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On The Cover...

Seismic operations in Alaska.

Image courtesy of Global Geophysical.

EDITOR'S NOTE

To ensure your information reaches the GSH members in a timely manner, please note the following deadlines and plan accordingly. Please submit your articles and any questions to Alvaro Chaveste, editor, at AlvaroChaveste@hotmail.com

GSH JOURNAL DEADLINES

Feb 2020	Dec 13
Mar 2020	Jan 10
Apr 2020	Feb 7

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A Word from the Board

By Maitri Erwin, Society of Exploration Geophysicists (SEG) Council Representative

Greetings from one of your representatives on the Society of Exploration Geophysicists (SEG) Council! During my terms as first vice-president-elect (2017-18) and first vice-president (2018-19) of the Geophysical Society of Houston, I also served the society as one of the SEG section representatives and continue in this capacity. Now, if you are anything like me up until four years ago, you're probably wondering what the SEG council is, and what exactly is its function. The council "represents the Sections, Associated Societies, and Technical Sections of SEG and serves as advisors to the SEG Board of Directors" and its stated purpose as stipulated in the SEG Bylaws is:

a. To approve the Annual Report, changes to dues rate structure or dues beyond cumulative inflation, and Bylaws revisions at the Annual Council Meeting or other Council Meeting called by the President.

b. To provide the Board of Directors with suggestions and recommendations in the form of motions from the floor on any topic considered to be of interest to the membership of the Society.

c. To serve in an advisory capacity to the Board of Directors on topics requested for review by the Board of Directors.

d. To represent the members of the Society regarding Society matters; serve the needs of the Sections, Associated Societies, Technical Sections, and Districts; channel information between the Society and the Sections, Associated Societies, Technical Sections, and Districts; promote cooperation, and provide a forum for Members of the Society.

For a more in-depth understanding of the roles, composition, and responsibilities of the SEG council, please visit https://seg.org/About-SEG/Governance/SEG-Council and https://seg.org/About-SEG/Governance/SEG-Bylaws.

The Geophysical Society of Houston is currently represented on the SEG Council by Craig Beasley, Peter Duncan, Tommie Rape, Haynie Stringer, Dennis Yanchak, and me. During my tenure on the Council, I have participated in several voting and decision-making activities previously mentioned above in bullet 'a'.

A critical discussion was held at the 2018 Annual Council Meeting that involved granting voting rights and the right to petition to associate members of the society. The multiple tiers of membership offered by the SEG have been confusing to new and/or junior members, who are often not aware that it takes eight years of experience and some paperwork to "graduate" from associate to active member status. Both sides of the debate had good points. Those against the extension of voting rights argued in favor of the reputation of the society and maintaining its high standards of membership as it grows and becomes increasingly global. There was also concern that a Section or Associated Society (SAS) with a preponderance of associate members would receive more council representatives. Council members favoring voting rights for associate members, including me, countered that it is critical to include emerging professionals (who constitute the bulk of associate members) in full ownership of SEG matters if we wish them to remain a part of the society. The profession of applied geophysics and the SEG are at a critical juncture, where we only stand to be reinvigorated by the inclusion of all full-dues-paying members, while still upholding our renowned standards. The ayes had it and, as of 2019: Active, Honorary, Life, Emeritus, and Associate Members are entitled to vote on all matters submitted to the membership and are referred to henceforth as 'voting members'.

Somewhere between fraught debates on "controversial" topics and seemingly inconsequential

negotiations over the wording of amendments of bylaws before they are voted on, I sense a year-long opportunity for all members to be heard at council. This is in keeping with giving "the Council a more prominent role inside the SEG Governance" that new Council Chair, Gustavo Carstens, would like to see going forward. As he rightly states in a recent note, "The Council is the truly global essence of the SEG and we have an opportunity now to become more active. This is the right place for all members to be heard."

GSH members, here's your opportunity to bring up any topic of importance - to your SIX representatives - that you believe we need to address as part of a larger society. What can the SEG do for the GSH? How can the GSH and other SAS scale up a best practice to the global level? What are things we should be talking about? It's usually the case that such a matter is considered by members of other SAS and discussing it in the larger group helps a much bigger audience than just ourselves. This is how we make progress.

Speaking of progress, council meetings can now be attended virtually and Council Chair Carstens would like to hold more virtual meetings to discuss items that you provide. Council meetings are open to any member of the SEG while respecting that representatives alone maintain council voting rights. You have probably grown tired of me saying please participate, but you must do so for the future relevance and health of GSH, SEG, and applied geophysics.

It has been my pleasure and a great learning experience serving you on the SEG Council. Here's to the happiest of holidays and a successful 2020! □

"Cutting advertising to save money is like stopping a clock to save time."
- Henry Ford

GSH Media Kits

From the Other Side

By Lee Lawyer

You should be aware of my history. I learned about seismic acquisition and interpretation while on a company seismic crew. In the first three years of employment, I moved with the crew about twenty times. Over time, I learned all there was to know about seismic acquisition and interpretation. Things have changed a little since the 1950s. These days, I am not sure I know anything of value. Are there weathering corrections? Do we correct to a datum? I won't bore you with the things I don't know because it'd take up too much time, *but* I will share with you three widely used terms that bug me. The three terms are: "Machine Learning", "Artificial Intelligence", and "Neural Networks". I decided to do a little online research to see what these peculiar terms mean (if anything).

In a site from *Data Science and Data Bases,* I found an item by Nick McCrea entitled, *"An Introduction to Machine Learning Theory and Its Applications: A Visual Tutorial with Examples".*

The article started by asking, *"So what exactly is machine learning anyway?"* The answer was illuminating, *"ML is actually a lot of things."* I thought, here we go again, but Nick expanded on the subject with a few quotes.

Arthur Samuel, way back in 1959: *"Machine Learning is the field of study that gives computers the ability to learn without being explicitly programmed."*

Tom Mitchell gave a "well-posed" definition that has proven more useful to engineering types: *"A computer program is said to learn from experience E with respect to some task T and some performance measure P, if its performance on T, as measured by P, improves with experience E."*

ML solves problems that cannot be solved by numerical means alone.

"What else do I need to know", I thought. Then came *the following:*

Among the different types of ML tasks, a crucial distinction is drawn between supervised and unsupervised learning:

Supervised: The program is "trained" on a pre-defined set of "training examples", which then facilitate its ability to reach an accurate conclusion when given new data.

Unsupervised: The program is given a bunch of data and must find patterns and relationships therein.

The article goes on to discuss 'training' a machine. Where did the term, "machine" come from? I like "computer", which might be synonymous with "machine." Mike McCrea's article is a good tutorial on machine learning. I recommend it, but you must have a machine to find it.

Now comes my second favorite term: Artificial Intelligence. How does ML differ from AI? Back online I found an item from "Techopedia" on the subject.

Artificial Intelligence is a branch of computer science that aims to create intelligent machines. It has become an essential part of the technology industry.

Egad! An intelligent machine? Define intelligence. Define machine. Then the next statement helped my understanding.

Machine learning is also a core part of AI. Learning without any kind of supervision requires an ability to identify patterns in streams of inputs, whereas learning with adequate supervision involves classification and numerical regressions.

So much for ML and AI. How about ANN (Artificial Neural Networks)?

Dr. Robert Hecht-Nielsen defines a neural network as, *"…a computing system made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs"*. And then a clarifying paragraph….

ANNs are processing devices (algorithms or actual hardware) that are loosely modeled after the neuronal structure of the mammalian cerebral cortex but on much smaller scales. A large ANN might have hundreds or thousands of processor units, whereas a mammalian brain has billions of neurons with a corresponding increase in the magnitude of their overall interaction and emergent behavior.

How Do Neural Networks Differ from Conventional Computing?

ANNs are not sequential or necessarily deterministic. There are no complex central processors, rather there are many simple ones which generally do nothing more than take the weighted sum of their inputs from other processors. ANNs do not execute programmed instructions; they respond in parallel (either simulated or actual) to the pattern of inputs presented to it. There are also no separate memory addresses for storing data. Instead, information is contained in the overall activation 'state' of the network. 'Knowledge' is thus represented by the network itself, which is quite literally more than the sum of its individual components…(defying some Newtonian law of physics).

From one mammalian to another mammalian (you), I haven't got a clue as to what all of this means. However, I do know that I need more *non*-AI. □

Technical Luncheons
Azimuthal P-P Seismic Measurements: Past, Present, and Future

Speaker: Dr. Heloise Lynn, Lynn Inc.,
SEG 2019 Honorary Lecturer, North America

Heloise Lynn

Westside

Tuesday, Dec. 17, 2019
11:00 a.m. – 1:00 p.m.

Location: Norris Conference Center
816 Town & Country Blvd.
Houston, TX 77024
(Free parking off Beltway-8 northbound
feeder or Town & Country Blvd.)

Downtown

Wednesday, Dec. 18, 2019
11:00 a.m. – 1:00 p.m.

Location: Petroleum Club of Houston
1201 Louisiana, 35th Floor
Houston, TX 77004
(valet parking onsite)

Northside

Thursday, Dec. 19, 2019
11:00 a.m. – 1:00 p.m.

Location: Repsol
2455 Technology Forest Blvd.
The Woodlands, TX 77381

** Please allow some extra time to
sign in with security, and required
escort to auditorium on 2nd floor.

Abstract:

Azimuthal (az'l) seismic analyses give rise to better-imaged data and insights into the in-situ stress field and the aligned porosity (fractures) that make fluid flow. Ignoring azimuthal seismic information, which in the past was quite easy to do, is now inexcusable because of vast improvements in: (a) platforms to view, map, and analyze az'l prestack or partial stack data; (b) acquisition (more data); and (c) processing algorithms (e.g., orthorhombic prestack depth migration [PSDM]).

Understanding the past gives insight into today. In 1986, the first "anisotropy" session of the SEG Annual Meeting featured five paradigm-shifting Amoco papers and one paper from Stuart Crampin, an early anisotropy pioneer. The Amoco papers documented six years of confidential applied research into shear-wave splitting, as visible in S-wave reflection seismic data. The cause for azimuthal variations in seismic measurements are the two different shear moduli seen by vertically propagating S-waves. These are a result of aligned porosity (vertical penny-shaped cracks or squashed vertical pancake porosity). The porosity geometry is the root cause of shear-wave splitting and azimuthal effects in P-P seismic. The P-wave velocity depends on the bulk modulus and the shear modulus (as influencing various elastic constants): when these moduli vary by azimuth and angle of incidence, then the P-wave velocity varies by azimuth and angle of incidence.

In 1995, Lynn et al. published the case story of two orthogonal 2D 9C lines, deliberately laid out in the principal planes of the az'l anisotropy: one line parallel to the maximum horizontal stress (N30W) and fracture parallel, and the other line perpendicular to that direction, in the Bluebell-Altamont field, Utah [US DOE Contract No. DE-AC21-92MC28135]. The S-S reflections traveled

as S1-S1 or S2-S2 depending on the azimuth of their particle motion (SH or SV). The birefringence of the rock layers was directly measured in the difference between the S1 versus S2 interval travel times between key reflectors. In the Upper Green River (the zone of interest), the az'l change of the PP AVA gradient at the tie-point was proportional to the contrast in S-wave layer-birefringence (contrasts in fracture density) at the boundary. In the following decade, the AVA gradient change by azimuth (AVAZ) became an industry standard for detecting and describing natural fracture sets. Closer to the present, in 2017, the use of az'l anisotropy to obtain better-imaged 3D P-P reflection seismic has been most recently demonstrated in 4C 3D offshore Vietnam and Bohai Bay: both complex geology settings.

Lynn and Goodway (2018) published az'l P-P reflection seismic amplitudes wherein the effect of vertically aligned porosity in a naturally fractured carbonate oil reservoir has a specific effect upon the az'l variation of the gradients as well as the near-angle (6-20° incident angles) amplitudes. In the Bluebell-Altamont 1995 data set, az'l variation in the P-P near-angle amplitudes at the tie-point was also observed. The az'l variation of the near-angle amplitudes is currently controversial. More geophysicists need to examine their own az'l seismic, with calibration data, and publish!

Biography:

Heloise Bloxsom Lynn is a geophysical consultant and instructor with Petroskills and Nautilus World. She started working in seismic reflection data in 1975, processing U.S. onshore data for Texaco in Houston. Lynn worked for Texaco, Amoco, BP, and then in 1984, she and her husband, Walt, formed Lynn Incorporated. Her consulting experience includes working in North America, Hungary, Qatar, Kuwait, Saudi Arabia, Pakistan, Australia, Thailand, China, and Japan. She specializes in the use of 3D multi-azimuth and/or multi-component data to obtain structure, lithology, porosity, pore fluids, in-situ stress, and aligned porosity (aka natural fractures). She also includes conventional VSP data processed for split-shear waves in these projects because there is nearly always a source-generated S-wave, a near-source mode-converted S-wave, and/or mode-conversions at impedance boundaries. In the fall of 2004, she was the SEG/AAPG Distinguished Lecturer, speaking on "The Winds of Change – anisotropic rocks, their preferred direction of fluid flow, and their associated seismic signatures." 2014 brought an Honorable Mention and Best Paper at the SEG Annual Meeting to H. Lynn, W. Lynn, J. Obilo, and V. Agarwall for "Azimuthal pre-stack depth migration for in-situ stress evaluation, in a fractured carbonate oil reservoir: predrill prediction of instantaneous shut-in pressure gradients. In 2016, she presented the Geophysical Society of Houston webinar, "Applied Azimuthal Anisotropy - Azimuthal 3D P-P Seismic: Why Bother?" In 2017, she was invited back to present "Basics and Updates on Anisotropy: Azimuthal P-P for Better Imaging, Fractures & Stress Analysis -- Acquisition, Processing & Interpretation." Both webinars are available through SEG. She earned a BA in geology-math from Bowdoin College, Maine; an MSc in exploration geophysics from Stanford University; and a PhD in geophysics from Stanford University. She is a member of SEG, EAGE, the Geophysical Society of Houston (GSH), AAPG, and SPE. □

Technical Breakfasts

Geological Facies Extracted From Seismic Data Guided by Well Information and the Geologist's Insight

Speaker: Kim Gunn Maver,
Qeye Labs

Kim Gunn Maver

North

Tuesday, Dec. 3, 2019
7:00 – 8:30 a.m.

