OCTOBER FOCUS: Seismic Interpretation

CHASING DENSITY – AN INTRODUCTION TO SEISMIC ACQUISITION, PROCESSING AND INTERPRETATION METHODS LEADING TO QUANTITATIVE INTERPRETATION

NATURAL FRACTURE CHARACTERIZATION FROM 3D STRUCTURAL ATTRIBUTES

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PRESIDENT
Rob Vestrum
Thrust Belt Imaging
215, 605 – 11th Avenue SW
Calgary, AB T2R 0E1
P: 403-618-9824
rob@tbi.ca

VICE PRESIDENT
Rachel Newrick
Racian Ventures Ltd.
Calgary, AB
P: 403-464-3224
rachel@racian.ca

EDUCATIONAL SERVICES
DIRECTOR
Kurt Wikel
Parex Resources
1900, 2nd Street SW
Calgary, AB T2P 0C1
P: 403-237-1721
kurtis.wikel@parexresources.com

ASSISTANT DIRECTOR
Paul Anderson
Apache Canada Ltd
2800, 250 – 2nd Street SW
Calgary, AB T2P 4K9
P: 403-261-1200
paul.anderson@apachecorp.com

MEMBER SERVICES
DIRECTOR
Tammy Willmer
Osum Oil Sands Corporation
1900, 255 – 5th Avenue SW
Calgary, AB T2P 3G6
P: 403-270-4765
TWillmer@osumcorp.com

ASSISTANT DIRECTOR
Stephen Kotkas
Sigma Explorations Inc.
200, 630 – 6 Avenue SW
Calgary, AB T2P 0S8
P: 403-294-6404
stephen.kotkas@sigmaex.com

FINANCE
DIRECTOR
Larry Wellspring
Synterra Technologies Ltd.
304, 10th Avenue SE
Calgary, AB T2H 0P4
P: 403-216-1630
Larry@synterratech.com

ASSISTANT DIRECTOR
John Bertsch
Divestco
400, 520 – 3 Avenue SW
Calgary, AB T2P 0R3
P: 587-952-8000
john.bertsch@divestco.com

COMMUNICATIONS
DIRECTOR
Meghan Brown
Shell Canada Limited
400 – 4th Avenue SW
Calgary, AB T2P 2H5
P: 403-384-8680
Meghan.M.Brown@shell.com

ASSISTANT DIRECTOR
Keith Millis
OptiSeis Solutions Ltd.
1827– 30 Avenue SW
Calgary, AB T2T 1P8
P: 403-660-6965
keith.millis@optiseis.com

PAST PRESIDENT
Ron Larson
RPS Energy Canada Ltd.
700, 555 – 4 Avenue SW
Calgary, AB T2P 3E7
P: 403-233-2455
larsonr@rpsgroup.com

MANAGING DIRECTOR
Jim Racette
Canadian Society of Exploration Geophysicists
570, 5th Avenue SW
Roslyn Building
Calgary, AB T2P 0L6
P: 403-262-0015
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November Luncheon
3D seismic image processing for interpretation of faults and horizons
Dave Hale, SEG/AAPG Fall Distinguished Lecturer

Interview
With Sudhir Jain

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Looking over the variety of committees and activities of our society, it strikes me that for such a group of science nerds, we certainly punch above our weight class in social activities. The Doodlebug Golf Tournament is nearly as old as the CSEG itself and clever volunteers are creating new social activities all the time, whether it is a significant event like the T-Wave or a hilarious twist on mentorship with “speed mentoring” at the season wrap-up party of the Geophysics Mentorship program.

So, what makes us, as a technical society, such a socially active group? Aside from our need for human contact after all of this time with our machines, the nature of geophysics necessitates collaboration. There are so many fluctuations in our industry that, at any moment, our primary competitor could be our boss, client, or partner within a month’s time, so we have learned that friendly competitors are much better than bitter rivals.

We work in a field that requires a wide range of skills and talents. Problems without unique solutions haunt us at every turn. The science of geophysics requires us to be creative to find solutions and open to accepting approximations and imperfect solutions. Faced with these conditions, we also need the ability to assess risk and judge the sensitivity of our assumptions and uncertainties in our final product. It doesn’t matter if we are seeking trade-offs in cost/effectiveness in acquisition, producing an interpretable subsurface image, inverting for velocities or rock properties, or mapping the seismic event for the drilling location, we need to develop our creative minds as well as our technical skills. Planning, organizing, and participating in our society’s social activities helps develop our creative brains.

We could – and we do – socialize with a variety of people outside of our industry who share other interests and hobbies. But, we find ourselves getting together with our fellow professionals because we have additional needs outside of the social. Socializing with geophysicists not only puts us together with like-minded individuals – and by “like minded”, I mean “nerdy” – but we also create opportunities to meet people to share ideas and experience.

On the job, we need to understand the geology and physics of the problems we are trying to solve. In the tortured career path of the typical Canadian geoscientist, most of us have varied experience and expertise that we can leverage, and, when we are stuck trying to figure out a technical problem in a new basin, it is helpful to have people to call. The call may not result in an easy answer, but a brainstorming chat or sympathetic ear should at least put the problem into perspective.

In addition to the mental-health benefits, the opportunities to connect with fellow scientists is good for business and for the science.
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EXECUTIVE MESSAGE

I hope that everyone had a relaxing summer and that you are all refreshed and ready for the final few months of this 2014 year.

August saw the return of CSEG social events. The T-Wave kicked things off when it returned to Inglewood Golf Club for another spectacular tournament. The committee hosted a well-organized, fun-filled afternoon with amazing weather, great prizes and a delicious dinner. This year a combined total of approximately $5,000 was raised for the CBE’s ‘Fuel for School’ and ‘Light Up the World’ charities. I would like to acknowledge the committee for all their hard work! The 62nd annual Doodlebug Golf tournament was held at Trickle Creek Golf Course in Kimberley, British Columbia. Patrick Tutty and his committee did an outstanding job delivering a weekend of competitive golf, networking and various social events for both participants and their guests. The Saturday night costume theme was “Sci-Fi Convention” which I am sure produced many embarrassing photos that I myself cannot wait to see… This year the Doodlebug chose to sponsor a Calgary grown charity called “Made by Momma” which aids families with young children that have been affected by some form of illness, injury or adversity. These are just three of the many causes that our social committees raise money for and this truly is an inspiring and remarkable reflection of how our CSEG members not only value giving back to their society but how the CSEG gives back to the community. We should all be proud to be part of such a generous organization.

The CSPG/CSEG/CAPL Road Race is scheduled to take place in September, followed by the Women in Seismic Golf Tournament. These two events are always well run and well attended. Make sure to get out there and participate, you will not be disappointed. Our last event of the year will be the Junior Geophysicists Forum which is slated to take place the first week of November.

This spring we conducted a survey to assess how satisfied our volunteers are with their volunteer experiences and what we could do to better recognize the efforts that have been made. 39% of our volunteers took the time to fill out the survey. We found that the majority of volunteers are very satisfied with their overall volunteer experience and quite satisfied with how they are being recognized. That being said there is always room for improvement and we will continue to work to retain our current volunteers, to recruit new volunteers and to ensure that everyone feels valued for their contributions. One new initiative is the “spotlight articles” highlighting the history, efforts and successes of some of our CSEG volunteer committees each month. We hope these articles provide our membership with an awareness of the considerable amount of volunteer time and energy that has gone into making these events what they are today and how they have helped to shape our society as a whole. The first article focuses on two very impressive social committees; the Doodlebug, which is the society’s longest running social event and the Women in Seismic Golf Tournament.

It is with great excitement that I announce to all of you that I will be stepping down from my position as Director of Member Services a few months early, as my husband and I are expecting our first child in mid-January. It has been a pleasure to serve on the Executive for close to two years and I am so very proud of all the amazing work that our membership has accomplished over this time. I wish all of you the very best!

CSEG CALENDAR

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In January 2010, BP signed an agreement to explore and appraise the 7,200 sq km Risha Concession, located in Eastern Jordan, bordering Syria, Iraq and Saudi Arabia. A short Exploration and Appraisal period mandated acquisition of 5000 sq.km. of high fold 3D data, to be completed within the first 18 months. This in turn required acquisition rates and costs (per sq km) typical of marine seismic surveys, and represented a challenge best addressed using BP’s simultaneous source technology, DS3. Distance Separated Simultaneous Sweeping (DS3 or DSSS) is a sim-source technology first developed and implemented by BP in 2008 Armed with this technology, the crew acquisition rate steadily climbed to a peak rate of 1,500 sq km. per month with a record rate of 59 sq. km. per day, producing a state of the art, high fold, wide azimuth, dataset.

The survey objective was to acquire a high quality (> 1200 stack fold at 7km mute-offset), wide azimuth, 3D survey suitable for structural interpretation, attribute analysis and anisotropy studies. Data quality in Risha is affected by a complex near surface with significant karstification causing a high degree of scattered noise which masks reflection data (near invisible reflectors). Previous 3D vintages are challenging to interpret, fail to adequately image the Ordovician reservoirs, are characterised by poor signal to noise, lack resolution, and continuity of key reflectors.

The 3D design used a 22 line recording patch, with 600m receiver line spacing. The nominal receiver line was 27.5km long, resulting in 12,100 traces recorded with each VP, using an active spread spanning from 350 sq.km to more than 490 sq.km. Receiver groups were spaced 50m apart and a simple linear array of 6 geophones was intended to further assist line crew productivity. Source lines were positioned 50m apart, parallel to receiver lines with a 50m VP interval, creating both long source lines to maximise vibrator efficiency and a fully sampled source grid (50m x 50m) to attenuate scattered noise and create a high fold dataset.

Eighteen active vibrators were operated in three sets of six vibrators. Individual vibrators were situated on one of the twelve source lines between the centre pair of receiver lines in the active recording patch, while the three sets were spaced 11km (or greater) apart, a requirement of the DS3 technique.

Figure 1 compares 2D vintage and 1999 3D seismic (156-187 fold, narrow azimuth) data with 2011 DS3 fast track. Overall, even with limited processing, the newer dataset shows significant improvements in data quality in terms of S/N and reflection continuity throughout the section. The speed of acquisition, combined with the ability to process the data quickly, without the requirement for simultaneous source separation software, has helped put high quality image volumes in the hands of the interpreter far in advance of the deadlines for well planning.
As I wrote a year ago – the same still holds true now: “Obama continues to make no decisions on Keystone – maybe the end of the year, maybe next year, maybe never.”

The following piece written this past summer by Robert Skinner of the U of C is an interesting perspective in an age of political environmentalism and absolute stakeholder involvement through the Internet. Unfortunately social media largely supports the activist view simply because they use the platform and our Industry is slow to adopt social media as a media platform.

**Keystone XL and President Obama: history, science and his legacy**

From The School of Public Policy, University of Calgary*

By: Robert Skinner – June 18, 2014

Canada and the United States have generally been on the same side of history in confronting threats to our shared values and interests. We have therefore often found common strategic purpose in developing oil and gas pipeline infrastructure.

In the 1940s, just weeks after the Japanese attack on Pearl Harbor, the two governments agreed on plans to build the Canol Pipeline from Imperial Oil’s Norman Wells field in the Mackenzie Valley to Whitehorse in the Yukon, and on to the Alaskan coast to support the war effort against Japan, which at the time had gained the upper hand in the Pacific war.

In the early 1950s, during the Korean War, the U.S. government determined that oil supply to the west coast was at risk and asked Canada for assistance. The Canadian Parliament passed an Act to expedite the approval and construction of the Trans Mountain Oil Pipeline from Edmonton Alberta over the mountains of British Columbia to the refineries in Washington State’s Puget Sound.

In the sixties, Canada agreed to a higher, US-set oil price west of the Ottawa Valley in order to maintain access to the US oil market for the surge of oil from new oil fields in Alberta following the Leduc discovery.

The US reluctantly made this exception to its restrictive oil import policy aimed at protecting its oil industry in the lower 48 states. It was not lost on Washington that US companies produced most of the new Alberta oil so the US agreed to limited imports.

In the seventies, on the eve of Jimmy Carter’s inauguration on January 20 1977, with 90% of Lake Michigan frozen over, snow fell on Miami for the first time in history. During that extraordinarily cold winter Canada approved emergency exports of natural gas to keep US schools and hospitals open. Later that year, recognizing the strategic importance of natural gas, Canada and the US signed the Treaty on Principles Applicable to a Northern Natural Gas Pipeline and Canada subsequently passed legislation to expedite construction of an Alaskan Natural Gas Transportation System (ANGTS) across Canada. While the ANGTS was never built, Canada agreed to build Phase I, the so-called Prebuild in 1982, consisting of two large diameter pipelines to Chicago and San Francisco transporting western Canadian gas to in effect write down part of the eventual cost of the Alaskan system.

In the late eighties Canada and the US signed the Free Trade Agreement that gave the US access to all of Canada’s oil and agreed to pro-rate exports in the event of government-inspired cutbacks. The US for its part reluctantly granted Canada access to no more than 50,000 b/d of Alaskan crude, the only American source then likely to be of interest to Canada – provided it was shipped in US-flagged tankers.

In the nineties we reconfirmed the FTA in NAFTA. Today, with Mexico re-opening its hydrocarbon sector, the U.S. stands out on the continent as not much of a free trader when it comes to oil. Its refusal to lift the 40 year old ban on crude oil exports stands in stark contrast with the policies of its NAFTA partners.

This brings us to the Keystone XL pipeline, a major strategic project for Canada and for the United States. It would allow more exports to the US Gulf Coast, bolstering continental energy independence – a long standing objective of US energy policy. But its approval.

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*http://policyschool.ucalgary.ca/?q=content/keystone-xl-and-president-obama-history-science-and-his-legacy&utm_source=hootsuite&utm_campaign=hootsuite
has been stalled for half a decade. President Obama declared last June that approval will be predicated on whether it “will significantly exacerbate the problem of carbon pollution”. Let’s examine that condition – objectively. If all 170 billion barrels of oil sands reserves were produced at once using current technologies, the total resulting emissions would equal 157 days of the world’s emissions, or five years’ of the US’s. So, the pipeline would not exacerbate ‘carbon pollution’. The oil would also back out imports from Venezuela and Saudi Arabia. So, from scientific and strategic perspectives Keystone XL makes sense to America.

And might we be encouraged by the President’s avowed principle of making decisions based on science? On March 9, 2009 when signing the Executive Order allowing stem cell research, he said,

“[Promoting science] is about letting scientists …do their jobs, free from manipulation or coercion, and listening to what they tell us, even when it’s inconvenient – especially when it’s inconvenient. It is about ensuring that scientific data is never distorted or concealed to serve a political agenda – and that we make scientific decisions based on facts, not ideology”.

As President Obama reflects on the facts about the Keystone XL pipeline and whether its denial will be his legacy, he should consider a much longer legacy – that of the long-standing relationship between our two countries in confronting threats to our continental strategic and energy interests. To lightly dismiss that long history of cooperation would say far more about the United States than most Americans would want.

The CAGC posts articles of interest onto our blog site on a regular basis – see our website www.cagc.ca and click on the B (blogspot) up in the top right area.

From Brainy Quotes on the Internet:

“Everyone here has the sense that right now is one of those moments when we are influencing the future.”

STEVE JOBS

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Tell us about your educational background and your work experience and what you are engaged in doing these days?

As a kid I was made to believe that my destiny was to be a doctor. But the idea of cutting a frog, albeit a dead one, was abhorrent to me and I decided, much to the disappointment of my family, to do Physics and Mathematics instead. When I applied for admission to Indian Institute of Technology (IIT) at Kharagpur, a thousand miles from my home town, I chose Geology and Geophysics intending to specialize in Geophysics. At that time, IIT was where every parent wanted their kids to go for studies and by some strange coincidence I was accepted. I was fortunate to have Amalendu Roy teaching us Geophysics. He had a talent for explaining complex ideas and getting his students really involved in what he was teaching. Dr. Roy also supervised my Master’s thesis which was published in Geophysics in 1961. The interesting aspect of this work was that it was a simple form of inversion for potential field and resistivity data. Conventionally, potential field data interpretation is a modeling exercise but Dr. Roy and I showed a simple procedure which could lead to source parameters directly from the data.

I worked for a year collecting gravity-magnetic data in India and then won a scholarship paid by Assam Oil Company but administered by the Government of India to do postgraduate work in England. For reasons I have never understood, High Commission of India in England placed me at the University Of Liverpool. The University had a very good Department of Geology but only one lecturer in Geophysics and hardly any equipment. After some trial and error research, Dr. Wilson, the lecturer, and I settled on the investigation of sediments under the Irish Sea using magnetotelluric method which was being developed by Russians as an exploration tool. My work suggested thick conductive sedimentary rocks north of Wales and between Ireland and the Isle of Man which was not yet known, certainly not at Liverpool. The work resulted in papers in European and British journals culminating in Van Weelden award for 1966 by E.A.E.G.

After graduating from Liverpool, I worked for GSI for a little over four years. Those were the days digital processing was being introduced and GSI were the leaders in the field. They sent me to Dallas for five months of training where I mostly worked in the Research Department leading lights of the day, Milo Backus and Bill Schneider. GSI had a very good correspondence course program which I joined. I learnt a lot of practical things from these courses. After a little over two years in London I spent another two years with GSI in Libya before switching over to Mobil there. Mobil Libya received a set of seismic processing software from Mobil Canada and I was given the job of installing it. I worked on improving it in various ways to make it more suitable for poor data quality. That was a great learning experience.

