Nov 2020

GSH Journal

GEOPHYSICAL SOCIETY OF HOUSTON
Volume 11 • Number 3

The Epicenter of Geophysical Excellence

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Collaborating during the E&P workflow.

Photo courtesy of Emerson E&P Software.

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

Jan 2021	**Nov 14**
Feb 2021	**Dec 14**
Mar 2021	**Jan 11**

GEOPHYSICAL SOCIETY OF HOUSTON ORGANIZATION CONTACTS

Karen Blakeman, Office Director • Kathy Sanvido, Webmaster/Membership Manager
14811 St. Mary's Lane, Suite 204, Houston, TX 77079 • Office Hours 8 a.m. - 5 p.m.
Phone: (281) 741-1624 • Fax: (281) 741-9364 • Email: office@gshtx.org • Website: http://www.gshtx.org

GSH Board of Directors = GSH Executive Committee + SEG Section Representatives

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Office	Frank Dumanoir		713-594-2371	dumanoir@swbell.net
PAST PRESIDENT	**Craig Beasley**		713-689-6818	cbeasley@slb.com
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Data Science and Machine Learning	Eduardo Alvarez		321-745-5872	ealvarez@quanticoenergy.com
Potential Fields	Andrea Balza			abalza@edcon-prj.com
Rock Physics	Sue Pritchett		281-451-6522	spritchett@ikonscience.com
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TREASURER ELECT	**Lucy Plant**		713-452-0185	lucy.plant@geoteric.com
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COMMUNICATIONS				
SECRETARY	**Laurie Geiger**	281-841-6400		laurie.geiger@iongeo.com
Editorial Board	Lee Lawyer	281-531-5347	713-628-3513	llawyer@prodigy.net
EDITOR	**Alvaro Chaveste**		832-707-6505	Alvarochaveste@hotmail.com
Assistant Editor	Courtney Anzalone		713-689-5741	canzalone@slb.com
Assistant Editor	Kara Detro		713-689-6226	kdetro@slb.com
Assistant Editor	Kristoffer Walker	832-854-3753	650-814-4452	KristofferWalker@chevron.com
Technical Article Coordinator	Scott Singleton		832-524-8382	Scott.Singleton@comcast.net
Publications	J Haynie Stringer	281-491-2045	832-606-3993	hayniestringer47@yahoo.com
Website	Paul Schatz	713-975-7434	713-829-5254	Paul.Schatz@int.com
Social Media Coordinator	Liza Yellott		713-204-0998	liza.yellott@gmail.com
SEG SECTION REPRESENTATIVES	**Dennis Yanchak**	713-296-6109		Dennis.Yanchak@apachecorp.com
	Craig Beasley		713-689-6818	cbeasley@slb.com
	Peter Duncan	713-395-2408	713-725-4806	pduncan@microseismic.com
	Klaas Koster	713-215-7703		klaas_koster@oxy.com
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SEG ALTERNATE REPS	Eduardo Alvarez		321-745-5872	ealvarez@quanticoenergy.com
	Mike Graul	713-465-3181	713-248-3562	mgraul@texseis.com
	Bill Gafford	281-370-3264		geogaf@hal-pc.org
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SEG Wavelets (U of H) SIG	Michael Martinez		832-776-5598	michaelrubenmartinez@gmail.com
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Historian	Bill Gafford	281-370-3264		geogaf@hal-pc.org
SPG-NA Rep.	Samarjit Chakraborty			chakraborty.samarjit@gmail.com
ECH liaison	Rose Marie Geetan	281-366-6614		Rosemarie.Geettan@bp.scom
HPAC	(unassigned)			

A Word from the Board

By Phil Schearer, Second Vice President

Back in May 2018, the GSH membership elected the Board of Directors whose terms ended June 30 this year and in May 2019, then elected the current board. The outgoing board was in place when the COVID-19 pandemic struck, and the current board has wrestled with it since July 1st. As members, when you cast your vote, you are enabling the board to make decisions based on our best abilities to keep the GSH fiscally sound, maintain technical relevancy and offer benefits, social or otherwise, and to keep the membership vibrant. As you know, at the August board meeting, we, as a group, made the decision to cancel all in-person events through the end of 2020, and revisit spring 2021 events come November. It was a decision based on the realities of the pandemic (mask mandates, social distancing measures, crowd sizes), current rounds of redundancies within the industry, slashed budgets, work from home measures and on and on. We collectively hope the membership understands the measures taken as a "safety first" moment. If we had not postponed these events, if one person infected another at a GSH event, the board, and all members, would share responsibility for the unnecessary spread because we had the means to prevent it. Thank you for your understanding.

Random thoughts during a pandemic and stuck at home. The week of September 21 is newsworthy on multiple levels.

Perhaps there is another revolution headed our way. California Governor Gavin Newton signed this week an executive order that will require new cars and trucks sold in the state to be electric or zero-emissions by 2035. The order also requires medium and heavy-duty trucks to be zero emissions 10 years later. Will it work? Can it happen in 15 years? There are several obstacles to overcome. First, cost. The upfront costs of electric vehicles have historically been higher that gas powered cars. New technologies are emerging, but cost is still worth considering. Maintenance in EV's is less expensive and over time, with continued government tax credits, may make them on par. Powerful in-home charging stations are expensive too. That is however, if you have enough battery power to get you all the places you want to go. Second, battery life. A Nissan Leaf gets 100-200 miles (less if you run the AC or heat). A little research shows in 2019 only Tesla made EV's getting over 260 miles per charge. Third, where to dispose or recycle the Lithium-Ion battery, a polluter itself. Fourth, in 2019 only 2% of the 17 million cars sold in the US were EV's or about 325,000 units. California had over 15 million registered cars in 2018. At current EV sales it will take 46 years to replace the 2018 fleet of just California cars. At last count there were 49 other states. A start perhaps.

On September 25th, President Trump expanded a ban on exploratory drilling off the coasts of North Carolina and Virginia. Earlier he placed a similar ban offshore Florida, Georgia, and South Carolina. The ban, "prevents consideration of this area for any leasing for purposes of exploration, development, or production during the 10-year period beginning on July 1, 2022 and ending on June 30, 2032." It stands in contrast to the Trump administration's record of supporting oil and gas production. Not that the areas will be missed much since I believe the last seismic acquired on the eastern seaboard was in the 80's (or 90's??). Just that energy security should be shared by all 50 states. Texas and Louisiana have coastlines, fishing and tourist industries as well.

Another election is upon us and it has been described as a turning point in our history. Borrowing from a recent Op-Ed by historian and author, Joseph J Ellis, in 1787 Benjamin Franklin reportedly left the last session of the Constitutional Convention and was asked, "Mr. Franklin, what have you sdone?" "Given you a republic," Franklin replied," if you can keep it."

Let us not devolve into the Divided States of America. Vote November 3rd □

From the Other Side

By Lee Lawyer

A while back I received a note from Dave Hale. I told him we (GSH Friends) wanted to stay in touch as he continues his trek to conquer the Continental Divide. Unfortunately, the pandemic has slowed him down. Also, by the time this is published, there will be a significant amount of snow on the Continental Divide. He cannot ski the divide. To ski is to head down. The divide has two down directions and neither helps him get to Canada.

"Feet have never been better. I worry more about ticks. The gaiters and socks and pants and ... in this photo are treated with permethrin. This is Geode (my trail name) calling Laura (wife) from Bridger Peak at 11,000 feet. Mexico to Rawlins is well over halfway to Canada! Rawlins is easy to get to from Boulder/Denver. I will continue north when I can safely take the 5-hour direct Greyhound bus from Denver to Rawlins but not this year."

A question: What is ahead for our profession? Maybe I should define our profession. Maybe I should start by defining a "profession". Definition: A vocation or an occupation requiring advanced education or training and involving intellectual skills. That clearly defines a geophysicist. I am proud to be a professional. Not an applied professional, although many of us apply our knowledge to specific problems or issues. I do not know who put "applied" in front of the name, "geophysicist". It happened quite a few years ago. Let us get away from that nomenclature. I do not mind the term "GeoScientist", but that clearly includes geologists, which seems reasonable to me.

