significantly amplify the LH-related elongation or compression of the effective ellipse (Table 1). To obtain an accurate interval NMO ellipse in the reference homogeneous medium, the influence of LH on the effective NMO ellipses should be removed before applying Dix differentiation. The correction for LH requires estimating the circular (isotropic) approximations of the interval NMO velocity for all layers, as well as the second horizontal derivatives of the interval vertical traveltime in the LH layer(s).

The method is applicable not just to transverse isotropy, but also to lower-symmetry (orthorhombic and monoclinic) media with a horizontal symmetry plane. The correction term, however, may become inaccurate if anisotropy or lateral heterogeneity is strong, or when the model contains dipping or curved reflectors. In addition, to account for lateral velocity variation in nonhyperbolic moveout inversion of long-spread wide-azimuth data, we proposed an efficient prestack correction algorithm that involves computation of the LH-induced traveltime distortion for each recorded trace.

Figure 1 - Stratified HTI model with an isotropic LH layer (left) and the velocity surface in the LH layer (right).

<table>
<thead>
<tr>
<th></th>
<th>Interface 3</th>
<th>Interface 4</th>
<th>Interval (layer 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analytic (%)</strong></td>
<td>7.3</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td><strong>Numerical (%)</strong></td>
<td>8.1</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td><strong>Background (%)</strong></td>
<td>3.5</td>
<td>4.9</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Table 1 - Eccentricity of the effective NMO ellipses for interfaces 3 and 4 and that of the interval NMO ellipse for layer 4 from the model in Figure 1. The azimuth of the major axis of all NMO ellipses is 45°. The numerical values are obtained by finite-difference modeling. The background ellipses are computed in the reference laterally homogeneous median.

Mamoru is a CWP Ph.D. student who works with Dr. Ilya Tsvankin. He joined CWP in August 2008 after working for 10 years for the Japan Oil, Gas and Metals National Corporation (JOGMEC) where he was in charge of imaging and anisotropy research projects for oil and gas fields. Mamoru’s current research interest is in anisotropic parameter estimation in the presence of lateral heterogeneity. Read his other article under “2011 EAGE Annual Meeting” on page 9 in this newsletter.
Geophysicists have used full waveform inversion (FWI) for decades to retrieve quantitative models of the subsurface from recorded seismograms. FWI, however, may generate geologically imprecise models and may be impractically expensive for estimating large-size models.

For example, we want to invert for the Marmousi II velocity model, given an initial model in Figure a and a band-limited data set (peak frequency 12 Hz, effective band 3-27 Hz, and 11 shots). We invert the entire frequency band simultaneously.

Under the guidance from my CWP advisor, Dave Hale, I work on image-guided FWI that employs subsurface structures as constraints and therefore, produces geologically sound models. Figure b below, a migrated image, can apparently provide the structural constraints (orientation, coherence, etc.). The yellow dots in Figure b represent a sparse model space, where image-guided FWI is posed as a sparse optimization. In this sparse space, FWI inverts for substantially fewer parameters and so quasi-Newton methods become feasible.

We implement a quasi-Newton method by using a projected BFGS method to construct a projected Hessian matrix. The projected Hessian built in this manner significantly reduces both computation time and memory consumption.

Figure c shows the eigenvector of a projected Hessian matrix, corresponding to the largest eigenvalue. This eigenvector indicates a part of the model that can be best determined by FWI. Likewise, Figure d (below, top) shows the eigenvector that corresponds to the smallest eigenvalue, indicating a part that can be least well resolved. Figure e (below, bottom) is the quasi-Newton estimation in the 10th iteration of image-guided FWI. It recovers the Marmousi II model well.

Yong is a CWP Ph.D. student who joined CWP in August 2007. He is working on image-guided full waveform inversion with his current CWP advisor, Dr. Dave Hale. In summer 2009, 2010 and 2011, Yong interned at ConocoPhillips in Houston, Texas, to work with geophysicists in the Seismic Velocity Modeling group on a full waveform inversion project. He authored this article during his summer internship at ConocoPhillips, where he had the opportunity to test his method on real data.
Velocity model building methods using full seismic wavefields have been recently gaining more attention, because of their ability to construct more accurate models of the subsurface. As the computing power increases, it is becoming more feasible to effectively research and develop these methods.

