

# CWP Commits to High Performance Computing

The Center for Wave Phenomena is pleased to announce a significant investment in developing our High Performance Computing capabilities. This initiative follows on a broadly-supported proposal made to the CWP sponsors at the Annual Meeting in May 2010.

In several phases spread over the next few years, we will acquire a significant portion of a large computer cluster that is administered by the Golden Energy Computing Organization with support from the Colorado School of Mines. This computer cluster is shared by several groups at Mines with each research group receiving computing time proportional to the number of cores contributed to the machine. This year CWP is adding 192 compute cores and over the next few years we plan to sustain a similar growth trend, leading toward 500-1000 compute cores.

This expansion in the area of High Performance Computing is motivated by our interest in addressing some of the wave propagation and imaging challenges that are central to our research portfolio.

The computer cluster "RA" housed on the Colorado School of Mines campus and administered by the Golden Energy Computing Organization (GECO).

This new computational tool will enable us to pursue research relevant for velocity analysis and imaging of wide-azimuth 3D data in complex geologic environments, which is one of the key areas of interest for our research sponsors. We also anticipate that this increased computing capability will enable us to greatly expand our research in wavefield tomography and inversion.

This cluster will help us educate our students in modern computational methods, thus preparing them for what we anticipate to be required skills in the future, while leveraging faculty expertise already available in our group.

Many thanks to our sponsors for their continuing support of our research and educational mission.

— CWP Faculty



CWP faculty Ilya Tsvankin, Dave Hale, Paul Sava, Roel Snieder, and Research Associate John Stockwell.



# Behura & Tsvankin Awarded Best Paper

**CWP** graduate Jyoti Behura along and professor Ilya Tsvankin have been selected to receive SEG's Best Paper in Geophysics Award to be presented at the SEG's Annual Meeting in Denver. "It is an impressive achievement for Jyoti to receive this award for a paper written when he was in graduate school," states Tsvankin, Jyoti's Ph.D. advisor. Jyoti completed his degree in May 2009 and is a geophysicist with the Imaging Research and Development team of BP America, Inc., Houston.

The paper, "Role of the inhomogeneity angle in anisotropic attenuation analysis," presents a thorough treatment of a complex wave-propagation problem with far-reaching implications in seismic inversion. The possible influence of the so-called inhomogeneity angle (the angle between the directions of wave propagation

and maximum attenuation) on attenuation coefficients had long confounded inversion and interpretation of seismic attenuation measurements even in isotropic media.

The fundamental result obtained by Jyoti and Ilya for arbitrarily anisotropic media is that the

group attenuation coefficient measured from seismic data is practically independent of the inhomogeneity angle and reflects the intrinsic attenuation of the material. This conclusion provides a basis for using directionally-dependent attenuation coefficients in fracture characterization and lithology discrimination.



May 2009 CWP graduate Jyoti Behura with his Ph.D. advisor Ilya Tsvankin.

## 2010 CWP Annual Meeting: 26 Years of Progress

*The 2010 CWP Annual Project Review meeting stayed home this year, gathering attendees on the Colorado School of Mines campus, May 17-20. Keen observer and invited speaker Sven Treitel shares his impressions of the meeting.*



Not long after I had first met the inseparable pair of Norm Bleistein and Jack Cohen I learned of their

desire to move to the Colorado School of Mines and to establish an industrial consortium on its campus. What I particularly liked about these two mathematicians is that they actually wanted to listen and learn about which geophysical problems were interesting and important, rather than to merely throw theory over the wall in the stochastic hope that some geophysicist might see it, grab it, and run. Along with a few other R&D people in the industry, I helped Norm and Jack found CWP. It began in 1984 with a faculty of four: Norm Bleistein, Jack Cohen, John DeSanto, and Frank Hagin. Since then, CWP has thrived and evolved beyond all reasonable expectations.