There are two components in being a GeoScientist. I call them the "Why" and the "What". The geophysicist is big on the "What". We leave the "Why" to the geologist. As a geophysicist that practiced his profession for almost 40 years with Chevron, I was a "What" and specifically, looking for a possible hydrocarbon trap in the data. I should not spend a lot of time wondering how that anticline was generated. If it has closure, drill it. Simple, "what". But I loved the "WHY". Our goal is to make geological sense from a bunch of wiggles. That combines both What and Why (Also a good reason we should consider merging the SEG and the AAPG. I never give up.)

That does not answer the question I posed. Our Profession has changed a great deal, in say the last 100 years. I just finished a book on the History of Geology (Gabriel Gohau). It showed how far we have progressed in 'planet' science. When I started my academic study of geology, I learned the time scale of the Earth. It seemed simple and straight forward. The older rocks were below the younger rocks (That had to be discovered. Can you believe that?), Geophysics did not go back that far. Seismic has a long history which includes the dropping of a large Iron ball and measuring the resulting tremors at a distance using a Seismograph. (Mintorp—1902 +/-) Gravity and Magnetics go back a lot farther.

If you think I am going to answer the question of where our profession is going, you are wrong. Where is the Oil and Gas Industry going? BP and Shell have announced a fundamental shift away from finding and producing oil/gas. They will be Carbon Neutral by 2050 (2040 +or-). They will focus on "Energy". Chevron and ExxonMobil have not made similar announcements (Yet). I think the downward spiral in the price of Oil/Gas has in0uenced our long-range planners. Let us review this a year from now when the Pandemic is controlled, and people are taking vacations again. Remind me. □

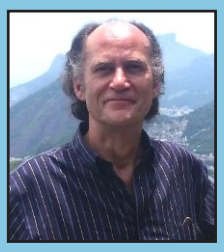
A Live Webinar!

Velocities, Imaging, and Waveform Inversion

The Evolution of Characterising the Earth's Subsurface

Featuring Dr. Ian F. Jones - ION Geophysical

November 9-11, 2020 9:00 am – 1:00 pm Houston Time



The course is designed for practising geoscientists and geoscience students who desire a better understanding of the principles and limitations of both current and emerging technologies involved in subsurface parameter estimation and imaging. The material is designed to help readers better understand how contemporary velocity estimation methods work, and what approximations are involved in obtaining computationally tractable solutions. The evolution of the industry's approaches to building earth models with ray tomography and full waveform inversion is covered, as are some of the emerging possibilities for replacing imaging techniques with direct subsurface parameter inversion methods. The approach will be mostly non-mathematical, concentrating on an intuitive understanding of the principles, demonstrating them via case histories.

This **12 hour course** can be taken in the comfort of **your office** or even **your own home**. It works on **PC's, iPads, iPhones**, or even two tin cans with a taut string (not recommended). **No travel costs**. **The Course Fee: $335!** With major discounts for Groups and Students. 1.2 CEU's are awarded.

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GSH Technical Events

Technical Lunch

Deep Learning for Automation of the Subsurface Model Building Applications

Aria Abubakar, Head of Data Science – Exploration and Field Development Platform, Schlumberger

Abstract and Bio

Online presentation

November 18, 2020 - 11:00am-12:00pm CST

Register

Technical Breakfast

Some Perspective on the Use and Application of Borehole Image and Vintage Dipmeter Logs for Seismic Interpreters

Thomas Howard, Manager at PayZone, Inc.

Abstract and Bio

Online presentation

November 7, 2020 - 7:00-8:00am CST

Register

Unconventional SIG

South Texas Microseismic Learnings; Correlating Temporary Fiber to Microseismic Geometries

Stephanie Cook, Geophysicist with Chesapeake Energy

Abstract and Bio

Online presentation

November 5, 2020 - 12:00pm-1:00pm CST

Register

Under a Different Rock

The Emerging Nexus Between the Electrical Power Industry and Geological Pore Space

Richard A. Esposito, Manager of Energy and Geosciences, Department of R&D, Southern Company

Abstract and Bio

Online presentation

November 16, 2020 - 6:00-7:00pm CST

Register

Potential Fields SIG

Shallow Velocity Modeling with Airborne Full-Tensor Gravity (FTG) Data

Scott Payton, Bell Geospace and Dr. Matt Duiker, Front Range Geoscience

Abstract and Bio

Online presentation

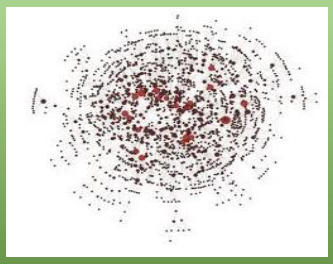
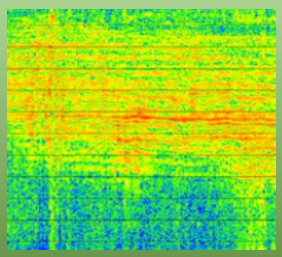
November 19, 2020 - 4:00-5:00pm CST

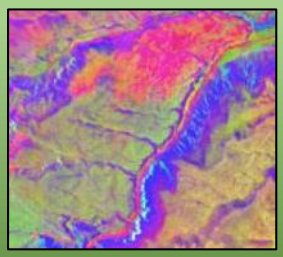
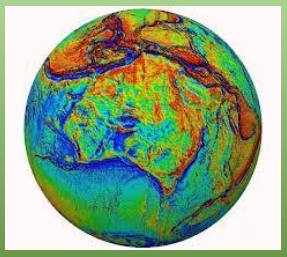
Register

GSH Gets Down to Business: a new business-oriented online series

The traditional technical marketing meeting, whether it is a proprietary client in-house event or a booth presentation at a convention, is another casualty of Covid-19. The GSH has now started a new online presentation series, where geophysical companies are able to deliver information on their latest products and services to GSH members and friends! Key features are:

* A vendor offers their commercial presentation as an online event through GSH.
* The event is announced, promoted and managed by GSH; attendance is free.
* As in a booth presentation, both potential customers and competitors may be attending.
* After the presentation, there will be an interactive Q&A session.
* Attendees contact information will not be shared by GSH, however, vendor contact is available and attendees are free to share their contact information.

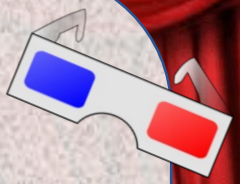




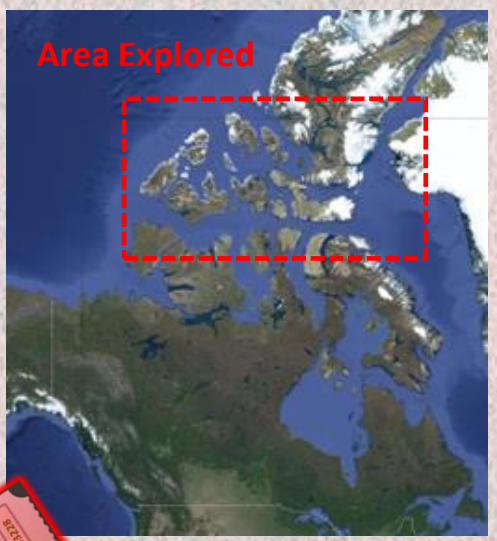
Interested vendors please contact the GSH at 281.741.1624 or office@gshtx.org

GSH Movie Time

Now Showing

Breaking the Ice Barrier*





GSI's vessels were in the arctic islands since 1972. In 1973 the *Carino* explored the eastern arctic islands, and in 1974 the *Arctic Explorer* became the first vessel into the channels between Melville and Prince Patrick Islands. The same year, the *Carino* would pass through a region perhaps fitting the name: "Perseverance Point" and became the first vessel to traverse the northwest passage through M'Clure strait.