Conventional waveform inversion is a data-domain method, in which the velocity model is constructed by minimizing the difference between recorded and simulated seismograms. Alternatively, we may instead formulate the inverse problem in the image domain, and construct the velocity model by optimizing image gathers.

Figures 1 and 2 show an example of the image-domain waveform inversion. Figure 1a shows the true model, which contains a low velocity Gaussian anomaly and a reflecting interface, and Figure 1b shows the image migrated using a smooth background velocity model, which we also use as the initial model for the inversion.

To evaluate the correctness of the initial model, we first construct common-image-point gathers (CIPs) along the reflector at locations indicated by the dots in Figure 1b. Compared to the more conventional common-image gathers (CIGs), which sample image points more densely in the vertical direction than lateral direction, CIPs are not biased toward any direction and can provide additional velocity update information from steeply dipping reflectors in the model.

Figure 2 shows the gradient of the objective function computed using different groups of CIPs, indicated by the dots. Notice that the CIPs located on the horizontal reflector (Figure 2a) provide higher resolution laterally, whereas the CIPs located on the vertical reflector (Figure 2b) provide higher resolution vertically. To fully resolve the Gaussian anomaly (Figure 2c), we must use all CIPs.

Tony is a fourth-year CWP Ph.D. student and works with Dr. Paul Sava. In summer 2009, Tony interned with Statoil in Norway, working on the implementation of WEMVA based on the time-shift imaging condition. In summer 2010, Tony interned with ConocoPhillips in Houston. His project mainly focuses on differential semblance optimization with common-image-point gathers. Tony makes extensive use of Mio, one of Colorado School of Mines’ high-performance computing clusters, which hosts nodes acquired by CWP. Read more about Mio in Dr. Sava’s article on page 6.
The Tohoku-Oki earthquake (MW9.0) on 11 March 2011 is one of the largest earthquakes in recent times, and the resulting tsunami caused much damage in Japan including its nuclear reactors. This unprecedented earthquake has weakened the soil in the near surface throughout northeastern Japan.

We analyze earthquake data from 1 January 2011 to 26 May 2011 recorded by KiK-net, the strong-motion network operated by NIED in Japan, to measure shear-wave velocities. Each station has two seismographs at the surface and the bottom of a borehole, a few hundred meters deep. By applying seismic interferometry to these two sensors, in which we deconvolve the seismogram at a top receiver with that at a bottom receiver, we retrieve the shear wave propagating from the bottom sensor to the top sensor at each station and then compute shear-wave velocities.

Using velocities of all available stations (blue dots on the map), we create shear-wave velocity maps before (1 Jan. - 10 Mar. 2011) and after (12 Mar. - 26 May 2011) the Tohoku-Oki earthquake (“Before” and “After” maps in the figure). By subtracting the “Before” velocity from the “After” velocity, we obtain the map of the relative velocity change after the Tohoku-Oki earthquake (“Difference” in the figure).

As shown in the figure, the shear-wave velocity was reduced by about 5% after the Tohoku-Oki earthquake over an area in northeastern Japan about 1,200 km wide. The reduction in the shear-wave velocity is delimited on the western side by the known tectonic lines (the dashed lines in the figure). The shear-wave velocity is related to the shear modulus, which measures the strength of the soil; hence the reduction of the shear-wave velocity over northeastern Japan implies that the Tohoku-Oki earthquake reduced the shear strength of the near surface throughout northeastern Japan.

Nori is a CWP visiting scholar from Kyoto University in Kyoto, Japan, where he is a Ph.D. candidate. Nori currently works with Dr. Roel Snieder at CWP, with whom he also worked in 2009 when he was visiting CWP for two months. Nori’s research interests are: seismic interferometry, inverse scattering and signal processing. Read his other article under “CWP visiting scholar reflections” on page 23.
Since its inception, CWP has nurtured many graduate students majoring in geophysics and math. CWP alumni have gone on to work in diverse fields for various employers and do some amazing things. CWP alumni Phil Anno, Matt Haney, Pawan Dewangan and Kurang Mehta share their experiences and thoughts.