Sponsored by Oxy

Location: Oxy (formerly Anadarko Bldg.)
1201 Lake Robbins Drive
The Woodlands, TX 77380

West

Wednesday, Dec. 11, 2019
7:00 – 8:30 a.m.

***Sponsored by Schlumberger
and WesternGeco***

Location: Schlumberger Facility
10001 Richmond Ave., Q Auditorium
Houston, TX 77042

Abstract:

Seismic AVO data is the preferred technology for mapping the subsurface between wells. The acquisition process has become very cost effective and, with recent advances like broad-band seismic and full azimuth ocean bottom seismic, has made it possible through seismic inversion to predict subsurface rock and fluid properties as well as pressure and fluid changes from time-lapse seismic data.

When doing AVO seismic inversion for elastic properties the variation in rock properties is only partly resolved and as a result, many facies and fluid configurations are similar in the seismic domain. The seismic domain space is also horizontally and vertically "unaware" of the geological ordering (young above old bedding), porosity distributions, depth trends, and fluid ordering (gas/oil/water). Geological knowledge is also difficult to quantify and, in a consistent manner, integrate into the seismic inversion process. Finally, reservoir related decision-making and risk analysis requires an increasing degree of assessment of the uncertainties associated with any interpretation and statements based on the seismic data, which is not an integral part when inverting seismic data for elastic properties.

Direct Probabilistic Inversion makes it possible to design a geological framework of prior information within which the seismic AVO data is transformed. In turn, it provides reliable results when performing an inversion for elastic properties by handling many of the described limitations and uncertainties in the seismic AVO data.

It is a one-step inversion process that honors multi-domain inputs and assumptions and respects the confidence of these inputs by using a fully Bayesian probabilistic formulation. A key attribute of the Direct Probabilistic Inversion process is the flexible geological framework of prior information, defined as probability density functions. The more likely solution has a higher probability and the less likely solution has a lower probability. This enables an optimal propagation of uncertainty and handling non-uniqueness by probabilities.

The probabilistic inversion problem is solved by defining natural neighborhoods in the rock physics, elastic, and seismic domains that influence a certain point in space the most. In the initial state, a subsurface model is defined based on the data from the different domains. This is updated with the information from angle stack data, which measures, in terms of probability, the misfit between forward-modeled seismic data and the processed angle stacks. The likelihood of the model being correct contains, in addition to a seismic noise model, the combination of a statistical rock physics model from facies to elastic property domain, and a seismic convolutional AVO forward model from elastic properties to the seismic angle-stack domain.
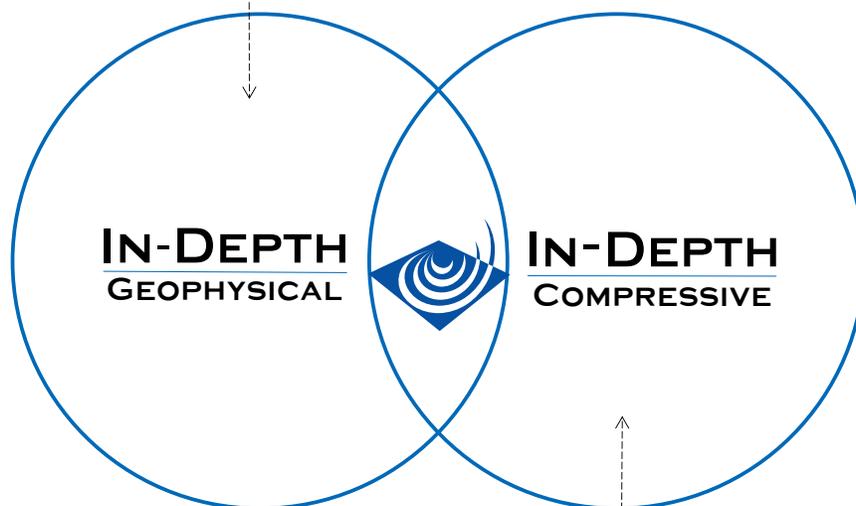
The result of the Direct Probabilistic Inversion is a probability volume for each of the defined facies. All of the facies can be combined into a final volume that represents the most probable facies distribution with corresponding probabilities.

Case studies will be used to present the Direct Probabilistic Inversion process.

Biography:

Kim Gunn Maver has extensive global oil and gas service company experience within management, strategy, and sales. He has a Ph.D. in geology from Copenhagen University and MBA from Copenhagen Business School. He was managing director of the seismic inversion company Ødegaard when the company was acquired by Schlumberger in 2006 and he stayed on in various management positions. In 2009 he started as VP of sales and marketing at the OBC company RXT and later moved to Spectrum where he served in various Vice President positions. Since 2018 Kim has worked as an executive consultant and is currently working with Qeye Labs developing the US market for QI consultancy services. □

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Unconventional SIG

An Integrated Data Analytics / Seismic Fault Attribute / Petrophysics Workflow for Diagnosing and Mitigating Excess Water Production in the Permian Basin

Speaker(s): David Paddock, Schlumberger

Authors: Sergey Makarychev-Mikhailov, Vasudhaven Sudhakar, David Paddock, Ryan Williams, Erik Rylander, and Dean Willberg, Schlumberger

Thursday, Dec. 5, 2019
11:30 a.m. - 1:00 p.m.

Sponsored by TGS

Location: TGS
10451 Clay Rd.
Houston, TX 77041

Dave Paddock

Abstract:

Produced water is a major operational expense increasing the total cost of production for Permian basin assets. All Wolfcamp and Bone Spring wells produce some water, even under ideal conditions. This water is necessary for hydrocarbon production, and, in some sense, can be considered "good" water. However, many wells produce excess water – increasing operating costs with no incremental oil production – due to fracture completions intersecting water bearing faults, or due to the lateral being inadvertently landed in a high water-cut zone. How does one know if the observed water production is "good" and necessary for oil production, or excessive leading to higher production costs? How can one preemptively avoid excess water production hazards on new wells by optimizing well placement, completion strategy and hydraulic fracturing designs? The good news is that water production hazards can be identified proactively, and technologies exist to avoid these features on future wells.

This paper demonstrates an integrated workflow employing data analytics, seismic fault attributes, and petrophysical analysis to identify and avoid excess water production hazards in the Wolfcamp and Bone Spring formations. It combines joint analysis of well production data, 3D seismic data and wireline logs. The workflow creates value by reducing water management costs.

Biography:

David Paddock is a scientific advisor in WesternGeco's North American Onshore Unconventionals Exploration team. He has consulted on dozens of unconventional development projects throughout North America as well as in South America, Europe, the Middle East, and North Africa. A baby boomer, Dave has had only two employers, ARCO for 18 years and now Schlumberger for 19 years in their Consulting and Geophysical product lines. Dave has won Best Speaker Award at AAPG's Southwest Section meeting, has had talks selected for SEG's Best of AAPG session, and has two silver medals and two bronze medals from Schlumberger's Performed by Schlumberger program (an internal project success recognition program). He holds an MBA from the University of Louisiana at Lafayette and both a masters degree in geology (with a geophysics option) and a bachelor of science degree in Mathematics from Michigan State University. He is recognized by industry as the leading expert in Ant Tracking, a detailed seismic fault identification application widely utilized, particularly in the development of unconventional resources. □

Data Processing & Acquisition SIG

Uncovering Permian Unconventional Resources with High Density Seismic

Speaker: Anastasia Poole, WesternGeco
APoole1@slb.com

Tuesday, Dec. 10, 2019
4:30 p.m. Sign-in, Snacks, Social Time
5:00 p.m. Start of presentation

Sponsored by Schlumberger

Location: Schlumberger
Q Auditorium
10001 Richmond Ave.
Houston, TX 77042

**Anastasia
Poole**

Abstract:

Although simultaneous vibroseis acquisition techniques were introduced a decade ago, these methods are not commonly used in the Permian Basin. Slow take on high-productivity techniques is related to obstructions, permitting, and the amount of extra noise introduced in the data that potentially has a very negative impact on seismic data quality in already challenging geological settings. This, combined with the restricted nodal channel count and the requirement to image from very shallow (1,000 – 3,000 ft) to deep (16,000 ft plus), puts significant limitations on the future seismic survey designs.

During this talk Anastasia will discuss the first commercial application of the new simultaneous-source acquisition technique in which interference was managed in time and frequency domains through encoded dynamic sweep allocation. This resulted in minimal seismic source noise interference after the correlation process. No additional deblending was required as part of the data preparation for production processing; thus, minimizing the processing effort and reducing the project's timeline. The dataset was of superior resolution, both in shallow and deep sections, when compared to previously acquired data.

Biography:

Anastasia Poole is a Geophysics Lead for WesternGeco in North America, providing a technical oversight of land seismic acquisition and all seismic processing projects for WesternGeco Houston Land Multiclient as well as Calgary and Denver Discovery centers.

Previously, Anastasia was based in Gatwick as a Principal Geophysicist assisting in testing and rolling out of new technologies for WesternGeco land operations worldwide. She also did advanced testing and commercialization support of new land time processing technologies; and provided advice, leadership and technical support to WesternGeco Geosolutions covering Middle East (MEA) and Europe and North Africa (EAF) regions.

She started her career in the oil in gas industry in 2001 as a summer intern working for Gazprom in Russia. In 2004 she graduated from Moscow State University with a MSc in geology and joined WesternGeco as a field geophysicist in a land seismic crew in Egypt. During her last 15 years, Anastasia has worked various types of seismic data acquisition techniques (Land 2D, 3D and Ocean Bottom Cable), covering the full range of data types from many places around the world. She has lived and worked in the Middle East, Australia and Europe.

Anastasia has a number of publications covering various aspects of seismic survey design and modelling, acquisition and processing. □

Offshore Mexico Example of Joint PP-PS Model Building in Complex Geology

John Mathewson and Miguel Acosta Perez, WesternGeco;

Edgar Serrano Casillas, Silvino Dominguez Garcia, and Jorge Diaz de Leon Chagolla, PEMEX

Summary

PS converted-wave seismic data is beneficial in many ways, including situations where images are distorted by the presence of shallow gas, and for obtaining more accurate estimates of density and shear impedance using seismic inversion. However, processing both PP and PS data naturally requires more effort than processing of PP data alone, and for this reason much PS data remains unprocessed. Efficient workflows for processing of PS seismic data are required to minimize the extra time required for PS processing.

Model building for depth imaging of PS data is more complicated than for PP data because both compressional and shear velocities are required, and both data types must be input. However, these extra requirements are not only a complication, but also provide an opportunity to build better models that satisfy all input data in a joint PP-PS tomography.

In this case study, we describe the application of PP-PS model building and depth imaging to an ocean-bottom cable seismic survey in the southern Gulf of Mexico. The area is characterized by complex structure combined with large velocity contrasts, both of which are problematic for PS model building. We applied a state-of-the-art workflow incorporating joint PP-PS tomography that maximized use of well data and required very little interpretation effort. High-quality PP and PS results were produced in a reasonable timeframe.

Introduction

The southern Gulf of Mexico has been a source of significant quantities of petroleum for many years. Huge reserves remain, but production rates in older fields have decreased over time. Efforts are being made to extend the life of these fields, and improved seismic data is an important part of these efforts. Recently an ocean-bottom cable (OBC) survey was acquired using high-density orthogonal acquisition, with high fold and long-offset coverage over 360° of azimuth. Seismic data from the new OBC survey are greatly superior to data from previous surveys in the area in terms of bandwidth, signal-to-noise ratio, and full-offset/azimuth illumination.