In this movie see how both, the *Arctic Explorer* and the *Carino*, journeyed through unexplored waters in the Arctic Archipelago to acquire more than 3500 miles of seismic data; some of it in new ice more than six inches thick.

* GSI vintage videos courtesy of Schlumberger – WesternGeco

Welcome to
the Second HGS and EAGE Conference on Latin America Online

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WHY SHOULD YOU ATTEND?

The HGS (Houston Geological Society) and EAGE (European Association of Geoscientists and Engineers) will host for the second time the Latin American conference that will take place in a fully virtual format, between the 1st and the 3rd of December 2020. On this occasion, the HGS/EAGE will bring an integral and exceptionally enriched conference on Latin America.

Since the last two decades, the Latin American region has faced continuous development in energy resources, which has opened to increased investment. In recent years, the oil and gas industry has significantly increased exploration and production activities in the southern Caribbean margin, the Andean foreland, Guyana-Suriname offshore, deep-water Brazil, Argentina and Uruguay offshore, unconventional exploration in Argentina and Colombia, and the opening of exploration areas on the Pacific margin of South America. All this makes the second HGS/EAGE Conference on Latin America a perfect setting to keep up with the latest in Petroleum Geoscience for Conventional and Unconventional E&P, Natural Resources and Ore Geology, Machine learning present and future role in exploration, Seismic Imaging in E&P, that in overall, contribute to open to constructive dialogues on energy integration and prosperity of the region.

The Technical Committee has prepared a flagship event that includes special sessions on the Caribbean Offshore and the Special Session on Venezuela "*Venezuela's Upstream to Downstream - Past, Present and Future*", oral presentations, and poster sessions that will be widely attended by academic and industry participants from the USA, Europe and Latin America.

We look forward to seeing you at the second Latin American conference hosted by the HGS/EAGE!

Mystery Item

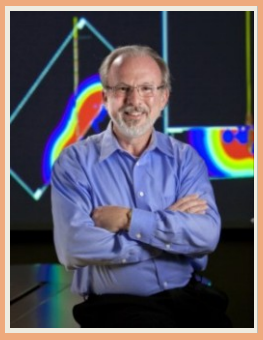
This is a geophysical item...

Do you know what it is?

This month's answer on page 22.

A Live Webinar

Microseismic monitoring: what I have learned in the last four years



Peter M. Duncan, PhD

President & CEO, MicroSeismic, Inc.

January 27 & 28, 2021 10:00 am – 2:00 pm

"In 2016 I presented a 2-day overview of microseismic monitoring as I understood it at that time. Over the last four years the application of microseismic data, particularly to the development of unconventional resources through hydraulic fracturing, has made great strides particularly through integration with other reservoir geology and engineering practices. In this course I will try to bring you up to date on what has been accomplished using case histories of recent projects."

This **8 hour course** can be taken in the comfort of **your office** or even **your own home**. It works on **PC's, iPads, iPhones**, or even two tin cans with a taut string (not recommended). **No travel costs**. **The Course Fee: $250!** With major discounts for Groups and Students. 0.8 CEU's are awarded.

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Earthquake Clusters Show Temporal Changes in Shear-wave Anisotropy in the US Midcontinent

Keith A. Nolte and George P. Tsoflias, The University of Kansas, Department of Geology

Summary:

The US midcontinent has seen a large increase in seismicity over the past decade. Spatiotemporal correlations of earthquakes and wastewater injections as well as pore pressure fluid models have been used to relate induced seismicity to high-rate wastewater disposal wells and hydraulic fracturing. Here, we examine the link between changes in shear-wave anisotropy and induced seismicity. Shear-wave analysis shows that the anisotropy in central Sumner County, south-central KS has significantly changed from 2015 to 2017, which coincides with the time period of high earthquake activity and wastewater disposal in the region. The analysis of anisotropy identified changes (flips) in the orientation of the fast shear wave (ϕ) from along maximum horizontal stress to an oblique orientation. This change has been shown in other settings to be linked to rocks with critically stressed pore fluid pressure. We present a large change in S-wave anisotropy, which aligns temporally with in situ pressure monitoring in the Wellington oil field. We conclude that S-wave anisotropy change may be used to identify remotely critically pore pressure stressed regions in the subsurface that are at risk of experiencing induced earthquakes.

Introduction:

The US midcontinent has experienced a dramatic increase in earthquake occurrence since 2012 [Ellsworth, 2013; Langenbruch and Zoback, 2016]. Most studies have correlated earthquake increases to pore fluid pressure increases caused by high-rates of injection of wastewater [Ellsworth, 2013; Keranen et al, 2013; Keranen et al, 2014; Ellsworth et al, 2015; Walsh and Zoback, 2015; Langenbruch and Zoback, 2016; Rubinstein et al., 2018; Dempsey et al., 2019]. Recent studies also showed that hydraulic fracturing is causing seismicity in Oklahoma [Skoumal et al., 2018]. However, little is known about fluid flow and pore pressure diffusion pathways in the shallow basement [Keranen et al., 2013; Dempsey et al., 2019]. Finding a means to detect elevated pore fluid pressure *in situ* without costly drilling or equipment would provide near real time information on the current status of increased pore fluid pressure. This would help inform decisions on injection volumes and locations.

S-wave splitting occurs in all anisotropic rock [Crampin, 1985; Crampin et al, 2002; Gao and Crampin, 2003]. S-waves split into two components, a fast and a slow wave. The fast S-wave travels parallel to the anisotropy and the slow S-wave travels perpendicular to the fast component. The split is described by two variables, δt and ϕ. δt is the separation in time between the fast and slow arrivals, and ϕ is the orientation of the fast S-wave [Crampin, 1985; Crampin et al, 2002; Gao and Crampin, 2003].

The most common type of anisotropy is that from fractures. The shallow basement of the midcontinent is highly fractured [Baars, 1995]. The orientation of the major tectonic structures in south-central KS are approximately 310° and 30° [Baars, 1995]. Since fractures occur in nearly all directions, the dominant

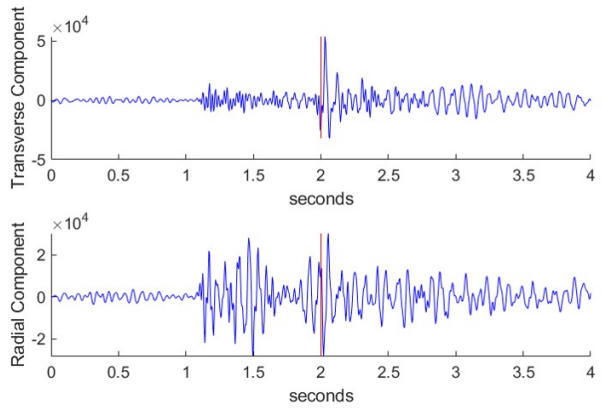

Figure 1: Example of a raw seismogram from an M 1.3 earthquake in May of 2015 in T and R components, where R is the radial component that is in the direction of source to receiver and T is the transverse component perpendicular to the R component. Here, the shear-wave arrival is marked as the red line. The p-wave arrival can be identified approximately 1 second ahead of the shear-wave.

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Technical Article continued from page 11.

