June 2021

GSH Journal

The Epicenter of Geophysical Excellence

GEOPHYSICAL SOCIETY OF HOUSTON
Volume 11 • Number 10

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A Cloud Based Platform for Unconventional Production Optimization.

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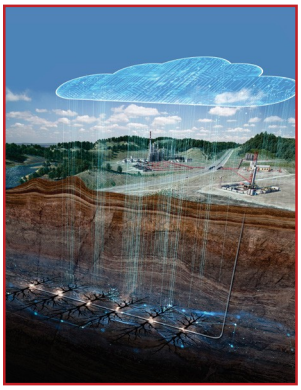

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To ensure your information reaches the GSH members in a timely manner, please note the following deadlines and plan accordingly. Please submit your articles and any questions to Alvaro Chaveste, editor, at AlvaroChaveste@hotmail.com

GSH JOURNAL DEADLINES

Sept 2021 ..... Jul 16
Oct 2021 ..... Aug 16
Nov 2021 ..... Sept 16

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A Word from the Board

By Alvaro Chaveste, Editor

With this issue I close my two-year tenure as GSH Editor. Exciting two years, characterized by a continued decline in exploration for Oil and Gas (O&G) fueled, mainly, by the exploitation of resource plays (which require little or no exploration); the push to move away from fossil fuels into renewable energy; and, in 2020-2021, a global pandemic that slowed demand for oil to, almost, a complete stop.

The shift of the energy industry, from fossil fuels to renewable resources, is evident in the GSH Journal (GSHJ) and other scientific publications. Their content is evolving. NextGen (a subgroup of the GSH), for example, had the series *"**Under a Different Rock**"*, in which the presentations were focused on geophysical applications unrelated to exploration for O&G. Themes like: *"**Geophysical Applications in Mineral Resources**"* and *"**Revisiting how we use seismic data to detect explosions**"* were presented in this series.

Experts in the Geophysical Industry acknowledge the shift often. The column *"**Word from The Board**"* gives GSH board members a space to express their views. In the March issue Marianne Rauch, 1st VP Elect, expresses hers saying "… renewable energy sources will eventually replace most of the hydrocarbons and less and less exploration will be performed… I believe that it is essential that we adapt with the times and adjust the usage of geophysics…". Katja Akentieva, 2nd VP Elect, mentions, in the April issue, that "… we are, as an industry, grappling with fundamental change in the energy sector, the rise in renewables and transition toward a lower carbon future". She exemplifies geophysicists' inventiveness in adapting to the challenge with the Geothermal Eavor loop in Calgary. In personal communication, Katja expressed that; while renewable energy is on the rise, fossil fuels are expected to be a critical share of the energy portfolio during the next decades.

Klaas Koster, President Elect, looks, in the January issue, at changes in working habits associated to the lockdown due to COVID-19. The reduced membership and corporate sponsorship that resulted from it are also related to changes in the energy sector. With the intention of setting the GSH up for a healthy future, Klaas proposes a wild idea: "… recast independent local societies as local chapters of a large organization that provides the business backend. This would get rid of all the expensive and time-consuming business of running a multitude of independent, non-profit organizations…". After January, when Klaas's paper was published, an ad-hoc committee was formed, and recommendations to the GSH board have been made.

In the early 80's the growing concern that oil, a non-renewable resource, would be depleted pushed the O&G industry into developing innovative technologies to find new reservoirs. In February's GSH Movie Time, the video *"**Seeing the Unseen**"* documents these concerns, as well as efforts in the development and application of the new technology. The movies in the October 2020, November 2020, and April 2021 GSHJ issues illustrate, with operations carried out in Alaska and Canada's Northern Territories in the early 80's, the complex logistics involved in using the developed technology. Today we see the possibility of having renewable energy sources replace fossil fuels before these are depleted.

The geophysical industry has adapted, through its existence, to meet humanity's energy needs. Seismic exploration was born from the need of creating subsurface images when surface geology was no longer enough for finding traps. Later, the need of better images resulted in the extension of the seismic method to creating three-dimensional images. The 3D method required the development of hardware to store and process vast amounts of data, as well as the creation and application of sophisticated algorithms to interpret it. As the energy industry shifted towards exploitation of non-conventional resources, the geophysical industry shifted its focus into characterizing the mechanical properties of rocks. Today we, geophysicists, are modifying and accommodating geophysical methods again; this time to support the flourishing renewable energy industry.

I have had an interesting career as a geophysicist; characterized by continuous change, optimization of tools and methods, and adaptation to ever-changing needs of the energy industry. The latest adaptation is underway. Geophysicists are making use of available methods or inventing new ones to facilitate energy generation from renewable sources. □

From the Other Side

By Lee Lawyer

"The origin of the Geophysical Society of Houston dates to the fall of 1947. On October 7th of that year, Walter J. Osterhoudt was named as temporary chairman of a Constitutional Committee and Dr. E. E. Rosaire was made chairman of a Nominating Committee. At 4:00 PM on Thursday, November 20, 1947, 108 geophysicists met in the Houston Engineers Club to form what was then called the Houston Section of the Society of Exploration Geophysicists (the name was not changed to the Geophysical Society of Houston until about ten years later)" *. The GSH was not the first Section of the SEG. There were several others at about the same time. These early Sections were a result of new bylaws put into place by the SEG, codifying the procedures for Section affiliation.

The governing body of the SEG was made up of all the SEG Sections. That was the beginning of the Council of the SEG. Each Section was represented on the Council by several delegates, that was based on the Section membership. The Council was the Governing Body of the SEG. There was an elected Executive Committee that conducted the annual meeting of the Council with the President of the SEG as Chair. The bylaws stated that the Executive Committee (elected officers) would act for the Council during its absence. Since most business was conducted while the Council was in recess, the Council slowly lost its original intent. But it had stated responsibilities. The Excom would report to the Council annually. The Council would review and approve that report and the annual Finance report. Any dues increase by the Excom required a vote by the Council. The Council was alive and well for many years but played a very small role in SEG governance.

Recall that all Sections sent delegates to Council meetings. (usually annually) The delegates were Section members. In the 70's (?), the issue of representation for non-Section members surfaced. The non-Section members had no say on the Council. The SEG bylaws were changed so that non-Section members of the SEG would elect delegates to the Council. This required some interesting membership lists. A Section would state its membership on a given date. But who was reporting non-Section members? Usually this was done by comparing total membership in an area versus Section membership. Only non-Section members could vote and elect District delegates from non-Section members. Clearly this left much to be desired.

A few years ago, this was resolved by defining large geographical divisions of the SEG. Houston was in Division one. If you are interested the geographical divisions, check the SEG website. The changes were implemented by having ALL SEG voting members in each Division, elect two additional delegates to the Council. These were District Delegates. In one Division there would be delegates from the Sections and two elected delegates from the entire membership within a specific Division. Since there were ten Divisions, twenty District delegates were added to the total of Section Delegates. Does that sound complicated? It was a lot easier than separating out non-Section members for a vote. This could be roughly compared to our US congress where we have both Senate members and House members.

About ten years ago, there was a complete re-write of the SEG bylaws. No longer was the Council the ruling body of the SEG. The Council still existed but on paper, it lost its original purpose. But it is still the only group in the SEG that represent the entire membership. The GSH has five or six delegates on the Council depending on our changing membership numbers. Recently the Council in a virtual meeting discussed the SEG stance on Climate Change. They voted in favor of a Climate Change position. The SEG Board followed suit and established a position paper on Climate Change. I strongly support the Council. Our delegates should report to the GSH membership (via our Journal), stating results of Council meetings. Whether to have a unit rule or ask each GSH delegate to vote individually is an issue left to the delegates.

* This is from the "*History of the GSH*" found on the GSH Website and written by Art Ross. □

Unconventional SIG

Multi-Faceted Fracture Characterization Case Study at Hereford Field, Colorado

Tanya Inks, IS Interpretation Services and Mark Willis, Halliburton

Abstract and Bio

Online presentation - June 3, 2021
11:00am-12:00pm CST

Register

GSH Gets Down to Business

ACTeQ-Advanced Survey Design and Optimization

Damian Hite (Founder and CEO), and Dave Ridyard (Co-Founder)

Abstract and Bio

Online presentation - June 23, 2021
12:00pm-1:00pm CST

Register

3rd Annual GSH/SEG Web Symposium on

3D seismic survey design

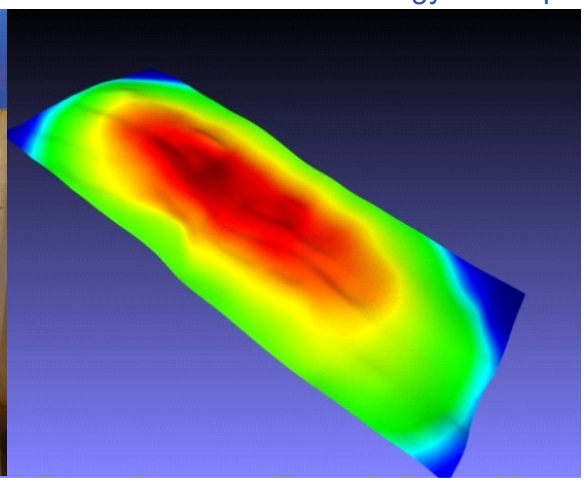
Seismic surveys represent a significant investment for operators. In this web symposium attendees will hear and interact with industry thought leaders discussing the latest tools to optimize the design of 3D surveys. The focus will be on applying the right planning, acquisition and processing tools to balance the often-competing demands of cost, quality and environmental impact.

