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GEOPHYSICAL SOCIETY OF HOUSTON
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The Path to a Zero Carbon Future – Page 8**

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Final testing of continuously armored, permanent ocean bottom cable (OBC) with sensor pods at Houston, Texas manufacturing facility.

Photo courtesy of OYO Geospace.



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A Word from the Board

By Simon Voisey, First Vice President Elect



"Don't Panic." - Douglas Adams - sprung to mind when I went into lockdown in March 2020. I still recall those early days. Yet, today, I am a different person. Working from home was an alien concept pre-pandemic, but now I seamlessly float between the office and home without a second thought. MS Teams has been a massive help to bridge

the home and office link. Document sharing, video calling, plus chat. So much constructive communication can be done through the team's chat.

Similarly, at the SEG, I was encouraged by the great discussions on the chat. People throughout the world are commenting on a particular topic. Fantastic. I was fortunate enough to field questions on my presentation virtually. I enjoyed answering the questions on the chat because I had the opportunity to provide solid, unrushed replies. In addition, viewers who could not attend the event live (primarily due to time zone or presentation clash) can view the recorded interactions.

But, let's be honest. None of this is new technology. I can recall my first chat on the internet around 25 years ago.

Nevertheless, the pandemic has forced us to depend on these tools and experience the benefits. For instance, hybrid meetings appear to be the norm now and most likely into the future. It may not be convenient to attend a meeting in person. Therefore, allowing a remote connection is a solution that otherwise would have meant missing the discussion entirely. Again, hybrid meetings are not new, but we are becoming more accustomed to them.

As First VP Elect, I am the SIG (Special Interest Group) coordinator. We have started a GroupMe account to help with communication amongst the SIG chairs. GroupMe has been excellent for fluid discussions and avoids the confusion of long email chains because it is a chat-based app.

I am amazed by the number of helpful collaboration tools available. However, we all need to keep a couple of points in mind. Firstly, choosing the right tool for the job, and secondly, people need to use the tool. Both are essential for productive knowledge sharing. At the GSH, we are actively strengthening the connection between our members through social media devices.

We live in a different world compared to life before early 2020. And in the wise words of Douglas Adams, *"Don't Panic."* □



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GSH Technical Events



Rock Physics SIG

Frequency-dependent Seismic AVO Modeling and Analysis

Dhananjay Kumar, BP

[Abstract and Bio](#)

Online Event - Nov. 3, 2021 - 12:00pm-1:00pm CST

[Register](#)



Evening Tech Event

The Search for Extra-Terrestrial Intelligence (SETI)

Dr Donna Jurdy, Professor Emeritus, Northwestern University

[Abstract and Bio](#)

In Person Only - Nov. 3, 2021 - 5:30pm-8:30pm CST

[Register](#)



Unconventional SIG

Evaluating 3D and 4D DAS VSP Image Quality of Subsea Carbon Storage

Mark Willis, Halliburton

[Abstract and Bio](#)

Nov. 4, 2021 - 12:00pm - 1:00pm CST

[Register](#)



Data Processing and Acquisition SIG

"Good to Go": Permitting Multi-Client Seismic Surveys in the USA

Joseph Farah, Schlumberger

[Abstract and Bio](#)

Online Event - Nov. 9, 2021 - 5:00pm - 6:00pm CST

[Register](#)



Tech Breakfast

Geophysical Investigations of Enchanted Rock, Texas

Casey Kuo, University of Houston, PhD Student

[Abstract and Bio](#)

Online Event - Nov. 10, 2021 - 7:00am-8:00am CST

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Tech Lunch

On the Use of Seismic Phase to Predict Reservoir Properties

John Castagna, Sheriff Chair in Geophysics, University of Houston

[Abstract and Bio](#)

Hybrid Event - Nov. 17, 2021 - 11:00am-1:00pm CST

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Dr. Donna Jurdy,
Professor Emeritus,
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2021 GSH FALL FORUM

Carbon Capture, Utilization & Storage (CCUS) The Path to a Zero Carbon Future November 18, 2021

Topics Include:

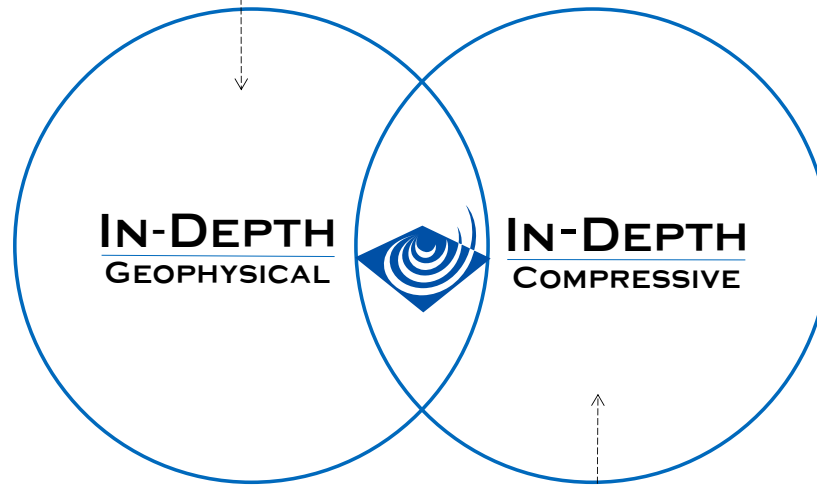
- Surface Operations and Economics
- Reservoir and Caprock Characterization
- Injection Operations and Induced Seismicity
- Containment Monitoring and Leakage Risk Mitigation
- CO2 EOR and Economics
- Regulatory Environment and ESG

Presenters:

- Ali Tura, Professor of Geophysics, Co-Director of the Reservoir Characterization Project, Colorado School of Mines
- Camelia Knapp, V. Brown Monnett Chair and Head, Boone Pickens School of Geology, Oklahoma State University
- Hamdi Tchelepi, Professor of Energy Resources Engineering, Stanford University
- Autumn Haagsma, Research Geoscientist, Battelle; AAPG CCUS Committee Chair
- Deniz Dindoruk, Senior CCS Front-End Development Manager, Shell
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- Josef Paffenhotz, SEG SEAM CO2 Project
- Kurt Strack, President, KMS Technologies
- Sallie Greenberg, Principal Scientist, Energy & Minerals Division, Illinois State Geological Survey
- Steve Carpenter, Director, Enhanced Oil Recovery Institute, University of Wyoming; SPE CCUS Technical Section Chair
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Application of 3D LSRTM to an Onshore Walkaway VSP for CO₂ Monitoring

Henning Kuehl¹, Jonathan Hopkins¹, Stephen Harvey², Johannes Grimm¹; 1 Shell Global Solutions Canada Inc.; 2 Shell Canada Ltd.