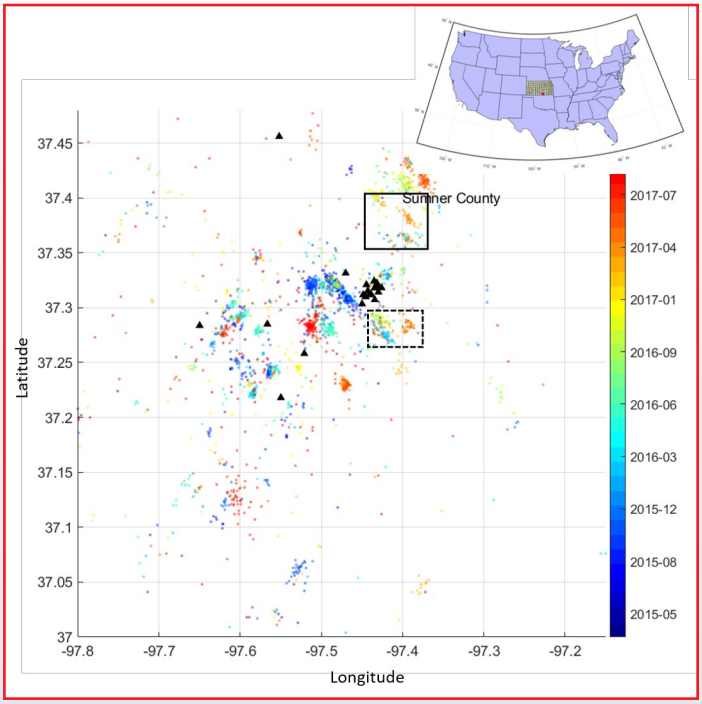

Figure 2: Earthquake catalog from the Wellington Monitoring Network in Sumner County, Kansas. The Two black boxes show the clusters of earthquakes investigated for this study. The black box with solid lines is the north cluster and the black box with dashed lines is the south cluster. The yellow star in the map denotes the location of the pressure monitoring KGS 1-28 well.

source of anisotropy will likely be from those that are parallel to the maximum horizontal stress (SH-max) and are therefore open because of their orientation within the stress field. The maximum horizontal stress in the region of study is between 75° [Schwab et al., 2017] and 80° [Alt and Zoback, 2016].

S-wave splitting analysis has been used on natural earthquake zones to identify regions around the fault that are critically stressed from pore fluid pressure. Critically stressed pore fluid pressure is identifiable because the fast S-wave polarization flips by 90°, orienting it perpendicular to the maximum horizontal stress [Crampin et al., 2002; Crampin et al, 2004]. 90° flips can be seen when the raypath travels the majority of its distance through rock that is critically stressed from pore fluid pressure [Crampin et al, 2004]. These effects have also been seen in active source seismic surveys, where prior to injection of fluid, the fast S-wave aligns with the maximum horizontal stress, but after injection, the S-wave polarization is flipped [Angerer et al, 2002].

Here, we look at S-wave splitting events in southern Kansas to identify evidence of this critical change in pore fluid pressure. Correlating temporal shear wave anisotropy changes to pore fluid pressure changes in induced earthquakes was first proposed by Nolte et al. [2018]. This study expands the previous work by examining clusters of seismicity, presumably from earthquakes occurring on the same segments of neighboring faults, and thus eliminating uncertainty in the anisotropy analysis that can be introduced when raypaths vary in distance and azimuth.

Methodology:

Earthquakes are cataloged in Seisan [Havskov and Ottemoller, 1999]. The resulting catalog is automatically processed using a shear-wave splitting analysis adapted from the methods described in Teanby et al. [2004]. The splitting algorithm is based on the technique used by Silver and Chan [1991]. These methods take shear-wave arrival information *(Figure 1)* and automatically calculate the best solutions for the shear wave splitting parameters in a large number of windows around the shear-wave arrival [Teanby et al., 2004]. These arrivals are then clustered, and the best solution is chosen [Teanby et al., 2004]. Here, we perform the shear-wave splitting analysis on a small spatial cluster of earthquakes. Small spatial clusters are used to reduce the differences in raypath caused by azimuth and angle of incidence [Bokelmann and Harjes, 2000]. These clusters of earthquakes can be seen in *Figure 2* in the solid black box and the dashed black box. A cluster to the north and one to the south were chosen to look for potential spatiotemporal differences in shear-wave splitting parameters on the basis of the distance from large scale injections of waste water to the south and west of the study area. Earthquake clusters of varying distance from the source of pressure increase may show differences in seismic anisotropy due to timing of pore fluid pressure change (increase or decrease) and magnitude of pore fluid pressure change.

Results:

Figure 3 presents polar histograms of S-wave anisotropy analysis of two clusters of earthquakes, referred as the north cluster the south cluster. The locations of the two clusters are identified by black boxes in *figure 2*.

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In *Figure 3*, the north cluster during years 2015 and 2016 shows ϕ orientations that are in line with the structural trends in southern Kansas, trending ~30° and ~310° and identified by the blue arrows. Although neither 2015 nor 2016 has a large data set, combined they provide compelling evidence that the ϕ orientation was aligned with structure during that time period. Then, in 2017, nearly all ϕ orientations rotate to be aligned with the maximum horizontal stress direction (75°-80°), identified by the black arrow.

The south cluster shows a distinctly different temporal change in the ϕ orientation when compared to the north cluster. In 2015 and 2016 most of the ϕ orientations are nearly perpendicular to the maximum horizontal stress direction (black arrow). Previous work suggests that this change in ϕ orientations (flip from SH-max) indicates that the shear-wave has traveled through rock that is critically stressed by pore fluid pressure [Crampin et al., 2002]. These changes align closely with change in pore fluid pressure from downhole monitoring in the Arbuckle. *Figure 4* shows pressure data from the KGS 1-28 well which is located in the center of the study area. The pressure increased 30 psi (200 kPa) since the well was completed in late 2011. This pressure seemed to reach a maximum in late 2016 before beginning to decrease. Other pressure models of this region suggest a similar timing for reaching the maximum pressure [Langenbruch et al., 2018], followed by a decline in pressure related to regional reduction in injection rates imposed by state regulatory agencies.

Discussion:

Change in ϕ orientation is clear in both tightly spaced earthquake clusters. In the tectonically stable US midcontinent, over the time period of this study, anisotropy change may be explained by the regional rise and fall of pore fluid pressure.

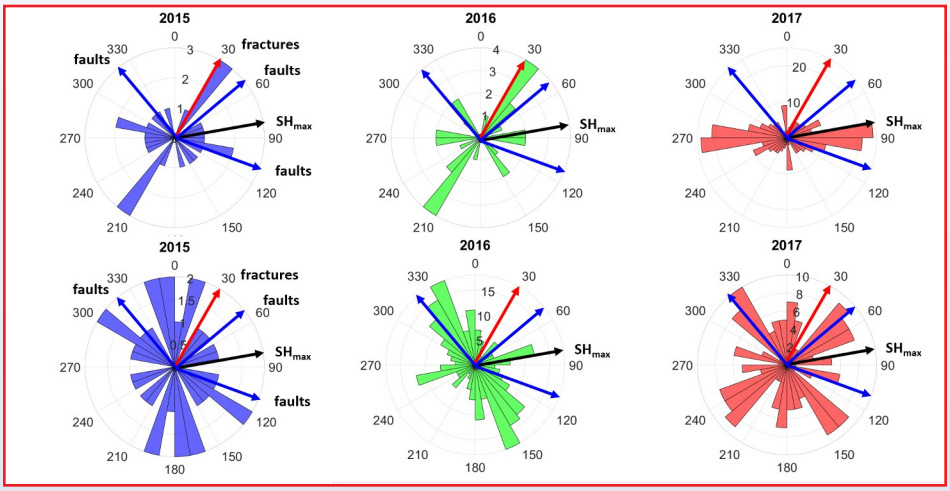

Figure 3: Polar histograms of s-wave anisotropy orientation (ϕ) from the analysis of the Wellington Network in Sumner County, Kansas. The blue arrows indicate the orientation of structure in southern Kansas (from Baars, 1995) and the black arrow is the direction of the maximum horizontal stress (from Schwab et al., 2017). S-wave anisotropy shows temporal changes over the monitoring period 2015 to 2017. Results are shown for two clusters of earthquakes at differing distances from major injection wells to the south of the study area.

