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October 2019

GSH Journal

GEOPHYSICAL SOCIETY OF HOUSTON

Volume 10 • Number 2

**U of H Wavelets:
A Machine Learning Approach to Predicting Magnetization
Directions – Page 27**

**Doodlebugger Diary:
My Experience as the Mobil Oil Technical Lead for
the Exploration of the Madre de Dios Basin, Peru
Part 3: The Secrets of the Las Piedras Block, Peru – Page 43 |**

**Upcoming Events:
Saltwater Fishing Tournament, October 11, 2019
– Page 16**

**GSH Fall Forum, Save the Date - November 1, 2019
– Page 37**

TABLE of CONTENTS

• • MEETINGS • •

Technical Luncheons 8 |

Frac Hit Prevention and Engineered Treatment Design in the Permian Basin Using In-Situ Stress from 3D Seismic

Technical Breakfasts 10 |

Use of Seismic Attributes and Open-hole Log Data to Characterize Production Variability in a Fractured Carbonate Play: A Case Study From Madison County, Texas

Unconventional SIG 11 |

*Microseismicity in Texas, Part 2:
The Geology of Active Earthquake Sequences in Texas*

Data Processing & Acquisition SIG 12 |

New Methods for Processing and Acquisition to Improve Land Seismic Data Quality

• • FEATURES • •

Technical Article 17 |

Time-lapse Seismic Monitoring of Individual Hydraulic Frac Stages Using a Downhole Distributed Acoustic Sensing Array

U of H Wavelets 27 |

A Machine Learning Approach to Predicting Magnetization Directions

Doodlebugger Diary 43 |

*My Experience as the Mobil Oil Technical Lead for the Exploration of the Madre de Dios Basin, Peru
Part 3: The Secrets of the Las Piedras Block, Peru*

• • CHECK THIS OUT • •

HGS - GSH Family & Friends Fall Fun Day 13 |

Saturday, October 5, 2019

GSH-HGS Joint Society Dinner 14 |

*October 7, 2019
Plates to Prospects: Integration of data at multiple scales to enhance exploration, with insights from the deepwater fold and thrust belts offshore NE Mexico*

Saltwater Fishing Tournament 16 |

October 11, 2019

Fall Warm-Up Sporting Clays 35 |

Wrap Up

GSH Fall Forum 37 |

Save the Date - November 1, 2019

GSH-SEG Webinar Series 39 |

is Online

Tennis Tournament 40 |

Save the Date - November 8, 2019

• • LOOK INSIDE • •

3 • • • Organization Contacts

4 • • • A Word From the Board

*By Peter Wang,
First Vice President*

5 • • • Letters to the Editor

6 • • • From the Other Side

By Lee Lawyer

9 • • • Annual Sponsors

25 • • • Corporate Members

25 • • • Mystery Item

Do You Know What This Is?!

26 • • • GSH Outreach

Committee Activities

32 • • • Geoscience Center

On The Cover...

Environmentally friendly seismic surveying.

*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

Dec 2019 Oct 11
Jan 2020 Nov 8
Feb 2020 Dec 13

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A Word from the Board

Generations

By Peter Wang, First Vice President



Who can forget that memorable scene from the 1997 movie, "Good Will Hunting"? Chuckie (played by Ben Affleck) delivers a moving monologue where he is trying to encourage his friend Will (played by Matt Damon) to engage his incredible

mathematical talents, seize life by the horns, and get the heck out of South Boston:

CHUCKIE:

"Every day I come by your house and I pick you up. And we go out, we have a few drinks, and a few laughs, and it's great. But you know what the best part of my day is? It's for about ten seconds from when I pull up to the curb to when I get to your door. Because I think maybe I'll get up there and I'll knock on the door and you won't be there. No goodbye, no see you later, no nothin'. Just left. I don't know much, but I know that."

We on the GSH Board have pondered and fretted about how to engage the talents and energy and participation of early career Geophysicists. We ask ourselves frequently, with sincere puzzlement, "What do the Millennials want from the GSH?"

The way the question spills from our mouths... it sounds like Millennials are a mysterious species from an unknown continent. The deeper problem is this - in ten years, we will all be retired or even more retired than we are now. Which means we won't be participating in the GSH very much at all. This is a common problem faced by the GSH, Rotary Club, GOP,

mainline Protestant churches, and many other organizations. The membership and leaders are aging-out.

Here's what I think needs to happen. It has to play out for GSH the way Chuckie wants it play out for Will in "Good Will Hunting". I think a squad of early career Geophysicists needs to stand for election to the leadership of the GSH, and just replace all of us older people in one fell swoop. Sort of like what happened to the Houston Energy Corridor's U.S. Congressional District Seven Representative, and the Harris County Judge. Two older men were replaced by young women on Election Day 2018.

Like Chuckie, I'd like nothing better than to open up the GSH Journal in Spring 2020 and find that people my age and older are gone from key leadership roles. "No goodbye, no see you later, no nothin'. Just left."

Then GSH won't have to ask what do Millennials want. The new officers would just drive the organization to meet their needs.

I think of the words of another Bostonian, President John F. Kennedy, who said during his inaugural address in January 1961:

"Let the word go forth from this time and place, to friend and foe alike, that the torch has been passed to a new generation of Americans, born in this century, tempered by war, disciplined by a hard and bitter peace, proud of our ancient heritage..."

Gen X, Millennials and Gen Z: The torch is ready to be passed. Are you going to step up to receive it? We veterans are here to assure a successful hand-off. □



Dear GSH Journal readers,
Please feel free to contact us with any and all questions or suggestions that you may have. My email is listed below. Additional Organization Contacts can be found on page 3.

Sincerely,
Alvaro Chaveste, Editor, at
Alvarochaveste@hotmail.com



Upstream Oil & Gas Hiring Event SPE Gulf Coast Section

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- Registration **PRIOR** to Attending - **(NO WALK-INS!)**



From the Other Side

By Lee Lawyer



I have been beating the tom-tom (drum) for a polite merger of the SEG and the AAPG. The overlap in missions is large. The overlap of membership, while unknown, is probably about 20%. Forty years ago, it was larger, maybe 40%. Geophysicists became more data-oriented and less interpretative, however, despite the differences my

question is “why not merge?”

I apologize to the GSH for using the journal to plug for a move that would not affect them. For those of you who don't know a red rock from a green rock, there is a geological society in Houston called the HGS. Have you noticed the similarity in nomenclature? I believe it was Rob Stewart who responded to my June FTOS column asking why the GSH and HGS haven't merged. Good question, Rob. They were housed in the same office for a few years but never merged. I say, “why should we”, rather than, “why not”. Am I being inconsistent in this position, for SEG and AAPG to merge but not GSH and HGS? Wow!

I have no idea how much overlap in membership exists in GSH/HGS. I think that it is less than the SEG/AAPG, but I don't know that for sure. The GSH/HGS are hands-on, local societies. This is not true for SEG/AAPG. Local societies meet at board and technical meetings monthly and occasionally for fund-raisers, whereas the AAPG/SEG meets twice yearly for workshops, etc. I need to get the AAPG/HGS in this discussion, somehow... pass the word.

[The following headline showed up on my screen few weeks ago. It caught my eye because I like gold, especially when geophysical methods are used to find it.]

Application of Geophysical Methods to Gold Prospecting: An Example from Loulitou District, Jiaodong Peninsula, Eastern China

In this study, based on analyzing previous geological data, some geophysical methods, such as high magnetic measurement, DC resistivity combined profiles, induced

polarization (IP) survey, were applied to constrain the distributions of the stratum, structure and magmatic rocks as well as ore-controlling factors in the Loulitou district, Jiaodong Peninsula. Finally, the interpretation of surface and underground IP data were used to guide ground prospecting. Through above geophysical work, several possible favorable abnormal locations for concentration of ore-bearing sulfides were distinguished and several locations for gold prospecting were verified by drilling.

This is a paper written by a person (*Langeo Instruments*) whose language is probably Mandarin. The paper needs a little editing for us English speaking types. I worked with Chinese delegations coming to the U.S. 40 years ago. Chevron hosted several of them. Also, I attended the first technical meeting in Beijing, where 40 SEG members met with 40 Chinese geophysicists to exchange ideas. I will do a little editing or paraphrasing but remember what they call a person who has only one language... wait for it... AMERICAN. That includes me.

Also note that there is no mention of Seismic Data. You ask, “How do they know seismic won't work, if they haven't tried it?” Chevron bought a minerals company many years ago, thinking that they had a lot of expertise in exploration. Why not minerals? The Chief Geophysicist of the minerals company decided to discover the value of seismic data. He shot a fairly long line across some igneous outcrops (eek!) and found out why we don't use seismic data in mineral exploration. (Or maybe he just shot the data in the wrong area? Or used the wrong acquisition parameters?)

We ‘arrogant’ seismic types use various names for other geophysical methods. We usually group them into a category called “non-seismic methods”. For example, potential fields and electrical methods. The Schlumberger brothers measured resistivity using an electrical source. Essentially, they put current in at point A and measured how much came out at point B. It may be a little more complicated than that. One of the brothers decided to try the same method down a hole and that's how an industry was founded.

I have no clue what “induced polarization” is. I know we induce small earthquakes, seldom over one or two on the Moho's Hardness scale... no that's

From The Other Side continued on page 7.

not right... whatever. While I have deduced the locations for many interesting Oil and Gas prospects from seismic data, I have never induced anything that is polarized. I am kidding. Thinking about polarization, maybe one could equate anisotropy with polarization. Anisotropy means the formation is different in different directions, but we don't induce it. We measure it using velocity.

Be cool non-seismic people. I am extolling the virtues of geophysical methods used when prospecting for gold. How about using a metal detector? It doesn't detect anything very deep or under water. I don't know that. Maybe there is a water-proof metal detector that would sweep the lake bottom for gold nuggets. I saw a TV program where people were searching an area with metal detectors looking for meteorites (containing iron, not gold).

I tried to get the GSH Journal to publish the article. No dice, so I included a synopsis in this column. □



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is like stopping a clock to save time."
- Henry Ford*

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Technical Luncheons

Frac Hit Prevention and Engineered Treatment Design in the Permian Basin Using In-Situ Stress from 3D Seismic

Register
for Tech Lunch
Westside

Register
for Tech Lunch
Downtown

Register
for Tech Lunch
North



Dr. Michael Shoemaker

Speaker: Dr. Michael Shoemaker, Callon Petroleum Company

Westside

Tuesday, Oct. 15, 2019

11:00 a.m. – 1:00 p.m.

Location: Norris Conference Center (City Centre)
816 Town & Country Blvd.
Houston, TX 77024
(Free parking garage)

Downtown

Wednesday, Oct. 16 2019

11:00 a.m. – 1:00 p.m.

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

Abstract:

E&P companies in the Permian Basin typically implement basin-wide development strategies that involve cookie-cutter type methods that use multi-well pads with identical geometric stage and cluster spacing.

Such development strategies however fail to recognize and account for subsurface stress heterogeneity, and thus assume similar geomechanical properties that are homogeneous and isotropic which may cause well-to-well interference or “frac hits”, particularly near “parent” wells as fields continue to mature.

Minimum horizontal stress (S_h) is the leading parameter that controls hydraulic fracture

Northside

Thursday, Oct. 17, 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.**

stimulation, but is next to impossible to measure quantitatively, especially far field and in 3D space. In-situ stress differences from fluid depletion, combined with stratigraphy and subsequent mineralogy contrasts, control fracture containment vertically and laterally which define fracture propagation and complexity. Far field preference of virgin rock towards brittle vs ductile deformation is governed by mineralogy which defines the elastic moduli or geomechanical behavior of the rock. When integrated with pore pressure and overburden stress, the elastic rock properties are characterized by the Mechanical Earth Model (or MEM) which defines key inputs for calculating S_h using the uniaxial Ben

Technical Lunch continued on page 9.

Eaton stress equation. However, implementing this model historically produces incorrect calculated stress, when compared to field measured stress, due to an assumed homogeneous and isotropic subsurface.

Parameterization of fracture geometry models for well spacing, frac hit mitigation, and engineered treatment design in shale (or mudrock) requires an anisotropic in-situ stress measurement that accurately captures subsurface stress states. A method herein is proposed that achieves this using a modified version of the anisotropic Ben Eaton stress equation. The method calculates minimum horizontal stress by substitution of AVO seismic inversion volumes directly into the stress equation, replacing the bound Poisson's ratio term with an equivalent anisotropic corrected Closure Stress Scalar (CSS) defined in terms of Lamé elastic parameters, specifically λ or incompressibility and μ for shear rigidity. The CSS volume is corrected for anisotropy using static triaxial core and is calibrated to multi domain data types including petrophysics, rock physics, completion engineering, and reservoir engineering (DFIT) measurements.

Successful application of said method in the Delaware and Midland sub-basins (of the greater Permian Basin) is shown. Anisotropic minimum horizontal stress (S_h) volumes from 3D seismic defined at 1 ft. vertical log resolution were interpreted quantitatively regionally, particularly as a prevention tool near parent wells prone to frac-hits. Moreover, the method provides an anisotropic measurement of in-situ stress variability (or stress differential) to qualitatively model 3D fracture geometries for engineered

treatment optimization. Current stress modeling methods rely on the propagation of geomechanical properties from well control, which do not necessarily represent rock properties and stress states at the area of interest.

Biography:

Dr. Michael Shoemaker is the Chief Geophysicist at Callon Petroleum Company with 20 years of

industry experience in both conventional and unconventional plays. Current operations at Callon include geomechanical characterization of Permian Basin stacked intervals for horizontal well spacing and landing, and for hydraulic fracture modeling and treatment design using innovative technology that integrates 3D seismic with interdisciplinary geoscience models and reservoir engineering.

