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"Organized to promote the science of geophysics and to promote fellowship and co-operation among our members"

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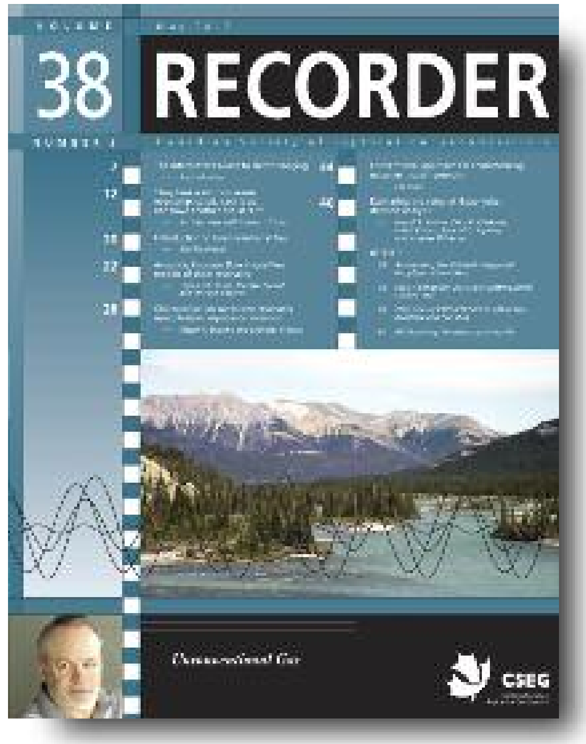
RECORDER

Official Publication of CSEG



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Canadian Society of Exploration Geophysicists

RECORDER

Official Publication of CSEG

North Saskatchewan River. Banff National Park, Alberta. (Photo by Rob Taerum.)

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ARTICLES

REGULAR FEATURES

PRESIDENTIAL COLUMN

A long winter / late spring extended the seismic season on the prairies, and caused much elevator chatter about the frequent April snow showers in Calgary. Record cold in parts of Ontario in early April were followed by floods in cottage country. It is unpredictable.

By the time this issue of the RECORDER goes to press the BC election will have taken place. The results may have a national impact. The Alberta Single Regulator framework is set to start next month. A White House Keystone decision may happen as early as August. Pundits will predict, but the outcomes will speak for themselves and it probably won't be dull. Coffee conversations I have sometimes stray towards a question that is phrased something like this: When did last have a 'normal' year? Who knows, change is a constant. La plus ca change, le plus ce meme.

In terms of change, there are a few new CSEG events that may be of interest. The Microseismic Users Group has initiated plans for MUG's MicroSeismic Technology days. From inception, the MUG has had a non-commercial mandate. While understandable, that mandate has limited MUG offerings. Accordingly MUG is planning the Technology Days event in order to let the commercial providers of microseismic services showcase the evolution of their individual and collective capacity. Microseismic remains a very dynamic aspect of geophysics, and the crucible of commercial competition is driving rapid improvements. At time of writing, the MUG-MTD had passed through the 'notional' stage and was concrete enough to have identified a venue and dates. Preliminary plans called for a downtown Calgary venue and dates in Mid June. By the time this goes to press those details will probably be announced. If you have missed them, please contact the CSEG office.

Another event to look out for is one being considered by the Chief Geophysicists Forum's Microseismic subcommittee. The CGF Subcommittee has begun to consider an Induced Seismicity Forum to be run next fall. Watch for details in the coming weeks and months. Induced seismicity has been a subject of concern. The US National Academy of Sciences has conducted a study and has issued a report. The Royal Society has done the same. BC's OGC has conducted a study using sensors installed by industry in the Horn River Basin (a summary talk was given at MUG last year). Subsequently Geo Science BC has funded the installation of a sensor array in that general area. The Council of Canadian Academies has been asked by the Federal Government to investigate Shale Gas. Information can be found at http://www.scienceadvice.ca/en/assessments/in-progress/shale-gas.aspx. In 2012 the CSEG executive sent a letter to the CCA indicating our willingness to connect the Council's project team to qualified CSEG members should the Council so wish. The Council's Expert Panel will hold its final meeting in June 2013.

The Canadian Federation of Earth Sciences, an umbrella organization of some 12 Canadian member societies including the CSEG, has signed a publishing contract for the production of a 'popular' book on the geology of Canada entitled Four Billion Years and Counting. I've been given a look at the 'final' text and it looks excellent. Initially a project associated with the International Year of Planet Earth (2008). The book will sell for a modest price, around $40 if memory serves, and all figures and photographs in the book will be available on line in an effort to foster public understanding of earth sciences. More information is available at http://www.earthsciences-canada.com/4by/. Sponsors include NEXEN, corporately, and individual chapter sponsors, some of whom are long time CSEG members.

GeoConvention has concluded. As I write this, however, it is two weeks in the future. Presumably it will have been an enriching experience. Matt Hall's experimental "Un-session" is notable to me, in a pre-convention sense at least. Our best wishes go to the winners of Challenge Bowl. They have big shoes to fill at the 2013 SEG Challenge Bowl competition: at the 2012 SEG a Canadian team took first prize. That winning team wasn't even the team that won at GeoConvention. US visa problems prevented the 2012 GeoConvention team from attending the SEG event in Las Vegas, so a 'pick up' team competed in its place. It was like science competition street hockey, with the visa situation being the car followed by a notably successful 'game on'.

GeoConvention is on the way to a more permanent footing, enabled for growth by a new 'structure' that has GeoConvention operated by the GeoConvention Partnership whose general partners are the CSEG, CSPG, and CWLS. The structure should provide GeoConvention additional continuity, competitiveness, and a platform for continued growth and success. The three societies planned a signing ceremony of sorts at GeoConvention.

Signing ceremonies have been frequent in 2013. Rob Kendall signed the cooperative MOU with the EAGE in February, and will sign a similar cooperative MOU with the SEG i June – oddly enough at the EAGE Conference in London. Part of those agreements is booth space for societies at each other's annual conventions. SEG and EAGE were planning to attend GeoConvention. CSEG is planning to attend the SEG Convention in Houston.

CSEG rebranding continues. The web site is running, and has been since our March AGM, but we continue to ferret out non-functional bits. Please be patient with the staff and the Director(s) of Communication as we work towards completion.

The fall technical Luncheon Schedule is set through November, featuring a couple of touring SEG speakers, including the SEG Distinguished Lecturer. The CSEG Distinguished Lecture series will be featured at a later Luncheon date.

Summer will officially arrive next month. If it means a slightly less hectic work day – enjoy it. If it means the exact same work day – enjoy it. Stay well, stay safe and have fun – always. *R*

Ron Larson
CSEG President

EXECUTIVE MESSAGE

Larry Herd our past past CSEG President called me about a year ago to join the Finance team as Assistant Director, giving me the opportunity to serve with him on the CSEG Executive. I was please to see Ron Larson elected to the Vice Presidents role I have known Ron a long time and played volleyball with him when we could still jump. He was a good team player then and I believe we have an excellent team in place. I am looking forward to the year as the CSEG Finance Director. Glen Malcolm has kept the CSEG finances in good shape and I plan on doing the same. I would like to thank Glen for his commitment and direction over the past year, the viability of the CSEG relies on Volunteers' like Glen. I would like to welcome Larry Wellspring he will take on responsibilities as Assistant Director during my term. I look forward to working with Larry.

In the industry we see some optimism with natural gas prices and oil prices have been able to hold despite ongoing chaos with pipeline approvals. We are a resilient industry and when there are challenges we seem to be able to innovate our way through them. We need to continue to demonstrate that geophysics provides a solid value contribution to our industry and emphasize our contribution to providing innovative solutions. Your Directors are committed to delivering services and resources that will enhance its membership, build bridges across other technical organizations, provides mentorship and opportunity to enhance the growth and conduct of our professional members and activity levels for our service sector.

The CSEG finances continue to support our membership, DoodleTrain, luncheons and RECORDER publications along with our upcoming convention. The CSEG Foundation continues to be well funded, in excess of the million dollar level, providing us with available resources to have an active society this year and in the future. The many committees and services we provide use this financial base to serve our members.

My responsibilities and others on the team are made simpler with the support of the office staff, Jim and Sheryl, who manage the day to day activities of our society. They are efficient and effective at keeping our team well informed and aware of the work in the office and across the committees. I feel the society is in good hands, financially sound, and ready to make a difference. If you are interested in volunteering on any of the committees please let us know. I assure you it is a rewarding and enjoyable experience to work with a team with a positive attitude and energy. Thank you for allowing me to be a part of that team. *R*

Wade Brillon
Director, Finance

CALENDAR

May			
6-10	**GeoConvention 2013: Integration**	TCC, Calgary	www.cseg.ca
8	**CSEG Challenge Bowl (Students) at Geoconvention**	Calgary	www.cseg.ca/students
June			
19	**CSEG Technical Luncheon** **Scott MacKay** (MacKay Consulting, Inc.), *"The Interpreter's Guide to Depth Imaging"*	TCC, Calgary	www.cseg.ca
6-8	**CSEG GIFT (Geophysical Industry Field Trip)**	Calgary & Canmore	www.cseg.ca/students
24	**CSEG T-Wave Golf**	Calgary	www.cseg.ca
August			
22-24	**CSEG 61st Doodlebug Golf**	Kimberly, BC	www.cseg.ca
September			
9	**CSEG Technical Luncheon**	TCC, Calgary	www.cseg.ca
11	**CSEG/CSPG Road Race and Fun Run**	Calgary	www.cseg.ca
12	**Women in Seismic Golf**	Calgary	www.cseg.ca

The Interpreter's Guide to Depth Imaging

Scott MacKay
MacKay Consulting, Inc., Denver, Colorado, USA

Compared to time migration, depth imaging should yield simpler structure, higher spatial and vertical resolution, and a more stable phase response. It is also the appropriate input for inversion and other attributes that estimate reservoir properties and mitigate risk. However, the interpreter must actively guide the depth-imaging process to ensure a reasonable, geologic result. This presentation reviews the planning and QC of depth imaging projects in a manner that establishes an appropriate dialogue between the interpreter and the processor.

Planning a depth-imaging project begins with the bidding. The company (or companies) selected must provide the level of technology suitable for the interpretive goals. As such, the dialogue should include:

- Defining deliverables in terms of interpretive goals
- Establishing a minimalist approach to initial time processing
- Choosing appropriate migration and tomography algorithm(s)
- Establishing the target (final) velocity resolution
- Defining a schedule for the tomographic updates
- Ensuring deliverables are compatible with 3rd-party software

When beginning the imaging process, a critical step is the formation of the initial velocity model. Figure 1 is an example of an acceptable, smoothly-varying model. It is becoming popular to introduce shallow, refraction-based velocity solutions. In general, the addition of detail early in velocity-model formation must be approached cautiously.

Depth imaging is an iterative procedure that seeks to add detail to the velocity model by means of tomographic refinement. Therefore, early in the planning of a project, it is important to establish realistic goals for the resolution we may expect from tomographic updates. Figure 2 illustrates an intuitive approach to establishing the target velocity resolution for an anomaly assumed to be halfway between the surface and the reflector. Basically, hyperbolic scanning of (offset = depth

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Scott MacKay is a petroleum geoscientist with over 30 years of experience. He graduated from Colorado School of Mines in 1979 with a Master's Degree in Geophysics and started working with Tenneco Oil in Denver as an exploration geophysicist developing structural and stratigraphic plays. He joined Tenneco's Special Projects Group in Houston in 1986 integrating the efforts of multidisciplinary teams in areas including the Bahamas Carbonate Platform, North Slope, Offshore Gabon, North Sea, Colombia, and the Gulf of Mexico. He joined (now) WesternGeco in 1988 as a research geophysicist developing new methods for imaging complex structures using prestack depth migration. In 1992 he obtained his Ph.D. from the University Houston and was appointed Manager of R&D for WesternGeco in Denver where he also served as World-wide Coordinator for Depth Imaging, Time-lapse Reservoir Characterization, and Multicomponent Imaging. Scott has been granted five U.S. patents and has numerous publications on applying innovative and practical solutions to exploration and exploitation challenges. Scott became an independent consultant in 2003 working international projects and advising on the application of new technologies and their impact on risk reduction.

GeoConvention 2013: Integration – *May Luncheons*

AL HANCOCK

Sponsored by BAKER HUGHES enerPLUS

DEBORAH YEDLIN

Sponsored by IHS nexen

CSEG May Luncheons

Monday, May 6, 2013
Al Hancock
11:30am – 1:30pm; Macleod Hall A, TELUS Convention Centre

Tuesday, May 7, 2013
Deborah Yedlin
11:30am – 1:30pm; Macleod Hall A, TELUS Convention Centre

JUNE LUNCHEON

Tuesday, June 18, 2012

"The Interpreter's Guide to Depth Imaging"

Scott MacKay *(MacKay Consulting, Inc.)*

The CSEG June Luncheon is sponsored by Canadian Discovery Ltd.

The Interpreter's Guide to Depth Imaging

Continued from Page 7

Figure 1. Initial depth-imaging velocity model.

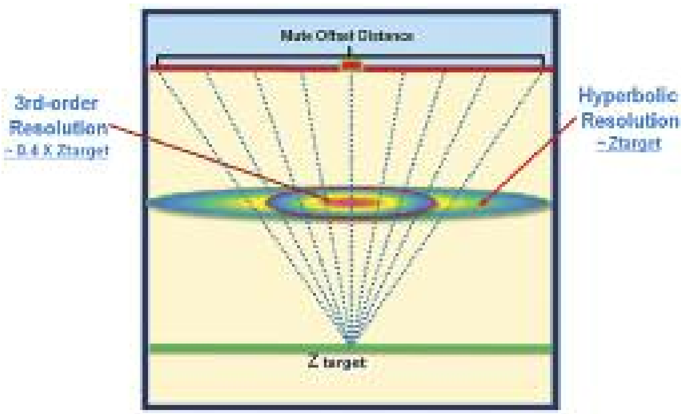

Figure 2. Establishing target-velocity resolution.

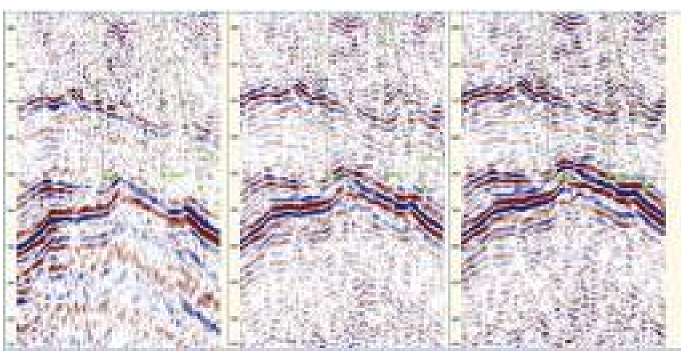

Figure 3. Sequential improvement (left to right) in focusing with iterations of tomography.

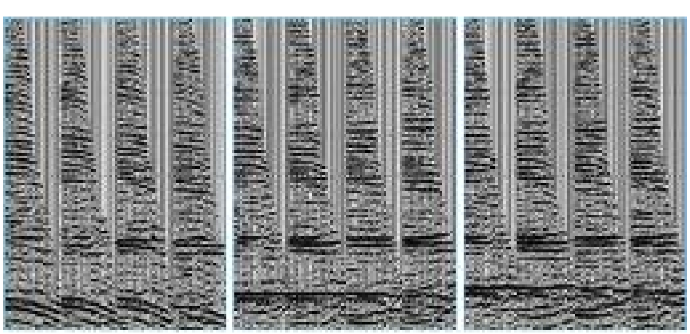

Figure 4. Sequential flattening of gathers with iterations (left to right).

muted) gathers can only resolve an anomaly having a width equal to the depth of the reflector. A simple 3rd-order fit can resolve a narrower anomaly within the "ray" coverage of the gather. By establishing the target velocity resolution we may next establish a well-defined start and end of the tomographic-update process that avoids introduction of excessive velocity detail and potential instability in the solutions.

During depth imaging it is important for the interpreter to utilize geologically-intuitive data QCs to ensure reasonable results. The QCs are always reviewed sequentially from the initial model to the current iteration. The data are reviewed as in-lines, cross-lines, and depth sections that include:

- Depth Images: Better focusing and structurally simpler?
- Velocity and Delta-Velocity: A minimum of velocity bubbles?
- Tomographic Ray Density: Eliminate updates from areas of low coverage?
- Common-Image Point (CIP) Gathers: Progressively flatter (but not completely)?

The criteria for a successful iteration are better focusing and simpler structure. Note in Figure 3 the sequence of depth images showing both the qualities described. Another important data review involves the CIP gathers. Figure 4 demonstrates that the goal of tomography is to achieve relatively flat gathers within the target velocity resolution. Perfectly flat gathers would likely yield non-geologic velocities and potential instability in the tomographic solutions.

After isotropic depth imaging, depth calibration with formation tops consists of vertical corrections to the depth volume to tie the well control. For anisotropic depth imaging, calibration is more intricate as the formation tops are used as constraints in the vertical

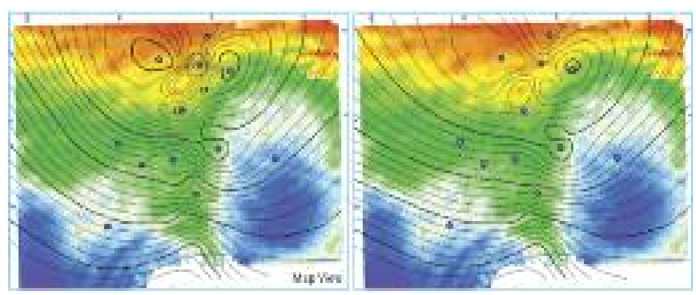

Figure 5. Unedited depth-difference map (left) and edited (right).

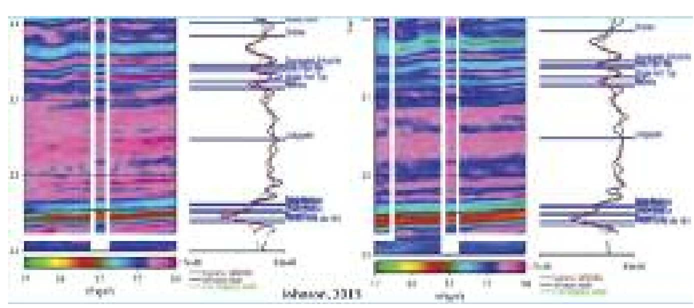

Figure 6. Fast Shear Impedance (left), Slow Shear Impedance (right) from azimuthal inversion (AVOAz).

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The Interpreter's Guide to Depth Imaging

Continued from Page 8

velocity field and the anisotropic parameter estimates during the iterative updates. Therefore, another important interpreter goal is:

- Database Validation: Establish consistency between formation tops and seismic horizons

Figure 5 shows depth-difference maps (seismic horizon depth minus formation tops) before and after editing. The map on the left contains local "bubbles" indicating problematic seismic ties to the formation tops. Corrections were made to the KBs, deviation surveys, and interpreted tops resulting in the smoother map on the right. Since errors in the database result in errors in the anisotropic parameters, early detection prevents the formation of a compromised depth image.

Stable depth-imaging results allow for the optimal extraction of information from the seismic. After depth calibration, they are also ideally suited for input to inversion and reservoir modeling. Figure 6 shows prestack azimuthal inversion to Fast and Slow Shear Impedance. High-resolution inversions yield the details needed to better define the combined effects of lithologic variations (density, incompressibility, and rigidity) and directional fracturing and/or stress fields.

In summary, the translation of the seismic response to measurements of significance to drilling and development engineers remains a challenge in the drilling-dominated "resource plays". Depth imaging is established as the only viable approach to creating attributes that truly mitigate risk. It is the interpreter's responsibility to guide this process. *R*

By Mike Doyle

Hurricane Katrina in 2005 was in many ways the poster child used for global warming by climate change environmental activists. In terms of overall hurricane activity (number and intensity of storms), the 2005 Atlantic hurricane season was the most active season ever recorded. However with the global economic downturn the wind came out of sails – so to speak – in terms of the impetus placed on the issue of climate change. Global treaties and conferences failed to produce much in terms of real results as different countries sought to advance their own agendas. The Earth's biosphere is infinitely complex and predicting what will happen in the future remains largely in the realm of perceptional educated guessing. Meteorologists have a difficult enough time with predicting weather accurately past a few days from the current day.

Interestingly enough The Economist recently wrote a couple of articles on the matter. I have put together pieces of both articles in the following column.

The Economist – Mar. 30th 2013

"Apocalypse perhaps a little later – Climate change may be happening more slowly than scientists thought. But the world still needs to deal with it." (excerpts in blue)

http://www.economist.com/news/leaders/21574490-climate-change-may-be-happening-more-slowly-scientists-thought-world-still-needs

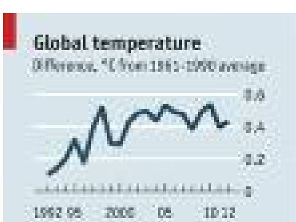
Climate science – A sensitive matter

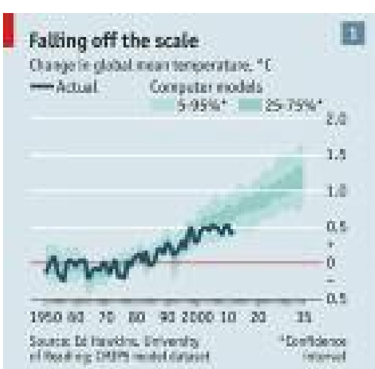
"The climate may be heating up less in response to greenhouse-gas emissions than was once thought. But that does not mean the problem is going away." (excerpts in brown)

http://www.economist.com/news/science-and-technology/21574461-climate-may-be-heating-up-less-response-greenhouse-gas-emissions

"IT MAY come as a surprise to a walrus wondering where all the Arctic's summer sea ice has gone. It could be news to a Staten Islander still coming to terms with what he lost to Hurricane Sandy. But some scientists are arguing that man-made climate change is not quite so bad a threat as it appeared to be a few years ago. They point to various reasons for thinking that the planet's "climate sensitivity"—the amount of warming that can be expected for a doubling in the carbon-dioxide level—may not be as high as was previously thought. The most obvious reason is that, despite a marked warming over the course of the 20th century, temperatures have not really risen over the past ten years."

"OVER the past 15 years air temperatures at the Earth's surface have been flat while greenhouse-gas emissions have continued to soar. The world added roughly 100 billion tonnes of carbon to the atmosphere between 2000 and 2010. That is about a quarter of all the CO put there by humanity since 1750. And yet, as James Hansen, the head of NASA's Goddard Institute for Space Studies, observes, "the five-year mean global temperature has been flat for a decade."





Temperatures fluctuate over short periods, but this lack of new warming is a surprise. Ed Hawkins, of the University of Reading, in Britain, points out that surface temperatures since 2005 are already at the low end of the range of projections derived from 20 climate models (see chart). If they remain flat, they will fall outside the models' range within a few years.

The mismatch between rising greenhouse-gas emissions and not-rising temperatures is among the biggest puzzles in climate science just now. It does not mean global warming is a delusion. Flat though they are, temperatures in the first decade of the 21st century remain almost 1°C above their level in the first decade of the 20th.

The mismatch might mean that—for some unexplained reason—there has been a temporary lag between more carbon dioxide and higher temperatures in 2000-10. Or it might be that the 1990s, when temperatures were rising fast, was the anomalous period. Or, as an increasing body of research is suggesting, it may be that the climate is responding to higher concentrations of carbon dioxide in ways that had not been properly understood before. This possibility, if true, could have profound significance both for climate science and for environmental and social policy."

"It is not clear why climate change has "plateaued". It could be because of greater natural variability in the climate, because clouds dampen warming or because of some other little-understood mechanism in the almost infinitely complex climate system. But whatever the reason, some of the really ghastly scenarios—where the planet heated up by 4°C or more this century—are coming to look mercifully unlikely. Does that mean the world no longer has to worry?

No, for two reasons. The first is uncertainty. The science that points towards a sensitivity lower than models have previously predicted is still tentative. The error bars are still there. The risk of severe warming—an increase of 3°C, say—though diminished, remains real. There is also uncertainty over what that warming will actually do to the planet. The sharp reduction in Arctic ice is not something scientists expected would happen at today's temperatures. What other effects of even modest temperature rise remain unknown?

The second reason is more practical. If the world had based its climate policies on previous predictions of a high sensitivity, then there would be a case for relaxing those policies, now that the most hell-on-Earth-ish changes look less likely. But although climate rhetoric has been based on fears of high sensitivity, climate policy has not been. On carbon emissions and on adaptation to protect the vulnerable it has fallen far short of what would be needed even in a low-sensitivity world. Industrial carbon-dioxide emissions have risen by 50% since 1997.

Any emissions reductions have tended to come from things beyond climate policy—such as the economic downturn following the global

Mike Doyle is the President of the CAGC – the Canadian Association of Geophysical Contractors – representing the business interests of the seismic industry within Canada. The CAGC website may be found at www.cagc.ca

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CAGC…

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financial crisis, or the cheap shale gas which has displaced American coal. If climate policy continues to be this impotent, then carbon-dioxide levels could easily rise so far that even a low-sensitivity planet will risk seeing changes that people would sorely regret. There is no plausible scenario in which carbon emissions continue unchecked and the climate does not warm above today's temperatures."

"Other recent studies, though, paint a different picture. An unpublished report by the Research Council of Norway, a government-funded body, which was compiled by a team led by Terje Berntsen of the University of Oslo, uses a different method from the IPCC's (Intergovernmental Panel on Climate Change). It concludes there is a 90% probability that doubling CO_2 emissions will increase temperatures by only 1.2-2.9°C, with the most likely figure being 1.9°C. The top of the study's range is well below the IPCC's upper estimates of likely sensitivity.

This study has not been peer-reviewed; it may be unreliable. But its projections are not unique. Work by Julia Hargreaves of the Research Institute for Global Change in Yokohama, which was published in 2012, suggests a 90% chance of the actual change being in the range of 0.5-4.0°C, with a mean of 2.3°C. This is based on the way the climate behaved about 20,000 years ago, at the peak of the last ice age, a period when carbon-dioxide concentrations leapt. Nic Lewis, an independent climate scientist, got an even lower range in a study accepted for publication: 1.0-3.0°C, with a mean of 1.6°C. His calculations reanalysed work cited by the IPCC and took account of more recent temperature data. In all these calculations, the chances of climate sensitivity above 4.5°C become vanishingly small.

If such estimates were right, they would require revisions to the science of climate change and, possibly, to public policies. If, as conventional wisdom has it, global temperatures could rise by 3°C or more in response to a doubling of emissions, then the correct response would be the one to which most of the world pays lip service: rein in the warming and the greenhouse gases causing it. This is called "mitigation", in the jargon. Moreover, if there were an outside possibility of something catastrophic, such as a 6°C rise, that could justify drastic interventions. This would be similar to taking out disaster insurance. It may seem an unnecessary expense when you are forking out for the premiums, but when you need it, you really need it. Many economists, including William Nordhaus of Yale University, have made this case.

If, however, temperatures are likely to rise by only 2°C in response to a doubling of carbon emissions (and if the likelihood of a 6°C increase is trivial), the calculation might change. Perhaps the world should seek to adjust to (rather than stop) the greenhouse-gas splurge. There is no point buying earthquake insurance if you do not live in an earthquake zone. In this case more adaptation rather than more mitigation might be the right policy at the margin. But that would be good advice only if these new estimates really were more reliable than the old ones. And different results come from different models."

"Bad climate policies, such as backing renewable energy with no thought for the cost, or insisting on biofuels despite the damage they do, are bad whatever the climate's sensitivity to greenhouse gases. Good policies—strategies for adapting to higher sea levels and changing weather patterns, investment in agricultural resilience, research into fossil-fuel-free ways of generating and storing energy—are wise precautions even in a world where sensitivity is low. So is putting a price on carbon and ensuring that, slowly but surely, it gets ratcheted up for decades to come.