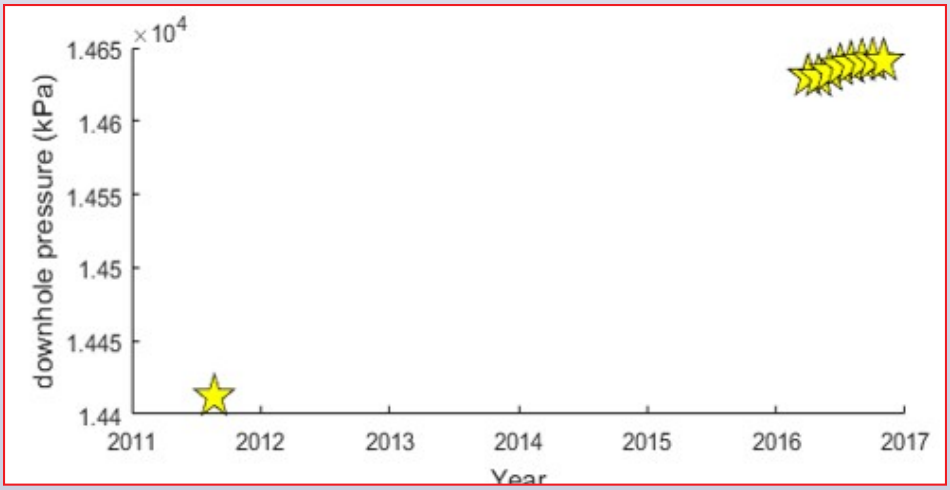

Figure 4: Arbuckle pressure measured in KGS well 1-28. The well is located in the Wellington oil field in the center of the study area. The initial pressure data point is from the completion of the well in 2011. The 2016 data is from real time pressure monitoring in the well. There is an increase of approximately 30 psi (200kPa) from 2011 to the peak of pressure in 2016. Pressure has been declining since.

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However, the changes appear markedly different between the two clusters which can be interpreted based on the relative distance of each cluster to sources of pore pressure change (injection wells) located south of the monitoring area. The cluster to the south shows 90° flips in ϕ orientation in the 2015 and 2016 polar histograms relative to the expected ϕ along maximum horizontal stress orientation (black arrow). These flips most probably indicate that the raypath has traveled through rock that has undergone a critical change in pore fluid pressure [Crampin et al., 2002]. However, the 2017 data shows ϕ orientations that are mixed between flipped and in line with the maximum horizontal stress direction, indicating the critical pore fluid pressure change is no longer occurring at the magnitude to cause homogeneous flips. We interpret this as a transition period. This transition period could indicate that there is still sufficient elevated pore fluid pressure to cause the maximum horizontal stress to not be the only source of detectable anisotropy.

The cluster to the north shows ϕ orientations that are in line with the structural control in southern Kansas in both 2015 and 2016. Then in 2017 ϕ orientations are nearly all in line with the maximum horizontal stress direction. This change most probably indicates that the region had undergone an increase in pore fluid pressure great enough to reduce the effects of the maximum horizontal stress on shear wave anisotropy, but not large enough to cause 90° flips in ϕ. In 2017, pore pressure reduction yields the expected ϕ orientation for the region along maximum horizontal stress.

These interpretations are in line with our previous studies and modeling in the region. Our earthquake catalog identifies a northward progression of earthquakes from 2015-2017 *(Figure 2)*. These results support a changing pressure gradient across Sumner County, where pressure increases occurred earlier in the south and now appear to be moving northward. The pressure increases in the north seem to be smaller than those observed at the height of pressure increases in the south, in line with models [Ansari et al., 2019] of pore fluid pressure movement through the Arbuckle. This is in line with the hypothesis that the increased pore fluid pressure is the result of high volumes of wastewater injection in Oklahoma, south of our earthquake monitoring area.

Monitoring for changes in shear-wave splitting parameters may prove to be a useful tool for gaining *in situ* understanding of pressure changes in the shallow basement. Thus, we conclude that the use of passive seismic networks to monitor for anisotropic changes can be a valuable tool for identifying risk from wastewater injections.

Future Directions:

The Teanby et al. [2004] methodology used herein is easily implemented and allows for rapid collection of data and results. However, further analyses are available to refine and improve data output, reducing uncertainty and constraining ϕ orientations and delay times.

The Savage et al. [2010] methodology uses strict quality control measures that grade data based on cluster quality identified in the Teanby method. The Savage method avoids confounding factors that result in two clusters being of comparable quality, allowing for better determination of high-quality results. Utilization of this more rigorous method will reduce error, increasing confidence in the conclusion that small anisotropic changes are correlated to changes in pore fluid pressure.

This analysis focused heavily on ϕ as a preliminary understanding of pressure changes. However, it is likely that significant data on small pressure changes will be identified based on analysis of dt. Li et al. (2019) identified small changes in dt that correlated to pore fluid pressure changes induced by hydraulic fracturing; although hydraulic fracturing is distinctly different than regional pressure changes from waste water injection, the study of Li et al. (2019) supports the model proposed here that changes in pore fluid pressure can cause significant changes in dt.

Current work is implementing the Savage methodology and is incorporating dt analysis, providing additional insight and support to the results presented here.

This work is ongoing and will continue to focus on understanding changes in pore fluid pressure resulting from wastewater injection and the effects of this change in anisotropy at regional scale injection. □

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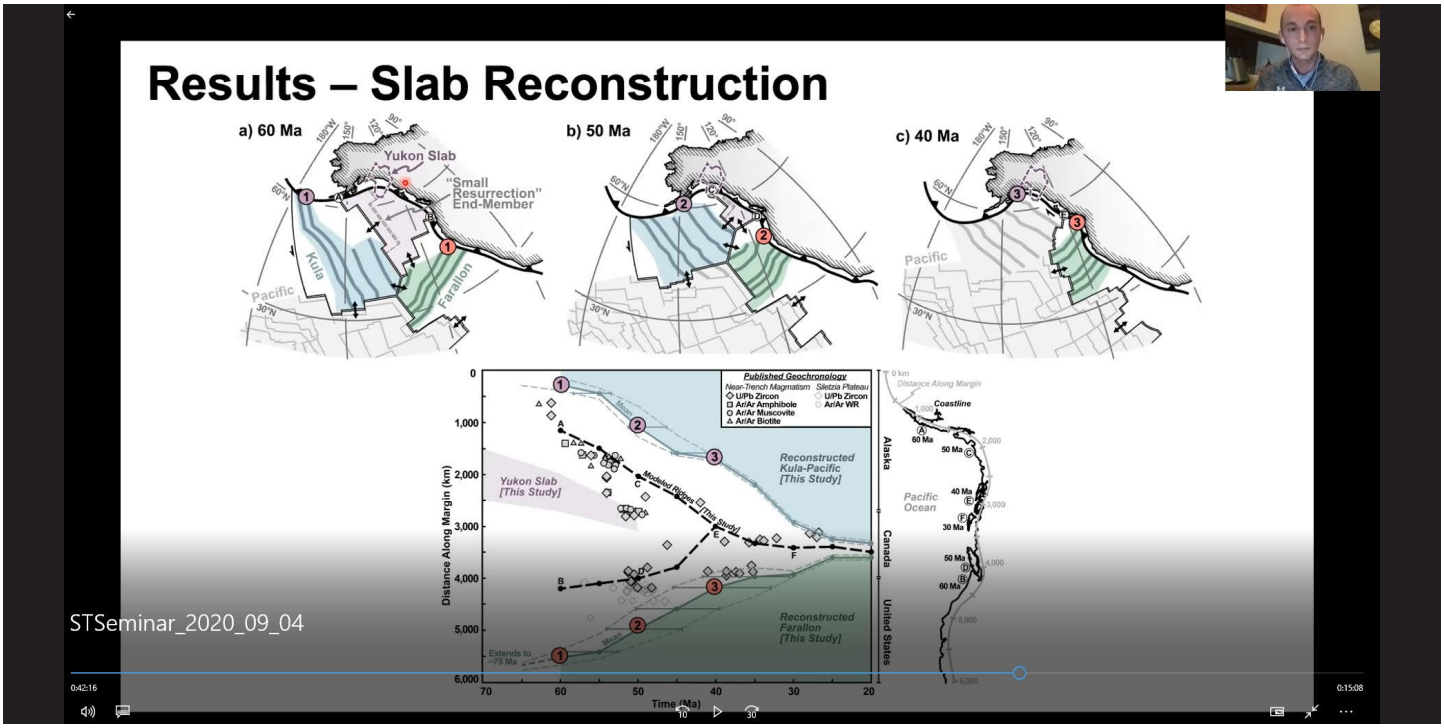
U of H Wavelets

By Faith Walton and Michael Martinez



College is back in swing, and with that, the SEG Wavelets events have begun. The first two weeks of events focused on career preparation. August 15th, the SEG Wavelets hosted the Earth and Atmospheric Sciences Department of the University of Houston. The EAS Department brought in career counselors to give students advice on interviewing and resume building, and the counselors gave out a resume template for students to follow. To find this template and other resources, visit our website listed at the end of this article.