The main objective of this survey was to produce better PP seismic volumes that will reduce structural uncertainty, suitable for fracture characterization and analysis of seismic attributes. However, horizontal components were recorded during acquisition and these were also processed to produce PS converted-wave images. Reasons for processing the PS data include improved imaging in areas affected by shallow gas as well as potential benefits for reservoir characterization, geomechanics and rock physics.
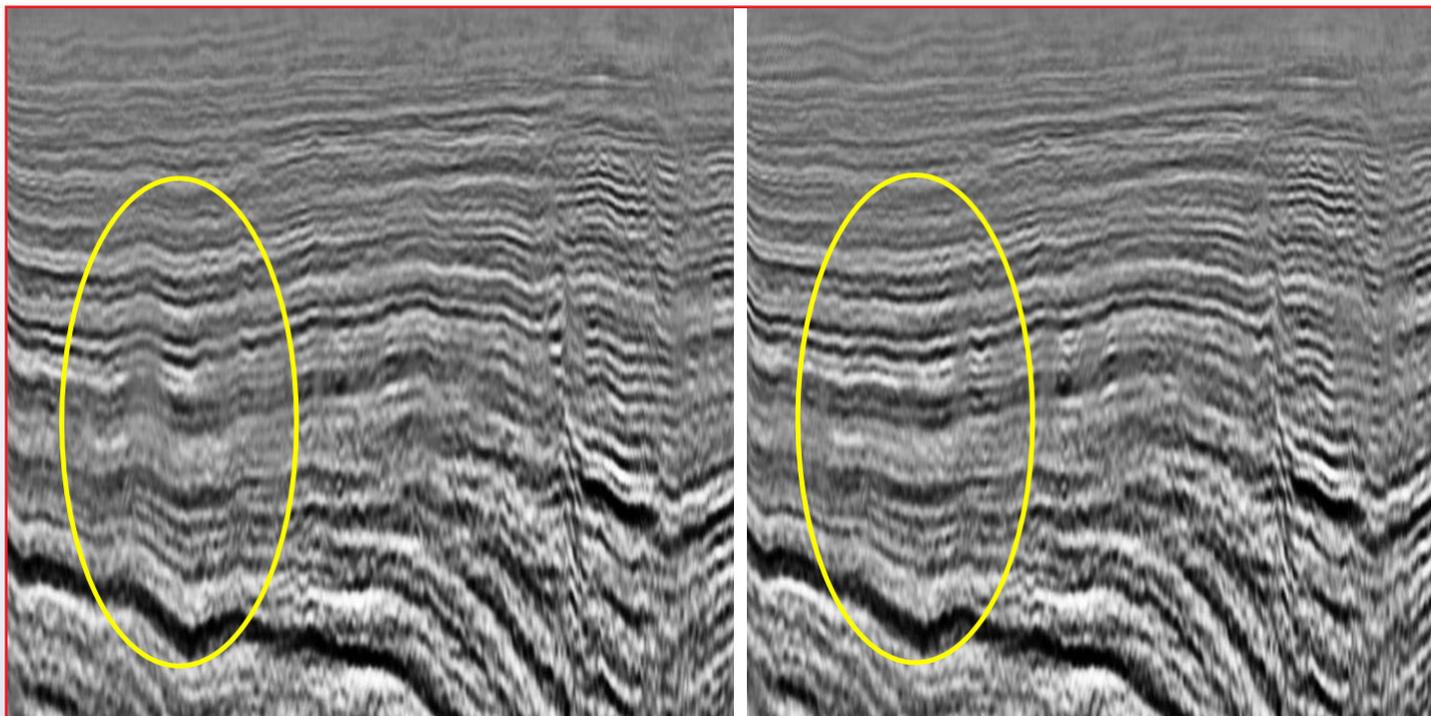
Velocity model building was carried out using an advanced workflow featuring multiple iterations of joint PP-PS common image point (CIP) tomography with floating event constraints performing simultaneous updates of Vp, Vs and anisotropic parameters (Mathewson et al., 2013). The workflow incorporated extensive use at every stage of the large amount of high-quality well data available in the project area, minimal interpretation requirements for model building, and use of surface-wave inversion to define shallow shear-wave velocity.

Initial model for PP-PS depth imaging

Model building for imaging of PS seismic data is complicated by the requirement for both P-velocity and S-velocity, and by the greater sensitivity of PS imaging to errors in anisotropic parameters. In our case, we were fortunate to have a high-quality tilted transversely isotropic (TTI) model produced during an earlier phase of the project using iterations of PP CIP tomography (Woodward et al., 2008) with well constraints. Vp, anisotropic parameters and TTI dip and azimuth were all extracted from this model to form the initial model for PS depth imaging.

Figure 1: Depth-migrated sections without (left) and with (right) shallow shear velocity from surface wave inversion.

Creation of the initial S-velocity model was greatly aided by the availability of many wells with dipole sonic logs sampling the entire Tertiary section as well as Mesozoic carbonates and Jurassic layers. A crossplot of Vp and Vs from dipole sonic data was used to derive a Vp/Vs relationship, which was then used to calculate Vs from the initial Vp model. On prestack depth migration (PSDM) images produced using the resulting model some areas were noticed where variations in Vp caused by shallow gas degraded the PS image and these were addressed by localized editing of the Vs model.

Determination of shear velocities using reflections in the very shallow section is problematic given the sparse shallow illumination of orthogonal OBC acquisition and the lack of shallow well data. Surface-wave inversion (Boiero et al., 2013) was performed to resolve Vs variations just below the water bottom. *Figure 1* shows depth-migrated sections produced with and without velocities from surface-wave inversion. A false shallow structure is apparent in the image on the left, which is totally removed by Vs updates based on surface-wave inversion.

Figure 2 shows a depth-migrated PS section with color overlay of the initial Vs model. The image is of very good quality given that this is the initial model. Large velocity contrasts and complicated structure are clearly seen.

PP-PS registration and initial Vs update

An important requirement for converted-wave model building and depth imaging is that PP and PS depth images should tie, although the tie may not be obvious. For example, PP and PS reflectivity can be very different and there may be a difference in phase between images. To understand the PP-PS tie, we produced synthetic seismograms from dipole sonic log data calibrated with checkshot information.

An analysis of the PP and PS synthetics led us to conclude that the images should tie with opposite polarity. In *Figure 3* are displays of the PP and PS synthetic ties at one of the wells. The most obvious feature is the high-velocity zone in the center of the displayed interval. For PP data this produces a positive reflection coefficient at the top and negative at the bottom, while PS has a negative reflection at the top and positive at the bottom.
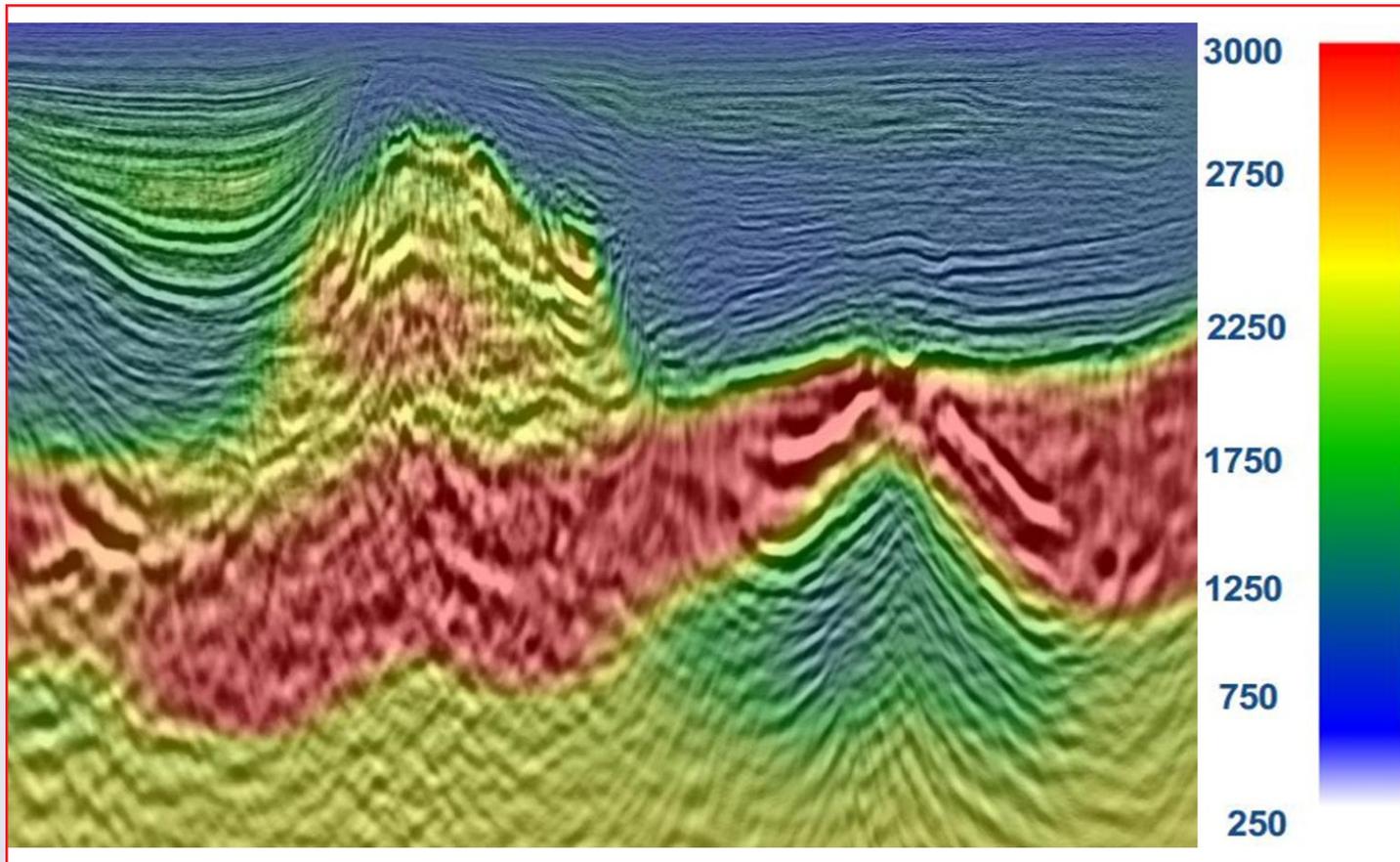
*Figure 2: Initial PS depth-migrated section with Vs model overlaid.*
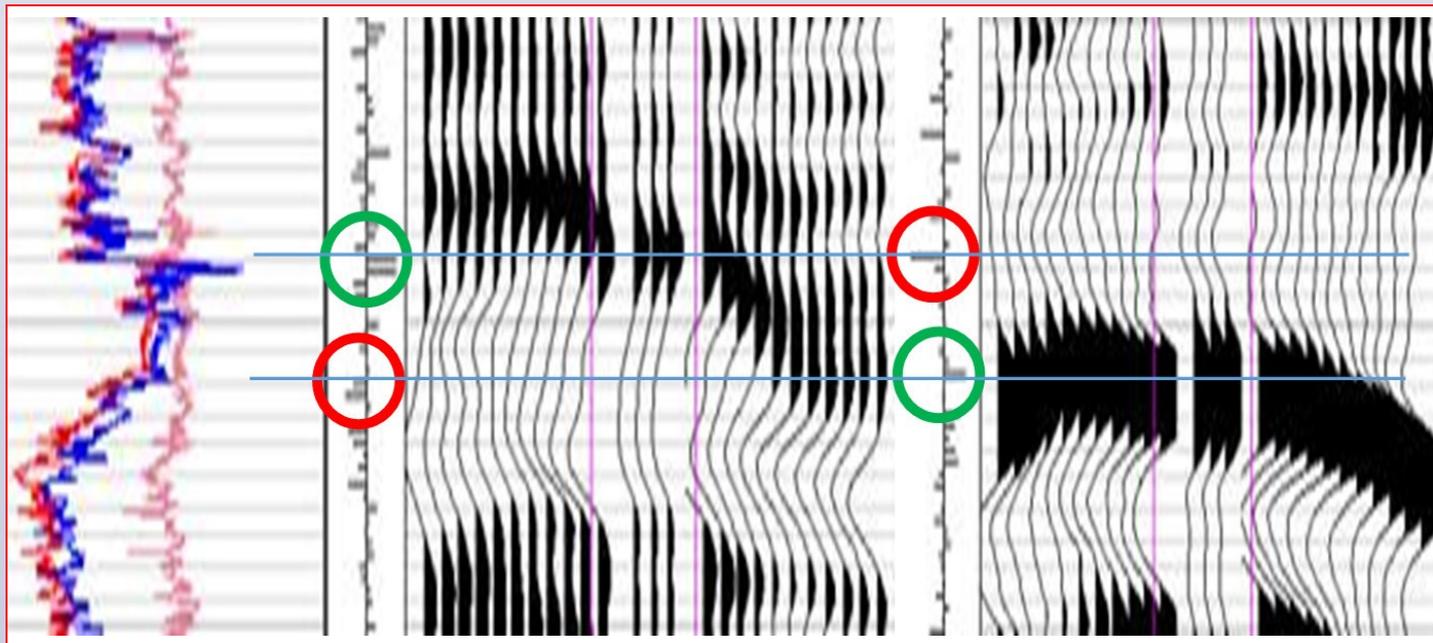
Figure 3: Vp, density and acoustic impedance (left), PP (middle) and PS (right) reflectivity and synthetic tie.
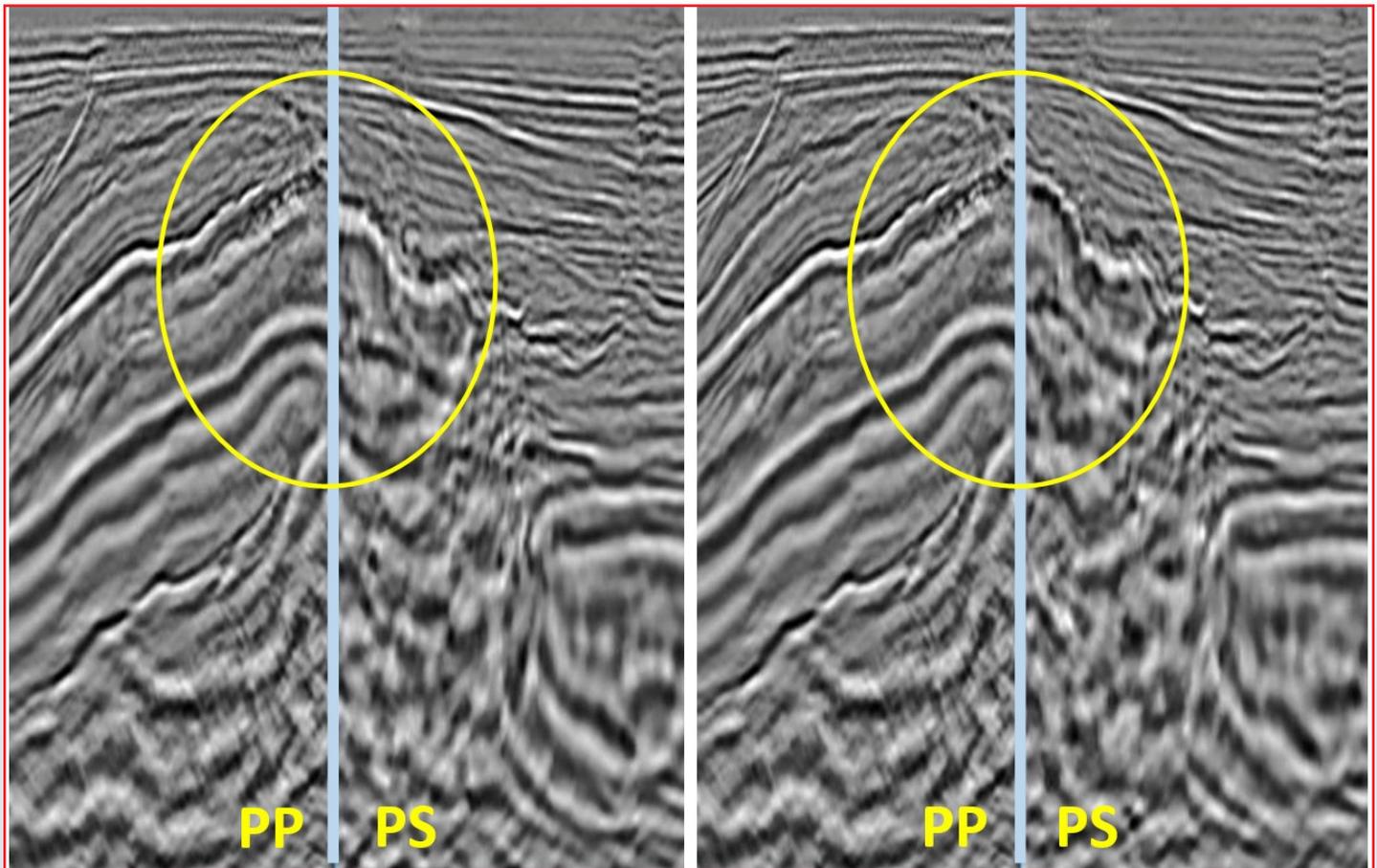
Figure 4: PP and reverse-polarity PS depth images before (left) and after (right) Vs update.

