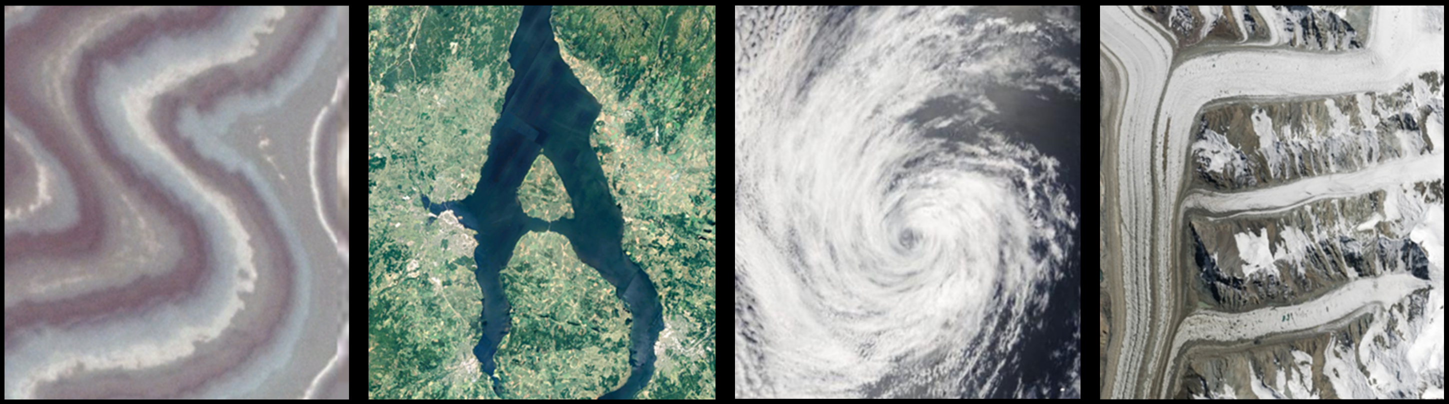
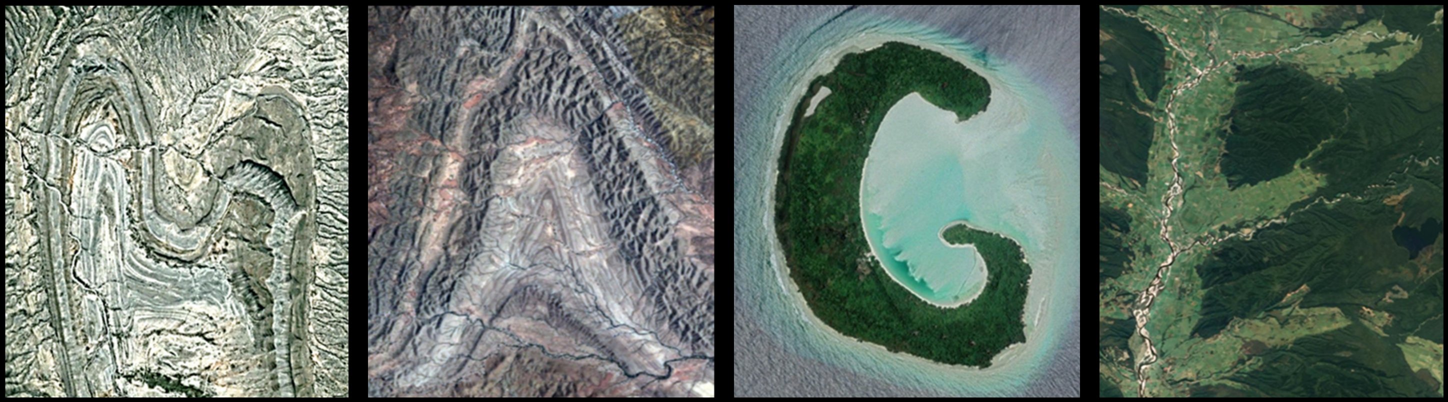
SAGEMAGE

SAGE Magazine of Applied Geoscience & Engineering

MARCH 2022 • VOL. 1 • NO. 1





News and Commentary

- About SAGE
- SAGE 2022 Convention, 23–25 March, Lafayette, LA, and Virtual
- SAGEkids & SAGEteens Initiative

Featured Articles

- A Primer on CCUS Laws in Louisiana
- The Submergence of Fort Proctor
- New Insights into Alaskan Permafrost via Rock Volatiles Stratigraphy

SAGE
Society of Applied Geoscientists & Engineers

sagetech.org

SPECIAL CORNERSTONE MEMBERSHIP

From Friend ($20) to Diamond ($5000+), your contribution helps support our activities, especially our K–12 SAGEkids & SAGEteens initiative, student research grants, publications, and more. Open to members, non-members, corporations, and organizations. Please visit sagetech.org for details.