Having had some part in the founding of several such consortia in our industry, I developed an interest in what one might call "the pathology of consortia"

— why is it that some thrive, while others wither on the vine? During recent years, I was lucky enough to participate in several CWP project review meetings. What strikes me most and what is in such stark contrast with my own grad school experience is the nurturing and caring environment the present CWP faculty provides for its students, be they grads or undergrads. I can see not only why an undergraduate at CSM would develop a passion for geophysics, but also why the student might later choose to work toward an advanced degree. Clearly the CWP faculty's passion for our field is contagious; and the students are all infected.

At CWP the emphasis is not only on pure academics and the need for mastery of the mathematical and physical underpinnings of our field. Emphasis is also on a student's ability to write clearly and to deliver a coherent technical message with slide contents visible by those in the back of the room. Students can take a course in the ethics of research, along with other issues a scientist often faces in the workplace. Roel Snieder and Ken Lerner recently published a book on the subject, "The Art of Being a Scientist" (Cambridge Univ. Press, 2009). CWP students not only learn that good science is crucial; they also learn that good science must be "marketed" (I beg forgiveness for using this cliché) to make an impact.

I can't possibly do justice to all the exciting material that was presented at the 2010 Project Review meeting, so let me

— Sven Treitel

just paint a broad picture. I should first mention an outstanding tutorial by Gerhard Pratt (University of Western Ontario) on the practicalities of seismic inversion; luckily, Gerhard gave a lucid, jargon-free presentation even though he had not taken Roel's course!



Short course presenter Gerhard Pratt (University of Western Ontario) and his wife Bernadette.

The CWP talks were divided into five broad categories: seismic imaging, velocity estimation, image processing and interpretation, interferometry, and seismic anisotropy. These topics pretty much span the interest spectra of the present full-time CWP faculty, along with its two "retired" members (Norm Bleistein and Ken Lerner), who in actuality are an ongoing disgrace to the "retired professor" category.

I learned from Roel Snieder that the new field of seismic interferometry is still undergoing growing pains: its practical implementation is not yet fully developed. Paul Sava talked about some new and intriguing imaging conditions; Dave Hale and his students continue to carry out innovative work in geophysical image processing; Ilya Tsvankin and students are looking into anisotropic imaging algorithms and into the use of anisotropic pa-

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# Looking Ahead: 2011 CWP Project Review Meeting

## Revised Format Accommodates Travelers – Save the Dates

CWP has revised the format of the 2011 Annual Project Review meeting to better accommodate those traveling to other professional meetings that are closely scheduled during the spring and early summer. The dates of the 2011 CWP meeting are Monday, May 16 through Wednesday, May 18.

Deviating from recent years, there will be no tutorial prior to the meeting. In place of the tutorial, meeting sessions will begin Monday afternoon, followed by a reception Monday evening. Sessions will continue throughout Tuesday and Wednesday. The meeting will conclude Wednesday evening.

Those who have attended the annual meetings appreciate the quality of the



CWP students Tom Cullison and Francesco Perrone during a session break at CWP's 2010 Project Review meeting.

presentations and the opportunity to exchange ideas and experiences with colleagues. Colin Thomson of Schlumberger Cambridge Research says,

“The CWP meeting is always regenerating.”

## CWP News Briefs

**Roel Snieder** was recently elected a foreign member of the Royal Netherlands Academy of Arts and Sciences. At CSM, Roel is the W.M. Keck Distinguished Professor of Basic Exploration Science and is also the current director of CWP.

For his “notable and meaningful accomplishments” in the offshore oil and gas industry, University Emeritus professor **Ken Larner** has been elected to the Offshore Energy Center’s Hall of Fame in the category “Search for Oil & Gas: Three Dimensional Subsurface Imaging.”

In spring 2010, Professor **Dave Hale** was chosen by graduating GP students to receive the Outstanding Faculty Award for geophysics.

In November 2010, University Emeritus professor **Norm Bleistein** will present the seminar “Reflector Maps and Earth Parameter Estimation from Seismic Data: From Ruler and Compass Construction to Gaussian Beam Propagators,” at the Courant Institute of Mathematical Sciences.