Another major difference often seen between PP and PS images is that PS has narrower bandwidth than PP data. We applied a preconditioning flow consisting of high-cut filtering of both images and polarity reversal of the PS data which produced an excellent PP-PS match, though significant differences in the depths of equivalent events remained. These misties would be addressed by an update to Vs, based on measurements of PP-PS depth differences.

PP-PS registration for early stages of model building usually requires manual interpretation of equivalent events, as automatic registration methods may be prone to cycle skipping and the character of PP and PS reflections may be quite different. In our case, the characters of PP and PS images were very similar after the preconditioning described above, and we believed that automatic registration should produce good results if we could find a solution for the cycle-skipping issue.

We tested dynamic warping (Hale, 2013) to automatically determine the spatially varying displacement between PP and PS depth volumes, and found that it produced consistently accurate results, better than we could produce by manual interpretation. The dynamic warping algorithm is particularly resistant to cycle skipping in the presence of large shifts. In general, PP and PS depths for the input images matched well, but in a few places there were vertical shifts of up to 400 m that were successfully resolved by this method. No interpretation input was required and no issues with cycle skipping were observed.

The output shift volume from dynamic warping was input to CIP tomography to update the S-velocity, and the resulting model was then used in subsequent model building steps. *Figure 4* shows PP and PS depth images before and after the Vs update.
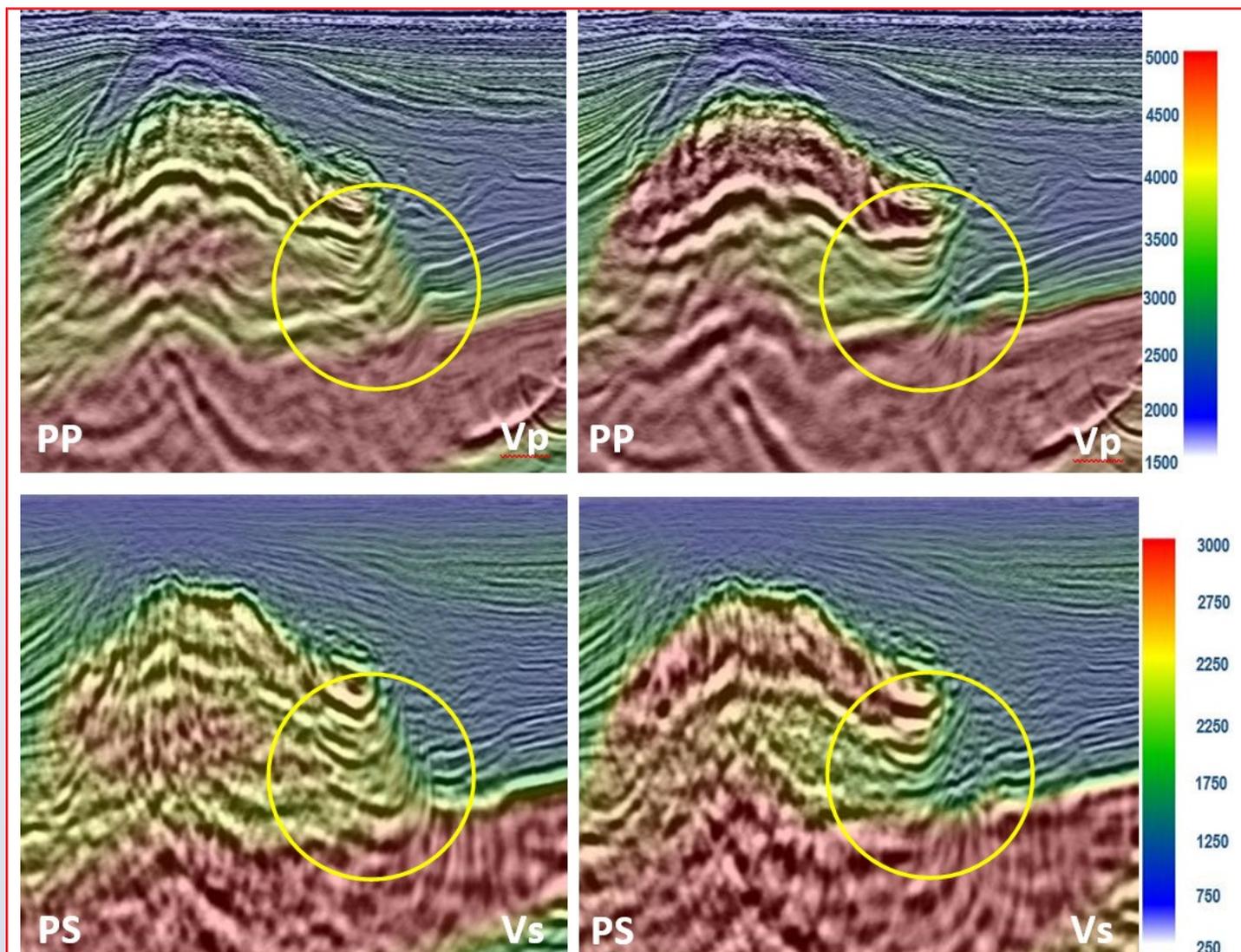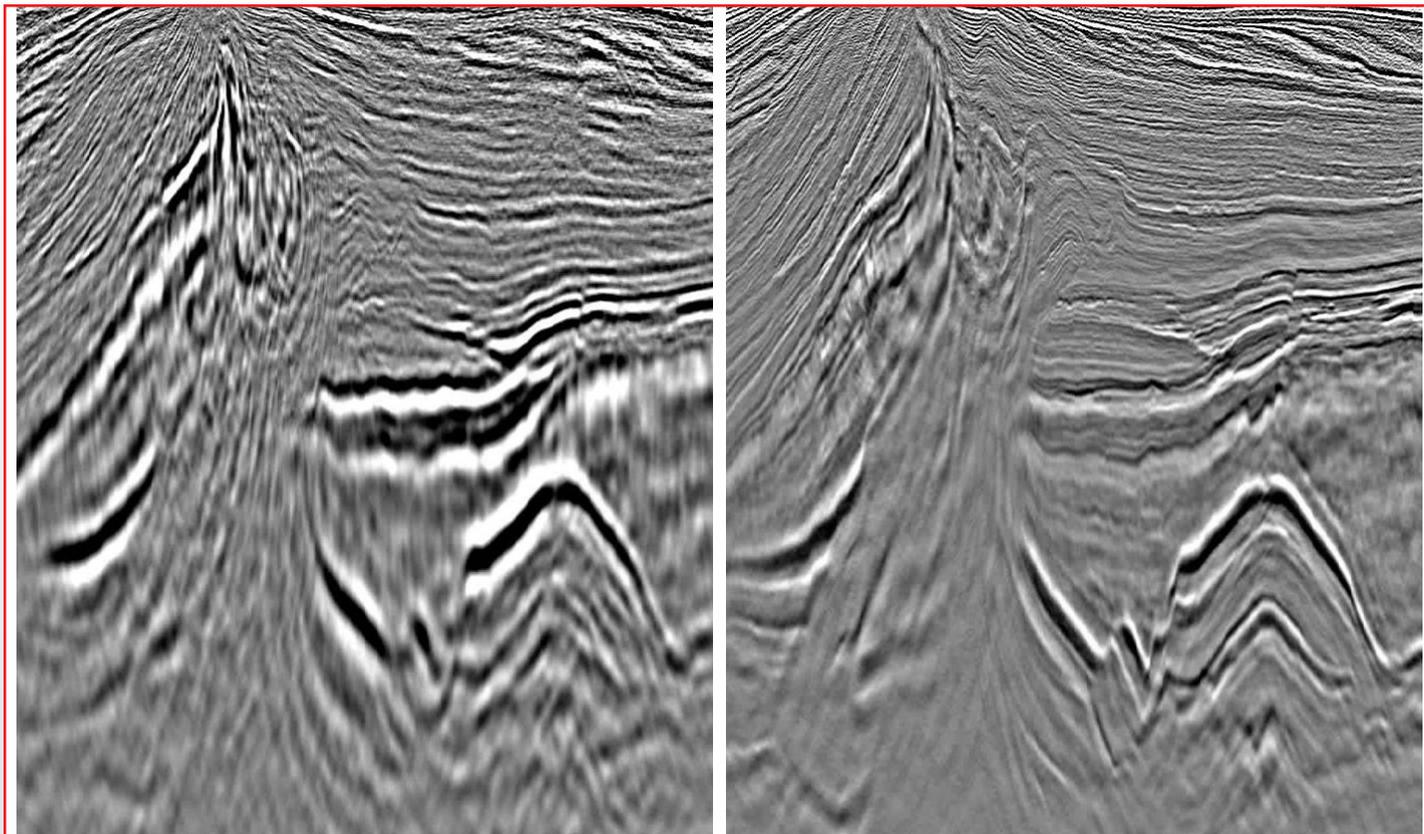
Figure 5: PP (top) and PS (bottom) images with model overlay before (left) and after (right) modeling of carbonate velocities.

Joint PP-PS tomography with well constraints

Joint PP-PS tomography (Mathewson et al., 2013) is a robust algorithm in which residual moveout picks for PP and PS depth gathers are combined with floating event constraints in ray-trace CIP tomography. It is capable of solving simultaneously for Vp, Vs, and anisotropic parameters δ and ε (Thomsen, 1986). It provides better estimates of anellipticity than either PP data alone or separate PP and PS updates, as well as a more accurate Vp/Vs ratio for an improved PP-PS match. It should be noted that updating of δ requires well depth constraints.

Joint PP-PS tomography was performed after the Vs update to update Vp, Vs, δ, and ε. A combination of vertical seismic profile (VSP) travel-times, sonic logs, and well marker/horizon misties was used to constrain the solution. The solution was further constrained to only update the Tertiary section above the Mesozoic carbonates. Floating-event constraints that relate PP and PS depths came from a PP-PS displacement field derived using dynamic warping with no interpretation input. The updated model after joint PP-PS tomography produced flatter events, better PP-PS match, improved well misties and better agreement with sonic logs and checkshots down to the top carbonate interface, compared with the input model.

Figure 6: Example of final PS (left) and PP (right) depth images.

Modeling carbonate velocities

Velocities of the Mesozoic carbonates are significantly higher than the Tertiary section, and some modeling was required to include the large velocity contrasts in the model.