Before joining Callon, Dr. Shoemaker was a lead prospecting geophysicist at BP America in conventional onshore plays where significant hydrocarbons were discovered. Prior to that, he was an expatriate geophysicist working for various foreign companies located in the United Kingdom, United Arab Emirates, and Malaysia where he prospected for Petronas.

He's a member of SEG, AAPG and SPE, and holds a Ph.D. in Geophysics from the Missouri University of Science and Technology (formally the University of Missouri-Rolla). □



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Technical Breakfasts

Use of Seismic Attributes and Open-hole Log Data to Characterize Production Variability in a Fractured Carbonate Play: A Case Study From Madison County, Texas

Speaker: Courtney Beck, Geologist/Earth Modeler,
Halliburton North America Reservoir Solutions Group

Authors: Courtney Beck, Anna Khadeeva, Bhaskar Sarmah, Trey Kimbell

Register
for Tech Breakfast
North

Register
for Tech Breakfast
West



Courtney Beck

North

Tuesday, Oct. 1, 2019
7:00 – 8:30 a.m.

Sponsored by Anadarko Petroleum and Quantico Energy Solutions

Location: Anadarko Petroleum
1201 Lake Robbins Drive
The Woodlands, TX 77380

Abstract:

Understanding natural fracture systems is key for tight carbonate plays in which production is dependent on secondary interconnected porosity networks. Locating geographic areas and stratigraphic sections with high natural fracture density and optimizing well locations and perforations to connect these fractures can enhance well performance and asset value. There is substantial production variation in the Cretaceous stacked carbonate play in East Texas, despite similarities in well completion and perforated intervals. Petrophysical property models did not explain the significant variation in well production; therefore, we have developed a multidisciplinary workflow combining seismic and log data with the goal of identifying faulting and natural fractures and understanding their effect on production. We used seismic discontinuity to map faults as the main indicator of presence of fractures. We calibrated triple combo logs with an image log to generate an indicator curve to identify natural fractures. The fracture indicator curve provided a good prediction of where natural fractures may occur, and discontinuity maps revealed a good correlation to well

West

Wednesday, Oct. 16, 2019
7:00 – 8:30 a.m.

Sponsored by Schlumberger and WesternGeco

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

production. Furthermore, we concluded that drilling too closely to large faults negatively impacted production and correlated with increased water production. The workflow developed here can be used to optimize well placement in the stacked carbonate play of Madison County, Texas, and it can be applied to other fractured carbonate reservoirs.

Biography:

Courtney Beck received a B.S. (2010) in geology from Texas A&M University and an M.S. (2013) in geological sciences from the University of North Carolina at Chapel Hill. She is a geologist/earth modeler in the Halliburton North America Reservoir Solutions Group, based in Denver, Colorado. She joined Halliburton in 2013 as part of the North America technology group and has worked on numerous exploration and asset development projects with oil and gas operators in the Utica shale, Eagle Ford shale, Midland basin, Montney shale, and East Texas stacked carbonate plays. Her research interests include 3D subsurface modeling and analyzing seismic attributes to detect natural fracture networks. □

Unconventional SIG

Microseismicity in Texas, Part 2:

The Geology of Active Earthquake Sequences in Texas

(Note: Part 1 of this series was presented at the Microseismic SIG meeting on Sept 5 at MSI)

Register
for
Unconventional



Dr. Peter Hennings

Speaker(s): Dr. Peter Hennings

Research Scientist at The University of Texas Bureau of Economic Geology, Principal Investigator in the Center for Integrated Seismicity Research and a Lecturer in the Department of Geological Sciences

Thursday, Oct. 3, 2019

11:30 a.m. - 1:00 p.m.

Sponsored by TGS

Location: TGS

10451 Clay Rd.

Houston, TX 77041

Abstract:

The TexNet Earthquake Monitoring Network and its partner dense seismic networks are now providing detailed information on seismicity in Texas. Areas of active seismicity include the Delaware Basin, Midland Basin, Scurry Co, Texas Panhandle, Fort Worth Basin, East Texas Basin, and the Eagle Ford operating area. Each of these areas has unique geologic and operating histories that need to be considered when assessing seismicity at the local to regional scale – the earthquake habitat. What are the similarities and differences in the habitats of these areas? Each area has a unique stress state, fault architecture, fluid pressure regime, tectonic history, operational history, and earthquake sequence history. Some areas appear to have mainly induced seismicity, some have mainly naturally-caused events, and others have a mix. Comparing the geology of these areas to each other provides insight into the specific characteristics that may be important to understanding earthquake cause and to defining the scope of steps required to reduce the hazard where possible.

Biography:

Dr. Peter Hennings is a Research Scientist at The University of Texas Bureau of Economic Geology where he is Principal Investigator in the Center for Integrated Seismicity Research and a Lecturer in the Department of Geological Sciences. Peter retired after 25 years in the petroleum industry where he worked as a research scientist (Mobil Oil and Phillips Petroleum) and technical manager (ConocoPhillips). Peter received his B.S. and M.S. degrees from Texas A&M University and his Ph.D. from The University of Texas. Peter's technical specialties include structural geology, seismic structural analysis, reservoir geomechanics, induced seismicity, and geology of Texas and the Rocky Mountains. Peter is an AAPG Distinguished Lecturer, GSA Fellow, and a founder of the AAPG Petroleum Structure and Geomechanics Division. Peter has taught more than 250 field seminars and classroom courses on seismic structural analysis, reservoir geomechanics, and Rocky Mountain structural and petroleum geology. □

Data Processing & Acquisition SIG

New Methods for Processing and Acquisition to Improve Land Seismic Data Quality

Register
for Data
Processing

Speaker(s): Dr. Edward Jenner
Research Geophysicist
Land Seismic Noise Specialists

Sponsored by
Schlumberger

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



Dr. Edward Jenner

Tuesday, Oct. 8, 2019

4:30 p.m. Sign-in, Snacks, Social Time

5:00 p.m. Start of presentation

Abstract:

Noise in land seismic data continues to be a challenge for both imaging and quantitative reservoir characterization. A main source of noise appears to be caused by the near surface; particularly by the scattering of primary energy at both the source and receiver. We see evidence of this when shots are repeated at the same shot location; what appears to be random noise is often highly repeatable. A 50% scattering can reduce signal/noise by 10x, while an 80% scattering can result in 67x signal/noise reduction. This becomes a significant issue that cannot be addressed by increasing the density of shots and/or receivers.

Since the near surface is laterally heterogeneous, large variations in signal/noise can occur within a survey. Often these changes can be directly observed from surface expressions such as forestation, soil moisture, outcrops, cities, and infrastructure. However, in some cases, the reasons for subsurface scattering are less obvious. Therefore, we propose that acquisition should be designed not based solely on uniform or high fold coverage, but also considering noise variations across the survey.

In this talk I will show examples of using machine learning to address scattered noise. While this technique shows great promise and can significantly

improve the ability of statistical methods to further attenuate noise, it has limitations. Therefore, I will also demonstrate a novel algorithm to better optimize 3D land seismic surveys which takes into account numerous factors such as acquisition holes, cost, desired offset/azimuth coverage, noise and ability to place shots and receivers.

We believe that such optimized acquisition, in conjunction with processing techniques that can attenuate scattered energy, will allow for a step-change in providing quantitative attributes for interpretation.

Biography:

Dr. Jenner is a research geophysicist at Land Seismic Noise Specialists. After completing his Ph.D. at the Colorado School of Mines in 2001, he joined AXIS Geophysics and in 2003 Dr. Jenner was awarded the SEG Clarence Karcher Award for his work in the field of azimuthal anisotropy. From 2002 to 2015 Dr. Jenner was Land R&D manager for ION Geophysical where he continued to focus on velocity anisotropy, AVO, azimuthal AVO, anisotropic imaging, and frequency enhancement for seismic data.

Edward also holds a B.Sc. in Physics with Astrophysics from the University of Birmingham, UK, and an M.Sc. in Geophysics from the University of Leeds, UK. □

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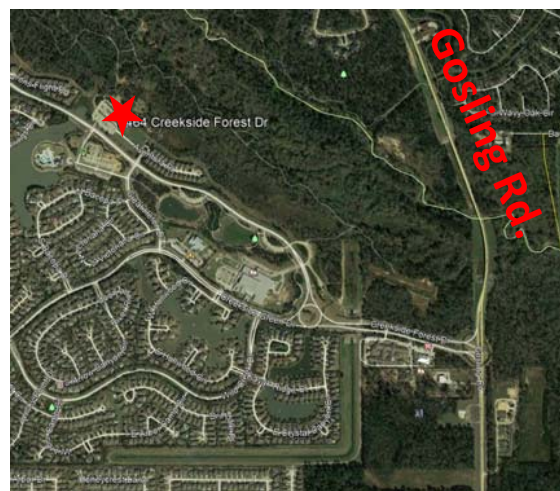
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Plates to Prospects: Integration of data at multiple scales to enhance exploration, with insights from the deepwater fold and thrust belts offshore Northeastern México

Dr. Carl Watkins
CGG GeoSolutions

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Joint Society Dinner continued on page 15..



GSH - HGS JOINT SOCIETY DINNER

Plates to Prospects: Integration of data at multiple scales to enhance exploration, with insights from the deepwater fold and thrust belts offshore NE Mexico



Dr Carl Watkins

**Director of
Global Business
Development**

**CGG
GeoSolutions**

Carl graduated with a degree in Geology and Geography and did his PhD at Oxford Polytechnic working on the sedimentology, palaeogeomorphology and basin fill of the North Pyrenean Basin in SW France. He joined Robertson in 1991 and worked as a sedimentologist and reservoir geologist on projects ranging from frontier exploration in far eastern Russia to detailed reservoir characterisation and modelling studies in Norway, North Africa, SE Asia and the Americas. After managing several large integrated studies, including a 2007 study of the Russian and Norwegian Barents Sea, and developing novel techniques in drainage network and hinterland analysis, he joined the senior management team of Robertson in 2011, then part of Fugro.

Following the acquisition of Fugro's geoscience arm by CGG in 2013 Carl took an expanded role covering business development and marketing for CGG's GeoConsulting group, whilst finding ways to keep his technical expertise sharp. Carl currently works for CGG's MultiClient and New Ventures with responsibility for business development within the GeoSolutions Group. His focus is on identifying and realising incremental value by combining leading geoscience expertise with CGG's extensive seismic library to address clients sub-surface problems. □

As deepwater exploration continues to gradually emerge from a relative lull in activity, the challenges to success remain as complex as ever. In the new reality of more limited exploration budgets and increased scrutiny, there is a greater requirement to extract maximum value from all available data spanning multiple disciplines and scales. Truly integrated approaches to exploration workflows represent one way of addressing this problem.

The recent relaxation and opening of Mexico to international exploration represents both challenge and opportunity. The challenges to deepwater exploration stem from a wide variety of technical, economic and political risks. The opportunities are clearly large, with an enormous exploration footprint and large structures in an area with a proven and prolific petroleum system. Significant advances in imaging below salt and shale have been a critical step that, when linked to the adoption of an integrated geoscience approach, have allowed us to address these problems. In addition to the geophysical challenges surrounding salt, shale provides an additional challenge. Deformation is extremely complex in the deep waters often displaying disharmonic shortening across stacked detachment levels of salt and shale. As we look to understand the continuity of prolific play fairways such as the Wilcox, Frio and Vicksburg, understanding the origin, timing and distribution of the deep water foldbelts is essential.

Deepwater foldbelts are inherently related to base of the paleo-slope

and or bathymetry of the detachment surface. Using the latest seismic data, calibrated to the regional stratigraphic framework these foldbelts have been mapped, allowing their timing and distribution to be known. Further interpretation, and integration with potential field data show their origin to be closely related to the underlying rift structure. The adoption of this fully integrated approach has helped to illuminate their origin, timing and evolution. The results have direct implications for source rock development, preservation and maturity as well as all other elements of the petroleum system including reservoir.

Deepwater exploration in Mexico targets Tertiary siliciclastic deposits from a variety of hinterland sources around the periphery of the GoM. With only limited well penetrations in the offshore and much of the play fairway below salt, the wider geologic context becomes important for de-risking plays. Consideration of the entire depositional system is therefore important when de-risking reservoir presence and quality for exploration. An integrated approach to stratigraphic architecture, detailed depositional process evaluation and regional mapping all play an important role. The seismic data are invaluable in extending detailed reservoir and play level understanding away from the limited well control. This has enabled us to address the large scale depositional polarities that help to answer fundamental questions related to regional exploration potential in frontier parts of deepwater Mexico and also to propose some new ones. □

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Time-lapse Seismic Monitoring of Individual Hydraulic Frac Stages Using a Downhole Distributed Acoustic Sensing Array

Gary Binder¹, Aleksei Titov¹, Diana Tamayo¹, James Simmons¹, Ali Tura¹, Grant Byerley², David Monk²; 1. Colorado School of Mines, 2. Apache Corporation.

Abstract

In 2017, distributed acoustic sensing (DAS) technology was deployed in a horizontal well to conduct a time-lapse vertical seismic profiling (VSP) survey before and after each of 78 hydraulic fracturing stages. The goal of the survey was to more continuously monitor the evolution of stimulated rock throughout the treatment of the well. From two vibroseis source locations at the surface, time shifts of P-waves were observed along the well that decayed almost completely by the end of the treatment. A shadowing effect in the time shifts was observed that enables the height of the stimulated rock volume to be estimated. Using full wavefield modeling, the distribution of time shifts is well described by an equivalent medium model of vertical fractures that close as pressure declines due to fluid leak-off. Converted P to S waves were also observed to scatter off stimulated rock near some stages as confirmed with full wavefield modeling. The signal-to-noise ratio is a limitation of the current dataset, but recent improvements in DAS technology can enable stage-by-stage monitoring of the stimulated rock height, fracture compliance, and decay time as a well is completed.