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Willis School of
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AdvancedHydrocarbon.com

GOLD

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SAGE ACADIANA CHAPTER
Society of Applied Geoscientists & Engineers Lafayette, Louisiana

AAG Association of Applied Geoscientists
Linking Geoscience with Application

LISKOW&LEWIS

Lafayette Geological Society
Founded December 1952
Lafayette, Louisiana

STRATAGRAPH

A. Summerfield

apt Applied Petroleum Technology

BRONZE

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Terry Lolan Mattalino
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Harris Pantlik
Brian Brennan
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Glenn Bixler
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From the musings in one's own mind to the fun of forming a new "club" with some dear friends and colleagues to the reality of organizing a new international professional society, it has been truly an amazing and enjoyable adventure.

A common question asked of me is "Why?" My response is typically "Why not?" Our group felt that a need existed that was more focused on an applied-based niche but with a broadened membership of geoscientists and engineers, while deemphasizing financial gain. Of course, organizations need funding to exist but should be mindful of waste. As such, SAGE organized to be member focused, running lean and trim with full financial transparency, to serve our mission of promoting and advancing the applied geoscience and engineering professions through research, scholarship, and enjoyment, wherein our members, sponsors, and benefactors can clearly see and appreciate where resources are being utilized.

Apparently, people are agreeing with our conceptualization and mission statement, as our formal membership and social media presence continues to grow, including many U.S. states and countries, through primarily grass roots efforts and natural growth.

SAGE is excited to be hosting our inaugural convention, SAGE 2022, later this month (23–25 March) in Lafayette, Louisiana, and Online. There's even still time to take advantage of our early-bird rates. Our convention fees echoes my earlier statement about seeing where the money goes. In-person non-member fees ($250) includes a diverse and robust technical program on energy, CCUS, legal, and other applied geoscience/engineering topics with a conference proceedings volume (the *SAGE Record*) of papers, extended abstracts, and abstracts, but includes an Icebreaker food and drink extravaganza (welcome champagne, extra drink tickets, multiple pass-through hors d'oeuvres, meat carving station, pasta station, and even an oyster bar!), complimentary lunches on both days, President's Reception/Happy Hour, and more! Of course, there's a member discount, but for non-members the fee difference is the same as member dues, and thus includes complimentary 2022 membership. Rewarding speakers for their efforts in providing content, there's a big speaker discount too! Student members who are presenting pay $0 to attend our event! Similar benefits apply to our virtual attendees and speakers, starting from a base fee of $75 for non-presenting non-members, with $25 of that applied to complimentary 2022 membership.

I am also really excited about our developing initiatives, especially our K–12 SAGEkids & SAGEteens program and our publications, including our quarterly (for now) *SAGE Magazine of Applied Geoscience & Engineering* (*SAGE MAGE*), but also our conference proceedings, the *SAGE Record*, and planned open access, peer reviewed publications.

If you are interested in joining our organization, we have three membership tiers, Professional, Associate, and Student (which includes casual learners and hobbyists), at reasonable rates (see Page 4 or visit sagetech.org). We are ready to welcome you aboard!

If you are interested in volunteering, starting a professional or student chapter, etc., please feel free to reach out to me at james.willis@sagetech.org (or jwillis3@lsu.edu).

Sincerely,
James Willis, SAGE President

COVER CREDITS

All images used on the cover of this issue of the *SAGE MAGE* are courtesy of Google Earth®, except the first "G," which is courtesy of Zoom Earth.