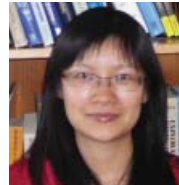
**Roel Snieder** has made numerous trips to present his talk “The Global Energy Challenge,” including a presentation at The Australian National University as part of the Toyota-ANU Public Lectures Series 2009.

**Paul Sava** continues to offer his short course on Wavefield Seismic Imaging. Dur-

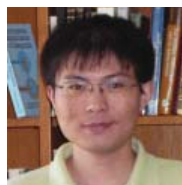
ing summer 2010 his destinations included Romania, France, and Japan. For information visit <http://newton.mines.edu>.

At the Annual SEG meeting in Denver, **Ilya Tsvankin** will present his Continuing Education Course “Seismic Anisotropy: Basic Theory & Applications in Exploration & Reservoir Characterization.”

CWP students **Yongxia Liu** and **Yong Ma** completed master’s degrees in geophysics during spring 2010. Yongxia’s thesis under advisor Ilya Tsvankin is entitled, “Gaussian beam modeling in heterogeneous anisotropic media.”



Yongxia Liu

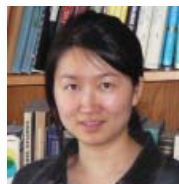


Yong Ma

Yong Ma’s thesis under advisor Dave Hale is entitled, “Full waveform inversion with image-guided gradient.”

In August, **Jia Yan** successfully defended

her Ph.D. thesis, “Wave-mode separation for elastic imaging in transversely isotropic media.” She was co-advised by Paul Sava and Ilya Tsvankin. Jia will join ExxonMobil.



Jia Yan

Jon Sheiman of Shell comments,

“[The CWP meeting] gives me a chance to get into an intellectual pressure cooker with the real thought leaders in geophysics, and lots of strong young minds.”

The Colorado School of Mines campus will again be the meeting site with lodging available in nearby downtown Golden. Specific lodging and travel information will be sent to sponsors early in 2011.

If you are a member of a sponsor company, please save the date and make plans to join us.

## Sven Treitel: 2010 CWP Annual Meeting

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rameters to characterize reservoirs; while Norm Bleistein is working on a forthcoming book on Gaussian beams. To me one of the highlights of every CWP meeting is John Stockwell’s listing of what’s new in his ever-growing seismic software collection. I then feel like the proverbial kid in the candy store: I’d like to run all those nifty programs as soon as I get back to my computer, but then realize that the day is but 24 hours long, some eight of which are devoted to sleep.

And last, but by no means least, this year’s CWP meeting ended with a dinner in celebration of CWP co-founder Norm Bleistein’s 70th birthday—well, it was actually his 71st, but then mathematicians can’t count (see back page). It was a joyous moment in Norm’s life; one which he could share with so many of his good friends. I’m already looking forward to his 80th.

**CWP**

Colorado School of Mines  
Golden, CO 80401  
<http://www.cwp.mines.edu>

# Incoming Students Add to CWP Diversity

CWP is pleased to introduce five new students supported by the Consortium for the 2010-11 school year.

Farhad Bazar-gani, Ph.D. student, earned a M.Sc. degree in geophysics from the University of Tehran, and was employed by WesternGeco and PGS before joining CWP. His home country is Iran. His advisor is Dave Hale.



Pengfei Cai, M.Sc. student, received a B.Sc. in mathematics and applied mathematics from Tsinghua University. His home country is China. His advisor is Paul Sava.



Nishant Karmath, Ph.D. student, earned a M.Sc. degree



in geophysics from the Indian Institute of Technology, Kharagpur, and worked for WesternGeco from 2008-2010 as an on-board data processor. His home country is India. His advisor is Ilya Tsvankin.

Chinaemerem Kanu, Ph.D. student, earned a M.Sc. degree in geophysics from Indiana University in 2010. His home



country is Nigeria. His advisor is Roel Snieder.

Allison Knaak, Ph.D. student, earned a M.Sc. degree in physics and mathematics from Presbyterian College in Clinton, South Carolina in 2010. Her home country is the USA. Her advisor is Roel Snieder.