By Phil Anno, Ph.D.

I currently hold a position as Principal Research Scientist for the Subsurface Technology Center of ConocoPhillips. In my latest role I have organized and now lead a new computational science initiative. The mission of the initiative is to research and develop disruptive technology that can be applied across a broad spectrum of our upstream and downstream business areas – reservoir modeling, computational fluid dynamics, commercial trading, geophysics, geomechanics – to name a few. We treat computational science as a sort of numerical laboratory for discovery and innovation, analogous to a physical lab.

I also travel and consult for ConocoPhillips businesses worldwide, bringing many of these problems back to the Technology Center for additional investigation. I have the pleasure of working with people from many different countries, races, and faiths. As a graduate student I found the cultural "stew" at the Center for Wave Phenomena to be equally stimulating.

The Center for Wave Phenomena was where I first experienced a world class research environment. The faculty under whom I studied and the students with whom I studied left an indelible imprint on me for how science should be done, as well as how people should work together. For those who are considering CWP for graduate education, I believe you will find it to be a great springboard into a life of scientific discovery, rich in cultural stimulation, where much can be learned about the art of being a scientist.

Phil Anno graduated from CWP in 1993. He is currently employed by ConocoPhillips at the ConocoPhillips Subsurface Technology Center in Houston, Texas, USA.

By Matt Haney, Ph.D.

My current work focuses on the chain of volcanoes along the Aleutian Trench, a subduction zone at the southern edge of Alaska. The trench forms the boundary between the Pacific Plate and the North American plate. Over 40 Alaskan volcanoes are classified as active, meaning that they have erupted at least once in the past 300 years. The goal of my research is to provide improved forecasts and assessments of volcano hazards to the public. Of particular concern in Alaska is the impact of airborne volcanic ash on aircraft.

I have significant experience responding to volcanic eruptions, having been part of the official response teams during eruptions at Pavlof Volcano (2007), Kilauea Volcano (2008), Okmok Volcano (2008), Kasatochi Volcano (2008), and Redoubt Volcano (2009). I have also deployed a temporary network of 4 broadband, three-component seismometers at Hekla Volcano in Iceland that acquired seismic data during 2009 and 2010.

At my job, half of my time is spent on research and the other half on seismic network operations. A major part of my research involves the interpretation of low frequency seismic waves for discovering volcanic structure and the dynamics of volcanic sources. I am particularly interested in volcanic tremor and very-long-period seismic radiation during eruptions. The study of these phenomena requires a strong understanding of seismic wave theory, something I gained in spades while a student at the Center for Wave Phenomena (CWP). Recently, I have also become involved in research on low frequency sound waves, known as infrasound, and the synthesis of models based on seismic and deformation (e.g., GPS and InSAR) data. I also help maintain the network of approximately 200 seismic stations operated by the Alaska Volcano Observatory and help manage the seismic data acquisition system that allows the data to be analyzed in real-time.

My advice to students is to bring a great deal of intensity to your work. This is easiest when you are working on something you are passionate about. The group of people at CWP can help you discover what you are passionate about and expose you to skills and research techniques that will be of considerable benefit to your career.

Matt Haney graduated from CWP in 2005. He is currently employed as a Research Geophysicist with the U.S. Geological Survey at the Alaska Volcano Observatory in Anchorage, Alaska, USA.
I am currently employed by Shell: working in the research laboratory located in Houston, TX, USA. My current research focus is on integrated time-lapse interpretation using downhole seismic and in-well temperature data. For a field in South Oman where steam injection based EOR is pursued, we have a suite of time-lapse in-well and downhole seismic (3D VSP and cross-well) datasets. These datasets are used in integration to monitor the extent of the injected steam. The ultimate goal of this project is to continue monitoring the steam front using time-lapse datasets at regular intervals. This is the first thing I learnt at CWP: always be ready to learn new things.