After Gaddafi’s revolution in September 1969, oil exploration in Libya came to a standstill. Mobil offered me a couple of transfer possibilities in Europe but I was intent on doing research. I applied to Canada and the U.S. for immigration visa and moved to the U.S. because they were prompt in issuing the papers. Aero Service Corporation in Philadelphia offered me a job to develop interpretation software for aeromagnetic data. That was a great opportunity to broaden the
field of geophysical experience. Two and a half years later, Digitech enticed me with the big title of Research Manager and a decent raise and we moved to Calgary in the first week of February 1974. After two years, I decided to set up my own shop and Commonwealth Geophysical was born. I developed proprietary inversion software for seismic, gravity and magnetic data. Some companies liked what I was doing and the company expanded to as many as ten technical people doing inversion related processing and interpretation in all branches of geophysical prospecting.

What am I doing these days? Not much or a lot. Depends on how you look at it. Some of my friends have entrusted me with their retirement funds. This is not much work in itself but I do take this responsibility seriously; it is my dear friends’ old age I am looking after. More of my time is spent on writing and what goes with writing – editing and reediting the work, sending it to prospective publishers, promoting the books. Writing itself has many aspects – generation of ideas on what to write, maturation of these ideas, what form is appropriate for the subject, not the least who should be the narrator. Weeks and months can go by before the germ of an idea gets to the point when you can hit the keyboard. Even then, you can be half way through when you find it is not working and you start again. Every once in a while, particularly with essays, you complete the piece and decide to forget about it because it no longer makes sense to you. Good thing is that while you are writing a particular essay or a story, other ideas are criss-crossing the brain and hopefully one will be ready when the current project is finished.

• How would you describe yourself in five words?
  Hardworking, confident, trustworthy, calm under pressure, ambitious.

• What is it you loved about our industry, where you remained active for a long time?
  In my forty years in Geophysics, I did not come across one instance of prejudice, whether for colour, nationality or religion. The people hired you if you could do the work they needed done and if it did not work out your personal relationship stayed the same as before. There was never any problem with being paid for the work. Most geophysicists I came across loved what they were doing. They had strong opinions but kept the ears and minds open. Working atmosphere was as good as one could ever wish for.

• Who are the geophysicists of your time that you admired for their work?
  First of all, I was very lucky in the geophysicists and systems analysts who agreed to work at Commonwealth and I derive great satisfaction from what we achieved together. As I said earlier, I admired so many people I could write a book about them. Maybe I will someday. But for now, Rob Stewart is the most brilliant person I have come across anywhere, although I never had the good fortune to work with him. I admired Easton Wren for his ready grasp of a new idea and the ability to explain it better than the person whose idea it was. Peter Savage was perhaps the best Exploration Manager I worked with. He knew what he wanted from his people and his consultants and how to get it. Lorne Kelsch was a Chief Geophysicist in a class by himself. He knew what data he needed, how to use it most effectively, listened to new ideas, and supported them but only when they made sense to him.

• Everyone has a driving goal in life. What has it been for you?
  I say this, neither with pride nor humility but for the sake of honesty. I was driven by an ambition to be a major success, to set an example to others with my achievements. I realized much too late that I did not have the innate talent or the extraordinary ability to achieve this and it has been very hard to reconcile my very modest achievements relative to my great ambition.

• I have come across many of your papers written and published in the late 1970s and the 1980s. You were active in delivering talks as well. Tell us about those experiences? Do you have some memorable incidents from your professional successes?
  I enjoyed writing papers and delivering talks since my postgraduate student days. I was unduly nervous and therefore mumbled a lot in my
Q&A:
SUDHIR JAIN

first few presentations. Then an old hand, I did not even know him, told me something like “You know more than anyone in the audience and there is nothing to be nervous about. So you can speak clearly and confidently and every one would be better off.” I took the advice and it helped my writing as well.

I like to think that although the material I presented was related to the services I offered, my presentations were not marketing gimmicks because I tried to point out what could not be done as much as what could be achieved by the processes. A proof is that it was rare indeed when someone contacted me for my services after a presentation. I never deliberately oversold any of my services and did not offer them when they were not likely to work. Of course there were times they did not work after my recommendation but things don’t often turn out the way you expect them to.

The papers and talks to CSEG, SEG, EAEG, AGU and luncheons made me friends in the geophysical research community and the exchange of ideas was very helpful to me, perhaps to them too. One memorable incident, from a personal point of view, was after my talk on Magnetotelluric methods in Madrid in 1965. A research chief in a major oil company in California approached me. In my ignorance I brushed the gentleman aside. I have often felt a tinge of regret over that folly.

What problems in geophysics particularly fascinated you in your hay days and you pursued them vigorously?

In sixties the properties of the sediments were deduced by modeling. My work for the Master’s thesis introduced me to deriving the properties directly by analyzing the data. This process got to be known as inversion and most of my development work was related to it. True Amplitude Recovery introduced in the early seventies was necessary for meaningful inversion and that is what attracted me to it when I joined Digitech. Inter-bed multiples introduced confusion for inversion in areas of Devonian reefs and it induced me to work on their attenuation. Estimating velocity fluctuations from the amplitudes and integrating them with low-frequency velocity component from normal move-out was my main occupation throughout my career in Canada and, I must say, the main source of my family’s financial wellbeing. I developed software for magnetic and gravity data inversion and used it successfully. It was a life saver when seismic business was slow.

Do you still read the CSEG RECORDER?

I stopped receiving the RECORDER a few years ago due to the confusion about my address. The problem has now been rectified and I can stay abreast of the developments in the profession.

Give us a day in the life of Sudhir Jain in say the 1980s and 2014?

1980s were difficult years for our family and there was not a day (or year) that was typical. Our daughters were 12, 9 and 2 in 1980. Evelyn, my wife, was taking science undergraduate courses as a precursor to five years of medical training which she completed in 1989. My services were in great demand at that time. I got up at 5:30 and got to work downtown around seven. In early 1980s I had Dan Petch working with me. We had two rooms on the eighth floor of the building Digitech was in. I used Digitech’s computer facilities for an hourly fee. I also had an agreement with PanCanadian to spend twenty five to thirty hours a week on their jobs in the office they had provided in their building in Palliser Square. I would work from seven till nine on other clients’ jobs, help data processors of two companies who used my software (if the help was needed) and then walk over to Palliser Square. I would work there till four or so, walk back to my other office to work for an hour and get home by six. Evelyn insisted that we had a dinner together as a family and our girls still cherish that rule. I spent the evening helping in the kitchen and children’s activities, putting the girls to bed and then work on the software development or publication project for a couple of hours. It was always a very full but a very satisfying day. The routine changed somewhat in the late eighties when some more professionals joined me but workload was always about the same. I must say here that Evelyn was absolutely amazing in those years carrying the tremendous workload of a medical student as well as managing a family with three growing daughters at various stages of schooling. Looking back I am amazed that we pulled through it all in one piece.

2014 is very different. Now there is nothing that must be done, there are no deadlines and the daughters have moved away, two to Vancouver, one to San Francisco. I still get up around 5:30. There are exercises prescribed by physiotherapists over the years which take an hour every morning and the day goes by in a little reading, some writing, some work on investments and of course the necessary jobs around the house. The people our age have one of the four major preoccupations: receiving medical attention, tending grandchildren, cruises and other travels and finally golf or bridge. Evelyn and I have none of these things to occupy us except for odd weeks our grandchildren visit us from their home in San Francisco. But both of us like reading, Evelyn still does lactation consulting three mornings a week. She is an avid gardener, a wonderful cook and an excellent editor of what I write. Most of the time, we do what we enjoy much of the day blessed with good health and the company of great people who have kindly chosen us as their friends.

You have had a full cycle/life. Is there anything else you wish you had?

I am finally reconciled to the life I had. I do wish I had done more voluntary work with CSEG when I was
consulting and had been able to support cultural organizations to the level justified by the joy they provided me. I am grateful for the support I have received all along from the colleagues and the family although my temperament, and you could call it lack of social graces, must have made it very hard for them.

How is it you gradually put a stop to practicing geophysics?

I realized that I was not able to focus on the research side of my work and that had been the sustaining part for me. About that time I got involved in a couple of exploration projects which could be in conflict with the consulting business. In what turned out to be a huge misjudgment, I decided to pursue the exploration projects and ‘retired’ from geophysics. Both projects bit the dust and caused me much grief.

How did you reconcile your very busy career in Geophysics with the needs of your family?

I worked long hours but I always placed the family first. I made time to watch the concerts and games of our girls, did my chores at home and took time off from office when I was needed. However, I worked late in the evenings and over the weekends, went to the office early, worked without a break all day and believe it or not, enjoyed every moment of it. I was doing what I loved; doing it for the woman and the girls I adored, my work was appreciated by my clients who retained me year after year. I was happy and, dare I say, fulfilled.

How did your family help or hinder with what you wished to do in your careers?

My wife was always supportive in my career. She moved to three different countries in nine years leaving friends and family behind. She has this great capacity to make friends for life which helped us settle in new places. She does not find faults in me just to put me in my place but does correct me when it would be helpful. She edits all my writing and makes suggestions for improvements. She helped me in promotion of my business in old days and promotes my books now, even joining me in book readings. Most of all, she has been a wonderful mother even when she was a medical student and a resident. My daughters make constructive comments on my writing and these have helped my books, particularly the novel.

I have had an inner peace in my family relationship and that has freed all my energy for the works I undertook. What more can a man wish.

Once you stopped practicing geophysics, you turned to writing letters on a variety of subjects and published in newspapers. Tell us how this happened.

I am, as a character in one story describes himself, like a wide but a shallow lake. I have an opinion about everything under the sun. That may not be bad in itself, but I also think that others should be told of my reaction to the events occurring at any time anywhere. What better
Q&A: SUDHIR JAIN

方式 to do it than send a letter to the newspapers. For whatever reason, editors liked my fulminations and published them. That encouraged me to write more and send them to a wider field. Fortunately, it took me just a few minutes to do it so other activities were not impacted.

That brings me to another question: Einstein once said ‘If you cannot explain something simply, you don’t understand it well’. For someone like you, who is writing fiction, it is telling enough that you are able to simplify and describe well. You could have contributed well in geophysics. Why did you not continue to write in geophysics?

That is an excellent question and a very difficult one to answer. I did try to do it in some RECORDER articles in the late nineties and some people liked these articles. However, classical music and literature were my pastime since childhood. I wrote a story on the love of young Gustav Mahler, a German composer (1860 – 1911) and an older married woman. I also wrote some about the events in my daily life. I could write these stories quickly, in a few hours spread over a few days. These were popular among literate friends who encouraged me to write more. On the other hand, geophysical articles require considerable reading, a period of gestation and then very careful writing and editing. Technical writing needs concentration and uninterrupted time periods. My kind of fiction needs very little research, it is a combination of what I remember and what I can imagine. No one is going to complain about accuracy and any learning from it is incidental. To make it short, it was easier to write for readers’ amusement than writing for information and I chose the easy path.

What is the central theme in your recently published book entitled ‘Princess of Aminabad: An Ordinary Life’?

The central theme is how the changing social and political environment of twentieth century India impacted on the life of an ordinary woman and how her actions accelerated these changes. The broad structure of the novel is loosely based on the life of my mother who lived through most of the twentieth century. I thought that weaving real events from her life with social and political changes going on around her was a good base for a novel. Of course, the life events had to be modified and many new ones invented. It is not a biography, not even a bio-novel because so much of it is my imagination.

Your first book entitled ‘Isolde’s Dream and Other Stories’ was published in 2007. What was that about?

It is a collection of two types of stories. Two bookend stories are fictionalized accounts of love affairs. In the title story Richard Wagner, German opera composer (1813 – 1883) falls in love with the wife of his patron when he was composing the opera on an illicit love affair between a courtier and the queen. The first story is the tragic story of composer Mahler and Marion von Weber I referred to earlier. It is the most moving heart-on-the-sleeve story you are likely to read. I can’t believe I wrote it. I have always had a close affinity with Mahler’s music and Wagner’s operas and people tell me that this comes out in the stories.

Most of the other stories are sourced in events from my life and are told with self-deprecating humour. These are short stories you can read before going to sleep without worrying about nasty dreams. There is a contemplative essay on the time I got lost for three days in the forest near Prince George which readers won’t let me forget. It was a popular book and the library copies are more often out than on the shelves.

We’ll also like to hear about the book you published in 2012, ‘Pages from an Immigrant’s Diary’.

These are the stories of immigrant experience, some funny, some serious and not necessarily my own. After leaving India I lived in three other countries for extended periods before settling in Canada. The stories are based on events from these countries, from student days to some recent experiences.

Last chapter of the book is a series of essays, some published previously in the media, about what I learned in life. I don’t believe that one necessarily gains wisdom with age but being a thinking type, there could be some things I learnt that may be of interest to the readers. A former geophysicist who read the book found this section more interesting than the rest, but he was an exception.

Having achieved so much in terms of name and fame, what is it that motivates you now?

As for the name and fame, I concluded a while ago that I did not achieve the level of success I always dreamed about but it was because I overestimated my talent and skill level and it was too late now to do anything about it. At my age I have at best a few healthy years left. I want to spend these in doing my bit to help my family and community and spend my spare time in writing amusing stories or instructive essays which will be positive experiences for the readers. Motivation is really to do the least harm and as much good as I can do for those around me.

With a life-long experience behind you and the fact that you are a writer, we could ask you a couple of philosophical questions: Some people opine that experts are more persuasive when they are less certain. Would you agree? Could you elaborate on this?

I have learnt that I am absolutely certain only when I am wrong. I am ashamed to think how many times I became angry and told off colleagues or family members and later found that it was my mistake. To be persuasive one must be less certain because there is a give and take in discussion then. No one likes orders. The best way to persuade people to do what you think should be done is to convince them that it was what they always wanted to do. You can only do that when you are patient and working out the solution together, even though only the final phases of it.

You may be in a situation where you think it seems right, but it doesn’t feel right. What would you do in such a situation?

I almost always go with feeling because it is my subconscious telling me something that is based on what I experienced but do not want to face. Thought and feel are in harmony only when logic is consistent with experience.

What differences did you notice when you turned 30 years, 40 years, 50 years, and 60 years old, and then at present? As an
example, some people think 30s allowed them to experiment with options, 40s gave them time for self-introspection or naughty at 40, and so on. Your comments?

At the age of 30 I was living in Libya and had a one year old daughter. Everything was rosy and I looked forward to a great career in geophysics and a happy family life. Ten years later, I had moved to Canada via USA, was consulting and my seismic inversion process called Soniseis had taken off. We had three daughters now and we liked our life in Calgary. The expectations were being realized and I thought Commonwealth Geophysical would grow into a major operation. But I had to temper my growth plans for family reasons although I developed some very useful software, published some good papers and the company grew to ten or twelve people during the decade. My wife completed her medical training the year after I turned fifty and started her medical practice which was very successful. Introspection came at this stage and I began writing, mostly on classical music and religion, to clear my thinking. We built his and her office buildings on the same lot, one for the practice of geophysics and the other for the practice of medicine. When sixty, I got involved in two projects, one for oil exploration and the other for iron ore. These were at least partly instrumental in my retiring from geophysics. I worked hard on these but they both failed and embarrassed me no end. I began writing letters to the media and essays and stories a couple of years later. My first publication was around this time, an essay on atheism.

Life now is very different. Our daughters have grown into fine women with successful careers. My wife and I do worry about our two young granddaughters who have some problems. Other than that, I have all I need and could possibly need for the rest of my life. I am reconciled to the past, content in the present and prepared for the future.

What would be your message for youngsters who have joined our industry recently?

You are in a profession where the level of uncertainty is high. It is much better than a blind person throwing darts but if you hit the bull’s eye every time, even most of the time, something is wrong. There will be pieces of puzzle missing. But the decision has to be made, to drill or not to drill before land expiry by an Exploration Manager, or a reef or a multiple by the geophysicist. But you can’t be sloppy in a situation like this. Do the best you can do with all the data available in the given time frame. The rest is in the hands of God if you are religious or the game of statistical probability if you are a non-believer.
INTRODUCTION TO OCTOBER FOCUS:
Seismic Interpretation

Chasing Density – An Introduction to Seismic Acquisition, Processing, and Interpretation Methods Leading to Quantitative Interpretation
BRIAN SCHULTE, DAVID MANTHEI

Natural fracture characterization from 3D structural attributes
DAMIEN THENIN, RON LARSON

Optimising resource plays – an integrated “GeoPrediction” approach
STEPHEN O’CONNOR, SCOTT MILDREN, MICHEL KEMPER, CRISTIAN MALAVER, JEREMY GALLOP AND SAM GREEN

This issue of the RECORDER focuses on modern seismic interpretation through three interesting articles. Highlighted are critical elements such as best practices and the importance of integrating the earth mechanics for a better subsurface understanding. I invite you to come along to see the present and future of seismic interpretation.

The first article, “Chasing Density – An Introduction to Seismic Acquisition, Processing, and Interpretation Methods Leading to Quantitative Interpretation” by Brian Schulte and David Manthei of Talisman Energy, provides a comprehensive tutorial on quantitative interpretation presented within the framework of seismic density estimation. The authors take a seismic value chain approach whereby the emphasis is that a successful quantitative interpretation study relies on the proper road-mapping of the desired result, via processing, all the way back to acquisition.