Mon. 30th August 2021
9:00 am to 1:00 pm (CST)

Registration

General public	$125
GSH/SEG Members	$ 90
Students	$ 25

Who should attend ? : Geoscientists, technical managers and field operation specialists seeking to remain current with the latest technology developments.



Speakers

This informal and interactive event will feature presentations by Dave Monk (Past President of SEG, formerly Apache), Malcolm Lansley (Consulting Geophysicist/ACTeQ), Mark Meier (University of Houston, formerly ExxonMobil), Christof Stork (Land Seismic Noise Specialists) and John Brittan (ION)

Visit gshtx.org, Events Tab to register and see full presenter information (when available)

Event sponsors

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Images courtesy of (top left) Neptune Energy, (lower right) ACTeQ

2021 GSH ANNUAL MEETING and HONORS & AWARDS

2021 President's Award Matt Blyth

2021-22 Elects: Tony, Simon, Rene' and Jennifer

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Lee Lawyer

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Annual Meeting and Honors & Awards continued from page 9.

Tad Smith 2021 Honorary Membership Awardee

Dennis Yanchak 2021 Honorary Membership Awardee

Lillian Comegys Jones Lifetime Membership Awardee

Peter Lanzarone Lifetime Membership Awardee

Thank you to all who attended our Annual Meeting and Honors & Awards Celebration. After over a year of virtual meetings it was great to come together again in person with new friends and old to network, reminisce and reconnect. Congratulations again to our awards recipients and thank you to all who attended and made this event such a success. Thanks to Lucy for Chairing and all of the volunteers.

We hope you will be able to join us for our next in person events, the Fall Warm-Up Sporting Clays in August and the Ice Breaker in September.

Peter Duncan, GSH President (2020-2021)

GSH Fall Warm-Up Sporting Clays Tournament

Save the Date
Friday, August 20, 2021

8:00 am to 3:00 pm

Includes breakfast and lunch.
Family and non-GSH members' participation is encouraged.

American Shooting Center
16500 Westheimer Parkway
Houston, TX 77082

Early Bird Registration
$150/Shooter • $750/Team of 5

The tournament is a social networking event
and a fundraiser for the Geophysical Society of Houston.
Sponsorship and Registration @ gshtx.org

For more information, please feel free to contact
Scott Sutherland, at **346.366.0288, scotts@dug.com**,
or the GSH Office at 281-741-1624.

GSH Icebreaker 2021
Thursday, September 9th

Icebreaker begins at 6:00 pm and ends at 9:00 pm

Karbach Brewing
2032 Karbach St
Houston, TX 77092

This year's Geophysical Society of Houston kickoff event will be as big as Texas!

Mingle with Houston and industry-wide colleagues
Enjoy Houston Craft Beer and Lite Bites
Meet the Geophysical Society of Houston Board

For more information or sponsorship opportunities, please contact the GSH office at 281.741.1624 or Tony LaPierre at tony.lapierre@rpsgroup.com

Further Insights on the Role of Aseismic Slip in Hydraulic Fracturing-induced Seismicity

Thomas Eyre[1,2], David Eaton[1,2], Dmitry Garagash[3], Megan Zecevic[1], Marco Venieri[1], Ronald Weir[1] and Donald Lawton[1]
[1] University of Calgary, Calgary, AB, Canada [2] Aseismic Solutions Inc., Calgary, AB, Canada [3] Dalhousie University, Halifax, NS, Canada

Summary

Earthquakes induced by hydraulic fracturing are typically believed to be caused by elevated pore pressure or increased shear stress. However, according to a recent study, these mechanisms are incompatible with experiments and rate-state frictional models that predict stable sliding (aseismic slip) for faults with high clay content or total organic carbon, as well as observations of the timings and locations of the seismicity. An alternative model was therefore proposed, in which distal, unstable regions of a fault are loaded by aseismic slip on stable regions of the fault stimulated by hydraulic fracturing. This model has significant implications in terms of mitigating induced seismicity, as it suggests that there may be a potentially measurable deformation signal tens of hours before earthquake nucleation. However, the conclusions of that study were based on a relatively small number of events from a small local broadband network. In this study we integrate a high-resolution microseismic dataset from the same treatment with that previous work and demonstrate that the microseismic data provides an even more compelling case that aseismic slip plays a role in induced seismicity.

Introduction

In recent years, a number of hydraulic fracturing operations have been linked to induced seismicity. In the Western Canadian Sedimentary Basin, ~ 0.3 % of operations have been linked to earthquakes of $M_w > 3$ (Atkinson et al., 2016), and several earthquakes with $M_w > 4$ have been induced within a region ~ 25 km south and west of the town of Fox Creek in central Alberta, where hydraulic fracturing operations target the Duvernay formation.

Several models have been proposed to explain the mechanisms of fault activation by fluid injection (Eyre et al., 2019b). The first suggests that an increase in pore pressure within the fault zone leads to a reduction in effective normal stress acting on the fault (Raleigh et al., 1976) and requires a hydraulic connection between the injection and the fault. A second hypothesis is that fault activation is caused by stress changes arising from poroelastic coupling between hydraulic fractures and the rock matrix (Segall and Lu, 2015). This can alter fault-loading conditions without any hydraulic connection, but the magnitude of the stress change is relatively small and diminishes quickly with distance (Deng et al., 2016). Finally, a third model was recently proposed by Eyre et al. (2019), where distal, unstable regions of a fault are loaded by aseismic slip on stable regions of the fault where it is in close proximity and stimulated by a hydraulic fracturing treatment.

Eyre et al. (2019b) proposed this alternative model principally because they found that earthquake nucleation due to hydraulic fracturing is often significantly vertically offset from the injection zone. Additionally, the timings of these events is difficult to reconcile with either the pore pressure or poroelastic stress models. In particular, they showed an unusually comprehensive case study, with 3D seismic, broadband and well data. The 3D seismic data showed a series of approximately N-S oriented subvertical strike-slip faults that originated in the basement and terminated significantly above the reservoir. Some of these correlated well with the locations of the seismicity recorded on the local broadband network. Given the locations of the seismicity significantly above the reservoir, any change in stress or pore pressure would load the fault at the reservoir depth more significantly than at the depths at which the seismicity occurs due to the closer proximity to injection. They also observed migration of seismicity upwards along the fault over a timescale of tens of hours, much faster than expected given the extremely low matrix permeabilities of the reservoir rocks (typically on the order 10^{-18}-10^{-21} m^2 (Moghadam and Chalaturnyk, 2015)).

Eyre et al. (2019b) also referred to laboratory experiments and in-situ experiments which indicate

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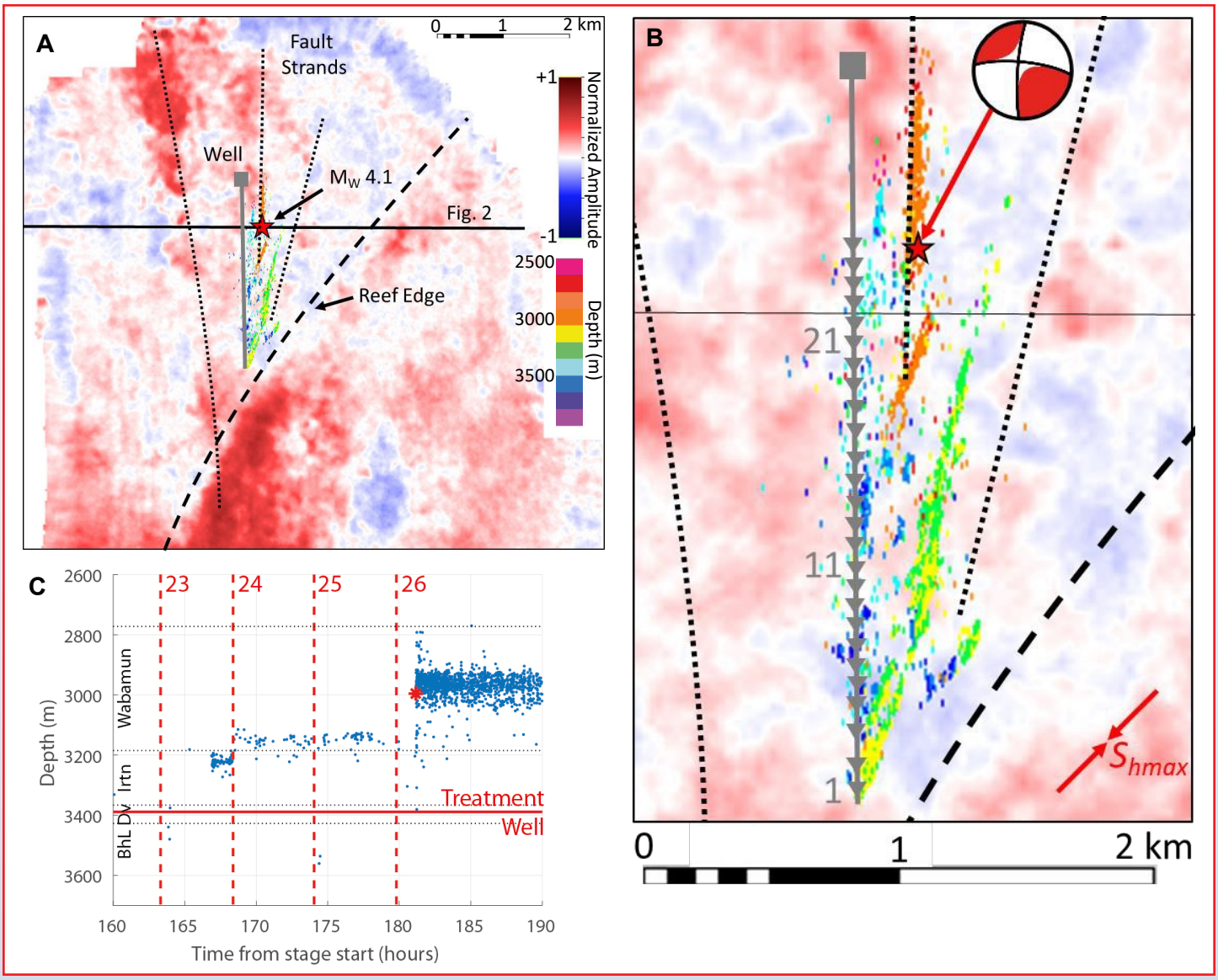