Introduction

Distributed Acoustic Sensing (DAS) has opened new possibilities for seismic monitoring of unconventional reservoirs. Using a laser interrogator to launch light pulses down a fiber optic cable, dynamic strain changes can be sampled along the cable from the phase shift of light backscattered to the interrogator (Hartog, 2017). Since the fiber optic cable can be permanently cemented outside the casing in a borehole, highly repeatable vertical seismic profiling (VSP) surveys can be acquired frequently without costly wireline geophone

deployments that interfere with well treatment activities (Mateeva et al., 2017; Meek et al., 2017) time-lapse vertical seismic profiling (VSP).

As described by Byerley et al., 2018, a unique interstage DAS VSP survey was conducted in 2017 during the stimulation of a horizontal well targeting the Wolfcamp formation in the Midland Basin, Texas. Using two vibroseis source locations offset about 1 mile from the heel and toe of the well, DAS data was acquired in the treatment well before and after each of 78 hydraulic fracturing stages. At the expense of fewer source locations, this type of acquisition allows the evolution of the stimulated rock volume (SRV) to be monitored on a stage-by-stage basis as the well is treated.

The dominant time-lapse effect observed in the survey was a ~ 1 ms time delay of the direct P-wave arrivals along the horizontal well from both source locations. Time shifts show a shadowing effect that is directly related to the height of the SRV above the well. Scattered waves were also observed in the time-lapse difference of shot records following some stages. Both time shifts and scattered waves tended to vanish over a few days. This illustrates the value of more frequent surveys that capture effects otherwise missed if only one monitor survey is conducted following stimulation.

In the rest of the paper, first the DAS data acquisition and processing to recover P-wave time shifts will be described. To understand the distribution of time shifts along the well, full wavefield modeling will be conducted. The model can be used to determine height, fracture compliance, and decay time of the SRV from observed time shifts. The model also confirms that observed scattered waves in the SRV are consistent with P to S conversion.

Technical Article continued on page 18.

For Information Regarding Technical Article Submissions, Contact GSHJ Coordinator Scott Singleton (Scott.Singleton@comcast.net)

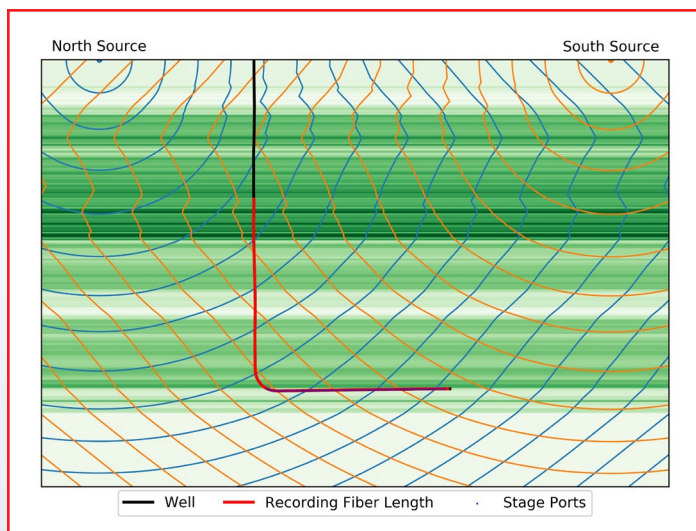


Figure 1: Geometry of the interstage DAS VSP showing the two source locations and well.

Acquisition

The geometry of the interstage DAS VSP survey is shown in [Figure 1](#). There were two source locations located approximately 1 mile north of the heel of the well and 1 mile south of the toe of the well, and both were approximately in line with the horizontal well. Since DAS has an angle-dependent sensitivity $\propto \cos^2 \theta$ for P-waves and $\propto \sin 2\theta$ for S-waves where θ is the angle with respect to the fiber (Wu et al., 2017), the locations were chosen to achieve an incident angle of $\sim 45^\circ$ so that there is sensitivity to both down-going P- and S-waves passing through the stimulated rock above the horizontal well.

VSP shot records were acquired before fracturing and after each of 78 stages of fracturing. A sliding sleeve completion was used with a single entry point, or port, per stage. For the north and south sources, the goal was to perform 20 sweeps in the ~ 15 min shut-in period immediately after pumping ended for each stage, but this number was variable. The sweep parameters were 15 second sweep duration, 4 to 80 Hz frequency range, and 4 second listening time. The DAS laser interrogator measured the optical phase shift of backscattered light that is proportional to the average strain over a gauge length of along the fiber. The optical phase shift is sampled every 1.02 m along the fiber for a total of 3200 channels with a time sample interval of 1 ms. As shown in [Figure 1](#), the sampled points

extend along the entire horizontal section of the well but only part way up the vertical section. In addition to the DAS VSP data, sonic logs from a pilot well were available, and the resulting 1D P-wave velocity model is shown in [Figure 1](#).

Processing

DAS VSP shot records are processed to search for time shifts of direct P-wave arrivals along the horizontal well. Data processing begins by removing interrogator noise common across all DAS channels as explained by Olofsson and Martinez, 2017 through subtracting the median trace formed from DAS channels in the vertical well section. Following correlation with the vibroseis sweep and

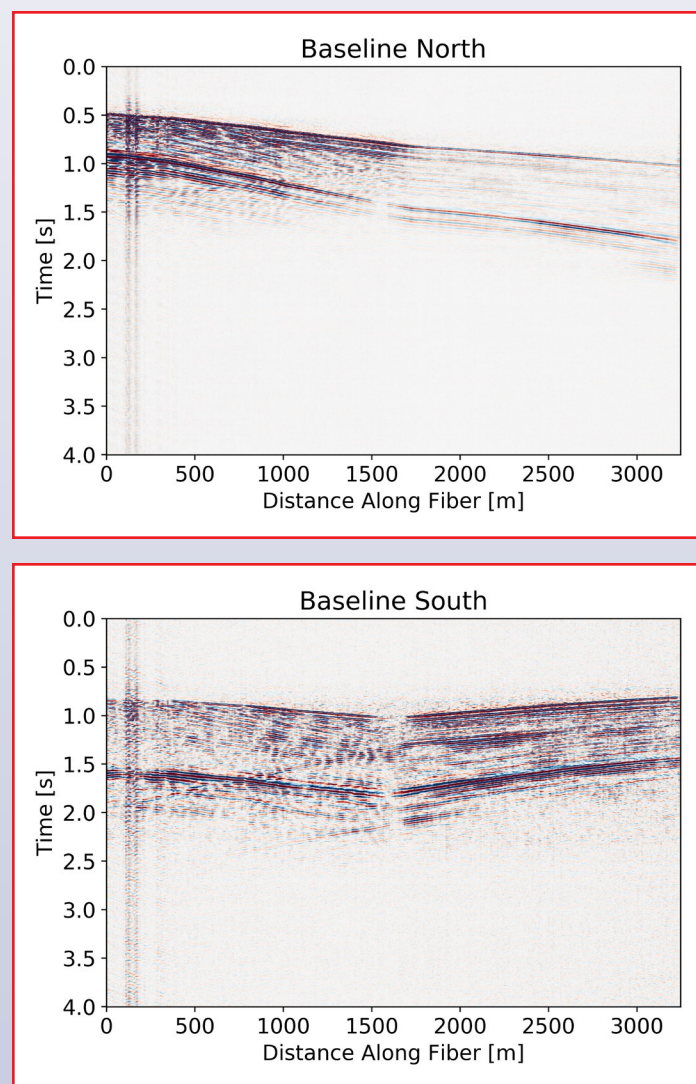


Figure 2: Processed shot records from the north and south sources.

stacking, the listening time was 4 seconds. To further suppress noise, $f - x$ deconvolution, dip filtering, and a 4 to 90 Hz bandpass filter were applied. Processed shot records from the baseline survey are shown in [Figure 2](#).

Time shifts are calculated using cross correlation in a 50 ms window around the direct P-wave arrival. They are shown in [Figure 3](#) for all 78 stages from the north and south sources. The cross correlation is cubically interpolated to obtain time shifts below the 1 ms sample interval. Rather than cross correlating against the baseline shot record alone, the SNR can be improved by forming a stack of the shot records from all previous stages. As indicated by red lines in [Figure 3](#), DAS channels are only included in this stack if they are more than 300 m (600 m) to the heel-side of the stage port for the north (south) shot records. This choice is intended to exclude regions along the horizontal well where time shifts could be previously observed. A static correction was applied to the time shifts for each stage that was estimated from the median time shift of channels in the vertical section of the well. This corrects for a small drift in time shifts over the course of the treatment that is correlated with temperature (Byerley et al., 2018). For the south source, this also compensates for a small shift in the vibroseis locations following stage 57 after excessive ground compaction occurred. Due to residual noise associated with fluid flow in the wellbore, time shifts near the stage port can be unreliably large for some stages. Time shifts close to the toe can also be unreliable since only the baseline shot record is available as the reference for cross correlation.

Observations

With the caveats above, a ~ 1 ms time delay from the north source is observed along the well extending from near the stage port to the toe of the well for most stages. For the south source, a ~ 1 ms delay is also observed but occurs on both sides of the stage port. For both sources, time delays tend to diminish moving towards the toe of the well. Equivalently, this indicates a decay of the time shifts over time as the treatment proceeds.

To better understand these observations in the presence of limited SNR, it is convenient to stack time shifts from all stages to better understand their

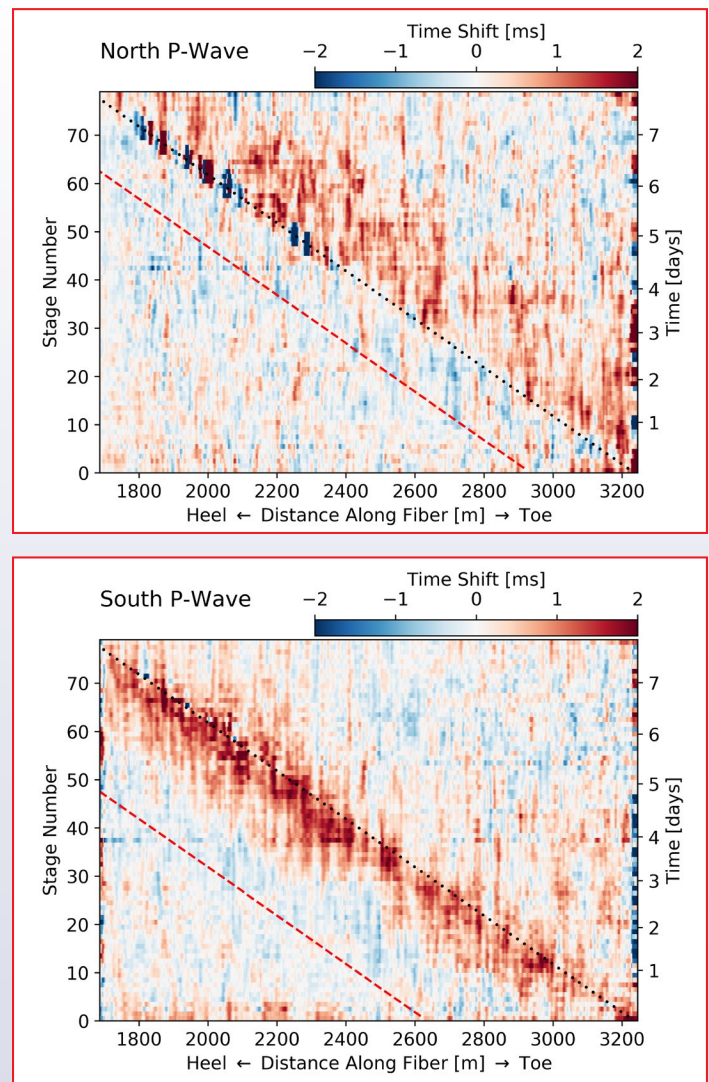


Figure 3: Time shifts after each stage along the horizontal well for north and south sources.

average behavior. As illustrated in [Figure 4](#), this can be done by plotting time shifts as a function of the distance along the well from the port for each stage and applying a 10 m rolling median filter. Though the changing P-wave incidence angle changes the expected time shift distribution for all stages even if all rock properties are unchanged, this is a small effect compared the noise level as will be seen later from modeling in the next section. For the north source, time delays remain consistent with zero until nearing the stage port from the heel. Moving past the stage port, they increase to a maximum and then diminish moving towards the toe of the well. Interpreting this in terms of seismic velocities, this indicates a velocity slowdown in the stimulated rock volume that diminishes with time. As estimated from

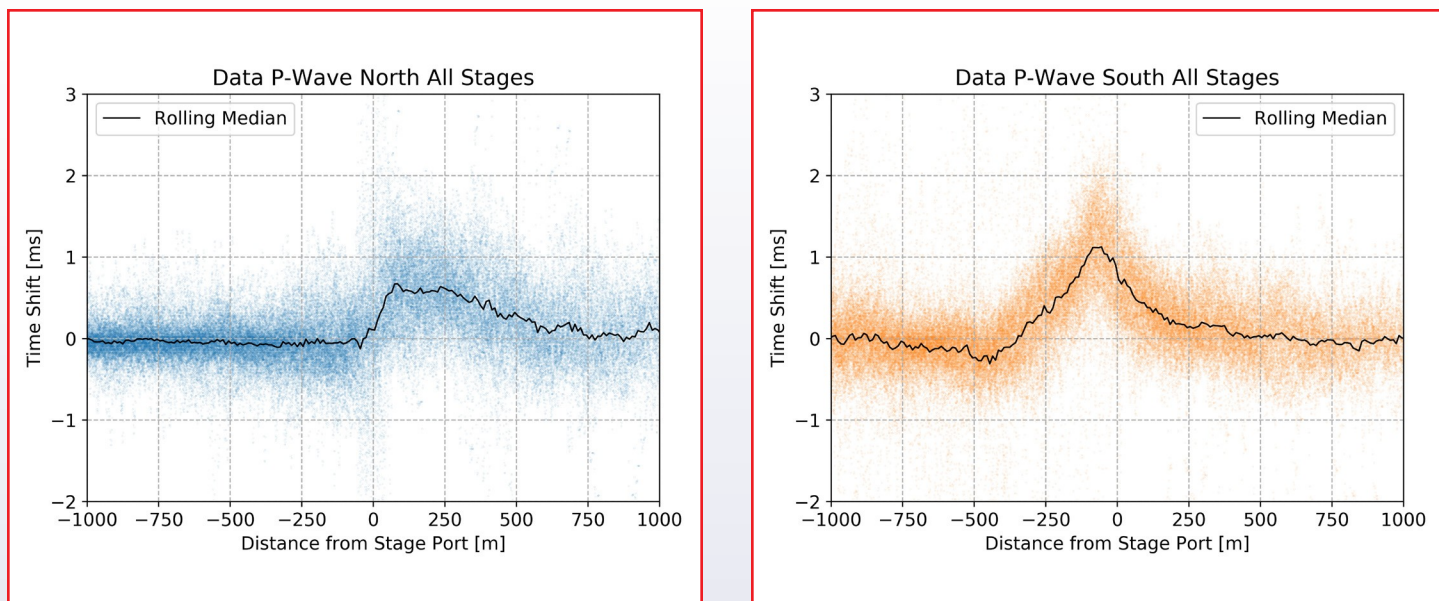


Figure 4: Stack of time shifts from all stages for north and south sources.

the heel-side of the stage ports, the noise level is comparable or larger than stage-to-stage variations in the time-shift distribution that occur on the toe-side of the port. For the south source, time delays rise above zero at a point about 350 m towards the heel from the stage port. This can be thought of as a shadowing effect as waves from the south source pass through stimulated rock above the stage port. The location of this zero crossing thus indicates the height of the SRV. Moving towards the toe, again the time delays diminish as the velocity slowdown in the SRV decays over time.