The second article, “Natural fracture characterization from 3D structural attributes” by Damien Thenin, of EMZED Exploration, and Ron Larson, of RPS Energy Canada, presents a novel workflow intended to free up the interpreter’s time to actually interpret, rather than “pick”, the data. The essence of the approach is to automate most of the structural and stratigraphic picking, transform to the chrono-stratigraphic domain in an advanced manner and integrate geomechanical information.

The third article, “Optimising resource plays – an integrated ‘GeoPrediction’ approach” by Stephen O’Connor and co-authors of Ikon Science Ltd., discuss an integrated subsurface workflow for “sweet spot” characterisation in resource plays which can be used to drive field development. The authors argue to move beyond using brittleness as the sweet spot proxy to a ‘GeoPrediction’ based characterisation using an earth model that includes pore pressure, rock physics and geomechanics.

Ayon Kumar Dey received his B.Sc. at Memorial University, his M.Sc. from the University of Calgary and then completed a Ph.D. at Delft University of Technology. His experience is generally focused on integrated seismic reservoir characterisation. After various roles in academia and private industry (including a decade overseas), he repatriated back to Calgary in 2012 as a senior geophysicist for Sasol Canada.

Ayon Kumar Dey
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For any given reservoir or resource play, there are geological and geophysical measurements that impact the exploitation of in-situ hydrocarbons. Correct interpretation of these measurements is important to the overall economic success of an Exploration and Production company’s endeavors. As geoscientists, the integration of our conditioned geological and geophysical data in regards to reservoir engineering, drilling, and completions need to be done in a meaningful way. One of these ways is to use and analyze log responses from previously drilled wells.

Various log curves help identify components of a reservoir such as the stratigraphy, structure, and rock properties inherent in the subsurface (Hunt et al, 2012). Well logs are important for geophysical work as we can cross-plot measured and/or derived properties that are achievable through seismic methods and manipulations. For instance, if a key play driver were porosity, an acoustic impedance and porosity well cross-plot could direct one towards an acoustic impedance inversion if there was a reliable correlation. However, there is a large resolution difference between well logs and seismic data. Well logs can be up-scaled to seismic frequencies as well as synthetically modeled to overcome this resolution disparity. Understanding vertical resolution limitations of seismic data leads to the identification of which rock properties can be appropriately utilized (Hunt et al, 2012). This knowledge can influence future seismic survey design and the processing parameters chosen, so that the eventual interpretations are tailored for the target reservoir (figure 1).

A myriad of seismic attributes can be derived from the seismic data (figure 2) but all of these seismic attributes can be broken down into two categories:

1) Geometrical Attributes (Structural) – Attributes that enhance the visibility of the geometrical characteristics within seismic data. Examples include dip, azimuth, continuity, etc.

2) Physical Attributes (Stratigraphical) – Attributes that enhance the lithological properties inherent in seismic data. Examples include frequency, amplitude, phase, porosity, etc.

Most plays have both structural and stratigraphical elements that need to be understood properly to characterize a reservoir. The link
between these types of seismic attributes to well, completion, and production data is crucial to this characterization. As mentioned previously, a stratigraphical attribute like acoustic impedance may indicate rock porosity that is known to be important for good production within a reservoir. As well, a structural attribute such as semblance can highlight lateral discontinuities important to finding features such as sand channels. The combination of these two example attributes can significantly hone exploration efforts if the main goal is to identify and drill porous sand channels.

Within interpretation software packages today, there are simple ways to enhance features inherent in these structural and stratigraphic volumes. Once key attributes for a given reservoir are identified, the creation of uniformly spaced intervals between two interpreted seismic horizons (stratal slices) can aid overall seismic interpretation (Zeng, 2006). Another prospecting tool is the ability to blend attributes by colour and opacity. Simple colour blending combines up to three attributes by assigning each separately to red, green, and blue colours. Important geologic features can be made visually appealing and into a play risk or ‘fairway’ map by manipulating the attribute colour combinations.

All of these elements contribute to the understanding of the subsurface, and leads to making informed decisions in:

1) Purchasing leases in land sales
2) Whether or not to participate in a proposed partner drilling operation
3) Offset drilling requirements

These scenarios need to be considered by an asset team and sometimes require a swift response if there is little time to act. Having the pertinent information available for these occasions may avoid poor capital commitments.

Density

A volume of density is obtainable from conditioned pre-stack seismic data, along with p-wave and s-wave volumes, by means of a ‘joint’ or simultaneous pre-stack inversion (figure 3). Through the combination of these inversion products, other seismically derived rock properties such as Poisson’s Ratio, Young’s Modulus, Lambda-rho, and Mu-Rho can be calculated. Another key attribute obtained from these pre-stack inversion derivatives is brittleness. Brittleness has become widely used to help characterize unconventional plays and is calculated using Poisson’s Ratio and Young’s Modulus. However, density as a seismically derived attribute has been long viewed as unreliable for various reasons, those of which will be reviewed later. However, density can be utilized in many ways for successful reservoir characterization. An example of a density’s use relates to a characterization problem known as ‘fizz gas’ in certain reservoirs. Fizz gas is a term used to describe reservoirs that are very lowly saturated in gas (Sg < 10%). These reservoirs look like promising drilling prospects due to the fact that a just a small amount of gas will cause a large change in p-wave velocity, which coincidently has a similar seismic and amplitude versus offset (AVO) response to that of a highly gas saturated reservoir. There have been many failed exploration endeavors due to this problem. Density can be used to distinguish low and high gas saturated reservoirs as the bulk density response of a fizz gas reservoir is ten percent higher than that of a highly gas saturated reservoir (Han and Batzle, 2002).

AVO anomalies caused by fizz gas reservoirs are hard to distinguish from gas saturated reservoirs (figure 4), but can be reliably verified through fault seal analysis. If a reservoir’s seal has been broken by a fault, the gas may slowly leak out into the overlying formations depleting the reservoir creating a fizz gas scenario. This type of analysis is rarely done prior to the unsuccessful exploration of a fizz gas reservoir. However, the viability of an AVO anomaly can be tested if it conforms or does not conform to the geologic structure in which it is occupying. If the anomaly conforms, a gas saturated reservoir is expected to be encountered.
Using Shuey’s (1985) definition of AVO response (figure 5), the density component of a gather can be isolated using the angle of incidence. Gatherers are broken into three components based on the angle of incidence; a near-offset term from 0° to 15° that relates to the intercept, a mid-offset term from 15° to 30° that relates to the gradient, and a far-offset term from 30° to 45° that describes the curvature. If these terms are manipulated such that the intercept is subtracted from the curvature, an isolation of density is obtained.

$$R(\theta) = A + B \sin^2 \theta + C \sin^2 \theta \tan^2 \theta$$

Where:
- $A =$ Intercept
- $B =$ Gradient
- $C =$ Curvature

$$\rho = \frac{1}{A}$$

For $\theta = 0^\circ - 15^\circ$:

$$\alpha = C$$

For $15^\circ - 30^\circ$:

$$\alpha = B$$

For $30^\circ - 45^\circ$:

$$\alpha = \frac{1}{2}$$

$\Delta T = \Delta t$ = Shear wave velocity
$\Delta r = $ Density

Figure 5. The mathematical for Shuey’s (1985) three-term AVO equation, where $A$ is the intercept, $B$ is the gradient, and $C$ the curvature. The relationship between the intercept, curvature, and density terms is also shown. Curvature tends to be unstable due to noise within gathers; at these far-offsets there is significant amounts of NMO stretch occurring.

Since the curvature term is being derived from angles of incidence greater than 30°, there are significant limitations to its usefulness as issues in acquisition occur at these far-offsets that many seismic processing flows try to deal with. Problems such as move-out calculations and multiple elimination are mitigated in seismic processing. In order to trust the curvature term, a greater investment needs to be made during the acquisition stage to obtain better far-offset data (particularly in land surveys). Improvements made to survey design will benefit near-offset data as well, resulting in better inversion results and density approximation.

**Seismic Acquisition**

In order to acquire further far-offsets during seismic acquisition additional receivers need to be turned on or laid out, and both are fairly inexpensive to do when compared to the initial mobilization of the recording crew. A prior rule of thumb was that a receiver’s offset should be equal to that of the target’s depth, but in order to get proper angles of incidence to produce a reliable curvature term the ratio between offset and target depth should be 1.75. For example, if a target was known to be roughly 2000 meters deep, the furthest offset attempted for needs to be greater than 3500 meters.

In order to acquire better near-offset data, there is a need to reduce line spacing and add additional source points, but doing so raises the price of seismic acquisition significantly. There have been recent ideas proposed in seismic acquisition such as using a single vibrator, doing a single sweep at more locations, instead of traditionally having multiple vibrators at fewer locations. This method would acquire denser data, or further offsets, rather than a stronger signal at far fewer source points.

Additional seismic acquisition tools and methods such as nodal systems and simultaneous vibroseis acquisitions can lead to higher density surveys. Although 5D interpolation has become increasingly popular in recent years for seismic processing, it may have negative impacts on seismic acquisition efforts. Many acquisitions have been reduced in source and receiver density as 5D is able to infill traces at a significantly reduced cost compared to acquiring raw data. It is important to keep acquisition density as high as possible, since 5D will typically infill many more middle-offsets than near and far-offsets, which are crucial to interpretation.

**Seismic Processing**

Having acquired seismic data, it is good idea to approach the processing or re-processing of a data set with an understanding of ideal deliverables, especially if reliable density volumes are required. Processing workflows can be highly tailored to suit these needs, especially if AVO compliance is necessary for good far-offsets and ultimately density. A major issue with near-offsets however is multiple contaminations. Multiples can disrupt near offsets (figure 6), since they have a similar move-out or $\Delta T$ to that of primary events; it is hard to remove them without affecting the actual signal. It is important that these multiples be removed as near-offsets help improve fluid knowledge in AVO classification and seismic attributes such as acoustic impedance.

![Figure 6. Graph showing that water bottom multiples in marine acquisition can overlap with primary reflections in near-offsets.](image-url)
Recent processing technology called Surface Related Multiple Elimination (SRME), developed by Delft University, can predict surface related multiples from the acquired data and does not require additional information. The strength of SRME is that it can adaptively account for mismatches of amplitude, phase, and source wavelets between multiples and primary reflectors (Verschuur and Berkhout, 1997; Dragset et al, 2006; Lui and Dragoset, 2012). SRME is also capable of removing interbedded multiples, all while preserving the original signal.

Decontaminating seismic data of multiples allows for better, truer amplitudes on near-offsets. It is then possible to achieve better seismic attributes such as acoustic impedance and with Acoustic Impedance we can gain information such as porosity and fluid content since the fluid information can be found on the near offsets (figure 7).

While SRME removes multiples from near-offsets, there is still a need to apply additional techniques to handle multiple effects on far-offsets. These can be handled by a noise reduction and multiple removal process known as Parabolic Radon Transform or a high resolution Radon proposed by Sacchi and Ulrych (1995). Radon transforms can eliminate multiples by fitting parabolas to recorded reflection events; multiples are parabolic in shape (in time-offset plots) compared to primaries, the process can then be instructed to remove events that appear to be multiples once it has fit a parabola to them. High resolution Radon eliminates multiples by separating events in Tau-p space (time versus slowness), and then applying a mute (figure 8).

A mute can be designed within Tau-p space to eliminate multiple signals from the gather. High resolution Radon can typically separate multiple events better than normal Radon transforms as they usually do not overlap at all in Tau-p space, given a proper mute is applied. An improper mute will allow some energy from the multiple to return to the Time-Distance domain, causing the primary to be aliased (brightening of near-offsets). In deep water seismic, some run a Radon rather than an inside mute to remove this aliasing.

Other seismic processing advancements such as noise attenuation allow for better AVO compliant data. Noise has certain characteristics to it that can be modeled in different seismic domains, and then isolated within real data. Noise within the data can then be surgically removed enhancing the signal without harming it.

Figure 7. Graph showing intercept versus angle of incidence for class 2 wet and gas sands described by Rutherford and Williams (1989). Notice that the type of fluid saturating the rock’s pores affects the intercept or reflection coefficient. Looking at the slope of these curves, the gradient term, it is apparent that they are similar. This is due to the fact that the gradient is more representative of lithological information. It is unaffected by fluid type since it is based on s-wave measurements.

Figure 8. Diagram illustrating how high resolution radon works. A typical input gather (A) showing how multiples appear to overlay primaries in near-offsets and then separate in further offsets, this separation is referred to as $\Delta T$. The primary (blue) and multiple (red) are separated within Tau-p space (B). The final gather with multiple removed (C).
A recent targeted area for focused seismic processing is the cross-spread domain (figure 9), where all geophones in a given unique receiver line are recording shots from a given unique shot line. The cross-spread domain is a continuous 3D subset of the 5D pre-stack wave field, which is comprised of inline, cross line, offset, absolute offset, and azimuth (Vermeer, 2007). It varies smoothly from trace to trace in each of the 5 spatial attributes.

There have also been recent developments in interpolation and regularization techniques, processing methods that fill in missing data for certain domains while regularizing the fold of the data. Missing data or irregular fold creates aliasing artifacts during pre-stack time and depth migration. This is because pre-stack migration relies on constructive and destructive interference to image the data. Regularized data is necessary to perform advanced interpretations such as seismic inversion, AVAZ, and AVO.

One such interpolation and regularization technique is 5D interpolation. 5D interpolation fills insufficient data areas in seismic surveys, especially in the near-surface, and is capable of reducing various noise sources. For example, 5D interpolation can decrease the effect of an acquisition ‘footprint’ that is easily seen in horizontal slices of seismic data. This is important for the imaging of some reservoir bodies, such as channels (figure 10), as they have great lateral extent rather than vertical (Zeng, 2006). Improving the fidelity in time, horizon, and stratal slices directly benefits the ability to reliably map these sometimes small geologic bodies.

**NMO and Imaging Higher Incidence Angle Data**

Processing seismic data beyond 30° (incidence angle) becomes critical in the chase for a reliable density. Many processing algorithms are designed for an incidence angle of 30° due to the prior rule of thumb mentioned, where offset is equal to depth. Such is the case for the standard two-term normal move-out (NMO) equation as well as imaging methods like straight ray pre-stack time migration.

The two-term NMO equation however fails beyond 30° (incidence angle) and causes a rather dramatic effect called ‘hockey sticking’, where an event (peak or trough) turns upwards in the far-offsets of a gather, appearing similar to the shape of a hockey stick (figure 11). This problem, more detailed, is due to the fact that NMO is plagued by a short offset approximation associated with Snell’s Law; as velocities change between different geologic layers, curved ray paths occur.
instead of straight ones. Velocities then change with offset, creating the hockey stick effect. NMO 'stretch' is another common occurrence, where there is a shift toward lower frequencies in the far-offsets. The combined result of this stretching of frequencies and hockey sticking causes the wavelet to be significantly altered. An assumption made by Shuey’s (1985) approximation is that the wavelet used is supposed to be constant, so there is a need to deal with these NMO problems if AVO characterization is required (Cambois, 2002).

The short offset approximation for the two-term NMO equation is:

\[ T_{nmo}^2 = T_0^2 + \frac{x^2}{v_{nmo}^2} \]

(Taner and Koehler, 1969)

The non-hyperbolic move-out is generally handled by a third and fourth order NMO equation such as:

\[ T_{nmo}^2 = T_0^2 + \frac{x^2}{v_{nmo}^2} + \frac{2nx^4}{v_{nmo}^4} \left( n_1^2 + n_2^2 \right) \]

(Alkhalifah and Tsvankin, 1995)

NMO stretch can be mitigated when using at least an extra term since it defines the shape of the parabola better in move-out. Generally, \( \eta \) is used to flatten the hockey stick effect in far-offsets.

\( \eta \) can be thought of as a 'fudge' factor to obtain flatter gathers. \( \eta \) is one of the Thomsen parameters and can be related to \( \varepsilon \) and \( \delta \) through the equation \( \eta = (\varepsilon - \delta)/(1+2\delta) \) (Thomsen, 1986).

Straight ray pre-stack time migration (PSTM) produces the same issues since ray paths in real data are curved. Migrating data with a Kirchhoff straight ray PSTM will result in hockey sticking due to curved data, but also to vertical transverse isotropy (VTI). VTI can occur in geologic formations as the same properties may occur laterally within rocks, but may also vary throughout the vertical extent of them. A lithological example of such a rock is shales. Although VTI’s effect on data is expected to be weak, data corrected for curved ray paths exhibits hockey sticking, suggesting that VTI is large enough to require additional processing. These problems have resulted in the shift in processing flows to curved ray PSTM instead of straight ray methods.

Curved ray PSTM take into account bent ray paths that occur in a velocity changing medium. It can be run in several ways:

1) Through ray tracing
2) Using a fourth order move-out equation, where \( \eta \) is reasonable to 18000 feet
3) Using a sixth order move-out equation

Solving for curved rays has the additional benefit of imaging anisotropy through VTI as well as \( \eta \) being representative of certain rock properties. Prior to curved ray PSTM, the difference between time and depth migration was how each treated curved rays, with depth migration being able to account for them. However, the difference now is that time migration utilizes stacking velocities to flatten gathers. Time migration inverts stacking velocities to interval velocities, producing physically impossible values. It is obvious then that the result of time migration is to simply produce and image, which is not necessarily geological valid.