Figure 1. Microseismic monitoring data from a treatment associated with a M_w 4.1 earthquake. (A) Depth slice through the 3D seismic volume showing normalized seismic reflection amplitude at the level of the Beaverhill Lake Group (Eyre et al., 2019b) (at 3386 m depth, Figure 2), which directly underlies the Duvernay Formation (gray line = treatment well location, solid black line = profile in Figure 2, red star = M_w 4.1 earthquake). Structural features can be interpreted, including the edge of the Swan Hills reef structure and a series of roughly N-S lineaments. Microseismic data is overlain, colored by depth. (B) Enlargement of A around the treatment well (triangles = injection stages, numbered at intervals, beachball = focal mechanism of M_w 4.1 event). (C) Depth of microseismic events versus time for events in the immediate vicinity of the mainshock (dashed red lines = stage start times, black dotted lines = stratigraphy (BhL = Beaverhill Lake, Dv = Duvernay, Irtn = Ireton), red star = M_w 4.1 earthquake).

that slip on a fault within a shale host rock is expected to be stable due to the rate-state frictional parameters of rocks with high total organic carbon (TOC) and clay (Kohli and Zoback, 2013). They carried out measurements on core samples taken from near their study area to estimate the TOC and clay content and found that indeed the seismicity correlated well with layers that contained only trace amounts of TOC and clay, whereas the reservoir and surrounding formations contained much higher quantities.

Taking all of these observations, Eyre et al. (2019b) constructed a realistic rate state model

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of fault slip. Increased pore pressure on the fault at reservoir depth caused by hydraulic fracturing accelerated aseismic creep along the stable portion of the fault. This creep propagated along the fault significantly faster than pore pressure diffusion and loaded the unstable part of the fault ~ 200 m above the reservoir, leading to a M_w 4.1 earthquake that nucleated ~ 300 m above the reservoir. The timing, location and magnitude of the event were very similar to those observed in reality and demonstrated the plausibility of the model. As mentioned previously, these observations are much more difficult to reconcile with the other models.

Eyre et al. (2019b) based their work on data from the local broadband network, which consisted of four stations at < 8 km distance. During the period studied, 108 events were detected on this network. However, at the same time a microseismic monitoring network of 93 shallow borehole arrays recorded data from the same treatment. In contrast, this array recorded 9769 events with high resolution locations (Eyre et al., 2019a), and therefore gives a much clearer picture of the seismicity and evolution over time. Here we investigate whether the observations from this dataset are consistent with the aseismic slip model.

Method

The hydraulic-fracturing operations associated with the M_w 4.1 event were monitored using a network of 93 shallow borehole arrays of sensors, where each array consisted of two one-component sensors at 13.9 m and 20.9 m depth, and a three-component sensor at 27.3 m depth. The continuous ground-motion recordings from these sensors were commercially processed (Eyre et al., 2019a). Well log data from a stratigraphic well ~ 2.9 km north of the well pad were used to create a blocked P-wave seismic velocity model. Candidate template events were first detected using a synthetic template generated from travel times in the velocity model, for source locations located on a grid with spacings of 200 m in the E-W, N-S and vertical directions on the first pass of the data. Five template events were selected from these candidate events, located at roughly regular intervals along the length of the treatment well and characterized by high signal-to-noise ratio so that first arrivals can be picked on as many receivers as possible. The locations of the template events were then refined by processing and detecting perforation shots, to provide control points with known locations (Eaton, 2018). The template event locations were adjusted by fine-tuning the velocity model until the hypocenters of the perforation shots coincide with their true locations. Mean average absolute errors between true and calculated locations for the 69 detectable perforation shots in the E-W, N-S and vertical directions are 7.1 m, 23.8 m, and 30.0 m, respectively, validating the velocity model. This gives good confidence in the depths of the events, which is vital for the interpretation.

A beam-forming approach was used to relocate the events relative to the template event, associated with a grid-search in the region of interest (Eyre et al., 2019a). Waveforms were summed across all shallow arrays of greater than the threshold of 25 is required for a detection (a stack sum equal to 1 can be considered the baseline value, and noise triggers are very common even at a threshold of 25). All detections were manually screened, based on noise and waveform alignment between traces once the calculated moveout is applied. A signed template approach was taken which has been shown to increase event detection (Roux et al., 2014). All large events exhibited similar strike-slip focal mechanisms (the focal mechanism of the M_w 4.1 event is shown in *Figure 1*).

For the 3D seismic reflection data, amplitude normalization is performed such that the highest observed reflection amplitude has a value of unity. Geologic horizons are identified based on a calibration well that was drilled to a total vertical depth of 3607 meters from a surface elevation of 890.9 m (Weir et al., 2019). Reflections at the Wabamun Formation top are then flattened to highlight geological features that were present before and during deposition of this layer (Eyre et al., 2019b).

Results

Figure 1A and B show the microseismic event locations from Eyre et al. (2019a) in map view plotted on a horizontal slice through the 3D seismic volume at 3386 m depth (at the depth of the Beaverhill Lake formation, a reflector just below the Duvernay formation reservoir). The treatment

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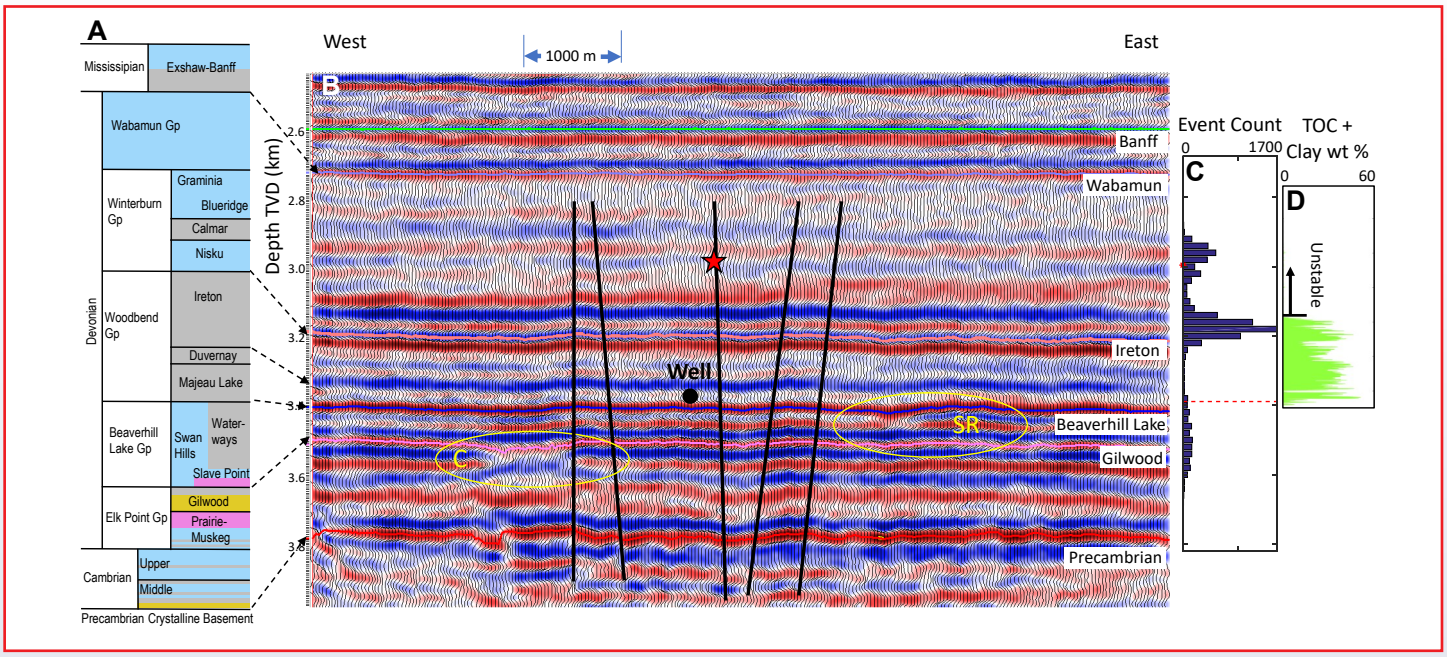