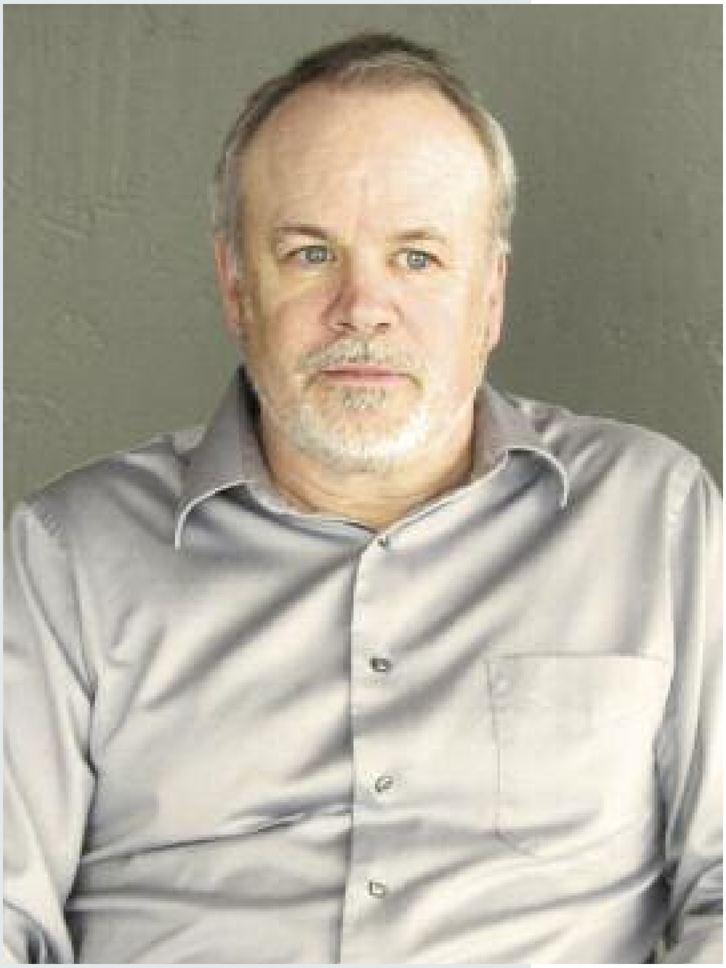
If the world has a bit more breathing space to deal with global warming, that will be good. But breathing space helps only if you actually do something with it." *R*

From the Thursday Files

Surely, if Mother Nature had been consulted, she would never have consented to building a city in New Orleans.
– Mortimer Zuckerman

Nature is regulating our climate for free. Mother Nature, she's been doing that for free, for a long, long time. Now do you really want to get in there and do geo-engineering and all this kind of stuff?
– Thomas Friedman

"Any time a solution seems overcomplicated, back it up and have another run at 'er."



An interview with Stewart Trickett

Stewart Trickett is a highly experienced geoscientist who works as Manager of Research and Development at CGGVeritas, Calgary. Though trained as a mathematician and also having studied computer science, Stewart has researched and developed geophysical processing software for the last 33 years. During this time he has worked at Veritas Seismic Ltd., Seismic Data Processors Ltd., Kelman Technologies

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Inc., which was later taken over by Fugro and more recently by CGGVeritas. Stewart was the chief architect of Kelman's 'Kismet' system and the 'Sage' processing system that Veritas used for 2D and 3D land data processing. Glimpses of his contributions in different areas of geophysics emerge as one runs down his impressive list of publications. These range from surface consistent statics, phase, wavelet instability, deconvolution, noise suppression, stretch free stacking, and trace interpolation to name the prominent ones.

Stewart is a versatile technical writer and presenter. His presentation at the 2012 SEG Convention, Las Vegas was adjudged to be in the top 30 presentations.

Stewart agreed rather reluctantly to our request for an interview, as he shies away from getting photographed. Following are excerpts from the interview.

(Photos courtesy: Melanie Bauce)

S: Please tell us about your educational background and your work experience.

T: I studied computer science and mathematics at the University of British Columbia in the late 1970s. The double honours program was more work than I could handle, so I switched to pure computer science in my final year, and graduated in 1979.

I was looking for a job as a numerical analyst, which is an expert in mathematical computation. There didn't seem to be much call for it in Vancouver, but Calgary was booming due to the energy crisis which had sent oil prices soaring, so I spent a week there dropping off my résumé. The major oil companies weren't falling over themselves to offer me a job, but I managed an interview with a tiny company called Veritas. Actually the receptionist sent me into the interview by mistake, thinking I had booked it beforehand, so Mike Galbraith was confused when I walked into the room. Still, I got the job as a programmer for their Aurora seismic processing system.

S: That must have been in the early days of Veritas – what was it like?

T: It was a shock. Veritas took up a couple of floors of rather seedy looking offices overtop of a bar. Programming was done using card decks and RDS 500 computers with 64 kilobytes of memory that you had to book beforehand and bootstrap yourself. Coming from a university that used mainframe computers and a file system, it was like entering the dark ages. But soon Veritas was in a new building with modern computers.

Mostly I worked on graphics software, but Mike Galbraith had conceived of this program called SPL, which stood for Signal Processing Language, and I got to develop it. SPL was a language made up of basic signal processing operations that you could insert in your processing job deck. You could design all sorts of filters and procedures without programming or compiling. Even though it was too

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difficult for most seismic processors to write their own SPL decks, it turned out to be immensely successful, and processors were constantly coming to me to build SPL jobs to help solve their problems. It was a great way to learn signal processing in a hurry. It became a valuable tool for Veritas researchers like Dan Hampson, Brian Russell, Rob Stewart, and Graham Millington. When Veritas leased the Aurora system to the University of Saskatchewan, I heard it also became popular among the geophysics students there. Today, of course, they would use Matlab or something similar.

S: You got your B.Sc. degree in computer science, worked at Veritas for some time, and then decided to go back to school. How did you choose University of Waterloo for doing your Masters?

T: I wanted to resume studying applied mathematics which I had suspended in my final year at UBC, so in 1982 I left Veritas to attend the University of Waterloo in Ontario. Waterloo was a young university with an excellent reputation for mathematics, computer science, and engineering. They are sometimes called "MIT North". My thesis went well and I enjoyed doing research, but I wasn't keen on the course work, so after earning my Master's degree I returned to Calgary.

S: So you worked as a programmer at Veritas once again, from 1984-1992? Tell us about those years.

T: Well actually it wasn't exactly like that. When I returned to Calgary from Waterloo in 1984 I thought I would have no problem finding a job, but the oil industry was in a downturn. I eventually joined Seismic Data Processors, or SDP, a small processing firm that used SSC's Phoenix system. I developed a first-break picking and weathering interpretation system called Winter, which I thought worked rather well. It incorporated robust statistics rather than the usual least-squares inversion. But in 1987 the industry went into another downturn, a severe one this time, and SDP was nearly wiped out. With my salary reduced and hours cut, I realised I wasn't going to get rich there, so I rejoined Veritas Seismic Processing.

S: OK, so you rejoined Veritas in 1987 then – got it! Those must have been exciting times, the heyday of Veritas was it not?

T: Actually, most of the Veritas programmers and researchers had moved over to Veritas Software, a software-leasing company, leaving the seismic processors poorly supported. I was hired to help fill the gap. I give Dave Robson, the main owner of Veritas at the time, credit. He invested in software development at a time when most other centres could only complain about how tough things were.

Around 1989, Veritas Seismic realized that the Aurora seismic processing system was not going to meet their future needs, so they decided to build a new system. After some pleading on my part, I was made the chief architect. We couldn't decide what to name it, so Wilf Reynish, the president of Veritas Seismic, declared it was to be called the Sage system, for no particular reason that I can tell. Perhaps it was his favorite herb.

It took us about two years to build a complete processing system, an astonishing feat by today's standards. That's more of a testimony to how far seismic processing has advanced in the last 20 years than a reflection on our programming. Sage was intended to handle both 2D and 3D land seismic equally well, perhaps the first system designed from the start to do so. The job decks were free format and the interface for each processing module was guided by a team of processors. It was written in C rather than Fortran 77, a more modern programming language which allowed us to escape from the memory constraints that were crippling seismic processing systems with arbitrary limits. And I think the results showed. Veritas dominated the Calgary 3D processing market for many years. The Sage system is still in use today, despite management's efforts to retire older processing systems.

S: After all these successes, how or why did your stint at Veritas end?

T: Reorganization resulted in a software manager who I did not get along with, so despite my success at designing and developing Sage, I was laid off in 1992 during yet another industry downturn. It didn't last long. I joined Kelman Seismic Processing at the start of 1993 as a programmer for their Seisrun processing system.

S: You stayed at Kelman for 20 years or so – well really you haven't left, the company has just gone through ownership changes. Tell us about this phase of your career, some of the highlights.

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T: One memorable project or initiative I recall involved surface consistent deconvolution. Myself, my boss Brian Link, and Bill Goodway, then at PanCanadian, had an idea that we could improve wavelet stability across the seismic section by quality controlling the source and receiver amplitude spectra derived from surface-consistent deconvolution. Noise should have a distinct shape on these spectra. We found that noise was pervasive. Often the only clean part of the spectrum was between 15 and 55 Hz, even on good data, leaving me skeptical about the results of surface-consistent deconvolution. This drove us to develop better methods to remove noise on prestack data, and Kelman eventually ended up with an impressive suite of tools to do so.

Another highlight was more of a computer science or programming achievement. In the late 1990s, Jim Jiao and I got tired of developing software in Fortran, and wrote a wrapper around the ancient software that allowed us to write seismic processing modules in the C++ language. C++ is object-oriented, and makes possible more modern programming methods. The goal was to make software development as simple and free of constraints as possible, and to maximize reuse.

In 2002 I was promoted to manager of research and development at Kelman. At that time we had a serious problem, as the Seisrun system ran only on expensive Sun computers and could only use 32-bit addressing. To exploit the cheap Intel and AMD machines then available, I wrote a program called Kismet which had three processing modules that read seismic traces from files, performed 3D Kirchhoff migration, and wrote seismic traces to files. It used the C++ processing modules we had written for the Seisrun system and it ran on any platform. Kismet immediately started making us money, since we could now exploit the cheaper hardware. We then hired Alan Dewar to extend Kismet so that it could run all of the C++ processing modules from the older system. Over the last ten years we've been completing and expanding the Kismet system, including extensive interactive graphics.

S: ***Recently your name has been associated with applications based on Cadzow filtering techniques. How did this come about?***

T: Around 2000 I started looking at rank-reduction methods for removing random noise. Rank-reduction is also known as the Karhunen-Loeve transform, truncated SVD, sub-space filtering, dimensionality reduction, and many other names. Before then, rank-reduction filtering on seismic data had

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been done almost entirely in the time domain, and as a result one had to take heroic steps to apply it to structured seismic data. I figured rank-reduction filtering applied to complex constant-frequency slices could solve that problem. I developed a method called f-xy eigenimage filtering and proved mathematically that it could handle structured data as easily as it could handle flat data.

Although f-xy eigenimage filtering had lots of great theoretical properties, it was a weak noise attenuator and worked only in two spatial dimensions. I found a 1988 paper by James Cadzow, a former professor of electrical engineering at Vanderbilt University, that showed how to rank-reduction filter in one dimension by arranging the values into a Hankel matrix. Cadzow was not the only one to discover this – it had been developed by others at the same time. I applied this method, which had previously been used in medical imaging and astronomy, to frequency slices in one spatial dimension, and it seemed better at preserving signal and removing random noise than the popular f-x deconvolution.

In 2007 I figured out how to extend Cadzow filtering to more than one spatial dimension. In retrospect it was kind of obvious, and I don't know why it took me so long. But it was like striking a rich vein of ore, opening up all sorts of possibilities which myself, Lynn Burroughs, Andrew Milton, and others at Kelman have since developed. Mauricio Sacchi, head of the SAIG consortium at the University of Alberta, also realized these possibilities, and his students have written many papers based on it. In the last four years. Kelman and SAIG have been leap-frogging each other's work. Rank reduction on frequency slices has been extended to prestack noise removal in up to four spatial dimensions, 5D and de-aliasing interpolation, tensor completion, erratic and coherent noise removal, and simultaneous-source deblending.

S: ***Where are things at now with Kelman in its latest incarnation?***

T: In 2011, the geophysical division of Kelman Technologies was sold to Fugro, who were looking to improve their land processing. And in early 2013 we were sold to CGGVeritas, now renamed to simply CGG. It's still uncertain how we're going to fit in, as CGG already has half a dozen processing systems. This February I visited the head office outside of Paris. It was a big modern glitzy office building with the words "CGG Veritas" in bright lights on it. It occurred to me that we had come a long way from the seedy looking office overtop of a bar.

S: ***What is it that you love about our industry?***

T: If you listen to certain political pundits, free enterprise is driven by naked greed. Unbridled exploitation. Dog-eat-dog savagery.

And it's pure tripe. Our industry is a great example of enlightened self interest. The level of professionalism and co-operation between commercial competitors and between business and academia is amazing. People do well in this business by working with others and endlessly seeking to do things better, and rarely through some Hollywood fantasy of ruthless exploitation. And I really love that aspect.

And that will be the last of the politics.

S: ***Do you have a memorable incident from your professional successes that you would like to share with us?***

T: In the last few years I've given talks in smaller geophysical centres like Pittsburgh, Tulsa, Midland, and Denver. Many of these societies have their meetings in bars, often with free drinks. I think the CSEG can learn from this. In Tulsa I was heckled, which was a first for me. I thought it was funny but it mortified the organizer. The heckler eventually dozed off, perhaps a result of the free drinks. One of the questioners was an older gentleman who seemed to know what he was talking about. He came up afterwards and introduced himself as Turhan Taner, who is one of the pioneers of computerized seismic processing.

S: ***So, you have basically developed seismic processing software, correct? Tell us about the kinds of problems you have worked on.***

T: I've worked on almost every kind of land seismic processing software there is. Leaving aside any specific technical problem, the most relentless foe is complication. Needless complication wastes time, creates errors, and hinders our understanding. I've never bought into the idea that power and simplicity are incompatible. Any time a solution seems overcomplicated, *back it up and have another run at 'er.*

S: ***What personal and professional vision are you now working towards?***

T: Professionally my goal is to provide the best land seismic processing system possible. It's not easy, as such a system must be simple and intuitive but at the same time have immense flexibility, capable of standing up and dancing the Macarena when needed.

S: ***According to a recent survey of 2000 people in the U.K., people aged 68 or 69 years are the happiest, as their priority in life is 'to have fun'. What is your take on this?***

T: I'm not sure how I'm going to take to retirement. What do I do with myself without some kind of problem to work on? There is the possibility of semi-retirement, but I suspect that many people will be trying to do the same, and younger generations likely won't appreciate a lot of geezers crowding the hallways.

S: ***Looking at your list of publications, I notice you have worked in quite a few areas of geophysics. Beginning***

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with surface consistent statics problems, wavelet instability, various ways in which noise can be suppressed, interpolation etc. You seem to be all over the place. Your comments?

T: My career has been building seismic processing systems, so I've worked on every aspect of traditional seismic processing except for imaging. That's a little strange given that I wrote my Master's thesis on the numerical solution of partial differential equations, which is what migration is. The biggest theme to my research has been removal of noise, which I define as any energy on the seismic records that we don't know how, or can't be bothered, to use.

S: ***What according to you is your most important contribution to geophysics?***

First, the design and construction of two seismic processing systems that, I think, were popular with both processors and programmers. Second, the development of rank-reduction filters on constant-frequency slices ("Cadzow filtering") for noise suppression and interpolation. Ten years ago, the industry lacked powerful prestack random noise suppressors, particularly for structured data. I think this has helped to fill that gap.

S: ***Are there other areas of geophysics that fascinate you in particular?***

T: Robust statistics in processing. We tend to rely on least-squares estimation for most inversion problems. But seismic data, particularly for land, often contains erratic noise which least-squares methods do a poor job on. Even when robust statistics are used, our approaches are sometimes outdated, such as when we use least-L1-norm estimators. We also tend to perform robust inversion using iteratively reweighted least-squares, whereas a lesser known strategy called iterative

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pseudo observations should have broader application.

Another area is software. The industry depends heavily on software development, and yet we rarely bother to share advice on what works and what doesn't.

S: What are the directions in which future R & D worldwide will be focused in our industry? Any important developments that we will see in the next five years?

T: Acquisition is changing rapidly. Simultaneous shooting, single-point receivers, time lapse, targeted and randomized shooting patterns, urban acquisition, multi-component and spatial-gradient recording, massive increases in recorded channels, broadband acquisition, and so on, will not only change things in the field but in the processing centres.

S: What do you think are 5 top technical articles that in your opinion had an impact on your thinking and which are widely hit on the website, whether it is the SEG, EAGE or CSEG? You might want to keep these to the processing of seismic data.

T: The most influential articles for me have been outside of geophysics. Signal processing is used in many fields, and most problems we face have been tackled in another guise elsewhere. Within geophysics, I like old-time articles that inspired entire fields of research.

"Robust Modeling with Erratic Data", 1973, Claerbout and Muir. They foresaw a future where almost every geophysical statistical estimation was robust. It didn't come true, but modern robust statistical methods might still make it possible.

"Estimation and correction of near-surface time anomalies", 1974, Taner, Koehler, and Alhilali. This was the first geophysical paper I recall reading, and it still reads very well today. It describes surface-consistent statics, a technique now extended to deconvolution and scaling, and is a foundation for land seismic processing.

"Outer Product Expansions and Their Uses in Digital Image Processing", 1975, Andrews and Patterson.

"Eigenimage processing of seismic sections", 1988, Ulrych, Freire, and Siston.

These two papers demonstrate that rank reduction is a powerful and fundamental tool for noise removal.

"Earth Soundings Analysis: Processing versus Inversion", 1992, Claerbout. This book takes a single theme – processing versus inversion – and applies it to dozens of seismic processing problems.

S: Have you thought of volunteering your time with the professional societies like the CSEG and the SEG?

T: Is that a hint? I primarily help out the SEG by peer reviewing papers and occasionally chairing conference sessions. I don't think I'd be happy sitting in committee meetings. I can probably help more on the technical side.

S: What do you do first when you get your copy of the RECORDER?

T: The CSEG has a trade magazine? Actually I find the quality of the RECORDER to be excellent, although this interview might bring down the average. I usually go to the back pages first to see who's moved where.

S: What other interests do you have? I notice you are active in yoga, skiing, canoeing, etc.

T: Yoga? I think you've confused me with someone else. I have the flexibility of a potato chip. I golf (increasingly poorly), garden, and box. Well anyway I used to box on a recreational level. I still do a boxer's workout but I haven't sparred for years, and if you're not getting punched in the face, it's not really boxing. I downhill skied a lot when I was young, as I grew up in a ski town in B.C. I now prefer cross-country.

S: What would be your message for young geophysicists entering our profession?

T: I don't consider myself a geophysicist. I'm more of a software developer and mathematician who has carved out a niche in the geophysics community.

Still, learn to communicate. Students spend years studying mathematics and science, but almost nothing on how to get ideas across. I guess we figure communication skills come naturally, or perhaps that it's unteachable, but this is plainly untrue. We should be studying and practicing communication as intensely as we do any other useful skill. Read books and take courses on it. Learn to write and to build presentations. Learn to speak clearly and simply, without ums and uhs, and to project your voice to the back of the room. Constantly get people's feedback.

And second, if you profess some challenging goal for your career, more experienced hands might wisely lecture you on how tough it is and how unlikely it is you'll achieve it. Thank them for their advice and ignore them. R

Introduction to Unconventional Gas

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Recent years have brought a rapid expansion of activities around shale gas. The successes in shale gas exploitation have been mainly attributed to advances in engineering. In particular, hydraulic fracturing has contributed immensely towards this success. Till date, geophysics has yet to assume a major role in the development of this important resource. There are three major reasons for the tepid response to geophysical applications for shale gas exploration and development. In this issue, we show a few applications for shale gas development. There are still areas needing urgent attention in shale gas exploration. Some of these are listed below:

- **Resolution:** Shale gas reservoirs can be very thin. Seismic mapping has traditionally been confounded by existence of thin beds. Resolving them can be a non-trivial task.
- **Pressure and fluid sensitivity:** Many shale gas reservoirs are found at large depths. These are competent rocks that demonstrate very little sensitivity to changes in fluids or in depths. Thus, there is little understanding about any Direct Fluid Indicators for gas saturations in shale gas reservoirs
- **Heterogeneity:** Shale gas lithologies are very heterogeneous. For example, the Monterey shale lithology can encompass quartz (opals and porcellanites), clay minerals, and limestone-dolomite, in addition to organic matter. Detecting the mineralogy and distinguishing between changes in maturation, mineralogy, and saturations can be a difficult task.
- **Anisotropy:** Although the shales are anisotropic, the changes in anisotropy with maturity are still poorly understood.
- **Organic Content:** Velocity of shale formations depends on the clay and the organic contents and maturities. However, elastic properties and its changes with maturity are not well understood.
- **Organic Maturity:** Empirical correlations have been derived between elastic moduli and maturity. The exact reason for these correlations is poorly determined and thus useable and useful theoretical models are lacking.
- **Resistivity:** Resistivity increases with maturity – it is used for mapping potential sweet spots. Again, the reason for this change in resistivity is disputed. For example, it could be due to changes in saturation or wettability, or due to dehydration of clay minerals.

Shale gas has become profitable (some say too profitable!) mainly due to advancements in horizontal drilling and fracing. The resources devoted to these two are much higher than for other branches of the oil field business. The resources used to gather information to make informative decisions for frac designs pale in comparison to those needed for fracing. Furthermore, these decisions are based on empiricisms that might be fraught with even errors. Even the terminology used is inexact. Shale reservoirs need not necessarily contain any clay minerals. They need not even have a common lithology: some shale reservoirs are carbonate muds while others are siliciclastic. Numerous alternate terms have been used for shale reservoirs: unconventionals, self-resourcing rocks; organic-rich rocks, mudstones, etc. But, the term ***shale*** appears to have stuck.

Other branches suffer from similar problems of inexact terminology. For example, for fracturing a rock, the brittleness ratio is often used. This Brittleness Ratio is derived from sonic data from well logs – mostly Young's modulus and Poisson's Ratio. However, stiffness, modulus and velocity are elastic properties, while brittleness (or its cousin, the newly minted term "Fracability"), hardness, and toughness are fracture or static deformation properties. Brittleness is the ratio between Hardness and Toughness, where Hardness is resistance to deformation and Toughness is resistance to fracture! In relating the elastic properties to static deformation properties, we need site-specific dynamic to static conversions. Young's modulus and Poisson's ratio are derived from Vp and Vs measured in well logs by assuming an isotropic and homogeneous system. If the reservoir rock is anisotropic, Poisson's ratio calculations will be in error. If the reservoir rocks change from gas saturation to water saturation, the Young's modulus – Poisson's ratio plots will be reversed. At the very least, operators might want to account for changes in saturation and use anisotropic equations to calculate the stiffness coefficients before using them for Fracability.

With the articles in this focus section, we hope to provide you with highlights about possible ways to think about the problems. We show how seismic information might be understood to derive important properties of fluids. We also show how flow properties might change over the life span of a reservoir given pressure changes that it experiences.

In the first article in this section entitled ***"Characterization sandstone reservoirs using Poisson impedance inversion"***, Sharma and Chopra show how to detect and characterize the often thinly-bedded reservoir sequences. They use the difference between Vp and Vs to demarcate gas zones. They show in a $\lambda\rho - \mu\rho$ cross-plot, gas-saturated zones often plot in a distinct location away from water- or oil-saturated zones: gas-saturated zones have lower $\lambda\rho$ values and higher $\mu\rho$ values than the background shale. Their lithology impedance (LI) can help differentiate clean zones from shaly zones while their fluid impedance (FI) can help predict fluid contents.

In the next paper entitled ***"Conventional approach for characterizing unconventional reservoirs"***, Sharma and Chopra discuss various workflows to characterize shales. They present an integrated workflow to determine P- and S-impedances. They use a model based inversion to compute P- and S-impedance, and further using these impedance information, they derive other attributes, such as $\lambda\rho$, $\mu\rho$, and Vp-Vs ratios. They demonstrate usefulness of their approach with an example from the Montney formation and are able to make maps of seismic attributes that might help delineate areal extent of fracable zones.

The last article entitled ***"Assessing Knudsen flow in gas-flow models of shale reservoirs"***, by Kuila et al. uses a theoretical framework to calculate the gas flow in nanoporous systems. These calculations show that diffusion flow can be important in gas shales and indiscriminate drawdown might move the reservoir from Darcy flow to diffusion flow regimes.

Exploration and exploitation of shale reservoirs is an exciting new field that has rejuvenated the industry. We hope that the readers find these articles interesting and inspiring! *R*

FOCUS ARTICLE *Coordinated by Manika Prasad* / Mohammed Al-Ibrahim / David Cho*

Assessing Knudsen flow in gas-flow models of shale reservoirs

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Summary

Shale reservoirs are characterized by extremely small pores and very low permeability. Detection and quantification of these small pores is a challenge. Furthermore, in such small pores, the gas flow need not flow in a Darcy flow regime. The Knudsen diffusion and slip flow gain significance and might account for at least partial flow. This flow depends on the pore size as well as the internal fluid pressure. Thus, in a depleting reservoir, the flow regime might change given a fast drawdown and loss of fluid pressure. It is postulated that gas flow in shale gas reservoirs falls in the transition regime between Darcy and Knudsen flows. The intermediate flow regime is modeled as a combination of Knudsen flow and Darcy flow. In this paper, we show how to compute the contribution of Knudsen flow to total flow as a function of pore-size and fluid pressure.

Introduction

Over the last decade, gas shale plays have become the major source of natural gas production in the United States. In spite of their large proven and potential reserves, they possess many unique challenges. The concept of porosity, permeability and flow that is applied in conventional plays cannot be directly applied to shale reservoirs. These reservoirs are extremely fine-grained rocks with more than 50% clay as a part of their matrix. Shale matrix has predominantly micro (pore-width less than 2 nm) to meso pore [pore-width 2-50 nm]†. The presence of clays and organic materials result in extremely fine pore sizes and low permeability in nano-Darcy range. Gas production from these resources is much greater than anticipated and cannot be described by conventional wisdom. In this paper, we will review several different approaches to gas flow in shales. We will specifically show the applicability of Knudsen flow regime in modeling gas-flow in shale for laboratory measurement and reservoir engineering applications. An SEM image of a typical shale reservoir rock is shown in Figure 1. In the image (Figure 1), while cracks and larger pores are visible but not the smaller pores.

In this paper, we use pore size distribution data obtained from Mercury Intrusion Porosimetry (MIP) and Nitrogen gas adsorption. These data show presence of pores from a few nm diameter to a few µm. Such small pope sizes carry important implication about the flow regimes. Since velocity – porosity transforms use only the volumetric porosity information, the pore sizes need to be derived from additional data. Fluid pressure is a valuable parameter needed in the flow calculations. In this case, seismic data can be of enormous help. Both in the planning stage as well as during production, it is important to monitor and maintain reservoir pressures at a level that will ensure sustained production. Given the importance of flow characteristics, such information about pore size and fluid pressure is critical when assessing production scenarios as well as field development schemes.

Permeability and Flow Regimes

Gas flow in shale reservoirs is described by a combination of mechanisms acting at different scales (Javadpour et al., 2007; Javadpour, 2009: Wang and Reed, 2009; Freeman, 2010; Ozkan et al., 2010. These are:

1. Desorption from kerogen and clay surfaces, and subsequent surface diffusion of the adsorbed gas molecules under a pressure gradient.
2. Knudsen diffusion and slip flow in micropores, and
3. Darcy flow in larger meso- and macropores.

In this paper, we will limit our discussion to the Knudsen diffusion, slip and Darcy flow mechanisms. Flow of fluids in rocks is generally modeled using Darcy's equation, which is also known as advective flow. Flow of gases in tubes (including capillaries) is described by Hagen-Poiseuille equations with no-slip boundary conditions. The no-slip boundary condition indicates viscous bonding of fluids to the wall and is modeled by assuming the particle velocity to be zero at the wall of the pipe (or pore).

As the characteristic length (characteristic length is dimension that defines the scale of a physical system, and for porous media, characteristic length most commonly used is the pore-diameter) of the physical system decreases, the assumption of standard continuum approach falls apart. The dimensionless Knudsen number ($Kn = \lambda \backslash R_h$, where λ is the mean free path of the gas, i.e. the average distance between two consecutive molecular collisions, and R_h is the characteristic pore diameter) is used to determine the degree of appropriateness of applying continuum approach. For $Kn < 0.01$, the mean free path of the gas molecules is negligible compared to the characteristic dimension of the flow geometry (i.e. R_h parameter), the continuum hypothesis of fluid mechanics generally holds true. Rarefaction effects become important as Knudsen number increase and consequently the pressure drop and mass flow rate cannot be predicted from the continuum model of fluid flow (Hagen-Poiseuille's equation or Darcy-like flow). At $Kn > 10$ the gas molecules collide with the flow boundaries more often than inter-molecule collisions. Thus the molecules move independently of each other and in this condition the gas composition have no importance. This flow regime is known as Knudsen diffusion or free-molecule flow.

The intermediate region in between $0.01 < Kn < 10$ cannot be considered neither as a continuum flow nor a free-molecule flow. A further classification is done for that region is given by Karniadakis et al. (2005):

- Slip flow ($0.01 < Kn < 0.1$)
- Transition flow ($0.1 < Kn < 10$)

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Assessing Knudsen flow...

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In the slip flow regime (0.01 < Kn < 0.1) the no-slip boundary conditions doesn't hold true, and a layer of about one mean free path thickness, known as the Knudsen layer, starts to become dominant between the bulk of the fluid and the wall surface. This results in a finite particle velocity value at the wall, and the corresponding flow regime is known as the slip flow regime. In petroleum engineering literature, Klinkenberg applied this slippage condition to the flow of a gas in a porous medium to derive a first order correction for the gas slippage (Freeman, 2010). As we increase the Knudsen number, either by increasing the mean free path of gas (i.e. gas flowing at very low pressure) or decreasing the pore size, the contribution of the Knudsen layer increases. It goes to a transition flow and then finally to pure Knudsen flow. However, the limits of the Knudsen number for each flow regime is purely empirical and are based on pipe flow experiment and will vary for other geometries and surface roughness (Karniadakis et al., 2005). Another important point we have to remember, that these theories were developed to explain rarefied gas flows at very low pressure. These models are experimentally verified or developed for sub-atmospheric (near vacuum) pressures. In our application, the gas flow happens at much higher pore pressures. Hence one need to make the assumption that physics of the system remains the same at high pore pressure and is governed by the Knudsen number or the ratio of mean free path of the gas at particular condition to the pore diameter (Javadpour, 2009).