S—Folded evaporites from a salt dome in Iran. 34°50'49"N, 53°46'58"E.
A—Lake Mjøsa, Norway. 60°44'N, 10°59'E.
G—Tropical Storm Douglas, July 4, 2014, Eastern Pacific. 21°42'N, 118°18'W.
E—South Inylchek and feeder glaciers, Tien Shan Mountains, Kyrgyzstan. 42°08'N, 80°03'E.
M—Subsidiary folding on plunging nose of anticline, Mexico. 27°08'N, 101°54'W.
A—Plunging syncline, South Australia. 30°49'S, 138°59'E.
G—Eriyadhoo Island, Maldives. 6°06'12"N, 73°17'10"E.
E—Grey River and tributaries near Ahaura, New Zealand. 42°21'S, 171°32'E.

SAGE Society of Applied Geoscientists and Engineers, Inc.

The Society of Applied Geoscientists and Engineers, Inc. is a nonprofit 501(c)(6) professional organization whose mission is to advance the applied geoscience and engineering professions through research, scholarship, and enjoyment.

In 2019, a small group of individuals started the Association of Applied Geoscientists (AAG, www.applied-geoscience.org), with highlights being field trips and sponsoring GeoGulf 2020 and AAPG ICE 2020. AAG remains active today under the SAGE umbrella, with a focus on publishing *Applied-Geoscience*, our open access, peer reviewed journal linking geoscience with application.

Recognizing the need for inclusion of our engineering colleagues, our group later expanded and officially incorporated in 2021 as the Society of Applied Geoscientists and Engineers, Inc., a nonprofit 501(c)(6) professional organization.

SAGE is hosting its first conference and exposition, SAGE 2022, March 23–25, in Lafayette, LA, and Virtually. We have a diverse program with multiple concurrent hybrid sessions, including energy studies, CCUS, and other applied geoscience and engineering topics (please see Page 5 and/or sagetech.org for details). As part of the "enjoyment" within our mission, in-person registrants will be treated to an Icebreaker to remember on the 23rd, with welcome champagne, additional cocktail tickets, multiple hors d'oeuvres, carving station, pasta station, and an oyster bar (!!); complimentary buffet lunches featuring fried catfish (24th) and fried shrimp (25th) and additional entrées, vegetable selection, salad bar, and dessert selection; President's Reception and Happy Hour on the 24th with more food and drink; and a multi-course Awards Banquet Dinner on the 24th, honoring Mr. Frank Harrison, Jr., as our inaugural SAGE Legend Awardee and other honorees. One of our door prizes is a custom labeled bottle of whiskey!

Registration for SAGE 2022 is now open via sagetech.org, so hope you can join us and pass a good time in Lafayette or online! All non-member registrations include complimentary 2022 membership in SAGE.

Another facet of SAGE's mission is research and as such in addition to conferences and symposia, with our *SAGE Record* conference proceedings volume and Special Publication volumes, SAGE will also be publishing multiple peer reviewed, open access journals, including the aforementioned *Applied-Geoscience* journal, as well as the *Journal of Energy Geoscience and Technology* and the *Journal of Downhole Technology and Geoscience*. We are also planning to publish journals focused on our K–12 SAGEkids and SAGEteens efforts.

While we started off as a small gathering of friends and colleagues, we have big plans, especially our K–12 SAGEkids and SAGEteens initiative, and hope that you consider joining us.

(*Continued on Page 29*)

MEMBERSHIP LEVELS AND DUES

Professional, $25 • Associate, $25 • Student, $10

Our distinguished Cornerstone Membership is also open for members, non-members, corporations, and organizations for Special Recognition in supporting SAGE, especially our K–12 SAGEkids & SAGEteens initiative, student research grants, and more.

SAGE2022

Society of Applied Geoscientists & Engineers ◊ 23-25 Mar. 2022 ◊ Lafayette, LA, and Virtual

Registration is NOW OPEN

Registration is now open for our first international conference, **SAGE 2022**, a **hybrid event** of both speakers and attendees focused on aspects of Applied Geoscience and Engineering. With multiple concurrent hybrid sessions, with post-convention on-demand access to presentations for all attendees, come join us and enjoy some Cajun hospitality with our Icebreaker event on Wednesday evening, Complimentary Lunches on both Thursday and Friday, and Happy Hour on Thursday evening.