Figure 2. (A) Stratigraphic column from the study area (blue = limestone and dolostone, gray = shale and mudstone, orange = sandstone, pink = evaporites). (B) West-east slice through a 3D seismic volume (vertical exaggeration 4.25, for location see Figure 1), showing location of the M_w 4.1 earthquake (red star). TVD = total vertical depth from surface. Several N-S oriented faults can be distinguished (black lines), including one coincident with the location of the earthquake. C = possible channel visible as a "bowtie" structure, SR = edge of Swan Hills Formation reef structure. (C) Histogram of microseismic event locations versus depth for 20 m bins (M_w 4.1 earthquake = red star, treatment well depth = dashed red line). (D) Estimated TOC + clay weight percentage derived from well log data, from Eyre et al. (2019b).

appeared to activate a series of N-S to NNE-SSW faults. The seismicity does not appear to align with the indicated maximum horizontal stress direction, in contrast to what would be expected for typical hydraulic fracturing microseismicity (Eaton, 2018). Although the features in the 3D seismic data are subtle due to the strike-slip nature of faults in the region and the layercake structure, many of the linear features observed in the microseismic data appear to correlate with lineations in the 3D seismic data. Due to their subtle nature, these would have been difficult to flag as problematic before combining with the microseismic locations.

Figure 2 shows a W-E cross-section through the seismic volume, as well as a stratigraphy for comparison. It can be seen that the subtle faults identified in map view can be tracked from significantly above the reservoir into the basement and are subvertical. Depths of the microseismic events are also shown. These appear to peak at the interface between the Ireton formation (predominantly shale) and the Wabamun formation (carbonate). Also shown is the clay plus TOC weight percentage estimated from a nearby well core by Eyre et al. (2019b), which shows that the transition between the Ireton and Wabamun formations should indeed result in a transition between stable and unstable slip. The microseismic depths are therefore predominantly located where they would be expected based on the model of Eyre et al. (2019b).

Figure 3 shows the evolution of seismicity in cross-section both before and after the M_w 4.1 event. A small cluster of seismicity initiates ~14 hours before the mainshock just below and coplanar with it. This seismicity gradually migrates upwards along the fault with time leading up to the event. Afterwards, the aftershocks are all located at similar depths to the mainshock, suggesting that they also occur within the unstable part of the fault. This migration is also shown in *Figure 1C*. The spatial and temporal pattern is similar to that observed by Eyre et al. (2019b), but can be seen with much better resolution. They interpret this as being consistent with the upward

Technical Article continued on page 16.

Technical Article continued from page 15.

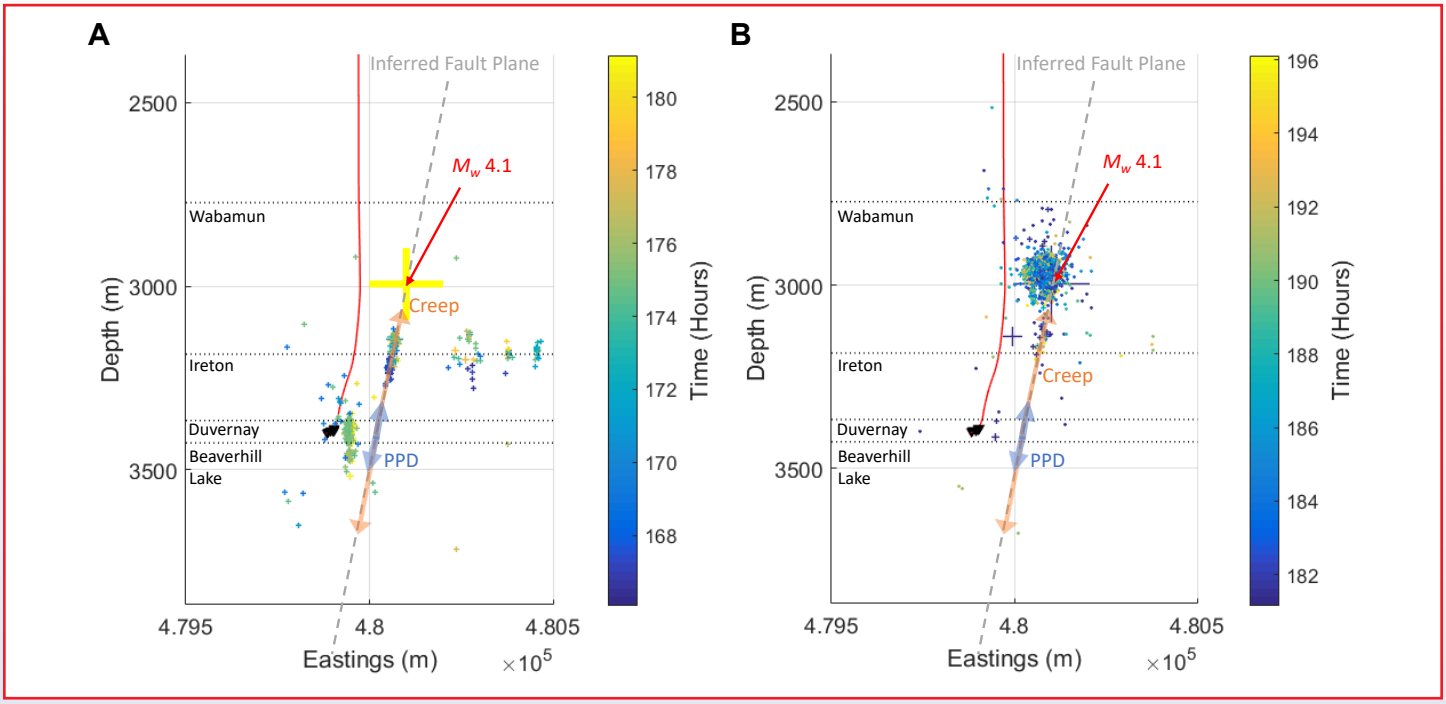

Figure 3. Foreshocks and aftershocks of the M_w 4.1 earthquake over time in west-east cross-section. (A) Microseismicity leading up to and including the M_w 4.1 earthquake. (B) Microseismicity after and including the M_w 4.1 earthquake. Treatment well (red line), stage locations (black triangles), stratigraphy (black dotted lines), and estimated position of the steeply dipping fault plane is shown. Creep outpaces the pore-pressure diffusion (PPD) front on the fault plane.

propagation of an aseismic slip transient passing through some unstable asperities followed by the initiation of dynamic rupture where the deformation front impinges on the unstable region of the fault.

Conclusions

By carrying out a similar analysis as Eyre et al. (2019b) but using microseismic data, instead of the much sparser regional data, a much clearer picture of the spatiotemporal evolution of the seismicity leading up to the M_w 4.1 earthquake is apparent. For example, it is much clearer that the majority of seismicity occurs within the unstable Wabamun formation, and the migration of foreshocks along the fault leading up to the mainshock is also much more apparent. However, the observations are similar to those of Eyre et al. (2019b), and support the role of aseismic slip as an important mechanism in hydraulic fracturing-induced seismicity. An improved understanding of the fundamental processes of fault activation during hydraulic fracturing is key to developing effective mitigation strategies. One exciting aspect of this model is that it suggests that a potentially measurable deformation initiates hours before the mainshock, which may be sufficient warning to change operations in order to mitigate against the occurrence of an earthquake, or at least to provide early warning. The model also has implications for expected magnitudes and timings of events.

Acknowledgements

We are very grateful to Repsol Oil & Gas Canada Inc. for providing the microseismic data, which were processed by Magnitude. TGS Canada Corp. is thanked for providing the 3D multicomponent data used in this study. TOC data were measured by Weatherford and XRD data were collected by Chevron; these data were sourced from the Alberta Energy Regulator database. This research was supported in part by funding from the Canada First Research Excellence Fund and from Discovery Grant 05743 by Natural Science and Engineering Research Council. We thank the sponsors of the Microseismic Industry Consortium and CREWES for their financial support of this study. □

Technical Article continued on page 17.

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References

Atkinson, G. M., D. W. Eaton, H. Ghofrani, D. Walker, B. Cheadle, R. Schultz, R. Shcherbakov, K. Tiampo, J. Gu, R. M. Harrington, Y. Liu, M. van der Baan, and H. Kao, 2016, Hydraulic Fracturing and Seismicity in the Western Canada Sedimentary Basin: Seismological Research Letters, 87, 631–647.

Deng, K., Y. Liu, and R. M. Harrington, 2016, Poroelastic stress triggering of the December 2013 Crooked Lake, Alberta, induced seismicity sequence: Geophysical Research Letters, 43, 8482–8491.