In this section, we will discuss the operational gas flow regimes that interests us. Figure 1c (adapted from Javadpour et al., 2007; Sondergeld et al., 2010) shows the Knudsen number as a function of pore size for different pore pressure ranging from 100 psi to 3000 psi. The Knudsen number increases with smaller pore size. The ranges of pore sizes in shales are shown in the figure. In Figure 1c, the line is drawn on the basis of the experimental data of compacted clay pellets obtained from N_2 adsorption experiment. Figure 1c reveals that the dominant types of gas flow in those mesopores of clays are slip-flow and transition-flow.

Under high reservoir pore pressure, the Knudsen number indicates that pure Knudsen flow seems to be unlikely; it is rather expected to fall in the transition between Knudsen and Poiseuille flows (slip-flow and transition flow regimes). The pore pressure and the pore sizes are too large for pure Knudsen flow. The contribution from diffusion flow to the total flow will be more important when gas flow experiments are conducted under lab conditions. Current GRI technique measures gas permeability in crushed samples using pulse-decay techniques at STP. The equations for obtaining permeabilities assumes Darcy-like flow and do not account for slip, transition flow regime and associated diffusion effects. The diffusion effects needs to be modeled while measuring permeabilities in lab and should also be accounted for while extending the studies to reservoir conditions.

Historically, the slip flow and transition flow regime have being modeled as a combination of Knudsen flow and Poiseuille flow. Klinkenberg gave a first order approximation by suggesting simple addition of Knudsen and Poiseuille flow constants. Javadpour (2007) suggested similar approach of addition of Knudsen flow constant and Poiseuille flow constant multiplied by some factor to account for factors like wall smoothness. Karniadakis et al. (2005) suggested a unified equation to model the entire flow regime where the addition of Poisuelle flow

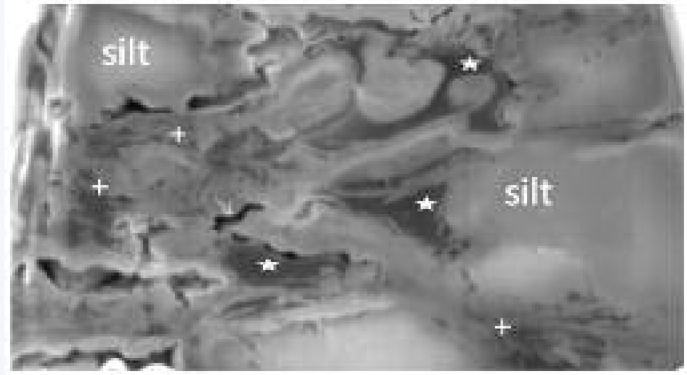

Figure 1a. SEM image of a shale sample with a view area of 6 µm wide x 4 µm high. In the image, kerogen is marked by stars, clay-silt-kerogen mixtures are marked by +, and slit-shaped pores or cracks are marked by arrows. Silt grains are marked as silt. (Image courtesy of B. Gorman).

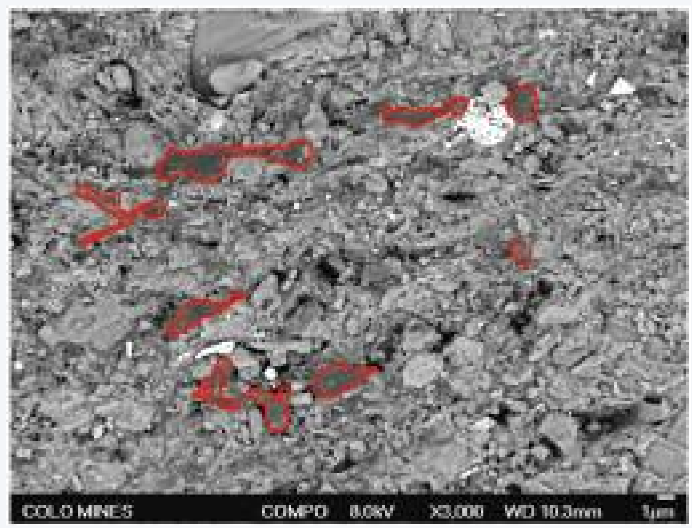

Figure 1b. SEM image of a shale sample with a view area of 40 µm wide x 30 µm high. In the image, kerogen zones are outlined by red. The rest matrix consists of clay-silt-kerogen mixtures. Pores are black and slightly rounded (Image courtesy of S. Zargari).

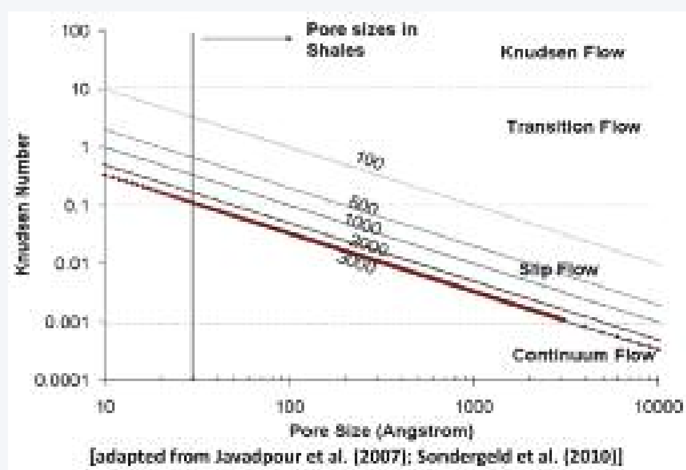

Figure 1c. Knudsen number for methane as a function of pore diameter for various pore pressures at 100°C . Figure adapted from Javadpour et al. (2007); Sondergeld et al. (2010).

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Assessing Knudsen flow...

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constant and Knudsen flow constant multiplied by factors to account for rarefaction of gas and slip coefficient. Schofield et al. (1990) used a two-parameter semi-empirical equation combining the two flow constants to explain experimental data of gas flow through microporous membrane. All of these studies show that the transition regime of the gas flow can be modeled as weighted contribution of pure Knudsen flow and pure Poiseuille flow. In the following sections, we will show the relative contribution of Knudsen flow and Poiseuille flow as functions of pore size and pore pressure.

Modeling Gas Flow Regime in Shales

In this section, we will try to understand the control of pore-sizes on the flow regimes of gas. In the next section, the different flow regimes are discussed. A general equation of flux for gas permeation through porous media can be written as:

$$J=K\Delta PL \qquad (1)$$

where, J is the mass flux per unit area, ΔP is the pore pressure gradient across the sample with thickness L and K is the mobility constant. Several processes are being described to the mass transport of gases. If the pore-width is large relative to the mean free path of the gas molecules (at high pore pressures and large pore radii), there are two major types of mass transport mechanisms. If a total pore pressure gradient exists, mass transport may take place as a result of Poiseuille or forced flow. If a partial pressure gradient exists, mass transport may take place as a result of molecule-to-molecule collision (molecular diffusion or Fickian diffusion). Fickian diffusion is not applicable for single-phase gas flow as the partial pressure will always be equal to one. Another important mechanism is surface diffusion which works for an adsorbed gas on the pore walls but in this case we are not considering this particular phenomenon. If the pore-width is small relative to the mean free path, mass transport occurs as a result of molecule-to-wall collision in the presence of either a total pressure or a partial pressure gradient (Knudsen diffusion or molecular flow).

Equation 3.2 (Hagen-Poiseuille flow equation) describes the advective flow of gas through a capillary pipe which occurs under total pressure gradient.

$$J=18r21\eta MPRT\varnothing PL \qquad (2)$$

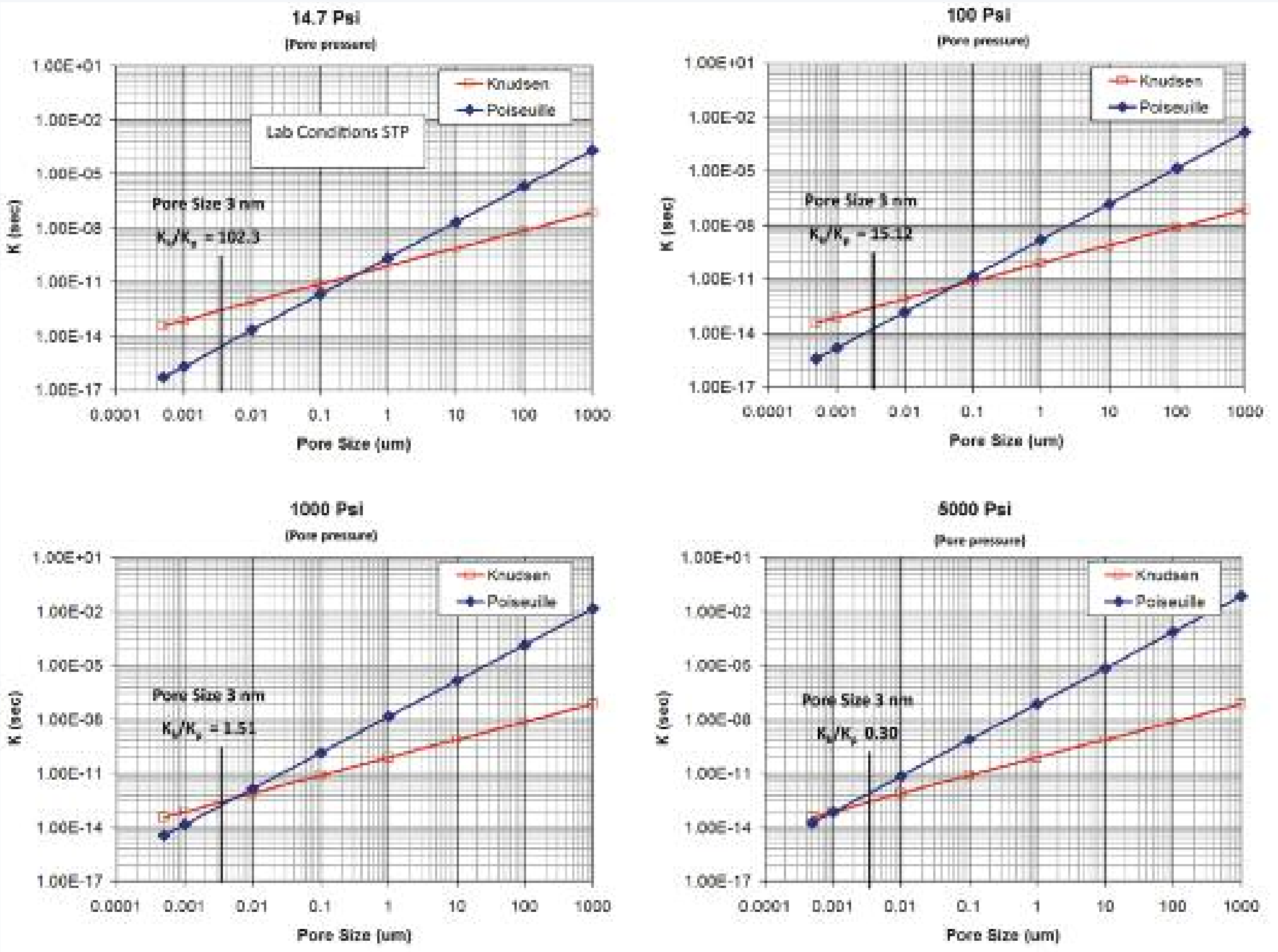

Figure 2. Flow constants as a function of pore-radius at different pore pressures.

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where, J is the mass flux, r is the pore radius, R is universal gas constant, M is the molecular weight of the gas, T is the temperature. For tortuous porous media, the equation becomes

$$JP=18r2\varphi\tau1\eta MPRT\Delta PL \qquad (3)$$

The porosity φ of the porous media restricts the cross-sectional area available for transport. A second factor called tortuosity, τ accounts for the increase in the path length which the gas molecule flow. The ratio 'φ/τ' is also called the obstruction factor. These obstruction factor combined with the characteristics radius of the pores in the porous media gives the permeability k

$$k=18r2\phi\tau \qquad (4)$$

Then Equation 3.3 becomes

$$JP=k\eta MPRT\Delta PL \qquad (5)$$

The term 'MP/RT' represents the density of an ideal gas. For real gas, the gas-deviation factor needs to be added. Equation 3.3 can be written in the following form with the oil-field units

$$JP=157.9k\eta MPzRT\Delta PL \qquad (6)$$

where, J_P is mass flux in lb/ft²/Day, k is the permeability of the porous media in Darcy, η is the viscosity of gas in centipoise, P is the average pressure in psi, T is the temperature in Rankine, R is the universal gas constant (and is equal to 10.731) and L is the length in ft.

At low pressure, collisions are dominantly between molecules and the walls, and the free path is restricted by the geometry of the void space. In this regime, termed Knudsen diffusion, the flux depends only on the density gradient of the gas and can be written as

$$JK=DK\partial\rho\partial L \qquad (7)$$

Note equation 3.7 has the same form as Fick's diffusion equation. D_K is the Knudsen diffusion coefficient of gas and it is different from Fickian diffusion coefficient. Knudsen diffusion coefficient D_K is proportional to the mean velocity of the gas. In a long, straight, circular capillary of radius r < λ, the diffusion coefficient is given by

$$DK=23\nu r\phi\tau \qquad (8)$$

Where ν is the mean molecular speed of the gas given by ν=8*RT* π*M* and 'φ/τ' is the obstruction factor modification for porous media. D_K is also self-diffusion coefficient and equation 3.8 shows that D_K is independent of pressure and changes as $T^{1/2}$ with temperature. From equation 3.7 and equation 3.8, we get the following equation assuming isothermal conditions (T constant)

$$JK=23\nu r\phi\tau\partial\rho\partial L \qquad (9)$$

$$JK=23\nu r\phi\tau\partial(MP/RT)\partial L \qquad (10)$$

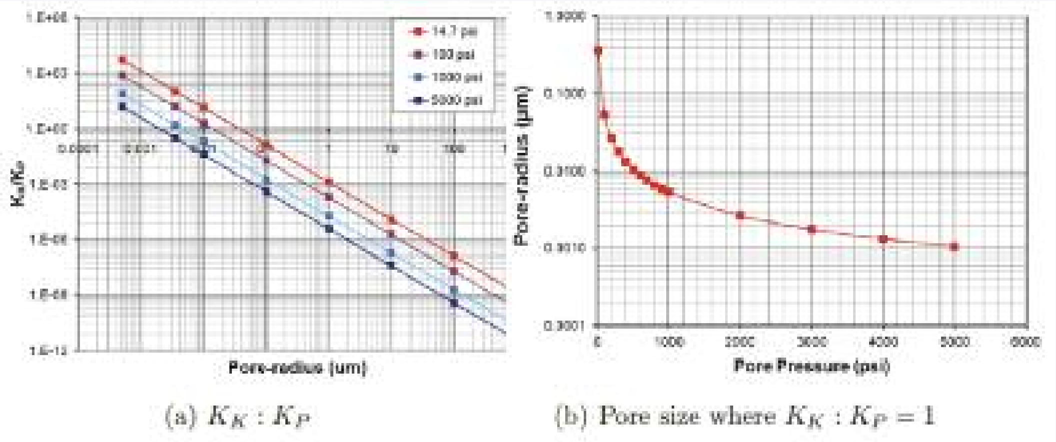

Figure 3. (left) The ratio of Knudsen flow to Poiseuille flow as a function of pore size at different pore pressures. (right) Pore sizes where the Knudsen flow contribution is equal to Poiseuille flow at different pore pressures.

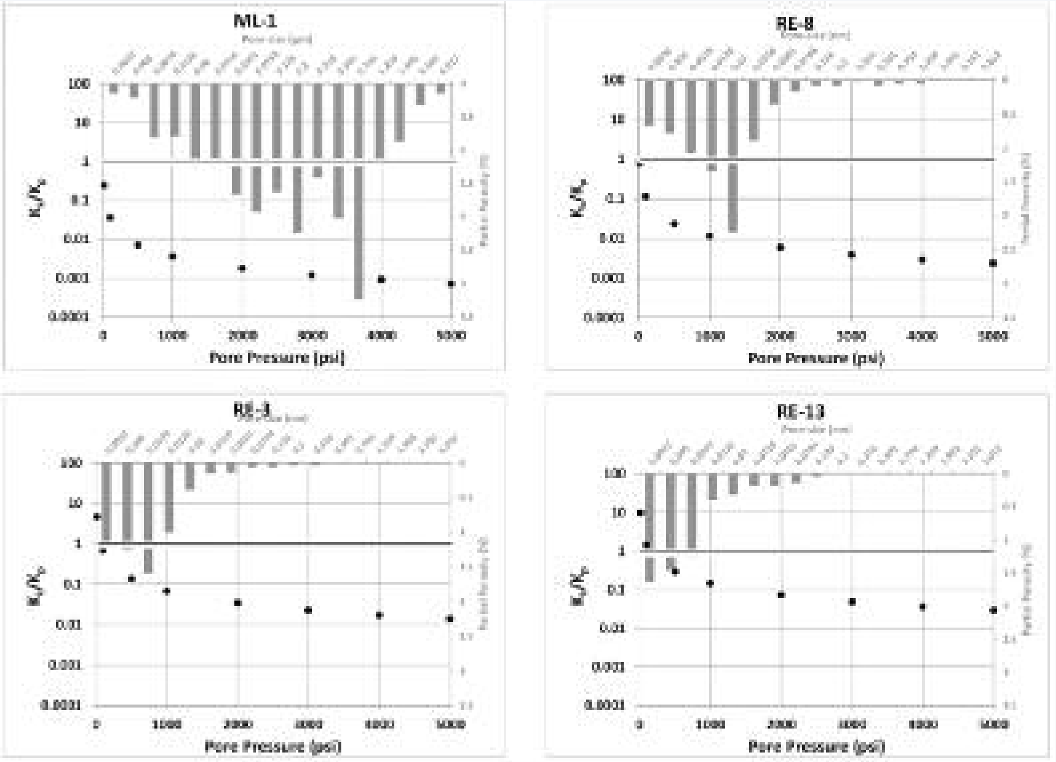

Figure 4. Flow constants for four different shales Conell-Madore and Katsube (2006) with different pore-size distribution. The circle indicates the ratio K_K/K_P for each shale and corresponding pore-size distribution is plotted as a histogram in grey. ML-1 has largest mode and majority of porosity contributed by larger pores. Contribution from Knudsen flow will be important at STP but under reservoir conditions the contribution to total flow will be negligible. RE-13 has the smallest mode of pore-sizes and Knudsen flow will contribute to the total flow in reservoir conditions as well as STP.

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Jk=238RTπM0.5rϕτMRTΔPΔL (11)

Comparing equation 3.11 and equation 3.3 with equation 3.1, the flow constant can be obtained for Knudsen flow and Hagen-Poiseuille flow as follows:

KK=23rϕτ8RTπM0.5MRT (12)

where, K_K is the flow constant for Knudsen flow and

KP=18r2ϕτ1ηMPRT (13)

where, K_P is the flow constant for Poiseuille flow. It should be noted that the Knudsen flow constant K_K is independent of pressure while the Poiseuille flow constant is dependent on pore pressure. Comparing the flow constants K_K and K_P at different pore radius r will give us an idea about the relative importance of these flow regimes and their contribution to total flux.

Flow Constants for different pore-sizes

Figure 2 shows the flow constants as a function of pore radius at different pore pressures. The porosity φ and the tortuosity τ values used are typical for shales (0.08 for φ and 3.00 for τ). At low pore pressure (14.7 psi) Knudsen flow will dominate over Poiseuille flow for pore-sizes below 0.2 μm. Since K_K is independent of pore pressure and K_P is directly proportional to pore pressure, at higher pore pressures, Poiseuille flow dominates over Knudsen flow.

The pore size at which K_P dominates over K_K moves towards smaller pores as pore pressure is increased. An example of the relative dominance of Poiseuille flow and Knudsen flow for smallest pore-sizes revealed in shales (3 nm) is shown in figure 2. The ratio of K_K to K_P decreases from 102.3 to 0.3 as pore pressure increases from 14.7 psi to 5000 psi. Figure 3a shows the relative dominance of Knudsen flow over Poiseuille flow for all pore-sizes at different pore pressure. Figure 3b shows the pore-sizes at which contribution of Knudsen flow is equal to the contribution of Poiseuille's flow as a function of pore pressure.

Flow Constants from pore-size in shales

The above plots suggest that flow from larger pore throats generally follow Darcy flow but contribution from Knudsen flow will be important in flows through the small pores. Shales are lithified clays, which constitute more than 50% of the rock with organic materials (kerogen) and detrital grains present in varying amounts. The presence of these extremely small pores (generally associated with clays and the kerogen) are documented in several studies. Shale gas reservoirs can possess a high degree of heterogeneity and widely varying porosity distributions. High pressure mercury injection data for Beaufort-MacKenzie Basin shale samples (Conell-Madore and Katsube, 2006) suggest a pore-size distribution with mode 2.5-25 nm. The pore-size distribution from Conell-Madore and Katsube (2006) is used to model the contribution of Knudsen flow and Poiseuille flow for shale systems. The pore-size-distribution data are modeled assuming the pores to be a bunch of straight capillary tubes and the Knudsen flow constant and the Poiseuille flow constant are calculated using the following formulae:

KK=r23riφiτ8RTπM0.5MRT (14)

KP=r18ri2φiτ1ηMPRT (15)

where, K_K is the flow constant for Knudsen flow, r is the range of pore-sizes, φi is the partial porosity for the pore-size *ri* and τ is the tortuosity (1 in this case) and K_P is the flow constant for Poiseuille flow.

Figure 4 shows the ratio of Knudsen flow over Poiseuille flow for four shale samples from the Connell-Madore and Katsube data with different pore-size distributions (plotted in the background). ML-1 have the highest porosity (21.30%) and largest relative proportions of macropores. RE-8, RE-3 and RE-13 have respectively more relative proportions of mesopores. The contribution of Knudsen diffusion over the Poiseuille flow increases from ML-1 to RE-13. For the finer pored shales, under reservoir conditions (around 1000-2000 psi pore pressure), there is a significant contribution of Knudsen diffusion to the total flow.

Discussion

The pore-size dimensions of these shale systems can vary widely, potentially ranging from 10 nm to 5 μm. The distribution of pore throat sizes will vary reservoir by reservoir. The results of this modeling show that the ratio of Knudsen flow constant to Poiseuille (Darcy) flow constant increases sharply as pore sizes reduce to smaller than 100 nm. Also, Knudsen diffusions contributions to flow increase as pores become smaller. The modeling results specifically shows that presence of small micro and mesospores is important but more importantly the relative abundance of these small pore sizes compared to large pore sizes control the gas flow behavior of shales. This model provides a strong basis for future work, such as to incorporate and account for Knudsen diffusion while measuring permeabilities of shale in laboratory conditions and also in reservoir modeling in shales. We will also investigate the applicability of pore-size distribution data for shales to make qualitative and quantitative prediction of flow properties of shales. R

Acknowledgments

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Utpalendu Kuila bio

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Manika's main interests lie in understanding the basic principles governing the physical properties of rocks, fluids, and rocks with fluids. She is also interested to understand how ant-sized phenomena control elephant-sized features. She has published in geophysical, geological, petroleum engineering, and non-destructive testing journals.

Hossein Kazemi bio

Characterization sandstone reservoirs using Poisson impedance inversion

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We demonstrate the application of Poisson impedance (PI) inversion for characterizing sandstone reservoir encased in shale, when the impedance contrast between them is very small. Poisson Impedance is defined as the difference between the P-impedance (I_P) and a scaled version of the S-impedance (I_S), where the scalar (c) can be determined from the slope of the regression line between I_P and I_S. Using well data, if the PI curve is correlated with the Gamma Ray (GR) curve, the porosity (ϕ) curve, or the water saturation curve for different values of *c*, it is possible to determine the maximum correlation coefficient in each case. The c value corresponding to the maximum correlation coefficient for *GR* is used to compute another attribute called *lithology impedance* (*LI*). Similarly, *fluid impedance* (*FI*) can be computed using the *c* value that corresponds to the maximum correlation coefficient for the *porosity* (ϕ) curve. The cross-plot between *LI* and *GR* shows the advantages of *LI* in distinguishing sandstone from shale. Pore content is predicted using the linear relationship exhibited on the cross-plot of *FI* versus ϕ.

Introduction

The increasing demand of oil and gas motivates geoscientists to not only explore new reservoirs but to try and characterize the existing ones in a robust way as well. One of the challenges in doing so is to be able to differentiate lithology and fluids in the reservoir. Rock physics constants such as, bulk modulus (k), shear modulus (μ), Young's modulus (E) and Lambda-rho ($\lambda\rho$) attributes are commonly used for discriminating lithology (sandstones versus shale) or fluids (gas, oil, water). *P*-wave velocity (V_P) and S-wave velocity (V_S) or P-impedance (I_P) and S-impedance (I_S) plus density (ρ) are prerequisites for the computation of all the attributes mentioned above. Over the last few years, pre-stack seismic inversion has been used to estimate these attributes. This seismic inversion yields I_P, I_S, Poisson's ratio (via V_P/V_S ratio) and density. The robust determination of density from seismic requires really long offsets and noise-free data which is seldom available. In order to avoid this stringent requirement of density, we usually compute it as its product with other attributes such as $\lambda\rho$, $\mu\rho$, $k\rho$ and $E\rho$. Finally, the cross-plotting pair of these attributes is used for discriminating lithology and fluid content.

The method

It is usually noticed that the cross-plotting of I_P versus I_S for data from a thin zone enclosing a gas sand reservoir yields a cluster of points corresponding to gas sand somewhat separated from the cluster of points coming from the background shale. The separation between these clusters depends on the impedance contrast between the litho-fluid and background lithology. Moreover, for enhanced separation between gas sand and background shale, another attribute combination such as the $\lambda\rho$ - $\mu\rho$ cross-plot is used. This cross-plot exhibits more separation as gas sand shows lower values of $\lambda\rho$ and higher values of $\mu\rho$ than the background shale.

On these cross-plots, it may be difficult to discriminate the litho-fluid distribution where clusters are not completely separated. But in such cases, rotating the axes to be parallel with the trends would ensure a distinct discrimination of the litho-fluid distribution. This rotation can be achieved by computing an interesting attribute namely Poisson impedance (Quakenbush et al., 2006). It incorporates the information of Poisson's ratio and density. Mathematically, it can be expressed as $PI = \boldsymbol{I}_P - cI_S$ where c is the term that optimizes the rotation. The value of c needs to be determined from the regression line of the cross-plot of the I_P and I_S logs for the wet trend. The inverse of the slope can be used as the c value. Additionally, the target correlation coefficient analysis (TCCA) method (Tian et al., 2010) can be used to calculate c.

The automatically generated correlation coefficient between the *PI* curve with different *c* values and the *Gamma Ray* and *porosity* curves is computed. The *c* value corresponding to the maximum correlation coefficient for *GR* is used to compute an attribute that would emphasize lithology and so is known as lithology impedance (*LI*). Similarly, fluid impedance (*FI*) is computed using a *c* value that corresponds to the maximum correlation coefficient for the *porosity curve* (Direzza et al.,

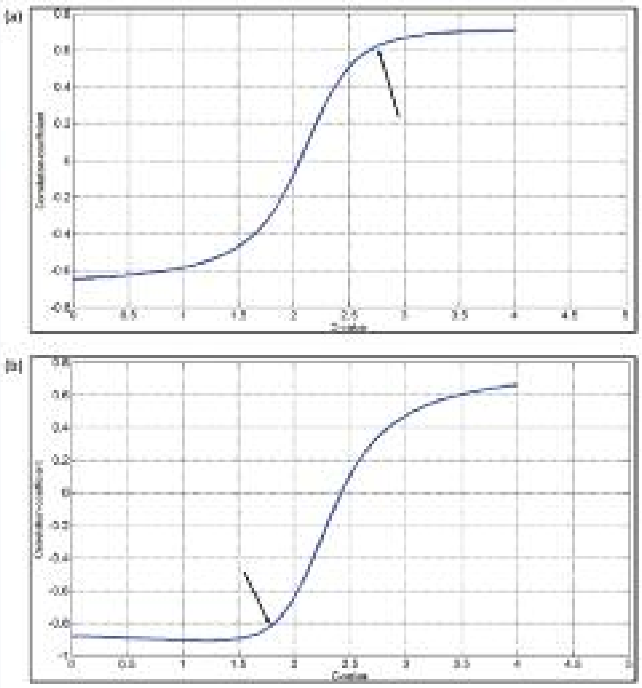

Figure 1. Target Correlation Coefficient Analysis (TCCA) for (a) Lithology impedance. (b) Fluid impedance. The c-value in (a) is 2.78 and in (b) is 1.75. These values are used for computing LI and FI.