Summary

Distributed acoustic sensing (DAS) in vertical seismic profiling (VSP) can be an effective method to monitor time-lapse signals on land. We investigate the efficacy of time-lapse least squares reverse time migration (LSRTM) applied to a DAS VSP. The goal is to monitor the CO₂ plume for a carbon capture and sequestration (CCS) facility while the injection volumes are relatively small. The DAS VSP acquisition was designed as a walkaway VSP with four 2D shot lines arranged in a star pattern centered around the CO₂ injection well. The near vertical injection well also serves as the DAS fiber observation well. We use synthetic tests to demonstrate that 3D LSRTM can give interpretable images within a radius of about 400m from the well, despite the pre-dominantly 2D nature of the VSP acquisition. The synthetic tests demonstrate that higher iterations of the LSRTM give improved resolution and amplitude fidelity over a single iteration LSRTM. The tests also help to guide the expectation for the real data results in terms of resolution and amplitude interpretability. The application of LSRTM to real VSP data delineates a credible time-lapse signal within the resolution limitations of the acquisition.

Introduction

The Quest carbon capture and sequestration facility captures and stores about 1 million tons of CO₂ per year from the Scotford Upgrader, located near Fort Saskatchewan, Alberta, Canada (Tucker et al., 2016). The CO₂ is injected with multiple wells into a deep saline aquifer, the Basal Cambrian Sand (BCS), at a depth of about 2 km below ground. The initial time-lapse strategy called for 3D surface seismic to be employed after a few years of injection operations, but borehole VSPs were proposed as a cost-effective and flexible alternative while injection volumes are small. In order to demonstrate containment of the CO₂ plume, pre-injection baseline 2D walkaway VSPs, and three monitor walkaway 2D VSPs have been acquired. Here we are focusing on the 8-19 injection well and analyze the DAS VSP time-lapse signal between the 2015 baseline and the monitor VSPs acquired in 2016, 2017, and 2019. The well location and the four walkaway shot lines, arranged in a star pattern centered near the

well, are shown in **Figure 1**. The data were acquired using a three vibroseis source 'bumper to bumper' array with shot spacings of 100 m and offsets out to approximately 2500 m from the well. The injection well also serves as the DAS observation well.

Typically, the DAS VSP would be processed with a 2D processing and migration workflow based on the predominantly 2D nature of the acquisition geometry. However, the 8-19 well location is offset from the 2D lines by up to 200 m for operational reasons. Additionally, the

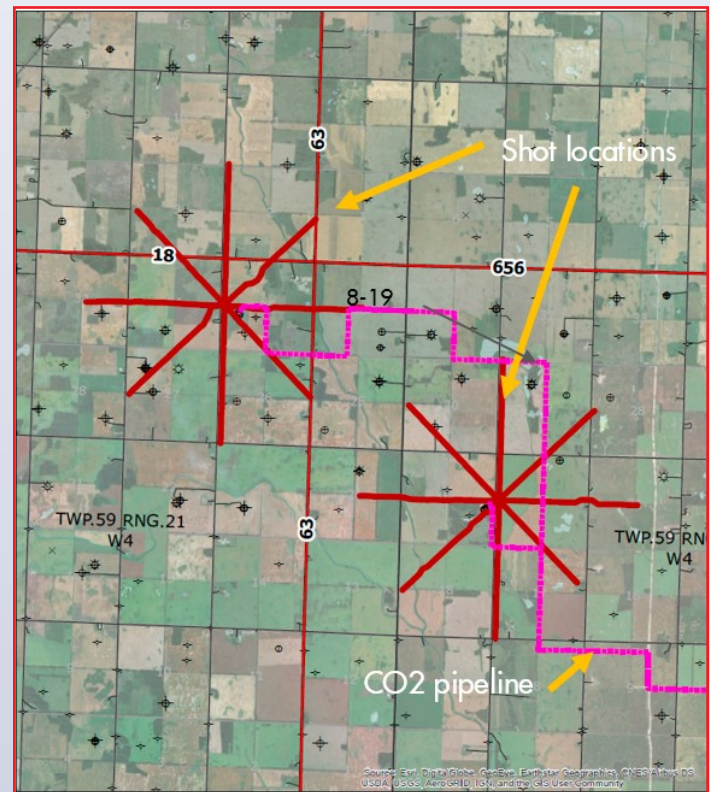


Figure 1: Location of the Quest storage site. The study focuses on well site 8-19. The walkaway VSP shot lines are shown in red. The near vertical CO₂ injection well located near the center of the intersection of the shot lines has been equipped with a DAS fiber. The deepest DAS receiver sits at a depth of about 150 m above the reservoir. The pipeline that carries the CO₂ from the Scotford upgrader to the well sites is shown in pink.

Technical Article continued on page 11.