In depth migration, interval velocities will have representative values of the geologic units. Depth migration’s velocity field is created using seismic horizons, sonic log responses, check shot data, and vertical seismic profiles (VSP’s) in an attempt to accurately model the Earth’s subsurface. Seismic wave behavior is then modeled better through depth migration than time migration (Gray et al, 2001). Whenever there is a known rapidly-varying lateral velocity, pre-stack depth migration is the correct process to use. However, time migration still has its own advantages over depth migration. Time migration is computationally inexpensive, is less sensitive to velocity, and adequately images most reservoirs for interpretation purposes. If pre-stack depth migration is chosen, there needs to be an appropriate geological model built while time migration can be run for initial results.

Another problem with wide azimuth data is horizontal transverse isotropy (HTI), similar to VTI, which produces a sinusoid shape to the gathers. HTI parameters, as well as VTI, are being used in proprietary pre-stack time migration algorithms; producing more accurately positioned dipping and faulted planes. These methods preserve correct offset amplitude information, especially in far-offsets (McLain, 2013).

AVO attributes are calculated through a linear regression of a single sample’s amplitudes. If gathers are not flat, AVO attributes will have an inherit noise within them. Amplitude leakage from the intercept into the gradient is a common problem (Hermann and Cambois, 2001; Cambois, 2002). AVO attributes such as the ‘fluid factor’ may be reduced to the far-off stack (Cambois, 2002), it will also cause the gradient to be an order of magnitude noisier than the intercept (Whitcombe et al, 2004). Again, gathers need to be properly flattened to compensate for these affects. Some processing methods such as trim statics attempt to fix the litany of problems caused by residual and higher order move-out, vertical transverse isotropy (VTI) and horizontal transverse isotropy (HTI). There is difficulty and risk in trim statics, where some AVO anomalies like class 1 (figure 12) and 2P cases can be mis-aligned destroying their AVO response.

[Figure 12. Rutherford and Williams (1989) class 1 AVO signature in a synthetic gather (made using Geokinetics dTips software). This diagram shows the risk in the application of trim statics to possible subsurface responses.]

Continued on Page 24
In these types of AVO anomalies, it is apparent that aligning for a maximum energy there will be issues picking the correct velocities. In order to obtain optimal velocities for these classes, methods such as Automatic Continuous High Density High Resolution (ACHDHR) velocities like Swan’s velocities may be used. These velocities use a Residual Velocity Indicator (RVI), which is a real part of the intercept convolved with the gradient’s conjugate (Swan, 2001). Using RVI, velocity errors within the gradient are reduced, resulting in flatter gathers and better AVO attributes.

3) Deterministic Inversion – This inversion is constrained by the solutions of well models. Low frequencies are replaced by these well models in the inversion process. Deterministic inversions are averages of all possible non-unique stochastic inversions. Results from these inversion types can be used to estimate reservoir properties’ uncertainties. These uncertainties arise from a stochastic inversion’s statistical calculations. Uncertainty in lithology, porosity, and overall reservoir connectivity can be produced in the form of probability maps and volumetric measurements.

Attempting more than one type of inversion helps verify the validity of the rock properties produced. Having multiple forms of the properties allows for the use of a geostatistical neural net; an algorithm that predicts seismic attributes based on the correlation of reservoir properties to a targeted attribute. Ultimately, the goal of these predictive software solutions is to create numerous quantitative rock properties to aid seismic interpretation (figure 14), known as Quantitative Interpretation (QI). QI is the tying of multiple seismic data, various attributes, and conditioned geological or engineering data in a way that adds considerable value to the characterization of a reservoir. To perform QI, a set of reasonable questions should be in mind in order to identify the rock properties pertinent to a given reservoir (Hunt et al, 2012).

If these attributes successfully correlate to initial well log observations, an extrapolation to further attributes can be made. Neural nets allow for multiple inputs and iterations, substantiating derived rock properties such as density.

Seismic Inversion

Although many seismic surveys have data that is beyond a 45° angle of incidence, the data has to be correctly processed to have reliable near-offsets, far-offsets, and therefore seismic inversion. Different types of inversions will produce different solutions as there many combinations of p-wave, s-wave, and density values in the original seismic signal. This problem of non-uniqueness can be addressed through the comparison of different inversion results (figure 13), such as the following:

1) Relative Acoustic Impedance – This type of inversion is directly estimated from the seismic data, with no other inputs. It is fairly robust and is generally used in exploration scenarios where there is limited or no well control. Relative inversions are trendless vertically and laterally due to the lack of low frequency features inherit in the seismic data.

2) Stochastic Inversion – Stochastic inversion uses multiple solutions and statistically verifies them against production data and key measurements to calculate rock parameters.

Figure 13. A flow chart showing the appropriate inversion to use based on the amount of well control.

Figure 14. Diagram showing the attributes created by pre-stack inversion and how they can be manipulated to produce other attributes.
Conclusion

Initially, seismic should be acquired to have an appropriate amount of data at 0°-45° angle of incidence for a zone of interest. Next, processing methods need to maintain the truest primary signal for this set of data. Finally, inverting this seismic data multiple ways helps resolve the non-unique problem. Once multiple sets of rock properties and attributes are produced, neural nets can find specific combinations of these inputs to recreate targeted properties.

The aforementioned work not only identifies drilling locations, but can shape ongoing drilling and completions efforts, benefitting exploration and development. Reservoir models are improved integrating the geological, geophysical, and engineering disciplines.

Key elements such as completion and production information tend to not be included in geological and geophysical analysis. These efforts should be regularly fed back into interpretations to have an up-to-date model at all times (figure 15). Quantitative interpretation can become static, leading to potentially poor reservoir characterizations when moving to new drilling locations.

This type of work is routinely done in offshore environments due to the high costs of drilling wells. In a mature oil and gas area like the Western Canadian Sedimentary Basin, the cost of drilling and completing a well is relatively inexpensive. There is not necessarily a need to do the level of interpretation discussed in this paper. Seismic is sometimes dismissed as the amount of well control in Alberta is immense. However, this information can bolster seismic interpretations in such a way that should not be ignored. Through a similar workflow described in this introduction, seismic can be taken to another level, expanding a company’s economic possibilities through quantitative interpretation.

Figure 15. Flow chart illustrating how seismic interpretation brings together integrated interpretation system. Interpreters may focus only on the stacked volumes and none of the available information shown, data that can enhance any reservoir's characterization.
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As seismic interpretation continuously evolves, it seems that interpreters have not kept pace with technological innovation provided in commercial software: workflows may be more persistent than technologies. Despite having access to 3D seismic for close to three decades, the majority of an interpreter’s time is spent picking inline and crosslines profiles with the objective of making surfaces.

The aim of this paper is to make a snapshot of the current seismic interpretation practices commonly used, and to provide a possible alternative workflow that will allow geoscientists to spend their valuable time on interpreting the sub-surface rather than picking seismic. This workflow automates most of the otherwise tedious picking of the structural and stratigraphic information, and then converts the seismic and interpretation data into the chrono-stratigraphic domain, representing the theoretical time of deposition of the sediments. A useful application of this workflow is the prediction of fracture probabilities given geomechanical rock properties.

Geophysical interpretation history

Seismic data, and well log data, are used to develop an understanding of the earth’s interior. Such an understanding is generically termed a ‘model’ of the earth, or an ‘earth model’. Prior to the widespread use of computer workstations the geoscientist’s earth model was purely a 2D construction: plan view maps constructed from 2D profiles in the case of seismically derived ‘models’, and plan view maps and 2D cross sections derived from point data in the case of geologically derived models. 3D renditions of the model lived inside the heads of the geoscientists themselves; difficult to share amongst an asset team in the manner that a modern geo-cellular software model is shared.

Approaching three decades after the introduction and subsequent rapid improvement of 3D seismic data and workstation software the workflows remain largely two dimensional: correlate seismic data to logs; pick major reflectors on generally orthogonal sets of 2D profiles, generate surfaces. Then iterate with increasing attention to subtlety to reveal and map smaller features. Somewhere in the procedure time/depth conversion is undertaken. It is a legacy workflow familiar to geophysicists who started their careers working on 7.5 inch / second paper plots using a yellow pencil and a timing ruler – including one of the co-authors of this article. Workflows persist in part because the industry relies on experienced practitioners to mentor new graduates. The most influential period in any ‘journey’ is the beginning – the formative workflows learned in one’s early career are passed on across generations. While valuable and appropriate, this dynamic may fail to exploit the power of modern software, and may fail to position all workers to be effective in the face of rapid change.

The legacy workflow emphasizes the production of surfaces. Time structure surfaces are generated and used to build depth structure surfaces and isochron/isopach grids. Effort, time and ‘mindshare’ are typically focused on the generation of large surfaces – ones that are consistently mappable over large areas of the seismic survey area. Mapping the richness of geometrical and geomorphological information contained in aerially smaller reflections or reflection fragments tends to take a lower priority due to the time involved in more or less manually picking over the survey area. While effective for conventional hydrocarbon extraction projects, the legacy workflow may fall short when viewed in the context of the increasing demand for understanding heterogeneity imposed by so called ‘resource’ hydrocarbon extraction projects (typically scalable, repeatable, tight, impermeable and/or self-sourced).

An alternative workflow is proposed wherein automated reflection horizon tracking is used to pick a very large population of reflections, including reflections limited in area which we call stratigraphic trends. The geoscience team (geophysicist, geologist, geomorphologist) are able to spend more time, after appropriate quality check, interpreting the results; by which we mean they spend time extracting geological insight from the seismic data and the suite of ‘trends’ and capturing that insight in geological modeling software.
Automating the geophysical interpretation workflow

There are many workflows available to the interpreter to extract valuable subsurface insights. Geoscientists should take advantage of what can be automated (without compromising for interpretation quality) to allow time to be spent on what matters.

Starting from a seismic line or volume, thousands of seismic reflector patches can be automatically picked. Thousands of seeds are dropped at a user specified bin spacing and then snapped onto seismic reflectors (peaks, troughs or zero-crossings). Each seed point is then being used to auto-track patches following a seismic reflector. The workflow then automatically discards the patches that are too small to be relevant and merges the overlapping patches (Figure 1).

Automating the picking of seismic frees the geoscientist’s time for real interpretation: checking the validity of the trends extracted and making sense of them geologically. Working with thousands of trends means a lot of data to check. To quickly scan through them, the geoscientist can sort the trends by various attributes (size, location, chrono-stratigraphic age, dip, azimuth…).

A typical workflow usually starts with a first pass using sparse seed points to extract the main continuous events that can be interpreted as key seismic stratigraphic horizons. Then a second pass within each stratigraphic unit with a much higher density of seed points will extract most of the relevant stratigraphic trends (Figure 2).

Another part of the interpretation workflow is to extract faults. They can be interpreted using fault attributes of likelihood, strike and dip. The method used to compute these attributes is based on semblance (Taner and Koehler, 1969), and is therefore similar to methods proposed by Marfurt et al. (1998). Like Marfurt et al. (1999), semblances are computed from small numbers (3 in 2D, 9 in 3D) of adjacent seismic traces, after aligning those traces so that any coherent events are horizontal. The fault likelihood attribute is then scanned over multiple fault orientations in order to find the strike and dip angles that maximize the fault likelihood. When complete, the results of this scan are images of maximum fault likelihoods and corresponding fault strikes and dips (Hale, 2012) (Figure 3).

Faults surfaces can then be picked automatically or manually using the maximum fault likelihoods. A good way of identifying the faults surfaces to interpret is to display the seismic amplitude (gray scale), co-rendered with the fault likelihood attribute (bright color scale) and the thin fault-likelihood attribute (black intensity), with the stratigraphic trends (Figure 4). The trend terminations often line up with the high fault likelihood and therefore help the interpretation of fault surfaces.
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Figure 3. 3D view showing a crossline and a time section displaying seismic amplitude co-rendered with fault likelihood attributes (Netherlands Offshore F3 Block).

Figure 4. Cross-section showing stratigraphic trends automatically extracted from seismic with amplitude co-rendered with the maximum fault likelihoods attribute in the background (Northeast BC, Canada).

A particular advantage to a workflow involving semi-automatic extraction of faults, horizons and stratigraphic trends is that geoscientists are letting the data talk, while spending their valuable time checking the quality and validity of the automatically interpreted data.

But geoscientists should not stop at the interpretation of the faults, horizons and stratigraphic trends. Historical boundaries between interpretation and modeling are being erased with the implementation of full seismic interpretation tool kits within most major commercial geomodeling software. This offers the opportunity to model while interpreting. The challenge for geoscientists is to learn how to take advantage of this: traditionally, interpreters are not modelers, and modelers are not interpreters.

Fortunately the construction of 3D structural models has also been simplified. All the faults, horizons and stratigraphic trends extracted can be used to automatically build a fully sealed 3D structural model where the horizons are interpolated using geological rules that honor the stratigraphic column and associated layering structure, and are properly truncated against fault, salt, and erosion surfaces (Figure 5). This is done using the concept of space/time mathematical framework introduced by Mallet (2004, 2008). In this framework, the subsurface is curvilinearly parameterized by a uvt-transform which maps every \((x,y,z)\) point in the geological space to a \((u,v,t)\) point in the parametric space. The uvt-transform is computed such that an iso-\(t\) surface corresponds to a stratigraphic horizon and an iso-\(t\) is discontinuous across the faults (Labrunye et al., 2013).

A huge advantage for the interpreter is that the process automatically creates a full 3D chrono-stratigraphic time volume, where the data has been restored to the time of deposition. This means that the seismic volume is unfolded and unfaulted.

There are many applications to working in the chrono-stratigraphic domain. The first one is the ability to easily and quickly validate (and correct if necessary) the structural and stratigraphic interpretation. If all the faults and stratigraphic events have been picked correctly, then all the reflectors should be flat and no fault throw should be visible on the seismic in the chrono-stratigraphic domain (Figure 6).

The chrono-stratigraphic domain is also useful to facilitate the interpretation of geomorphologic features as discussed by Dulac (2011), Labrunye et al. (2013) and Thenin et al (2013). Another novel application of the conversion of a seismic volume to the chrono-stratigraphic domain is the estimation of fracture probability.
Application to shale and tight reservoirs exploration

Most geophysical studies in unconventional gas rely on inversion techniques and simple structural attributes to characterize the natural fractures of reservoirs. These studies tend to overlook the structural and stratigraphic information embedded in 2D and 3D seismic data and do not typically use geomechanical data as input.

The 3D structural model derived from the seismic interpretation can be converted into a 3D geological grid without loss of structural or stratigraphic information. The geological grid represents the final state of deformation that took place between the time of deposition of the horizons (chrono-stratigraphic domain) and today (geological space). A one step structural restoration to the state of deposition, before all the deformations, is done assuming the horizons are deposited horizontally and given the location of each part of the geological grid truncated by the faults.

The dilatation is computed on the geologic grid using the uvt-transform previously defined and the geomechanical parameters of the rock. The dilatation takes into account the sum of deformations from the time of deposition (state without deformation) to now (state which has registered all the deformations of the field). It is computed as (Volume of the actual time – Volume at time of deposition) / (Volume at time of deposition). This gives local information on the type of deformation the structure has undergone (compression where dilatation is negative and extension where dilatation is positive) with the sum of deformations of the field (Prieto-Ubaldo et al., 2014).

The uvt-transform links both the geological grid at time of deposition (chrono-stratigraphic domain) and the geological grid at present state (geological space) which has undergone the sum of all deformations which have affected the field. The vector of displacement for each grid cell between the moment of deposition and present is consequently known and allows the computation of a strain tensor. The stress tensor is computed from the strain tensor using Hooke’s law and the Lame’s parameters (computed from the Poisson ratio and the Young modulus). The sensitivity of the rock material to the fractures can be assessed through a failure criterion, like the Mohr-Coulomb criterion (using Mohr-Coulomb cohesion and friction angle parameters). Ranges of geomechanical parameters values are used in order to take into account their uncertainties, allowing

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**Figure 5.** 3D structural model automatically built using faults, horizons and stratigraphic trends interpreted from seismic (Netherlands Offshore F3 Block).

**Figure 6.** Cross-section showing seismic amplitude with interpreted horizons and faults in the depth domain (left) and in the chrono-stratigraphic domain (right) (Dulac, 2011).
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the computation of a fracture probability (Mace, 2004) (Figure 7). The fracture probability estimation is assuming that the natural fractures present in the reservoir have been created by the deformation which produced the faults and folds (structural deformation) of the study area.

This fracture characterization workflow has been applied as a sweet spotting technique in prospective shale formations in Northeast BC, Canada (Figure 8).

The fault and fracture attributes prediction should then be cross-validated at the wells with the available natural fracture information (from core description and FMI interpretation), the initial production volumes and the fracking related information (stimulation interval, volume of injection, microseismic).

Figure 7. Probabilistic mechanical rock properties estimation (Mace, 2004).

Figure 8. Map of fracture probability within a prospective shale formation (Northeast BC, Canada). The faults are displayed as colored lines.

Conclusions

Automating the seismic interpretation and coupling it with the 3D structural modeling workflow enables geoscientists to extract as much structural and stratigraphic information as possible from seismic amplitude data and to work in the chrono-stratigraphic domain.