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2012). Cross-plots between *LI* and *GR* can now be constructed that show the advantage of *LI* in distinguishing sandstone from shale. Fluid content is predicted using the linear relationship exhibited on the cross-plot of *FI* versus ϕ.

Examples

In the present study, we demonstrate the application of the above methodology for characterizing the sandstone of Halfway and Doig Formations of northeastern British Columbia, Canada. The Doig Formation is generally a mixture of shale and siltstones. The lower levels of the Doig Formation are radioactive, whereas the upper levels are not. The contact between the Doig and Halfway Formations is more problematic but is generally assigned to the top of the uppermost prominent shale interval below the distinct and widespread sandstone facies assigned to the Halfway sandstone. However, in places relatively thick sandstone in the Upper Doig Formation are developed near or immediately below the Halfway Formation sandstone, and this poses a problem in assigning the contact between the two formations. Locally, tidal channels, which are part of the Halfway shore-face cut into the Doig siltstones and shale, and again create difficulty in distinguishing the two formations.

In this study, we automatically calculate the correlation coefficients between the *PI* curve with different *c*-values versus the *GR* curve and the porosity (ϕ) curve. This correlation of *PI* with *GR* is shown in Figure 1a. The maximum correlation coefficient reached in for the *c*-value is 2.78 (cc=0.678). Similarly, the correlation of *PI* with ϕ is illustrated in Figure 1(b). The *c*-value 1.75 (cc= -.875) corresponding to the maximum correlation of the PI with the porosity curve is noticed. Thus, Poisson impedance attributes, namely, Lithology impedance (*LI*) using equation I_P-2.78*I_S, and Fluid impedance (*FI*) using equation - (I_P-1.75*I_S) can be derived. They are useful because of their sensitivity to lithology and porosity respectively. The cross-plot of *LI* versus *GR* is shown in Figure 2a. On this the red polygon encloses the points having low *LI* and *GR* while points corresponding to high *LI* and *GR* are enclosed by the blue polygons. The back projection of these polygons on well-log curves is shown in Figure 2b. Notice that the points corresponding to red polygon are coming from the Halfway sandstone while shale formation is highlighted by the points coming from blue polygon. Thus, the cross-plot of *LI* versus *GR* shows the advantage of *LI* in distinguishing sandstone

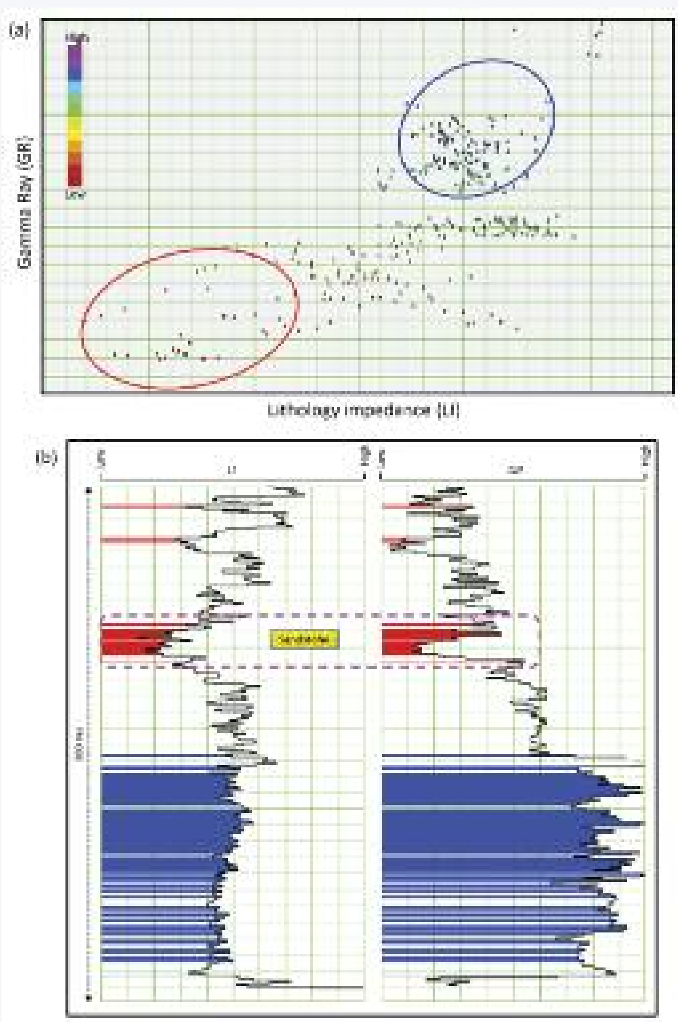

Figure 2. (a) Cross-plot of LI versus GR color coded with GR. Different clusters corresponding to shale and sand stone are noticed here. The red polygon corresponds to low GR and LI. Points corresponding to high GR and LI are enclosed by the blue polygon. (b) The back projection of these polygons on well curves reveals that points from the red polygon come from the Halfway sandstone while shale exhibits the points from the blue polygon.

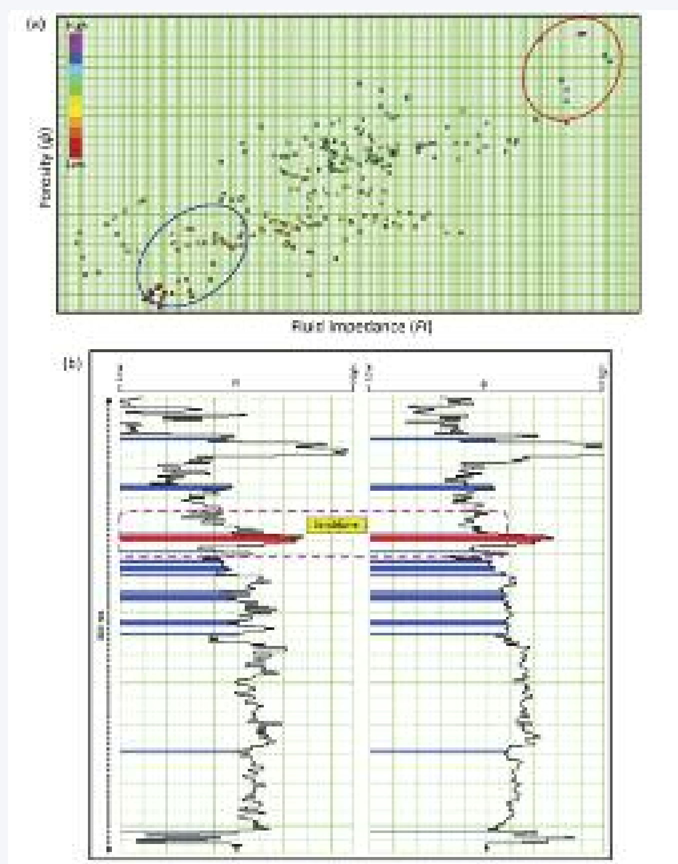

Figure 3. (a) Cross-plot of FI versus   color coded with . Different clusters corresponding to shale and sandstone are noticed here. The red polygon corresponds to high   and FI. Points corresponding to low   and FI are enclosed by the blue polygon. (b) The back projection of these polygons on well curves reveals that points from the red polygon come from the Halfway sandstone while shale exhibits the points from the blue polygon.

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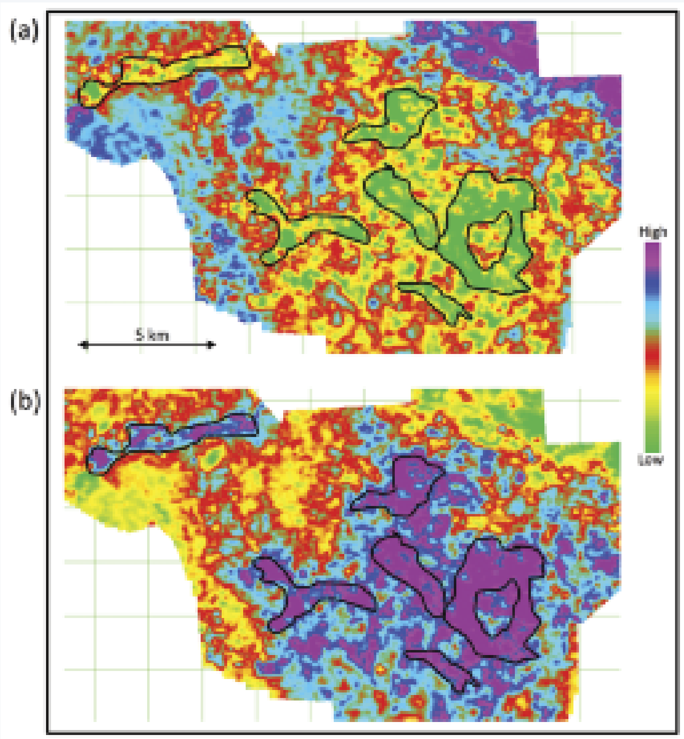

Figure 4. Horizon slices of (a) Lithology Impedance and (b) Fluid Impedance over the 10 ms window centered at the Halfway horizon. As low LI and high FI correspond to the sandstone; we have mapped the presence of sandstone, laterally.

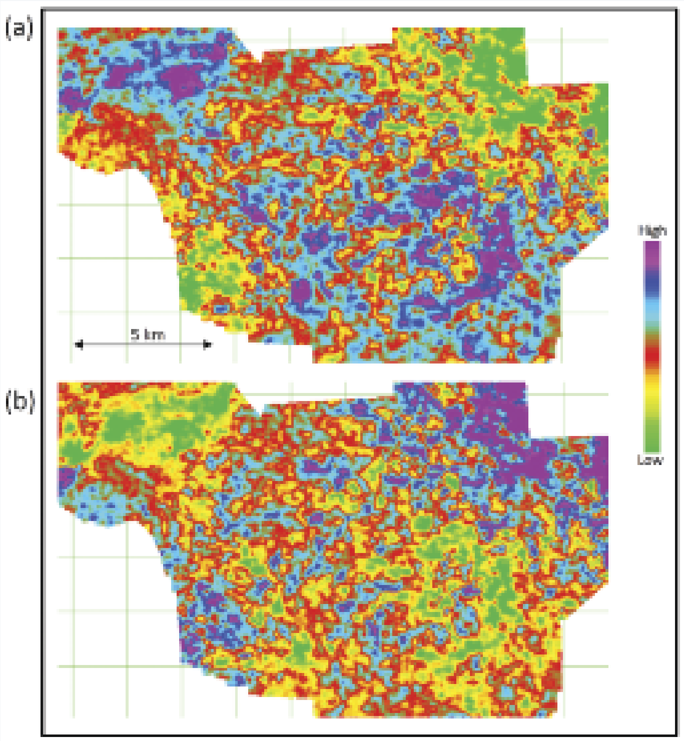

Figure 5. Horizon slices of (a) Lithology Impedance and (b) Fluid Impedance over the 10 ms window centered at the Halfway horizon which is shifted 30 ms below. The disappearance of sandstone laterally is noticed.

from shale. The cross-plot of *FI* versus ϕ is shown in Figure 3a and it shows that we can predict the porosity information from its "linear relationship". Two polygons corresponding to high and low (*FI*, ϕ) are considered on this cross-plot. The back projection of these as shown in Figure 3b reveals that the high (*FI*, ϕ) corresponds to Halfway sandstone while shale exhibits low (*FI*, ϕ).

Poisson impedance from seismic data

The workflow for Poisson Impedance (*PI*) involves computing I_P and I_S volumes from pre-stack seismic data. For computing these prerequisites, simultaneous inversion is performed. This inversion method facilitates the estimation of the P- and S-impedance directly from the pre-stack seismic gathers, without first estimating the P- and S-reflectivities from pre-stack seismic data and then transforming them to impedance. In this inversion, we start with an initial low-frequency model and generate synthetic traces from it. For generating synthetic traces, angle dependent wavelets are computed statistically from the input data by assuming it to be zero phase, and are then convolved with the modeled reflectivities. Further, the model impedance value is changed in such a manner that the mismatch between the modeled angle gather and the real angle gather is minimized in a least squares sense. Having I_P and I_S volumes, *LI* and *FI* are then derived using equations derived from well log curves analysis.

Figure 4a shows the horizon slice of *LI* taken at the Halfway horizon. The same horizon slice of *FI* is shown in Figure 4b. From the analysis carried out at well log curves, it was concluded that low *LI* and high *FI* correspond to the sandstone; with that in mind we have mapped the presence of sandstone, laterally, on these slices as indicated with the black outline. Similarly, the horizon slices of *LI* and *FI* are shown in Figures 5a and 5b, respectively, when the Halfway horizon is shifted 30 ms below. It is noticed here that the presence of sandstone disappears on these slices.

Conclusions

In conclusion, *PI* is very favorable attribute for sandstone reservoir characterization. Using TCCA method, we can derive two attributes of *PI* namely Lithology Impedance (*LI*) and Fluid Impedance (*FI*). The results on log data show that sandstone and shale can be well distinguished by *LI*. Also FI provides a potential pore space content identification. Integrating with geological, petrophysical, and well test data, the sandstone reservoirs can be characterized properly and new prospect can be identified directly. R

Acknowledgements

We thank to Arcis Seismic Solutions and TGS for allowing us to present this work.

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Characterization sandstone reservoirs…

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He received several awards at ONGC, and more recently has received the AAPG George C. Matson Award for his paper entitled 'Delineating stratigraphic features via cross-plotting of seismic discontinuity attributes and their volume visualization', being adjudged as the best oral presentation at the 2010 AAPG Annual Convention held at New Orleans, the 'Top 10 Paper' Award for his poster entitled 'Extracting meaningful information from seismic attributes', presented at the 2009 AAPG Annual Convention held at Denver, the 'Best Poster' Award for his paper entitled 'Seismic attributes for fault/fracture characterization', presented at the 2008 SEG Convention held at Las Vegas, the 'Best Paper' Award for his paper entitled 'Curvature and iconic Coherence–Attributes adding value to 3D Seismic Data Interpretation' presented at the CSEG Technical Luncheon, Calgary, in January 2007 and the 2005 CSEG Meritorious Services Award. He and his colleagues have received the CSEG Best Poster Awards in successive years from 2002 to 2005.

He is a member of SEG, CSEG, CSPG, CHOA (Canadian Heavy Oil Association), EAGE, AAPG, APEGGA (Association of Professional Engineers, Geologists and Geophysicists of Alberta) and TBPG (Texas Board of Professional Geoscientists).

Announcing the Value of Integrated Geophysics Committee

Lee Hunt, John Duhault, George Fairs, Dave Gray, Ron Larson, and Kurtis Wikel

The CSEG has a new initiative the purpose of which is to encourage, promote, and help develop the greater use of value oriented geophysical methods. The coordination of this initiative will be carried out by a group called the Value of Integrated Geophysics Committee. The committee will carry out this effort by several means including by coordination with other groups such as the Annual Convention, the CSEG Recorder editorial staff, and the CSEG Symposium. The committee will also author several unique efforts of its own which will include reaching out to engineering, business, and geological societies.

The primary goal of the committee is to facilitate the better use of geophysics for business purposes. This effort will include the encouragement of case study works that show the value of geophysical technology and interpretive techniques. The committee will also spearhead the creation of prestigious awards for Best Case Study in the RECORDER and at other venues to provide greater support to value of geophysics efforts.

A call to action, call for papers

Consider this initiative as support for your own efforts to prove and improve the value and meaning of your own work. This is also a call to action: step up and help us all develop and demonstrate the value of the geophysical method today and tomorrow. If you have a case study that demonstrates value, contact us. We will help you find a place to publish the work and get you in touch with other like minded professionals. Let us create value together.

Contact: George Fairs, Chair of the Value of Integrated Geophysics Committee (George.Fairs@divestco.com), or Ron Larson, CSEG President (LarsonR@rpsgroup.com). R

Coordinated by Manika Prasad* / Mohammed Al-Ibrahim / David Cho

Conventional approach for characterizing unconventional reservoirs

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Shale resources characterization has gained attention in the last decade or so, after the Mississippian Barnett shale was successfully developed with the application of hydraulic fracing and horizontal drilling. For characterization of shale gas formations different workflows using 3D surface seismic data have been introduced. We propose an integrated workflow for the characterization of the Montney shale formation, one of the largest and economically viable resource plays in North America. We also compare results to those that were obtained by an existing workflow described elsewhere.

Introduction

Shale-gas plays differ from conventional gas plays in that the shale formations are both the source rocks and the reservoir rocks. There is no migration of gas as the very low permeability of the rock causes the rock to trap the gas and it forms its own seal. The gas can be held in natural fractures or pore space, or can be absorbed onto the organic material (Curtis, 2002). Apart from the permeability, total organic content (TOC) and thermal maturity are the key properties of gas potential shale. Generally, it can be stated that the higher the TOC, the better the potential for hydrocarbon generation. In addition to these characteristics, thickness, gas-in-place, mineralogy, brittleness, pore space and the depth of the shale gas formation are other characteristics that need to be considered for a shale gas reservoir to become a successful shale gas play. The organic content in these shales, which are measured by their TOC ratings, influence the compressional and shear velocities as well as the density and anisotropy in these formations. Consequently, it should be possible to detect changes in TOC from the surface seismic response.

The method

Passey et al. (1990) proposed a technique for measuring TOC in shale gas formations. Basically, this technique is based on the porosity-resistivity overlay to locate hydrocarbon bearing shale pockets. Usually, the sonic log is used as the porosity indicator. In this technique, the transit time curve and the resistivity curves are scaled in such a way that the sonic curve lies on top of the resistivity curve over a large depth range, except for organic-rich intervals where they would show crossover between themselves.

TOC changes in shale formations influence V_P, V_S, density and anisotropy and thus should be detected on the seismic response. To detect it, different workflows have been discussed by Chopra et al. (2012).

Rickman et al. (2008) showed that brittleness of a rock formation can be estimated from the computed Poisson's ratio and Young's modulus well log curves. This suggests a workflow for estimating brittleness from 3D seismic data, by way of simultaneous pre-stack inversion that yields I_P, I_S, V_P/V_S, Poisson's ratio, and in some cases meaningful estimates of density. Zones with high Young's modulus and low Poisson's ratio are those that would be brittle as well as have better reservoir quality (higher TOC, higher porosity). Such a workflow works well for good quality data and is shown in Figure 1.

We propose an integrated work flow in which well data as well as seismic data are used to characterize the hydrocarbon bearing shale as shown in Figure 2. We begin with the generation of different attributes from the well-log curves. Then, using the cross-plots of these attributes we try and identify the hydrocarbon bearing shale zones. Once this analysis is done at the well locations, seismic data analysis is picked up for computing appropriate attributes. Seismically, pre-stack data is essentially the starting point. After generating angle gathers from the conditioned offset gathers, Fatti's equation (Fatti et al. 1994) can be used to compute P-reflectivity, S-reflectivity, and density which depends on the quality of input data as well as the presence of long offsets. Due to the

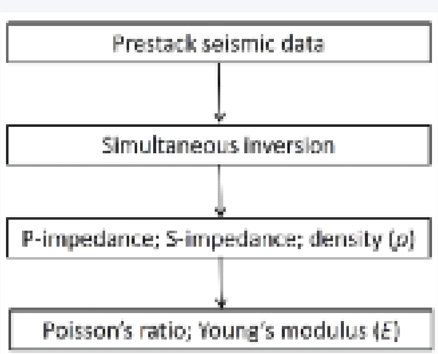

Figure 1. Rickman et al. (2008) workflow for characterizing shale gas formation.

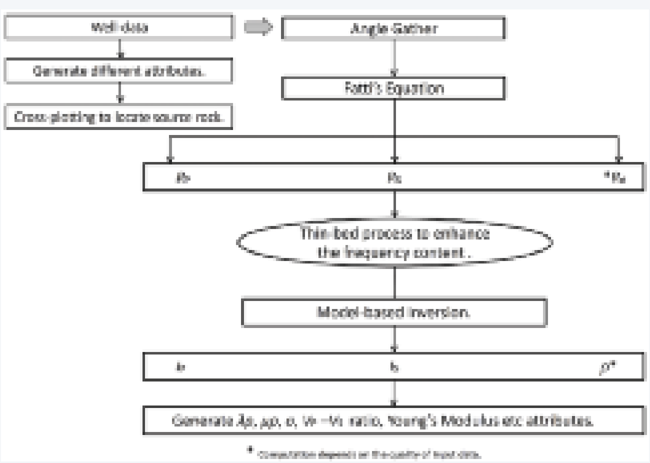

Figure 2. Proposed integrated workflow for characterizing the unconventional reservoirs using conventional tools.

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Conventional approach…
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band-limited nature of acquired seismic data, any attribute extracted from it will also be band-limited, and so will have a limited resolution. While shale formations may be thick, some high TOC shale units may be thin. So, it is desirable to enhance the resolution of the seismic data. An appropriate way of doing it is the thin-bed reflectivity inversion (Chopra et al. 2006; Puryear and Castagna, 2008). Following this process, the wavelet effect is removed from the data and the output of the inversion process can be viewed as spectrally broadened seismic data, retrieved in the form of broadband reflectivity data that can be filtered back to any bandwidth. This usually represents useful information for interpretation purposes. Thin-bed reflectivity serves to provide the reflection character that can be studied, by convolving the reflectivity with a wavelet of a known frequency band-pass. This not only provides an opportunity to study reflection character associated with features of interest, but also serves to confirm its close match with the original data. Further, the output of thin-bed inversion is considered as input for the model based inversion to compute P-impedance, S-impedance and density. Once impedances are obtained, we can compute other relevant attributes, such as the λρ, μρ and V_P/V_S. These are used to measure the pore space properties and get information about the rock skeleton. Young's modulus can be treated as brittleness indicators and Poisson's ratio as TOC indicator.

Examples

The Montney play is one of the active natural gas plays in North America. It is a thick, regionally charged formation of unconventional tight gas/shale distributed in an area extending from north central Alberta to the northwest of Fort St. John in British Columbia. The Montney play covers approximately 3.8 million acres in the South Peace region and includes major facies of fine grained shoreface, shelf siltstone to shale, fine-grained sandstone turbidities, and organic rich phosphatic shale. Primary focus is on the Upper and Lower Montney for horizontal drilling.

In order to characterize the Montney Formation, we begin with the Passey's method and overlay the resistivity and sonic curves covering the Montney formation, as shown on the left track of Figure 3(d). The cross-over between these curves is noticed in the Upper Montney (UM) formation. As the resistivity volume cannot be extracted from the seismic, it is desirable to explore the seismically derived attributes that can be used to characterize the shale gas formation. To work towards this goal, cross-plots of a pair of different relevant attributes is undertaken. The commonly considered attributes are I_P-I_S, λρ-μρ and I_P-V_PV_S ratio, which are shown in Figures 3(a), 3(b) and 3(c), respectively. The points enclosed by the red polygons on the cross-plots show the characteristics of the hydrocarbon bearing zone. The back projection of the red polygons onto the log curves helps us understand where these points are coming from, as shown in right track of Figure 3(d). It is noticed here that the anomalous points are coming from the Upper Montney, thus showing consistency with the interpretation of the Passey et al. (1990) method. Moreover, it shows that the characterization of unconventional reservoirs can be carried out using conventional tools.

Following the workflow shown in Figure 2, we compute different attributes from the seismic data. Figure 4(a) shows the λρ section computed using the Rickman et al. (2008) workflow,

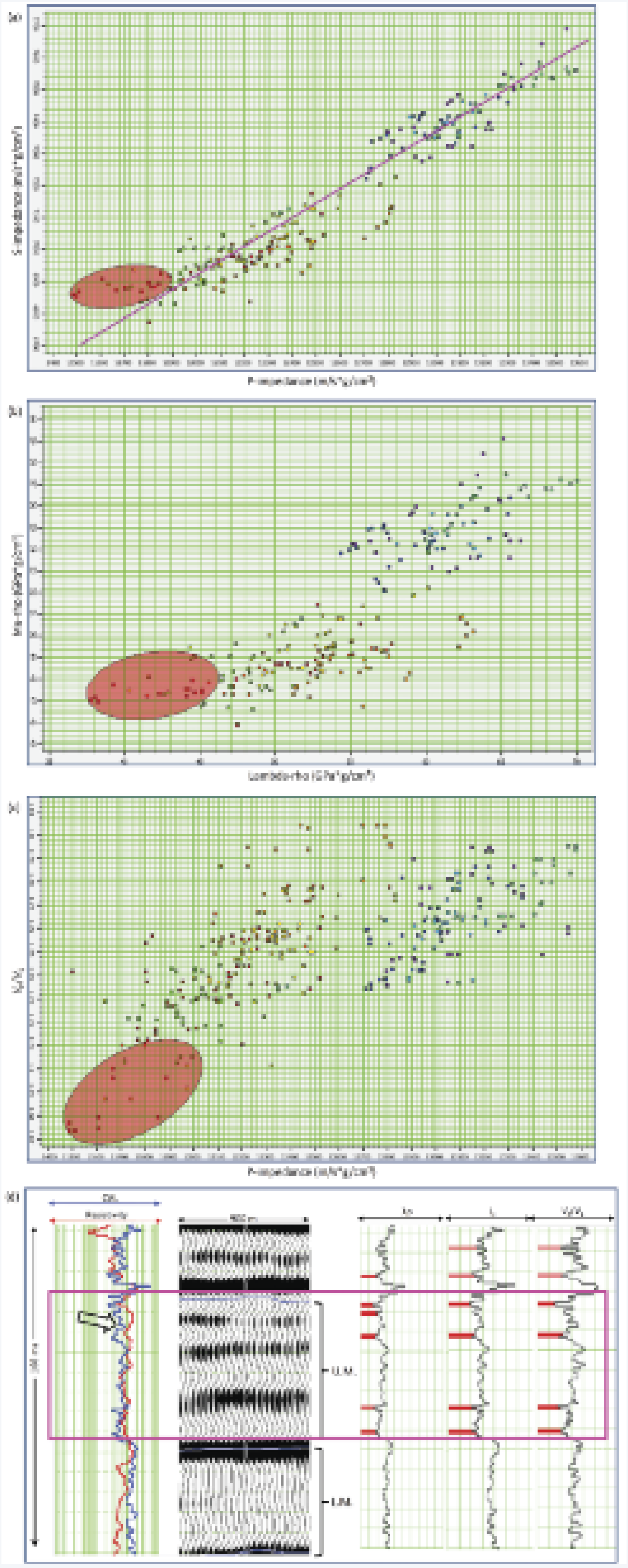

Figure 3. Cross-plotting of (a) I_P - I_S (b) λρ - μρ, (c) I_P-V_P/V_S (d) On the left, resistivity and sonic curves are overlaid according to Passey et al., (1990) method and show the crossover in the Upper-Monteny (U.M) Formation. Red polygons on the cross-plots show the anomalous zone and their back projection is shown on the right track of Figure d.

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Conventional approach...

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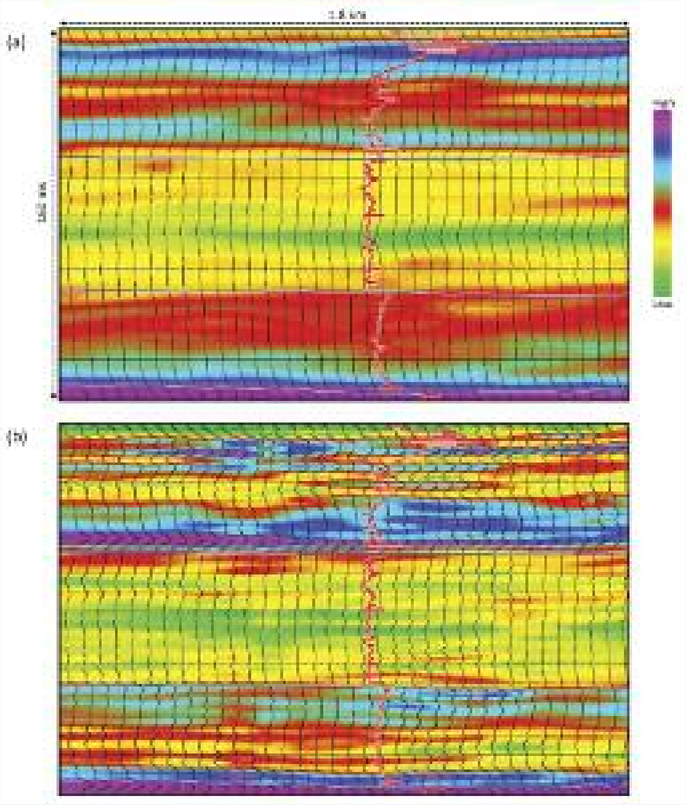

Figure 4. λρ section computed (a) using Rickman et al. (2008) workflow (b) using the proposed workflow. Notice the higher resolution, more detailed information and its correlation with the well data.