At CWP, I worked with Dr. Roel Snieder for my Ph.D. program. My dissertation focus was on seismic interferometry (also referred to as the virtual source method). Apart from learning exhaustively about geophysics and seismic interferometry, during those four years of my Ph.D program I went through a very comprehensive personal development. Given that I am a geophysicist by background, I view this project as an excellent opportunity for me to learn about other disciplines.

This is the first thing I learnt at CWP: always be ready to learn new things.
What did you say?

Effective communication and collaboration

By Diane Witters

Effective communication is the “oil” that keeps the machinery of a team running smoothly. If you work among people of different nationalities – whether in industry, the service sector, a government office, or an educational institution – you perhaps know that international collaboration presents both the challenge and the opportunity for developing strong communication skills and cross-cultural sensitivities. I’ve had the privilege of working with students and faculty in the dynamic academic and research environment of CWP where we have great opportunities to grow as a cross-cultural team. Here I offer a few of the evolving tips and related questions that continue to guide my work. If you have experiences or ideas that you’d like to share on this topic, I would enjoy hearing from you.

- **Realize that the cultural background of our international colleagues may be shaping their perspective, responses, and habits.** Rather than be offended or frustrated by surprising behavior or words, consider the cultural context behind them. Is there a place for these differences in your work or academic environment? Can you introduce protocol by example or reinforce do’s and don’ts with an explanation that conveys appreciation for the transitions that your colleague is negotiating? If your own culturally-induced behavior or attitude is out of sync with your surroundings, can you make the needed adjustments by careful observation and thoughtful integration of new ways of thinking and doing?

- **Try communicating your trust in a colleague’s capabilities and watch the “magical” effect this can have on performance.** Have you ever had the experience when someone you admire has had confidence in your ability (even when you lacked confidence in yourself) and you strove to rise to the occasion and live up to their high expectations?

- **Recognize that expressing honest opinions and differing viewpoints may be difficult for some, especially if they come from a culture where authority figures are the only ones allowed to formulate direction for a group.** Is a diversity of perspectives and the exploration of alternatives encouraged in your setting? How can we create an environment of mutual trust that respects the ultimate decision-makers but also welcomes questions, polite disagreement, and creative solutions for the good of the team?

- **Words can take on strange and unexpected meaning as they leave a mouth and travel to an ear.** Just because you’ve said something, don’t assume that your listener has heard and clearly understood exactly what you intended. Conversely, as a listener, confirm the accuracy of what you’ve heard. Check and double check for clarity on expectations, intentions, and priorities. Reinforce important points in a variety of ways (for example, by writing them down, reformulating them using fresh words, revisiting them in subsequent meetings, or asking a listener to paraphrase them.)

- **When a colleague falls short of expectations, consider the difference between reacting (which is often triggered by anger or resentment) and responding (which implies more thoughtful, measured, deliberate communication and is designed to bring about a desired outcome).** Can you

(continued on page 22)
Where does my year go?
A year in the life of CWP’s program assistant

By Pam Kraus

Where do I begin? My job never seems to be the same and that is what I like about it. I work with three different calendars; one is the regular calendar, January 1st – December 31st, another is our fiscal year calendar July 1st – June 30th and yet another is our Consortium calendars, either January 1st – December 31st or June 1st – May 31st.

I begin January with preparations to discuss the schedule for the Annual Project Review Meeting. I also start receiving signed agreements back from those that were mailed out in November. At the end of every month, I reconcile the budget for that particular month.

February begins with designing, printing and mailing out the annual meeting notice to all Technical Representatives, CWP Alumni and Government Agencies.

In March I start working on summer contracts for those students who are staying on campus. I first need to ask faculty about their students and by which account they will be funded.

April is busy with mailing out the consortium agreements for those with June sponsorships, finalizing the agenda for the annual meeting, arranging and posting student rehearsal schedules, sending student summer contracts to HR and ORA for approval, setting the staging area for all resources and materials to be used at the annual meeting, finalizing logistics like menus and room set up for the annual meeting.