Based on the shadowing effect from the south source, ray tracing can be used to obtain a simple estimate of the height of the stimulated rock volume on stage-by-stage basis using the P-wave time shifts from the south source. The height of a ray path above the stage port can be calculated for all channels towards the heel from the stage port for all 78 stages. This enables a coordinate transformation from measured depth along the well to ray path height above the port for each stage. As shown in **Figure 5**, time shifts can be plotted as a function of ray path height above the stage port. The ray path height where the time shift vanishes gives an upper bound on the height of the stimulated rock above the stage port. As seen in **Figure 5**, this shows that stimulated rock exists up to ~ 300 m above the stage port. The height estimate is only an upper bound

since newly stimulated rock may lie entirely in the shadow of stimulated rock from previous stages. The height estimate may also be unreliable near the toe of the well since only the baseline survey is available for time shift calculations. Lastly, height estimates cannot be obtained for stages near the heel because of poor DAS angular sensitivity to normal incident waves at the heel of the well. Another drawback of the ray-based approach is that seismic wavelengths

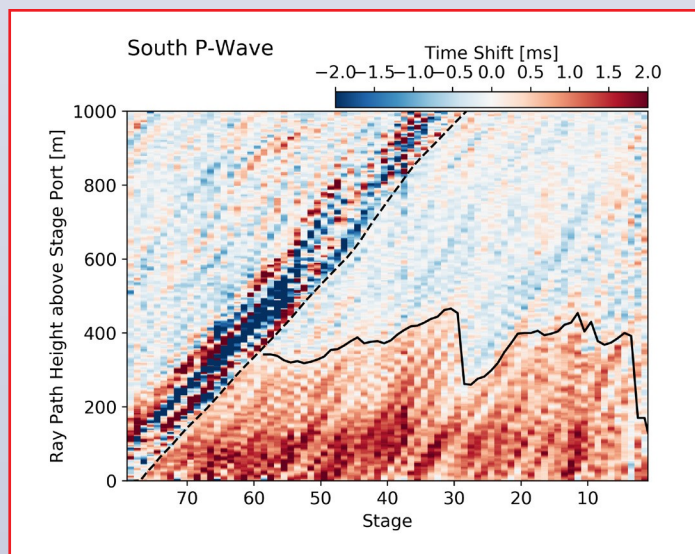


Figure 5: South source time shifts as a function of height above the port of each stage.

are comparable to the stage spacing and scattering may become an important issue that influences time shifts.

Waves scattering off newly stimulated rock can be observed near some stage locations. For example, in the time-lapse difference of shot records from the north source with respect to the baseline, a scattered wave is weakly visible that originates near the stage 30 port location. The scattered wave is visible for shot records from stage 30 to 35. This is illustrated in *Figure 6*, where the difference between a stack of shot records from stages 30 to 35 and the baseline is shown centered on the stage 30 port location. The scattered wave is kinematically consistent with P to S conversion as will be seen with full wavefield modeling later.

Modeling

To understand the complete space and time dependence of the seismic response observed in the survey, 2D finite difference wave equation modeling in a fractured medium is conducted. The seismic response of fractures can be modeled using the equivalent medium theory of Sayers and Kachanov, 1991, 1995; Schoenberg and Sayers, 2002. Aligned vertical fractures opened during hydraulic fracturing act to increase the compliance of the rock normal to the fracture planes by Z_N and tangent to the fracture plane by Z_T . The ratio of fracture compliance can be a useful diagnostic of the material in the fractures. For gas-filled fractures, $Z_N/Z_T \sim 1$ while for ideal fluid-filled fractures $Z_N/Z_T \rightarrow 0$. A ratio of $Z_N/Z_T = 0.1$ will be used here to represent fluid-filled fractures following injection. As pressure declines following fluid leak-off, the fracture compliances tend to decay exponentially in time, and this decay time may be connected to permeability and other formation properties as shown by Binder et al. (2019).

Further details of the fracture compliance model can be found in the work of Binder et al. (2019), but the essential idea is to parameterize the distribution of fracture compliance created by the stimulation of each stage with a characteristic height, width, fracture compliance, and decay time. *Figure 7* shows the modeled

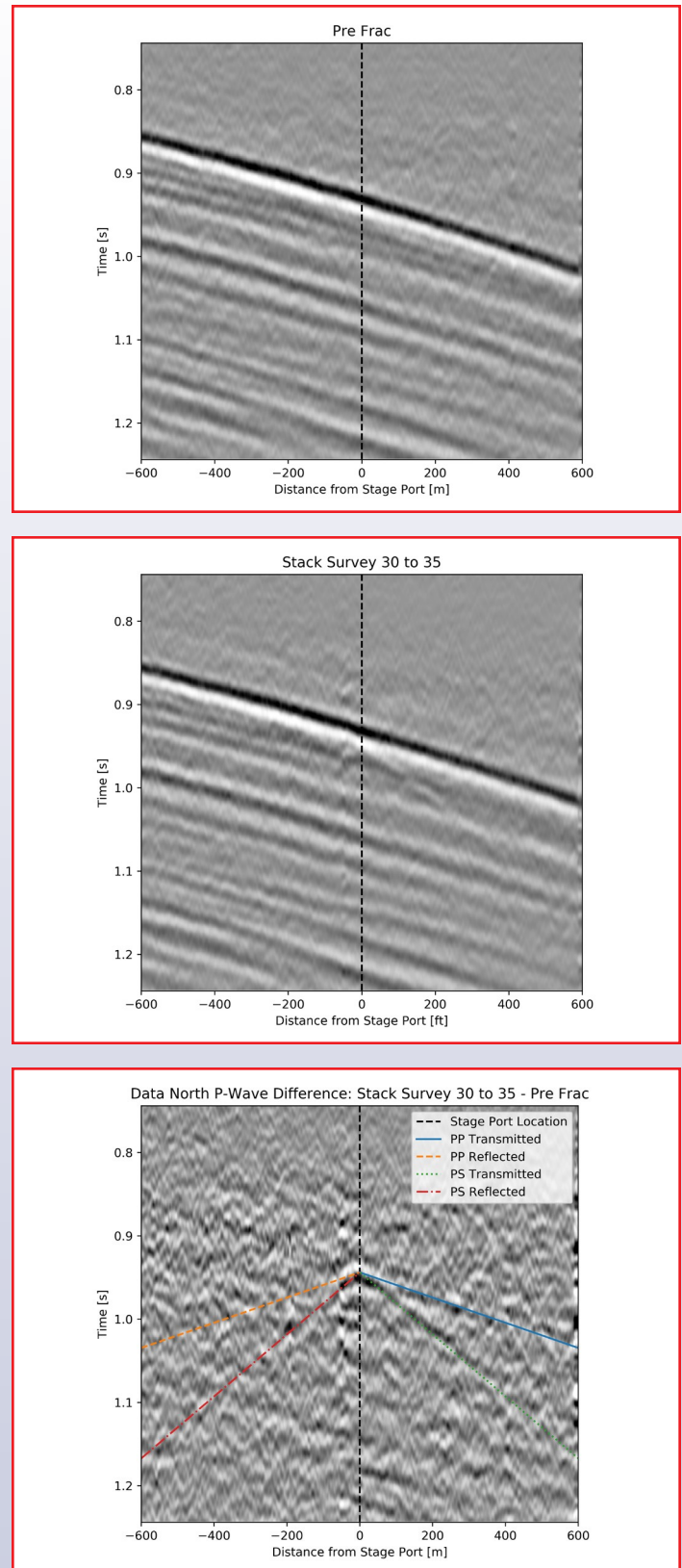


Figure 6: Baseline north shot record, a stack of records from stage 30 to 35, and their difference illustrating scattered waves.

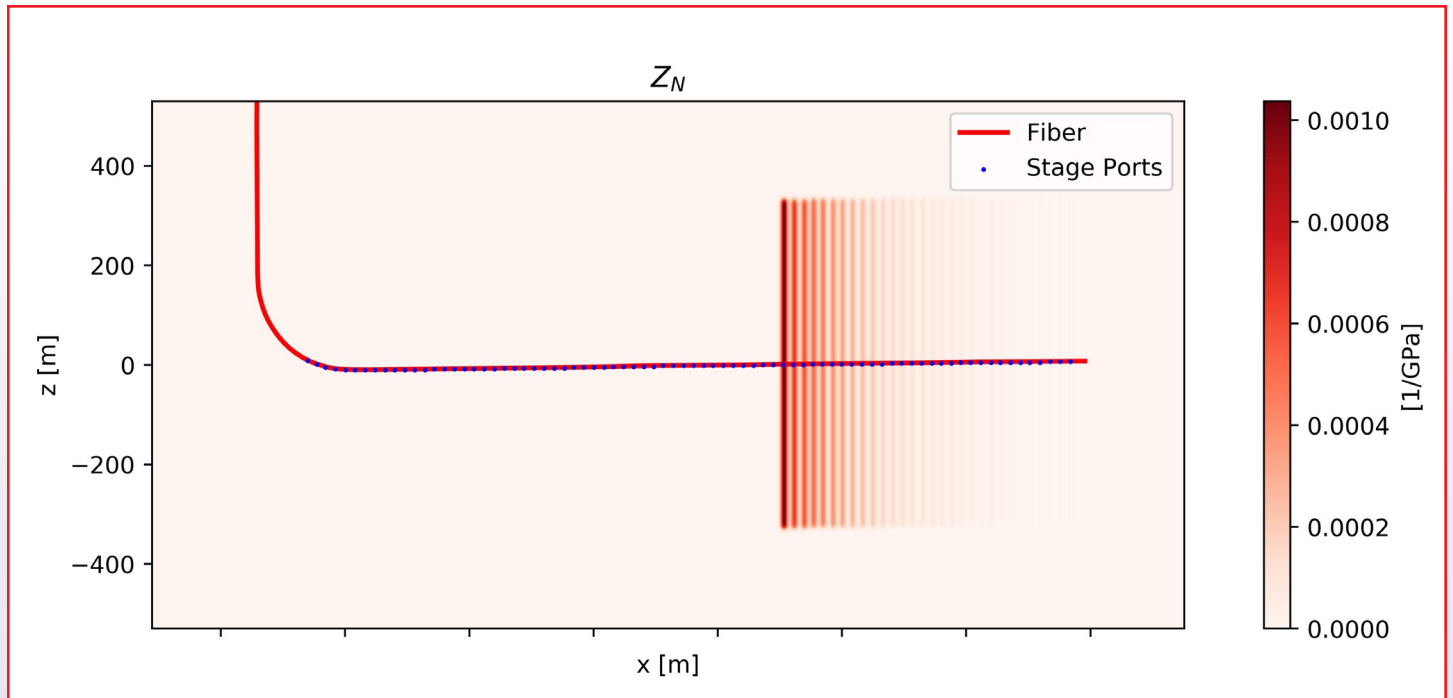


Figure 7: Modeled distribution of decaying fracture compliance following stage 30.

distribution of exponentially decaying fracture compliance after 30 stages. Each stage creates a fracture compliance distribution with the same height 330 m, width 5 m, decay time 0.65 days, and overall fracture compliance $Z_N = 0.1Z_T = 1.3 \times 10^{-11}$ m/Pa. 2D finite difference elastic modeling is then done using the

fracture compliance model in [Figure 7](#) and background elastic properties estimated from the sonic log. Since finite difference modeling is usually done in terms of particle displacement, special care is taken to convert the simulation output to strain as measured by DAS (Correa et al., 2017).