## Voice of Experience: Tips for Success Offered to International Students

— Yuanzhong Fan and Diane Witters

Students and faculty from around the globe give CWP a wonderful international flavor. It takes courage, persistence, and a variety of cross-cultural skills for international students to negotiate the academic and personal transitions they encounter here in the USA. But the rewards are big!

Below we offer some tips, based on our experience, for international students who are embarking on academic study within the CWP program. We are happy to share our ideas if you have questions about the “how-to” of any of these points,

- ✓ Improve your communication by taking advantage of all opportunities; give focused attention to making progress in writing and oral skills, especially. Don’t believe the common misconception that your English will automatically improve simply by living in the USA.

- ✓ Find an advisor you can work with as soon as possible and make an effort to maintain a good relationship. Listen, ask questions, express your



Yuanzhong Fan (Ph.D. student) and Diane Witters (writing consultant).

opinion, clarify priorities and deadlines, and double-check to make sure you understand the expectations of you.

- ✓ Tackle challenges with a sense of adventure rather than a negative attitude. Of course, you probably miss much from your own country — native food, family and friends, better public transportation. Focus instead on the good that this new experience offers you: opportunities to make international friends, exposure to new ways of thinking and living, collaboration with specialists in your field of study.

- ✓ Observe cultural differences in your new academic environment and be willing to ad-

just your behavior and attitude. For example, you might be surprised to learn that it is not disrespectful to call your professor by his/her first name. And perhaps unlike your previous experiences, you are expected to ask more questions, contribute more actively in class discussions, or take more independent initiative in your research work.

- ✓ Use your common sense. Even though American culture might be more flexible and open than you are accustomed to, realize that there are still boundaries that you shouldn’t cross. For example, you don’t need to sit up straight (military-style) in class, but don’t fall asleep; even though you might have relaxed meetings and conversations with your advisor, don’t ignore what he/she asks you to do.

- ✓ Be aware of the definition of “plagiarism” in this country and practice ways to give proper credit to others.

- ✓ Use official sources, rather than your friends, when you need information about specific policies (such as program standards and thesis guidelines).

- ✓ Pay attention to details. Whether you’re writing an email, reviewing research data, editing a paper, or having a conversation with your sponsor, strive for quality.

- ✓ Recognize that despite our differences (in personality and cultural background), we are a team. Find ways to connect to your colleagues and respect the unique contribution that each of us makes to the program.

And finally,

- ✓ Have a life beyond the classroom and office. Realize that your research is an important obligation, but if you carve out some time for friends, recreation, and rest, your health and productivity will benefit.



Fan takes his own advice and enjoys time away from campus with his wife Jing and daughter Jessica.

# 14IWSA = A Great Journey

— Mamoru Takanashi



Perth Harbor, the scene near the 14IWSA meeting venue in Australia. Photo by M. Takanashi.

Mamoru Takanashi, CWP Ph.D. student and employee of Japan Oil, Gas and Metals National Corporation (JOGMEC).

It was the longest journey of my life: I flew to the other side of the globe, from Denver to Perth, Australia, traveling on five different airplanes for a total of 30 hours, with one flight delay on the way from Los Angeles to Brisbane. Still, it was worth the effort to travel to Perth in April, 2010 for the 14th International Workshop on Seismic Anisotropy (14IWSA).

Perth, which is known as one of the top-ranked cities for livability, is beautiful, warm, safe, and offers great seafood. Another important characteristic is that it is the capital of the most resource-rich state in Australia, and a large portion of the natural

resources is exported to my home country of Japan. I would like to devote myself to research relevant for the regions from where Japan imports oil and gas.

The meeting attracted more than 80 geoscientists from Australia and all over the world. It was a good opportunity to present my research and learn about state-of-the-art technologies from other anisotropy experts. It was also interesting to hear from local geoscientists about the status and problems in gas/oil exploration and production in Western Australia.

The next IWSA meeting will be held in Bahrain in February 2012. Hope to see you there!