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

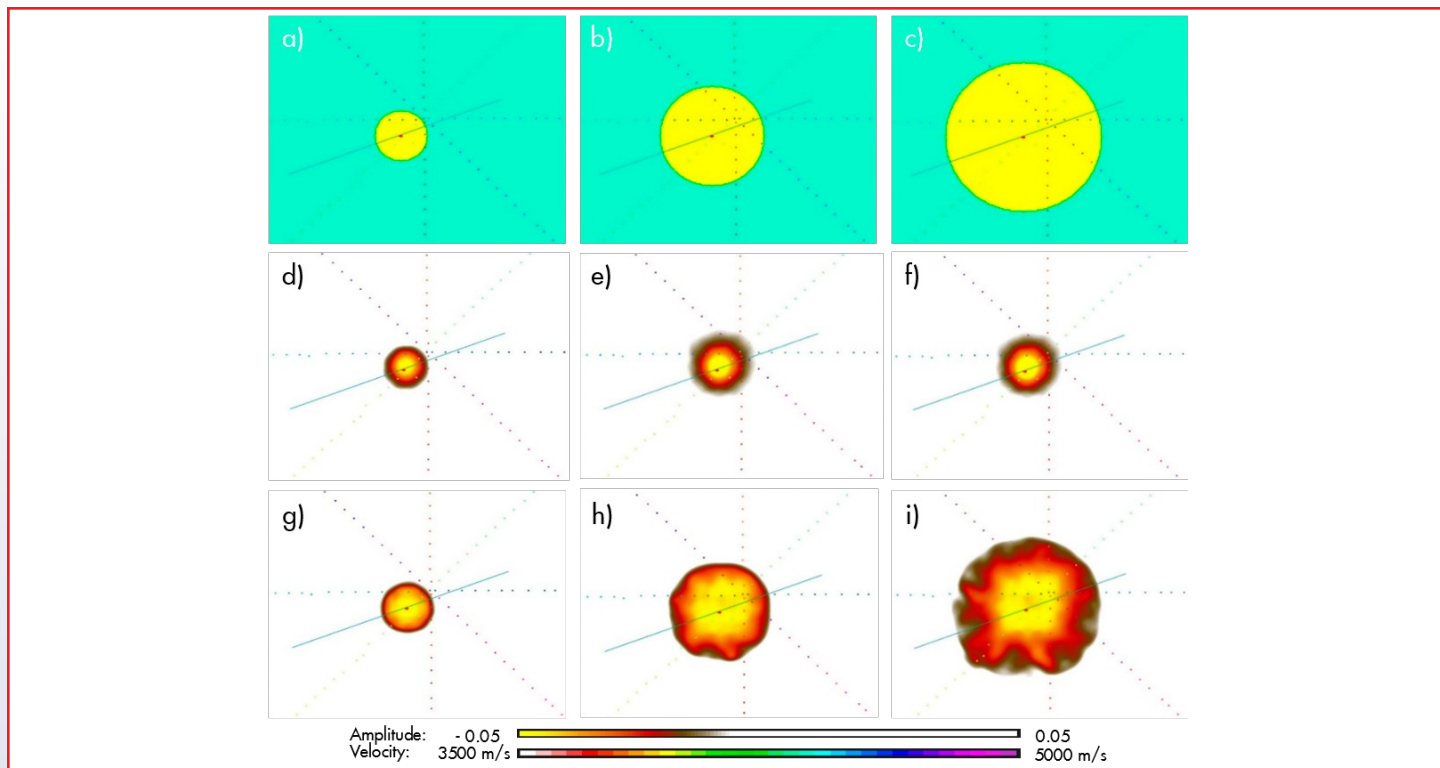


Figure 2: a) - c) Depth slices through the top of the plume anomaly. The plume is simulated as a 10% velocity drop over a smooth background velocity at the reservoir level. The 40 m thick disks are varying in radius from 200 m to 600 m. The closest receiver to the reservoir in the near vertical injection/observation well is marked as a red dot. The four dotted lines are the surface shot point locations. The solid line marks the cross-sections in Figure 3. d) - f) Single iteration LSRTM time-lapse reflection amplitudes at the top of the anomaly in a) - c). The amplitude colorbar was chosen to highlight negative reflection coefficients. Amplitudes dropping below $\sim 30\%$ of the maximum absolute reflection coefficient are transparent. g) - i) LSRTM iteration 10 of the time-lapse reflection amplitudes at the top of the anomalies in a) - c). Notice the improved lateral resolution, but also notice the remaining amplitude variation within the anomaly.

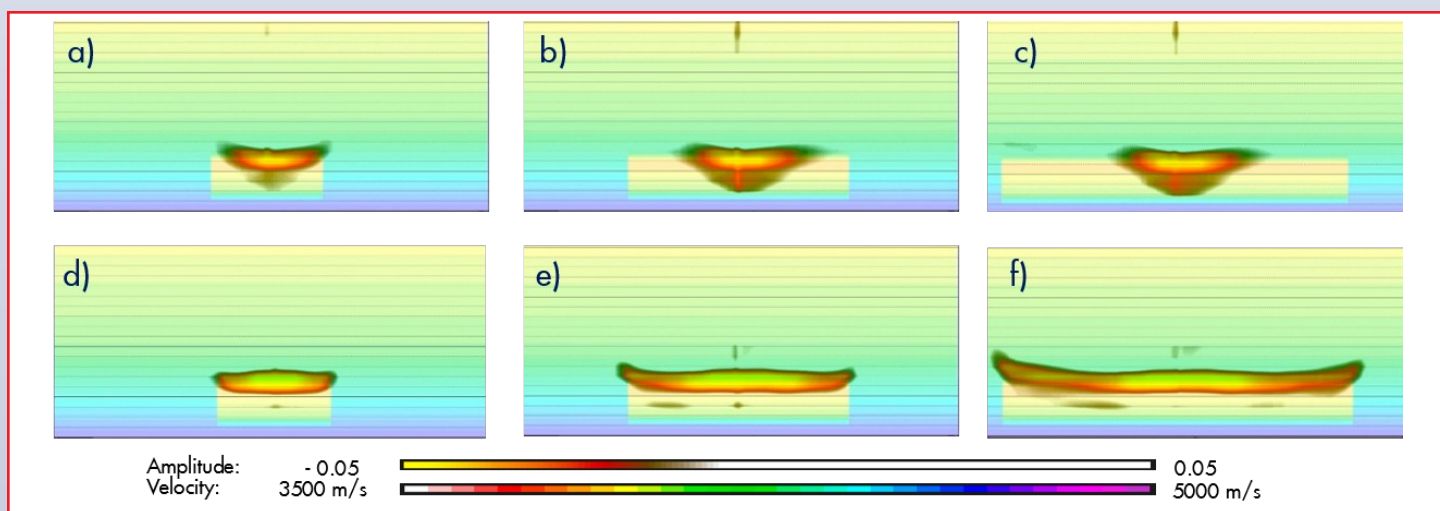


Figure 3: a) - c) Cross-sections of the plume anomaly and the single iterations LSRTM as indicated by the solid lines in Figure 2. d) - f) Cross-section of LSRTM iteration 10 result. Compare to Figure 2.

well is not strictly vertical, and the 2D lines are not strictly straight. Furthermore, a full 3D interpretation is desirable, which raises the question if 3D imaging of this sparse walkaway VSP geometry is feasible.

Least-squares migration (LSM) is known to be able to mitigate against the illumination effects of sparse and irregular acquisition geometries by iteratively solving a linear inverse problem with the Conjugate Gradient method (Nemeth et al., 1999; Kuehl and Sacchi, 2003). In this study we use a least-squares reverse time migration implementation described by Duveneck et al. (2019). There have been numerous case studies that demonstrate the efficacy of LSRTM to deal with illumination issues (e.g., Kuehnel et al., 2019). Shang et al, 2019, give an illustrative example of joint LSM for time-lapse imaging in the Gulf of Mexico. We follow an LSRTM approach that inverts for a stacked image ('angle independent' LSRTM). That means our primary goal is to delineate the location of the CO₂ plume. Quantitative amplitude interpretation is challenging, even after LSM, because of the very limited and uneven illumination coverage. We therefore do not attempt to resolve the angle/azimuth dependence of CO₂ plume's reflectivity.

The study is divided into two parts: First, we generate three time-lapse DAS VSP synthetic datasets for different hypothetical CO₂ plume sizes about the 8-19 well. We apply 3D LSRTM to the synthetic datasets and analyze the results in terms of their interpretability of plume geometry and amplitude fidelity. Second, we apply 3D LSRTM to the 2015 baseline and 2015/17/19 monitor VSPs, and we discuss the real time-lapse results using the learnings from the synthetic data tests.

3D LSRTM synthetic tests of walkaway VSPs

The walkaway VSP acquisition geometry shown in [Figure 1](#) was primarily designed for 2D VSP analysis. As mentioned in the introduction, deviations from a 2D acquisition geometry and the offset of the 8-19 DAS fiber trajectory from the 2D lines effectively create localized 3D coverage around the CO₂ injection point, which suggests that a full 3D approach may be feasible, and even preferable over a 2D approach. In order to judge the efficacy of 3D LSRTM for imaging the time-lapse signal, we have created three 3D finite-difference VSP synthetics for hypothetical CO₂ plumes varying in radius from 200 m to 600 m. See [Figure 2](#). The synthetic data are generated in three steps: 1) We forward model synthetic acoustic finite-difference

data up to 60 Hz in the background model that is based on a smooth velocity profile derived from a sonic log (baseline synthetic). 2) We then forward model the data using a plume model (monitor synthetic) to simulate the effect of brine-CO₂ substitution within the 2 km deep BCS reservoir. The plume is created by introducing a 10% percent velocity slowdown over the 40 m thick BCS reservoir. The model plume is disk shaped and centered about the 8-19 well. 3) Finally, we subtract the baseline synthetics from the monitor synthetics, effectively creating a synthetic with only the upgoing wavefield related to the CO₂ plume.