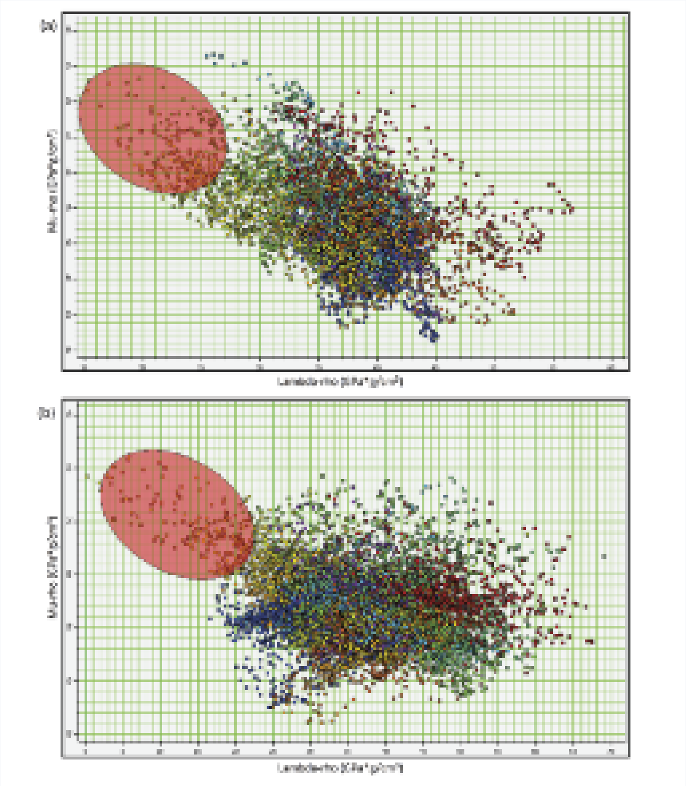

Figure 5. λρ- μρ crossplot computed (a) using Rickman et al. (2008) workflow, (b) using proposed workflow. The anomalous points enclosed by red polygon show more separation here on the later.

while the same section computed using the proposed workflow is shown in Figure 4(b). Notice the higher resolution in the latter display. The cross-plotting of the λρ and μρ attributes is usually used to delineate the hydrocarbon bearing shale pockets. Figures 5(a) and 5(b) show this cross-plotting for both the workflows mentioned above. A red polygon is drawn on the cross-plots to highlight the points that have characteristics of hydrocarbon bearing zones. It is noticed that the anomalous zones show greater separation on Figure 5(b). The back projection of the red polygon drawn on these figures on the seismic section is shown in Figures 6(a) and 6(b), respectively. While a broad red paint-brush pattern is seen in the former, more detailed information can be seen on Figure 6(b).

Shale source rocks must exhibit high brittleness (as they would then frac better) and low Poisson's ratio, and so we generate a cross-plot of these two attributes as shown in Figure 7(a).We show the brittleness increasing in the direction of the arrow. Ductile shale is expected to have low Young's modulus and high Poisson's ratio, while brittle shale shows the reverse behavior. Thus, blue and red polygons are drawn corresponding to ductile and brittle rock, respectively. The back projection of both polygons on the seismic section is shown in Figure 7(b). Hydrocarbon bearing and brittle shale is noticed in the Upper Montney formation. The horizon slices of E and σ are shown in Figures 8(a) and 8(b), respectively. Brittle and hydrocarbon bearing shale is mapped by black polygons.

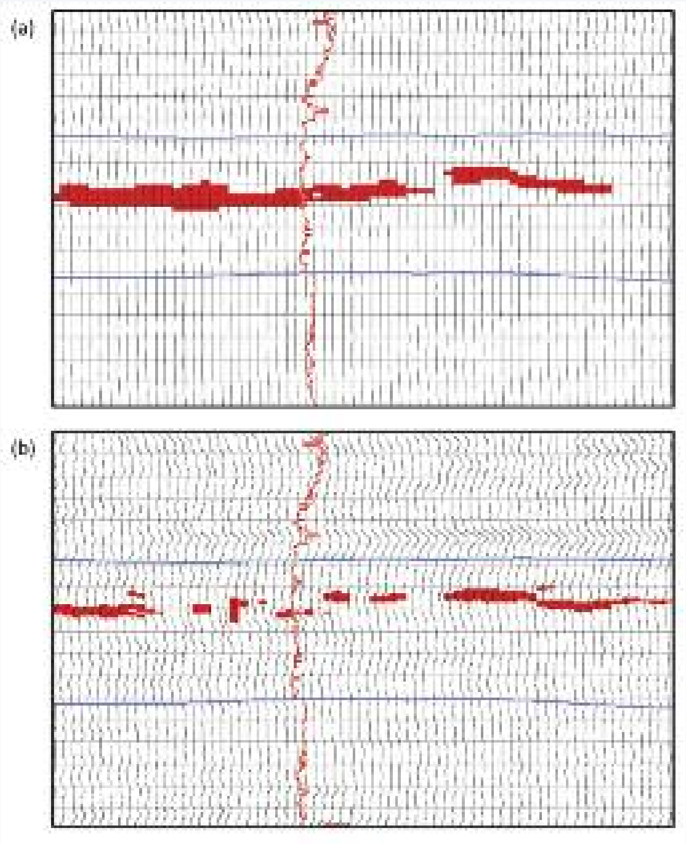

Figure 6. (a) Back projection of the points enclosed by the red polygon drawn on Figure 5(a) and (b) on Figure 5b on seismic section respectively.

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PRODUCT DEVELOPMENT
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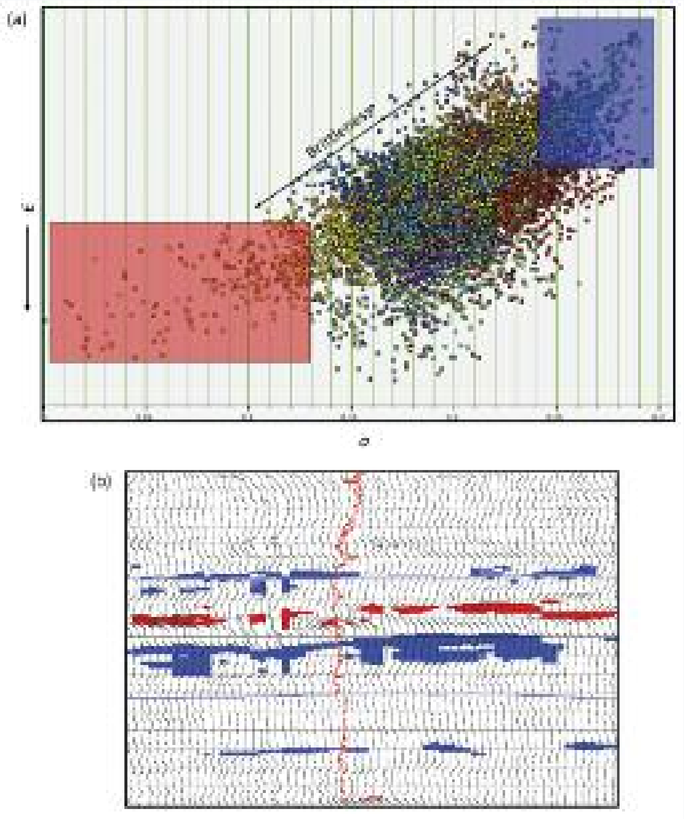

Figure 7. (a) Cross-plot of Young's modulus and Poisson's ratio attributes derived from seismic data. Brittleness increases in the direction of arrow. Blue and red polygons are drawn corresponding to ductile and brittle rock, respectively. (b) The back projection of both polygons on the seismic section. Brittle shale is noticed in the Upper Montney formation.

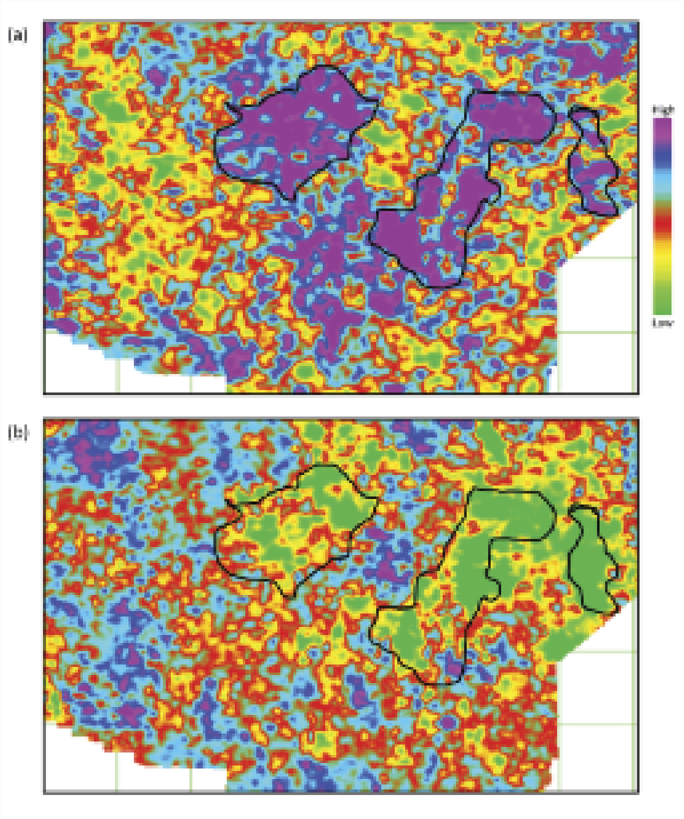

Figure 8. Horizon slices from (a) Young's modulus and (b) Poisson's ratio derived from the seismic data. Brittle and hydrocarbon bearing shale is mapped by black polygons.

Conclusions

Following the Passey et al. (1990) method, it was noticed that the Upper Montney shows the characteristics of a source rock. Using our proposed workflow we demonstrate that seismically derived attributes can be used to characterize the Montney formation directly. On comparison, the derived attributes using the proposed workflow are seen to delineate the Montney Formation better than those of the Rickman et al. (2008) workflow. *R*

Acknowledgements

We thank Arcis Seismic Solutions, TGS, for allowing us to present this work.

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Answers for "Blast from the Past" in Tracing the Industry

In the picture (in no particular order) are Oliver Kuhn, Norbert Bernoth, Leo Macht, John Simmonds, Bob Macht, Steve Fuller, Bob South and Carmine Militano. Some people might recognize Kent Fargey and Vince Sisko who used to work in the industry.

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Value of Integrated Geophysics
Canadian Society of Exploration Geophysicists

Estimating the value of Geophysics: decision analysis

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Summary

This paper discusses the value of geophysical data in the resource play paradigm. Specifically, it shows how well known decision analysis techniques can be applied to estimate the value of seismic for resource play examples. We examine the sensitivity to the accuracy of the seismic interpretation and to the spread of expected values of the drilling being considered. The results are strongly supportive of the investment of the seismic under certain conditions. Sensitivity to seismic reliability also implies economic support to low cost efforts such as processing that may increase the reliability of the interpretation. Even under conditions where the initial economic success of the wells is as high as 75% to 80%, and the seismic data only adds a small additional advantage, it can be strongly economic to buy and use the seismic data. This argument for the value of seismic is practical, conservative, and reasonable because it recognizes seismic as imperfect information through the use of Bayes' Theorem. The use of decision analysis techniques, including sophisticated techniques such as Bayes' Theorem, is of particular use because the results are manifest in the language of engineers; that is in the form of decision trees, statistics, and expected value.

The question of the value of seismic is topical. The oil and gas resource business environment has changed, particularly in the perception and economic meaning of risk. Risk has always been a short form for describing the probability of various desirable or undesirable outcomes, and in the resource play environment we have vastly reduced the probability of not encountering reservoir or hydrocarbons. Somehow this change in conditions has led many to incorrectly assume that there no longer exists a spectrum of outcomes with associated desirability. Even in resource plays there is commonly a significant variation in the flow rates, ultimate recoveries, and values of individual wells. The value of seismic in these new resource plays is dependent on the probability distribution *of* and economic differences *in* the spectrum of outcomes available. We will show that if we understand these probabilities and their economic differences, we can quickly assess how valuable seismic data is.

Introduction

Geophysical data and its interpretation should only be invested in if it has value to the investor. This is no surprise; we should not invest in anything that lacks a value argument, otherwise it is charity. We do not perform geophysics for intrinsic reasons; in business we have no interest in it as a thing in itself. The value of geophysical data may be estimated in a variety of ways, none of which are materially different from the way of determining the value of other kinds of information such as log data. We shall briefly discuss the case study method of determining the value of geophysical data, but we will spend more time on the decision analysis method of estimating the value of seismic data. The decision analysis approach is often overlooked for many reasons. Some people overlook the method because they do not understand how to handle the imperfect nature of seismic. We will address that with Bayes' Theorem. Some geoscientists and engineers are fond of suggesting they can just "high level" (or guess) the decision, which may be because they have already gone through the decision analysis technique exhaustively, but is more often a pococurante excuse to avoid trying anything. Many others do not use decision analysis because they have a hesitancy to commit to a single set of parameters for the study. We will use sensitivity analysis to mitigate the problem of committing to only one set of parameters. Sensitivity analysis is essential to achieving sufficient understanding of a question so that the act of "high levelling" the problem becomes rational and reasonable.

The resource play framework, as created by our cousins in engineering, carries the explicit conditions that our drilling will encounter productive reservoir whose production behavior is statistically describable in an area. These explicit conditions clearly allow for some variation in productive capability, and further imply that we have some statistical description of that variation. Since the natural world universally contains variation, this allowance and implication is fundamental to the reductionist resource play concept being considered as reasonable. The economic value of investing in information such as seismic data therefore is heavily dependent on the magnitude of the statistical variation in well productivity and the seismic data's probability of correctly predicting these variations in outcome.

Case studies

The value of geophysical data may be estimated from observation, but only if we have knowledge of sufficiently similar decisions being made with and without the information, together with an accurate description of the economic differences in the results. This observation, or case study-based approach requires the data be adequately controlled; that is, the only variable being changed is the effect of information. This requirement is heavy. Hunt et al (2012), showed the value of

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Estimating the value...
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seismic versus no seismic and even the value of a new seismic processing technique versus an old seismic technique in the Viking play in West Central Alberta. The valuation of the processing technique in the Viking case specifically measures the economic effect of the reliability of the seismic data, and is unusual in the literature. The work required statistics from 69 different wells from which the knowledge of the Viking reservoir parameters and state of pre-drill geophysical effort was accurate. The results showed seismic related net present value (NPV) differences on the order of a million dollars per well as measured by differences in reservoir bulk storage and their associated rates, estimated ultimate recoveries, and decline analysis. Hunt et al (2012) also showed that improved steering accuracy generated economic improvements as measured by modeled barrels of oil per day in a Saskatchewan and Manitoba Devonian horizontal oil play.

The case study method of estimating the value of seismic is very important, and typically straight forward to understand. Gray (2011) cites other case study based examples, and the annual CSEG Symposium typically contains several value oriented case studies. What do we do when we do not have an applicable case study to refer to, but instead a new investment decision to make? What do we do when we are challenged to comment on how much we can or should spend on seismic in an area?

Decision analysis

Decision analysis is the science of formal decision making, and was developed in the 1960's and 1970's. Newendorp (1975) summarizes the science of decision analysis in an appropriate form for our discussion on the value of seismic data. Decision analysis uses tools of logic, and considers multiple possibilities arising from choices or decisions. Typically, the best decisions in petroleum business have the best economic outcomes, although preferences may also be considered. A key aspect of oil and gas decision analysis is the explicit handling of uncertainty and imperfect information. The inclusion of uncertainty and imperfect information require the analysis to include not only choice milestones, but also chance or probability milestones. A key tool in decision analysis is the decision tree, wherein the decision milestones are called decision nodes (represented as squares) and the chance or probability milestones are called chance nodes (represented as circles). Decision trees are solved backwards towards the time zero beginning. The imperfect nature of seismic information requires us to use Bayes' theorem in our handling of probability in our decision analysis.

Newendorp's method: Bayesian decision analysis

Newendorp (1975) describes a general approach that may be used to estimate the value of any imperfect information prior the point of making a decision that has uncertainty. Geophysical information belongs to a large class of knowledge coined by Newendorp as "imperfect information" because it is subject to multiple interpretations, and does not precisely tell us the true state of nature. The uncertainty or imperfection of this knowledge necessitates the use of conditional probability, usually in the form of Bayes' Theorem within the decision tree structure of Newendorp's method. The method requires some estimate of the probability (reliability) of the interpretation from the imperfect information, the possible states of nature described by the work and the expected values of all possible outcomes. The original, or initial, probability of each possible outcome is also an important aspect of this analysis. This initial information and its accuracy can sometimes be a cause for controversy, as it has an impact on the final revised probabilities being considered. In the examples that follow, consider carefully the original probabilities we use.

Bayes' Theorem, defining the probability of any event E_i given the interpretation, B, is:

$$P(E_i \mid B) = P(B \mid E_i)\, P(E_i) \,/ \sum_{i=1}^{N} [P(B \mid E_i)P(E_i)],\ i=1,2,..N \qquad (1)$$

Let us explain this further.

The original, initial, or absolute probabilities, are $P(E_i)$, which come from prior knowledge. These are the likelihood of each of the E_i events occurring.

The information that we bring in (say geophysical data such as seismic) defines event B. In the case of seismic, B might be an interpretation from the data that a channel is present. The reliability of the information indicating event B is given as $P(B \mid Ei)$. This is the probability, accuracy, or reliability of the interpreted information being correct.

Bayes' theorem is useful because it combines the reliability of the information with the original probabilities of each event. The solutions to Bayes' theorem, $P(E_i \mid B)$ may be thought of as a new or revised probability of occurrence for event E_i, given the information B, and the original probability $P(E_i)$.

The "probability of the interpretation" and the expected values of the outcomes are key measures that may also be understood as the observed data in the case study or observation based method we discussed earlier. Geophysicists can add value best by focusing on information or efforts that improve the reliability of their interpretation of reservoir quality, or by applying the imperfect information to problems with the greatest variation in expected values. Timing of effort is also important: since reservoir uncertainty is the largest early in a project, geophysical data has the greatest impact then. This has long been intuitively understood, which is why geophysical data has been most frequently used in exploration. The high capital nature of resource plays often make geophysical data of economic benefit throughout the life of projects.

Example: Mannville channel well and seismic

A decision is being contemplated as to drill a well into a well-defined, thick, and broad, Mannville channel system in West Central Alberta. The well costs $5,000,000 to drill, complete, and tie-in or $3,000,000 to drill alone. There are several choices of well positioning available. If this decision well is not drilled, another location will be picked. There are two possible (states of nature) outcomes for the well's production and consequent present value: the well misses the channel system, or the well encounters the channel system and hits statistically average rock for the system. The stabilized initial rates (excluding liquids) and present value of these states of nature are:

1. Misses the channel: 0 mmcf/d, $0 present value (PV)
2. Average well: 4mmcf/d plus liquids, $6,500,000 PV

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The probabilities of encountering each of these states using existing well control are: 0.2, 0.8, respectively. That is, there is an 80% chance that any given location on the land will encounter the channel system.

The company is contemplating buying trade seismic data over the area. The seismic will change the perceived risk of the well, and perhaps determine whether this well is drilled or is set aside in favor of other locations. The seismic costs $100,000 for every well being examined. Using the seismic data, any of the two states may be interpreted: first that the well being proposed will encounter channel sand, or secondly that the well will not encounter channel sands. The probability of the interpretation being correct in either case is 0.9. That is, there is a 90% chance that the well will encounter the geology predicted by the seismic.

There are two broad strategies that can be employed: the first being the so-called "gamble strategy" where we choose to drill the well without seismic. Given the high chance (80%) of encountering the channel, this approach may be tempting, and many operators would choose it. The play is in fact being treated as if it were a resource play where reservoir is locally guaranteed. This is not actually correct, but the high chance of success is driving perception. The second strategy is to acquire the seismic for a cost of $100,000 per well decision. The seismic itself is uncertain or imperfect information. Within the seismic strategy, there is also the possibility to ignore the seismic interpretation. This could be influenced by the high initial probability of encountering channel or by land, pipe, or surface conditions. In describing the best decision, and the value of the seismic strategy, we will use Newendorp's method. We will refer to Chart 1, the decision tree throughout the analysis.

In Chart 1, we see that we have several choices: first, at decision node F we choose to either gamble and drill using our original estimate of probabilities, or do we choose to purchase the seismic. If we purchase the seismic, we come to chance node E where the seismic may yield an interpretation that the well location will encounter channel, or the interpretation may be that the well will miss the channel. Node B follows the "interpreted channel" probability and explores the possibility that the well either encounters channel or it does not. Decision node D follows the "interpreted no channel" branch and explores the possibility that a decision is then made to either not drill the well, or to drill the well. Chance node C explores the possibility that despite the "interpreted no channel" outcome from the seismic, the decision was made to drill the well anyway. The NPV for each outcome is given. But which of the decisions yield the highest expected NPV? Should we gamble or acquire the seismic? If we have the seismic, should we accept the interpreter's advice? The answers to these questions use Bayes' Theorem as Newendorp explained.

Let us first define the events and probabilities succinctly:

E_1 = event or state of nature 1 = the channel will not be present

E_2 = event or state of nature 2 = the channel will be present

The original estimated probabilities are:

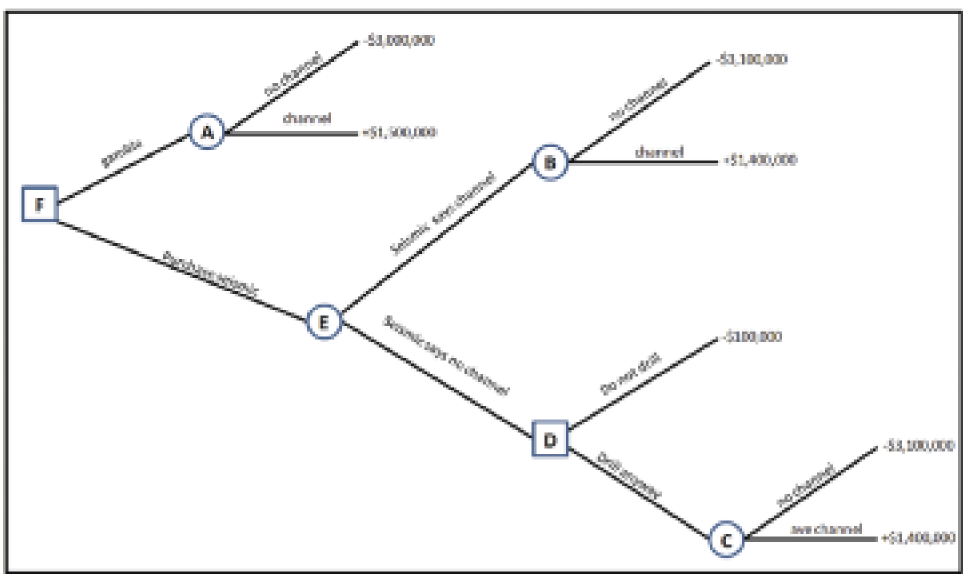

Chart 1. Decision tree of the Mannville channel example with decision and chance the nodes indicated. NPV data is shown, but is not yet weighted by probability.

Probabilities when seismic interprets channel will be encountered				
State of nature	Original risk (probabilities) $P(E_i)$	Conditional Probability by interpretation $P(B\|E_i)$	Joint Probabilities $P(B\|E_i)\ P(E_i)$	Revised Risk Estimates $P(E_i\|B)$
i=1: no reservoir	0.2	0.1	0.02	0.027
i=2: average reservoir	0.8	0.9	0.72	0.973
Totals	1	1	0.74	

Table 1. Table of the probabilities at node B, when the seismic interpretation suggests the channel will be present.

$P(E_1)$ = original estimate that channel will not be present = 0.20

$P(E_2)$ = original estimate that channel will be present = 0.80

The outcomes from the seismic interpretation are:

B = the seismic suggests the channel will be present, B' = the seismic indicates the channel will not be present

The conditional probabilities of the seismic interpretation B given the states of nature:

$P(B|E_1)$ = 0.1 = probability that the seismic says there is a channel present when there is in fact not a channel present.

$P(B|E_2)$ = 0.9= probability that the seismic says there is a channel present when there is in fact a channel present.

The B' seismic interpretation probabilities are simply interchanged with the B probabilities.

If we are going to evaluate the decision tree, we must remember Bayes' Theorem, defining the probability of any event Ei given the interpretation, B, which is given by equation (1).

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Let us work through the solutions to Bayes' theorem for the two interpreted seismic cases corresponding to each of the two events we defined; that our interpretation could indicate a channel, or that there is no channel where we wish to drill the well.

Table 1 shows the solution to Bayes' theorem if B indicates a channel. Column three in Table 1 shows the calculation of the numerator of Bayes' Theorem. These values arise from the multiplication of the values from columns one and two. We also call these probabilities the Joint probabilities. The joint probabilities sum to 0.74, which is the denominator of Bayes' Theorem, and is the total probability that the seismic interpretation will suggest a channel will be encountered. Column four in Table 1 shows the solution to Bayes' theorem, and is thus each value in column three divided by the sum of column three. The solution to Bayes' theorem is also called the revised probabilities or revised risk estimates of each event given the interpretation.

Table 2 shows the solution to Bayes' theorem if B' indicates there is no channel at the well location. Column three in Table 2 shows the calculation of the numerator of Bayes' Theorem. Just as was the case for interpretation event B in table 1, this is the result of the multiplication of the values from columns one and two. These joint probabilities sum to 0.26, which is the denominator of Bayes' Theorem, and is the total probability that the seismic interpretation will suggest a channel will not be encountered. Column four in Table 2 shows the solution to Bayes' theorem, and is thus each value in column three divided by the sum of column three.

Now we have all the probabilities we need to solve the decision tree. Chart 2 illustrates the decision tree with the probabilities and expected values filled in. Let us go through the solution at each node.

The expected NPV at node A, the choice to gamble, is simple. It is:

$NPV(E_1) * P(E_1) + NPV(E_2) * P(E_2) =$
$-\$3,000,000 * 0.20 + \$1,500,000 * 0.80 =$
$+\$600,000.$

The expected NPV at chance node B, where the seismic interprets there will be a channel is:

$NPV(E_1) * P(E_1 | B) + NPV(E_2) * P(E_2 | B) = 0.027*(-\$3,100,000) + 0.973*(+\$1,400,000) = +\$1,278,500.$

The chance that we ever get to node B *from node E* and enjoy this positive NPV is 0.74, or the numerator of Bayes' Theorem.

The expected NPV at chance node C, where the seismic interprets there will be not a channel, and we still drill the well is:

NPV (E1) * P(E1 | B') + NPV (E2) * P(E2 | B') = 0.692*(-\$3,100,000) + 0.308*(+\$1,400,000) = -\$1,714,000.

The chance that we ever get to choose to go to node C *from node D and E* and enjoy this horribly negative NPV is 0.26. The choice to drill when the seismic interpretation suggests there will be no channel is thus seen as strongly uneconomic.

Let us now look at node D. This path comes about if the seismic interpretation, E, suggests there will be no channel. In such a case, we may choose at node D, to not drill a well. This would give us a NPV of -\$100,000, which was the value of the seismic. Deciding not to drill rather and lose \$100,000 is a much better decision than to drill and lose \$1,714,000. This means the no channel interpretation is now understood to mean no well is drilled, yielding an NPV of -\$100,000.

So, what is the overall expected value of the seismic, and should we purchase it? The expected value of the seismic is the chance the seismic would interpret channel multiplied by the expected value of the subsequent branch plus the chance the seismic would interpret no channel multiplied by the expected value of the subsequent branch. This is the expected value at node E:

0.74 * \$1,278,500 + 0.26 * (-\$100,00) = +\$920,090.

Note that the branch weights are the denominators of Bayes' theorem for each interpreted case.

Therefore, for each contemplated well, the NPV is +\$920,090 with seismic or +\$600,000 without it. The decision tree is filled in with all of this data in Chart 2.

Probabilities when seismic interprets no channel				
State of nature	Original risk (probabilities) P(E$_i$)	Conditional Probability by interpretation P(B' | E$_i$)	Joint Probabilities P(B' | E$_i$) P(E$_i$)	Revised Risk Estimates P(E$_i$ | B')
i=1: no reservoir	0.2	0.9	0.18	0.692
i=2: average reservoir	0.8	0.1	0.08	0.308
Totals	1	1	0.26	

Table 2. Table of the probabilities at node C, when the seismic interpretation suggests the channel will not be present, but we ignore the seismic and drill anyway.