## The Internship Experience

— Filippo Brogini

*Summer internship jobs are a large part of the CWP student experience. Below Filippo Brogini describes one such opportunity.*

On Monday mornings, most people do not want to go to work; but for employees at Schlumberger Cambridge Research (SCR) the beginning of the week has a “better taste.” At SCR, employees can start the week with an amazing crême brûlée, a French dessert prepared by the chef of the SCR cafeteria! This is just one of the many things that made my summer internship a wonderful experience.

I spent the summer 2010 at SCR as a student intern in the geophysics group. While there, I worked on a project involving surface wave interferometry, in which I had the opportunity to integrate theory with the analysis of real data that I acquired in a field nearby. This combination gave me many interesting insights and a better understanding of some of the equations that I already knew.

There’s a great atmosphere at SCR that fosters the interaction among all the employees. People willingly take the time to answer a question and there’s always a chance to exchange ideas while

sipping coffee during a break. And Friday soccer was the best way to start the weekend!

SCR is located in the wonderful city of Cambridge, with its famous and well renowned university. In my spare time, I became familiar with the city and even took a boat trip in a punt on the river Cam.



SCR research scientist and CWP alumnus Rodrigo Fuck (Ph.D., 2008) teams up with SCR intern Filippo Brogini for a Friday soccer game in Cambridge.

# CWP Faculty Attend SWLIM VII

## Seismic Waves in Laterally Inhomogeneous Media

Teplá Premonstratensian Monastery  
June 21-26, 2010  
(Web: [sw3d.cz/swlim](http://sw3d.cz/swlim))

— Norm Bleistein



Ilya Tsvankin and Norm Bleistein attended the SWLIM VII workshop in Teplá in western Czech Republic, which was organized by Ivan Pšenčík, Peter Bulant and their staff.

The SWLIM meetings have occurred at five-year intervals. This time, there were 46 presentations on theory and implementation in wave propagation, primarily for elastic media. The talks ran consecutively in one meeting room so that everyone had a chance to hear the wide spectrum of presentations. The participants were primarily from Europe with one speaker from Japan and others

from the USA, Brazil, Egypt and Canada. Industry, academia, and government laboratories were all well represented.

It was a great time to renew old friendships, make new friends, and share our science with the other participants. Because we were in this lovely isolated environment, the evenings were spent in informal group discussions, including postmortems on that day's presentations. This was a wonderful learning and bonding experience!

## Can We Steer and Focus Diffusive Fields?

— Yuanzhong Fan & Roel Snieder

Although beam steering and focusing have been used for waves in many important ways, these concepts have seldom been applied to diffusive fields because of a common belief that diffusion lacks directionality and therefore can neither be steered nor focused. We use the similarities between the Green's functions of waves and diffusion in a homogeneous space to show that diffusive fields can indeed be steered and focused.

In Figure 1, we construct a 5 km long linear source by summing distributed point sources. The frequency domain diffusive field from each point source is calculated using the 3D Green's function for the diffusion equation in a homogeneous medium. The top panel shows the real part of the total field at a frequency of 0.25 Hz on a logarithmic scale. The middle panel is the steered field after applying a linear phase shift and amplitude weighting to the individual sources in the array. The linear phase shift is designed to steer the field at approximately 45 degrees. The amplitude weighting is to compensate for diffusive loss for other sources. The bottom panel is the ratio of the field strength after steering and the strength before steering. The maximum increase clearly at an angle of 45 degrees.

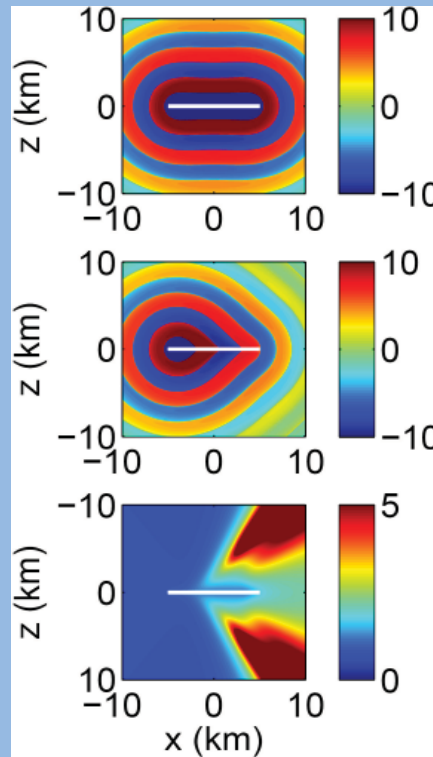


Figure 1

Instead of steering the field to a designed angle, we show in Figure 2 that the field can also be focused when applying appropriate phase shift and amplitude weighting. The upper panel shows the real part of the total field after focusing at location (0 km, 1 km). The lower panel is