Image-guided interpolation (Hale, 2010) is an efficient way to interpolate sparse input data using structural input from an image. VSP and sonic log data for over 100 wells were interpolated using this method to produce a detailed P-velocity model below the top carbonate. Following the interpolation, the shear velocity model was recalculated below the top carbonate, using the Vp/Vs ratio derived from well logs applied to the updated compressional velocity.
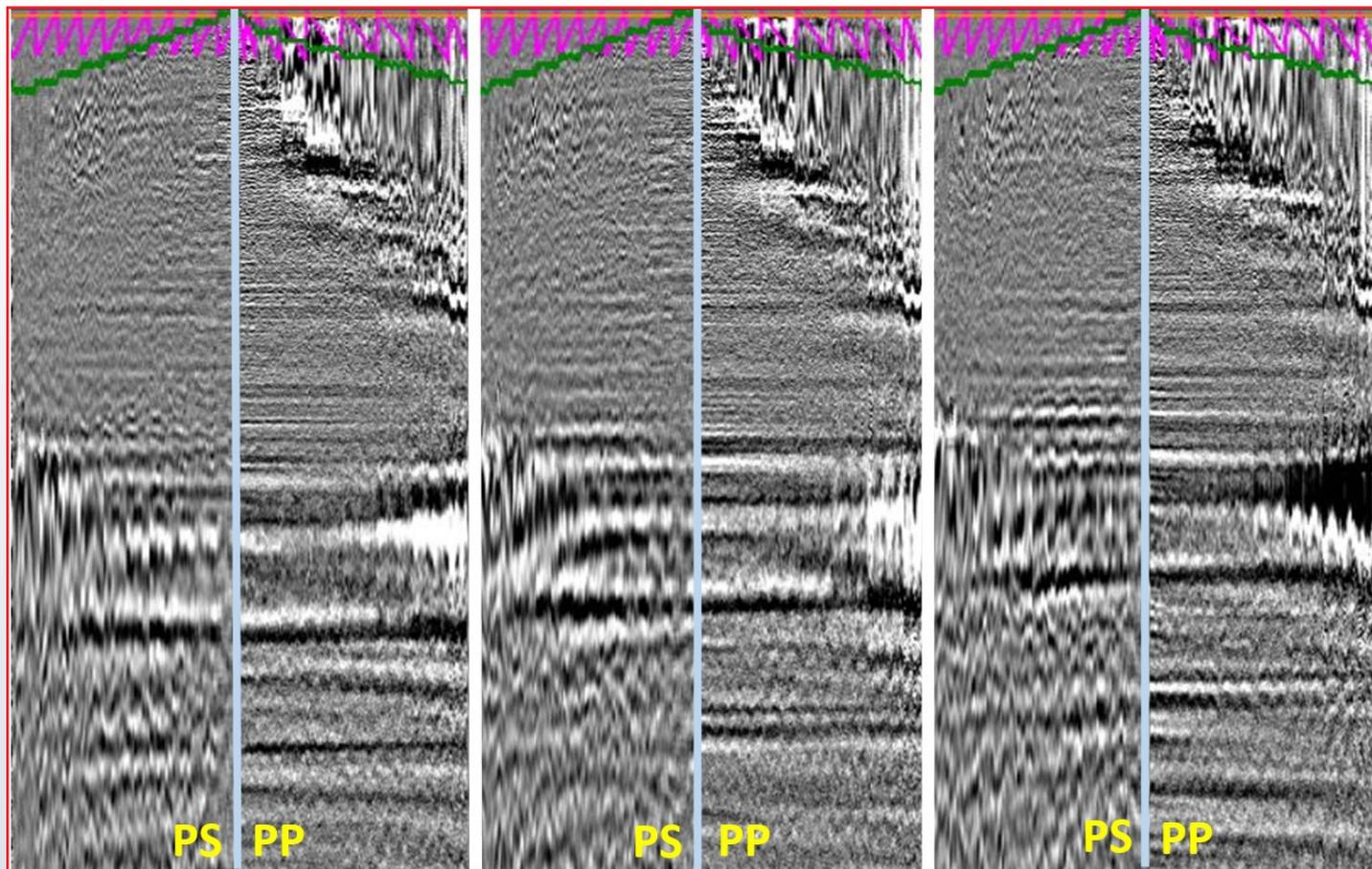
Artificial wells were inserted in some locations where no well information was available, as well as in structurally complex areas where known low-velocity regions below allochthonous carbonates were not well-modeled in the interpolation.

Figure 5 shows the image and model before and after carbonate velocity modeling with image-guided interpolation of the well velocity data. After the update, we see increased velocity in the allochthonous carbonates with velocity inversion below. The velocity changes have improved continuity and we also have a more reasonable structure of deeper events for both PP and PS images.

Results

After carbonate velocity modeling, further iterations of global joint PP-PS tomography, including dynamic warping to find the shift between PP and PS images along with well constraints, were performed to finalize the velocity model. Image quality, agreement with well data, and mistie between PP and PS images continued to improve for each iteration.

Figure 6 shows the PP and PS depth images for an inline migrated using the final model. The two

Figure 7: Example of final butterfly depth gathers, PS on the left of each gather and PP on the right. Azimuth (magenta) and offset (green) are graphed at the top of the display.

images look very similar, as they should. They show the same geology. The PS image is very interpretable, even in structurally complex areas below the carbonate, although it has a somewhat higher noise level and lacks higher frequencies that are present in the PP image.

Depth gathers from the right side of the same inline are displayed as butterfly gathers in *Figure 7*. Traces on the left side of each gather are PS data while the right side is PP. There is a nearly perfect match between the PP and PS data to the base of the high-velocity carbonate, although the PS data quality is not as good in the deeper section. Residual moveout on events down to the base carbonate is minimal for both PP and PS data, even at far offsets.

Figure 8 shows Vp and Vs functions calculated from dipole sonic logs at two well locations,

along with the Vp/Vs ratio calculated by dividing the two functions. In the well on the left, dipole sonic data were only acquired in the Tertiary section, whereas for the well on the right they were only acquired in the carbonate section. VSP interval velocity is also displayed for both wells. Vp, Vs, and Vp/Vs ratio from the final model are also displayed and match very closely with the dipole sonic information as well as the VSP data.
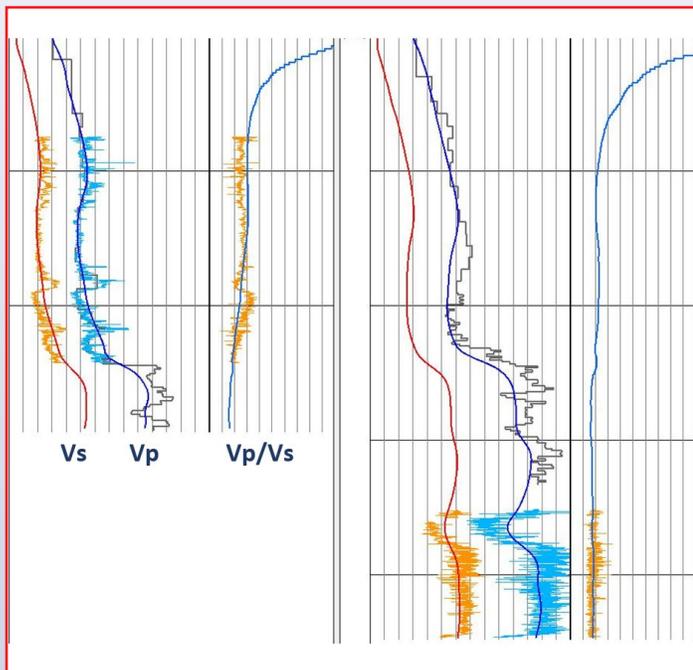
Conclusions

We applied PP-PS model building and depth imaging on a recently acquired full-azimuth OBC data set from offshore Mexico. We employed an innovative model building workflow, using the latest technologies to extract maximum information from both PP and PS seismic data and the large amount of well data in the area.

The resulting model matches closely with well data and produces excellent PP and PS depth images that tie. Model building turnaround was very reasonable considering the complexity of the task.

Acknowledgments

*Figure 8: Comparison display at two wells of Vs (orange), Vp (blue), and Vp/Vs ratio from the final velocity model with dipole sonic log data.*

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Woodward, M., Nichols, D., Zdraveva, O., Whitfield, P., and Johns, T. [2008] A decade of tomography. Geophysics, 73(5), VE5–VE11.

Permalink: https://doi.org/10.1190/segam2018-2995074.1

GSH Outreach
Committee Activities By Lisa Buckner, **outreach@gshtx.org**

Fall has been very busy for the GSH Outreach volunteers. We participated in 5 events in October. **Earth Science Week** is sponsored by the American Geological Institute and it's Member Societies (including SEG) on behalf of the geosciences community. *"Geoscience is for Everyone"* is the theme of **Earth Science Week 2019**.

The first event was **The Educator Event** held on the evening of **Friday, October 4 at HMNS**. I taught two 30-minute hands-on workshops with the assistance of Huw James. The first one was the *"Exploring for Petroleum using Geophysics"* activity for grades 6-12. I have conducted this activity twice before at this event. We split the teachers into two teams. They built Earth models by filling shoeboxes with sand, gravel, and a water balloon representing an oil field. One team found the "oil" by listening to the reflected sound waves while tapping on the box lid and then drilling with a bamboo skewer. The other team needed the answer keymap to find it. The other workshop was the *"Cupcake Coring"* and geology model building activity for grades K-5. The 27 teachers had a lot of fun taking core samples of their cupcakes using transparent straws and revising their cross-section models. After taking 3 core samples, they used a knife to cut their cupcake in half to reveal the unevenly baked colorful layers, just like the Earth. Then they enjoyed eating the experiment! We also distributed 20 USGS Tapestry

of Time and Terrain maps with supporting materials as part of the Maps in Schools Project.

The following day, **Saturday, October 5**, was the first **HGS-GSH Family & Friends Fall Fun Day** in The Woodlands. We brought out hands-on activities for the children and grandchildren of HGS and GSH members to enjoy and learn about what their family members do. GSH board Secretary Jennifer Graf brought her entire family, including her mother who is a teacher in the Dallas area. Thank you to Huw James and Wendy Liu for volunteering alongside me. We gave away 38 coiled toy springs. The GSH Geoscience Center also brought out a microscope and some interesting artifacts so everyone could learn about the history of our tools.

Two simultaneous events were held on **Saturday, October 12**. **The Reach for the Stars! STEM Festival at Rice University**, and the **Earth Science Celebration at the Houston Museum of Natural Science (HMNS)**. Both GSH and HGS had booths at the Reach for the Stars! STEM Festival for middle school girls. At the GSH booth, we had a laptop displaying an oscilloscope emulation program so the girls could knock on the table and observe the wave they had created. We also had crude oil samples and an interpreted seismic line. Volunteer Wendy Liu brought a tabletop plastic replica model of a 3000-year-old Chinese earthquake seismometer.

HGS-GSH Family & Friends

HGS-GSH Family & Friends

When an earthquake shook it, a ball would fall out of one of the dragon's mouths into a frog's mouth indicating the direction of the epicenter. We distributed 193 coiled toy springs and *"Earth is calling ... will you answer?"* brochures. Thank you to GSH Outreach volunteers: Rosemarie Geetan, Wendy Liu, Jagadish Maddiboyina, and Segun Adeniyi who volunteered alongside me.

The 16th Annual Earth Science Celebration at HMNS was organized by our friends & colleagues, the Houston Geological Society. The passport collection event consisted of 8 volunteer demonstration stations with hands-on activities from local earth science-related professional societies including GSH, UH SEG Wavelets, HGS, and Houston Gems and Minerals Society. Volunteers took turns running the "Drilling for Oil" game, explaining the cut-away geophone and demonstrating P & S wave motion with a coiled toy spring. Mr. Chakraborty demonstrated the concept of seismic surveys to students. He used a

Earth Science

Earth Science

Reach 4 the Stars

Reach 4 the Stars

Reach 4 the Stars
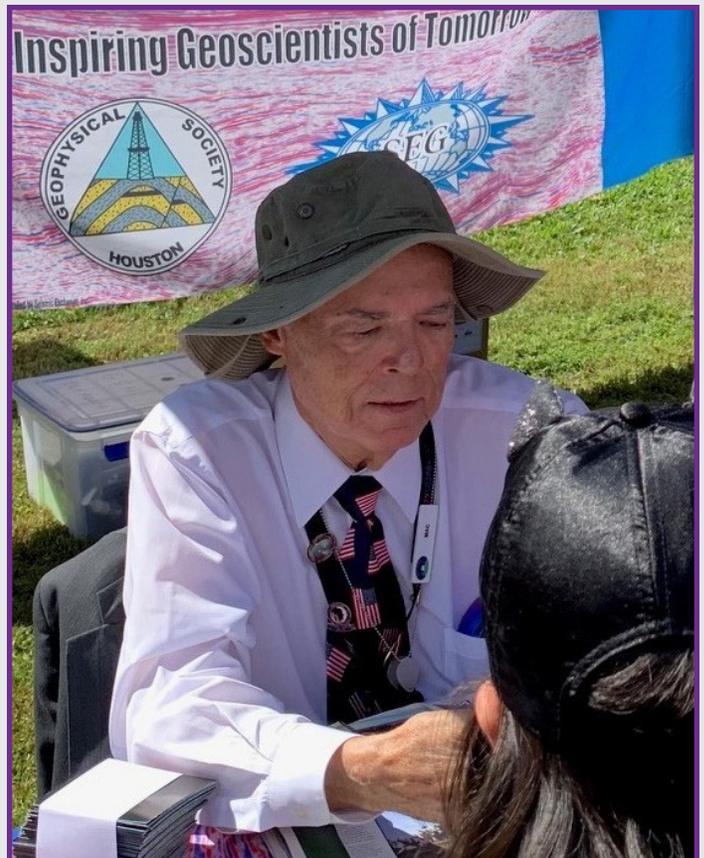
Energy Day

Energy Day

single component geophone to record sound waves using an application on the computer. The students then enjoyed listening to the recorded signal. Students were also excited to see the wavelets recorded on the computer screen. They had great fun shaking the geophone to simulate earthquakes. The volunteers then explained the Wiess Enrgy Hall museum exhibits to describe how seismic images obtained from onshore and marine surveys can be interpreted to find oil and gas deposits deep inside the Earth. The volunteers distributed 214 GSH coiled toy springs. Thank you to GSH volunteers: Huw James, Peter Lanzarone, and 3 new volunteers: Samarjit Chakraborty, Rao Yalamanchili, and Eduardo Alvarez.