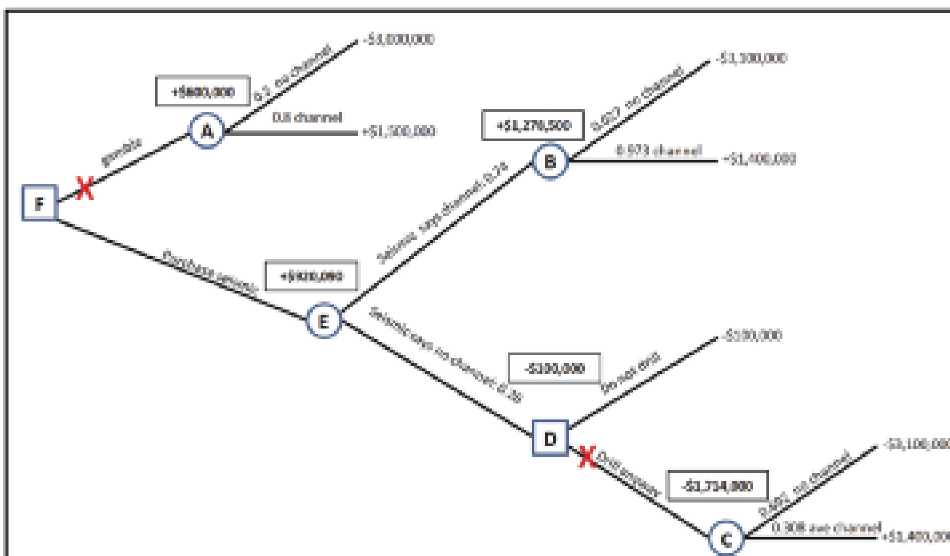

Chart 2. Decision tree of the Mannville channel example, with probabilities and expected values indicated at their respective nodes. The decision which maximizes the NPV is the "purchase seismic" decision, where the company will not drill whenever the seismic interpretation suggests there is no channel.

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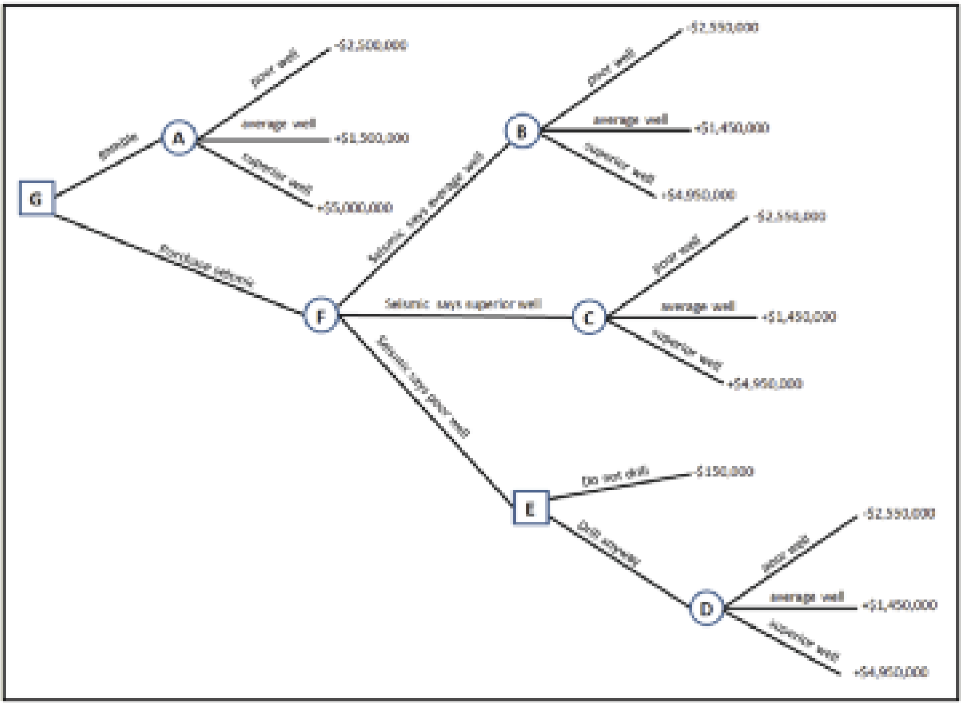

Chart 3. Decision tree of example II, the resource play with decision and chance the nodes indicated. NPV data is shown, but is not yet weighted by probability.

Probabilities when seismic interprets poor results				
State of nature	Original risk (probabilities) P(E$_i$)	Conditional Probability by interpretation P(B|E$_i$)	Joint Probabilities P(B|E$_i$) P(E$_i$)	Revised Risk Estimates P(E$_i$|B)
i=1: poor	0.25	0.9	0.225	0.857
i=2: average	0.50	0.05	0.03	0.095
i=3: superior	0.25	0.05	0.0125	0.048
Totals	1	1	0.2625	

Table 3. The solution to Bayes' theorem if B indicates a poor well is given in column four.

Probabilities when seismic interprets average results				
State of nature	Original risk (probabilities) P(E$_i$)	Conditional Probability by interpretation P(B'|E$_i$)	Joint Probabilities P(B'|E$_i$) P(E$_i$)	Revised Risk Estimates P(E$_i$|B')
i=1: poor	0.25	0.05	0.0125	0.026
i=2: average	0.50	0.9	0.45	0.947
i=3: superior	0.25	0.05	0.01	0.026
Totals	1	1	0.4750	

Table 4. The solution to Bayes' theorem if B' indicates an average well is given in column four.

Probabilities when seismic interprets superior results				
State of nature	Original risk (probabilities) P(E$_i$)	Conditional Probability by interpretation P(B''|E$_i$)	Joint Probabilities P(B''|E$_i$) P(E$_i$)	Revised Risk Estimates P(E$_i$|B'')
i=1: poor	0.25	0.05	0.01	0.048
i=2: average	0.50	0.05	0.03	0.095
i=3: superior	0.25	0.9	0.23	0.857
Totals	1	1	0.2625	

Table 5. The solution to Bayes' theorem if B" indicates a superior well is given in column four.

This suggests that the seismic should be used. The value of the seismic is much higher than its expense. Moreover, this is a per well value, so the project value of the seismic will be much higher. Sensitivity analysis of the seismic reliability and cost can be performed with this method, which could determine the maximum amount that should be spent on seismic, or the minimum change in the probability of success that the seismic can afford while still enjoying an advantage in expected value.

Example II: resource play quality

Let us look at another example involving a true resource play. This play is more expensive with drill, case, complete, equip, and tie-in costs of $6,000,000. The target is pervasive, and all wells that are drilled will be completed. This play is developed on a four horizontal wells per section basis, and there is some flexibility in drill order. Usually, development happens by surface pad and section (hub), which means there is a cost efficiency associated with fully developing (drilling four wells per section or pad) each hub at one time or in sequence. Therefore, there is an economic penalty to deferring drilling a well within a pad when the rest of the pad is being developed. This cost is minor, but fully accountable, and is $100,000 per well deferred.

The event outcomes for drilling have been studied and are reasonably well known. The events are:

E_1 = poor producing well. NPV = -$2,500,000

E_2 = average producing well. NPV = +$1,500,000

E_3 = superior producing well. NPV = +$5,000,000

The well understood, initial, probabilities of each of these outcomes are: $P(E_1)$, $P(E_2)$, $P(E_3)$, which are 0.25 for a poor well, 0.50 for an average well, and 0.25 for a superior well.

Seismic could be shot and processed for a cost that works out to be $50,000 per well location. Seismic discriminates the quality of the well locations through amplitude versus offset analysis (AVO) identification of superior reservoir

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quality and fracability (Goodway et al, 2006, Close et al, 2012). The seismic further discriminates the likely quality of the well by identifying undesirable stress regimes with azimuthal amplitude versus offset analysis and converted wave analysis of shear wave splitting (Close et al, 2012). The seismic reliability will be given a value of 0.90.

We can build a decision tree as we did in example I, to help guide us in this decision analysis. This decision tree is shown below in Chart 3.

Let us work through the solutions to Bayes' theorem for the three interpreted seismic cases corresponding to each of the three events we defined; that our interpretation could indicate a poor well, and average well, or a superior well.

Table 3 shows the solution to Bayes' theorem if B indicates a poor well. Table 4 below shows the solution to Bayes' theorem if B′ indicates an average well. Table 5 below shows the solution to Bayes' theorem if B″ indicates a superior well. The revised probabilities are respectively similar for the poor and superior well interpretations, as we would expect them to be. The revised probability of the average well interpretation has the highest probability for any event, the average well event of 0.947, which we would also expect given the original probabilities.

Now we have all the probabilities we need to solve the decision tree. Chart 4 illustrates the decision tree with the probabilities and expected values filled in. Let us go through the solution at each node.

The expected NPV at chance node A, the gamble scenario is:

= 0.25 * (-$2,500,000) + 0.5 (+ $1,500,000) + 0.25 * (+$5,000,000) = +$1,375,000.

The expected NPV at chance node B, the seismic interprets an average well is:

= 0.026 * (-$2,550,000) + 0.947 (+ $1,450,000) + 0.027 * (+$4,950,000) = +$1,436,842.

The expected NPV at chance node C, the seismic interprets a superior well is:

= 0.048 * (-$2,550,000) + 0.857 (+ $1,450,000) + 0.095 * (+$4,950,000) = +$4,259,524.

The expected NPV at chance node D, the seismic interprets a poor well is:

= 0.857 * (-$2,550,000) + 0.095 (+ $1,450,000) + 0.048 * (+$4,950,000) = -$1,811,905.

Decision node E becomes a choice of either -$1,811,905 from chance node D, or -$150,000 if the well is not drilled. The value of -$150,000 includes the -$50,000 cost of the seismic and the -$100,000 operational penalty from deferring to complete a surface pad in order. The decision is made to defer drilling the well.

The expected NPV at chance node F, the seismic interpretation is:

= 0.475 * chance node B + 0.2625 * chance node C + 0.2625 * decision node E = +$1,761,250.

This means that the purchase seismic decision yields a much higher expected NPV (+$1,761,250) than the gamble strategy, and is thus the choice made at decision node G.

Sensitivity to quality of seismic interpretation

We can create another version of the example II scenario where we consider the sensitivity of the results to the reliability of the imperfect seismic information. We can hold all other variables the same as in example II, except for the seismic reliability, and recalculate the expected values.

The seismic reliability will vary from 1.0 (perfect information) to 0.4. The results of this sensitivity analysis are illustrated in Figure 1. The gamble scenario expected values are invariant at +$1,375,000 as the seismic reliability changes. The seismic method expected values are shown by red circles, and change linearly with the reliability of the interpretation. The break even seismic reliability is just under 0.70. the maximum value of the seismic method, reached at perfect reliability, is +$1,925,000. At high reliabilities, the seismic method has significant value relative to the gamble scenario.

Sensitivity to poor well NPV

We can create another version of the example II scenario where we change the spread of NPV values associated with each case.

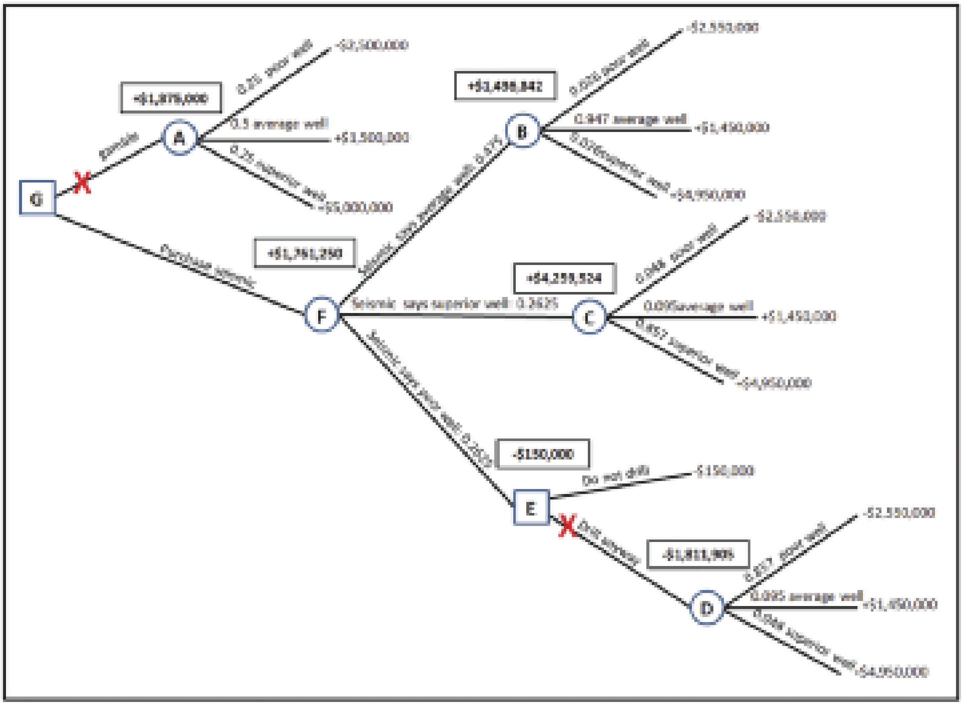

Chart 4. Decision tree for example 2, with probabilities and expected values indicated at the respective nodes. The decision which maximizes the NPV is the "purchase seismic" decision, where the company will not drill whenever the seismic interpretation suggests there is poor reservoir. This no drilling decision is the best economic choice given such a seismic interpretation despite the -$100,000 operational inefficiency penalty the decision carries.

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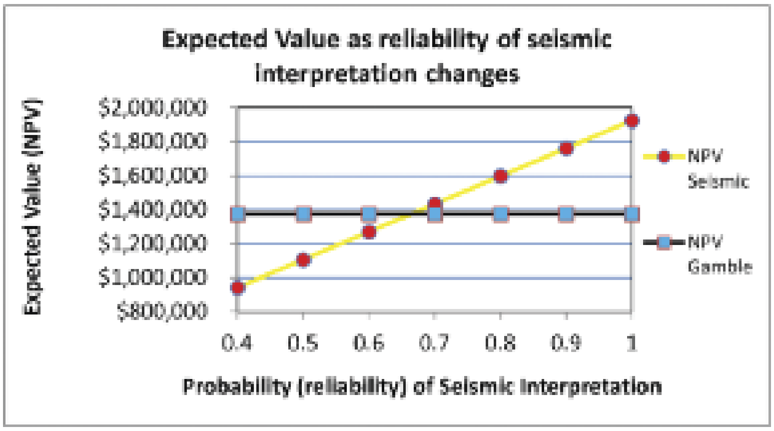

Figure 1. The variation of expected values from example II if we vary the reliability of the seismic data. The gamble scenario expected values are shown with blue boxes, and are invariant as the seismic reliability changes. The seismic method expected values are shown by red circles, and change linearly with the reliability of the interpretation. The break even seismic reliability is just under 0.70.

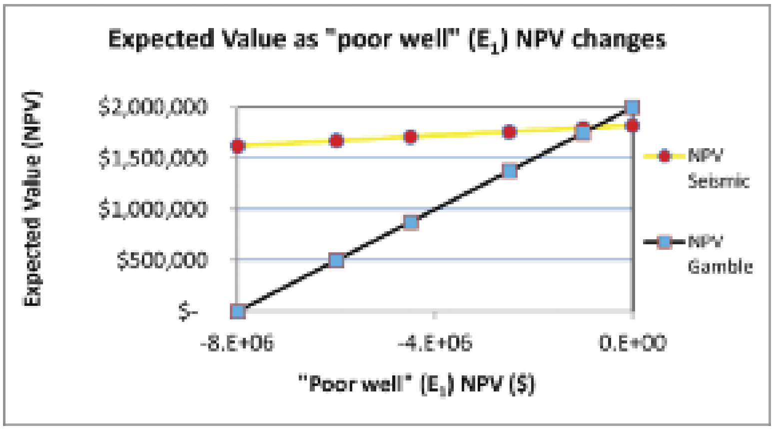

Figure 2. Graph of the expected values as a function of the NPV of the poor well event. The gamble approach expected values are shown by blue boxes, while the seismic method expected values are given by red circles. The expected value arising from the use of seismic is higher that the gamble approach through most of the graphed space. This is due to the low NPV range of the poor well scenario and the high reliability of the seismic.

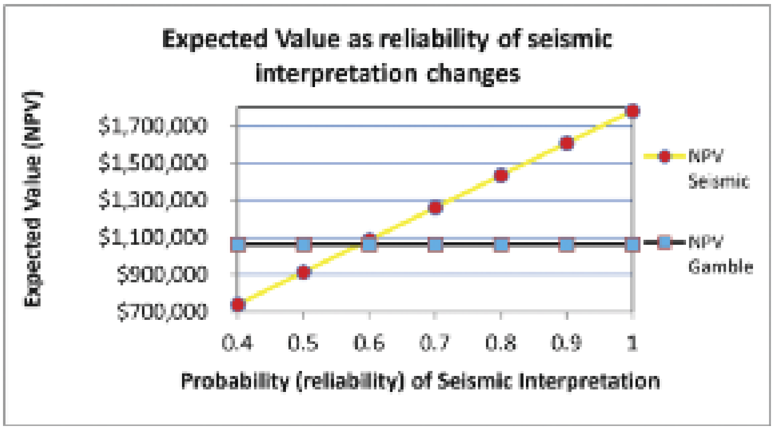

Figure 3. Graph of expected values as a function of the reliability of the seismic interpretation. The gamble approach expected values are shown by blue boxes, while the seismic method expected values are given by red circles. This graph differs from that in Figure 1 in that the initial estimated probabilities have been changed so that the average well has a probability of 0.65, and both the poor well and superior well events have the same probability of 0.175. The other change is that the poor well NPV is -$4,500,000. In this case, the break-even seismic reliability is less than 0.6. This sensitivity illustrates the importance of both initial probabilities and the spread of NPV values associated with each case and how they interact with the required reliability of the imperfect seismic information.

Specifically, we vary the expected value of the poor well or E_1 event and observe the effect this has on the expected value of the seismic method. The variation in the poor well event goes from an NPV of $0 to -$8,000,000. This worst case scenario could primarily come about if the well had unusual operational difficulties (in either drilling or completion, or both) and was not productive.

If we use the same decision tree structure as in example II, we can calculate the expected values for this scenario. Again, we have the gamble scenario versus the seismic scenario. Figure 2 illustrates the results graphically. The expected value of the gamble approach changes much more drastically than the expected value of the seismic approach. This is because the seismic information is purposefully used to avoid, within its reliability, the effect of the poor well. As a result, the expected value arising from the use of seismic is higher that the gamble approach through most of the graphed space. This is due to the low NPV range of the poor well scenario and the high reliability of the seismic. These cases show a significant value to the use of seismic.

Different conditions and sensitivity to reliability of seismic interpretation

We can create another version of the example II scenario where we change both initial probabilities and the spread of NPV values associated with each case. Given a change in these values, we can further explore the required reliability of the imperfect seismic information. In this example, the values of the initial events become:

E_1 = poor producing well. NPV = -$4,500,000

E_2 = average producing well. NPV = +$1,500,000

E_3 = superior producing well. NPV = +$5,000,000

The probabilities of these events are changed to: $P(E_1)$, $P(E_2)$, $P(E_3)$, which are 0.175 for a poor well, 0.65 for an average well, and 0.175 for a superior well. This new scenario describes a resource play where the average outcome is much more likely than either of the other events, but that the poor event is more economically damaging as compared to example II.

If we use the same decision tree structure as in example II, we can calculate the expected values for this scenario. Again, we have the gamble scenario versus the seismic scenario. We can evaluate the sensitivity of the economics to the reliability of the seismic by running our calculations for a variety of seismic probabilities, specifically from 1.0 or perfect reliability down to 0.4. Figure 3 illustrates the results graphically. The gamble scenario has an invariant expected value of +$1,062,500. The expected value when we use the seismic surpasses the gamble scenario prior to a reliability of 0.6, and has a maximum expected value of +$1,782,500 when it reaches perfect reliability. The seismic is thus more valuable in this example, mostly due to the fact that the poor well outcome is indeed quite economically damaging. The change in original probabilities was not as dominant as the change in poor well outcome.

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Implications of the value of reliability

The sensitivity of expected value to the reliability of the seismic as shown in graphs 1 and 3 have broad implications to how we shoot and process seismic data. Since expected values always increase with increasing reliability, then increasing reliability is good business. The reliability of the seismic is subject to many factors including the quality of its processing, the effort and appropriateness of the acquisition parameters to the specific geologic target, and also to the interpretive techniques being employed. Some interpretive techniques require additional processing and investment. This means that there is objective economic motivation to invest in better processing, acquisition, and the use of the most advantageous interpretive techniques. Hunt et al's (2012) Viking work demonstrated this principle explicitly on a real case. The limits of this investment could be studied further; however, in many cases the answers are obvious. Processing of seismic data is typically negligible compared to the costs being considered for the drilling and completion. This means that extra efforts in processing that increase the reliability of seismic are generally going to be worthwhile.

Conclusions

The meaning of risk in today's world, is better expressed as the probability of a spectrum of results with different economic values. The use of Bayes' Theorem makes the modeling of various economic scenarios reasonably straightforward even while recognizing that seismic is an imperfect kind of information. We showed a variety of examples in which sensitivity to the reliability of the seismic, initial probabilities, and variation in expected values were explored. The value of seismic is seen to be inextricably tied to its reliability and the degree of variation in the economic outcomes. A "high level" truism from this work is that the value of seismic can be very significant when it has a high reliability and when the variation in outcome economics is large. A second more specific heuristic from the sensitivity analysis is that it will often be worthwhile to invest in processing efforts that increase the reliability of seismic. R

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Lee Hunt was the 2011/2012 CSEG Distinguished Lecturer. Lee is an Ironman triathlete. He graduated from the University of Alberta with a B.Sc. in geophysics in 1990, after which he started his career working for PanCanadian Petroleum Ltd. At PanCanadian, he was mentored by Bill Goodway. His experience ranges from interpretation to managing a business unit, and he has conducted numerous winter access only drilling campaigns in NEBC and Northern Alberta. He has drilled over 300 wells in most of the play types within the Western Canadian Sedimentary Basin. These drilling experiences include heavy oil, shallow gas, deep carbonate exploration, deep basin, Peace River Arch, Saskatchewan and Manitoba oil, and include vertical as well as horizontal drilling. His work has focussed on performing quantitative analysis of multiple attenuation, resolution enhancement, depth and geo-hazard predictions, AVO, AVAz, VVAz, curvature, and the prediction of fluid, lithology, porosity, fracture treatment characteristics, and production.

Lee and his co-authors won Excellence of Oral Presentation for the 1997 SEPM Convention, the 2000 CSEG Convention Best Paper Award, the 2008 CSEG Convention Best Geophysical Abstract, the 2008 CSEG Best Technical Luncheon Talk, the 2010 CSEG Convention Best Geophysical Oral Presentation, the Best Exploration Paper at VII INGPET in 2011, and Honorable Mention for Best Paper in The Leading Edge in 2011. Lee is a recipient of the CSEG Meritorious Service Award. He was a participant in the creation of the CSEG MLA, APEGGA's Q.I. Practise Standard, as well as APEGGA's Guideline for the Ethical Use of Geophysical Data.

CSEG Foundation 2012-2013 Distinguished Lecture Tour

Don Lawton
Department of Geoscience, University of Calgary, Calgary, Alberta, Canada

I was very honoured to be selected as the CSEG Foundation Canadian Distinguished Lecture for 2012-2013. My CDL presentation was based on seismic reflection surveys that we undertook in Christchurch, New Zealand after a devastating earthquake there on February 22, 2011 which destroyed much of the city and resulted in the loss of 185 lives. Our work focussed on seismic reflection surveys to map previously unknown faults within and around the city that might trigger more earthquakes in the region. I think this topic was selected in part because the CSEG Foundation has a strong mandate to demonstrate the value of applied geophysics technology to the needs of society.

Based on advice from earlier lecturers, particularly Lee Hunt (thanks Lee!), who was the 2011-2012 CDL, I organized the tour generally so that legs to eastern Canada were completed before Christmas, and legs around western Canada were scheduled during the winter semester. The tour started in early October after most (but not all) of the universities had completed their fall field schools, with eastern legs completed by early December (prior to the start of exam season). The winter legs around western Canada and two visits to the United States started in mid-January and were completed by mid-March.

In all, I gave the presentation 28 times, with the locations listed in Table 1. I regret that there were a number of places that I was not able to get to, due to either scheduling issues or weather interventions. However, based on the many places that I did visit, I am pleased to report that the state of geophysics across Canada is very healthy. Enrolments are strong or increasing in many places and there is a lot of top-notch research being undertaken in Canada that competes at the highest level internationally. The future of our discipline is very bright. During the tour, I was pleased to be able to promote the broad range of activities that the CSEG Foundation actively supports, particularly for geophysics students from all across Canada.

Tour Leg #1

The initial eastern leg of the tour started in early October and the first stop was at the Bedford Institute of Oceanography (BIO) in Dartmouth, NS. BIO is federal research hub with approximately 600 staff in four departments, with a focus on oceanography. These are Fisheries and Oceans Canada (DFO), Natural Resources Canada (NRCan), Environment Canada (EC) and Natural Defence (DND). The group that I visited at BIO were from the Earth Sciences Sector of NRCan, and mostly from the Geological Survey of Canada Atlantic Branch. My schedule at BIO was well-organized by Jennifer Bates, who is the Science Editor, and my host was David Mosher who is the Program Manager for Canada's claim under Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS). David and his group are using seismic and other geophysical data to form the scientific basis for a claim on rights to the seabed beyond the 200 miles of Canada's current exclusive economic zone. I also had interesting discussions with Chris Jauer, a petroleum geologist working mostly off-shore developments. My presentation was well received, particularly in the context of the potential for earthquake-induced large-scale mass flows on the continental slope off the Nova Scotia coast.

After the Dartmouth visit, I took the short flight over to St. John's, NF to visit the active geophysics group at Memorial University. Because of the talk schedule, I had a nice afternoon spare to walk around St John's (albeit in the rain), and having lived in a port city (Auckland) when I was a student, I enjoyed exploring the docks and seeing what types of ships were in port. That evening, I was hosted to a most enjoyable dinner by Michael Slawinski and his wife Elena Patarini followed by a tour of their delightful house. Michael is from the University of Calgary (I taught him as an undergraduate student way back last century) and at MUN he teaches and undertakes research in continuum mechanics and theoretical seismology; I was delighted to receive a gift of one of his new books when I visited Michael and his research group the following morning. My presentation that day followed a pizza lunch (always a good draw) with attendance from a widespread group of geoscientists from the department. In the afternoon I was able to visit with geophysics colleagues Jeremy Hall and Chuck Hurich and get a tour of their seismic processing and interpretation facilities. Jeremy has been very active in the interpretation of seismic data from the Eastern Mediterranean and Chuck is researching challenging seismic data from the mining sector, including from the large Nickel deposit at Voisey's Bay.

Tour Leg #2

The second leg of the eastern part of the tour kicked off a week later at Dalhousie University in Halifax. Dalhousie has 3 campuses and the Faculty of Science is in the Studley Campus which is close to downtown. My contact there for the tour talk was Richard Cox from the Department of Earth Sciences, who swung by my hotel and we had a pleasant walk to campus. The presentation was scheduled over lunch hour and was well-attended by people from Earth Sciences as well as from the Department of Oceanography and I had the opportunity to see Chris Beaumont (geodynamics) and Keith Louden (seismic imaging). That evening I caught up with Grant Wach, who had missed the presentation due to a field trip class that day. Grant and his research group are very well known for research in reservoir characterization and he is also the faculty coordinator for the Dal team for the AAPG Imperial Barrel Award (this team won the Canadian competition last month – congratulations to them). The next morning, Grant kindly picked me up in Halifax and drove me up to Wolfville for my presentation at Acadia University that day. Acadia has a small but close-knit group of faculty members in the Department of Earth and Environmental Science and

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there we were met with a very warm welcome by contact Sandra Barr. The Department has well-known strengths in hard-rock geology and has a strong connection with the mining sector. We enjoyed a pizza lunch with students and faculty prior to the presentation, followed by a dynamic visit with Cliff Stanley, who undertakes research in geochemistry and economic geology and who also teaches the geophysics courses at Acadia. Grant drove me back to Halifax later in the afternoon and gave me a walking tour around some of the local geology and around the docks.

The next morning I was scheduled to fly to Fredericton, NB, for the presentation at UNB. I had booked an early flight to ensure that I would arrive there in plenty of time. As it happened, when I got to the airport, I discovered that my flight was 'cancelled due to unavailable crew'. I contemplated taking a flight to St. John and then driving to Fredericton, but there was another flight directly to Fredericton which was scheduled to arrive less than an hour before my presentation time, so I took the chance and opted for that. Fortunately, this flight was on time and the taxi driver in Fredericton responded to my tight timeline and I made it to the university with about 20 minutes to spare. There I was met by host Karl Butler from the Department of Geology and we quickly got set up for the talk, which was followed by a lively discussion about seismic monitoring for earthquakes and induced seismicity associated with fracking. Currently, there is a lot of debate and public concern about planned fracking in New Brunswick and expertise from the Department of Geology ata UNB has been quite involved in these discussions. Karl and his students have an active research program in a broad range of geophysical methods, with applications to groundwater flow in fractured media, detection of coastal seawater intrusion, imaging of impact craters, and in mining. Karl is also one of the foremost researchers in Canada studying seismoelectric phenomena. During the afternoon, I caught up with Joe White, a structural geologist whom I had met many years ago when we were both Department Heads. That evening, Karl treated me an excellent dinner in downtown Fredericton, along with Dave Keighley, who is a sedimentologist/petroleum geologist with an interest in basin studies for CO2 sequestration. I thought that Fredericton was a beautiful city, with intense late fall colours in the trees along the banks of the St John River. I stayed the night at a charming B&B and flew to Toronto the following morning.