In addition to being useful to validate the interpretation, the chrono-stratigraphic domain provides new applications to geoscientists to help better characterize the sub-surface. An important one is the ability to characterize natural fractures stratigraphically. This has proven a valuable sweet spotting tool for shale gas exploration in Northeast BC. This natural fracture characterization workflow provides several advantages compared with traditional seismic characterization workflows. It helps reducing project cycle time by automating the otherwise tedious interpretation of faults and horizons from seismic and it does not rely on pre-stack inversion.
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References


A mechanical earth model (or "MEM") is a fundamental tool for considering the relationships between stress, strength and elastic properties of unconventional resources. The ultimate aim of these MEM’s is to aid the targeting of producible “sweet spots” so that an intelligent stimulation plan can be developed that leads to efficient lateral fracture growth, enabling economic production.

Methods that focus on a single parameter, such as Brittleness Index, to model these sweet spots may not necessarily yield optimal results. The reason for this is that multi-variant factors such as variability in total organic content (TOC), varying clay volume and mineralogy, variation in temperature (both present day and in the palaeo-history) and natural fracture patterns and permeability, all act to control/influence the presence of sweet spots (as well as their producibility), not just a single factor.

There are many different methods to create empirical and numerical mechanical earth models, however, empirical well-centric analyses are key to constraining interrelated criteria that can be used to map unconventional reservoir properties such as fracture gradient, kerogen porosity or directional permeability. In order to construct a successful MEM, therefore, these parameters, broadly classified here in this paper into pore pressure, rock physics and geomechanical properties, have to be determined as accurately as possible. This paper reviews how this is or can be achieved.

Introduction

An unconventional reservoir is one that cannot be produced at economic flow rates or that does not produce economic volumes of hydrocarbons without assistance from stimulation treatments or special recovery processes and technologies, such as steam injection (Naik, 2004). Typical unconventional reservoirs are tight-gas sands, coal-bed methane, liquid-rich gas shales and heavy oil deposits. For instance, economical production of gas shales requires enhancement of the inherently low matrix permeability (<0.001 D or 1 mD) of these reservoirs (Hill and Nelson, 2000). Likewise, the gas-bearing formations of the Bossier and Haynesville shales are very tight shale gas plays with extremely low matrix permeability (0.00007- 0.0007 mD) (Zhang and Wieseneck, 2011). Other examples include the Marcellus and Huron shales where permeability is 10-2 to 10-7 mD (Soeder, 1988). Well completion practices employ hydraulic fracturing technology to try to access the natural fracture system and to create new fractures. There are two potential approaches to optimize unconventional reservoir development; a “Manufacture” approach and a “GeoPrediction” approach.

(i) The “Manufacture” approach involves drilling many hundreds of wells as cheaply as possible and assuming that the unconventional reservoir quality is uniform across the play. Pattern drilling and uniform “stimulation” methods are utilised while keeping each well and perforation identical; well orientations and horizontal lengths are kept the same as are pump pressures and the amount of fluid.

Figure 1, from the Haynesville play, would suggest that a small number of wells provide the majority of production. The reason for this is that reservoir quality is not continuous across this play but that in fact there are "sweet spots" controlled by depositional porosity, natural fractures and pore pressure. Brittleness Index is a calculated property based on various strength and elastic properties of rocks which has been defined differently by multiple authors for use in identifying sweet spots. Although this approach has been taken up by many...
looking to improve the efficiency of hydraulic fracture operations, it has had limited success and implies that rock properties alone are not the answer. The implication of this observation is that a significant portion of the cost of drilling is being spent on inefficient wells. For example, typical well costs to drill and complete a vertical well in the Cardium play in Alberta, Canada, typically range from CAD$1-$5 million. This cost can triple when the new plays in North-East British Columbia, e.g. Horn River Shale, are explored. Therefore, the cost of an inefficient well is far greater than the expenditure to perform smarter pre-drill analysis that integrates multiple geoscience disciplines, i.e. a “GeoPrediction” approach. At a smaller scale the same is true; a small percentage of the stimulated fractures produce almost all of the gas and therefore the rock quality is clearly not purely uniform.

(ii) The “GeoPrediction” approach, discussed in this paper, is based on understanding the processes at play and determining how to be selective in how you drill and fracture wells to optimize the gas recovery / cost ratio through a) identification of reservoir quality, b) avoiding drilling hazards, c) intelligent hydraulic fracturing and d) reducing environmental risk and impact. Figure 2 shows that correct understanding of fracture orientation and permeability can reduce the number of fracture events needed.

The solution to this “GeoPrediction” approach lies in defining a Mechanical Earth Model (or “MEM”) which is a representation of the rock properties, geopressure and stress distributions within the crust. Each of these elements are interdependent and a change in one can impact the other two. An integrated multi-disciplinary approach to model each of these accurately will permit better assessment of the following issues:

- Unconventional rock property analysis of borehole data;
- Multi-scale property calibration of static and dynamic property measurements;
- Reservoir quality assessment for sweet spot identification;
- Finding high pressure and thus enhanced porosity areas;
- Finding and evaluating natural fractures and directional permeability;
- Optimally intersecting natural fracture populations;
- Avoiding kicks due to overpressure, wellbore collapse, loss of drilling fluid;
- Optimising hydraulic fracturing and well completion operations;
- Understanding growth of hydraulic fracture azimuth and fracture containment.

**Methodology**

The following discussion has been broadly split into three sections on each of the main inputs to an MEM; pore pressure, rock physics and geomechanics. It should be noted that the same factor, e.g. TOC, may regularly influence more than one input discipline. As well as the three factors discussed, care should be taken to understand the geological regime in which the play is located as this affects the input property model. Published reviews such as Zhang and Wieseneck (2011), Li et al. (2012), Couzens-Shultz et al. (2013) and O’Connor et al. (2014) mention the importance of understanding the geology of unconventional plays, including the impact that burial and uplift history has. Also highlighted in some of the above studies is the importance of understanding variations in shale lithofacies, their constituents and their influences on log/seismic response. An example is shown below in Figure 3 where there is a wide variability of mineralogy, pore shape and distribution of total organic content (TOC) in resource shales (Miller, 2011). The majority of the geological influences on the MEM inputs are captured in the following discussion.

**Pore Pressure**

Pore pressure prediction uses wireline log data as a proxy for porosity and uses the assumption that a porosity-effective stress relationship exists such that porosity can be directly related to pore pressure. Unconventional plays are typically low porosity (inferring low pore pressure) due to a range of diagenetic (temperature, time and chemical) processes yet may retain high pressure.

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Furthermore, the link between pore pressure and log response may be disrupted due to the presence of organic material (high TOC). A variation in TOC is shown to significantly lower the magnitudes of velocity and density (Passey et al., 1990). Slow velocity and low density are typically attributed to an increase in pore pressure so this effect needs to be removed from log data in order to correctly predict pore pressure; high pore pressure can lead to “sweet spot” preservation and hydraulic fracturing that can enhance production without the need for artificial stimulation.

High TOC also, of course, makes for a richer source rock which is desirable. Interestingly work by Carcione and Helle (2002) suggest that the type of overpressure generation can influence both layer (AI, GI) and interface (AVO) responses. Overpressure with undercompaction (also known as disequilibrium compaction) gives brighter amplitudes and reduced AVO gradient, whereas pore pressure generated by unloading (fluid expansion, e.g. gas generation) dims reflections and increases AVO gradient. In a TOC-rich source rock, gas generation would be increased (if the appropriate macerals were present) thus the latter process may be more dominant. The presence of these mechanisms can be detected using rock physics models such as Vp/Rho cross-plotting (Bowers, 1995; Swarbrick et al., 2012). The effect of gas on the Vp log can be removed either using modified Biot-Gassmann or Kuster-Toksoz relationships (Lee, 2008) or via calibrated Vs logs in plays with non-viscous fluids.

Variation in clay content (smectite, illite, and kaolinite) would affect the magnitude of pore pressure as well as how the shales respond to the associated changes in effective stress and compaction. This influence has been highlighted in Yang and Aplin (2005), as well as in a recent paper by Bjorlykke (2014) where work by Mondol et al. (2007) shows that at an effective stress (presumed to be the vertical effective stress; vertical stress minus the pore pressure) of 20MPa at a depth of 2km, smectite clays have 40% porosity compared to kaolinitic clays which have 20% porosity. Katahara (2007) utilised Gulf of Mexico shales to demonstrate other rock physics approaches, i.e. CNL/Rho cross-plots, to determine shale lithofacies. A secondary, although important use, is to sense-check deviations on Vp/Rho plots to determine if these are due to varying overpressure mechanisms or, in fact, lithology changes due to increasing/decreasing clay percentage, either through variation in sediment provenance or through diagenesis.

If the shales have ever reached elevated temperatures, typically > 100 °C, they may enter the zone of chemical compaction whereby processes such as organic maturation and clay diagenesis will produce water, silica, oil and gas and other reactive components (e.g., Na, Mg and Fe ions). It should be noted that these processes are irreversible hence it is important to understand the palaeo-temperature history of the play and not just the present day temperatures. Porosity will reduce to approximately 5% and is no longer related to effective stress and therefore no longer related to pore pressure. Overpressure will increase, and effective stress reduces at low porosity. Eaton (1975) and Equivalent Depth methods will under-predict pore pressure if the same compaction model is used as for the cooler sediments. The pore pressure can increase due to processes such as fluid expansion and load transfer (where rock compressibility is compromised). Useful reviews of overpressure mechanisms are contained within Swarbrick and Osborne (1998), Swarbrick et al., (2002) and Lahann and Swarbrick (2011).

The importance of understanding the geology of these plays, particularly the impact that burial and uplift history was stressed above. Knowledge of shale lithofacies including porosity/permeability and TOC characteristics/content will be invaluable in determining whether the pore pressure returns to hydrostatic prior to subsequent re-burial for example. The changes in effective stress directly relate to rock physics models used as part of an MEM. A period of uplift (or perhaps a period of non-deposition; a hiatus) is often associated with these unconventional plays (although it is important to stress, not always). If an unconformity occurs (observed from missing biostratigraphic zones on composite log data), then overpressure will have begun to dissipate during the unconformity. The rate of pressure escape can be modelled using data described in Deming (1994) and He and Corrigan (1995), for instance, whereby seal thickness, permeability and time affect how shales can maintain pressure (Figure 4). In this figure, the lowest published permeability data for a selection of unconventional plays has been superimposed. The implication is that even at the low permeability present in these plays, pressure will revert to hydrostatic in 1 Ma unless gas generation and expansion occurs (or seals are very thick).

**Rock Physics**

Unconventional rock-physics-based “GeoPrediction” is a time- and resource-effective approach, compatible with the fast turnaround of unconventional drilling schedules. Rock physics, defined as the link between the geological knowledge from wells, fluids and organic material present in formation pore spaces and their intrinsic seismic signatures, provides valuable technical insight on independent physical rock properties. These properties are used to predict elastic, geomechanical and related geological conditions.
Continued on Page 40

In order to identify unconventional sweet spots with the best reservoir quality (e.g. Davie et al. 2012) the following steps are necessary:

- Identify mineralogy and lithofacies from core data (XRD, thin sections);
- Determine pore content and TOC volume from and core and calibrated logs;
- Estimating TOC thermal maturity of organic-rich facies from petrophysical logs;
- Determine the relationship between elastic properties and facies;
- Underpin rock physics models by developing a geological model taking into account pressure generation, shale diagenesis, and their effect on porosity preservation; and
- Quantitatively interpret most-likely indicators of reservoir quality at sweet spots, using models constructed from calibrated seismic elastic and mechanical properties representative of changes in facies, TOC, and pore type/shape.

Additional subsurface characteristics must be considered to calculate an optimal fracture placement that results in strong initial production and sustained flow. This includes understanding the natural fracture populations (Downton, 2014) as well as the ability to initiate productive new fractures. The latter is related to the geomechanical strength of the reservoir and the surrounding formations, and these properties are mapped through their relationship to elastic logs. Rock physics assessments explain observed variations in elastic properties in terms of constituent components, and relate them to properties that can be mapped extensively through 3D seismic. An example of this is shown in Figure 6 where clay content is seen to control the Vp/Vs ratio and hence Poisson’s ratio, which impact in-situ stress and strength. Alternate parameterizations are possible, such as the LMR approach of Close et al. 2012.

Figure 7 shows an example of the use of elastic properties at seismic scale (10^2 m) to characterize tight reservoir properties at log scale (10^-1 m). Limestone-rich facies show a marginal PDF distribution of porosities if compared to dolomite-rich facies, due to secondary
Continued from Page 39

porosity developed over the limestone-rich interval, as interpreted from elastic properties assessed geostatically at seismic scale. Note that dolomite-rich facies, considered as the main target of this tight reservoir, exhibit a scattered distribution of high porosities consistent with the rock physics model at log scale; this multi-scale result is used to assess optimal well path design leveraging high in-situ porosities (and permeabilities) along reservoir facies.

Geomechanics

Burial history as well as lithology of sediments dictates their stress history. For instance, in fractured basement reservoirs, brittle rocks host more fractures than non-brittle or ductile rocks. The primary controlling factors are rock type, grain size, cementation, porosity, temperature and the effective confining pressure (Stearns and Friedman, 1972). Natural fracture patterns are reflected by the local in-situ stress state and rock properties at the time of fracturing. In Figure 8, from the Cooper Basin, Australia, an example of Natural Fracture Network characterisation is demonstrated. Depending on fracture orientation, permeability will vary. Permeability is the function of effective pressure (effective stress); \( K = f(P_e) \). As an example, monitoring wells from the White Tiger field in Cuu Long Basin, Vietnam it was observed that increasing the effective pressure \( P_e \) to 400at, the fracture permeability \( K \) would reduce from 95-97% to 60% due to rock properties (Huy et al., 2008). Stress changes, also influence pore pressure. Vertical and horizontal stress increases result in overpressure in normally or unconsolidated, undrained low-permeability sediments; overpressure due to tectonic stresses can be far higher in these situations than that generated purely by rapid sedimentary loading and can be problematic to detect as there can be no associated porosity anomaly (Yassir and Addis, 2002).

Traditional permeability is partly controlled by the effective stress and, as mentioned above, this is typically the vertical effective stress. It is worth noting that geopressure and geomechanics disciplines use the term “effective stress” whereas the same parameter is often referred to as “effective pressure” within rock physics; within this paper we use the term “effective stress”. In unconventional plays, permeability is realised through either natural or artificial fractures.

Network characterisation is demonstrated. Depending on fracture orientation, permeability will vary. Permeability is the function of effective pressure (effective stress); \( K = f(P_e) \). As an example, monitoring wells from the White Tiger field in Cuu Long Basin, Vietnam it was observed that increasing the effective pressure \( P_e \) to 400at, the fracture permeability \( K \) would reduce from 95-97% to 60% due to rock properties (Huy et al., 2008). Stress changes, also influence pore pressure. Vertical and horizontal stress increases result in overpressure in normally or unconsolidated, undrained low-permeability sediments; overpressure due to tectonic stresses can be far higher in these situations than that generated purely by rapid sedimentary loading and can be problematic to detect as there can be no associated porosity anomaly (Yassir and Addis, 2002).

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An intelligent stimulation plan leads to improved fracture placement to facilitate fracture growth, connectivity to natural structural elements and constraint within the target resource layer enabling economic production and avoiding loss of hydrocarbons due to out-of-zone fracture growth.

Natural fracture populations and orientations can be characterized using image log analysis and geomechanically assessed to better understand their behaviour with respect to hydraulic fracturing. This is done using the technique described by Mildren et al. (2005) which determines a pressure change (ΔP) required to initiate failure for any particular fracture surface with a defined strength in a particular stress field. This measurement can provide a relative permeability ranking of all fracture orientations in that stress environment, i.e. how far from failure a fracture plane is within the applied stress field. Low ΔP means a greater likelihood of permeability which corresponds with risk of failure.

Brittleness index (BI) is a commonly used property when assessing properties only.

A Mohr Circle diagram is a visual representation of effective principal stresses and can be combined with a failure envelope representative to the strength of the material (rock, fracture, fault etc.) under consideration. The relationship between the Mohr Circle and the failure envelope depicts the occurrence of brittle failure, the orientation of failure and the mode of failure (tensile, shear or mixed-mode). Various failure criterion can be used, however, for the purposes of this paper the Coulomb failure criterion have been implemented. Failure is represented on a Mohr Circle diagram as the point where the Mohr circle intersects the failure envelope. An increase in pressure, decreasing the effective stress, is reflected on a Mohr diagram by shifting the Mohr Circle to the left towards failure. Resolving the principal stresses acting on a fracture surface permits it to be plotted within the Mohr diagram using shear and normal stress coordinates. The pressure change required to initiate failure and the relevant failure mode can therefore be determined. The advantage of this approach is that effective stresses are used in conjunction with rock properties to assess structural permeability whereas Brittleness Index is limited to rock properties only.

Brittleness index (BI) is a commonly used property when assessing unconventional resources and generally it is defined as a measure of the ease by which the rock can be fractured based on its total organic content, i.e. less TOC implies a more brittle material and therefore greater ability to be fractured. In this manner, it has been used as an indicator of suitability for hydraulic stimulation and a tool to map permeability “sweet spots”. There exist multiple ways to define brittleness index and most commonly include a term for compressive (σ_c) and tensile (σ_t) strength (Altindag, 2003). These algorithms are indicative of the “shape” or slope of a failure envelope and are related to rock strength, rather than the preference for brittle deformation. More importantly, this measurement remains independent of the stress distribution and therefore not necessarily a clear indicator of fracture likelihood.