The plume anomaly is assumed to be relatively thin with a 10% velocity change within the reservoir. Hence, the Born approximation is deemed appropriate and LSRTM using the smooth background model is an adequate choice to image the time-lapse signal.

The LSRTM results for the synthetic data are compiled in [Figure 2 and Figure 3](#). [Figure 2](#) shows depth slices and amplitude extractions for the plume velocity models for iteration 1 and iteration 10 of the LSRTM. [Figure 3](#) shows the corresponding vertical cross-sections using the same amplitude clipping in all cases. Reflection amplitudes dropping below ~ 30% (or -10dB) of the maximum absolute reflection coefficient extracted at the top of the anomaly are transparent. This number was determined by histogram analysis, and it represents the amplitude threshold that best highlights the plume geometry while suppressing spurious energy. In all cases, the top negative reflectivity peaks coincide with the top of the plume. However, the single iteration LSRTM fails to properly delineate the lateral extent of the anomalies. Our LSRTM implementation incorporates image-domain preconditioning and structural image constraints in order to improve convergence (e.g., Duveneck et al., 2019). In this example - because we are dealing with flat lying geology - we use a horizontal flatness constraint together with the image-domain preconditioner. Despite the flatness constraint being applied already in the first iteration, it takes several more iterations before the LSRTM converges to a solution that properly shows the lateral extent of the anomaly. We also notice the improved vertical resolution with higher iterations. The steep amplitude drop-off from the center of the anomaly towards its edge as a result of the uneven illumination has also improved. But even after ten iterations there is still a noticeable drop in amplitude strength towards the plume edge, and fine scale amplitude variations within the plume area remain, which renders a direct - uncalibrated - amplitude interpretation ambiguous.

From these tests we conclude that the geometry of a circular plume with a radius of 400 m can be resolved by LSRTM, assuming ideal data and no velocity errors. The 600 m plume is less well defined near its edge, leading us to doubt that plumes with edge distances much greater than 400 m can be confidently interpreted when dealing with real data.

Clearly, our synthetic analysis is not fully rigorous in terms of its applicability to real data. Real data is noisy and more complex (e.g., visco-elastic effects) than our acoustic synthetic data. We also neglect possible positioning errors and non-repeatable effects like changing near surface conditions. The combined effect of all that on a real data image is difficult to quantify, because the full range of these errors is not known. Our synthetic tests merely provide a guide to manage expectations, and to aid the interpretation of observed real data amplitudes, as demonstrated in the next section.

It could be argued that the decision to stop the LSRTM at 10 iteration is somewhat arbitrary. Since we are inverting noise free synthetic data, we should expect further improvements with higher iterations. **Figure 4** shows the evolution of the top reflectivity map for the 600 m plume up to 20 iterations. Indeed, while the greatest improvements happen during the first 10 iterations - as expected - additional iterations help

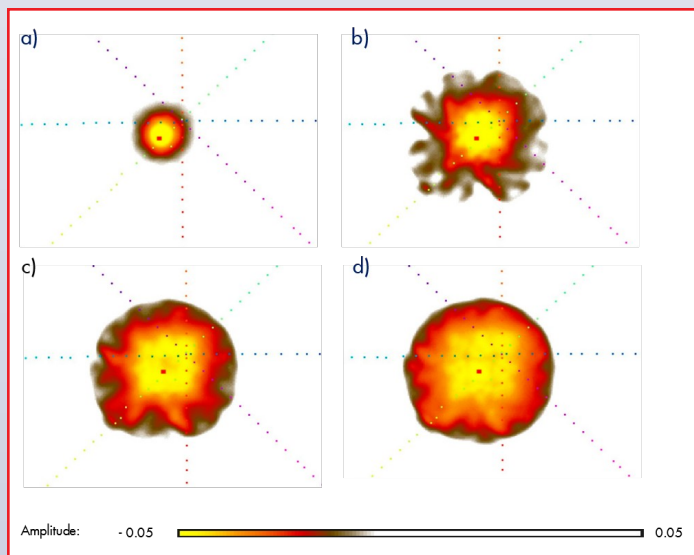


Figure 4: LSRTM results for the 600m plume at different iterations. a) Iteration 1. b) Iteration 4. c) Iteration 10. d) Iteration 20. For ideal synthetic data, iterating beyond 10 iterations does provide additional improvements, albeit with diminishing returns. But the additional iterations may not help for real - noisy and 'imperfect' - data as the risk of overfitting increases.

to improve the result further. But, as mentioned before, the synthetic data does not capture the full complexity of real data. The additional iterations will likely not help with real data, because the risk of overfitting real data increases with higher iterations, which can create spurious energy in the inverted image.

3D LSRTM applied to real walkaway VSPs

Encouraged by the synthetic tests we have applied LSRTM to the three VSP time-lapse datasets acquired at well 8-19. We prepared the raw data by separating the up-going reflection data from the down-going and shear energy. Several steps of noise attenuation on the upgoing data were required to remove spurious acquisition noise as well as linear noise inherent in the DAS interrogator data output. We performed careful amplitude balancing to remove the effects of shot coupling and channel amplitude variations. We also applied deconvolution using the direct arrival to derive the wavelet on a shot by shot basis. Data muting above and below the reflector of interest helps to further minimize potential noise contamination on the time lapse signal. Finally, we match-filtered and subtracted the monitor and baseline data to obtain the input for the LSRTMs as shown in **Figure 5**. Careful match-filtering of the base and the monitor data helps to reduce non-repeatable effects, e.g., changing near surface conditions, without harming the time-lapse response.

We apply LSRTM directly to the differences of the monitor and the base surveys and - just like in the synthetic case - include a flatness constraint as part of the inversion. The LSRTMs use the same sonic-derived velocity model. The previous analysis of the synthetic tests aids our 'quick look' interpretation of the real data results, and we follow a similar amplitude picking and thresholding strategy as with the synthetic example. See **Figure 6** for the results.

The time-lapse softening effect from the CO₂ plume is clearly visible. The expanding time-lapse signal is - broadly speaking - following our expectations for the expanding CO₂ plume over the time-period from 2015 to 2019. However, a more detailed and careful interpretation including rigorously derived time-lapse attributes and reservoir modeling is required to fully support our results.