The next day (Sunday), I caught an early flight from Toronto to Thunder Bay, where I was met at the airport by Scott Cheadle. Scott was my first Ph.D. graduate student at the UofC and he has had a long and distinguished geophysics career with the Veritas (subsequently CGGVeritas and now CGG) before 'retiring' to the shores of Lake Superior from where he continues to provide valuable services to the company. I stayed overnight with Scott and his wife Pat (who used to work in the office of our department at UofC years ago). Their place has a commanding view over the lake and I learned all about the complexities, interests, innovations and life-style patterns that are required to be living 100% off-grid (Photo 1). Scott took me on a field trip around the small community of Silver Islet (mostly of summer residences, commonly called 'camps') and pointed out details of an old silver mine on a tiny island out in the lake. Those miners must have been brave! The next morning Scott kindly drove me back into Thunder Bay where we rendezvoused with Dept. of Geology faculty members Mary Louise Hill and Pat Gillies and graduate student Breanne Beh for lunch (Breanne is a UofC alumnus). Lakehead has a very strong hard-rock program and a significant proportion of the research activities are related to the Canadian Shield and mineral deposits. The CDL presentation was mid-afternoon, followed by a nice reception. That evening, there was a meeting of the local Prospectors Association which I was invited to attend.

Photo 1. Scott Cheadle at the control panel for his 'off-grid' power system at Thunder Bay.

The evening of the Lakehead visit was when Hurricane Sandy hit the east coast of the US and did tremendous damage in New York State and then further inland. Because of flight delays into and out of Toronto that evening and early the following morning, I was forced to cancel my tour visit to McMaster University and took a direct flight back to Calgary from Thunder Bay. I had hoped to schedule a return visit to McMaster but the scheduling did not work out.

Tour Leg #3

Travel for this leg of the tour was easy, as it was at the University of Calgary! I was honoured to make the CDL presentation as the 2013 Tom Oliver Lecture in the Department of Geoscience. This lecture is an annual event to honor Tom Oliver, the first Head of our Department and the event coincides with a research exposition where faculty and students from the department put on a poster session about their research during the afternoon, culminating in the Tom Oliver Lecture in the late afternoon, followed by a reception in the Gallagher Library. The event was very well attended and enjoyed by all.

Tour Leg #4

The annual SEG conference in Las Vegas was sandwiched between tours down east. I had a short-form of the CDL talk as one of the new style e-poster presentations at the conference and I was honoured to find out subsequently that the talk was judged to be in the top 4% of papers presented at the 2013 SEG meeting. From Las Vegas, I travelled directly to Montreal as the Friday of SEG week was the only seminar slot available at McGill University. My visit there was coordinated by Eric Galbraith and my local host was Yajing Liu from the Department of Earth and

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Planetary Sciences. Yajing and her graduate students are focussed on understanding fault mechanical behavior and strength evolution in relation to a range of lithospheric deformation modes, including earthquakes and episodic aseismic slip events along plate boundaries, so we had lots to talk about. Prior to the presentation, I had an enjoyable lunch with graduate students Nils Backeberg, Ben Melosh and Tim Sherry. Ben and Tim are undertaking research on crustal-scale fault systems in Namibia, Africa, and Nils is researching structural aspects of the Superior PreCambrian Shield. Following the presentation, there was a reception where I caught up with geophysics faculty Olivia Jensen and Jafar Arkani-Hamed, and tectonics geologist Andrew Hynes.

Tour Leg #5

The third and final eastern leg started on November 19 at Queen's University. I travelled to Kingston the previous day which enabled me to visit over dinner with long-time colleague John Dixon and is wife Heather. John a structural geologist from Queens who was part of the Fold-fault Research Project, an industry consortium run by Deb Spratt, John and me when foothills gas was still a hot play, from the late 1990's through 2009. It was also gratifying to see Ray Price at my presentation. Ray is an icon in Canadian structural geology, particularly for his research over many decades in the Canadian Rocky Mountains. Queens is in the process of hiring a new geophysics faculty member. Recently the geophysics courses have been taught by Ph.D. student Gabriel Walton as well as several visiting instructors, and so it is good to see rebuilding in geophysics occurring. Gabriel took me to lunch with student Jessica Dongas who will be coming to the UofC for graduate studies with me starting in September this year. This was followed by interesting discussions with Laurent Godin, a faculty member at Queens who specializes in structural geology and continental tectonics, with a particular interest in orogenic belts.

Next, I headed to Sudbury and noted that Sudbury has the longest taxi ride from the airport of any city that I visited on the CDL tour (beating both Halifax and Edmonton). My host there was Richard Smith, a former CDL tour lecturer who holds a research Chair with the longest title I have ever come across (NSERC//Vale//KGHM//Xstrata Nickel//Wallbridge Mining//CEMI Industrial Research Chair in Exploration Geophysics) in the Department of Earth Sciences at Laurentian. Richard gave me a tour of the department and we met with his group or graduate students who are working on geophysical exploration related to the mining industry, including some leading edge research in the Sudbury Basin which is considered to be a large meteorite impact structure. After lunch with Richard and students Ladan Karimi Sharif, Oladele Olaniyan, Devon Parry and Omid Mahmoodi, Richard took Ladan an me to the outcrop of the original nickel discovery (Photos 2 and 3) which is about a 15 minute drive out from Sudbury. After the short field trip, I went to the airport and headed for Toronto.

At UofT I first visited with Dave Sinton who has large research group undertaking research in microfluidics and a 'lab on a chip' with applications to CO2 storage and flow of heavy oil. After that I met Bernd Milkereit, my host at UofT and we talked about the changes there due to the possible closer linkages of the applied geophysics group with the Dept. of Earth Sciences. Bernd is very active in stress measurement and anisotropy, including studies in deep mines. After lunch there was a visit to the lab of Farzine Nasseri in Civil Engineering who undertakes elastic wave measurements of rock samples in a very comprehensive triaxial test facility (Photo 4). The tour presentation was scheduled in the later afternoon, and had a lively audience. I was very pleased that Gordon West and Nigel Edwards were also in attendance, along with Claire Samson from KEGS. The seminar was followed by a vigorous discussion in the UofT faculty club with the UofT geophysics group.

The next morning was an early flight to Ottawa, with a presentation at the University of Ottawa, hosted by Pascal Audet, a young geophysics professor who has an active research program in subduction zones, continental strike-slip fault zones and deformation of continents. The talk was followed by an enjoyable lunch with students Benoit Lecavalier, Tianjiao Li and Azadeh Ahoor. The Ottawa visit was busy, as I then headed to the Geological Survey of Canada in Booth Street and gave a talk as a Logan Club speaker at the GSC later that afternoon, hosted

Photo 2. Richard Smith and student Ladan Karimi Sharif at the site of the original nickel discovery at Sudbury.

Photo 3. Plaque at Sudbury commemorating the nickel discovery there in 1886.

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by Dawn Kellett, who undertakes research in geochronology. After the presentation I met with André Pugin and Sue Pullen who have been undertaking high-resolution, multicomponent seismic surveys for relatively shallow targets, particularly shallow aquifers, using a novel land streamer system that they have developed. They have some spectacular data from parts of Ontario (recently published in the Leading Edge) and further discussions of shallow seismic programs were lubricated in a local pub. That evening I had dinner with James Meadowcroft, who holds a Canada Research Chair at Carleton University; James and I work together as research Theme Leads in Carbon Management Canada.

The last stop of this leg was at the University of Western Ontario (now known simply as 'Western University') in London, where I was kindly picked up at the airport by host Patricia Corcoran, a geology professor from UWO who studies PreCambrian geology and sedimentology. Western earth science seems to be thriving and Patricia had a well-developed schedule organized for me, starting with a visit with Burns Cheadle, the Bill Bell Chair in Petroleum Geology at Western. Burns (who is Scott Cheadle's brother) is a well-known petroleum geologist who worked in Calgary for a many years before moving to Western for an academic career. He has a vibrant computer lab with a full suite of petroleum application software. I also met with Robert Shcherbakov, a young professor who has undertaken research on the statistics of the Christchurch earthquakes, and also with Gail Atkinson, Canadian Research Chair in Seismology with active research in strong ground motion during earthquakes, so we had lots to talk about. Following lunch with Burns and Elizabeth Webb (isotope geochemist) at the fabulous faculty club at Western, I met with Department Head Gerhard Pratt and we compared notes on the joys of administration, then more importantly, Gerhard showed me some of the new FWI research he is undertaking with Michael Afanasiev, one of his M.Sc graduate students. The afternoon was capped with a lively CSEG Ambassador event in the campus pub with graduate students Laura Sanchez (volcano geophysics), Jessica Stromberg (Archean hydrothermal systems), David Edey (CT scan imaging), Favid Olutusin (petroleum geology), Behzad Hassani (engineering seismology), Lisa Cupelli (impact craters) and Attieh Eshaghi (seismology). The department hosted a dinner that evening with faculty members Patricia Corcoran, Phil McCausland (meteoritics) and Roberta Flemming (mineralogy), and they also funded my accommodation at a hotel on campus (thanks on behalf of the CSEG Foundation).

The Fall 2012 CDL tour program ended with an after-dinner presentation at the annual CREWES sponsors meeting, held in Banff in late November.

Tour Leg #6

The winter lecture program started with the first leg in western Canada, with visits to the University of Manitoba and the University of Saskatchewan. A stop at the University of Regina had initially been scheduled as part of this leg but had to be dropped at the last minute due to a scheduling conflict at Regina. It was a chilly day in Winnipeg when I arrived there early in the morning of January 17. I was met by host Ian Ferguson, Head of the Department of Geosciences in the Clayton H. Riddell Faculty of Environment, Earth and Resources in time to have a pizza lunch with staff and students prior to the presentation. Ian and his group work mostly in electromagnetics, and I also met with Andrew Frederiksen, who undertakes research in earthquake seismology. I did not have a lot of time there as I headed out to Saskatoon later that afternoon.

At the University of Saskatoon, I met with Department Head Jim Merriam, along with Igor Morozov and Sam Baker over lunch at the Faculty Club and we compared notes about the state of geophysics at our respective universities. The Department of Geological Sciences has a beautiful natural history museum/display at the entrance to the building. Jim and his group work mostly in electromagnetics in exploration geophysics and in global geodynamics, Igor and his group work in seismology at all scales, with an interest in seismic attenuation and anelasticity, while Sam's group works on mantle convection and fluid flow in porous media. At the lecture, I caught up with Emeritus Professor Don Gendzwill and after the talk we held an enjoyable Ambassor event at the campus pub with students and then Igor took me to the airport. I had hoped to see Zoli Hajnal but he was out of town that week.

Photo 4. Dr. Farzine Nasseri in Civil Engineering, University of Toronto, at the control system of the triaxial press for rock property measurements.

Photo 5. Doug Schmitt with students Mizan Chowdhury (left) and Arif Rabbani (right) in his physical properties laboratory at the University of Alberta.john

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Tour Leg #7

This leg had local travel within Alberta, starting with the CSEG luncheon presentation in Calgary on January 23rd to a full house, and I appreciated a lot of positive comments from my peers that I received about the lecture. The following week I gave an evening presentation at the Canmore Museum and Geoscience Centre, hosted by Rick Green who has been a driving force for many years in getting the museum established. The audience was made up mostly of people who are not geophysicists or geologists, so I had made some changes to the presentation with this in mind. Many had visited Christchurch on business or vacation travel and were interested in the current state of the city following the February 22, 2011 earthquake.

Later that week, I travelled to Edmonton to give the presentation at the University of Alberta. It was great that CSEG representatives Rob Kendall, Lee Hunt and Torr Haglund also came along for this visit. I met with Doug Schmitt and had a tour of his spectacular new rock properties lab (Photo 5) and met with a number of his students. After lunch, Lee and I visited with Dept. Head Mauricio Sacchi and had an interesting discussion about geophysics education and research. The talk later in the afternoon was well attended by students and staff and this was followed by an excellent Ambassador event at the beautiful Faculty Club at the University of Alberta, where we were able to chat with a large group of geophysics graduate students. It turned out that our flight back to Calgary was cancelled and Rob, Lee and I were rebooked onto a later flight, so we were able to extend our participation at the Ambassador event, enjoyed by all.

Tour Leg #8

The following week, I was invited by the University of Houston to give the CDL presentation there as the Milton B. Dobrin Annual Distinguished Lecture. The UofH kindly paid all the travel and accommodation expenses for this visit. Rob Stewart was my host and he was familiar with our seismic work in Christchurch, having heard the presentation at the 2012 CREWES sponsors meeting that he had attended last Fall. Rob and others from the UofH have a Geoscientists Without Borders grant from the SEG to undertake similar research in Haiti, as a follow-up to the catastrophic earthquake in that country in January, 2010. I was honoured to be invited as the Dobrin lecturer as all applied geophysicists have probably studied from his textbook "Introduction to Geophysical Prospecting" at one time or another. Milton Dobrin was a Professor in the Dept. of Geological Sciences at the UofH, and was the Editor of Geophysics (1953-1955) and SEG President (1969-1970). My lecture was followed by a very nice reception with graduate students,

Table 1. Don Lawton CSEG Foundation CDL Tour 2012-2013

	Date	Location
1	October 10, 2012	GSC Atlantic, Halifax
2	October 12, 2012	Memorial University
3	October 23, 2012	Dalhousie University
4	October 24, 2012	Acadia University
5	October 25, 2012	University of New Brunswick
6	October 29, 2012	Lakehead University
7	November 2, 2012	University of Calgary
8	November 7, 2012	Society of Exploration Geophysicists
9	November 9, 2012	McGill University
10	November 19, 2012	Queens University
11	November 20, 2012	Laurentian University
12	November 21, 2012	University of Toronto
13	November 22, 2012	University of Ottawa
14	November 22, 2012	GSC, Ottawa
15	November 23, 2012	University of Western Ontario
16	November 29, 2012	CREWES Sponsors Meeting
17	January 17, 2013	University of Manitoba
18	January 18, 2013	University of Saskatchewan
19	January 23, 2013	CSEG luncheon
20	January 28, 2013	Canmore Museum & Geoscience Centre
21	January 31, 2013	University of Alberta
22	March 4, 2013	University of Houston
23	March 6, 2013	University of British Columbia
24	March 7, 2013	GSC Victoria
25	March 13, 2013	CSPG International Group
26	March 14, 2013	Stanford University
27	March 19, 2013	Simon Fraser University
28	March 20, 2013	University of Victoria

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faculty and visitors, including the usual lively discussions with Rob Stewart, Leon Thomsen, Fred Hilterman, Jim DiSienna, and Bob Sherriff.

The day after Houston, I headed out to the west coast for visits to UBC and the Pacific Geoscience Centre. I had to teach at UofC that morning, so there was not a lot of spare time to get to Vancouver for the afternoon seminar there. As one might predict, the flight was delayed due to 'an equipment problem'. Fortunately, I was met at Vancouver airport by CSEG Vancouver representative Nancy Shaw, who got us to UBC with about 10 minutes to spare before the presentation. My host was Felix Herrmann, who is the Director of the UBC-Seismic Laboratory for Imaging and Modeling (SLIM) and he and is group are heavily involved in full waveform inversion and compressive sampling. His work was recently profiled in *International Innovation*, a global magazine that features technological innovations. The Department of Earth, Ocean and Atmospheric Sciences is located in a spectacular, new building on the UBC campus, with plenty of space, which made me rather envious given our cramped quarters at UofC. After the lecture there was an Ambassador event (thanks Nancy), with an opportunity to interact with the large group of strong geophysics graduate students at UBC. That evening, Ron Clowes organized a most-enjoyable dinner outing with Doug Oldenburg and Mike Bostock at 'The Boat House' a well-known restaurant in Kitsilano with a gorgeous view over English Bay.

The next morning, I took the 15 minute flight to Vancouver Island, where I was met by Kelin Wang from the Pacific Geoscience Center of NRCan. Their office in Sydney is only a 5 minute drive from the airport, so there was no danger of a delay this time! PGC is very strong in earthquake seismology and we discussed the Mw7.7 Haida Gwaii earthquake, that had struck near the Queen Charlotte Islands last October. Following the presentation, I had opportunities to meet with several staff members, including Honn Kao, Roy Hyndman, Trevor Allen, Garry Rogers and Joe Henton. Some of the discussions revolved around how we might undertake high-resolution reflection seismic profiling in urban areas around parts of the west coast to identify shallow fault hazards.

Tour Leg #9

Another opportunity to present the talk in Calgary arose in mid-March. I had a call from Trent Rehill, who is Chairman of the CSPG International Division. They had had a cancellation for their March luncheon meeting and needed a speaker at short notice. Torr Haglund had mentioned to him that my CDL presentation might be suitable for them, and I was pleased to be able to fit it into the schedule. A number of the attendees had worked in the Taranaki Basin in New Zealand and they were interested in seeing the Christchurch seismic results. The following day I left for California to give the presentation at Stanford University. Adam Pidlisecky, a geophysics colleague from the UofC is currently on a 6-month Research Fellowship at Stanford and he arranged an invitation for me to present the CDL presentation at one of the monthly seminars in the Geophysics Department at Stanford, with all travel and accommodation expenses paid, for which I am grateful. The Stanford Geophysics group is very dynamic and the day there was most interesting – Biondo Biondi gave me an update on SEP and imaging research that he is undertaking and I also met with several graduate students working with Adam and Rosemary Knight on hydrogeophysics topics. Tiziana Vanorio showed me some results from research that she is doing on rock-fluid interaction related to CO2 storage in carbonates. This work is very relevant to carbon capture and storage projects developing in Alberta. The day was capped by a splendid evening with the Canadian contingent at Stanford.

Tour Leg #10

The final leg of the tour was another trip out to the west coast. One of the realizations about the tour was the challenge in matching available seminar times with my schedule and perhaps I should have been planning further in advance (advice to future CDL's). This last leg started with a visit to Simon Fraser University, where I was met by my host Andy Calvert from the Department of Earth Sciences. Andy and his group have done a lot of work on new seismic data that were collected in the Nechako Basin in the interior of British Columbia by Geoscience BC to stimulate oil and gas exploration in that area. It is a challenging area for seismic data as there are high-velocity volcanics at the surface over a large part of the basin. I also met with petroleum geologist Shahin Dashtgard, who has a research project on CO2 sequestration in depleted shallow gas reservoirs in Alberta, funded by Carbon Management Canada, and I also met briefly with UofC alumnus Dirk Kirste, who has an active research program in aqueous geochemistry. That evening, I travelled (15 minute flight) to Victoria and was picked up the next morning by George Spence, a seismologist from the School of Earth and Ocean Sciences at UVic who is well-known known for his research on the geophysics and tectonics of the western Canadian margin and Cordillera. George informed me that he is retiring this coming summer, so we hope he continues to undertake research as an Emeritus Professor! I gave the presentation there to Jan Dettmer's undergraduate class in applied geophysics. After the lecture there was time for only a short visit with both Stan and Harry Dosso and students from the class before I had to head back to the airport to catch a flight back to Calgary. R

Acknowledgements

I am most grateful for the support from the CSEG Foundation that enabled me to go on this lecture tour. Andreas Cordsen now supports the CDL Tour costs through a dedicated multi-year sponsorship commitment to the CSEG Foundation. His support of the Foundation and CDL Tour is most appreciated. It was a very enjoyable experience and the opportunity to network with students and staff at universities from all across Canada was rewarding. The research that I presented in this lecture tour could not have been undertaken without the contributions of Malcolm Bertram, Kevin Hall, Kevin Bertram and Laura Baird, all of whom are CREWES staff at the University of Calgary, as well as logistic support provided by the University of Calgary and the University of Canterbury (NZ). The full costs of the program were covered by the New Zealand Government.

Westmount School Presentation

Rick Green

In February I made a presentation on geoscience to students of Christine Crane, a grade 7 teacher at the new Westmount School in Okotoks. Rachel Green, my great niece, had initiated it. The presentation was on behalf of the Canmore Museum and Geoscience Centre and CSEG-F Outreach. I showed a powerpoint presentation of about 45 slides, which included lots of pictures of mountains and how they are formed, using the school's smart board, and I talked about my career as a geophysicist.

I had discussed the grade-specific content with the teacher to ensure a fit with the curriculum, and given her the CSEG Teachers' package and some DVD movies that might be interesting for the class. Several days before the presentation I took to the school a number of posters on topics such as earthquakes, stratigraphic charts, rocks and fossils, surface geology, pictures of folded mountains and a seismic line. In addition, I took the CSEG banner and outreach materials.

On the day of the 50 minute presentation, two classes of students sat on the cleared floor (Figure 1). I put up the posters on both sides of the room. The CSEG computer, projector and banners were set up at the front of the room while another table contained rocks and fossils, some of which I passed around while I was presenting. There was some good interaction with the students and during the lunch period I chatted with some of the keener students. It was a great experience.

I started my presentation with a review of my geophysical career in the Arctic, recording earthquakes for the Federal Government, and in Calgary, Denver, New Orleans and Houston with Amoco Canada Petroleum Company Ltd. I continued with a simplistic discussion of my work at Talisman Energy Inc. in the Monkman area of NE British Columbia shooting seismic programs and drilling wells. I talked about oil and gas traps (source, reservoir and seal) and used the CSEG Mac computer and banner to show what a seismic wave looks like. A seismic line (compliments of Pulse Seismic Inc.) along Highway1A from Mt Yamnuska past Jumping Pound Gas field was shown and I discussed the financial rewards of finding oil and gas fields. Of course, while addressing students from Okotoks, it was important to point out the proximity to the Turner Valley Oil Field and to make some comments about the "Big Rock" glacial erratic near Okotoks. I also talked about the traits and abilities that would be helpful to a geophysicist – solid training as a geophysicist, experience, careful preparation and good presentation skills, persistence, team work, and hard work. Seeing one's ideas tested by the drill bit makes for an exciting career.

The teacher wrote a very nice thank you note. She said "It was our pleasure and honour to have Rick Green speak to 86 of our grade 7 Science students on February 15 for 50 minutes. Rick used an engaging powerpoint, seismac projections, at least 50 posters, and at least 20 rock samples including core samples and fossils". Her letter ending by saying "Rick's enthusiasm and passion for his field of study was contagious to the students and we look forward to future presentations from him."

Figure 1. Rick Green giving a presentation on geoscience to 86 grade 7 students at the Westmount School in Okotoks.

Upcoming CSEG-F Outreach events in 2013

May 8	Challenge Bowl (during the convention)	Calgary, AB
May 25	Canmore Museum and Geoscience Centre Geoscience Day	Canmore, AB
June 6-8	Geophysics Industry Field Trip	Calgary/Canmore, AB
October 1-3	Seismic in Motion for Students (with CAGC)	Waiparous, AB
October17-19	Atlantic Universities Geoscience Conference	St. Francis Xavier University, NS
October	Canadian Undergraduate Physics Conference	McMaster University, ON

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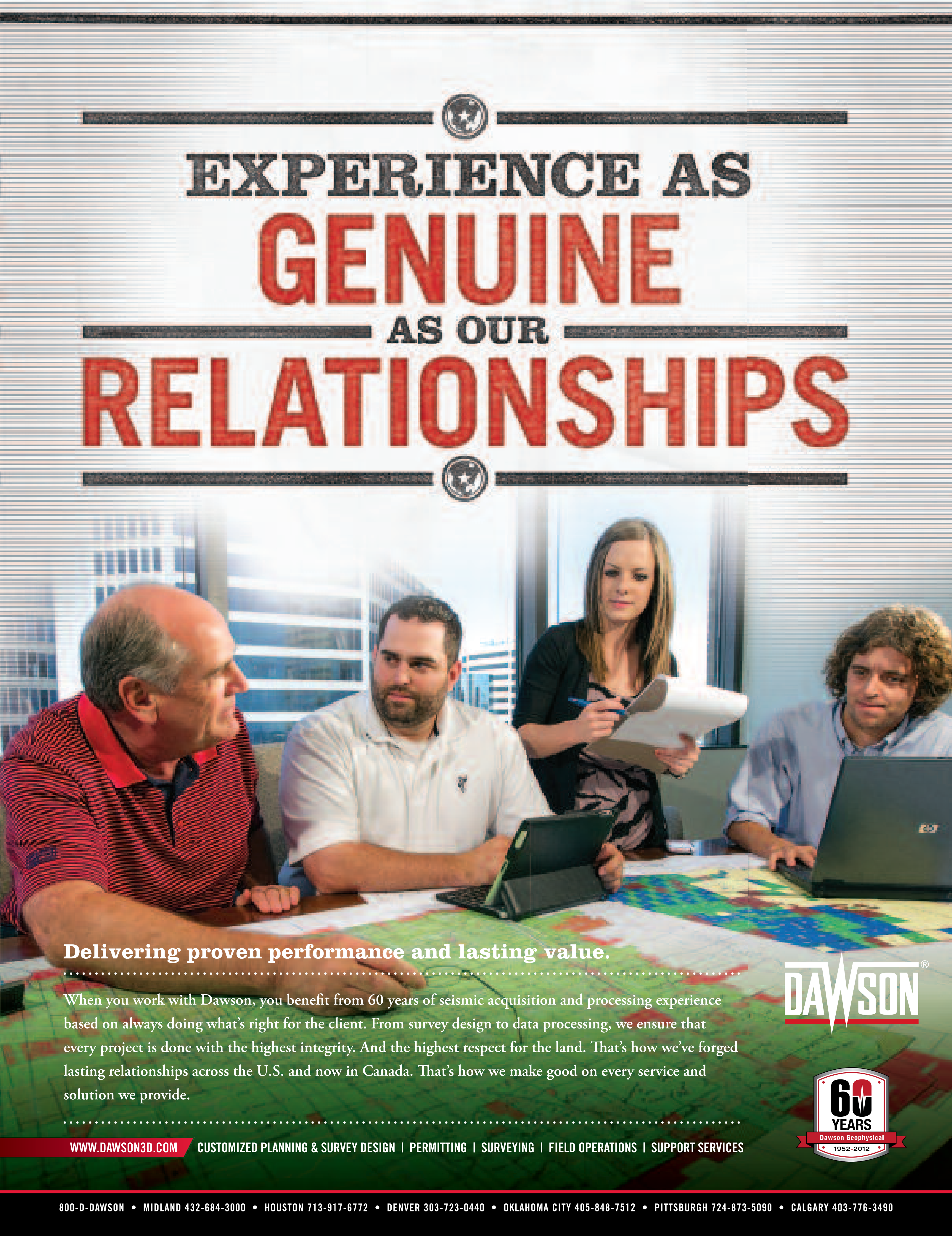
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CSEG Foundation Fundraising Campaign Recognition

September 2012 – March 2013

We are very pleased with the initial response to our first-ever fund raising Campaign. We announced the CSEG Foundation appeal at the September Technical Luncheon and we wrote to every CSEG member in December. The response was outstanding. We have now received $470,000 in donations and pledges, nearly all of it from individual donors. This was a wonderful start toward our goal of $3,000,000.

Please review this list of donors to our current campaign. Many of our members are contributing, and as you can see, some have made very significant contributions and pledges. Did you know that we are recognizing both actual contributions and pledges for future years? Our policy is similar to that of the SEG. In addition, future 'Recognition' documents will include 'lifetime' or cumulative gifts.

The CSEG Foundation has always invested in GIC's and will continue to keep sufficient funds in fixed income investments in order to provide a secure base. We have also decided to join many other Calgary groups and place some of our endowment with the Calgary Foundation, which has a successful record of investing its own capital and that of its partners.

More than two hundred CSEG volunteers are active with all of our programs. We are soliciting Scholarship applications from University students across Canada, have created two scholarships for Technical Institutes and are planning two entry-level scholarships for high school graduates into a Faculty of Science towards a degree in geoscience. In addition, we are planning two scholarships for graduating 'children of CSEG members' – into any faculty.

The Distinguished Lecture Tour has been a great success. Don Lawton is discussing the Christchurch, New Zealand earthquake and the subsequent seismic survey by the University of Calgary. The lecture will be given to more than 25 Canadian Institutions and, by invitation, to the University of Houston and Stanford University.

You can help. We are starting a Corporate Campaign and you can help promote this to your management. You can make a donation yourself and join this distinguished list of CSEG members who are contributing financially. Recognition levels are cumulative, so even a modest donation repeated every year could help to make the Foundation Activities financially independent of the society and to finance new activities. Our website: www.cseg.ca/foundation will soon have a list of all of our contributors, since inception of the CSEG Foundation in 2006. We hope you will encourage your employer to contribute, as well as consider a gift yourself. We'd love to have every member's name on that list.

Thank you for your outstanding support.

Brian Russell, Hampson-Russell Software
Co-Chair, CSEG Foundation Appeal

John Boyd, RPS Boyd Petrosearch (retired)
Co-Chair, CSEG Foundation Appeal

CSEG Foundation Fundraising Campaign Recognition

September 2012 – March 2013

$100, 000-$499,000

Andreas Cordsen

$50,000-$99,999

Anonymous

Larry Herd and Vicki Austin

Brian and Elaine Russell

$25,000-$49,000

Athena Resources Ltd.

CNRL Investor Relations

John and Nancy Peirce

$10,000-24,999

John Boyd

Brian and Heather Curts

Kendall Geophysics Ltd.