Our next event, on September 3rd, the Wavelets hosted Libby Ingram Storer from Shell. Libby is a former UH professional MS graduate student. She shared advice on persisting in the job market throughout oil and gas downturns, and how to network and socialize at events even during the current COVID-19 climate. Some of her networking tips included proactively reaching out for Zoom coffee chats with mentors, attending virtual conferences with research that you have completed, and joining the professional organizations. Watch the question and answer portion of our talk with Libby Ingram Storer at the SEG Wavelets YouTube page, linked at the end of the article.

The SEG Wavelets are hosting the University of Houston EAS Department Fall 2020 Structure and Tectonics Seminar. SEG hosts and moderates each installment through a Zoom webinar. Each event features undergraduate and graduate research, faculty members, and visiting students from China, and the EAS and audience give feedback. The Structure and Tectonics Seminar allows students to share their work with the department, connect with professors, and find potential committee members for graduate research.

The SEG Wavelets will host Dr. Sergey Fomel on November 17th, who will present machine learning applications in the geosciences. To keep up with the latest SEG Wavelets news, follow us on our LinkedIn and Facebook at "SEG Wavelets" to keep up to date with our activities this academic year. Join SEG today at the local level with the Wavelets and the national level following our site's instructions!

Wavelets Webpage: https://sites.google.com/nsm.uh.edu/segwavelets/resources?authuser=0

Wavelets YouTube: https://www.youtube.com/watch?v=jdYz-72XTIA&t=19s □

Stunned Guru Gives In to Mob Demands

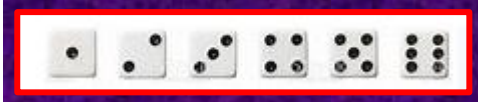
Stunned Guru

Angry and thirsty Mob

Promises Probability & Statistics for Elders and Less Gifted

The Guru recognizes the growing importance and interest in this subject. **Inversion**, **artificial intelligence (AI)**, **Bayesian concepts,** etc, all depend on a bluffing acquaintance with fundamentals. We will begin our journey in quest for probable enlightenment along a parallel and somewhat intertwined paths: **Discrete** and **Continuous** which bear uncanny resemblance to **sampled** and **analogue** data. We'll give **precedence** to the **discrete** since the math is easier; for instance, we get to use Σ instead of the dreaded $\int$, assuming the reader finds summing easier than integrating.

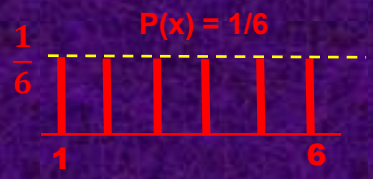
Let's start with the **classic dice** example. If we roll a single honest die, with 6 faces, we may reasonably expect any one of the faces to appear on top (face up).



-Classic

Probability is a number (usually a fraction), which expresses the relative likelihood that a particular event will occur. Here the event might be that a 4 will appear on top out of the 6 possibilities. Therefore the **probability of a 4** is **P(4) = 1/6**. If we designate **x** as the **face value,** then we can state the **probability function as -**

$$P(x) = \frac{1}{6}$$



This is a discrete probability distribution since x = {1, 2, 3, 4, 5, 6} only, and is discontinuous.

Note that the sum of the 6 probabilities is, as it should be, **equal to 1**. This simply says something has to happen when the die is cast (kind of a poetic Great Truth).

$$\sum_{x=1}^{6} P(x) = 1$$

It was discovered by the **troops of Caesar's army** that gambling with a **single die** was a dull undertaking. Many were forced to take up hobbies such as the invention of **pointless tools such** as the **wireless mouse**.

With all the extra unused dice laying around, one of the Centurions casually **cast 2 dice** and noted the **sum** of the resulting faces was **7**, a particularly popular number in the Legion. The **Game of Dice** was thus invented (53 BC).

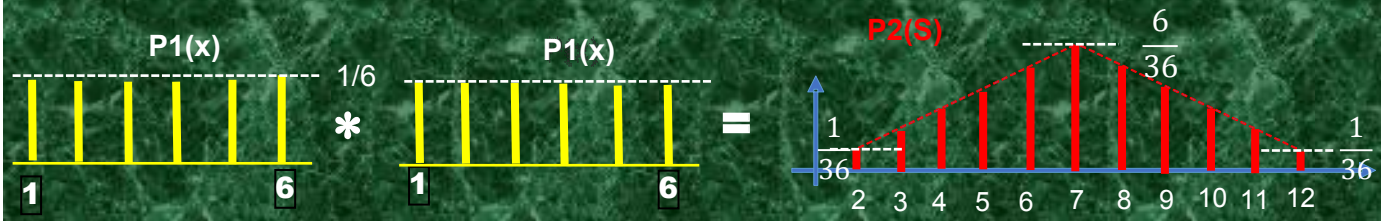
Tutorial Nuggets continued on page 18.

Tutorial Nuggets continued from page 17.

It will come as no surprise to avid but lonely readers, that there is and interesting and useful **tie** between determining the **P(x)** of possible outcomes of the dice roll where **x is the sum** of the **two dice faces**, and it is our old friend, **convolution.** Yes, **convolution** which your Guru explained many years ago in Nuggatory Philosophy, was somewhere in **all processing** applications of good repute.

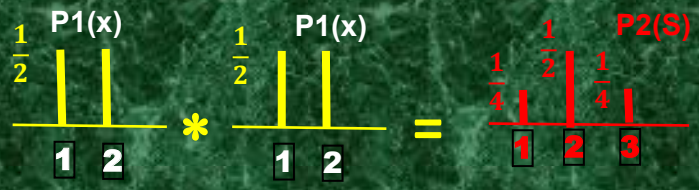
Gaius J. Caesar

The possible outcomes of the roll of 2 dice range from a sum **2 (1 + 1),** AKA, **"snake eyes",** to **12 (6 + 6)**, **"box cars".** The 11 **P2(x)** are determined by convolving the original **P1(x)** of each single die with each other as shown below.



The two probability distributions functions, **PDFs**, on the left, for a single die face, are uniform (equal probability for all 6 possible outcomes of rolling one die **(P1[x] = 1/6).** The probability distribution on the right, **(P2[S])**, is **triangular** and represents the probability of possible outcomes of summing the values of **2 dice** resulting in **11 possible values** for the **36 possible outcomes** of the roll. Note a sum of **7 is the most likely** outcome with a probability of 6/36 = **1/6.** This results from the fact that there are **more ways to sum to 7** than for any other possible outcome **(1+6, 6+1, 2+5, 5+2, 3+4, 4+3).** The sum of all the probabilities shown is **1**.

For all of you aspiring statisticians and probabilists, a quick way to compute these simple PDFs is to invoke the **Z-transform** method and use the synthetic mode keeping track of the random variable position (the "Z" value) we'll use a very simple example, that with a **2-point PDF,** the **coin flip** for Heads or tails. This event results in either a H or T with equal **probability (½).**



Multiply Coefficients

1 1
1 1
1 1
1 2 1

Keeping track of the denominators allows us to simplify the multiplication and write the product as

1/4 1/2 1/4

Curiously, if we extend the problem to **adding** the faces of **multiple dice** or adding values of many coins, sides, the resulting **PDFs** become smoother, and even after **4 or 5 convolutions** of uniform PDFs the resulting PDF has the shape strikingly similar to a bell-shaped Gaussian curve. This same effect has been observed by the Guru in the **sequential convolution** of a source wavelet as it passes through many filters (near surface, intra- and inter-bed multiple generation, Q-filters, receiver and instrumental filters) the **envelope** shape rapidly approaches a **bell shape.** This effect is seen both in discrete and continuous data. [To be continued]

Tutorial Nuggets continued on page 19.