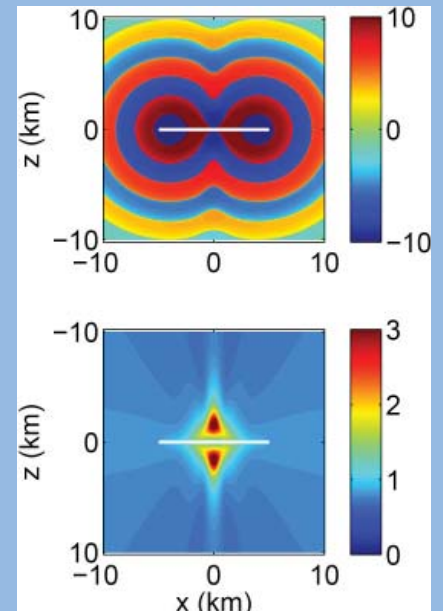


Figure 2

the ratio of the field strength after and before focusing.

These examples show that diffusive fields indeed can be steered and focused. The applications of steering and focusing would open new research directions for diffusive fields such as low frequency CSEM, submarine communication, and medical imaging with diffusive light.

# Smart People Moving Fast

— Dave Hale

After thirty years in exploration geophysics, it seemed wrong somehow that I had never traveled to the Middle East. So when Yi Luo and Panos Kelamis invited me to visit CWP sponsor Saudi Aramco this past summer, I jumped at the opportunity.

For two weeks we worked on geophysical applications of the Mines Java Toolkit (JTK), which Yi and his colleagues at Aramco had already been using to flatten 3D seismic images for interpretation. (Our implementation of image flattening is best described in the recent MS thesis of CWP graduate Derek Parks, now with Landmark.) It was exciting to see the impact that this technology was having on Aramco's exploration activities.

Our collaboration concluded with a short course on software development, using the programming languages Java and Python to exploit image processing and graphics packages in the JTK. Because we all learn programming best by actually programming, we spent most of our time writing software.

This group was fast. Most were programming so quickly that by the end of the

course I was simply trying to catch up with what they were writing, as they each focused on different technical problems of interest.

I met another fast group. Before arriving, I was a little concerned about losing fitness for a race I was running later in July. But less than 24 hours after stepping off the plane, I was concerned only with how far it was to the next water station. I was training with an amazing group of runners, at 4:30 PM, when the temperature was 117 degrees F. The Saudi Aramco Wellness Running team is coached by Ian Wilson, and currently includes 200 runners, with 40 more on a waiting list. So it was a privilege to train with these athletes during my brief two-week visit.

Humbling as well.

In that first run, I was reduced to walking after 45 minutes, and was guided home by a gracious Saudi runner named Abdu-



Yi Luo guides Dave Hale to the remote Shaybah oil field in the Saudi Arabian desert.



Flattening without picking horizons (and without seismic images). This educational display is part of the Saudi Aramco Exhibit in Dhahran.

laziz Al-Moqbel. (Note: drink three liters of water during the day before running.) This experience was typical of the hospitality I received by everyone I met during this unforgettable and long overdue trip to Saudi Arabia.