Some interpretation uncertainty remains due to the illumination challenges demonstrated in the synthetic tests, lower signal-to-noise of the real data, velocity model uncertainties, and unaccounted for near surface effects. Therefore, the map views in **Figure 6** likely

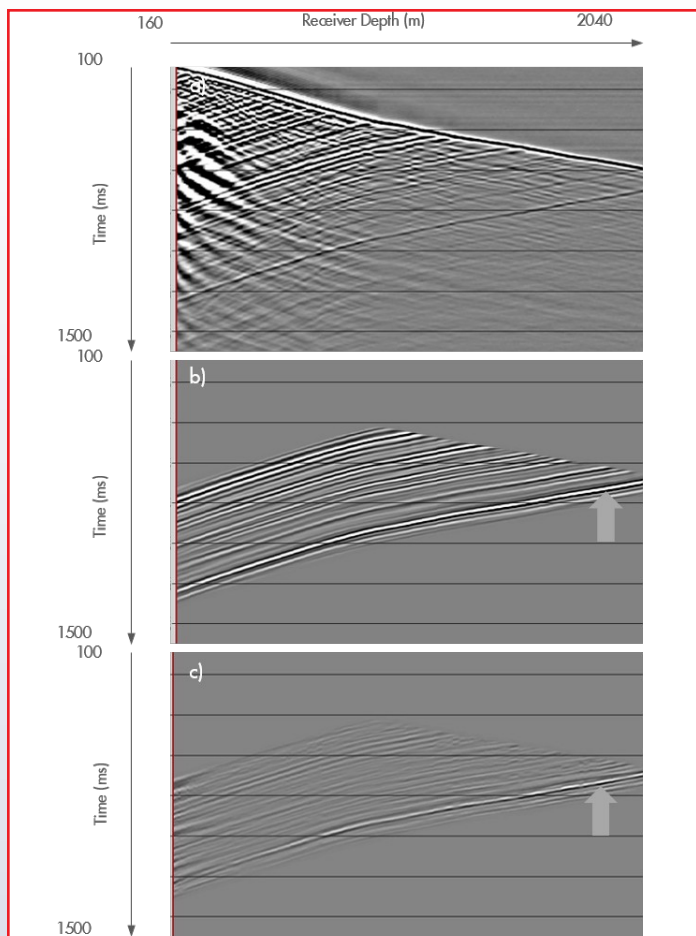


Figure 5: a) Raw DAS VSP baseline data at a selected shot position. b) Up-going DAS VSP baseline data after statics application, noise suppression, and up-down separation. c) Matched difference between monitor and baseline data. The arrows mark the target reflector.

underrepresent the true plume dimensions. Obviously, a more uniform 3D shot coverage would help to improve the subsurface illumination.

Conclusions

We have presented the application of LSRTM to a time-lapse onshore walkaway DAS VSP for CO₂ sequestration monitoring. The walkaway DAS VSP geometry is predominantly 2D. However, deviations from a strict 2D geometry create localized 3D coverage about the injection/observation well location. We demonstrate in synthetic tests that 3D LSRTM can delineate the 3D CO₂ time-lapse signal within a few hundred meters around the well. Amplitude variations due to the highly uneven illumination become less

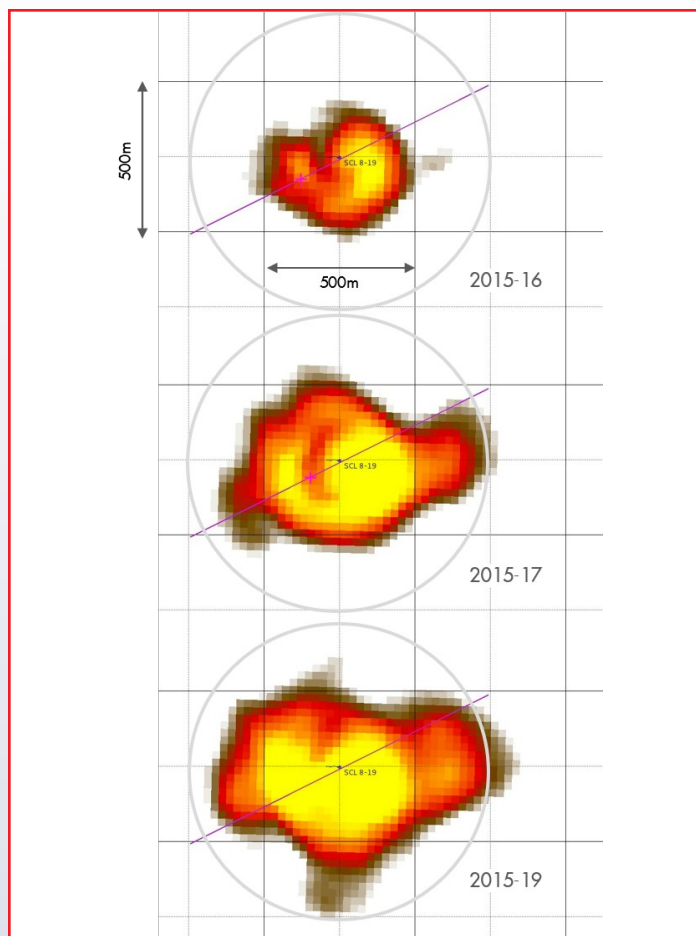


Figure 6: Map view of the time-lapse CO₂ softening signal from the VSP LSRTMs for the years 2016, 2017, and 2019 at well 8-19.

pronounced with higher iterations of LSRTM. The applications of LSRTM to real data time-lapse VSPs at Quest gives a credible and coherent time-lapse signal within the reservoir. The softening signal broadly conforms with our expectations for the expanding CO₂ plume.

Acknowledgements

We want to thank the Government of Alberta, the Government of Canada, Natural Resources Canada (NRCan), Shell staff in Calgary, Houston, EU and in the field, 3rd Party Contractors and our joint venture partners Canadian Natural Upgrading Ltd, Chevron Canada, and 1745844 Alberta Ltd. We also would like to acknowledge the support provided by our colleagues Sijmen Gerritsen and Albena Mateeva. We thank Shell for permission to publish this study. □

Permalink: <https://doi.org/10.1190/segam2020-3420166.1>



GSH Movie Time

Now Showing

GSI – Personal Development*

By Dolan McDaniel – GSI President – Mid 80s



In this month's GSH Movie Time, Dolan McDaniel, GSI president in the Mid 80s, goes over GSI's management philosophy and the impact it had in GSI reaching its business goals. According to Mr. McDaniel:

"Equipment and technology are important factors in conducting a seismic survey, but it is people that set GSI apart from its competitors. Since the beginning, GSI recognized the importance of people to its operations, and the importance of teamwork in keeping the company at the top of the seismic industry."