- All-Convention Luncheon featuring Louisiana Attorney General Jeff Landry, as well as a diverse array of additional Keynote Presentations
- Multiple Concurrent Hybrid Sessions, featuring energy, CCUS, land/legal, and additional applied geoscience and engineering topics
- Post-Convention On-Demand Access to Presentations (Speakers Permitting) for All Attendees
- Digital Copy of the *SAGE Record* Conference Proceedings Volume
- Continuing Education Short Course and Field Trip (Field trip is SOLD OUT!)
- Student Poster Session and Expo
- Exhibits and Prospects
- Lots of Food and Drink, with Icebreaker, Complimentary Lunches, Coffee Breaks, Happy Hour, and Awards Banquet Dinner (with special guest Mr. Frank Harrison, Jr., recipient of our Legend Awardl)
- Golf Tournament
- And More!

Registration Costs (by March 18)*

Professional Early-Bird: $175 to $250*
Professional Virtual Early-Bird: $0 to $75*
Student Early-Bird: $0 to $75*
Student Virtual Early-Bird: $0 to $40*

*Member discount and/or speaker discounts apply. Non-member registrations include complimentary SAGE membership dues for 2022.

Co-Hosted by:

Lafayette Geological Society
Founded December 1952
Lafayette , Louisiana

www.sagetech.org

Sponsorship Opportunities Available

We have great sponsorship opportunities with even Bronze ($500) level including complimentary in-person (1) or virtual (2) registrations!

SAGE2022

Society of Applied Geoscientists & Engineers ◊ 23–25 Mar. 2022 ◊ Lafayette, LA, and Virtual

Special Presentations

SAGE All-Convention Luncheon Presentation

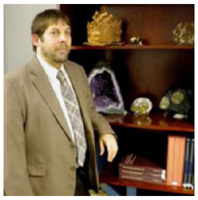
Jeff Landry
Attorney General, State of Louisiana,
Baton Rouge, Louisiana

"Louisiana Law"

Lafayette Geological Society Energy Luncheon Presentation

Sarah E. Stogner, Esq.
STOGNER LEGAL, PLLC,
Monahans, Texas

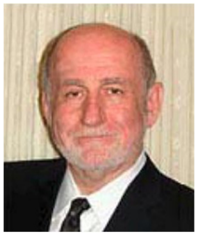
"Ushering in the Next Era of Texas Energy Independence"



SAGE Applied Geoscience Keynote Presentation

James J. Willis, Ph.D
SAGE President/WSAG/LSU

"Applied Geoscience through Time: How the 1761 Transit of Venus Led to Subsurface Contour Mapping with Energy and CCUS Applications"



SAGE Engineering Keynote Presentation

William K. (Bill) Ott, P.E.
Well Completion Technology,
Houston, Texas

"Sand Control Method Selection"

SAGE Acadiana Chapter Keynote Presentation

Lindsay Longman, Sr., P.E.
SAGE Vice President of Engineering/
Engineering Consultant, Maritime &
Continental, LLC, Lafayette,
Louisiana

"Musings on Gulf Coast CCUS—A Drilling Engineer's Perspective"

SAGE Libya Chapter Keynote Presentation

Salah S. El-Ekhfifi
National Oil Corporation of Libya,
Benghazi, Libya

"Foraminifers: A Bioindicator to Monitor Marine Pollution in North Africa"

SIPES Lafayette Chapter Keynote Presentation

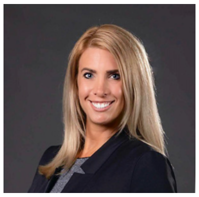
George Vassilellis and Ewert Munoz
Insight-Pegasus, The Woodlands,
Texas & Austral Integrated
Services, Inc., Conroe, Texas

"Upstream Integration for Independents"

Southwest Louisiana Geophysical Society (SWLGS) Keynote Presentation

Rui Zhang
University of Louisiana at Lafayette

"Direct Shear-Wave Seismic Survey in Sanhu Area, Qaidam Basin, West China"



Keynote Presentation

Dawn Porter
Stratum Reservoir, Midland, Texas

“Who Owns the Pore Space? Legal and Ethical Debates for Geologic Sequestration of CO_2”