Tutorial Nuggets continued from page 18.

The Impossibly Probable and Probably Impossible

In October, we left hanging the **bonus question** of the minimum number of balance pan weighings it would take to determine which (if any) of the **13 Duncans** was a **counterfeit** and whether it was heavier or lighter. The puzzle-solving reader was reminded that an **earlier puzzle** had the same conditions but with only **12 elements and no reference Duncan** to solve the same question. That problem was solved in **3 weighings using the principle of The Last Weighing**

This principle is that **the last weighing** can only lead to a **unique answer** if the number of unknown coins is reduced to **3 with possibility labels** (e.g., **HHH**, **LLL,** or **HH and L**, etc.) or **"(1) unlabelled (?).** With the **3 labelled**, just weigh **H vs H** and you have the answer. For the **single unlabelled**, weigh it against a **reference coin**. (See ***Tutorial Nuggets Book* II**, page 139 for the details and **pictures!**)

The **12-coin** problem is solved by starting with **4** of the of the **12** on one pan and **4** on the other. If they **balance**, it leaves **4 unlabeled** which can easily be reduced to **3 labelled** (**HHH** or **LLL**) or **one(1) unlabelled** (?). If the first weighing is unbalanced that tells us the offender is among either the LLLL or the HHHH side. This condition is also easily reducible to the required 3 labelled or one unlabelled. If the 1st weighing balances, those 8 coins are valid, and the counterfeit (if any) is among the un-weighed 4 remaining coins (**????**). These too are easily reduced to the required **3 labelled** or **single unlabelled.**

Unfortunately, the **13-coin problem** does not respond to this solution, even with a reference (**R**) coin thrown in. The best first weighing is **4? + R** on one pan and **5?** on the other. If it **balances**, it leaves **4 Unlabelled** (solve as above). Not balanced leaves **9 labelled** possibilities: either **5H and 4L** or **5L and 4H**. This can be reduced to the required numbers by weighing, for the 1st case, **3H + 3L** on one pan and **6 reference (R)** coins on the other.. **BUT we don't have 6R we only have 5R (4 from the first weighing + the donated R).** Alas, it will require **4 weighings for a unique solution.**

The November Brain Descrambler

You are in a completely dark room. I dump a bag of 1017 Othello chips on the floor. These chips are black on one side and white on the other. You can feel around for the chips, but you **cannot see which side** is up because it is dark. I tell you that exactly **23 have the black side** up. I ask you to divide the **chips into two piles** (every chip must be in one [and only one] of the piles) such that the two piles have the **same number** of chips with the **black side up** (they may have different numbers of chips with the white side up). **How do you do it?**

Item of Interest

On Monday afternoon, June 4, 1934, seven skilled reflection seismograph workers were killed by an explosion of an estimated 200 pounds of dynamite. The Petty Geophysical crew was working in McClain County, Oklahoma, approximately eight miles southwest of Norman, Oklahoma, the home of the University of Oklahoma. The crew was on contract to Sinclair Oil Company. Wendel Crawford, the Observer, was the sole survivor because he was in the nearby doghouse and shielded from the blast. Strict safety rules evolved from this terrible tragedy.

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

GSH Media Kits

The Mystery Item on page 10 is a **Century Geophysical cable checker from 1948.**

Geoscience Center

The History of Geophysics *By Bill Gafford*

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

The next Living Legends Doodlebugger social event is scheduled for next February unless restrictions on such social gatherings have been relaxed, and we are able to have one in November. We will send out a notification if a November event is scheduled.

Since the October SEG Annual Meeting was held virtually, we were not able to have an actual booth display of some of the artifacts from our Museum Collection that were used in the 1920's and 1930's. However, to support the 90th Annual Meeting program we were able to have a virtual booth and added pictures and details showing some of these artifacts to the Geoscience Center GSH web page. Pictures of a few of these artifacts are included with this article. Then, we had a link to the web page on our "booth" listing. We were also able to include information and pictures of some of the books and publications from the early days of petroleum exploration. Most of the artifacts featured are on display at the Geoscience Center, and we will leave the Annual Meeting pictures and details on our web page for a while.

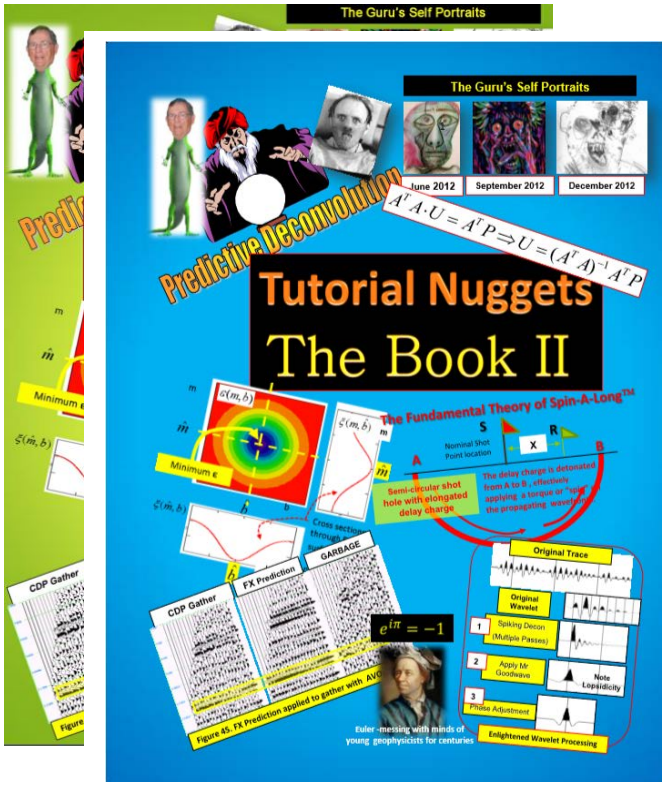
As many companies have downsized this year, some of our membership may be in the process of seeking employment. This might also be the time to update your knowledge about a different specialty or just an overview of developments outside your past job assignments. Over the past few years our Bob Sheriff Library has grown substantially and includes a large variety of training manuals and workshop notes on a large variety of subjects. We have many SEG and AAPG publications as well as some CD's and DVD's and all of these are available to be checked out. In addition to the text books and other geoscience related publications, the periodicals in our library include SEG *The Leading Edge, SEG Geophysics, SEG Annual Meeting Technical Program Abstracts, EAGE First Break, EAGE Geophysical Prospecting, AAPG Bulletins, Environmental Geosciences,* and *GCAGS Transactions.* □

Petty Submersible Refraction Detector from 1929

Petty Seismic Refraction Recorder from 1927

The Geoscience Center has been closed for the last few months due to the Covid-19 restrictions, but we hope to be open soon on Wednesday mornings from 9:00 until noon 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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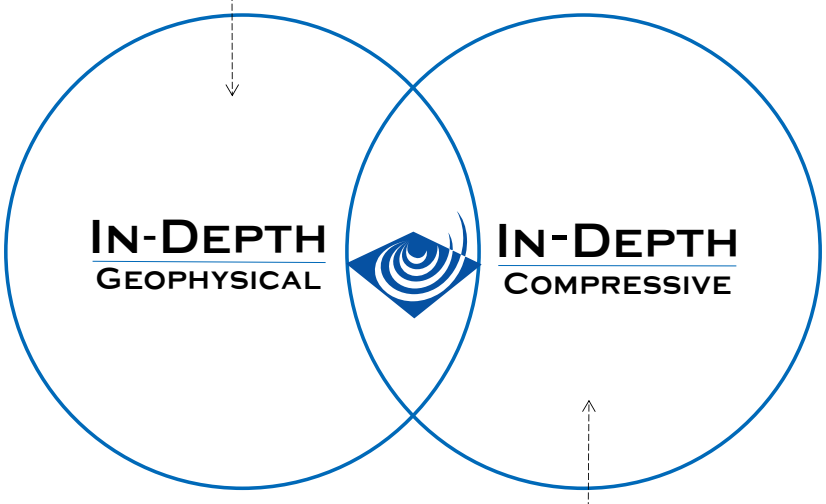