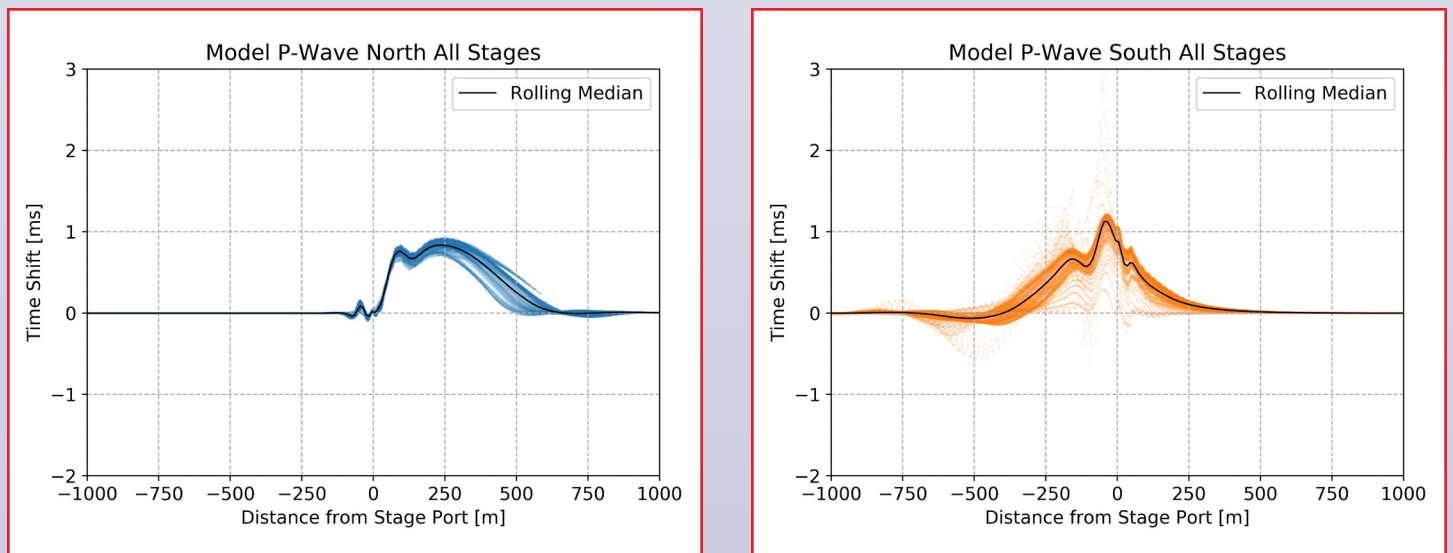


Figure 8: Modeled distribution of stacked time shifts for all stages.

Results

Using the full wavefield synthetics described above, P-wave time shifts can be calculated using the same cross correlation method as applied to data. The results are shown in [Figure 8](#). A remarkably good match between model and data can be found by tuning the five parameters, height, width, fracture compliances, and decay time to the values quoted above. This opens the route to an inversion scheme where these five parameters could not only be estimated for the entire SRV, but for each individual stage if the SNR can be improved.

Scattered waves as observed in [Figure 6](#) can also be studied using finite difference modeling. Synthetic shot records from the north source following stage 30 are shown in [Figure 9](#) zoomed in at the stage 30 port location. The synthetics show reflected and transmitted waves from the stimulated rock volume corresponding to both P and S wave velocities. The moveout of the P to S transmitted wave corresponds well to the strongest scattered wave seen in the observed data near the stage 30 port location. Understanding the mechanism that controls the amplitude of scattered waves will be the subject of future work, but it can be speculated that the reason the PS converted waves appear only near stage 30 is related to the larger apparent SRV height around stage 30 seen in [Figure 5](#).

Summary

This study highlights the benefits of acquiring VSP surveys in between each stage of hydraulic fracturing, a new capability made practical with DAS technology. Since time-lapse changes can disappear over days, an interstage VSP survey can reveal information on dynamic changes in the reservoir otherwise missed with only one monitor survey following well stimulation. It appears that in this study, many fractures were opened by the stimulation that subsequently rapidly close, leaving little remaining seismic response.

P-wave time shifts were the most easily observed time-lapse effect. Future work will address S-wave time shifts and amplitude changes that also exist in the data. Full wavefield modeling shows that the distribution of P-wave time shifts is explained

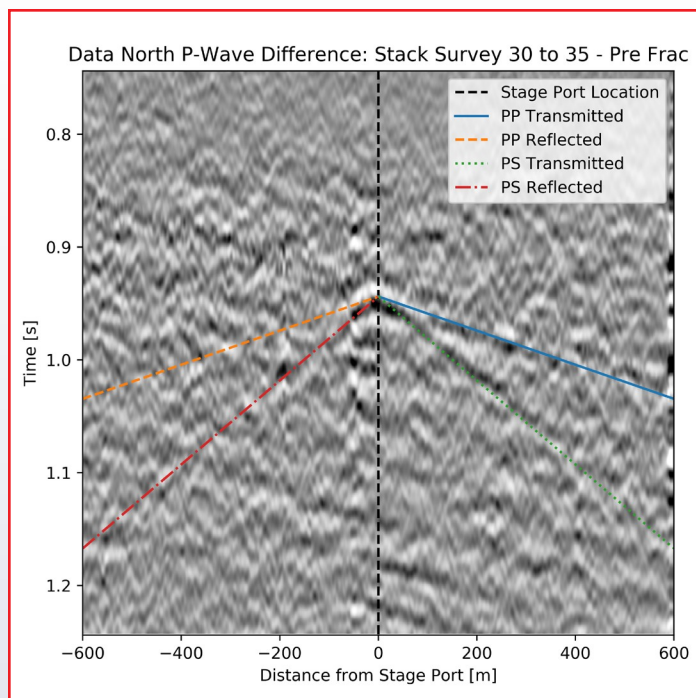


Figure 9: Comparison of modeled and observed scattered waves for stage 30.

well by an equivalent medium model of fluid-filled fracture compliance that decays exponentially with time. Estimates of fracture compliances, height, and decay time of the SRV can be obtained from the P-wave time shift data. The fracture compliances may be useful in detecting the aspect ratio and material inside fractures while the decay time can be connected to permeability in the SRV and other formation properties. Methods using the full wavefield can in principle be generalized to estimate height, fracture compliance, and decay time attributes stage-by-stage. The signal-to-noise ratio of the current dataset is also a major limitation, but with recent advancements in interrogators and engineered fiber leading to improvements in DAS SNR by up to 20 dB (Correa et al., 2017; Richter et al., 2019), monitoring the geometry of the SRV with an interstage VSP may become a new tool for completions evaluation.

Acknowledgments

The authors would like to thank Apache Corporation for providing the interstage DAS VSP data. This work was conducted with the support of the Reservoir Characterization Project at the Colorado School of Mines. □

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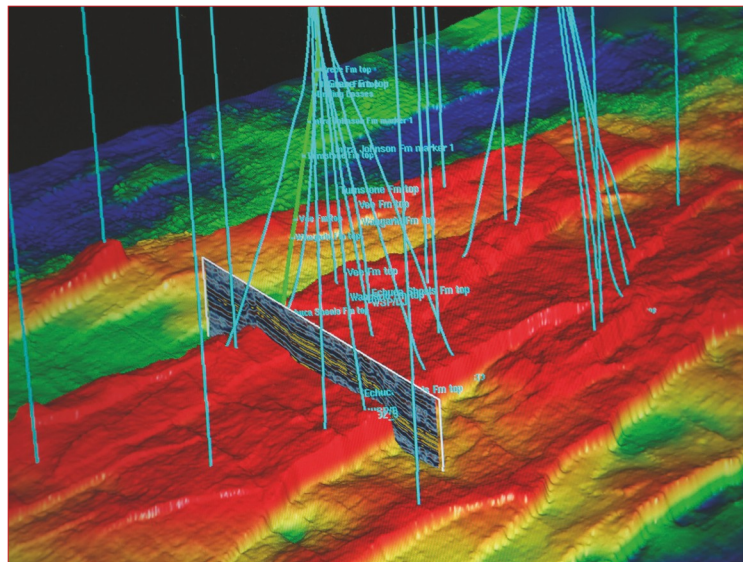
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GSH Outreach

Committee Activities By Lisa Buckner, outreach@gshtx.org

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About Earth Science Week - <http://www.earthsciweek.org/about-esw>

Since October 1998, the American Geosciences Institute has organized this national and international event to help the public gain a better understanding and appreciation for the Earth Sciences and to encourage stewardship of the Earth. This year's **Earth Science Week will be held October 13-19, 2019** and will celebrate the theme **"Geoscience is for Everyone."** This year's event, the 22nd annual Earth Science Week celebration, will emphasize both the inclusive potential and the importance of the geosciences in the lives of all people.

People of all ages are invited to join in this creative endeavor through our available learning resources and activities. The theme is meant to encourage individuals of all backgrounds, ages, and abilities to engage with the geosciences, whether that's a geoscience professional, a hobbyist, or through civic engagement.

.....

You can help by volunteering at the GSH booth during one of the events here in Houston, or by visiting your child's school. If you can't volunteer, I encourage you to bring the children in your life to one of the following events and enjoy a fun day of learning.

Earth Science Celebration - Saturday, Oct. 12 (11:00 AM – 3:00 PM) at HMNS

Energy Day Festival - Saturday, Oct. 19 (11:00 AM – 4:00 PM) at Sam Houston Park (FREE)

For more information about the HGS Earth Science Week events in Houston, go to <https://www.hgs.org/earth-science-outreach>

More information about Energy Day can be found at <https://energydayfestival.org/houston/>

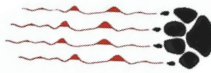
For information about volunteering at one of the GSH outreach activity booths during Earth Science Week contact Lisa Buckner (outreach@gshtx.org).

.....

Show your pride at industry conferences and outreach events by picking up your FREE "I'm a Geoscientist" lapel pin at any GSH meetings. The SEG is a member society of the American Geosciences Institute (AGI). <https://www.americangeosciences.org/im-a-geoscientist> □



Are you interested in volunteering? Do you know of a school that has a career day seeking speakers or a career fair at which GSH might be able to host an exhibit booth? Have you been invited to give a classroom presentation at your child's school? We can work together to bring awareness to students & their educators about the many rewarding and fun careers in the geosciences. Please contact Lisa Buckner at outreach@gshtx.org.



A Machine Learning Approach to Predicting Magnetization Directions

*By Felicia Nurindrawati, Master's student in Geophysics and Jiajia Sun, Professor in Geophysics at UH,
Department of Earth and Atmospheric Sciences, University of Houston*

Introduction

Widely regarded as a transformative technology, machine learning has achieved great success in the last few years in many areas including self-driving cars, healthcare, security, and others. The geoscience community has also started to embrace machine learning very recently and has already seen successful applications to various problems including seismic salt body interpretation, well logging data interpretation, seismic facies analysis among others. In this article, we report the latest results from our ongoing research on the use of machine learning, specifically, convolutional neural network (CNN), for the automatic prediction of magnetization directions based on a magnetic anomaly map.

Interpreting a magnetic anomaly map in terms of the magnetization directions of the source bodies has been instrumental in advancing our understanding of the Earth's dynamic systems at various scales because magnetization directions represent a record of the polarity of the geomagnetic field throughout geological time. Existing approaches involve either unstable data processing steps such as reduction-to-pole or component conversions in wavenumber domains, or computationally intensive processes such as inversion. Our goal is to develop a direct, data-driven, approach to automatically predict magnetization directions given a magnetic map without the need for data processing or inversion.

Inspired by the great success that CNN has achieved in recognizing patterns in images, we have developed a new

approach to predicting magnetization directions based on this technique. CNN, one type of deep neural networks, is particularly good at image recognition. It detects features of an image (e.g. edges, curves) through different layers and filters. As more layers are added, the network detects more complex features. The main aspect of CNN is the convolutional layers that detect features by sliding filter windows through an image and convolving the image values with various filters. The results that we have obtained show that CNN is an effective tool for predicting magnetization directions from a magnetic map.

Method

In the following paragraphs, we summarize the steps of the method and use a field data example from Black Hill, Australia. The airborne magnetic data, as shown in *Figure 1*, were collected over several norite intrusions, and are publicly accessible via

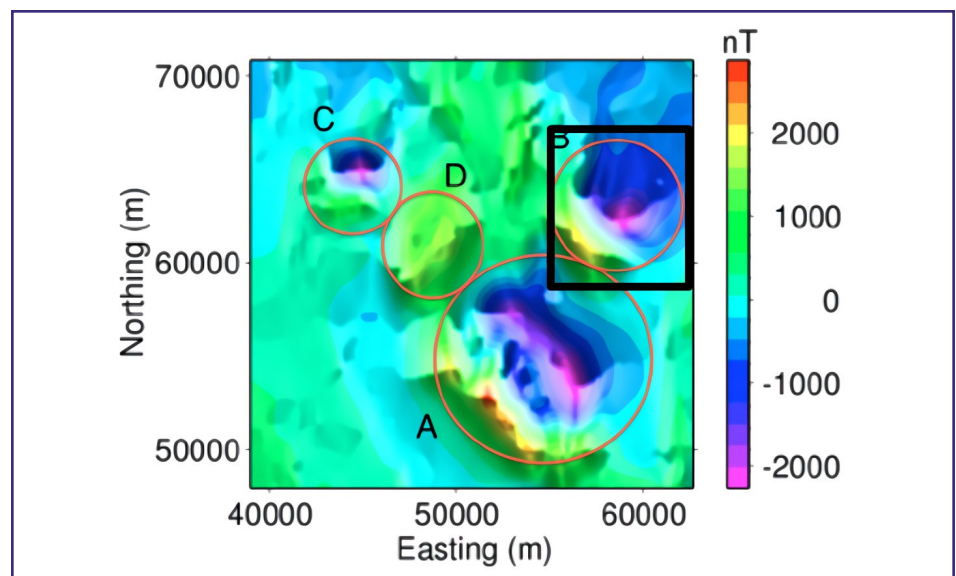


Figure 1: The magnetic data map of the norite intrusions. The anomaly in the black rectangle is used as an illustrative example in this article.