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The likelihood of failure/fracturing can be the same independent of the Brittleness Index if the stress distribution is appropriate (Figure 9). Used in isolation independent of the stress conditions, brittleness itself is unreliable. Improved criteria can be derived from evaluating the relationship between strength and stress which is more indicative of failure and therefore more closely related to natural permeability and improved production. Furthermore, an independent means of estimating organic content should be used to consider the likelihood of brittle or ductile deformation.

1D geomechanical models are commonly borehole-centric creations based on empirical data. Most of the data used to constrain MEMs come from existing wells (wireline, image log and drilling data) and laboratory tests of core/cuttings material. Where additional offset data are available, a wireline-based rock physics model can be used to generate compressional and shear velocities where none exist. Similarly, input properties could also be generated from seismic for model construction. Once offset 1D mechanical earth models have been constructed, spatial interpolation for predictive geomechanical assessment can be performed using a range of methods that fall within three categories; non-geostatistical methods, geostatistical methods and combined methods (Li and Heap, 2008). Seismic data can be used to guide interpolation of wireline data or, through inversion for density, shear and compressional velocities, form the basis for calculating stress magnitudes to create a 3D geomechanical model (e.g. Goodway et. al., 2012). Static property models derived through these methods can be used to construct property models for dynamic modelling of stresses and fluid pressures using numerical methods which can be projected through time. In all cases, stress, strength and elastic property based criteria can be applied to these models to identify permeability sweet spots.

Case Study

An unconventional borehole-centric dataset is used to demonstrate the use of multiple criteria to identify permeability zones. Figure 10 illustrates an empirical 1D geomechanical model for Cow Lagoon-1 located within the McArthur Basin, Northern Territory, Australia which was drilled by Armour Energy in 2012 to assess the unconventional prospectivity of the Batten Trough. Contemporary horizontal stress magnitudes vary considerably with depth and stress regimes range between strike-slip and extension within formations with differing elastic properties. This distribution of stress demonstrates the poroelastic effect expected in a high strain environment with low Youngs Modulus units correlating with low differential stress and high differential stress associated with high Youngs Modulus units. Stress, strength and elastic properties were analysed to identify relationships that correlate with natural fractures and documented hydrocarbon shows (Figure 11). Target horizons in the Batten Trough are characterised by low Young’s Modulus, low differential and low effective stresses and correspond with the following criteria: differential stress between 5 and 13.5 MPa, Youngs Modulus between 25 and 74 GPa and strength ratio (So/T) less than 3 (Figure 12).
Figure 11. Cross-plots of differential stress (σ1-σ3) versus Youngs Modulus (E), coloured with respect to strength ratio (So/T) for (a) the complete data interval and (b) data that meets the criteria that match natural fracture occurrence and hydrocarbon shows (see text).

Figure 12. Depth intervals (in green) that correspond with data that matches elastic property, stress and strength criteria. Note that intervals corresponding with natural fracturing and hydrocarbon shows (red squares) observed in the Lynott Formation and Reward Dolomite do not correspond with drilling related fracturing within the Coxco, Teena and Mitchel Yard Dolomites.

Michel Kemper

is a petroleum engineer with 26 years experience in Geophysics, Petrophysics and Reservoir Engineering. The first 13 years were spent with Shell International in The Hague, Nigeria and London, during which time Michel made contributions to the interface between Petrophysics and Geophysics.

In May 1999 he became team leader Petrophysics/ Petroacoustics at Ikoda Limited, working on a wide variety of projects. It is during this time that RokDoc – now one of Ikon Science’s main products – was started. One of the co-founders of Ikon Science, he is now responsible for the incorporation of latest techniques and developments in the area of rock physics, seismic inversion and (numerical) earth modelling in the Ikon Science software portfolio.

Cristian Malaver

has over 18 years’ experience in the oil and gas industry in Quantitative Interpretation and working knowledge in reservoir geophysics and rock physics. He has significant oil company experience with exploration and development projects across the 5 continents while holding geophysical positions at Oxy, ConocoPhillips, El Paso, Cepsa and BHP Billiton. He has also worked as a geophysical consultant and geosciences manager with reservoir characterization and geophysical operations groups based in Europe, Middle East, and South America. As a research geophysicist, he integrated rock physics and seismic analysis methodologies using petrophysical data and 4D/3C seismic inversions to characterize and monitor carbon capture and storage in depleted mixed reservoirs.

Cristian brings a strong background in QI technology excellence and innovation with broad expertise covering the entire E&P cycle around the globe. He holds a M.Sc. degree in Geophysical Engineering from Colorado School of Mines and a B.Sc. in Engineering from the Universidad de los Andes.

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These criteria can be applied to a 3D mechanical earth model to map locations with matching characteristics that include a greater potential for production based on the presence of permeable natural fracture populations with stress and strength conditions conducive to stimulation.

Conclusions

In unconventional plays the ultimate aim is to target permeability “sweet spots” and then develop an intelligent stimulation plan. This leads to an efficient lateral fracture growth, within the resource layer, enabling optimal economic production and recovery. There has been a tendency to develop or rely on methods that focus on a single parameter such as Brittleness Index as a way to high grade acreage for development.

Brittleness index (BI) is a commonly used property when assessing “sweet pots” locations but this measurement remains independent of the stress distribution and therefore not necessarily a clear indicator of fracture likelihood. A Mohr-Coulomb diagram is a better representation of stress and strength. It is the relationship between the Mohr Circle and the failure envelope that describes brittle failure occurrence, the orientation of failure and the mode of failure. Further, stress is a function of pore pressure as well as the properties of rocks, whether carbonate, sand or shale.

Hence, any models developed for exploitation of unconventional plays should include parameters that, broadly speaking, can be linked together under the groupings of rock physics, pore pressure and geomechanics. Many geological factors present in most unconventional plays can have a significant impact on the derivation of accurate pore pressure, rock physics and geomechanical inputs into a successful model; these include:

- An increase in TOC is shown to significantly lower the magnitudes of velocity and density which may lead to erroneous pore pressure and elastic rock property responses. Conversely, a lower TOC leads to a more brittle rock often considered a positive when placing wells and designing fracture stimulations.
- A variation in clay content would affect the magnitude of pore pressure as well as Vp/Vs ratio and Poisson’s ratio.
- Elevated temperatures promote clay diagenesis changing the rock framework, affecting factors such as clay mineralogy, hydrocarbon saturation, reactive components, compressibility, porosity, AI and permeability.
- Natural fracture patterns are reflected by the local in-situ stress state at the time of fracturing. Stress directions can be inferred from image log analysis. The order in which fractures are stimulated can affect their size and maximise reservoir contact from each stage of hydraulic fracturing.

Thus, in conclusion, we propose that the most robust model that can be developed to optimise these unconventional plays is an integrated mechanical earth model (or “MEM”). This is a fundamental tool for considering the relationships between stress, strength and elastic properties of unconventional resources. There are many different methods to create empirical and numerical mechanical earth models, however, empirical well-centric analyses are key to constraining inter-related criteria that can be used to map unconventional reservoir properties such as fracture gradient, kerogen porosity, or directional permeability. These parameters can determined from the property model and the pore pressure which are obtained from inverted seismic data to model in multi-dimensions.

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OFFSHORE EAST COAST: MODEL-BASED WATER-LAYER DEMULTIPLE BREATHES NEW LIFE INTO OLD DATA

Keith Wilkinson and Richard Bale, Key Seismic Solutions Ltd.

This article describes recent development and application of a model-based water-layer demultiple technique. We discuss some application details such as the water-bottom Green’s function and the necessity of a two-step prediction to handle both shot-side and receiver-side multiples. This method is tested using a finite difference synthetic dataset and then applied to two different 2-D marine lines from offshore East Coast of Canada.

Introduction

A recently announced discovery has brought renewed attention to the potential reserves in the Canadian Atlantic waters, complementing the huge reserves onshore in the Western Canadian Sedimentary Basin. According to Reuters “Statoil said its Bay du Nord find, around 500 kilometers (300 miles) northeast of St. John, could contain between 300 million and 600 million barrels of recoverable oil.” (Sep 26, 2013).

This is therefore an opportune time to take a look at one of the key issues for making best use of seismic data when mapping these reservoirs: the attenuation of problematic water-layer multiple energy. The variation in water depth from a few 10s of metres to several 100 metres poses a special challenge, as not all multiple attenuation methods work equally well in these different situations.

Surface Related Multiple Elimination or SRME (Verschuur et al., 1992) has become the de facto standard for marine demultiple. SRME is based on the prediction of multiples by convolving the data with successive estimates of the primaries in a recursive estimation procedure. It has been demonstrated repeatedly to be effective for both 2-D and 3-D multiple attenuation, in moderate to deep water. However, it is well recognized that SRME can struggle with shallow water multiples, especially in the presence of a hard water bottom. The main reason for this is that these water-layer multiples can have significant amplitudes up to high orders, where the “order” of a multiple refers to the number of downward bounces from the sea surface. The peg-leg multiples from deeper events often lie close to water-layer and shallow peg-leg multiples of high order, that are relatively over-predicted by SRME. This leads to the failure of any adaptive subtraction procedure to simultaneously match all orders of multiple. Moreover, accurate prediction of the water-layer multiples, requires primary energy at very near offsets which are typically not recorded.

For this reason a new breed of demultiple algorithms has been developed for shallow water, known variously as: “Deterministic Water-layer Demultiple”, or DWD (Moore and Bisley, 2006); “Model-based Water-layer Demultiple”, or MWD (Wang et al., 2011); and “Shallow Water Demultiple”, or SWD (Wang et al., 2012; Yang and Hung, 2012). We prefer the abbreviation MWD, though care is needed to avoid confusion with another MWD: “Measurement while drilling”! In this article, we review the principles of MWD and report on our implementation of an MWD method based on diffraction modelling for the water bottom Green’s function. We demonstrate the application of MWD using a synthetic dataset and then using two different East Coast 2-D marine lines.

What is MWD?

![Types of free-surface multiple.](image)

Figure 1 illustrates two different types of free-surface multiple. On the left is a water-layer multiple which is defined to be one which has at least one upwards bounce at the water bottom and one downward bounce at the surface. It is a special case of the more general free-surface multiple, which may or may not include an upward bounce at the water bottom. SRME addresses both of these types of multiples, but with limitations as outlined above. MWD on the other hand only seeks to attack the water-layer multiples and defers the remaining free-surface multiples for subsequent attenuation by an SRME type approach.
In Figure 2, we show two different orders of water-layer multiple. Each is constructed by combining the water layer Green’s function (shown in red) with a general ray-path (shown in blue), which represents events in the recorded data. Any higher order water-layer multiples will be predicted by the Green’s function applied on the previous order multiple which exists in the data. All orders of water-layer multiple are thus predicted by operating on the data with the Green’s function. The prediction may then be subtracted from the data to obtain a water-layer multiple-free record. Note that shot-side and receiver-side multiples have to be separately dealt with, a topic we return to below.

We have used terms rather loosely above such as “constructed” and “Green’s function”. We will now expand a little on what this means, describing it for the shot-side multiple removal. Similar to SRME, the MWD method relies upon cross-convolution, in this case cross-convolution of the water-bottom Green’s function with the data. The Green’s function used is the wavefield recorded at various points on the surface due to an impulse generated at the shot, with reflection from only the water bottom. Various methods are possible for generating the Green’s function. For example, Wang et al. (2011) make use of wave-equation extrapolation operators. Our method uses diffraction-based modelling of the Green’s function from the interpreted seafloor.

Given any input trace with shot position S and receiver position R, the water-layer multiples are then predicted by convolving the Green’s function from shot position S and receiver position X with the data from shot position X and receiver position R, where X is the downward reflection point (DRP) for the multiple. This is repeated for all sensible positions of X (based on aperture considerations), and the results are summed to produce our multiple estimate. This is illustrated for two such DRPs, X₁ and X₂, in Figure 3. Note that in Figure 3, position X₂ would correspond to a non-specular downward reflection for this relatively flat geology. However, this cannot be known a priori, and it might correspond to a specular reflection for some other dipping reflector. The MWD method relies on Fermat’s principle, such that the summation will naturally select the specular events by constructive interference and remove others by destructive interference.

For 2-D, the above multiple prediction is mathematically formulated in the frequency domain, \( \omega \), by the following equations, where \( s, r, x \) are coordinates for the shot, receiver and DRP respectively, \( D \) is the input data, \( Gwb \) is the water-bottom Green’s function, \( M_{sht/rec} \) are the shot and receiver side multiple estimates, and \( D_{nw} \) is the estimated data with no water-layer multiples:

\[
M_{sht}(s, r, \omega) = -\int_{-\infty}^{\infty} D(s, x, \omega)Gwb(x, r, \omega) dx \\
D_{sht}(s, r, \omega) = D(s, r, \omega) - M_{sht}(s, r, \omega) 
\]

for the receiver side, followed by,

\[
M_{rec}(s, r, \omega) = -\int_{-\infty}^{\infty} Gwb(x, x, \omega)D_{sht}(x, r, \omega) dx \\
D_{rec}(s, r, \omega) = D_{sht}(s, r, \omega) - M_{rec}(s, r, \omega) 
\]

for the shot side. Here \( D_{sht} \) is an intermediate result in which only receiver side multiples have been accounted for. It is important to use \( D_{sht} \) to predict the shot-side multiples rather than \( D \), as use of \( D \) would result in the double prediction of any multiples which have both a shot and a receiver-side peg-leg.

This separation into shot-side and receiver-side operations is not widely discussed in the literature (an exception is Jin and Wang, 2012). However, as shown below, it is absolutely necessary in situations where the seafloor has structure.
**Modelled Data Example**

Figure 4 shows the model we have used for testing the MWD algorithm. Finite difference modelling was performed by a client, who provided us with the synthetic data. We particularly want to focus attention on the challenge posed by the rugose part of the water bottom from about 4km to 8km lateral position. The variation in water depth implies that shot-side and receiver-side peg-leg multiples are not spatially coincident, and require the two step methodology outlined above.

Figure 5 shows a stack of the modelled data before and after application of MWD. The area shown within the blue rectangle is considered in greater detail in Figure 6, which shows a constant offset section from the data (offset = 587.5m) and illustrates the steps of the MWD procedure. We focus attention on the reflection at a depth of 1.5km, for which the primary appears at about 1.8 seconds in Figure 6. The first order peg-leg multiples appear on the input data (6a) as two separate overlapping arrivals (at about 1.9 seconds) which have different imprints from the variable sea floor geometry above. One of these is predicted during the first step, the receiver-side demultiple in 6(b), whereas the second is only predicted in the second step, the shot-side demultiple in 6(c) (note that 6c includes the results from both shot-side and receiver-side prediction). Likewise for the three 2nd order peg-leg multiples (at about 2.0 seconds): two of them are predicted in the first step in 6(b), (because they both have receiver side peg-leg components), but the third is not predicted until the second step in 6(c). Finally we subtract the full set of multiples to obtain an estimate of the primary only data in Figure 6(d). The key point to note is that application of the Green’s function by convolution on either shot or receiver side cannot predict a multiple unless it has a water layer bounce on that side. Of the multiples identified here, only the symmetric 2nd order multiple can be predicted by either a receiver-side first or a shot-side first approach. In Figure 6, it is predicted by the receiver-side demultiple, simply because that is the first one applied.

Returning briefly to Figure 5, the observant reader may have noticed a faint event below 3 seconds, which appears to resemble a mirror of the water bottom. This event is also a multiple, but not a free surface multiple. It arises from energy reflected from the interface at 1.5km depth, which hits the water bottom from below and bounces downwards before a second upward reflection. It is indeed a mirror image of the water bottom, with the event at 1.5km acting as the mirror! This multiple is a technically an internal multiple and would need the application of an internal multiple attenuation to remove it, beyond the scope of this article.

![Figure 4](image_url)  
**Figure 4.** Depth model for synthetic.

![Figure 5](image_url)  
**Figure 5.** Stack of modelled data before (a) and after (b) MWD. The blue rectangle indicates the part of the data that is examined in more detail in Figure 6.
East Coast Canada 2-D Marine Data

We now demonstrate the application of our MWD method on two datasets from offshore Eastern Canada.

The first of these examples is a 2-D line from North Flemish Pass, provided to us by Jebco Seismic (Canada) Company. The data were acquired in August, 1998, with shot and receiver spacing of 25m and 12.5m respectively, with maximum offset of 6100m. Over the total length of the line the water depth varies from approximately 165m to 1200m.

Figure 7(a) shows the stack of the input data for approximately half of the line, predominantly in the shallower end. Figure 7(b) shows the result of subtracting the water-layer multiples predicted using MWD from the input data.

From approximately 0.5 seconds to 2 seconds in Figure 7(a) the primaries are obscured by several orders of water layer multiple, which are significantly attenuated by MWD in Figure 7(b). Furthermore, peg-leg multiples generated by the strong reflector at approximately 2.5 seconds are also well attenuated by the MWD.