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Doodlebugger Diary

The Wild West: Adventures on the M/V Western Gulf in the Gulf of Mexico, 1979-1982

Operations Aboard a Seismic Vessel (Second Half)

By Scott Singleton

The Doodlebugger Diary recounts the experiences of geophysicists during their working lives. Since early 2018 I've been recounting my own experiences and encourage those of you with experiences of your own to contribute. Your fellow industry professionals would love to hear your stories. I've had a lot of great comments about Nancy House's 3-part series on her Peruvian jungle experiences in the 1990's.

Last fall I started reprinting early 1980's articles from the GSI Shotpoints that can be found at http://gsinet.us/. In March I shifted to reprints of Western Geophysical Profile articles that are repositoried at https://seg.org/Publications/Journals/Western-Profile.

My current series recounts my early doodlebugging experiences with Western Geophysical's Party 76.

Last month was part 1 of my description of the main parts of a seismic boat in the late 1970's. In that episode, I covered the doghouse and the guns. In this episode, I will conclude with a description of the shoot shack and the back deck.

The Shoot Shack – In Western's small 'Green Meanie' boats, there was a smallish shack on top of the doghouse (the recording room) where the gun mechanics could monitor gun performance *(Figure 1)*. This little room was barely big enough for one person to stand and a second to sit in a chair. Instrument panels lined one wall and consisted of pressure gauges and timing break monitors for all eight guns.

One of the known issues with these working boats was the huge amounts of noise generated by the two main diesel engines along with various generators and compressors. The exhaust stacks for most of these engines were directly behind the shoot shack *(Figure 1)*. Thus, it could be logically assumed that the shoot shack was not a place you would

Figure 1: Side shot of the M/V Western Gulf showing the cable reel (left) and the 'shoot shack' above the rear of the boat's upper deck. The 'doghouse' (recording room) is directly beneath the shoot shack. The two gun (seismic source) booms can be seen amidships and on the bow. At the rear of the shoot shack on the starboard (right) side the oxygen tanks can be seen (one labeled with 'oxy'). This was one half of the combustible material for the guns. The other material, propane, was located in similar tanks on the port (left) side of the shoot shack.

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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

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want to be if you were sensitive to noise. Measurements of this noise varied from in the 80's on the back deck to 90's near the compressors or the stacks (in decibels). This is pretty close to OSHA standards for max permissible exposure to continual noise (or may even exceed it for extended periods of exposure).

It was common to hear about people suing Western for various damages to their health after working for a long time on these boats. One suit I found in the online literature was Delahoussey vs. Western Geophysical filed in the Southern District of Mississippi on June 29, 1979 (*https://law.justia.com/cases/federal/district-courts/FSupp/476/54/1378606/*). It appears that Mr. Leo Delahoussey worked on the *M/V Western Crest*, and possibly other boats, from 1964 to 1976. During this period, he started working with dynamite as a sound source and then transitioned to Aquapulse in the late 1960's. He apparently helped construct the shoot shacks on several vessels. In the documentation, it says that in the early Aquapulse years the shoot shacks were not air conditioned and they left the door open all the time. That would have exposed the gunners to sound levels in the 90's (decibels). Then, he says after they installed an air conditioning unit they closed the door in the daytime, but had it open at night and during the winter. Eventually, it became the (common sense) policy to have it closed all the time.

So, he says that in the early 1970's, he started developing hearing problems (no wonder…). During his time, safety regulations were pretty minimal. As an example of this, you can imagine the risk of lighting a stick of dynamite and throwing it off the back end of a boat. Of course, that practice was from decades earlier, but you get the point. Mr. Delahoussey says in his lawsuit that hearing protection was not recommended or provided. (As a note, I can assure you that during my time offshore the gunners all had earmuffs to use if they wanted but most often used foam ear inserts). As an expert testimony in the lawsuit, Mr. Delahoussey went to an otolaryngologist (ear, nose, and throat doctor) who verified that he suffered nerve damage to both ears, which was more pronounced at high frequencies and which resulted in partial hearing loss.

The court found that the lack of safety measures to protect from high noise levels "constituted a hazard likely to be incurred by those performing the type of work performed by the plaintiff". The lawsuit sought reparations for "damages consisting of past and future hospital and medical expenses, loss of earnings and employment benefits, permanent impairment of his wage-earning capacity, permanent impairment of hearing and pain and mental anguish for the sum of $500,000.00". In the damages assessment part of the trial, they added up his salary for a number of years (for loss of wages), his past and possible future medical bills, and awarded him that amount. It totaled $107,081.94. They concluded he deserved no punitive damages.

Figure 2: Streamer recovery operations during 'back down and drag' acquisition. In this picture, I'm taking one of the chain strings off of the streamer while another person holds the streamer to keep it from spinning. The person to the right is holding a microphone/speaker that was connected directly to the bridge and which he would use to guide the boat so the streamer kept straight behind the boat as it was going in reverse.

The Back Deck – The back deck is where we did most of our maintenance work, including

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Figure 3: Streamer recovery operations complete! Back deck all tidied up and reroute to the next location. The only thing visible in this picture is the tail buoy with its radar reflector, transmitting antenna and light, and the large sausage buoys that were strapped to the top of the metal frame to (hopefully) keep it upright while being pulled behind the boat.

Figure 4: Sunset off the starboard stern silhouetting a gunner deploying his gun string in the peaceful Gulf.

deploying and recovering the streamer, any repair work to the streamer, changing out streamer sections, etc. On these small boats, it was a pretty limited area *(Figure 2; also a profile view of the stern of the boat is shown in Figure 3 of last month's Doodlebugger Diary)*. I would estimate our working area to be about 20' x 20' with the aft gun strings on either side, the streamer reel in the front and the stern roller in the rear. You can imagine that this space would get rather tight if we had a damaged streamer that needed repaired or changed out while offshore. We would bring on the damaged sections, tie the remainder of the streamer off with a metal connector, and pull off the damaged sections, coiling them on the back deck. We could really only work on one damaged section at a time, so other damaged sections needed to wait their turn.

Where this got messy is if we ran into any submerged obstruction, which did happen in the Gulf given all the rigs out there plus a large number of shrimping boats around us much of the year. Fortunately, we usually did not have any issues with shark bites. That was a worse problem in the tropics, such as the Middle East. But I have recovered a fair number of steamers that had partially or entirely scraped past the leg of a platform. You can fully well imagine the damage that would do to the plastic skin of the streamer. An additional risk was scraping the bottom when we were doing 'back down and drag' operations *(such as in Figure 2)*. In that case, it was common to pull up the streamer and have at least one or sometimes many sections with holes in them. We would tape up the holes with an under layer of black electrical tape and an upper layer of brown bulldog tape, adequately applying black goopy sealant to both layers. Then we would flush out the section and refill it with cable oil, and then check the electrical resistance of the internal wires (they should have no resistance). When we finished with the streamer, we would haul the tail buoy onboard and check it out for damage and to replace the batteries in the transponder *(Figure 3)*.

Epilog – in this Doodlebugger Diary I am starting a new feature. Each month, I will end my segment with a sunset picture for your enjoyment. I used to love taking sunsets. It gave me some peace and satisfaction as the day was ending. So now I will start sharing some of those pics with you at the end of each segment *(Figure 4)*. Enjoy! □