# Painting Seismic Images in 3D

— Dave Hale & Chris Engelsma

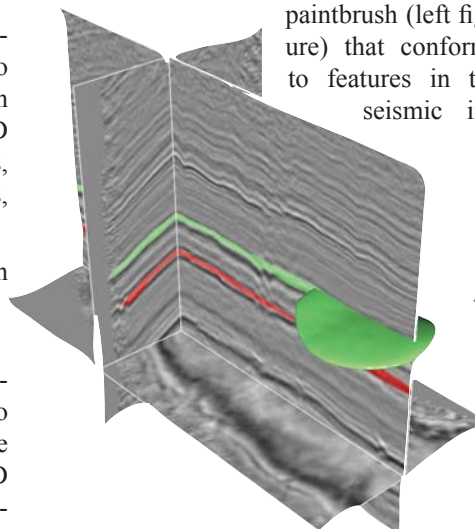
Decades ago geophysicists and geologists would use colored pencils to paint seismic sections of the earth's subsurface. Those sections were displayed on paper. We would use different colors and shades to represent different geologic layers.

As painting software became commonplace, so did 3D seismic images, and no one wants to paint the hundreds or even thousands of 2D seismic sections in a 3D seismic image. So today we pick horizons, the interfaces between geologic entities, rather than painting the geology directly.

Imagine instead that we could paint in 3D.

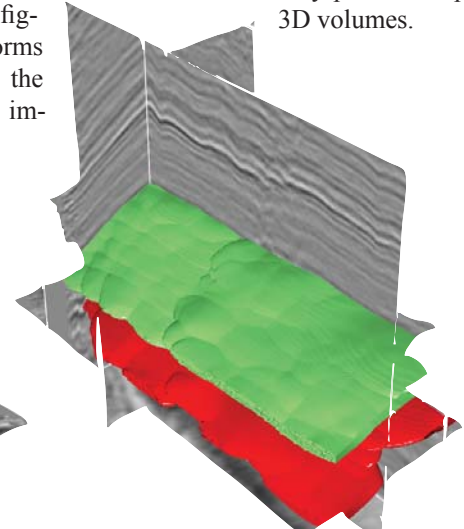
At the Center for Wave Phenomena we are blending geophysical image processing and interactive computer graphics to paint in 3D. The key step is to make the orientation and shape of our digital 3D paintbrush conform automatically to features apparent in 3D seismic images. Sim-

ple 3D brush shapes like spheres or cubes, analogous to circles and squares found in 2D painting software, will not do. 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. The example below displays a paintbrush (left figure) that conforms to features in the seismic im-



The paintbrush conforms to features in the seismic image.

age. With this brush we simultaneously paint many slices from the 3D image, not only the 2D slices displayed here. After 3D painting, geologic layers can be represented by their bounding surfaces (right figure). These surfaces resemble horizons, and are a natural by-product of painting 3D volumes.



After 3D painting, layers can be represented by their bounding surfaces.

# Celebration of a lifetime Happy Birthday Norm!

A grand celebration honoring CWP co-founder Norm Bleistein upon his 70th birthday and in tribute to his career achievements was attended by a large group of special colleagues, CWP alumni, friends, and family following the close of the 2010 CWP annual meeting. Masters of ceremony Ken Larner and Roel Snieder humorously led the dinner event, which included moving comments and stories from guests, as well as an entertaining pictorial review of Norm's life and career presented by his wife Judy Armstrong.



Norm Bleistein and Judy Armstrong check out the mathematical birthday cake.



Former CWP professor John DeSanto and Wenjie Dong (ExxonMobil).



CWP alumna Lan Wang (Landmark Graphics/Halliburton).



Carlos Theodoro (Petrobras) and Bernadete Theodoro.



Dan Whitmore (PGS) and Bee Bednar (Panorama).



Gregory Beylkin (Univ. of Colorado).



François Audebert (Total).



Lydia Deng (Landmark Graphics/Halliburton).



Martin Tygel (State Univ. of Campinas).



John Anderson (ExxonMobil) and Sergey Fomel (Univ. of Texas).



Phil Anno (ConocoPhillips) and Cindy Anno.



Shuki Ronen (CGGVeritas).



Tom Jorden (Cimarex Exploration).



Wes Mikulich (Chevron) and Nizar Chimengui (PGS).

Lihua and Zhaobo Meng (ConocoPhillips).



Sam Gray (CGGVeritas) and Jon Sheiman (Shell International).