The second example is another 2-D line from offshore Eastern Canada. The data were shot with shot and receiver spacing of 25m and 12.5m respectively, with maximum offset of 8230m. The water depth varies from approximately 100m to 420m along the line shown.

Figure 8 shows a comparison of stacks before (a) and after (b) application of MWD on this line. Again we observe that very strong multiple energy, which dominates the section from the first water layer multiple onwards, is significantly attenuated after application of MWD, allowing the previously obscured primary energy to become visible.

Conclusions

It can be worthwhile to revisit older datasets in the light of new technology. In this case, we have made use of recent advances in the understanding of multiple prediction and removal, especially for shallow water-layer multiples, to attack problematic multiples on 2-D...
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Keith Wilkinson graduated in 1983 from the University of Saskatchewan with a B.Eng. degree in Geological Engineering – Geophysics Option. He spent 12 years with Shell Canada Limited primarily in seismic acquisition and processing roles. Keith moved into the service sector in 1996 and held technical management positions at Enertec, Veritas, and GSI. Keith was a founding partner of Key Seismic Solutions Ltd. in 2004. He is currently Key Seismic’s Vice President – Technology.

Richard Bale is VP of Research and Development with Key Seismic Solutions.

After a B.A. in mathematics from Cambridge in the UK, Richard joined GECO (subsequently Schlumberger) and pursued seismic R&D in the UK and Norway. After 17 years in the industry, he moved to Canada where he completed his Ph.D. in geophysics at the University of Calgary. Richard then returned to industry with research and management roles in Veritas and now Key. Richard is interested in seismic processing and imaging, and especially in multicomponent processing, and has written a number of papers on these topics.

References


We thank Jebco Seismic (Canada) Company, owner of the North Flemish Pass data, for permission to show the first field example in this paper.

We thank two anonymous clients for permission to show the second field example.

We would also like to thank Jeff Deere for his meticulous review of this paper.

Figure 8. Stacked results of MWD on Canadian East Coast 2-D marine line showing: (a) input; (b) demultiple data.

We thank an anonymous client for provision of the modelled data used in this paper.

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The authors wish to thank Key Seismic for supporting the publication of this work.

We thank an anonymous client for provision of the modelled data used in this paper.

marine datasets. We have adopted a diffraction modelling approach for generating the Green’s function, for use in the MWD algorithm, which we have then tested with some quite challenging synthetic data. One lesson from this was the importance of separately handling shot-side and receiver-side peg-leg multiples, to properly deal with structure, especially variation in the water bottom. Application of MWD on two different 2-D marine lines produced what seem to be more coherent and geologically plausible sections.
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Geophysical practice within the province of Alberta has long been regulated by APEGGA (Association of Professional Geologists & Geophysicists of Alberta). Since 2012, the Engineering Geology and Geophysicists Act (EGG Act of Alberta) has been revised such that today, the Association is known at the Professional Association of Professional Engineers and Geoscientists (APEGA). This change was intended to be reflective of the fact that many geoscientists continue to work competently across geo-specialties and to coordinate better with other provincial jurisdictions, yet it does lead to some loss of identity for us as geophysicists.

Earlier this year, the Chief Geophysicists Forum of the CSEG (CGF) formed a Subcommittee to monitor and report on the matter of APEGGA’s Regulatory Review Process, an initiative that will renew and update the Alberta legislation that governs the practice of Engineering and Geoscience in this province. Members of the Subcommittee include:

- Paul Anderson, P.Geoph.
- Neda Boroumand, Geoph.I.T.
- Marian Hanna, P.Geoph.
- Fred Kierulf, P.Geoph.
- Tom Sneddon, P.Geol., FGC (APEGA delegate)
- Charles Welsh, P.Geo.
- Ken Mitchell, P.Geoph. (Chairman)

In this issue of the RECORDER, some commentary regarding the APEGGA Process is offered, with some discussion as to why this may matter to our geophysical community. The Subcommittee welcomes input from geophysicists, geoscientists and other professionals that may have relevant perspectives.

Unlike the Occupy Wall Street movement, if geophysicists in Alberta were ever inclined to civil protest, they might be chanting ‘we are the other 2%... (after rounding, of course)!’ And our engineering colleagues might respond with ‘we are the other 89.5634%, precisely... (as recorded in April 2014)!’. It is difficult to predict what, if anything, our geologic brethren might raise in chorus, but it seems that they would represent about 7.5% of this noisy throng. The 100% would be rounded out by geoscientists of non-declared specialty, and dual geologist-geophysicist-engineers. If you haven’t already understood, I refer to the breakdown by technical discipline of the membership in APEGGA, the Alberta professional association that governs Engineering, but also Geoscience.

This minority position of the geophysical discipline within APEGGA is relevant as the professional association has initiated a review of the legislation that empowers APEGGA – the “Regulatory Review Process”. Since APEGGA is the body that governs who may practice geophysics or geoscience and how we do our business in Alberta it may be wise to pay attention. Therefore, it is our purpose to inform geophysicists specifically and geoscientists generally to become aware of and engage with this Process.

At the March 2014 CGF Meeting, delegates heard from Tom Sneddon, APEGGA’s Director of Geoscience and Outreach, about the Regulatory Review. This Review should be a fairly innocuous administrative process to ensure that the Engineering, Geology and Geophysics Act (the EGG Act) is modernized, cleaned up and streamlined. It is important to note that the EGG Act is the primary legislation that also includes the subordinate Regulations and Bylaws of APEGGA as well as the Code of Ethics. The EGG Act and any changes have potential for impact on the way geophysicists operate on a daily basis. By extension, any impacts will ripple through to geoscience teams, technical support professionals and the corporations that employ or contract with geophysicists. This legislative spring-cleaning is certainly due as the last major overhaul of the Act was in 1980’s with numerous amendments and adjustments since. Changes in technology and an evolving business climate may necessitate update, while some of the incremental revisions over the years may have created contradiction, lack of clarity or obsolescence that needs attention.

Meanwhile, in the background, there is a cross-Canada engagement of Engineering Associations attempting to coordinate in support of national standards and mobility for members. Some of the other provincial Engineering Associations across Canada include Geoscientists in their numbers, others do not. Notably, none of the provinces in Canada specifically recognize ‘Geophysics’ as a unique profession and even APEGGA has recently discontinued this designation in favour of the more general “Geoscience”. Another national body – Geoscientists Canada – is also proposing policy and standards that might be applied more universally on the Canadian professional scene. These
The CGF APEGA ADVISORY Subcommittee was created to monitor and advise on APEGA matters impacting the geophysical community and reporting to the CGF and the CSEG Executive. We intend to keep the CSEG as well as the CSPG and CWLS informed of developments with respect to any adjustment to the EGG ACT and regarding APEGA consultations with other provincial or national professional associations. Without CCF initiative, we simply cannot expect the voice of the unique, perhaps niche perspective of geophysicists or geoscientists to be heard.

As national standards and legislative consistency is contemplated by the various provincial engineering bodies, the primary perspective is naturally that of engineering. The engineering profession comprises about 55,000 professional members of APEGA compared to roughly 6,000 geoscientists, while only about 1,000 members could be identified as geophysicists. The bias to engineering numbers versus geoscientists skews even further toward engineering in other provincial jurisdictions. While the majority of professional members of all disciplines are engaged with applied science, there are some fundamental differences among us: the practice of Engineering is largely a process-driven discipline while the practice of Geoscience is routed in observational science. In this context, it is easy for the perspective of geophysicists and geoscientists to be forgotten.

It is important to understand that APEGA, Engineers Canada, Geoscientist Canada and all the provincial professional associations are well intentioned. The Associations afford us the right to self-govern our professions rather than submit to policies administered by civil servants. The provincial associations are all created by statute and each report to a specific provincial ministry (in Alberta – the Ministry of Jobs, Skills, Labour and Training) as a check on serving public interest. In the case of APEGA, the Association is run by about 118 full-time administrative staff located in Edmonton and Calgary.

Despite our small relative numbers, APEGA has seen the wisdom in establishing a position related to Geoscience Affairs that to date has been filled sequentially by Penny Colton, P.Geoph., and most recently Tom Sneddon, P.Geol. While APEGA is interested in hearing about the unique perspectives from geoscience, the staff and volunteers are already well occupied fulfilling the basic APEGA mandate of professional registration and managing processes that protect the public interest. The onus falls to us, the geophysical and geoscience membership to support good policy that relates to our professions. In this regard, APEGA and our CSEG Executive met on Friday, June 13 2014 here in Calgary. While the date seems ominous, good dialogue was established. The CGF Subcommittee was active in ensuring that CSEG and APEGA Executive Staff collaborated at this meeting. This afforded CSEG a chance to formally meet with APEGA’s new Executive Director (CEO) Mark Flint, as well as Registrar Carol Moen and Deputy Registrar Mark Tokarik. Mr Tokarik is the lead for the APEGA Regulatory Review Process. Significantly there was understanding that APEGA would consult with CSEG regarding the Regulatory Review Process and give CSEG opportunity for timely review and comment on preliminary and final drafts of any recommended changes prior to finalization. It is a reality that once documents come before APEGA Council for ratification, little or no changes are made – the time for effective input is during the drafting phases.

Already, as a result of the June 13 meeting, some corrections have been made by APEGA where the area of practice of ‘Geophysics’ had been inadvertently omitted from the Annual Report forms for Permit Holders. This is perhaps one small example of how closer collaboration between CSEG Executive and APEGA staff has already been an effective method to ensure that the voice of the geophysical community is heard.

APEGA’s current plan is to conclude the Regulatory Review Process next year with presentation of recommended updates to the Act, Regulations, Bylaws and Code of Ethics in time for Council to approve changes by mid year and for APEGA Members to vote on these by December, 2015. With direction from the CSEG Executive and the CGF, our Subcommittee will follow the Review Process and share findings with the geophysical community. It is our intent to raise awareness among geoscientists and geophysicists of proposed changes to the EGG Act, and to stimulate meaningful input to this Process. Through awareness and communication, we intend to support renewal of the Act and coordination with the provincial and national Associations in the interest of good policy that also finds acceptance with the geoscience community.

Admittedly, APEGA Regulatory Review is not the most stimulating priority on busy geophysicists’ lists. However, any changes to APEGA legislation will have impact on our professional lives for many years to come. These changes will be made at a time when the role of geophysics in the energy sector is under major re-invention and the terminology of Professional Geophysicist is on the way out. Therefore, all the more reason for geophysicists to pay attention and speak up.

Background on the Alberta EGP Act is available at http://www.apega.ca/About/ACT/preface.htm

VP Geoscience
K A Projects Ltd.
kaprojects@shaw.ca
Rachel Newrick  
CSEG Vice President  
P: 403-464-3224  
rachel@racian.ca

Many volunteers work behind the scenes, ensuring that CSEG initiatives are successful. Those who want to volunteer, or to say thank you to those who do, don’t currently know what committees and opportunities exist.

This column aims to bridge those gaps. In addition to the column, the CSEG website will be updated regularly with committee and volunteer information.

– RN

2014 CSEG Golf Tournament Volunteers

Over one month in late summer, three CSEG golf tournaments are enjoyed by many CSEG members: Doodlebug, T-Wave and WiSE (Women in Seismic). WiSE has been running since 2001 and as a CSEG social event since 2013, T-Wave since 2009 and the Doodlebug since 1953, all run by teams of volunteers, with many personal and corporate donations and the support of the CSEG. The three chairpersons of the golf committees share some of their thoughts on volunteering below.

Patrick Tutty (Doodlebug) As a five year member of the Doodlebug committee Patrick Tutty is well served to act as the current Chair. He has a history of sticking with committees and since 2001, amongst other things, has dedicated 7 years to the Ski Spree and 2 years to the Executive as Director of Member Services.

Patrick enjoys the teamwork required to pull off an event such as the Doodlebug, creating long-lasting friendships and working relationships. He feels that without new faces and ideas on all committees the society can’t grow to its full potential. Although it isn’t hard to recruit volunteers it is hard to get volunteers for key leadership roles due to the time commitment. He points out that it helps to have an understanding employer who believes in the CSEG and the events we run.

“to have a strong society, we need volunteers at all levels”

Jocelyn Frankow (T-Wave) Jocelyn Frankow formed the T-Wave committee in 2008 to offer an alternative to the Doodlebug that was accessible to golfers of all abilities, focused on networking, and ran over a half day. But she didn’t start there. Jocelyn has volunteered for the CSEG since 1994 as Recorder Editor, Geo-Convention Sponsorship and the Digital Media Committee.

Those who know Jocelyn won’t be surprised to hear that she volunteers to meet and get to know a variety of people and to give back to the society. She always tries to “be fair minded and get others to focus on what the event is: a CSEG event first.”

Joanne Poloway (WiSE) Joanne Poloway has been volunteering with the Women in Seismic Golf Tournament since 2005 either as Chair or on the committee, and when asked why she volunteers she gives two answers ‘because it’s fun’ and ‘I can’t say no!’ So now you know who to ask for help! That said, she’s clear that there are always plenty of keen volunteers (whom she raves about) which makes for contagious energy and allows ideas to flow.

There are challenges such as raising sufficient sponsorship and obtaining prizes but any stress is offset by the satisfaction of seeing relationships form on the course between the women players and sponsors. After 10 years Joanne is still excited to be involved with the WiSE committee.

“surround yourself with a great team of people”

Interested in volunteering?

If you want to get involved with any of the CSEG golf committees please contact:

T-Wave: jocelyn_frankow@sensorgeo.com  
Doodlegbug: patrick@earthsignal.com or brendan@earthsignal.com  
WiSE: joanne.poloway@sigmaex.com,  
or any of the committee members listed on the CSEG website.
Geophysics Mentorship Program

The CSEG Foundation Mentorship Program is entering its sixth year as a formalized mentorship program for student geophysicists. As a committee we are excited to see what another school year holds for the program as it continues to grow. The past year represents Mentorship’s most successful to date, with 60 mentor/mentee pairings. We had an incredible response to both our student employability workshop in the fall of 2013, hosted by Alex Shrake with guest speaker Richard Gray of Chevron, and our Mentor workshop in February 2014, with guest speaker Dr. Bob Ritter of University of Alberta. Along with these two formal events we hosted our first ever mentor “Meet and Greet”. Mentors met over lunch to share their experiences, challenges and successes within the Mentorship Program. This year we’re looking forward to another busy season. Keep your eyes and ears open for more details on our student workshop to be held in the fall. We will also be hosting a Mentor workshop on November 13th, 2014, with guest speaker Stan Bissell, who is an award winning secondary science educator currently working with the Ministry of Education of the Government of Alberta. The workshop will be at the Nexen Conference Centre (+15) in Calgary – find more details on the CSEG Mentorship website.

The Mentorship Program falls under the CSEG Foundation’s University Student Outreach. Its main goal is to facilitate the interaction of student geophysicists with industry professionals by pairing one student with one industry geophysicist for the duration of the school year. The Mentorship Program allows students the opportunity to develop a strong professional relationship with their mentor. The development of this relationship may represent the beginning of professional networking, and a place to assess current goals and to discover new ones. The Mentorship Program breeds an environment where students can ask those ‘dumb’ questions they would not feel comfortable asking anyone else. Mentorship can take many forms. Where the relationship goes is decided upon mutually between each mentor and mentee.

The CSEG Foundation believes this individualized approach to professional development is fundamental to the growth of future generations of geoscientists and that this is an important step in maintaining the health of our industry in the future.

The success of this program is due in no small part to the commitment from our volunteering mentors. We are extremely grateful for the time and effort all of our mentors put in to help make this program a success. Thank You!

A special note of thanks to Jessa Lee of Apache, who has acted as director of communications and vice chair of the Mentorship committee for the past 4 years. She has decided to retire from her position with us, shifting her energy to other endeavours. We have had so much fun working with Jessa and she has been pivotal in the Mentorship Program’s growth and progress. Thank you for all the time and energy you poured into making this program what it is today.

If you are interested in participating in this program please fill out the application forms that are available on the CSEG website at cseg.ca/students/geophysics-mentorship-program and contact mentorship@cseg.ca.

Mentorship Committee 2014/2015
Paul Hausmanis
Alexandria Shrake
Usman Shahid
Nathan Fester
Stephen Kotkas
Jordan Vandean

Upcoming CSEG-F events

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This month I’m going to look at glues, or adhesives as they are also known. Everybody understands these terms – they refer to substances, liquid or viscous, used to bind two objects or materials together. Writing this article underscored for me how very interested I am in ancient history, the older the better. Glues have been around since time immemorial and are definitely one of the earliest forms of technology used by hominids – to help attach a stone tool to a wooden handle for example. I would be more than happy to devote an entire article to ancient adhesives, but I’m not going to, because the modern adhesives developed over the last hundred years or so are very, very interesting. So instead I will focus on modern adhesives, and try to keep the historical content to a minimum. In terms of organization, the first section will look at how glues bond to a material, the second will describe the ways in which glues harden, and then various types of adhesives will be discussed, under the following headings: plant-based, animal-based, and synthetics.

**How glues bond**

Two properties determine a glue’s effectiveness – its adhesiveness and its cohesiveness. The former refers to its ability to stick to the materials it is binding together, and the latter refers to its ability to stick to itself. If the glue in a joint separates from one or both of the objects it is holding together, that is an adhesive failure; if the glue in the joint itself comes apart, that is a cohesive failure. An example of a substance with good adhesiveness but poor cohesiveness is tar – things stuck together with tar can usually be easily separated, but the tar itself stays stuck to both objects.