Keynote Presentation

Jeffrey D. Lieberman
Liskow & Lewis, Lafayette, Louisiana

“An Introduction to CCUS Laws and Regulations”

Keynote Presentation

Ian Ussery, Brody Friesenhahn, and Sam Yun
U.S. Environmental Protection Agency, Region 6, Dallas, Texas

“Class VI Permitting Process”

Keynote Presentation

Mike Eros
Sage Geosystems, Houston, Texas

“Advanced Geothermal Technologies Applied to Geopressured Formations: The Gulf of Mexico, USA”

Technology Focus Presentation

Jacob McCreless and Richard Barr
Proserv, Houston, Texas &
Proserv, Aberdeen, Scotland, U.K.

“Subsea Sampling”

Come Join us at our 2022 Awards Banquet Dinner Honoring:

LEGEND AWARD

Frank W. Harrison, Jr.
Optimistic Energy, LLC
Lafayette, Louisiana

SPECIAL COMMENDATION AWARD

Michael P. Smith
Advanced Hydrocarbon Stratigraphy
Tulsa, Oklahoma

SAGEkids
SAGEteens

Society of Applied Geoscientists & Engineers Investing in Our Future

SAGEkids & SAGEteens is our major initiative to advance applied geoscience and engineering, including advancing diversity, equality, and inclusivity, by focusing efforts on the true future of our professions by engaging kids and teens through various means, including:

- Online Resources
- Guest Lectures and Visits
- Student Mentoring
- Student Chapters
- Science Fairs
- Science Kits
- Scholarships
- etc.

WE NEED YOUR HELP!! If you are interested in volunteering, mentoring, sharing ideas, providing support, developing K–12 chapters, etc., please contact us at sagekids@sagetech.org (primary schools) or sageteens@sagetech.org (secondary schools). We are especially interested in volunteers and mentors to engage underrepresented or underprivileged groups—children and minors that can see themselves in volunteers and mentors become more interested and engaged.

Help Support our SAGEkids & SAGEteens Initiative

Please consider joining our Cornerstone Membership to help support our SAGEkids & SAGEteens initiative and other activities as an individual, corporation, or other entity. Cornerstone Membership is separate from our professional/associate/student membership. Please visit sagetech.org for details.

As part of SAGE's mission to foster research, scholarship, and enjoyment of the applied geoscience and engineering fields, we are developing a series of publications, including the *SAGE MAGE*, our quarterly newsletter magazine; the *SAGE Record*, our conference proceedings volume*; Applied-Geoscience*, an open access, peer reviewed publication linking geoscience to application; the *Journal of Energy Geoscience & Technology*, an open access, peer reviewed journal on energy studies; the *Journal of Downhole Engineering & Geoscience*, an open access, peer reviewed journal on downhole studies; a Special Publication volume series; a Memoir volume series; *SAGEkids Research* & *SAGEteens Research*, our journals highlighting K–12 research; and more to be announced as we continue to build our Society.

SAGE MAGE

The *SAGE Magazine of Applied Geosciensce and Engineering (SAGE MAGE)* serves as our newsletter to convey SAGE news and updates, chapter and member highlights, cornerstone membership listing, short articles, news from other organizations, and more. *SAGE MAGE* will be published initially on a quarterly basis with this issue being our first. For more information, or if interested in contributing material or advertising, please contact us at sagemage@sagetech.org.

SAGE Record

The *SAGE Record* serves as our conferences proceedings volume with volume 1 to be published as part of our upcoming SAGE 2022 conference and exhibition to be held in Lafayette, Louisiana, March 23–25, as a hybrid event for speakers and attendees.

Applied-Geoscience

AAG Association of Applied Geoscientists

Linking Geoscience with Application

The Association of Applied Geoscientists (AAG), a companion organization under the SAGE umbrella, is now inviting submissions to *Applied-Geoscience*, a new open access, peer reviewed journal focused on linking geoscience with application or vice versa. For more information, please visit www.applied-geoscience.org or email Norman Rosen, *Applied-Geoscience* Editor, at publications@applied-geoscience.org if interested.