The last event held on **Saturday, October 19** was the **9th Annual Energy Day Festival presented by Consumer Energy Alliance**. This free, family-friendly downtown festival was held in partnership with the City of Houston at Sam Houston Park. It is intended to educate K-12 students and the general public about all forms of energy. Please visit the Energy Day website at http://energydayfestival.org/ for more information, photos, and videos. The GSH had a tented booth with the "Drilling for Oil" activity, wave motion demonstrations, interpreted seismic lines, and oil, rock, mineral & fossil samples. There was a non-stop line of enthusiastic and information hungry students. The volunteers distributed 392 GSH coiled toy springs. Thank you to GSH volunteers: Huw James, Segun Adeniyi, Mac Hooton, Mike McCardle, Patricia Henderson, and Judy Schulenberg.

Energy Day

There are many events in January and February including school career days, science nights, and science fairs.

If you are interested in volunteering for any future outreach events, please contact Lisa Buckner at outreach@gshtx.org. □

U of H Wavelets

SEG Wavelets Win SEG Award and Host TGS

By Zhongmin Tao

SEG Wavelets received a Summit-Level award by SEG at the recent annual meeting for the 2nd year in a row! This award honors the top 10 most engaged SEG student chapters from over 200 active chapters around the world. It's a great honor to be recognized for our efforts and we hope to take it even further this year by hosting weekly events ranging from educational talks, short courses, career workshops, field trips, outreach activities, and socials.

In early October, SEG Wavelets and AAPG Wildcatters hosted the world's largest geoscience data company, TGS, for a panel on exciting technical talks. It was followed by a sponsored happy-hour social at a University of Houston venue. Industry experts from TGS gave 3 attractive talks to students and faculty. They covered advances in technological imaging and processing, a Mexican GOM geology overview, and the application of data science and machine learning in exploration geophysics. We had a great turnout and a mix of geology and geophysics students which allowed for creative discussions and questions after each talk. We look forward to working with TGS in the future to arrange more educational opportunities like this one!

Another excellent talk followed the next week. On October 8th, SEG Wavelets hosted Dr. Tom
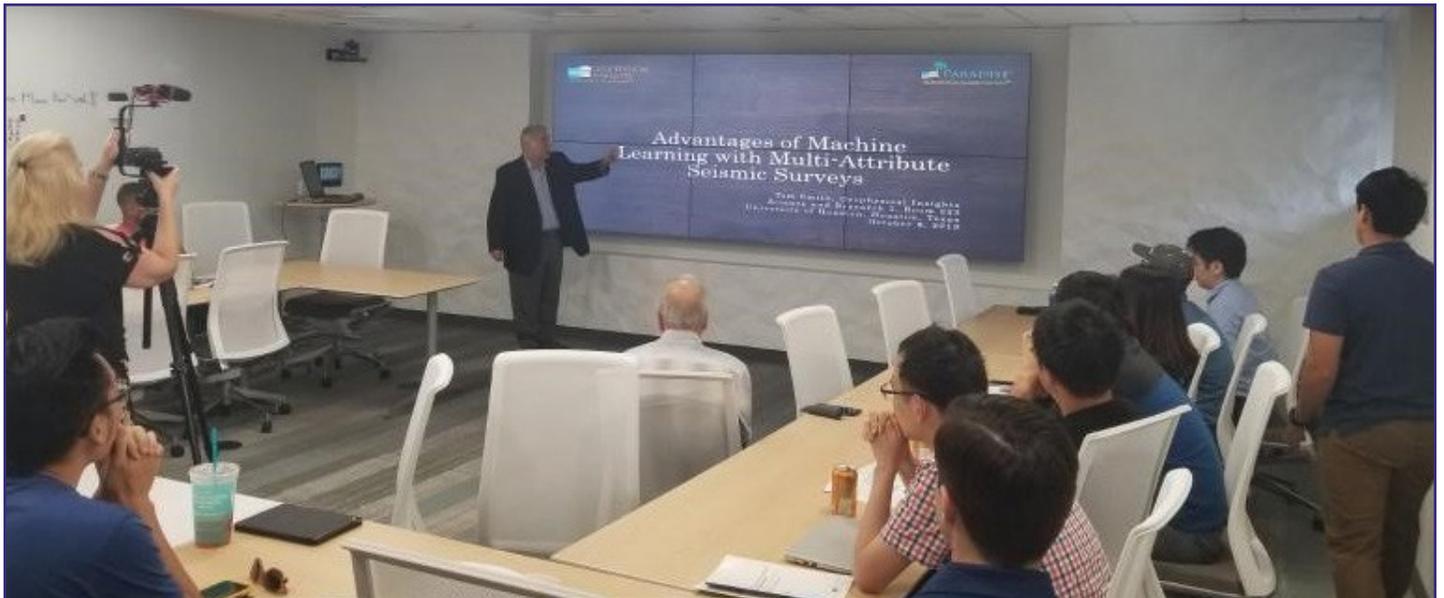
SEG Wavelets Summit Award. Left to right: Matthew Storey, Jackson Zerr, Dr. Robert Stewart, Dr. Yingcai Zheng.

Group photo after TGS talk.
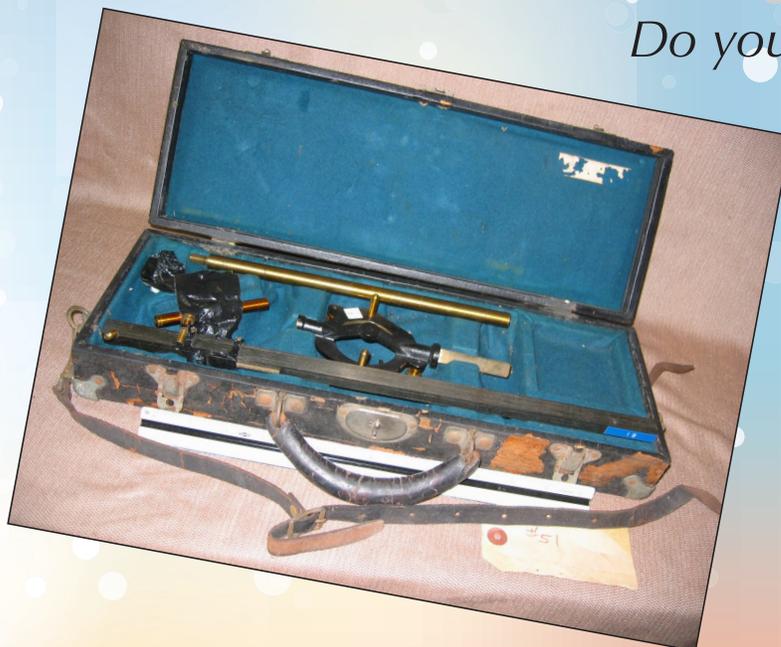
Tom Smith presenting to students about machine learning applications in geophysics.

Smith, a former UH alumnus, and president and CEO of Geophysical Insights in Houston. He introduced the application of machine learning in multi-attribute seismic surveys. Dr. Smith is a great presenter and we were glad to see students engaging with him after the talk! You can watch the entire recorded lecture at geoinsights.com. □

Mystery Item
This is a geophysical item...

Do you know what it is?

This month's answer on page 39

Geoscience Center
The History of Geophysics By Bill Gafford

1790 W. Sam Houston Pkwy. N. (Right on Shadow Wood)

HGC display 1

There is a new opportunity to support the GSH Geoscience Center through a **"Geoscience Center Challenge."** Scott Petty, Jr., Lee Lawyer, Tom Smith, and Dick Baile have pledged donations totaling $10,500.00 if that amount is matched from other individual donations. Donors will be recognized in our **"Friends of the Geoscience Center"** listing near our entrance. Financial support will continue to be solicited from companies. Donations can be made through the GSH website home page by using the **"Donate" button** or **checks** may be sent to the **GSH office at 14811 St. Mary's Lane, Suite 204, Houston, TX, 77079,** with a note that the donation is for the Geoscience Center Challenge. The GSH is a 501 (C) 3 organization.
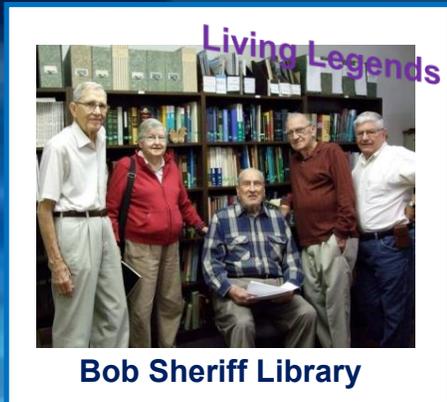
HGC display 2

GSH GEOSCIENCE CENTER CHALLENGE

Match donations by Scott Petty. Jr., Lee Lawyer, Tom Smith, and Dick Baile

DONATE NOW at https://www.gshtx.org/ or send a check to the GSH office.

Living Legends

Bob Sheriff Library

College Displays

Student Activities

Teacher Workshops

Geoscience Center

Meeting Space

Cataloged Artifacts

Donations support Programs and Activities of the GSH Geoscience Center including:
Geoscience Artifact Cataloging and Storage, Loans to Colleges and Universities for Display,
Bob Sheriff Library, Meeting and Seminar space and Living Legends. The GSH is a 501(c)3 organization.

Also, check to see if your company has a matching donation program and if so, those funds will be included in the challenge.
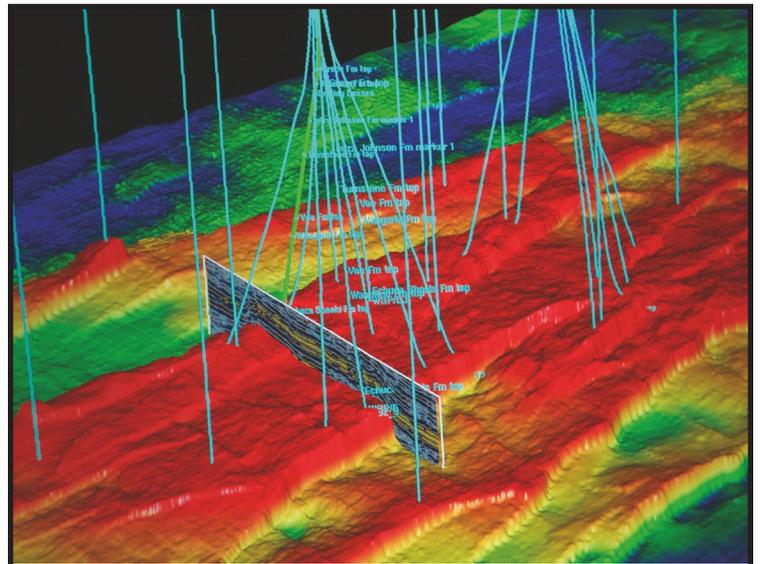
We participated in the First Annual HGS-GSH Family and friends Fall Fun Day on October 5, with two tables displaying some of the geoscience artifacts from our Museum Collection. This event, at the Rob Fleming Recreation Center in the Woodlands, was a family event so I was able to explain how some of the displayed items were used in early petroleum exploration to children as well as adults. I included a rotating slide show which included pictures of some of our artifacts and pictures of various Geoscience Center events and local displays of our museum items. Also included was a microscope with some fossil slides and a laptop showing the response of a cut-a-way geophone. Pictures of the table displays are included in this article.

We continue to receive donations of books, training manuals, and periodicals. They are all available to be checked out. We also have a bookcase of duplicate books and other publications that are free to anyone who visits the Geoscience Center.

Our Living Legends Doodlebugger social event in November was well attended and we enjoyed having some new attendees. While these free quarterly events were originally planned for retirees, everyone is welcome, and registration is not necessary. □

The Geoscience Center is open on Wednesday mornings from 9:00 am to 12:00 pm or by appointment, and visitors are always welcome.

Please contact me at:
geogaf@hal-pc.org or by phone at:
281-370-3264 for more information.

Recognizing Outstanding GSH Volunteers...

Russell Jones *By Tommie Rape*

The many social and technical opportunities offered by the Geophysical Society of Houston (GSH) for the geophysical profession of Houston and beyond are due largely to many dedicated volunteers. The GSH wants to recognize some of these dedicated volunteers and will do so through this series of articles where we will present a selected volunteer and provide our readers with some of the volunteer's professional and volunteer background. Hopefully this will increase our readers' appreciation of these volunteers and encourage them to join the GSH volunteer ranks where they can partake of the many benefits that this work provides.
— Tommie Rape

Russell Jones was born in Leamington Spa, England and raised in Wirral, near Liverpool. After obtaining a Bachelor's in Geology from Oxford University, he saw the error of his ways and then acquired a Masters in Exploration Geophysics from Leeds University. Russell went to work for Ensign Geophysics in Addlestone, England, in 1993. He moved to Houston in 1997 in what was supposed to be a six-month assignment, but as fate would have it, he ended up staying much longer. Russell changed employers to Geotrace in 2002 where he became General Manager of Marine Operations. After obtaining a Green Card, Russell went to work for Seitel in 2008. After holding the position of Processing Manager for six years, he moved to his current position as President of Seitel Data Processing and Seitel Solutions.