Eaton, D. W., 2018, Passive Seismic Monitoring of Induced Seismicity: Fundamental Principles and Application to Energy Technologies: Cambridge University Press, Cambridge, U.K.

Eyre, T. S., D. W. Eaton, M. Zecevic, D. D'Amico, and D. Kolos, 2019a, Microseismicity reveals fault activation before M_w 4.1 hydraulic-fracturing induced earthquake: Geophysical Journal International, 218, 534–546.

Eyre, T. S., D. W. Eaton, D. I. Garagash, M. Zecevic, M. Venieri, R. Weir, and D. C. Lawton, 2019b, The role of aseismic slip in hydraulic fracturing - induced seismicity: Science Advances, 5, eaav7172.

Kohli, A. H., and M. D. Zoback, 2013, Frictional properties of shale reservoir rocks: Journal of Geophysical Research: Solid Earth, 118, 5109–5125.

Moghadam, A. A., and R. Chalaturnyk, 2015, Analytical and Experimental Investigations of Gas-Flow Regimes in Shales Considering the Influence of Mean Effective Stress: SPE Journal, 21, 557–572.

Raleigh, C. B., J. H. Healy, and J. D. Bredehoeft, 1976, An experiment in earthquake control at Rangely, Colorado: Science, 191, 1230–1237.

Roux, P. F., J. Kostadinovic, T. Bardainne, E. Rebel, M. Chmiel, M. Van Parys, R. Macault, and L. Pignot, 2014, Increasing the accuracy of microseismic monitoring using surface patch arrays and a novel processing approach: First Break, 32, 95–101.

Segall, P., and S. Lu, 2015, Injection-induced seismicity : Poroelastic and earthquake nucleation effects: Journal of Geophysical Research : Solid Earth, 120, 5082–5103.

Weir, R., D. Lawton, L. Lines, T. Eyre, and D. Eaton, 2019, Application of structural interpretation and simultaneous inversion to reservoir characterization of the Duvernay Formation , Fox Creek , Alberta , Canada: The Leading Edge, 38, 151–160.

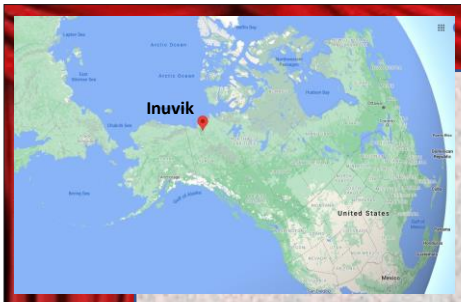
Permalink: https://doi.org/10.1190/segam2020-3421625.1

Mystery Item

This is a geophysical item...

Do you know what it is?

This month's answer on page 29.



GSH Movie Time

Now Showing
City on Sleighs*

Inuvik, the Canadian Northwest Territories. A tough location for a prospect. One in which the constantly blowing wind often brings the chill factor down to -90 deg Fahrenheit. When GSI went there they took their own *City on Sleighs*.

In this movie, one of GSI's parties is mobilized to Inuvik for operation there and in other cities. The vehicles and camp units were transported from Calgary by Hercules aircraft, and then assembled in the Inuvik yard. The Geophysical party, headed for a prospect near the McKenzie Delta, was prepared for the inclement weather of the frozen Beaufort Sea.

With the totally self-contained mobile camp, consisting of strings of camp units towed by Caterpillar tractors, GSI could not only get the crews out on the ice, but keep them there for long periods of time.

Click on red ticket to view movie

*** GSI vintage videos courtesy of Schlumberger – WesternGeco**

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

GSH Media Kits

Item Of Interest

The first discovery by any geophysical method in the United States was made by Rycade Oil Co. in early 1924 and confirmed by the drill in 1926. It was Nash Dome which was found using an Eotvos Torsion Balance. The first by seismic methods was Nash Dome found in June 1924 by a Seismos Refraction crew. □

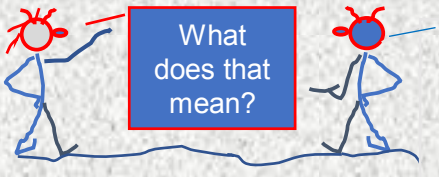
Tutorial Nuggets

By Mike Graul

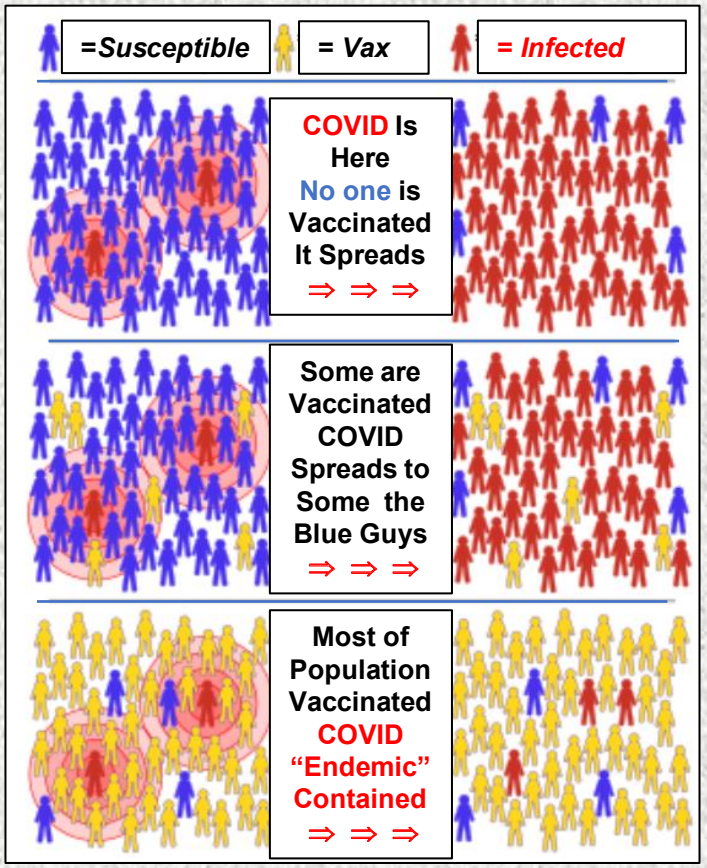
A special announcement from the Journal Editorial Board

In our continuing effort to serve the Geophysical Community, we have asked the Guru to suspend his learned discussions of the Stein Paradox with blessings of Rev Thomas Bayes, so that he may assist the Journal readers in understanding a key issue of the current Pandemic.

Understanding Herd Immunity from the Geophysical Point of View



I guess it means that geophysicists are a herd of a different wheelbase



As is my custom, I will take the high road and ignore the ignorant and snarky comments coming from the cheap seats by two guys who wouldn't know a **pandemic** from **fat meat.**

At the left is a chart (modified from a somewhat purloined Wikipedia article on **Herd Immunity** and mathematical modelling) that shows **3 stages** of the outbreak of **COVID-19** in a **homogeneous** population in which an **infected person (Red Guy)** has access to any and all **susceptibles** (not to be confused with **dispicables**).

In the **upper panel pair,** we see the widespread surge in new cases before anyone is **vaccinated**. Only edge people in the population fail to get it. In the **middle panel**, with only a **few** vaccinations, the spread is sill fast and furious with only the **Vax** immune and edgy recluses avoiding the disease.

The **3rd Panel** demonstrates **Herd Immunity** in which enough of the population has been vaccinated that the spread of the disease is limited to **no more than one new case per Red Guy (infected)** from the residual **susceptibles** (**blue**). The so-called **Herd Immunity Threshold** has been reached. If the **rate of new infections is exactly 1 per red guy**, this creates a steady state condition in which there is no increase nor decrease in the rate of new cases. The disease is said to be "**endemic**", beating the hell out of **epidemic**, and a homerun compared to the current **pandemic.**

The question now under discussion is what the **vaccination rate** to achieve **Herd Immunity**?

Tutorial Nuggets continued on page 21.

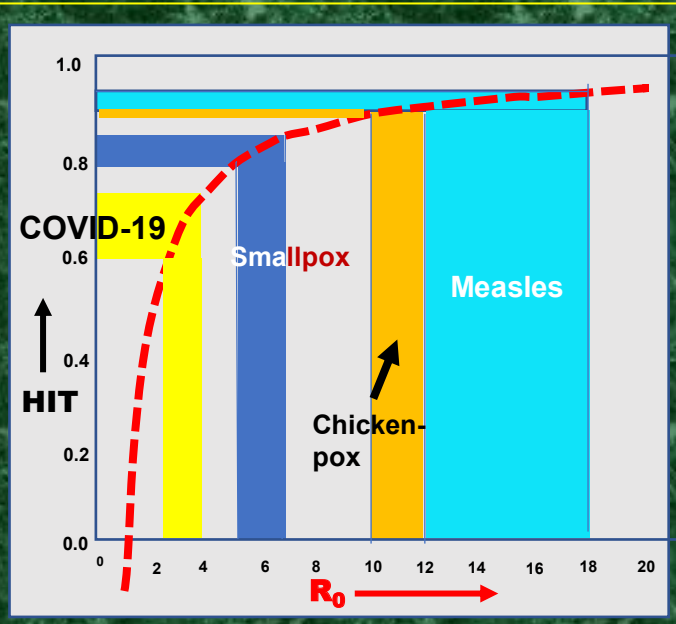
Tutorial Nuggets continued from page 20.