In May I need to have all handouts going in folders printed, make sure all nametags are printed, give final counts to catering and attend the annual meeting. Once the meeting is over, I finalize all billing and pay for the meeting.

In June I prepare the mailing of the project review book and USB drives containing other materials. June is also the end of the Fiscal Year, so I need to make sure that everything is paid from the correct budget. If there are any discrepancies, I need to contact the Controller’s Office and then create Journal Entries with the correct information.

In July, I need to send the Annual Financial Report to all Consortium Tech Representatives. SEG registration begins in July so I contact all CWP students and faculty for their registration preferences (for example, short courses and workshops), as well as housing, which requires that I create a student rooming list and then make reservations for them, in addition to making all travel arrangements. I also create fall student contracts, so I need to ask the faculty about funding for each student and arrange to conduct background checks on all new graduate students joining the CWP.

In August I design the seating arrangements with CWP for current and incoming students. I also contact the hotels for proposals to host the annual meeting. I need to let them know our choice for the next annual meeting. I reserve a meeting room at the venue of the next SEG meeting, develop the logistics, set the food and drink menus and mail postcards with details to our sponsors and stakeholders. Classes at the Colorado School of Mines begin in August so I work with all the new CWP students to show them where they will be sitting, where on campus they need to go get their paperwork done, receive their student ID and key requests, etc. If we have any CWP visiting scholars, I need to do the same for them.

With SEG taking place in San Antonio this year, I need to meet with all students and let them know about what to wear, what receipts to collect and everything that has to do with travel to San Antonio. I also need to get everything shipped to the hotel for our Semi-Annual Meeting. After returning from
address the problem with the particular project at hand without degrading the person? To keep standards and the quality of work high, it’s important to honestly convey that a colleague has missed the mark on an assignment; however, we can consider how our choice of words and tone (the attitude that our voice expresses) impacts the way our colleague receives and attends to our message. What will motivate others in our group to try harder or perform at a higher level? How can we highlight each other’s potential, progress, and efforts as well as address shortcomings?

- Avoid sending mixed signals. Conflicting messages and confusion can result when you allow a changing mood to color your view – or your verbal characterization – of a colleague’s work. Whether you feel stressed or happy or somewhere in between, if you can catch the influence of your own state of thought on your judgment and feedback, you can give yourself a moment to evaluate the situation with less emotion and more care and consistency.

- In conversation, practice the art of truly listening and interactively responding. This can involve pausing (even perhaps taking a deep breath) and reflecting on what a colleague has just said, rather than focusing on a preconceived message you want to get across. Empathy for another’s position can go a long way toward mending dysfunctional professional relationships.

- Consider the role that good humor and simple appreciation for another can play in your environment. Try to occasionally connect with those who are different from yourself in personality, style, or interests. Rather than hold a grudge or expect a difficult encounter, give your colleagues a “clean slate” and let them surprise you.

Upgrading our communication skills isn’t necessarily easy, especially in an environment where we are pressed for time, have multiple obligations, and are comfortable with our own habits. But as I’ve worked with students and their advisors on the points mentioned above, I’ve seen flexibility and a willingness to try new ways of connecting with each other bring definite rewards. Within any group, improving the quality of communication – and thereby enhancing relationships – can lighten the atmosphere, motivate others to give their best, increase productivity, help bridge an occasional disconnect, create an appreciation for diversity, and foster the personal growth of individuals on the team.

_What did you say? (continued)_

Diane is CWP’s writing consultant. She offers technical writing and oral presentation workshops and supports CWP students as they develop into more confident and effective writers, presenters, and collaborators. Diane encourages cross-cultural sensitivity on campus and helps international graduate students negotiate various transitions to successfully acculturate within a new academic environment. She welcomes your feedback at dwitters@mines.edu.

Where does my year go? (continued)

SEG, I need to collect all receipts and get the students and faculty reimbursed. Also I need to pay the final bill for the Semi-Annual Meeting. If SEG is in October, it will be the same as September. I start preparing Consortium Agreements for those that renew in January.