Russell and his wife Giuliana, who is from Venezuela, both became US citizens in 2013, and Houston is their home for the foreseeable future.

Russell has been a long-time member of the GSH, and he became much more active in the GSH six years ago, when he became the Chair of the GSH Tennis Tournament. He still chairs and organizes the very popular annual tennis event. Russell says he continues this organization task because he is gratified to see that the participants have such a good time and because he wants to stay heavily involved in the GSH. Plus, he has made some great friends through the tennis event and he looks forward to making many more. The GSH is very grateful for Russell's continued involvement in this event, which provides a very entertaining time for its members, raises funds that help the GSH continue to provide technical events for the Houston geophysical profession, and inspiring outreach to youth in the greater Houston area.

However, Russell's support of the GSH is not limited to the tennis event. Perhaps of even greater value to the GSH, he very actively promotes others to get more involved in GSH's technical and social activities. Russell's employer, Seitel, is one of the great corporate supporters of the GSH. Seitel, in addition to providing sponsorship to many GSH events, is a corporate member. Credit also must be given to Liza Yellot, who helps coordinate the significant funding for the GSH. Russell is not satisfied with just his employer providing very important funding for the GSH, he heavily encourages Seitel employees to become involved in GSH activities. Russell ensures that the individual memberships that go with Seitel's corporate membership are distributed to Seitel's employees, and he strongly encourages those employees to attend GSH events and to volunteer their help for the GSH. He helps his fellow employees, particularly the younger ones, and recognizes the many benefits to be gained by their active involvement in GSH (and other)

activities. He encourages them to broaden and deepen their technical knowledge by attending technical events and encourages them to take advantage of networking opportunities and get to know other geophysicists that may help their career now or someday in the future. In addition to making contacts, the interaction with other geophysicists helps young new professionals become more comfortable around other people in technical discussions. Russell also encourages his employees to take clients with them to both technical and social events. Russell strongly promotes the premise that companies, particularly service companies, will benefit from these contacts. And if it helps the GSH, so much the better.
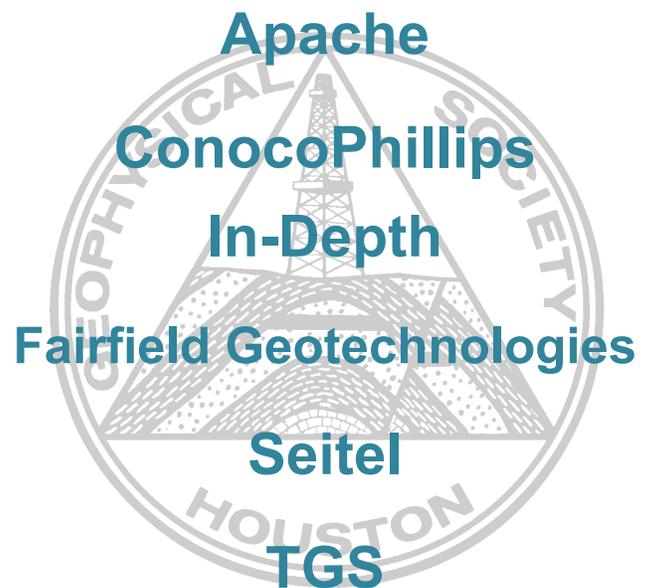
When asked to provide advice for other geophysicists he, of course, mentioned the potential benefits described above of getting involved in professional activities. Then Russell had strong advice for other companies as well. He said that other companies should not be content to tolerate its employees participating in professional society activities; the management of these companies should strongly encourage the involvement of its employees in professional societies because companies stand to benefit as much as the individuals. Many employees are often reluctant to get involved in these activities because they think it takes time away from their jobs, which may be frowned upon by their supervisors. Russell says that supervisors and management must

make their employees recognize that their involvement in professional activities is not time away from their job, it is an important and beneficial part of their job. This encouragement will help the employees and their companies benefit.

Russell's generous sharing of his time is not limited to professional activities. He also is dedicated to helping the youth of our community. Russell and other employees of Seitel are frequent workers and mentors at events for the Spring Branch School District. They work at school Field Days, undertake middle and high school mentoring, and they participate in the annual Dr. Suess 'Cat in the Hat' performance in English and Spanish, which aims to promote literacy within the community. When asked what he gets out of this nonprofessional volunteering Russell says that this volunteer involvement makes himself, and the person he is helping, feel better.

We are all very grateful for all that Russell has done for the GSH and us as individuals. If you are a tennis player, be sure to tell Russell that you hit an ace for him. If you are not a tennis player, be sure to tell Russell that you are grateful that he has helped make the GSH a better organization for all of us. □

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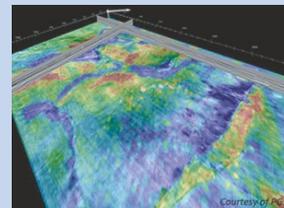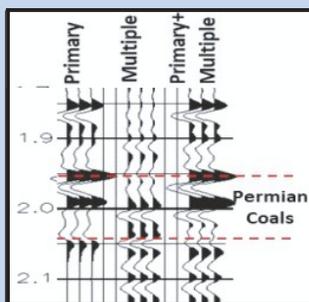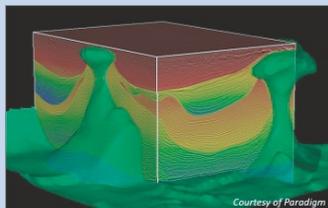
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A Conversation With... *Jim Gaiser*

By Alvaro Chaveste

Jim Gaiser

In this lively conversation (part 2 of 2) Jim goes, a bit, over the history of S-wave technology; addresses practical and technical aspects of past and emerging techniques; and talks about his view of the technology's future.

Alvaro: Thanks for accepting doing the second part of the interview Jim. I'd like to ask you now about S-wave technology. Seismic wave propagation results in mode conversions and propagation effects from which a wealth of information can be obtained, yet the industry is complaisant with using mostly P-wave data. From your perspective, what is the reason for this?

Jim: Yes, S-waves contain a wealth of information. They are unique compared with P-waves because there are usually two of them traveling in a given direction. The physics associated with S-waves makes them extremely valuable as a complement to P-wave applications. All three wavefields are coupled with each other.

I think that our industry is interested in using recorded S-waves. We must understand them better and demonstrate a clear cost benefit. We appear to be complaisant, because that hasn't happened yet. There are several factors involved. One of these is our reluctance to invest in new technology, because of a lack of proof that they are beneficial. Thus, we end up not learning about S-waves and becoming more familiar with them. We need to learn how to incorporate S-waves in with the interpretation process. I am speaking of the industry as a whole. There are areas of acceptance and we're seeing this grow.

Another factor is, keeping up with advancements in P-wave technology. This requires a tremendous investment and It is difficult to convince asset managers to also include PS-waves. Additionally, and unfortunately, we must admit that S-wave technology has occasionally been oversold. In our enthusiasm we claim that "S-waves will solve all our problems" – not in exactly those words, but you get the idea. This ends up giving the technology a "black eye". We must learn from this and be careful. One early example of this was the implication that "S-waves are best for lithology discrimination" – then came AVO! Well, the rest is history. Even though S-waves could help validate "bright spots", acquiring an expensive multicomponent (MC) survey did not make it cost effective. What we didn't appreciate at the time was joint AVO to use S-waves with P-waves.

Another one was that "S-waves are the best way to image through gas obscured regions". Initially that was true but with PSDM it could be done with P-waves, given the proper velocity model. Indeed, PS-waves helped initially but now they are no longer required. Again, we didn't focus on the benefits of joint PSDM.

There have been others as well: like S-waves from shape-charges and, in my opinion, the most recent example is converted SP-waves that utilize S-waves radiated from P-wave sources – like vertical vibrators and buried explosives. Although the potential upside is huge, we must be careful and understand the true limitations of the technique before making broad claims about how valuable they are.

Alvaro. I see your point regarding the industry needing to learn how to incorporate S-waves into the interpretation process. As a geoscientist, I can tell you that we don't always understand how field data was acquired and processed, or how it can be used in an exploration/production context. To help me and the readers better understand, could you briefly explain how are S-waves recorded?

Jim: Certainly, but it may not be so brief. ☺ The possible combinations to acquire and process S-wave data is extensive, however, the amount of information that can be acquired could be daunting and enough to scare the bravest of processing geophysicists. Take, for instance, an acquisition survey with 3 component sources (P-wave and two S-wave) and 3 (or 4) component receivers. This would result in a dataset 12 times larger than the P-wave alone. However, in the looming age of "big data" and "artificial intelligence" this amount of effort may become the norm.

Incidentally, I use the term "P-wave and S-wave source" loosely because technically it is not correct. Most sources radiate both P- and S-waves, except, of course, the marine air gun. It's technically more correct to call them vertical and horizontal sources in the case of vibrator and impact sources. Even buried explosives, close to the free surface, radiate S-waves from a point directly above the source at the surface.

Coming back to the acquisition techniques, the first technique to be developed extensively was to acquire pure mode S-waves (or SS-data). That is shear down and shear up. Here I am speaking about 9C data with 3 sources and 3 receivers. A subset of that is the 4C SS-wave data, which are just the horizontal sources and detectors. These S-wave sources radiate strong S-waves over a fairly wide range of vertical angles and azimuths and illuminate the subsurface very well.

In the '90s, P- to S- converted-wave (PS-waves) technology emerged commercially. This acquisition technique uses conventional P-wave sources which illuminate the subsurface with a tremendous angular range, from vertical to over 60 degrees in all azimuths. The physical "source" for the S-waves comes from the P-wave itself by creating S-wave reflections at shear impedance contrasts. Thus, it can be applied both on land and in marine environments. 3C receivers are required, which may impact cost and field operations for land but not for marine surveys, which mostly use 4C sensors. For land surveys, using 3C receivers does not increase the cost of field operations by a factor of three. Depending on the systems used, the operation's cost may not be impacted at all.

Recently, a variation on these techniques is Bob Hardage's SS- & SP-waves for land acquisition. It uses S-waves radiated from conventional P-sources that can record both pure-mode SS-data from horizontal receivers and converted-wave SP-data on the vertical receiver. But... is it advantageous to do SP acquisition instead of PS? We don't know yet – we need more examples. The potential is tremendous since all legacy P-wave land data could be reprocessed, although marine data couldn't since airguns don't radiate S-waves in water. If Bob's SP-wave proposal if successful, 3C receivers may not be necessary for land applications; although the challenge would be separating fast and slow S-waves without having the benefit of directionality.

Another upside of SP-waves, as Bob suggests, is that much of the multiple energy we experience with P-waves could be converted SP-waves. I agree with this in general because SP-waves are "primary" reflections with only one conversion—the S- to P-wave reflection coefficient (RC). P-wave multiples have at least three conversions: the primary P- to P-wave RC, plus two other conversions, one from an upgoing RC, and another from a down-going RC. These three conversions multiplicatively decrease the amplitude of multiples.

Challenges for SP-wave technology include the low S/N ratio of SP-wave data in the presence of strong pure-mode PP-wave reflections. Also, SP-waves do not illuminate the subsurface as much as Bob suggests. Illumination is limited to a narrow band of near-vertical incident angles: from around 5° to 35°.

Alvaro: Good to know! We can get some of the benefits of S-wave data without the need of an S-wave source and 3C receivers. You mentioned the importance of directionality of sources and receivers. Can you expand?

Jim. Remember how I said there are usually two S-waves? Well, there are fast and slow S-waves that interfere with each other. The good news is they can provide valuable information about stress and geomechanical properties. The bad news is they require special processing to separate fast from slow. This separation is easy if you have directionality from two horizontal sources and/or two receivers, but it is unknown for SP-waves with only vertical component receivers.

S-wave sources generate a horizontal ground force, which has complicated radiation even for isotropic or VTI (vertical transversely isotropic or layered) media without fast and slow S-wave splitting. SV-waves are radiated with particle motion in vertical planes. SH-waves, on the other hand, are radiated with particle motion in horizontal planes. The bottom line is that to fully illuminate the subsurface in all azimuths with both wave-types, we need two S-wave sources oriented perpendicular to each other. Unfortunately, this can be a big expense and deterrent for many companies. Nevertheless, these S-waves can have an excellent S/N ratio even when we assume isotropic or VTI media.

Historically, horizontal source data has also been acquired to measure S-wave splitting in azimuthally anisotropic media. This can be an important property for fracture characterization with proper constraints from borehole data. We should keep in mind that converted waves also experience S-wave splitting and this must be considered in the processing, even if they are not of interest for the reservoir.

Alvaro: From the previous comments it seems like the industry could be getting, now, the benefits of recorded S-wave with a small, or no, incremental cost and effort. You mentioned, at the beginning of the interview, reasons why this is not happening as much as it could. Would you like to add anything?

Jim: There was an interesting presentation in my 2017 post-convention SEG workshop by Peter Cary who addressed some of the issues. Although "large quantities of high-quality 3C surveys are now routinely acquired at virtually the identical cost as conventional 1C surveys" in Canada, S-wave exploration is not widely established. "Some individuals within some companies use it to gain value in their exploration effort." "The primary problem is not the quality or cost of the acquisition, lack

of available data or the processing". However, "we should not be quick to point the finger at interpreters either". The added cost of educating the workforce and developing the experience poses a dilemma to most companies since it is easier to use familiar techniques than to develop new ones.