Wavelets continued on page 28.

Geoscience Australia's Geophysical Archive Data Delivery System. The norites were formed during the Ordovician period and are mafic gabbroic intrusions. By comparing the anomaly patterns against the ambient field direction, we can tell the existence of strong remanence. Several major anomalies are readily identifiable in [Figure 1](#). In our work, we selected and focused on the magnetic anomaly located in the northeast of the region, marked as Anomaly B in the Figure. We note that this anomaly has also been studied by several other authors, which allows us to evaluate how predictions based on machine learning compare with other approaches.

The following steps were developed to estimate the magnetization direction of the source body responsible for Anomaly B in [Figure 1](#).

Step 1: Estimate the geometrical and physical parameters of the source body

First, the shape and position of the source body were inferred from the data map by visually examining the patterns of the magnetic anomaly. The tilted

rectangle in [Figure 2](#) represents our interpretation of the shape and location of the source body. We have also investigated other shapes such as a cube, a cylinder, a rectangular prism with different orientations, and an extremely elongated rectangular prism. We have found that the specific shapes of the source body do not affect our predictions, provided that the center position of the source body is reasonably determined.

We also assigned the source body three parameters: *magnetic susceptibility*, *depth*, and *thickness* to generate the data maps for training. Our study has shown that the susceptibility can be arbitrarily determined because a subsequent data normalization procedure removes the effect of any specific susceptibility value. Additionally, we have found that very rough estimates of the depth and thickness would suffice. The parameters that we have chosen for Anomaly B are summarized in [Figure 2](#).

Step 2: Generate data maps for training

Using the estimated geometrical and physical parameters from Step 1, as well as the survey

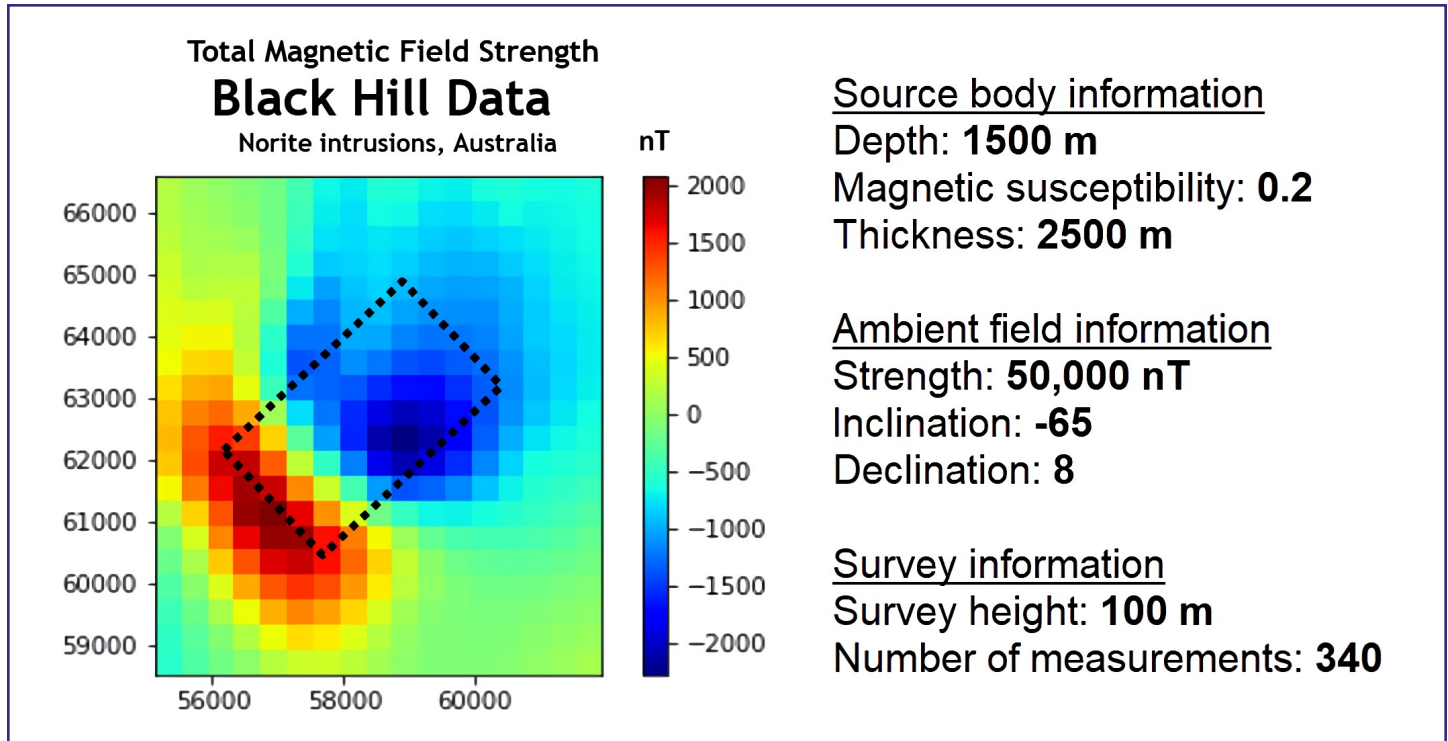


Figure 2: The selected magnetic anomaly along with the interpreted shape and position of the source body as shown with the dotted lines.

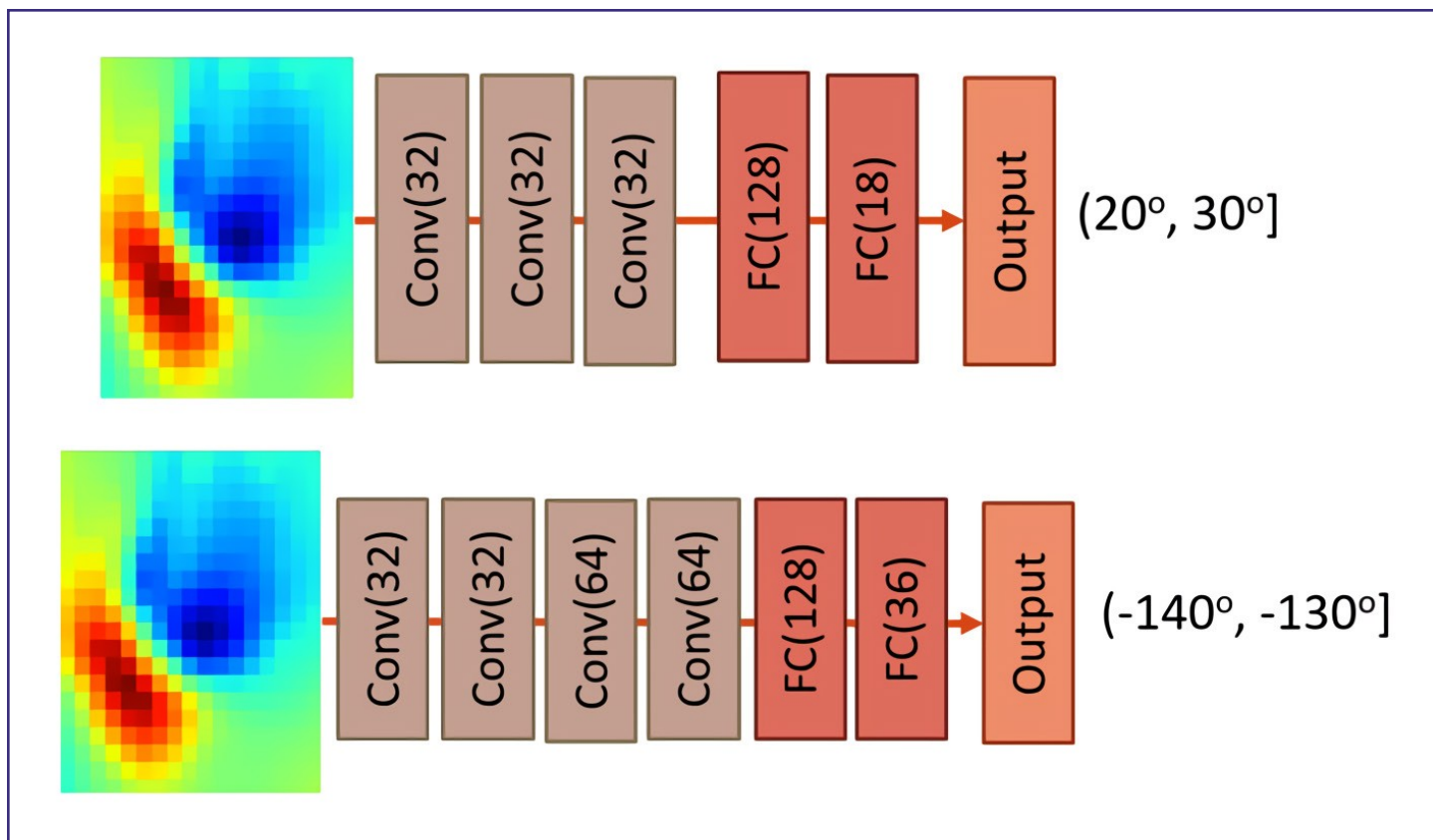


Figure 3: The CNN architectures used to predict (top) inclination and (bottom) declination. Conv refers to one convolutional layer, while the number in the parentheses refers to the number of filters used in each convolutional layer. Each filter detects a certain feature in the data map (diagonal lines, vertical lines, etc.). The filter size of each convolutional layer is 3x3 with a stride length of 1. FC refers to a fully connected layer with the number in the parenthesis referring to the number of neurons in each layer.

parameters specific to the field data, we generated synthetic data maps by assuming a large number of possible magnetization directions. The inclination that we considered ranges from -90° to 90° , and the declination from -180° to 178° with 2° intervals. This amounts to 91 different inclination angles and 180 different declination angles. Therefore, we generated 16,380 magnetic data maps for training, each resulting from a unique magnetization direction.

Step 3: Create labels

As with any other supervised machine learning method, CNN works with labeled data. Therefore, there must be a label associated with each of the magnetic data maps generated in Step 2. The label could be a continuously varying real number

(for regression tasks) or an integer categorical number (for classification problems). We decided to formulate the problem of predicting magnetization directions as a classification problem. Therefore, our labels are all integer categories. We created the labels using a simple binning approach. The range of inclination angles, i.e., $[-90^\circ, 90^\circ]$, was divided into several 10° angle bins, each of which is assigned an integer categorical number. For example, data maps with magnetization inclination values that fall into $[-90^\circ, -80^\circ]$ are all labeled as [0]. Correspondingly, data maps with inclination values that fall into the next bin, i.e., $[-80^\circ, -70^\circ]$, are labeled as [1]. The same procedure was applied to the declination angles. In total, there are 36 angle categories (or, labels) for declinations and 18 angle categories for inclinations. Each of the 16,380 data maps is associated with two labels, one for

its magnetization inclination and the other for its declination. The collective set of magnetic data maps and labels comprise our labeled data.

Step 4: Train two CNNs separately

With the labeled data properly prepared in Steps 2 and 3, we can now proceed to develop predictive models (also known as predictors or classifiers) for predicting magnetization directions. We chose to develop two CNN classifiers, one for predicting inclinations, and the other for predicting declinations. Before inputting the labeled data into the CNNs, all the data maps were normalized by dividing the data values by the maximum value in the whole dataset. The CNN architectures that we used for each classifier are summarized in *Figure 3*.

Step 5: Apply to field data

Once the training in Step 4 was done, we had in place the predictive models that can be used to predict the magnetization direction in terms of the inclination and declination angle categories. Our prediction of the inclination angle falls into the $[20^\circ, 30^\circ]$ category, and in the $[-140^\circ, -130^\circ]$ category for the declination angle. These results are consistent with previous studies performed by others in this area. Note that if one wants to find the magnetization direction of a different magnetic anomaly, e.g., Anomaly A in *Figure 1*, all the steps described above are to be repeated for the specific survey and source body parameters.

Conclusions

We have developed a workflow of using CNN to make predictions of magnetization directions based on a magnetic map. Our work shows that machine learning, specifically CNN, is an effective tool for predicting magnetization directions. Compared with existing approaches, the machine learning-based approach directly works with magnetic data maps and makes predictions by learning and analyzing the informative spatial patterns in the data maps. No component conversions, phase transforms, or inversions are needed. Our future work includes automating the estimates of a source body's geometrical and physical parameters and generalizing to magnetic anomalies caused by multiple source bodies. □

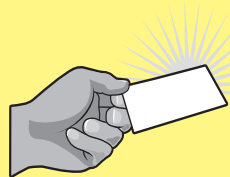


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Geoscience Center

The History of Geophysics By Bill Gafford

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

Our most recent quarterly Living Legends **Doodlebugger social event** was held on **Wednesday morning, August 7**. The **next such event** will be on **Wednesday morning, November 13**. These events are open to everyone and provide a time to visit with some of the legends in our industry and to see some interesting geoscience artifacts. No registration is required; light snacks, coffee, soft drinks, and water are provided.

The Geoscience Center is now on Facebook. You can find current information and pictures on the Facebook page: [The Geophysical Society of Houston Geoscience Center](#). We will add pictures of various items from our inventory from time to time and hope to receive comments and information about the history of these items. The inventory of our Bob Sheriff Library and our Museum Collection are available on the GSH web page under: [Outreach > Geoscience Center & Museum](#). Pictures of many of the Museum items are also included.