Mathematical Modelling of Herd Immunity

Defining R_0 as the basic "Reproduction No." indicating the number of new cases caused by each infected person (**Red Guy**), and S as the portion of the population susceptible (**Blue folks**) to the disease in question, we can mathematize the endemic stage as shown below:

$R_0 \bullet S = 1$. The basic rate of infection or "contagiousness" can vary significantly for different diseases, e.g., COVID-19 has a basic rate of 2.5 to 4, while Measles has an R_0 of 12 -18. This points out that different virus maladies will require different **vaccination rates** to reduce the product, R0•S, to 1. How does this come into play, you cogently ask? In the following manner.

We must reduce the **susceptible population** by **vaccination** (we'll assume, for this preliminary exercise, that antibodies from prior infection are not useful). Below, we define the **P** which is the VAX rate at which **Herd Immunity** should (damn well better) occur.. This number is called the Herd Immunity Threshold, **HIT.**



S = 1 – P. In this expression, **P** represents the rate of vaccination, so to the extent that it is effective, this rules the susceptibility. Plugging this in **$R_0 \bullet S = 1$**, we get **$R_0 \bullet (1 - P) = 1$**. To solve for P, we take the following steps.

$$P = 1 - \frac{1}{R_0}$$

Here we substitute **P_C** for P to show that this is the "**critical**" proportion of **immune** (**VAX peeps**) to total **population** to induce **H**erd **I**mmunity. The threshold vaccination rate is determined by the range of **R_0** projected at the curve of **$P_C = 1 - (1/R_0)$** onto the vertical axis (HIT). The safest single number to use is probably the upper value of HIT. In the case of Measles, the HIT is 95% while Smallpox, Polio and Mumps all require 86% and for the current pandemic, **COVID-19**, it will require **75% vaccination** to assure **Herd Immunity.** This, of course, does not apply to those who by race, religion, politics, fear, or moral turpitude, wish to decline.

A puzzle for September (unrelated to the current topic)

An **unwoke**, **gender-conscious** village follows a strange custom. They have babies only to have a **boy.** Whenever a boy is born in a family, they **stop** having babies and whenever a **girl is born**, they have a **baby again** and again untill a **boy is born**.

The **probability** of having a boy is same as the probability of having a girl, **P(B) = P(G) = 0.5.** What will be the **proportion of boys to girls** in the village after some time?

Tutorial Nuggets continued on page 22.

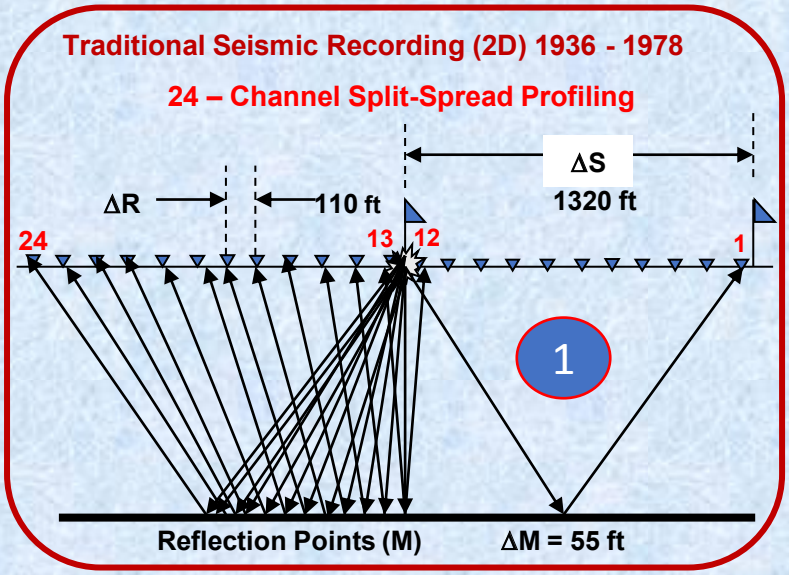
Tutorial Nuggets continued from page 21.

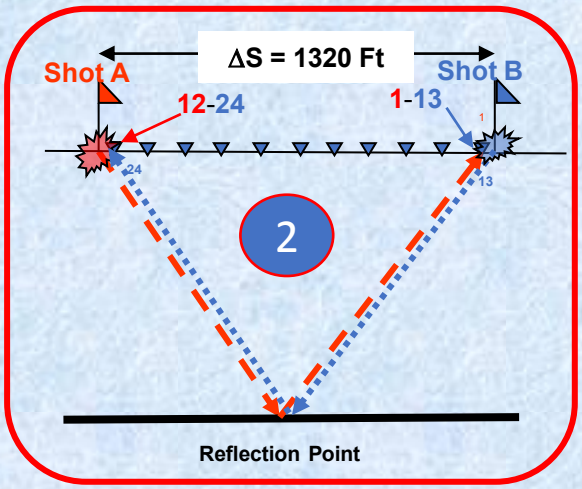
Easy Puzzle June

Puzzle: **(A)** Paul left home running for awhile, turned left and ran the same distance, turned left again, ran same distance, and repeated the left turn to return home where he was greeted by **2 masked men**, Who were they?

Answer: Clearly, Paul hit a homerun, so the welcome home team

(B) Lee Lawyer wrote in his **FTOS** column in **April**, that back in the **40's** and **50's**, when all seismic **interpretation was done on paper records**, the standard acquisition technique was done "**split spread**" (source in between middle channels (traces), **12 and 13 of 24** recorded channels spaced at **110 ft**. The next shot would be placed at the position just **55 ft** past where **trace 1** was and what had been channels **12-1** would become **24-13** of the **new recording**, with what had been **24-13** (the "back cable") would be moved forward to become the new traces, **12-1**. [Sketch it out]. **Why did they do it this way?** (So compelling that even **marine recording** was done the same way.) **How?**





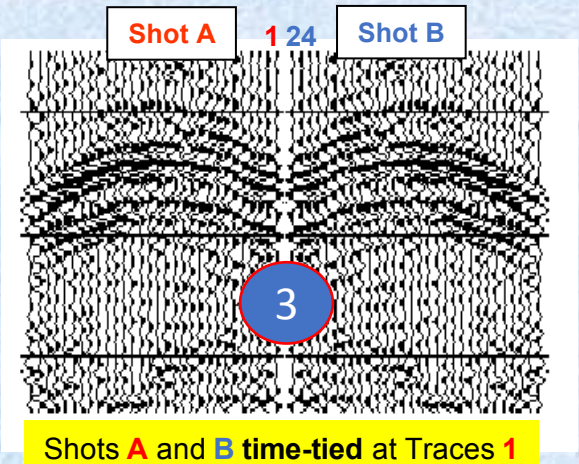


Fig. 1. This was the standard field configuration of cable layout and shot spacing in Lee's time (1940s and 50s) for land and marine (latter later).

Fig 2. Note that **channel 1** from the shot above coincides (closely) with the position of the next shot **(B).** This means they will have the same **static** and the **travel times** (including **NMO)** for trace **1** of shot **A** and trace **24** of shot **B**.

Fig 3. This results in time-tying the two paper records when adjacently displayed as shown here. While old timers only used times at 12-13, this assured the interpreter he was on the event.

GSH Outreach

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

62nd Annual Science and Engineering Fair of Houston

The Science and Engineering Fair of Houston (SEFH) is a world-class youth STEM program known to be the largest of its kind in Texas. It serves as the regional fair for all public, private, charter and home school Junior and High School students in Harris County and 22 surrounding counties throughout Southeast Texas. It is a wonderful platform for students to showcase their research ideas alongside with like-minded peers passionate about math, science, and engineering. In many cases, it is a student's first attempt to experience a major STEM event outside the classroom. Every project is judged by a number of reviewers who are experts in their subjects. The judges listen to their presentations and help select projects for awards and scholarships. GSH proudly supports this event as a Special Awarding Agency together with over 30 other professional societies and organizations in Houston.

Due to COVID restrictions, the event was held virtually from February 13 – March 3. New this year, the sixth grade was added to the Junior Division. A total of 696 exhibitors in grades 6 through 12 from 17 school districts showcased 616 research projects. They were requested to submit an abstract, notebook, PowerPoint presentation and an up to 7-minute video recording of their oral project presentation. Judges were able to view all items submitted but could not interact with the students.

Six GSH volunteer judges, working on their own, graded and reviewed projects deemed relevant to our professional interests. Then, they met via Zoom to discuss the best and determine which to award as first and second place. The judging committee selected 1st and 2nd place projects in the Junior (grades 6-8), and Senior (grades 9-12) divisions.

The GSH judging committee is proud to announce Special Award recipients and the titles of their research work:

Senior Division - 1st Place
Catherine Li, Academy of Science and Technology
Development of a bimodal life detection system for earthquake recovery via Doppler radar and machine learning

Senior Division - 2nd Place
Joyce Wang and Alisa Noro, Academy of Science and Technology
Assessing the Efficacy of Tsunami Mitigations Using Computational Fluid Dynamics

Junior Division - 1st Place
Kyla Dang, Brookside Intermediate School
Sturdiest Clay Types

Junior Division - 2nd Place
Braxton Allen, McCullough Junior High School
Sound Vs Humidity

The Awards Ceremony for the 2021 Science and Engineering Fair of Houston was held virtually on Saturday, March 10, 2021. *You can review the results online at* https://sefhouston.org/. The SEFH Winners tab has lists of Place Award Winners and Special Award Winners, and you can watch the awards ceremony recording from a link on the Home tab.