As a result, there was an amazing management philosophy at GSI to encourage personal development in each of the employees to give them the opportunity to grow in their jobs and reach their personal potential"

Click on red ticket to view movie



* GSI vintage videos courtesy of Schlumberger – WesternGeco

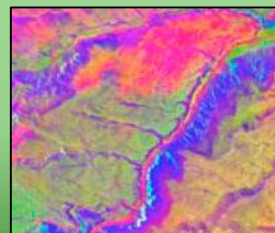
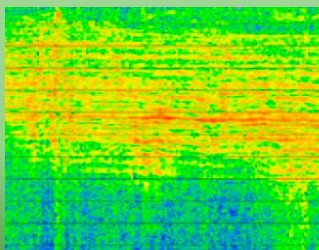


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The traditional technical marketing meeting, whether it is a proprietary client in-house event or a booth presentation at a convention, is evolving. The GSH has an online commercial presentation series where companies are able to deliver information 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.
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Interested vendors please contact the GSH at 281.741.1624 or office@gshtx.org

Geoscience Center

The History of Geophysics By Bill Gafford

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

Our next **Living Legends Doodlebugger social event** will be held on **November 10, from 9:00 until noon**. These events are open to everyone and provide a time to visit with old friends and share tales of the oil patch as well as experiences after retirement. Retired or nearly retired doodlebuggers, and their spouses are invited, as well as anyone who is interested in visiting our Geoscience Center. This is a chance to visit with some of the Legends in our industry and see some of our more interesting geoscience artifacts and some of the Mystery Items that have been featured in the GSH Journals. We have these events quarterly, they are free, no reservation is needed, and parking is free. Light snacks, coffee, soft drinks, and water are provided.

We are currently running a **"Challenge"** to raise funds to **support the Geoscience Center**. Sponsors of the Challenge have pledged **\$10,000 to be matched by donations** from GSH members and others. There is more information included elsewhere in this Journal.

In addition to donations of books and manuals, we have recently received a large conference table and four framed pictures of geoscience related subjects from Ralph Baird. The donation also included interesting publications related to the International Geophysical Year project in 1957, which involved 67 nations and collected geophysical data from around the world, including space and the oceans.

VOLUNTEERS

Volunteers are always needed to help **research** some of our **older instruments and artifacts** and help **prepare informational signs** for them.

We currently need help to prepare a **1980's GUS recording system for display**. It is partially refurbished, and we need help with signage and finishing up with some cleaning.

We are also always **interested in finding new locations** where some items from our museum collection can be put on display **to help educate the public**. This could be in company offices or educational facilities.

This is a reminder that we still have plenty of books, manuals, and periodicals that are duplicates to our inventory and are available for FREE. These include textbooks, training manuals, workshop notes, and a variety of geoscience related SEG and AAPG publications. Items in our permanent Library Collection are also available to be checked out. □

The Geoscience Center is usually open 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.

Mystery Item

This is a geophysical item...

Do you know what it is?



This month's answer on page 21.



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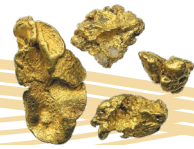
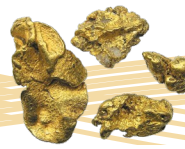
For information about Annual Sponsorship go to: gshtx.org

Item Of Interest

On June 4, 1934, eight miles southwest of Norman, Oklahoma, an explosion on Petty Engineering Co., Party #1, under contract to Sinclair, took the lives of seven crew members.

It is estimated that 200 pounds of dynamite were detonated. The only survivor was the instrument observer who was some 300 feet away in the recording truck and shielded from the blast.

It is possible that two charges were made up in advance, one was placed down the shot hole and one was on the surface. Hooking up the charge on the surface satisfied the observed facts but this is pure supposition. As a result of this terrible accident, stricter safety rules were enforced on all seismic crews. □



A Momentous Announcement From The Guru's Fall Headquarters



The Guru



MUCHO
BRAIN
POWER



LUCKENBACH TX - In a surprise press release, the Guru spokesman announced that after extensive negotiations with Stephan Pastis (**Pearls before Swine**) the Guru will meet with the **Wise Ass** on the Hill for a **joint sabbatical** during which GSH Guru hopes to find out what **he's talking about** (for a change) and will publish as **Tutorial Nuggets**.

The esteemed author and widely renown purveyor of truth in the deep sciences, allowed word to be leaked that his intent is to grasp the profundities of **Machine Learning** and practical knowledge of **Artificial Intelligence** so that these concepts along with **Python Language** (free) algorithms (and even coding) will be the faithful readers' reward for allowing The Guru this **time off**.



Staff
and
Students thrilled
for the Guru



What does all this mean to the **Nuggets** readers (**now at 4**)? It means deprivation of knowledge and enlightenment for the rest of 2021 and maybe (**gasp**) an issue or two in 2022!

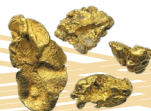
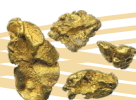
The Guru feels your pain and recognizes that this is indeed a **Tough Pill to Swallow**.



Actual Size

He suggests that to avoid **Brain Atrophy** and other dire consequences, the reader-student try basic Python coding and reading the collected works of the Guru in **Tutorial Nuggets – The Book** and its sequel, **Tutorial Nuggets Book II** now available at the GSH website for a limited time and unbelievable prices (ask for **Karen** or **Kathy**)

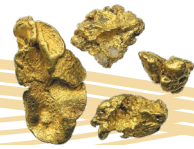
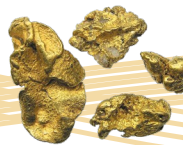
And now for one last (for a while) look at the **Stein Paradox** and its consequent **James – Stein Estimator (JSE)** of **multivariant parameters**. Translation: Efron and Morris published an article in *Scientific American*, in 1977 that showed, for a wide class of statistical problems, the **JSE is a better predictor** of the future and final values such as **the means** of a collection of variables, than was the **classic Most Likelihood Estimator (MLE)**. The latter is the average of past samples of the variables. An easy example of this type is given by Efron as the current **batting averages** of a group of **MLB players**.



Tutorial Nuggets continued on page 19.

Tutorial Nuggets

Tutorial Nuggets continued from page 18.



The example used, **with no loss of generality**, is that of the **batting averages (BA)** of **18 players** after **45 at bats (AB)**. The **Frequentists** (crotchety Old Statisticians) say the best estimator of their **BA for the rest of the season** is their average right now (**MLE**) It turns out the **JSE** is a better predictor and always will be as long as there are **more than 3 players (variables)** whose future values are to be **predicted**.



18 Variables awaiting results

The James-Stein Estimator (JSE)

$$z_i = y_i + C(y_i - Y); \quad i = 1, 2, 3, \dots, k$$

Individual
estimate

Individual
average

Shrinkage
Factor

Grand Average
of k players

$$C = 1 - (k-3)\sigma^2/\Sigma(y_i - Y)$$

The Frequentists (MLE)

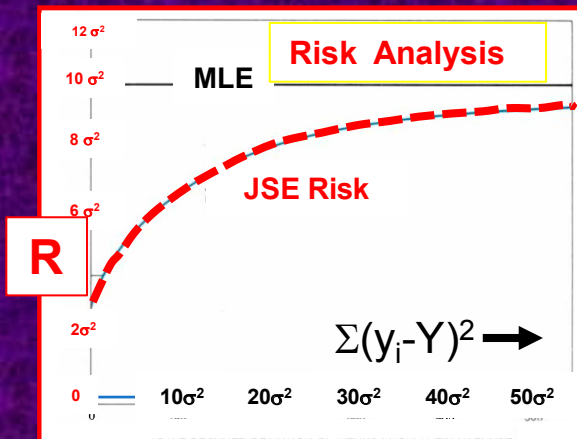
$$z_i = y_i$$

Individual
estimate

Individual
average

Shrinkage is the difference!