Last month I mentioned that some items from our Museum Collection had been returned from the Bullock Texas State History Museum

in Austin, where they had been on display since 2000. Some of these items, built as early as 1925 by Petty Geophysical Engineering Company, were used in some of the early seismic refraction exploration surveys. The items include a two-string galvanometer recorder, a horizontal component seismic detector, a blaster, a 50 cycle per second tuning fork; which added timing lines to the paper seismic records, a refraction amplifier, and a refraction-reflection vertical component seismic detector. This collection of seismic instruments is an excellent example of the components of

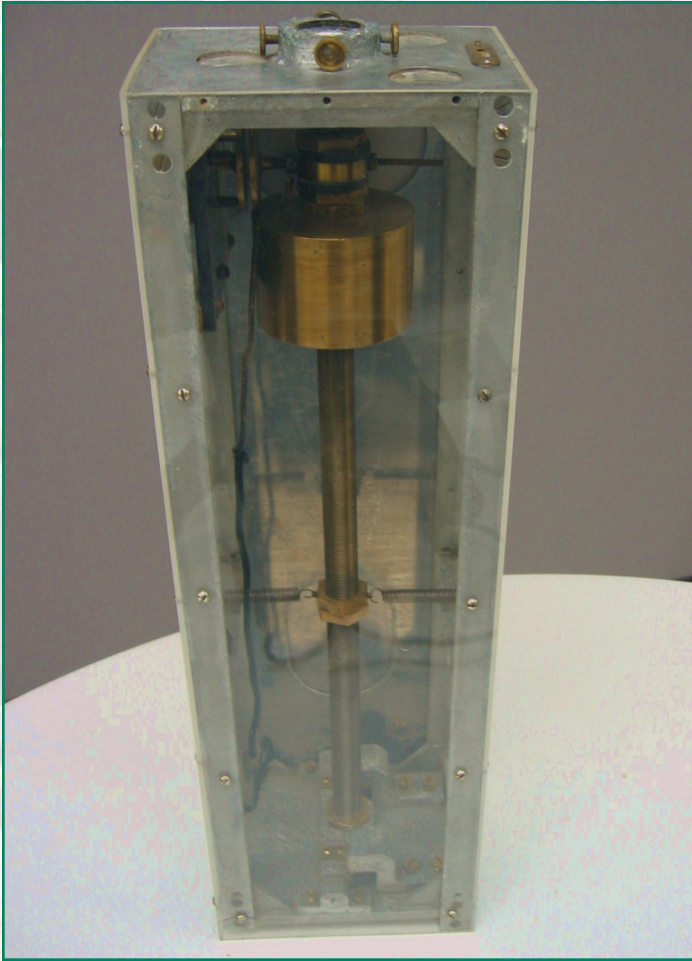


A 50 cycle per second tuning fork



Blaster

Geoscience Center continued on page 33.



Horizontal component seismic detector



Refraction amplifier



Vertical component seismic detector

an early seismic recording system. The items are currently on display at the Geoscience Center and pictures of these are included in this article.

Our collection of books, SEG, AAPG, and various company training manuals, as well as geoscience periodicals, continues to expand and are available to be checked out. □



Two string galvanometer recorder

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.



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GSH Fall Warm-Up Sporting Clays

By: Ryan Marshall, Sporting Clays Chairman (Dawson Geophysical)

Thanks to all who came out and supported the inaugural Geophysical Society of Houston's Fall Warmup Sporting Clays tournament! We had a great turnout and successful fundraiser for the society. 65 shooters came out and enjoyed a beautiful August morning with temps in the upper 80's. A big thank you to the folks at Archive Data Solutions for making breakfast tacos that morning and a fantastic fish/chicken fry for lunch! Thanks also goes to our gracious sponsors: Dawson Geophysical & Seitel were this year's Gold Sponsors. Silver Sponsors include NanoActive and Z-Terra. Recoil Resources and Paragon Geophysical came in as our Bronze Sponsors. American Shooting Center, Merrick Manister, Mohn & Associates and EPI Group were in-kind sponsors for donating prizes & drinks. Without courteous people/companies like these, this event wouldn't happen, so THANK YOU!!!



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IN-KIND



Sporting Clays continued on page 36.





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The Business of UNCONVENTIONALS and the Role for Geophysics

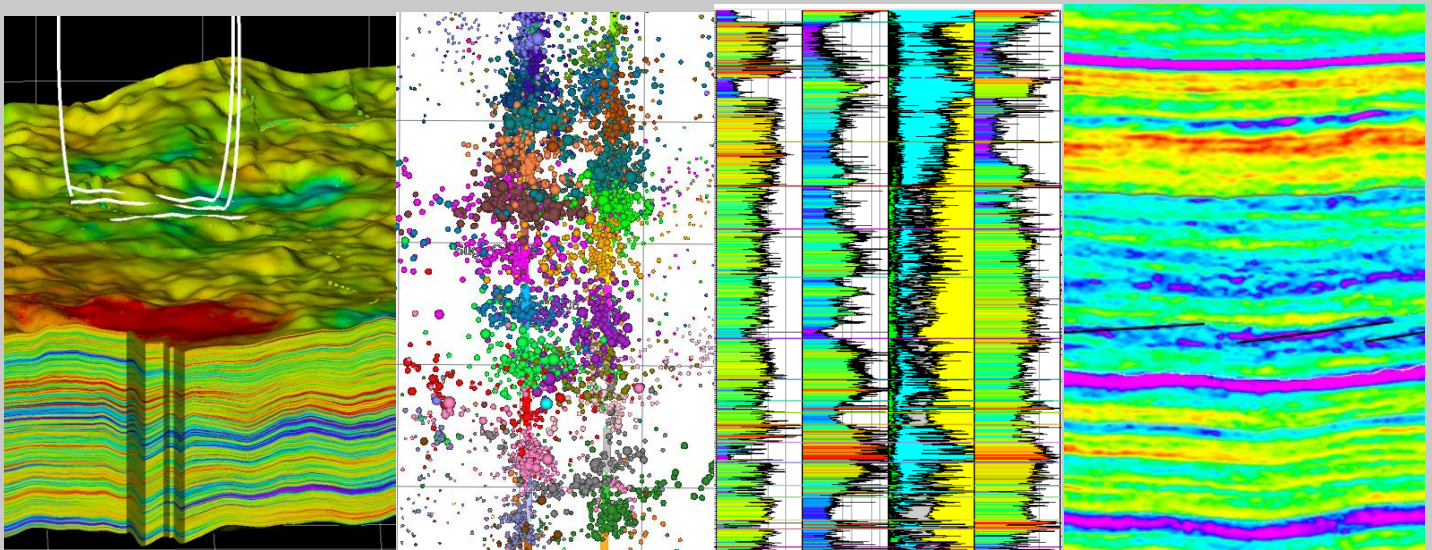
November 1, 2019

Norris Conference Center, Houston, TX

Exploring How Geophysics Is Used In Unconventional Resource Plays

- The business of unconventional (how to survive/be successful/competitive)
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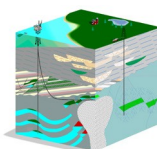
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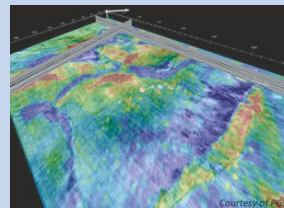
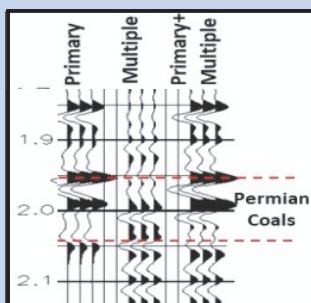
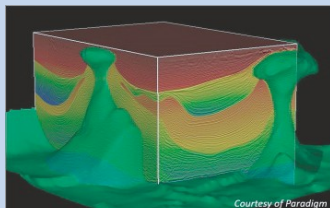
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- The Interpreter's Guide to Depth Imaging
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2019 GSH Tennis Tournament

SAVE THE DATE

Friday November 8, 2019

HGS Golf Tournament

Monday – October 21st, 2019

Format: 4-Man Scramble



Come join us for golf, food, friends and fun at the annual HGS Golf Tournament at our new location,

Sterling Country Club and Houston National Golf Club
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There will be prizes awarded for closest to the pin and long drive, putting games before we start, as well as many great door prizes for participants.

Entry Fee: \$175.00/Golfer or \$700.00/Team.

Early Bird Special (Through September 23):

\$150.00/golfer or \$600.00/team

Entry Deadline: October 14th.

Single players will be grouped to make teams of four.

Entries are limited & will be accepted on a first-in basis.

SCHEDULE OF EVENTS

8:00 – 9:45 a.m. Registration, free use of driving range and mini-games.

10:00 a.m. Shotgun start

3:00 p.m. Cash bar, open buffet

3:30 p.m. Door prizes and awards presentation

Apache

EXPLORING WHAT'S POSSIBLE



Doodlebugger Diary

My Experience as the Mobil Oil Technical Lead for the Exploration of the Madre de Dios Basin, Peru Part 3: The Secrets of the Las Piedras Block, Peru

By Nancy House

In Part 1 I described the exploration and eventual drilling of the Candamo 1X on a giant overthrust anticline in the Tambopata Block (Figure 1). In Part 2 I described the Las Piedras basecamp which of course was an adventure in itself. In this concluding Part 3 I describe the results of our exploration efforts in the Las Piedras Block.

After arriving at the Las Piedras basecamp in the Amazon forest and getting acclimated to the environment we first wanted to take a look at the field operations. Glenn Shepard and I visited the seismic line with our environmental lead and the party manager (Figures 2 and 3). Glenn showed me which beetles were edible and what leaves should be used to cure leishmaniasis. We were told that the crew was required to carry in all the food they ate and carry out any non-biologic waste they brought in. We observed the drilling of 5-meter shot holes and loading them with dynamite and reviewed the shot records from the days shooting later that evening in the processing trailer. On one of the shot records at the farthest traces there was a secondary event (upper right shot record in Figure 4). As we pondered what might have created a large impulsive 'thud' 9 km away from the shot, it occurred to us that it could have been a tree falling in the forest but with no one there to hear it (except of course for our eavesdropping seismic sensors). Part of our argument was why, so far from the shot, this high amplitude event occurred at the same time the ground roll from that shot was passing. So we were thus left with an intractable philosophical dilemma: "if a tree falls in the forest and there is no one there to hear it, does it make a sound?" We pondered this late into the night. Later Glenn suggested that this might be an ideal contribution to the *Journal of Irreproducible Results* (<http://www.jir.com/>) or at least a fun topic for geeks to debate.

During John's handover with me, he gave me an amplitude plot that changed my life. It didn't mean much at first, just a curious red blob around 900 msec in the middle of a seismic section covering

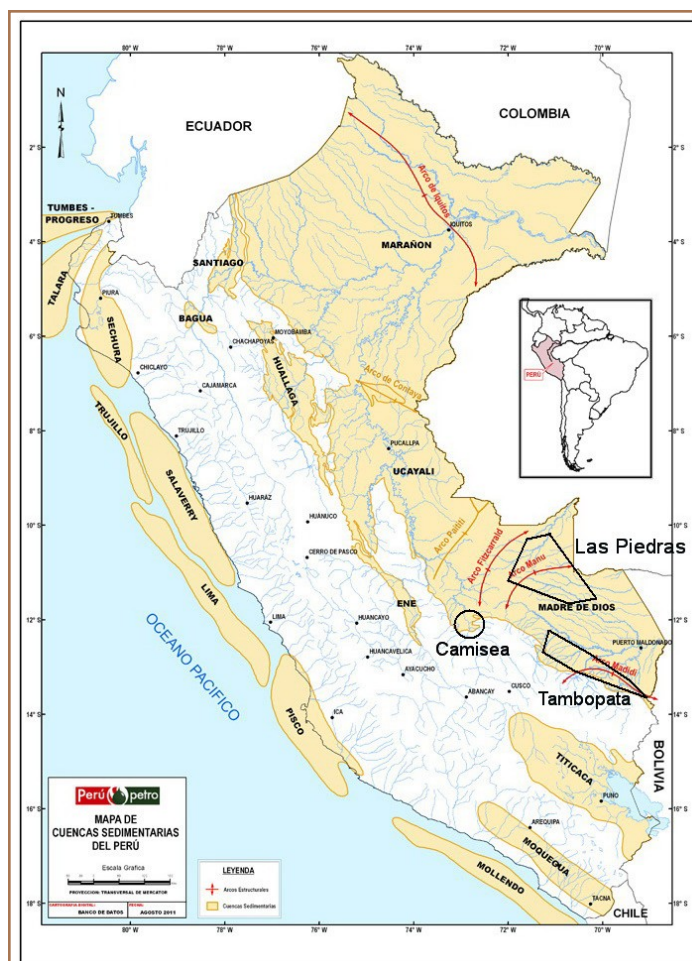


Figure 1: Sedimentary basins of Peru showing the Camisea discovery and Exploration Blocks 78 (Las Piedras) and 76 (Tambopata). From <http://www.perupetro.com.pe/wps/portal/corporativo/PerupetroSite/informacion%20al%20inversionista/%c3%a1por%20qu%c3%93%20invertir%20en%20el%20per%C3%91%20%2Fut%2Fp%2Fz1/>

Doodlebugger continued on page 44.