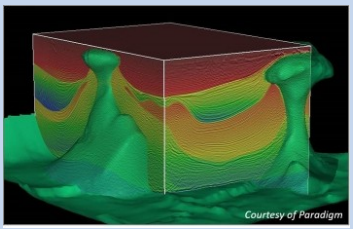
GSH mailed a letter of congratulations describing who we are to the students along with a Certificate of Accomplishment, *"Earth is calling … will you answer?"* poster brochure and Target gift card ($50 for 1st place; $25 for 2nd place).

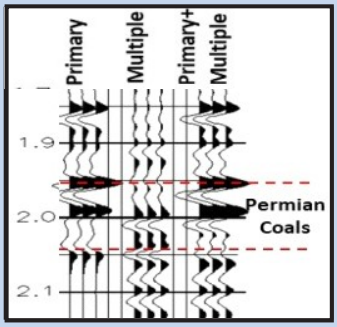
I would like to acknowledge the team of GSH judges who generously devoted hours of their time, diligently reviewing projects online and meeting via Zoom to select the winners. This year's GSH Special Awards Judges were Lisa Buckner (Judging Coordinator), Huw James, Peter Lanzarone, Ken Green, Mfon Udo-Imeh, and Courtney Anzalone.

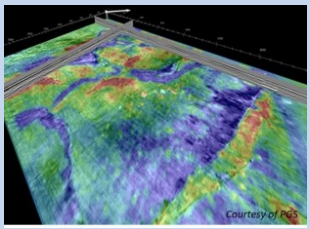
I would also like to take this opportunity to acknowledge Gokay Bozkurt for his help in recruiting judges, Kathy Sanvido for proving Zoom instructions, and Karen Blakeman for printing the certificates on special paper and mailing the award packets. They have been an integral part of this effort. Thank you! □

The GSH - SEG Webinar Series is Online

Access the recordings of these webinars originally presented live from the convenience of your home or office and according to your own schedule.







Title	Presenter
– Seismic Modeling, Migration, and Inversion	Bee Bednar
– Beyond AVO to Quantitative Inversion Interpretation QII	Bill Goodway
– Affordable S-Wave Reflection Seismology	Bob Hardage
– Simplifying and Lowering the Cost of S-Wave Reflection Seismology	Bob Hardage
– Carbonate Essentials	Chris Liner
– Basic Seismic Interpretation	Don Herron & Bob Wegner
– Basics and UPDATES on Anisotropy: Azimuthal P-P for better Imaging, Fractures & Stress Analysis Acquisition, Processing & Interpretation	Dr. Heloise Lynn
– Geophysical Signal Processing 101	Enders A. Robinson & Sven Treitel
– Seismic Amplitude 20/20: An Update and Forecast	Fred Hilterman & Mike Graul
– Extracting Geology from Seismic Data	Fred Schroeder
– Applied Azimuthal Anisotropy-Azimuthal 3D P-P Seismic: WHY Bother?	Dr. Heloise Lynn
– Understanding Seismic Anisotropy in Exploration and Exploitation	Leon Thomsen
– An Introduction to Borehole Acoustics	Matthew Blyth
– Topics in Land Seismic Data Acquisition, Processing, & Inversion	Oz Yilmaz
– Everything You Always Wanted to Know About Microseismic Monitoring	Peter Duncan
– Full-Wave Seismic Exploration: Acquisition, Analysis, & Applications	Rob Stewart
– Introduction to Applied Depth Imaging	Ruben D. Martinez
– The Interpreter's Guide to Depth Imaging	Scott MacKay
– Machine Learning Essentials for Seismic Interpretation	Tom Smith
– Modern Seismic Reservoir Characterization	Leon Thomsen
– Borehole geophysics: Using rock properties, well logs, & all kinds of seismic methods	Rob Stewart

View more details & access the recordings by visiting
seg.org/Education/SEG-on-Demand
then click on GSH/SEG Webinar Recordings on the right

The GSH 2021 Spring Symposium was held on April 27th and 28th and was an online only event, unlike all our other spring symposiums in year's past. This unfortunate consequences of current covid related events did mean we missed out on many of the traditional networking components of this event, but still allowed us to hold a very successful and well attended technical event that went off without a single technical glitch! Over the two days there were 8 technical presenters from a variety of companies, both Houston based and further afield, along with our keynote speaker from Chevron. The presentations were all live and followed by informative and open Q&A sessions. To try and break things up and to keep attendees engaged, we also had two unique lunch events. On the 27th we held the 2021 Gulf Coast Regional Challenge Bowl, where teams of students from regional universities tested their geophysical knowledge against each other to win a place at the global Challenge Bowl finals at the SEG this fall. Congratulations to the winning team from UT Austin! On the second day of the event, we announced the results of the GSH DSML SIG's Machine Learning Competition - "Geophysics in the Cloud". This event featured over 50 teams battling to come up with the best solution to the geophysical problem posed using machine learning tools. Thank you to AWS and Enthought who provided sponsorship for this competition! Lastly, I would like to thank everyone who attended the event, our speakers who made it a success and of course to our event sponsors listed below, who's kind contributions made the whole thing possible! Matt Blyth.

Thank you to our generous Sponsors!

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Spring Symposium continued on page 28.

Spring Symposium continued from page 27.

2021 GSH-SEG ONLINE SPRING SYMPOSIUM
Wrap-up

Jake Umbriaco - The Future of Petroleum Geoscience in a Digital World

Aria Abubakar - Deep Learning Applications for Automating Evergreen Subsurface Model Building

Elive Menyoli - Wavefield Separation Via Principal Component Analysis and Deep Learning in the Local Angle Domain

Tom Smith - The Scientific Universe from Square One to SOM

Jonathan E. Downton - Predicting Reservoir Properties from Seismic and Well Data Using Deep Neural Networks

Satinder Chopra - Some Machine Learning Applications for Seismic Facies Classification

Hugo Garcia - Automated Fault Detection from 3D Seismic Using Artificial Intelligence – Practical Application and Examples

Wenyi Hu - Progressive Transfer Learning for Low Frequency Prediction in Full Waveform Inversion

Yuting Duan - Estimation of Time-lapse Timeshifts Using Machine Learning

The Mystery Item
on page 18
is a
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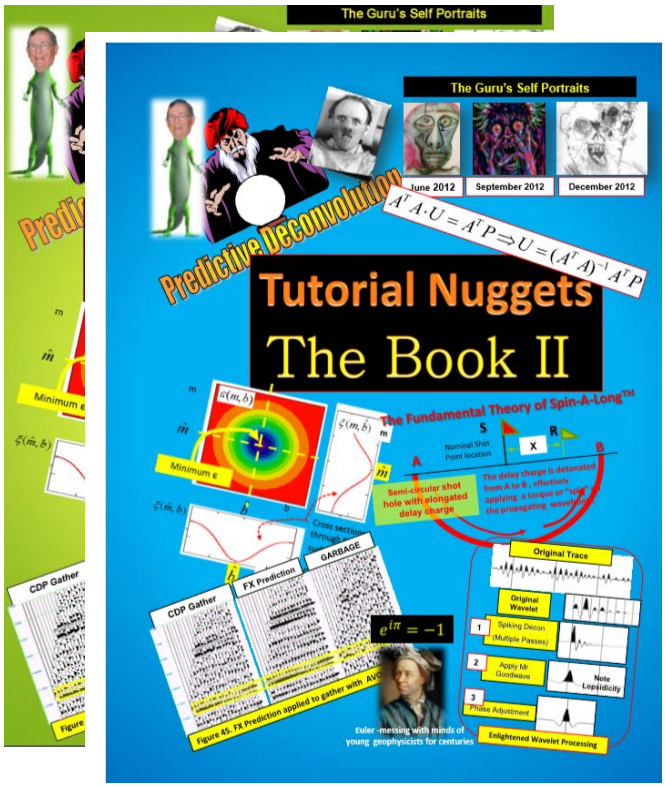

These just published, limited printing proof copy of the new industry standard for seismic theory (and other stuff) will surely be a valuable tool as well as a keepsake for your technical library!

$75

Member Price

Per the GURU...

Proceeds will be used to further scholarships, student memberships, educational outreach, and other activities of the Society.

2021 GSH GOLF TOURNAMENT

On Monday, April 12th, 2021, 30 teams of 4 competed in this year's Geophysical Society of Houston Golf Tournament held at the Woodlands Country Club Tournament course. I expected to see the course in great shape knowing that we would be the last group to play before the PGA made its annual stop to host the Insperity Invitational and I was not disappointed.

The day commenced with an enthusiastic crowd showing up to the course early for a bit of breakfast and some good ol' fashion face to face networking. After 3 delays and an eventual cancellation of the 2020 tournament, this year's event felt special. The energy was amazing, and it felt great to see all my fellow colleagues enjoying themselves as well.