One problem has been trying to use S-waves as a stand-alone tool when these should only be considered an aid to P-waves. We need to always ask the question, where can recorded S-waves help the P-wave effort? If they can provide better constraints or resolution and increase the petrophysical understanding of reservoirs, then we have added value. We should not expect that shear wave technology will be utilized in 100% of our business.

That being said: resolution and S/N of S-wave data can, at times, be disappointing compared to P-wave. There are probably many unpublished case studies where shear waves have failed to add value.

Alvaro: Can you give us your vision for the future of the technology?

Jim: Yes, never make predictions, especially about the future 🟡. Many times, I have been wrong!
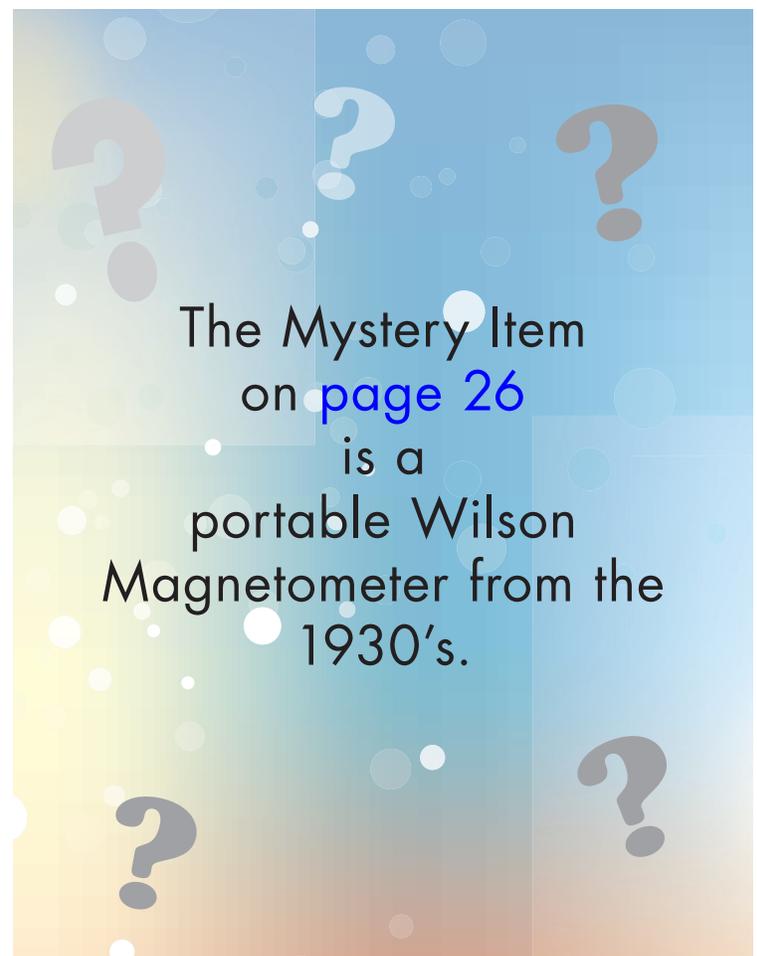
Seriously, I think we're beginning to see S-waves embraced a bit more. Many examples were highlighted in my post-convention workshop at the SEG this year, co-organized with Jim Simmons at the Colorado School of Mines and Henri Houllevigue at Total. The title was, "Joint imaging/inversion of S-waves with P-waves". It was about advances in characterizing overburden, elastic models and petrophysical properties related to conventional and unconventional reservoir development.

Numerous presentations and lively discussions were about topics from joint imaging in complex geology and advances in tomographic inversion for orthorhombic velocity models, to joint inversion of PP & PS-data for petrophysical applications and litho-facies classifications. Interestingly, there were mixed results in the fidelity to invert for

density: some studies showed density was well resolved and others showed it didn't work! There appeared to be a dependence on VP/VS. Also, there were several examples showing excellent quality pure-mode SS-data from horizontal sources that was as good or better than the P-wave data. Perhaps we've come full circle in the past 40 years since the original Conoco Group Shoot in the 1970s.

The bottom line is, anywhere that shear information is needed for petrophysical characterization there is an opportunity for recorded shear wavefields to contribute. In this era of large datasets and machine learning applications, maybe we'll begin to see S-waves incorporated more in our seismic-petrophysical analyses.

Alvaro: Thank you very much Jim. It has been informative and educational. I appreciate it and I'm sure the readership will appreciate it as well. □

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on page 26
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Doodlebugger Diary
Party 1620 Lasts Through Harsh Turkish Winter
By Roger Ticker
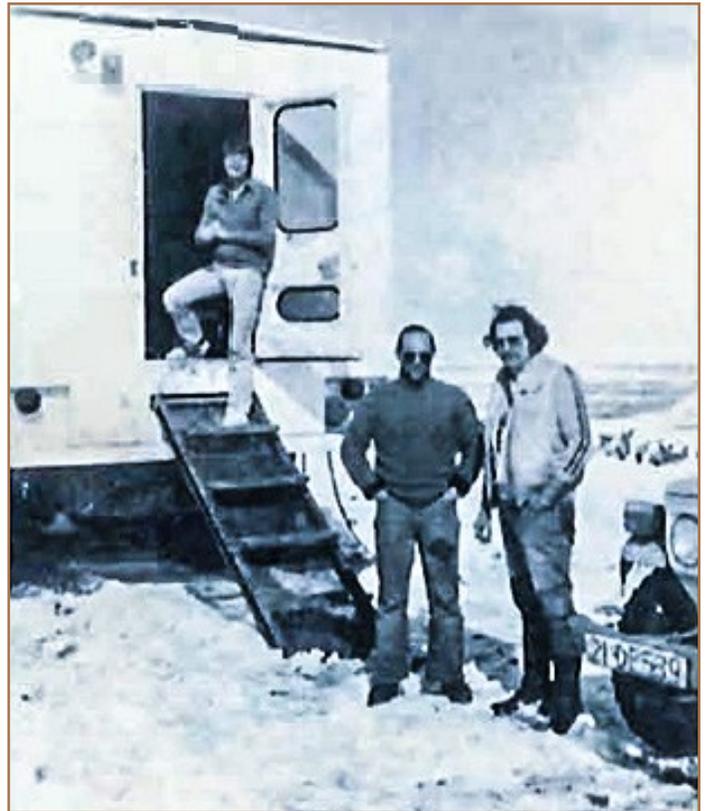
The Doodlebugger Diary recounts the experiences of geophysicists during their working lives. During the last two years I've been recounting my own experiences but in June of this year I shifted to publishing three episodes of SEG Past-President Nancy House's experience in the Peruvian jungles. This fall and continuing next spring I'll be reprinting a series of articles from the GSI Shotpoints which is one of many archived GSI publications maintained by Bill Boettcher at http://gsinet.us/. *This month's article comes from Vol. 2 #6, published in June 1982.*

GSI'S Party 1620 mobilized in southeast Turkey during October 1981 in the shadow of approaching winter. The advance party of John Jones, operations supervisor, and Bob Curley, survey supervisor, told tales of warm, pleasant summer weather, but there are those on the crew who have yet to believe them. With the challenge of being the first seismic crew to work through a Turkish winter ahead, the battle was on.

Party 1620's trailer camp had been specially modified for the cold weather including extra heaters, double glazing and a drying room for wet clothes, but little could be done to relieve the discomfort of the men in the field when winter set in. Most of 1620's personnel had worked in desert conditions before, but they soon packed away their shorts and sandals and donned parkas, gumboots and thermals.

The crew is equipped with 96 trace, DFS'V and FT 1 units and uses four TR-4 vibrators which have been specially winterized. Unimogs serve as cable trucks and are a great advantage in the half-frozen, muddy fields and in the ice and snow. A snow plough and snow blower are available and could easily be added to the front of a Unimog. Camp and vibrator

Bob Crumpler, Peter Wren and John Brittain enjoying the brisk snowy day at Party 1620's recording trailer.

mechanics had the "luxury" of having a large heated tent in which to tend their vehicles.

The major problems the recording crew encountered were those related to leakage in the geophone spread. On days of continuous rain and when the snow began to melt, the junior observers had an uphill battle.

To help eliminate the leakage problem, plastic bags were used to cover cable connections. The recording

crew, led by Colin Brown and instrument engineers Steve Brown and Malcolm Robertson with assistant instrument engineers Bob Crumpler and Peter Wren are to be commended for their perserverance and dedication in the adverse conditions.

Freezing conditions made access to the off-road lines relatively easy, but when the thaw started, the fun began. Frozen fields quickly turned to deep mud and operations had to be confined to lines along firm roads. The crew won't soon forget the heavy red mud caked on everything. Gravel paths that the crew constructed between the trailers kept everyone on his own two feet in the camp. Party 1620 made it through the Turkish winter, and summer is fast approaching.

Logistic support is primarily from the GSI office, staff house and yard in Diyarbakir, a large town located on the Tigris River in southern Turkey. The office is capably run by Hilmi Araz, administrator, who provides most of the crew's local purchase requirements, and offers accommodation for crew members in transit between Ankara and Party 1620. Other facilities in Diyarbakirinclude a survey office run by Bob Curley and an instrument workshop run by Bob White, Turkey recording supervisor. As more crews mobilize in Turkey the Diyarbakir base will become more and more important.

The main office for the Turkey operation is situated in Ankara and is staffed by Roger Tickner as operations supervisor, Steve Kroehnert, administrator, together with a capable staff of Turkish employees.

Several personnel changes have occured on 1620 during the winter due to the rapid expansion within Europe, Africa, and the Middle East. Operations supervisor, John Jones transferred to Egypt and was replaced by Roger Tickner. Les Wiseman, party manager, also transferred to Egypt and was replaced by Bob Rust who is presently party manager of 1620. Other personnel on the crew who have not yet been mentioned are QCs Doug Cook and Mehmet Valcin; APM John Brittain; vibrator mechanics, Keith McQuade, Robin Howden and Darren Wright; surveyors, Dave Calladine and John Hemingway; and camp mechanics, Trevor and Dave Poole (not related).

The 1620 Turkish Employees are too numerous to list but those deserving a mention are camp boss, Mike; medic, Rick, permitman, Hady, and last but not least the camp guard, a Turkish shepherd dog called Columbo. □

Party 1620's TR-4 vib trucks on line and getting ready to record a shot. Note that the first vib truck is lifted in the air being supported by its vib plate as it goes through its tests.

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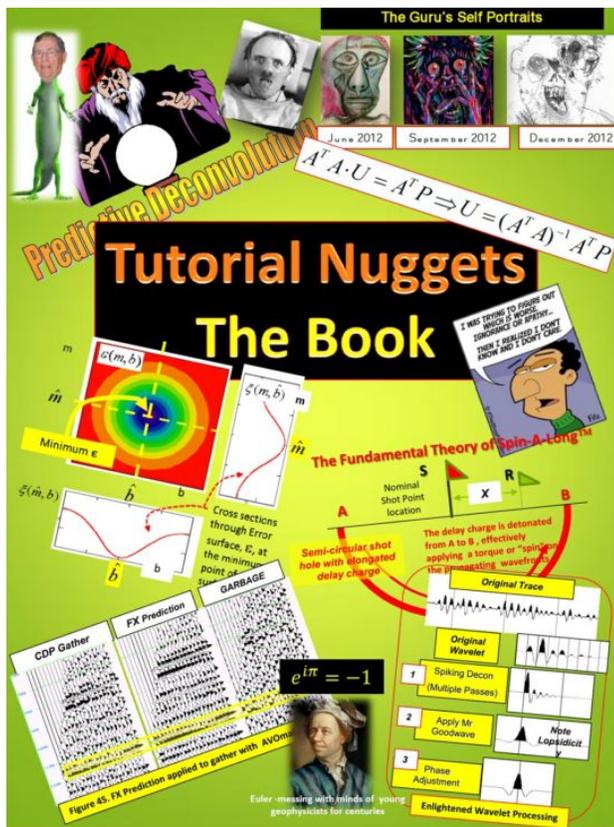
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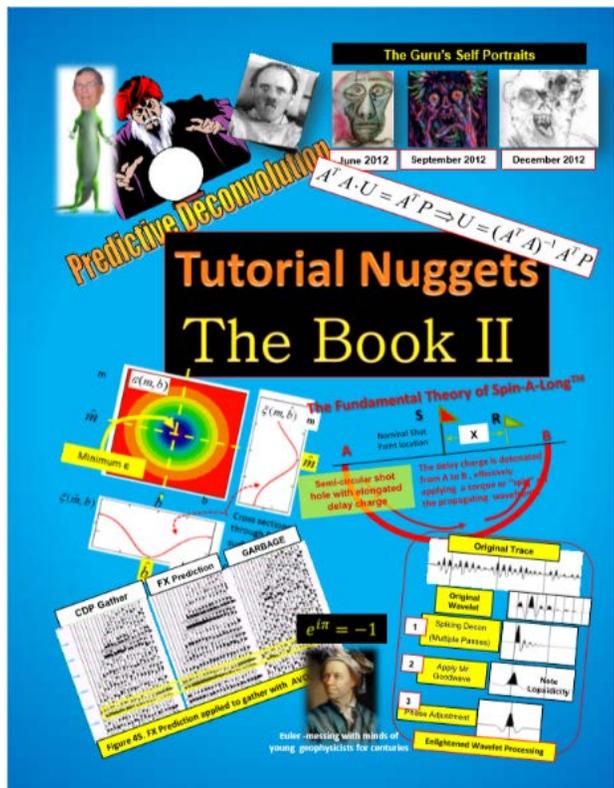
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