If you would like to add stories to the Doodlebugger Diary, send them to: Scott Singleton at scott.singleton@comcast.net or mail them to Box 441449, Houston, TX 77244-1449



Figure 2: Field operations in Las Piedras with Gil Davila, Environmental coordinator (right in white hardhat), Mobil birddog (left in white hardhat), and me (center). I am wearing one of 700 T-shirts printed with our Peru block outline and various jungle creatures. These were delivered as gifts to the field crew.

around 50 of the 90 miles of the second line (Figure 5). We discussed this seismic line and the apparent anomaly extensively. He actually provided me with several versions (see the blue plot on Figure 4). Finally, after a fascinating few days at the Las Piedras base camp mulling over these odd amplitudes, it was time for John to rotate off of the seismic crew and for me to visit the foothills operations at Tambopata. However, as I was heading out to change planes at the Manu airstrip I had an epiphany about that bright red area on the color amplitude plot: We had previously performed some AVO analysis on the key line through the incredible Camisea discovery and saw that the gas-filled sands clearly lit up on AVO displays (see Nancy pointing this out in Figure 4). We felt the Camisea anomaly likely was at the same stratigraphic level as our Las Piedras anomaly. I sent a satellite fax to the project geologist asking him to tell me the depths of the oil shows in wells drilled deeper in the basin. He replied back and with this information I carried my interpretation up section to just under the bright spot on the Las Piedras section, which was pretty exciting. It turned out the Las Piedras anomaly was a few hundred meters shallower than a regional unconformity we had been mapping



Figure 3: A view down a seismic line or "trocha".

all over the basin (Figure 5). The unconformity was also very bright but I discounted that as being caused by a lithologic contrast between a carbonate and sand/shale sequence. I was really excited by this find and was determined to pursue it as far as I could.

Mobil's head processing QC, Lynne Edelson, was in the foothills base camp with copies of proprietary seismic processing software and after I contacted her, she came to the Las Piedras base camp to determine if there was any non-geologic or operational explanation for the high amplitudes so she could ensure relative amplitudes and been preserved in processing. On the way the plane was grounded and she had to wait for 24

Doodlebugger continued on page 45.

hours camping out at the jungle airstrip. By odd coincidence, this is same airstrip I nearly got stranded at (with the baby monkey) as we were demobilizing from the base camp at the end of the foothills program. She eventually made it to our base camp and we got everything verified and validated. My first stop was to Lima for the partner operating committee meeting. I made a convincing case that we needed to reconfigure the remaining planned seismic lines to cover these anomalies as well as to shoot additional seismic. My enthusiasm infected everyone else and the partners were ready to go along with whatever we proposed.

However, my meetings to management in Dallas didn't go as planned. Mobil management told us to prepare exit plans from the block! I couldn't believe what I was hearing. I was devastated! Apparently there had been protests in Hamburg where a human chain was formed outside Mobil's office. There were weekly protests in London over the dastardly Mobil operation in the indigenous people's rainforest who were not represented in the negotiations and whom everyone was convinced would not approve of our plans. Apparently things had changed in the short time I was in the remote rainforest. But I was on a roll and was determined to keep pursuing my lead. I was able to interest the Mobil technical AVO teams as well as Elf Aquitaine's AVO experts in the anomaly, and in the end they all agreed it was likely due to a change in fluid and/or porosity. The shows down dip were significantly deeper, 2300 m, as opposed to my anomaly which was at about 1500 m.

As you can imagine, by now I felt I had the tiger by the tail and I wasn't going to let go. I met with our partners and was able to convince them to move one of the lines to a similar position along strike in order to map the lateral extent of the anomaly. By the time we were finished with those lines we had 4-5 anomalies identified in the same stratigraphic level near the area where the regional carrier bed, the Devonian 'Tarma Green' sand, was truncated by the unconformity (Figure 5). The leads were all named (!) and initial volumes calculated. We also had the large foothills structure at Tambopata, also with amplitude anomalies and a flat spot to the spill point, which I felt added to the total economics of the play. However, in the worsening political climate of that



Figure 4: Nancy showing the AVO response over the Camisea discovery. The various posters in the background are presentations about the field operations and exploration results. The color amplitude sections on the lower portion of the yellow poster board (upper center and right of figure) were produced by John Hefti while in the field (specifically the greenish image, reproduced in Figure 5, and the bluish image). The shot record on the right of the yellow poster board shows a high amplitude chevron presumably resulting from a tree falling in the forest at the far traces. Note that the presumed 'tree' response occurs at the same time the ground roll hits.

time the appetite for remote stratigraphic traps was pretty limited, and it pretty much sealed the fate of all of my leads in both areas. The block was dropped around the time of the ExxonMobil merger. It was later picked up by Hunt Oil, with whom I was fortunate to be able to repeat my studies. I expanded the interpretation to define large channel systems that contained the AVO anomalies. I felt it was quite elegant and had a geological basis. They were intrigued enough that they performed geochemical sampling over several of the anomalies where they found micro-seepage from the reservoirs. Unfortunately, despite all this work Hunt later dropped the block. I understand it was eventually acquired by CNOOC.

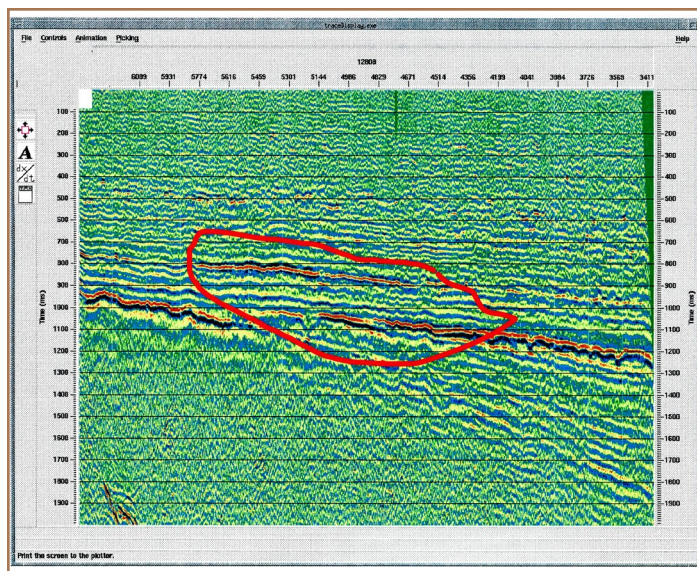


Figure 5: Seismic Amplitude anomaly in Las Piedras (800-900 ms, center of image) that was at same stratigraphic level as the famous Camisea discovery. The lower high amplitude reflector (~1000-1100 ms in center of image) is the regional carrier bed, 'Tarma Green', and lies immediately on top of a prominent unconformity. Note that the Tarma Green sands appear to lose their high amplitude character underneath the high amplitude reflector at about 900 ms.

So thus ended one of the most exciting finds of my early career. Looking back at it now, I would not have changed anything – I had found several frontier reservoirs in the Amazon jungle and was proud of it. I could have followed the traditional path of explorationists of the time and accepted the fickle changes in political winds, in other

words live to fight another day, but that's not who I was. I was one of the first female frontier geophysicists and I am now heartened to see the path I blazed has been repeated time and time again. Diversity and equality are now common and in fact expected. But we have a lot of work we still need to do (females still represent only a quarter or less of the O&G workforce). I for one am still pushing those boundaries. The good news is that now I have a whole lot more help doing it. □



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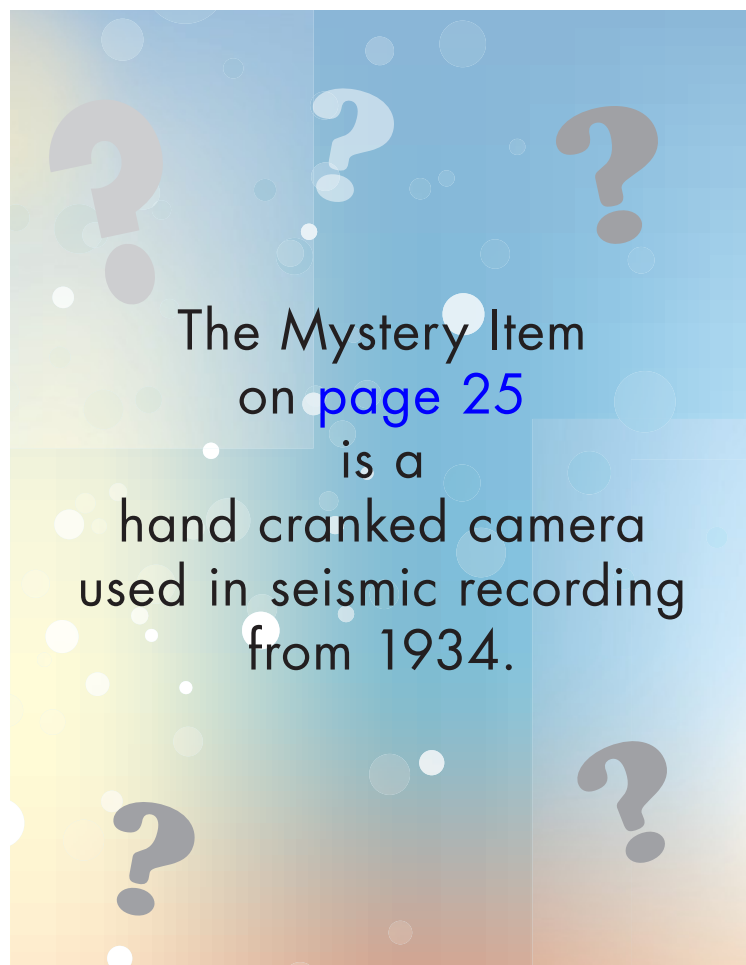
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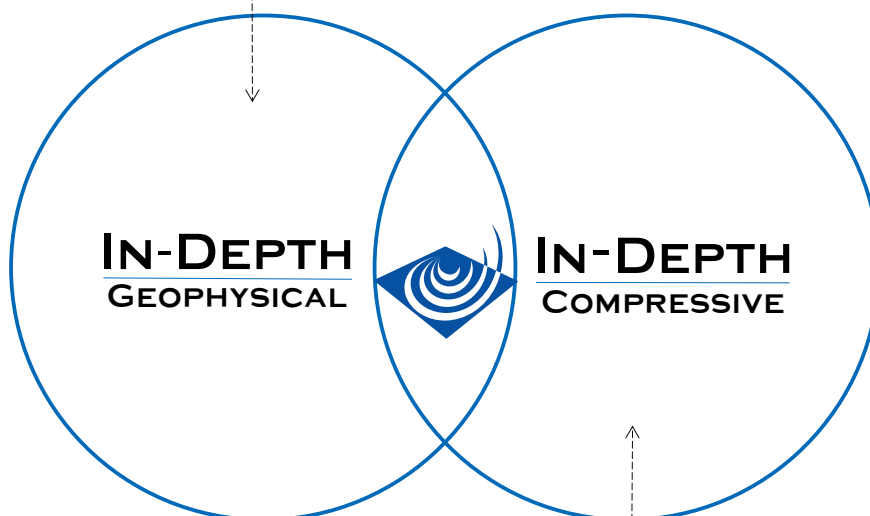
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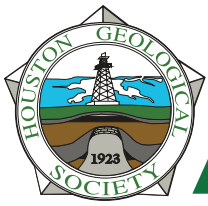
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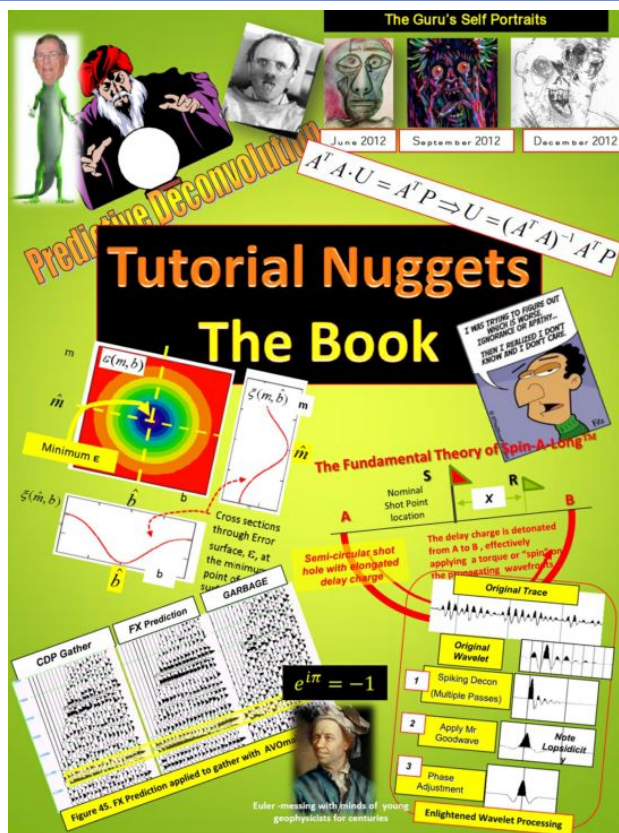
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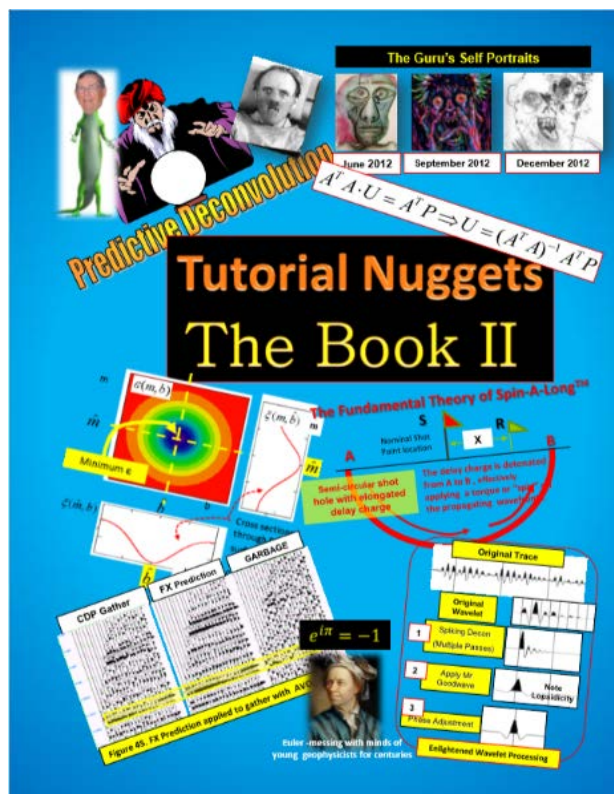




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