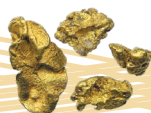
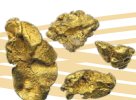
The **JSE** is uniformly better than the **MLE** in terms of **RISK** = $\Sigma_i (z_i - Z_i)^2$, where z_i is computed estimate of the true variable, Z_i , e.g., a player's final BA for the season. As the deviation of y_i from the grand average, Y , increases, the **Risk** of the **JSE** increases, but never to the level of the **MLE**: $R_{JSE} < R_{MLE}$. In the baseball case, the JSE proved closer to the true **BA** in all but **3** of the **18** final **batting averages**.



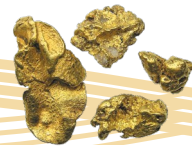
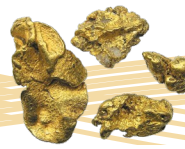
What might be a **geophysical application** for the **Stein predictor**? One useful and obvious example is that of estimating lithologies from statistical realizations. Example: **12 different lithologies** have been identified and organized (**Machine Learning?**).

From **statistical realizations** (say **15** taken at each location **x, y, z**) we obtain **12** distinct **estimated means** of different lithologies (including high porosity SS reservoirs and source rocks). What's the **best estimate** of the **true lithology means** after **60** realizations?

While you're pondering how to implement **JSE** in geophysical applications such a lithologic predictions, let's not overlook the prescient and abundant contributions of **Rev. Bayes** to these matters some 250 years ago. Efron points out that as the number of means (**k**) being estimated, grows large the **JSE and Bayes** equations become identical. Stein didn't derive his estimator from Bayes but could have. This point boosted the **JSE** in the enlightened statistical world when first published by Robbins. The **Risks of Bayes** is marginally better than **JSE**.



Tutorial Nuggets continued on page 20.



THE IMPROBABLY POSSIBLE AND IMPOSSIBLY PROBABLE

The **October Puzzle** Solution. As you will recall, a Nut Case (No. 1 in a line of **N** people) decides to cause a little havoc and chaos by simply selecting a seat at random, although everyone has been assigned a seat number, **n**, to their position in line, **n**.



Snapshot at front of queue of 99 solid, obedient citizens and 1 Nut Case (ID-ed)

When the **n**th passenger discovers his seat has been taken by the Nut Case, he simply takes another seat at random. The key question you were asked to solve was what the **probability** is that the passenger **N** will sit in his assigned seat, **#100**.

The key to solving this puzzle is to realize that the **chaos** all **stops** when some displaced passenger sits in the Nut Case's seat **#1**.

If, for simplicity, **N = 2**, then Nut Case may sit in seat, **#1** or **#2** (at random)

$P_1(\#1) = \frac{1}{2}$, so the answer here is that the $P_2(\#2) = \frac{1}{2}$.

For the more challenging case of **N = 100**, we've got some number crunching to do to prove the answer is the same, $P_{100}(\#100) = \frac{1}{2}$. **Not immediately obvious**, but look at it this way, the probability for someone to sit in Nut Case's seat range from $1/99$ for first guy, to $1/1$ for the last guy. The summation of those probabilities is shown below (In **Mathcad** notation).

$$n := 2, 3 \dots 98 \quad P := \sum_n \frac{1}{(n^2 + n)} \quad P_{\text{www}} := P + \left(\frac{1}{99}\right) \quad P = 0.5$$

Some Useful and fun Brain Teasers for 2022

(1) **Heads, I win.** There is a two-headed coin and 15 fair coins. One coin is chosen at random and flipped coming up heads. What is the probability that this is the 2-headed coin? Take all the time you need and consider this to have a **Bayes Theorem** solution.

(2) **A Baseball puzzle** from the past. There are **9** ways to arrive safely at First Base. Please name them before the **2022** Season begins. (NB: a hit of any kind is but one way to do it.)

In the meantime, **Scary belated Halloween**

Happy Thanksgiving

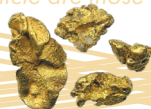
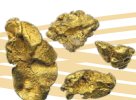
Merry Christmas

and

HAPPY NEW YEAR!!

See You in 22

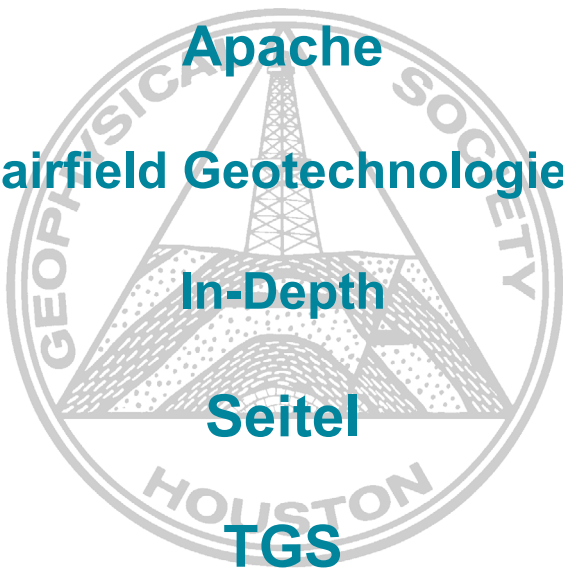
Disclaimer: The views and opinions expressed in this article are those of the author and do not necessarily reflect the position of the editor.



The Mystery Item
on [page 17](#)
is a

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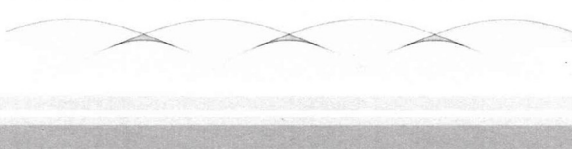
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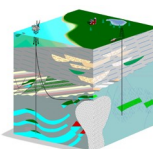
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Doodlebugger Diary

GSI's M/V Cecil Green Celebrates Completion of a Major 3D Survey off Mexico

By Story and photos by Scott Plotkin, GSI, 1980;
extracted by Scott Singleton

The Doodlebugger Diary recounts the experiences of geophysicists during their working lives. This month we have another in the series from GSI, this one from a periodical called 'Grapevine'. It is from vol 36, #2 in 1980. As before, these can be found online in an archive of GSI publications maintained by Bill Boettcher at <http://gsinet.us/>. This particular article comes to us courtesy of Dave Williams, now VP at Tricon Geophysics in Houston. In 1980 he was on the M/V Cecil Green and is shown in Figure 3 in the back row behind the man himself, Cecil Green. He recommended I reproduce this article because of its historical significance – the legend visiting his namesake vessel. I must admit, I would have been thrilled if that had happened to me during my offshore career. Enjoy!

If our readers have stories of their early careers they would like to share, please send them my way. I'll be happy to print them in this segment.

February 24 will go down as a special day for the M/V CECIL H GREEN family, for at the dock in Progreso, Yucatan, Mexico, Cecil Green, the grand old man of GSI Marine exploration, once again met his namesake.

The M/V GREEN was GSI's first boat built exclusively for seismic work. She is the oldest and smallest year-round vessel, but she is tough, and so is the man after whom she was named.