November begins with the mailing of letters and agreements to the Tech Representatives for continuing their consortium membership. November also has me working on the spring contracts for the students.

December is the quiet month with graduation and Christmas Break.

Then it starts all over again. My job is never boring and I do enjoy my work in CWP.

_Pam is CWP’s program assistant. She has been managing the Center for Wave Phenomena office since she came to CWP in January 2009. Pam enjoys spending time with her husband Dave, her family & friends, going to Colorado Rockies baseball games, watching NASCAR, as well as co-chairing Advancements for Boy Scout Troop 527 in Aurora, Colorado._
CWP visiting scholar reflections

My second visit to CWP
By Nori Nakata

As of the end of September 2011, I will have completed working at CWP for another year. This is my second visit to CWP and I very much enjoyed my time here. I came back to Colorado after I received my Master of Science degree in Japan. This time around, I was here for 10 months.

During this visit, I had many unforgettable experiences: a presentation at the CWP annual project review meeting (right), engaging discussions with friends and faculty at CWP, studying English, and a marvelous camping/hiking trip to the Grand Canyon.

The biggest surprise to me during my visit of CWP is that the Center employs four faculty members, each working on very different research topics. In addition, CWP has an important group of support staff who work with 20-plus students: a program assistant, a publication specialist, a research associate, as well as a writing consultant. It is interesting that CWP students are allowed to choose their favorite research topics and may change them if needed, as they devote themselves to their research.

I am tackling several research topics that are related to seismic interferometry with Roel Snieder, one of which is introduced in this CWP newsletter. My research topics extend across exploration geophysics and crustal seismology. I really enjoy my research work and I am very excited to working with Roel because his knowledge is vast and he has a friendly supervising style to his students. I hope I have the opportunity to return to CWP for a third visit.

Nori is a CWP visiting scholar from Kyoto University in Kyoto, Japan. Read his research on the weakening of the near surface in Japan after the Tohoku-Oki earthquake under “CWP Research” on page 17.
Thanks for reading our 2011-2012 newsletter. I hope you got as much fun and interest out of it as much as I had putting it together.

By the time you read this, a few months will have passed since I began working as the communications specialist at the Center for Wave Phenomena at the Colorado School of Mines. I succeeded an amazing CWP asset called Barbara McLenon. She is not an observably large person; yet she left me a HUGE pair of shoes to fill.

I admit that my first impression of CWP was something akin to university fraternities and sororities (students in and out all the time, Greek symbols floating around everywhere, etc.), so imagine my surprise when I grasped the reality of CWP: a wonderfully enthusiastic, diverse and rewarding research environment. As Dave mentioned earlier in this newsletter, CWP is a very culturally diverse group with a wide array of research interests. I would readily add that everyone here is very passionate about the research they are doing.

In addition to all the media and communications work I do here at CWP, it is also my priority to ensure that CWP research, publications, accomplishments - our everyday work - go out the door and into your hands. I aim this newsletter as one method to achieving that end and it provides you with a peek of what goes on within our walls everyday (and often, late into the nights).

This newsletter contains articles that tell stories about CWP – all of which define our people, research and our collective approach to relevant research for our consortium members and sponsors. CWP’s distinctive faculty and students, research areas, as well as our innovative approaches, truly set us apart from other organizations and contribute significantly to strengthening our sponsors’ stake in our work. It is my objective to communicate the CWP story via this newsletter in an interesting and professional manner, increase our name recognition and accompanying reputation, stoke our sponsors and stakeholders’ interest, as well as continue our strong commitment to a long tradition of excellence in geophysics research.

You have thoughts and suggestions regarding this newsletter? Or about the CWP? Or anything else of interest to you that you would like to see in a future newsletter? Send them on. Priority consideration will be given to all article submission requests!

I really enjoy my work here at CWP, so - please - happy reading. Greek symbols notwithstanding.

Sincerely,

Shingo Sean Ishida
Communications Specialist
Center for Wave Phenomena
Colorado School of Mines
sishida@mines.edu