Many glues have quite incredible cohesiveness and tend to experience adhesive failure, but this usually happens because an inappropriate glue for the task at hand was chosen. Early in my home handyman career I thought epoxy glue was the answer to everything (including mending clothes!), similar to the way the guy on the Red Green Show feels about duct tape. However, I soon found out that epoxy easily separates from some substances. So the adhesive property of a glue in relation to what is being glued together is really at the heart of how glues work. As with many areas of science, there exists active debate about what is actually going when one substance adheres to another, which I suppose is part of the reason science is so exciting – it’s an area of dynamic learning. Several mechanisms can be involved in adhesion, most importantly mechanical bonding, chemical bonding and Van der Waals forces. In some joints there may be a small amount of electrostatic attraction (i.e. ionic bonding) between glue and material, and perhaps some covalent bonding (the sharing of electrons between atoms) but my understanding is that these are second order factors, and I won’t discuss them any further.

**Mechanical bonding**

This type of bonding is easy to imagine. At a microscopic level materials have all sorts of gaps and imperfections, something we as geoscientists know very well – the oil and gas industry relies on rock porosity. Because glues are liquid, they will tend to flow into all these little surface cracks and gaps, and once hardened the glue is essentially anchored to the material in a physical sense. Looking at the magnified images of wood and metal in Fig. 1 it is easy to see that if a glue could flow into all that pore space and harden, then the effect would not be unlike millions of wall anchors in drywall.

**Chemical bonding**

Again, this one is fairly easy to understand. Some glues actually break down the molecular structure of the material(s) being bonded and mix together at a chemical level, and this mixture then hardens. A great
example of this is hobby glue used to build plastic models. Back in the day when I was building little cars (and getting glue all over my fingers and no doubt suffering brain damage from the fumes) what was used was polystyrene cement, which dissolves plastic. Nowadays there is a broader range of model glues employing chemical bonding, and they vary in the types of plastics they dissolve, and are generally safer to use and more environmentally friendly.

Van der Waals forces
These forces are essentially electrical, at a molecular level. Many molecules are slightly polarized, because there is some inherent asymmetry in their structures. For example water molecules (Figure 2), because the two hydrogen atoms are off to one side at an angle, display a dipole moment as shown. If a glue is liquid enough to get in really close contact to the material it is adhering to, then the positive poles of molecules in the glue will be attracted to negatives in the material being bonded, and vice versa. These electrical attractions are minute, but when multiplied by the millions (or billions?) of molecules in contact within a glued joint, then their sum can be quite powerful.

I prefer to think of the primary source of adhesiveness as being a combination of mechanical bonding at a small scale, and Van der Waals forces at an even smaller scale, with sometimes a certain amount of chemical bonding being thrown in as well. In some cases what is going on is not easily categorized as I have done above. For example, if a glue has long molecules whose chains can penetrate into the molecular structure of the material being bonded, is that mechanical or chemical bonding?

Slightly off topic, but I’m fascinated by the adhesiveness of gecko feet. I’ve seen that explained by a mechanical Velcro-like mechanism involving thousands of tiny hairs on their feet “hooking” on to a surface’s imperfections, but I’ve also seen it explained by Van der Waals forces between the hairs and the surface’s molecules. In the end I’m not sure it really matters – I believe having different descriptions of the same effect actually increases understanding, because words are never truth, they are just clumsy attempts to describe it. (Wow, that was quite a metaphysical thought!)

How glues harden
All this business about adhesiveness is fine, but how do glues only bond upon application? A glue is only useful if it can reliably be transformed from a liquid (that preferably can be stored, handled, and so on) into a hard or semi-hard bonding agent with predictable adhesive and cohesive properties. Different glues achieve this in different ways – chemical reaction, cooling, exposure to an external energy source, drying, and pressure/contact.
Drying
This type of glue has probably been around the longest; many natural glues contain enough volume of water that they are liquid, and then as the water evaporates (or is absorbed by the neighbouring material) the glue hardens and bonds. Nowadays drying glues fall into two types – solvents and polymer dispersions. It’s a fine distinction between the two. With the former category the glue substance is dissolved in the solvent, while with the latter it is dispersed in the liquid but not dissolved. Another way to look at it is that a solvent glue is homogenous while a dispersion is heterogeneous. If you’ve ever wondered what an emulsion is, it’s the same as a dispersion, but instead of a solid being dispersed within a liquid, it’s a liquid held in suspension within another liquid. Quicker drying glues use solvents or dispersants that evaporate or absorb more readily than water (e.g. alcohol), but lately there has been a swing back towards water-based glues because they are more environmentally friendly. White glue is a classic solvent adhesive and thinking of it reminds me of early school days. I was always baffled why some kids would eat white glue, and still am. What happened to those kids? Did they grow up to be normal adults?

Cooling
These glues exploit the simple natural law that substances are liquid at some higher temperature and solid at some lower temperature. So many types of glues are liquefied by heating, applied, and then as they cool they harden. A common example is that of glue gun glue, also known as hot melt adhesive (HMA). HMA’s are typically made up of a base material, usually some kind of polymer such as ethylene-vinyl acetate (EVAS) or polyolefins, plus additives that combined give the desired bond strength, melt temperature, flexibility, temperature range of effectiveness, viscosity, crystallization temperature and so on. A fuller explanation of what exactly polymers are will come later.

Chemical reaction
I’ve already mentioned an example of a glue that relies on chemical reaction – my favourite, epoxy. Glues like this come packaged as two or more separate components, which are mixed together when the glue is to be used. Typically the components contain different types of polymer which on their own are non-adhesive, but when mixed together combine chemically to form either acrylic, urethane, or epoxy. They are really part of the drying category, as once mixed they behave just like a solvent or polymer dispersion glue. I believe that an advantage of these types of glue is that the trouble of creating a single liquid that can be contained and stored until application is avoided, and likely more aggressive (in terms of adhesion and set time) adhesives can be created without requiring all the extra ingredients used to achieve those desired pre-application properties.

I should mention cement or mortar as a type of adhesive which does not fit into the categories I use below (plant-based, animal-based, synthetic). The ancient Greeks were the first to experiment with mixtures of sand, lime and water, but it was the Romans who really perfected the first cement capable of bonding stone with high levels of adhesion – they combined lime, volcanic ash from Mt. Vesuvius, and water to create pozzolanic mortar. It is said that the construction of the Colosseum would have been impossible without this mortar.

External energy source
It could be argued that these kinds of glues also rely on chemical reaction, because that is exactly what happens. Instead of the chemical reaction being caused by the combination of two reactants, it is facilitated by the introduction of some type of energy. Just last week I had a broken tooth fixed, and as I lay there with my mouth open I was thinking that what the dentist was using would be a great example of this type of adhesive. The material used to replace the tooth enamel is a composite resin designed to possess the desired properties of colour, malleability, cure time, adhesion, ultimate hardness, and all sorts of other aspects that the dental industry has improved over the decades since these substances first started replacing metal amalgam (mercury alloy) fillings back in the early 1960’s. The latest technology employs an LED light source in which a gallium nitride semiconductor emits intense blue light. This light cures the resins in the dental composite within 3 to 5 seconds, to a depth of 2-3 mm. This is why a dentist will build up a filling with several layers, because obviously you don’t want a thicker filling to contain a soft core.

Pressure / contact
Contact cement is a good example of this type of glue. Here the drying occurs before the two surfaces are brought together. As the glue dries, it creates a hard film on the surfaces of the objects to be glued. Once dry, as soon as the surfaces are brought into contact, they begin to bond at a chemical level. There are advantages to these kinds of glues – because they dry before the joint is made, they can be used to bond non-porous materials through which there is no way for solvents to escape. They are also perfect for use in situations where clamping is difficult, as the bond is almost immediate.

Another type of adhesive that could be mentioned here is the low-tack, pressure-sensitive, re-usable glue used with the ubiquitous sticky note. Here a sparse monolayer of acrylate copolymer creates a bumpy dimpled surface with just the right amount of stickiness. When you apply pressure the copolymers form a mechanical bond with the other surface, and then they just as easily separate under tension, ready to use again and again until dirt clogs up the monolayer.
Plant-based glues

For most of human history, these and animal-based glues were all that was available. Before launching into this topic, let me touch on what a resin is. A resin is a naturally occurring hydrocarbon produced by a plant, mainly to ward off damaging insects or to attract predators that eat the damaging insects. Resins are viscous, and tend to dry into a hard substance, like amber for example. They would have been an obvious choice as an adhesive to primitive humans – one only has to touch pine sap once by mistake to realize it’s very sticky! Resins tend to be water soluble and brittle once hardened, making them less than ideal as adhesives; however, early humans discovered that additives could make resins more water resistant and flexible. For example, 70,000 year stone hand axes have been found in South Africa with traces of an adhesive with a plant gum base and an iron oxide ochre additive.

I can’t let this opportunity pass to mention Ötzi, the 5,200 year old man found preserved in a Tyrolean glacier. The analysis of his remains, including his tools, represents to me one of the most exciting scientific stories in my lifetime; one big impact of his discovery was the knowledge gained about the technology of that time and place. He carried with him flint arrows and copper tools, and the glue used was birch pitch, a resin extracted from birch bark via heating (Spindler, 1994) (Figure 3).

Over the millennia humans developed all sorts of plant-based glues using flour and other starches (i.e. dextrins, which are mixtures of polymers and glucose), as well as a huge range of resins. I suppose you could include geologically derived hydrocarbons as being plant-based, but it’s a bit of a stretch. In my very first article for the Recorder (Odyssey of Oil, Dec., 2000) I mentioned references to the use of tar in Herodotus and the Bible, as well as other prehistoric uses of oil-based substances as adhesives and sealants.

Animal-based glues

This category demands the overdue explanation of what a polymer is. A polymer is a large molecule or macromolecule with repetitive sub-units. Many are long, chain-like structures, and I believe this is why they play such a large role in adhesives – their long dangly bits make it easy to get tangled up in other substances, both in a mechanical sense and in Van der Waals forces sense. Figure 4 shows an octyl cyanoacrylate molecule, which is a polymer used as the main ingredient of a range of medical glues which provide rapid, painless closure of wounds and incisions. The term polymer applies to a huge range of substances, both manmade and natural. Natural or biopolymers include DNA, and importantly here, the proteins collagen and keratin. It is primarily these polymers that are used in animal-based glues. Collagen is the most common structural material found in animals, especially in bones and connective tissues such as ligaments. Keratins are the structural components in hair and nails. Both these polymers have been extracted and used in adhesives, which until the advent of synthetic glues were the dominant glues of choice.

Glues formed from collagen (also known as protein colloids) were historically created by hydrolysis of animal bones and connective tissue. Basically this meant throwing animal remains (especially from horses and cows) into a big vat of water and boiling the crap out of them until the collagens separated out. The semi-purified collagens could then be mixed with water or other solvents to create a glue paste. Over the centuries these methods became more sophisticated and controlled, resulting in a broad range of glues for different purposes. Fish glues are typically made from the collagens extracted from fish bones, but a particularly pure form of glue called isinglass is formed from polymers extracted from sturgeon bladders. Besides its use as a fining agent to accelerate the clarification of beer and wine, isinglass was commonly used to re-adhere paints to parchment, such as in the repair of illuminated medieval bibles.
Other types of animal proteins can be isolated and extracted for glue use, including albumen from egg whites, and casein from dairy products and blood. Included in this category would also be beeswax, used as an adhesive and sealant since ancient times.

**Synthetics**

As I mentioned before, there has been an explosion of synthetic adhesives over the last 100 years or so, far too many to go through one-by-one. Once you understand the basic ingredients and mechanisms at play, it is quite easy to imagine the multitude of ways glues can be custom designed for very specific purposes; a look at the glue section at a hardware store can be quite mind boggling as there are so many to choose from. So why don’t we look at a few common glues before wrapping up for this month?

**Epoxy**

There are so many different types of epoxy glues available that it’s pointless to try to cover them all. Figure 5 shows a very common type of epoxy glue, with the two components clearly obvious. When these two are mixed together, they will start to cure, and form a hard interlinked structure that is a powerful adhesive. Commonly one component is known as the resin, and the other the hardener. The resin is typically some kind of polyepoxide, and the hardener or curing agent something like an amine, alcohol, thiol, phenol or acid. Epoxies can be made with a huge variety of properties (colour, temperature range, resistance to chemicals, etc.) so they are used in many, many industrial and commercial applications.

**Polyvinyl acetate (PVA)**

This class of synthetic glues includes Elmer’s white glue and common carpenter’s glue. Their popularity is due to the fact that they are good at binding to porous surfaces such as paper and wood, and are non-acidic in nature and so relatively benign in terms of damaging the materials they are binding together. The chemical formula for polyvinyl acetate is \((\text{C}_2\text{H}_4\text{O})_n\) and it is formed by polymerizing vinyl acetate monomers (a monomer is just a molecule that can bind to another molecule to form a polymer). Just typing out these chemical names makes me even more mystified why kids eat hardened white glue.

**Cyanoacrylates**

These glues, including brand names “Super Glue” and “Krazy Glue” had semi-mythical status when I was growing up. There always seemed to be urban myths (which most of us children totally believed) of people gluing their eyelids open, or bonding their mothers’ derrieres to the toilet seat. Later in life I was led to believe that they were originally developed during the Vietnam War as medical glues to quickly close wounds in the battle field. There is an element of truth to this as some cyanoacrylates are now used as medical glues to quickly bond wounds in the battle field. The reality is that scientists trying to develop better gun sights during WWII stumbled upon a substance that stuck to everything very quickly, but did not commercialize it as a glue. Kodak rediscovered cyanoacrylates in the mid-50’s, and came out with a commercial version in 1958.

The cyanoacrylates in liquid form in the tube are made up of acrylate monomers. As soon as they come into contact with even small amounts of water they quickly polymerize and cure; when applied, the humidity in the air is sufficient for curing. Their main claim to fame is their extremely fast set time, water resistance, and adhesive strength, but only to certain substances, mainly porous ones. They are not good at bonding smooth materials such as glass, they have a short shelf life, and they have poor shearing strength.

**Rubber cement**

I wanted to mention this kind of glue, just because rubber is such a cool material. I’ve actually considered doing an entire article on rubber, because it has so many unique properties. The polymers that make up rubber as we know it are polysoprenes, and are known as elastomers. This is because they can be stretched, but then return to their original shape. The polysoprene chains are a mix of really long linear and “wrinkled” chains, with the latter dominating. I wanted to show an image of a polysoprene molecule, but the best ones are stock photos meaning I’d have to pay to use them – just Google it and you’ll see how wrinkled up they are. When stretched the wrinkled chains elongate, but as soon as the tension is removed they return to their wrinkled shapes. In glues such as rubber cement the polysoprenes are held in a solvent such as water, acetone, hexane, heptane or toluene, and they set when the solvent evaporates. The beauty of rubber glues is that they form a strong bond that retains the unique flexible, stretchy properties of rubber.
I regret not being able to touch on the many other glues available and their unique properties and histories, but space is limited as is the mental adhesion of readers! I also need to get cracking on next month’s article, which promises to be an interesting foray into the social sciences.

References


Next month’s article: MORALITY

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Happy October! If you have any free time, you may want to consider volunteering for one of the many Outreach initiatives that the CSEG Foundation is undertaking over the next year. They are looking for volunteers outside the Calgary area, so if you are in the Edmonton, Saskatoon, Regina, Vancouver, Victoria and Kelowna areas, and are interested, please contact Ben Consolvo at benjaminconsolvo.cseg@gmail.com, Chair of Public Outreach, for dates/details.

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

CALGARY GEOSCIENCE DATA MANAGERS NETWORK “LEARN @ LUNCH”

Wednesday, October 15th 2014, 12pm – 1pm
Katalyst Data Management has generously donated a meeting space in the Aquitaine Auditorium, +15 level of 540 - 5 Avenue SW for this and future luncheons.

This session, our presentation will highlight: “Basic Seismic Processing Concepts”.

We are excited to have Patrick Tutty, Business Development Manager at Earth Signal, presenting a talk on the basics of seismic processing. The meeting is free (BYO Lunch) but space is limited so please RSVP to Denise Freeland at rsvp.cgdmnet@gmail.com.

Future Luncheons planned: “Land” in mid-November and a Networking Social late in the year. Stay tuned for details!

We invite all those who are interested to join our LinkedIn group ‘Calgary GeoScience Data Managers Network’ or check out our website: www.cgdmnet.com.

We welcome any and all ideas at: ideas.cgdmnet@gmail.com

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11:30 am, Telus Convention Centre

FRIDAY, NOVEMBER 7
TECHNICAL LUNCHEON & DOODLETRAIN KEYNOTE ADDRESS
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AMSTERDAM – EAGE 2014

The CSEG was a part of the EAGE this past June and we had a decent turnout in Amsterdam for the conference. The CSEG has an understanding with the EAGE that provides reciprocation between the two societies in terms of exhibiting at each other’s convention. In addition, we also share in joint programs like the recent CSEG/EAGE Land Seismic Workshop September 23-25, 2014 in Banff.

Front L to R: Gladys Gonzalez (EAGE Outgoing President), Jim Racette (CSEG Managing Director), Philip Ringrose (EAGE Incoming President), Ina Allenhofer (EAGE Staff: Communications Coordinator)

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