Under contract to Pemex, the M/V GREEN was just finishing a major 3D survey in the Bay of Campeche. It has been an exciting 17 months, during which the GREEN won "Vessel of the Month" honors three times.

Of course, this achievement was not as simple as leaving the dock and just "keeping

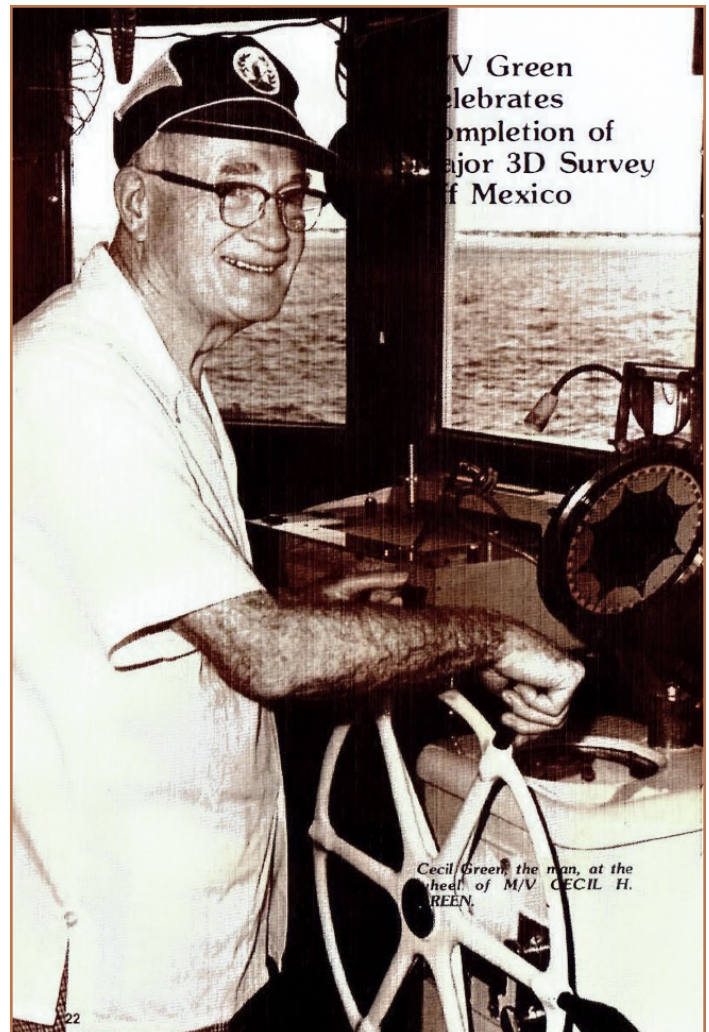


Figure 1: Cover photo for original article. Title is in upper right and caption in lower right. It reads "Cecil Green, the man, at the wheel of the M/V CECIL H. GREEN."

shooting." The vessel fell upon hard times. She was in Galveston, Texas, twice, having her compressors rebuilt. Even now she bears the scars of a bout with the Progreso dock, where

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or mail them to Box 441449, Houston, TX 77244-1449

she was battered by strong winds just two weeks previously.

Perhaps none of these feats would have been possible were it not for the 37-year friendship between Cecil Green and Ing. Antonio Garcia Rojas, the father of Mexican geophysics. When Pemex (Petroleos Mexicanos) was formed, Ing. Rojas was one of the prime forces behind its inception. Since his retirement as manager of exploration in 1966, Ing. Rojas has remained in the forefront as a special consultant to the government. It was only fitting that Cecil and Tony, as they call each other, should be together this day to celebrate the completion of this first phase of the Bay of Campeche Exploration program.

Also on hand for the occasion were Cecil's wife Ida; U.S./Latin America managers Stan Wilkowsky of Marine Data Collection and Dick Conroy from Marketing; Ing. Andres Ramirez, manager of GSI de Mexico; and J. Fred Bucy, president of Texas Instruments.

Accompanying Ing. Rojas were Ing. Francisco Tiburcio, superintendent of geophysical operations for Pemex, and Ing. Jose Santiago Acevedo, superintendent of exploration - Southern Zone.

It was an exciting time for both visitors and crew. Many "war stories" were swapped, some spanning three decades or more. A number of guests were accompanied by their wives, several of whom had never seen a seismic vessel before. During the vessel tour, Cecil Green took turns to inspect the bridge and pose at the helm (*Figure 1*).

En route to Merida for dinner, a stop was made – at Fred Bucy's request – at the infamous "Charlie's," a bar in Progreso often frequented by the crew. When questioned on the matter, Fred said he was concerned for the health and welfare of the crew and wanted to "check" the cerveza to see if it was properly chilled.

As the evening got underway, many subjects were informally discussed. One particular gripe concerned the Progreso pier, where the M/V GREEN is tied up at the very end. The pier is a full nautical mile long, and after a night at Charlie's,

it sometimes appears to extend over the horizon. During an address to the crew, Fred Bucy said he would order knee and elbow pads for the crew in an effort to make the crawl to the boat less painful.

Dick Conroy and Stan Wilkowsky took turns as MC and helped inform everyone on the M/V GREEN's future plans. They also introduced the delegation from Pemex to the crew. Ing. Rojas explained the special relationship Pemex and GSI have had over the years, and Fred Bucy congratulated everyone on the many contributions the vessel had made.

The highlight of the evening was when Cecil Green told of GSI's many achievements over the last 50 years. After recounting the M/V GREEN's many successes and paying tribute to the people associated with her, he presented the crew with a commemorative plaque, which was accepted by PM Paul (Pablo) Woodward.

Following the speeches, Bob Bredehoft of the M/V GREEN crew presented Cecil with an M/V CECIL H. GREEN cap, complete with scrambled eggs! It has at



Figure 2: On behalf of the crew, PM Paul Woodward accepts achievement plaque from Cecil Green.

The cover page reads:

“Presented to Cecil H Green with deep respect and fondness from the crew of the M/V CECIL H. GREEN in appreciation of the direction you set and the care that you give.”



Figure 3: M/V CECIL H. GREEN crew with ship's namesake:

*Front row --Tommy Grace, George Blair, Raymond Hoffman, Tom Varner, Darrel Lee;
second row - Tony Canepa, Jim Grady, Gary Dillon, Cecil Green, Fred Bucy, Scott Plotkin, Mike Boyle, Doug Chapman;
back row ---Bob Bredehoft, Jeff Johnson, Brian Kirby, Tommy Charles, Dave Williams,
Bill Roche, Bill Kennedy, Harry Secondine, Paul Woodward.*

least one-half dozen more than the cap presented to Ed Vetter at the commissioning of the M/V VETTER.

Then Cecil was presented with a book containing the history of the vessel in words, photographs, and news clips. The book is inscribed with the signatures of the entire crew.

The next day our boat manager Doug Chapman and administrator Norman "Speedy" Neighbors gave forth a collective sigh of relief: Their guests were on their way home, and the crew was back on board making final preparations for the transit back to the States. Hasta luego! □