The sun was shining and the bar was open, making for a great day of golf. It went especially well for our winners of the Steve Tyrrell Memorial Trophy, Team Cegal made up by… Matt Malouf, Pat Cauley, Pat Niemeyer and Mark Nicholls. Congratulations guys, heck of a round. I've heard some crazy stories about that traveling trophy, hopefully it makes it back in one piece.

The GSH also wants to thank all our volunteers this year: Josh Schonacher, Hunter Metoyer, Trenton Davis, Juan Flores and Rodney Lopez. You all did a wonderful job; the tournament could not have run smoother.

It was an honor to be a part of this special event and I'd like to send a special thanks to Phil Shear as well as the ladies at the GSH office, Kathy Sanvido and Karen Blakeman. Thank you again for your valuable contribution, your dedication and the spirt of teamwork you brought to this event. We should do it again this fall ☺ If not, I look forward to seeing everyone at next year's tournament.

Thanks again,
Wes

Wesley Tyrrell

Doodlebugger Diary

Black Magic in Geophysical Prospecting, Part 3

By L. W. Blau, Geophysics Department, Humble Oil & Refining Company

The Doodlebugger Diary recounts the experiences of geophysicists during their working lives. This month I am continuing to build on our January Doodlebugger Diary by Dan Plazak that discussed the early history of the term 'doodle-bugs', which was followed in March by Gene Sparkman's recounting of his early experiences with doodle-bugs. In April I started a 3-part series that reprints the very first article published in Geophysics in 1936. This month I submit part 3 for your amusement. I am particularly 'attracted' to Principle #5 and think it just might work if given the right subject matter.

If you have any similar stories you would like to share, please send them my way. I will be happy to print them. In the meantime, have a happy s ummer everyone!

Reprinted from *Blau, L.W, 1936, Black magic in geophysical prospecting: Geophysics, 1, 1-8, doi: 10.1190/1.1437076*

Principle #3: Substances do not attract according to Newton's law, that is the force of attraction is not proportional to the product of the masses and inversely to the square of the distance; the force of attraction is alleged to vary with the chemical constitution of the substances, and there appear to be grave doubts also to the effect that the exponent in the denominator is much, very much indeed, too large.

The idea that Newton's Law of Universal Gravitation does not hold has appeared in scientific literature; the subject was investigated by Eotvos and H. A. Wilson who found that the law holds to the limit of accuracy of their experiments, or to about one part in two million.

Having convinced himself that the oil attracts oil with greater force than anything else, one inventor provided himself with a small vial containing the "bait" oil; this he mounted at the end of a long slender rod the other end of which was provided with a beautifully engraved and chromium plated handle. Holding the instrument vertically with both hands on the handle, it was found that the "baited," swinging end came to rest in the direction of the greater oil fields; thus, it was possible to point out Conroe, East Texas, Sugarland, among others, from a room in a Houston hotel. When the "bait" was changed to whiskey, the device in the hands of the inventor stubbornly pointed to a leather bag lying on the bed; the inventor asked his friend how this could possibly be explained since they had finished the last bottle that morning and he had not bought more. Upon opening the bag, a pint bottle was revealed, and the friend admitted having bought it that afternoon without telling the inventor about it. Thus, it was proved that the device was not manipulated or influenced by the operator.

Another ingenious device operating on the same principle, was made by pouring a few drops of oil into a little vial, which was sealed and immersed in a bottle of transparent liquid. The bottle was then corked. When the inventor approached a can of oil standing on the ground, the vial was seen to descend in the liquid; on backing away from the oil can, the vial rose in the liquid to its former position. One could hardly refrain from asking for permission to make personal tests, but the inventor declined, because the instrument would work only for him and for nobody else. It was different in this respect, and perhaps in this respect only, from the ordinary Cartesian diver.

Two companion inventors discovered that if a bottle of oil was fastened to the end of a green sapling

Doodlebugger continued on page 35.

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***

Doodlebugger continued from page 34.

about six feet long and the other end held against the abdomen of one of them a distant oil field exerted a perceptible force on the bottle, pulling it in the direction of the field. The operator could then exert a force in the other direction, pulling the bottle back toward himself, after which the force from the field again became operative. An oscillation was thus built up and maintained, and the inventors had learned that each field had its own and characteristic period of oscillation. The periods had been determined for a large number of Gulf Coast fields. There was good reason for believing that these men were sincere and that they had done all this tedious work.

A Louisiana inventor built an instrument for sulphur finding. Delicately poised weights of sulphur were observed by means of an optical system; when everything was balanced one could read the direction of the sulphur deposit on a divided circle, the distance on a dial, and the depth could be calculated. The range of the device was 150 miles; the inventor was thus able to work approximately 70,000 square miles without leaving his office. An instrument for finding oil is now being developed against the time when all the sulphur shall have been discovered.

If Newton's law does not hold, it is a mistake to use torsion balances with gold weights. Salt masses ought to be used for finding salt domes; after these have been located it will be necessary to substitute sulphur masses to locate the sulphur deposits. The development work on this new type of torsion balance has been done in Europe; at the present time, attempts are being made to extend the principle to oil finding, but it has been reliably reported that no usable container for oil has yet been found. It seems that all solids thus far tried for containers cancel the force of attraction between the oil in situ and the oil sample in the bottle. It is apparent that this device will be extremely valuable if the difficulties can be overcome.

This sketch is satirical, but it may have been inspired by the doodlebug of Houston oil pioneer Peyton Standifer Griffith ("Consider the doodlebug," *Natural Gas*, Sept. 1922, v.3 n.9 p.18.).

Figure 1: This is Figure 1 from Plazak (GSHJ Doodlebugger Diaries, Jan 2021). It is similar to the techniques discussed in Principle #4 in this article.

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Doodlebugger continued from page 35.

Principle #4: oil and gas send out electromagnetic waves, which can be received with a sufficiently sensitive and properly tuned radio receiver.

Claims are made that very short radio waves penetrate through great depths of ground and are copiously reflected from oil and gas sands. No definite information about the wavelengths used seems to be available, but they are alleged to be very short.

Two inventors appeared with a box on which was mounted a glass tube containing a red liquid similar to the fuel gauge on automobiles. A pair of aluminum chains was attached to each of two opposite sides of the box; one pair of chains had a conical aluminum cup fastened to the end of each chain while brass rods were attached to the ends of the other chains. One of the inventors took a cup in each hand, while the other held the rods and pushed against the cups with a rod inserted in each cup. The deeper the oil, the more the men had to push against each other; it was explained that the intensity of the electromagnetic waves sent out by the little box depended upon the force exerted between the brass rods and the aluminum cups. When the waves reached the oil or gas sand, the red liquid began to rise; the height to which it rose depended upon the thickness of the oil sand, and gas sands had been found to give a smaller effect than oil sands. The men estimated the depth of the sand from the force which they had exerted; it is remarkable that they were thus able to give depths to a few feet in several thousand.

A better device was built by a young man who discovered that the short electromagnetic waves emanating from oil and gas sands could be caused to modulate the wave of a radio transmitter; the modulated wave actuated a loudspeaker. It was the thrill of a lifetime to drive to an oil field with everybody quiet, hardly able to bear the suspense, and not a sound coming from the loudspeaker. Upon reaching the first producer, a faint scratching could be heard which was soon followed by a gurgling sound, caused, so said the inventor, by the flowing of the oil in the pool. Upon driving toward the middle of the field, the gurgling became more distinct, then fainter, and ceased altogether on top of the field; soon, however, a hissing noise was heard which was due to the gas in the gas cap! The device was perfect; there was no chance for misinterpretations because no other substances gurgled or hissed. Salt water gave no sound whatever. Also, the waves emerged vertically, so that one could be sure that the oil was directly below the instrument when the gurgling was heard.

What seemed like a similar device, perhaps utilizing the same principle, was offered for sale by two foreigners. They connected their radio receiver to a telephone bell; when the receiver was vertically above the oil the bell rang and kept on ringing until the field had been crossed. This scheme is inferior to the previous one because it does not permit of differentiation between oil and gas.

Another invertor used a short-wave transmitter and a wire, about 100 feet long, which was laid on the ground as an antenna. He stated that he had difficulty in Oklahoma at times, because the rocks were too hard and dry; in the Gulf Coast there was no trouble on account of the soft and water-logged sediments. There were three dials on the little beautifully finished box: one indicated resistance, the next capacity, and the third the battery voltage. The dials were adjusted until a standing wave was set up between the transmitter and the oil sand. The three readings of the resistance, capacity and voltage were then multiplied to give the depth of the sand in feet.

Principle #5: organic substances exhibit sexual characteristics; sex, being one of the stronger emotions, can therefore be very profitably exploited in oil prospecting if the proper techniques employed.

It is not known how a certain investigator discovered that oil exhibits female characteristics; be that as it may, he alleged that oil was essentially female. Having made this startling discovery, he began a search for a male substance, preferably a liquid, which could be used in finding oil. After many years of painstaking investigation, he found such a liquid; he had a jug full of it, filled to the stopper. The presence of oil was shown by the response of a suitably connected indicator. □