Perry and Karen Kotkas

Neil Rutherford

Continued on Page 59

CSEG Foundation Fundraising Campaign...

Continued from Page 58

$1,000-$9,999

Martin Armitage
Marc Boulet
Bob Comer
John Duhalt
Tooney Fink
Don E. Gale
GeoSpace Technologies Canada Inc.
Dan Hampson
Helen Isaac
Cecil Keeping
Klukas Family
Kohlhammer Subsurface Geoscience Ltd.
Tako Koning
Stephen Kotkas
Ron Larson
Glenn Malcolm
Annette Milbradt
Kim L. Nevada
Tiffany Piercey
Jack Pullen
Laurie Ross
SAExploration
John Townsley
Frank van Humbeck

$100-$999

Ian M. Baker
Charles Boyer
Jim D. Bushell
Robert (Bob) A. Charters
Kevin Collings
Penny Colton
Gregory Davidson
Elizabeth Earl
Bruce Fenwick
Don J. Gendzwill
Donald Good
William N. (Bill) Goodway
V. Richard (Rick) Green
Ken Hedlin
Yajaira Herrera-Cooper
Blaine F. Holitzki
Terrence Jackson
Norman Kalmanovitch
Garry Kelman
Todd M. Knight
Pat Kong
George Kostashuk
Don Lawton
Larry Lines
Yongwang Ma
Desmond V. Maguire
Larry Matthews
Robert James McGrory
David Nordin
Ernest Pallister
David W. Paterson
Mike Perz
Arnold M. Rivett
Robert Stuart
Gary G. Taylor
Richard Willott

Thank you to another 80 Foundation supporters who donated up to $99 for a total of $2,595.75.

The Foundation gratefully acknowledges all gifts from our donors. Unfortunately due to space constraints, it is not possible to list the name of donors who gave less than $100. It is our intention to acknowledge our donors gratefully and accurately. If we have made a mistake, please accept our apologies and let us know by contacting Laurie Ross at laurie.ross@geo-x.ca. R

REPORT

25th Annual CSPG/CSEG/CAPL 10km/5km Roadrace and Fun Run

Armin Schafer
Race Director

On your mark! Get ready, the CSPG, CSEG, & CAPL will be running our annual Roadrace and Fun Run this September. This is the silver anniversary (25 years and counting) of this event and this year promises to be better than ever!

Again, we are offering both a 10km and a 5km race. We have secured Winning Time to provide chip timing and Events-on-Line will provide easy on-line registration.

The run will take place on Wednesday, September 11, 2013. Start time 6:00pm just north of the Eau Claire YMCA. The route will take you on an out-and-back course along the beautiful Bow River pathway, finishing at the Eau Claire YMCA. Following the race, all racers, volunteers, and guests are invited to gather at the Calgary Curling Club, just north of Princess Island for awards, draw prizes, refreshments, and some friendly camaraderie. So if you are looking for a competitive race or just want to have fun, come join us!

The race is open to all members of the CSPG, CSEG, and CAPL, and the general public, however, **space is limited to 200 participants. So register early to avoid disappointment!** There will be NO race day registration. For more information or to register, visit the CSPG Events website www.cspg.org\events. For sponsorship opportunities please contact: **Dan Cicero** 403-531-7711, dcicero@huntoil.com; **Shirley Fleming** 403-806-3212, Shirley.Fleming@Penngrowth.com; **Jocelyn Frankow** 403-260-6582, jocelyn_frankow@sensorgeo.com

To help you, Gord Hobbins of Gord's Running Store has developed a 10km race training guide for novice runners. Try it out and benefit from some expert advice, you may be surprised how easy it can be to gently get yourself in condition for your first race.

Many thanks go out to our sponsors and volunteers who make this event possible each year!

We hope to see you there!

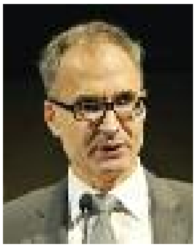
Gord's 12 Week Training Guide for Novice Runners

Minutes of running per day:

Week	Mon	Tues	Wed	Thur	Fri	Sat	Sun
June 24–June 30	-	10-15 min	-	10-15 min	-	-	15 minutes
July 1-7	-	10-15 min	-	10-15 min	-	-	20 minutes
July 8-14	-	10-20 min	0-10 min	10-20 min	-	-	25 minutes
July 15-21	-	10-20 min	0-10 min	10-20 min	-	-	30 minutes
July 22-28	-	10-20 min	0-10 min	10-20 min	0-10 min	-	25 minutes
July 29-Aug 4	-	10-20 min	0-10 min	10-20 min	0-10 min	-	35 minutes
Aug 5-11	-	15-25 min	0-10 min	15-20 min	0-10 min	-	25 minutes
Aug 12-18	-	15-25 min	0-10 min	15-20 min	0-10 min	-	40 minutes
Aug 19-25	-	15-25 min	0-10 min	15-25 min	0-10 min	-	25 minutes
Aug 26–Sept 1	-	15-25 min	0-10 min	15-25 min	0-10 min	-	45 minutes
Sept 2-8	-	20-30 min	0-10 min	15-25 min	0-10 min	-	25 minutes
Sept 9-11	-	Rest	**10 KM RUN**				

Guidance/Tips: For novice runners who wish a do-it-yourself program at your leisure.

- Run for short durations between 3 and 5 times per week according to schedule, with your long run days being the key to your training program.
- If your running shoes are giving you some problems, get some which fit and match your gait.
- Guide allows for a gradual increase to a comfortable load; your legs may need some conditioning at first.
- Yes, times are in minutes. The secret is to be regular and not beat yourself up.
- Wear a hat and cool shades. Keep well hydrated. It really helps.
- Gently stretch those calves and quads afterwards.
- Take along a friend and convince them to sign up for CSPG, CSEG and the RoadRace as well.



Bill Goodway

Bill Goodway: through a glass darkly

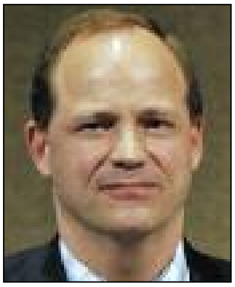
Lee Hunt
Mimir's Well Exploration Corp., Calgary, Alberta, Canada

Editor's note: This is a condensed version of the tribute to Bill Goodway delivered by Lee Hunt at the 2013 CSEG Symposium.

We never fully see or know the truth, and yet that is what we seek. After all, it is our duty and our responsibility to advise on the properties of this earth. The job can be difficult for each of us in different ways. Some focus on the rigorous truth of the most correct algorithm or formula. A few acquire the experimental data, but always executed within economic and physical limitations, rarely to fully conform to theoretical requirements. Some process that data, often with algorithms that fall short of rigorous perfection. Others are called to interpret and make practical business decisions with whatever data they have on hand. The effort to find the truth, to find perfection from an imperfect world ties us all together, and it should, as this concern is one of humanity's oldest and noblest pursuits. Plato sought the divinity of truth in the theory of ideas, Kierkegaard dreamed of the subjectivity of truth, Paul to the Corinthians lamented his glimpses of the Kingdom of Heaven as if they were viewed through a glass darkly, and here we all are trying so imperfectly to use actual reflection methods. Valuable it is indeed to have a colleague who can see and understand all of these problems at once, someone whose polymath abilities can touch on all these different people working to illuminate the world in different ways. Bill Goodway is one of those rare people.

Mentor, leader, CSEG President, founder of the Foundation, applied scientist, university instructor, rower, runner, friend. Bill Goodway has worked on many sides of the geophysical world, has found excellence there and elsewhere, never shied from a good fight or from staring into the sharp end of the bit. His numerous disciples will all tell you that Bill is indefatigable: he never tires, never stops, searching. Bill is inexhaustible, inexorable, and inescapable. He is Tennyson's Ulysses always ready to strive and seek one more time, for one more hour, on one more problem.

The breadth of Bill's work is staggering and staggeringly useful. He has made world class advances in acquisition, AVO, and the application of geomechanics. Bill's work has made many friends and a few enemies. Know the value of a man's work by the caliber of his critics. Bill's battles are legendary; his enemies icons. The story of Bill and his work is the story of a struggle to understand useful truths. He has spent most of his career trying to help oil and gas companies better predict the earth by solving ill-posed questions from inaccurate and under sampled data. Being close to the sharp end of the bit, Bill has been cut by the limitations of his data and economic expedience. Bill accomplishes useful things because of his practical perspective on these imperfections. This perspective is in accord with Kierkegaard's argument that how we relate to the facts is more important than the objective facts alone. Bill's understanding of relationship enables him to simultaneously recognize, embrace, and mitigate our limitations. This is a perspective that his critics may not fully appreciate; few of them live so closely to the bit. In Bill's world, we must make a call, invest our resources, stick our necks out; and we need to do it all better. Truth about the earth is Bill's Kingdom of Heaven. We stand for him today, at this great Symposium, because Bill has helped us all in our efforts to see through this glass, darkly. R



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email: oliver@apoterra.com

I get feedback on these Science Break articles, something I really enjoy. On the topic of war, encryption and crosswords, Jim Laing drew my attention to a WWII story involving a Surrey, England headmaster who was a regular crossword author. English intelligence noticed a suspiciously high number of their "secret" code words were showing up as answers in his crossword puzzles. Was he a German spy, passing on secret information in the most cunning of ways? Here are a couple of links with more on this story.

http://en.wikipedia.org/wiki/Normandy_landings#Crossword_panic_of_1944

http://www.telegraph.co.uk/news/uknews/1460892/D-Day-crosswords-are-still-a-few-clues-short-of-a-solution.html

Penny Colton pointed out my curious spelling of "magnetotron" versus the more commonly used "magnetron". I kick myself over that one, as I've always spelled it as "magnetron"! At some point during my research I came across the "magnetotron" spelling and switched over to it, assuming it was more correct without too much thought. "Magnetron" is definitely the more common spelling, and the one I should have stuck with. I think it's a British versus American spelling thing.

Pat McKenny brought up issues related to fluorescent lights, specifically compact fluorescent lamps (CFL's). First, as with all fluorescent lighting devices, there are concerns over the environmental impact of the mercury used in them. We wondered how the ballast is contained in CFL's (they are electronic versus the traditional magnetic, and thus much smaller, giving quicker starts and far less flicker). Pat also mentioned that recent studies are showing that the UV light emitted by CFL's can be problematic for people with sensitive skin, especially when the CFL is positioned within 1m of the skin, for example above your bathroom mirror. For safe, low cost, environmentally friendly lighting that fits standard sockets, Pat is a proponent of LED lighting, and even has a line on where to buy it, cheap!

Cogeneration

If there's anything that can help resuscitate the Canadian conventional gas industry, it's cogeneration power plants, or cogen plants as they are often called. I thought I knew what cogeneration was, but I was quite wrong. I thought it referred to electric power generation plants that could be fueled by either gas, coal, or oil, but my friend John Behr set me straight, as he often does. In fact, more than once he's given me the idea for a Science Break topic; we have a sort of dog and master relationship, where John throws me an idea and I chase it.

The term cogeneration has been around for a long time, and refers to using the waste heat created during power generation for some secondary use. This has been given the acronym CHP, or combined heat and power. All of us here in Canada are beneficiaries of a very common CHP application in our cars: gasoline drives the primary power generation, and then the excess heat produced is partly used to warm the passenger compartment. Under the general cogeneration heading are a number of specific applications, each with a catchy acronym.

For example, the hot water output from a power plant's steam-driven turbines could provide heat to a nearby community. This is called combined heat and power district heating (CHPDH).

CCHP – which stands for combined cooling, heating and power, and is also referred to as trigeneration, or polygeneration – applies to plants which are designed to output power, heating and cooling. When this is done within a single facility it is usually referred to as BCHP – building cooling, heating and power – and is a common way for large scale industrial operations such as pulp and paper mills to squeeze more utility out of their power. By generating their own electrical power and using the otherwise discarded heat to both heat the facilities (or to do other things) and provide cooling (for aircon or other purposes), they get way more bang for their buck.

Cogeneration is really an effort to make more efficient thermodynamic use of an energy source, something that is becoming more and more important as we anticipate the inevitable decline in cheap energy supplies, not to mention competition in industry to minimise cost structures. Which brings us to the prospect of a reliable long term supply of natural gas here in North America, due to the advent of shale gas production. So far the increase in supply has meant low gas prices and misery for the Calgary oil patch (and us geophysicists), but Adam Smith would surely predict the advent of some new demand to match the increase in supply. That is where CCGT comes in.

"CCGT (closed cycle gas turbine) is a special case of power cogeneration, and can achieve ~60% efficiency for electrical power generation; that's really high, almost twice the amount of a single cycle." (Behr, J., personal communication, April 11, 2013) Most new power plants being built use CCGT, with a two stage process. The first stage involves a Brayton cycle gas turbine (Figure 1), the second stage a Rankine cycle steam turbine (Figure 3).

Brayton engines are easily understood, with only three main components, and were first seen in the 1800's as steam engines. Today the same basic concepts are applied to turbines, such as jet engines, or in this case, gas turbines. First input air is compressed; second it is mixed with natural gas and combusted, producing a high-pressure, high-temperature flow of gas, primarily air; third, this air is directed to flow

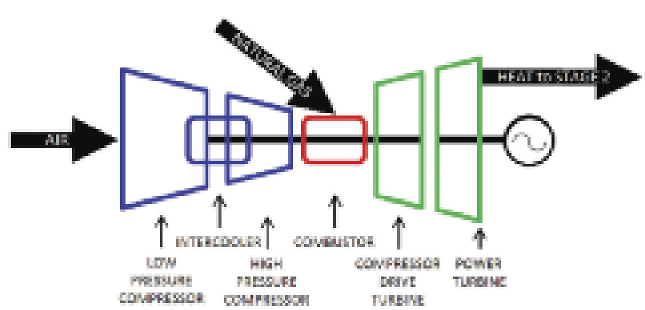

Figure 1. Schematic of stage one Brayton cycle gas turbine.

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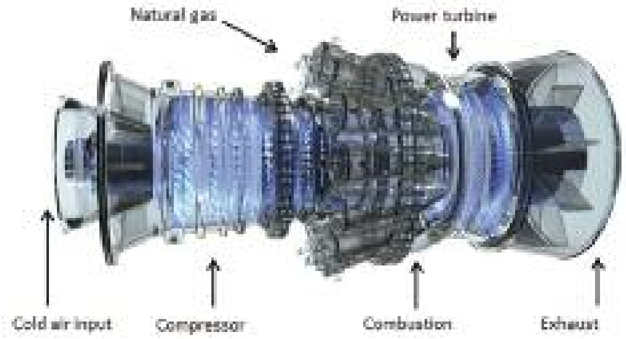

Figure 2. GE 7FA natural gas turbine (General Electric Company, 2009).

through an expansion turbine which it rotates as it rushes through and exits at a much lower exhaust pressure. The turbine's shaft drives the electricity generation and the input air compression. The energy produced by Brayton cycle turbines is directly proportional to the difference in temperature between the input air and the air after combustion; because of this, advances in the technology have focused on turbine systems that can get the air much hotter, and turbine components that can tolerate higher and higher input temperatures. It also explains the inter-cooler seen in Figure 1. Note that the turbine has the same basic steps as a piston-driven internal combustion engine – induction, compression, combustion, expansion – but it is elegantly rotary without the herky-jerky piston motion.

Incidentally, I sometimes play tennis with a guy whose company sources out decommissioned large jet engines, and sells them to be repurposed for electricity generation. I like to think of that as being similar to the old days where a retired race horse would enter a second career perhaps in a grain mill, or in front of a cart; a more pleasant fate than the scrap mill or glue factory. While used jet engines make excellent power generators, those that are built for stationary use are obviously superior, especially when they are purposely designed for use in a high tech CCGT power plant. But jet engines and power generation turbines are remarkably similar. Figure 2 is an image of a modern General Electric 7FA gas turbine used for power generation, but it looks very much like a jet engine.

Upon exiting the gas turbine, the hot air enters the second stage Rankine cycle steam turbine, where it is used to vaporise compressed water within a heat exchange unit / evaporator (step 1 in Figure 3). The high-pressure vapour then flows through an expansion turbine similar to the one used in stage 1. This turbine's shaft generates electricity, and drives the water compression later in the cycle. Upon exiting the turbine, the vapour passes through a condenser unit where much of its heat is extracted and it returns to a liquid state. The water then flows to the last step where it is compressed, ready to start the cycle over again. Note that the heat extracted in step 3 can be used to heat the plant or for other purposes. It is my understanding that some power plants are now cascading more than one steam turbine cycle, with each successive cycle operating at a lower pressure. These types of strategies can actually push the thermodynamic efficiency of such plants up to over 80%.

"Practically, you can only use natural gas to power CCGT because other fuels like oil and coal have too many impurities in them. Corrosion and ash deposition reduces the efficiency and

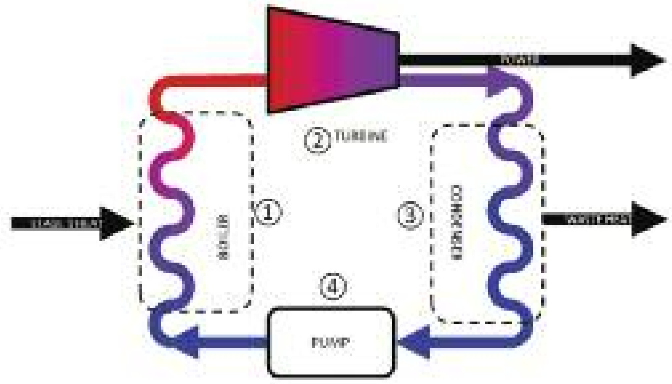

Figure 3. Schematic of stage two Rankine cycle steam turbine.

life of the turbines. The energy equivalence of gas to oil is 6000 ft^3 to 1 bbl. of oil; when used in power generation it would be closer to 3000 ft^3 to 1 bbl. Thus with CCGT, natural gas' value based on "energy density" almost doubles when compared to oil or coal." (Behr, J., personal communication, April 11, 2013) Note that synthetic gas produced from coal is perfectly usable within a CCGT plant.

So given the abundance of new domestic natural gas supplies, the economic advantages of producing electricity in CCGT plants, and the environmentally friendly aspects of natural gas, it is likely that over time, as older plants are retired, North American electricity generation will shift over to CCGT plants. In addition to restoring the supply-demand balance for natural gas, the availability of cheaper electricity should help restore the competitiveness of the North American manufacturing sector. (It must be spring, as I'm filled with optimism!) R

Key search words

Cogeneration, gas turbine, combined cycle

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Next month's article: Encryption (part 2)

Column Contributor
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This month I want to tell you about a great restaurant and deli that we found, Francesco's Food and Coffee. They make their own sandwiches, soups and daily specials on the premises. They also have one of the best and most reasonably priced cheese selections in town. I suggest you try the Prestige Bourgogne, it is the best cheese I have ever tasted. They have meals to go, frozen pizza dough, speciality fondue cheeses and European grocery items. It is located in Killarney at 26th Avenue and 33rd Street. For long time Calgarians it is where the Blaine MacLean pharmacy used to be. Try their turkey, pear, brie and cucumber Panini, you won't be disappointed.

If you have a new job, have been promoted, retired, or want to share your contact information, you can contact me at carmen.swalwell @shaw.ca or 403-560-8431.

On the Move…

Hampson-Russell are pleased to announce that **Emma Yu** has joined their Calgary software support team. Emma graduated in 2012 from the University of Calgary with a B.Sc. in Geophysics and is ready to help with AVO, inversion and related reservoir characterization questions. Emma can be reached at emma.yu@cgg.com or 403 205 6368.

Caroline Mongrain is pleased to announce that she has joined **Katalyst Data Management** as a Business Development Manager, Canada. Katalyst Data Management provides the oil and gas industry with an end-to-end solution that includes every step in the process, from data capture and verification to data storage and organization. With 30+ years of experience, Katalyst has consistently been able to handle the complexities of cleaning up, verifying and organizing our customers' geophysical data. Our clients are able to manage their data more efficiently, with a lower cost structure than traditional storage methods. You can reach her at 403-703-2142 or caroline.mongrain@katalystdm.com

There's lots of interesting news from **Pulse Seismic Inc.** including some great beginnings and a happy ending. It might be old news for some folks, but last November **Neal Coleman** was appointed to the position of President and Chief Executive Officer. Graham Weir, Chair of Pulse's Board of Directors, commented at the time, "Neal has been instrumental in driving Pulse's business development success, and has clearly demonstrated leadership skills during his time as Interim President."

Other news includes the promotion of **Trevor Meier** (trevor.meier@pulseseismic.com) to Manager, Sales and Marketing. We are also pleased to announce a new member of the sales and marketing team, Krista Nicholetts (krista. nicholetts@pulseseismic.com). Krista's energy, enthusiasm and previous sales experience make her a welcomed addition.

Moving on Out…

In February, **Brent Gale**, Senior Vice President and Chief Operating Officer, announced he will retire from **Pulse Seismic Inc.** effective May 22, 2013. Brent (brent.gale@pulse seismic.com) is looking forward to the many pursuits he has planned for his retirement. Brent had a long and distinguished history with Pulse. He joined Pulse in July of 1993 as one of four partners that eventually took Pulse public in October of 1999. His wealth of knowledge of the seismic industry and extensive personal connections were valued by the management team and the Board of Directors.

Those who know Brent, won't be surprised to hear that Brent will continue to be actively involved with Pulse after he retires. Pulse's Board of Directors has asked Brent to stand for nomination as a director at the May 22, 2013 Meeting of Shareholders, and he has accepted. "Brent has had an outstanding career in the seismic industry and we are excited that he has accepted our invitation to become a Director," stated Graham Weir, Chair of Pulse. "With over 35 years of seismic industry experience, Brent's knowledge of field operations, the oil and natural gas industry and business in general will further enhance the Board's strength. We look forward to Brent's contributions."

Blast from the Past…

I received this picture from John Simmonds at Apoterra Seismic Processing. Thanks John. CS

Have a close look at this photograph and see if you can name some of the CSEG members who played in this Air Canada soccer tournament in the mid eighties?

See page 38 for the answers. R

Column Contributor
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email: kristy.manchul@edge-tech.ca

Happy GeoConvention month!

I have had the entertaining image of Larry Lines singing "When I'm 64" in front of an audience of 200 of his peers in my head for the past month. For those who were(n't) at the awards luncheon at the Symposium, Larry burst into the Beatles song after he won the CSEG Special Commendation… and then proceeded to state "No applause… just send papers". He's such a great Journal Editor… please contact him directly if you'd like to submit a peer-reviewed paper or for more information: lrlines@ucalgary.ca. He really does need your help to make the Journal successful...

If you have any company or industry news, please send me an email to: kristy.manchul@edge-tech.ca or call at (403) 585-5204.

Doodlebug 2013 Details!

On behalf of the 2013 Doodlebug Committee, I would like to invite you to the 61st annual Doodlebug Golf Tournament. This year's tournament will once again be held at the Kimberley Alpine Resort with the golf event taking place at the nearby Trickle Creek Golf Course. This year's event dates are **August 22-24, 2013**.

The Doodlebug Golf Tournament is an event held each summer that provides a competitive yet fun golf venue for CSEG members of all levels and ability, from scratch golfers to true first-timers. Golfers are put in "Flights" based off of their handicaps with the goal of having a competitive and fun round of golf regardless of ability. Guests and spouses can choose from a full schedule of formal and informal social events throughout each day and on into the evenings.

Each year there is a charitable aspect to the Doodlebug event. This year, we are supporting a local cause that is important to the town of Kimberley. We will be supporting a young teenage girl named Jenna Homeniuk and her family as she recovers from an aggressive form of Leukemia and a recent bone marrow transplant. The Doodlebug committee is pleased to support Jenna and her family and is honoured to give back to a community that has been so welcoming to the Doodlebug.

For registration and sponsorship opportunities, please go to www.doodlebuggolf.ca We look forward to seeing you Kimberley!

Mark Watson
Chairman, 2013 Doodlebug Golf Tournament

SAVE THE DATE: Ex-Geo-X Reunion

For all of you who worked at Geo-X Systems Ltd. at some point in time (1969 – April 2006), there will be an Ex-Geo-X reunion at the Garage Sports Bar (#195, 200 Barclay Parade S.W., Eau Claire Market, Calgary) on Thursday, May 30th starting at 4 pm. If you have not RSVP'ed to this event yet and would like to come, please send an email to info@geo-x.ca and an invitation will be sent to you. We will need to have numbers for the venue so please let us know if you intend on joining the party.

Geo-Reservoir Solutions OFFICE RELOCATION

As of May 1, 2013 our new business address will be:

Geo-Reservoir Solutions Ltd.
Suite 350, 444-5th Avenue SW
Calgary, AB T2P 2T8
www.geo-reservoirsolutions.com

SAVE THE DATE: Geophysical Industry Field Trip *(GIFT)*

The CSEG Foundation's Geophysical Industry Field Trip is designed to supplement academic education by introducing undergraduate geoscience students into the world of professional geophysics. This is accomplished by touring 4 prominent companies that use seismic in the oil and gas industry. These companies will provide technical presentations in their respective specializations which will include; seismic survey design, acquisition, processing, and interpretation. GIFT has also been extended to include a geology-focused hike in Canmore guided by professionals. Students will gain perspective on the various career opportunities within the field of geophysics, and it will help bridge the gap between ones education and the work they will be performing after they graduate.

The Geophysical Industry Field Trip has evolved into a 3 day event that will be held on June 6th - 7th, 2013 in Calgary, and June 8th in Canmore. Registration is now open and available on the CSEG website. For sponsorship opportunities or any questions, please contact usofieldtrip@cseg.ca

SEISINFO USER GROUP MEETING

Thanks to Pulse Seismic for hosting the March 26th Seisinfo User Group meeting. The meeting was very well attended and a great opportunity to learn what is new with Seisinfo. The door prizes were a great golf kit donated by Pulse that went to Joanne Makela, and an awesome iPad Mini donated by Accu-Audit that was won by Denise Freeland.

Training sessions are being organized – please contact Denise Freeland at 403-781-2421 work, 403-815-0779 cell, denise.freeland@nuvistaenergy.com if you are interested.

SAVE THE DATE: Women in Seismic Golf Tournament

The Women in Seismic (WiSE) Golf Tournament was started in 2000 to allow women in the Seismic industry an opportunity to network and socialize with their peers. Our entrants are from all parts of the industry: geophysicists, geologists, technical staff, processors, copy houses, management, sales and support staff from service companies. Recently, the tournament has involved raising money for the Alberta Cancer Foundation (Breast Cancer). This year we are donating all proceeds to both Breast Cancer and Ovarian Cancer. With the support of corporate and personal donations, WiSe has raised over $60,000 in the past few years.

Please keep Thursday, September 12th, 2013 open for the WiSE Golf tournament. We will be holding the tournament once again at Fox Hollow in Calgary. If you have not receive a registration email, please email joanne.poloway@sigmaex.com and we will send you the information!

Continued on Page 67

CSEG New Members

APRIL
Coordinated by Sheryl Meggeson

Al-Mufti, Omar	Student
Anthony, Trevor	Student
Arenrin, Babatunde	Student
Baker, Keith	Student
Berk, Aaron	Student
Botterill, Scott	Student
Campbell, Gordon	Student
Coderre, Adam	Student
Daniels, Benjamin	Student
Durkin, Paul	Student
Eshaghi, Attich	Student
Funk, Sean	Student
Herbers, David	Student
Islam, Alvin	Student
King, Michael	Student
Medina, Erin	Santos Inc.
Myers, Reed	Student
Pilavci, Joan	ARC Resources
Pemberton, Erin	Student
Phillips, Anna	Student
Playter, Tiffany	Student
Reimchen, Aaron	Student
Rogers, Anna	Student
Round, Stephanie	Student
Roy Chowdhury, Priyanka	Unemployed
Shchepetkina, Alina	Student
Stuurman, Cassie	Student
Timmer, Eric	Student
Van Drecht, Leigh	Student
Walton, Gabriel	Student
Xia, Bing	Unemployed
Zhang, Shimeng	Student

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Grapevine…
Continued from Page 66

GEOSCIENCE DATA MANAGERS NETWORK: Lunch & Learn

If you are a Geoscience data manager in any capacity please mark your calendars for April 30th and plan to attend the inaugural **Calgary Geoscience Data Managers Network** 'learn @ lunch' meeting. Katalyst Data Management has generously donated space in the Aquitaine Auditorium, +15 level of 540 - 5 Avenue SW at 12.00 noon. Please stay tuned for more details. If you are interested in being on our contact list please send your details to:

Denise Freeland
Senior Geophysical Technologist
NuVista Energy Ltd.
403-781-2421 wk
403-815-0779
denise.freeland@nuvistaenergy.com

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TGS	33	www.tgs.com
Western Geco	IFC	www.slb.com/sdm

What's Coming in Future Issues of the RECORDER...

Theme	*Coordinators*	*Issue*	*Copy Deadline*
Seismic Inversion / Time Lapse / Rock Physics	Brian Russell* / Mohammed Al-Ibrahim	*Jun-13*	*15-Mar-13*

**Special Coordinator*