(Continued on Page 30)

Optimistic Energy, LLC

CRPlus & Associates

A. Summerfield

Travis A. Helms

Tim Rynott

SAGE ACADIANA CHAPTER

Society of Applied Geoscientists & Engineers Lafayette, Louisiana

Serving southern Louisiana and the heart of Cajun culture, where many of the founding members of SAGE live and operate, the SAGE Acadiana Chapter is serving as an official co-host, along with the Lafayette Geological Society and the Association of Applied Geoscientists, of the upcoming SAGE 2022 conference, March 23–25, in Lafayette and Virtually.

The SAGE Acadiana Chapter recently organized a joint meeting and presentation with the Lafayette Geological Society (LGS) and the Lafayette Chapter of the Society of Independent Professional Earth Scientists (SIPES) at the Petroleum Club of Lafayette on December 15, 2021.

Our guest speaker was Mike Smith, Ph.D. of Advanced Hydrocarbon Stratigraphy, Tulsa, Oklahoma, who presented “Cuttings Volatiles: Produce More Oil, More Gas, and Less Water.” With the lead off sentence of the abstract being “Cuttings are the Rodney Dangerfield of the oil patch—they get no respect,” the attentive audience really appreciated the concepts and likely gave those cuttings some real respect, especially with some case histories using decades-old cuttings but with modern analyses yielding valuable results.

Thanks are extended to Joe Morris, LGS President, and King Munson, SIPES Lafayette Chairman, for helping organize this event.

Mike will be returning to Lafayette for SAGE 2022, along with other members of the AHS group, including Chris Smith, who collectively will be presenting various topics relating to Rock Volatiles Stratigraphy. Mike is also the recipient of a Special Commendation Award.

ADVERTISE IN THE *SAGE MAGE*

The *SAGE Magazine of Applied Geoscience and Engineering* (*SAGE MAGE*) serves as our newsletter to convey SAGE news and updates, chapter and member highlights, cornerstone membership listing, short articles, news from other organizations, and more. *SAGE MAGE* will be published initially on a quarterly basis with our first issue published in March 2022.

ADVERTISEMENT COSTS

- Business card, $20 per issue or $50 per year*
- Quarter page, $50 per issue or $150 per year*
- Half page, $80 per issue or $250 per year*
- Full page, $120 per issue or $400 per year*

*Current yearly agreement includes 4 issues (3 quarterly 2022 issues and 1 quarterly 2023 issue). Non-profits receive 50% discount. No cost reciprocal organizational event listings are also available. Contact us at sagemage@sagetech.org for more details.

SAGE LIBYA CHAPTER

Society of Applied Geoscientists & Engineers Benghazi, Libya

SAGE is pleased to announce the chapter initiation process for our first international chapter, Libya, spearheaded by the efforts of Salah S. El-Ekhfifi, an exploration geologist with the National Oil Corporation of Libya.

Salah S. El-Ekhfifi

Mr. El-Ehkfifi has been of instrumental help with organizing a session of SAGE 2022 focused on Libyan geoscience and engineering and/or by Libyan geoscientists and engineers. The current speaker list includes a keynote presentation by Mr. El-Ekhfifi, "Foraminifers: A bioindicator to Monitor the Marine Pollution in North Africa"; Dr. Nuri Mohamed Fello, "Geopark Features and Characteristics in Libya"; Khaled S. Amrouni, Michael C. Pope, Ahmed S. El-Hawat, Ahmed M. A. Al-Alwani, Mohamed SH. Abdalla El-Jahmi, Hassan S. El-Bargathi, Adel A. Obeidi, Aimen Amer, Essa A. Elbileikia, and Salah S. El-Ekhfifi, "Analogues of Complex Carbonate Reservoirs from the Cyrenaican Miocene Carbonate Sequences, NE Libya"; Khaled S. Amrouni, Michael C. Pope, Ahmed S. El-Hawat, Salah S. El-Ekhfifi, Hassan S. El-Bargathi, Adel A. Obeidi, Aiman Amer, and Essa A. Elbileikia, "Global and Local Geo-Chemo-Stratigraphic Events in the Cyrenaican Miocene Carbonate Platform Ar-Rajmah Group (Central Mediterranean), NE Libya"; Ibrahim M. Abou El Leil and Ali M. Elfeituri, "Estimation of Reservoir Petrophysical Properties by Using Gas Well

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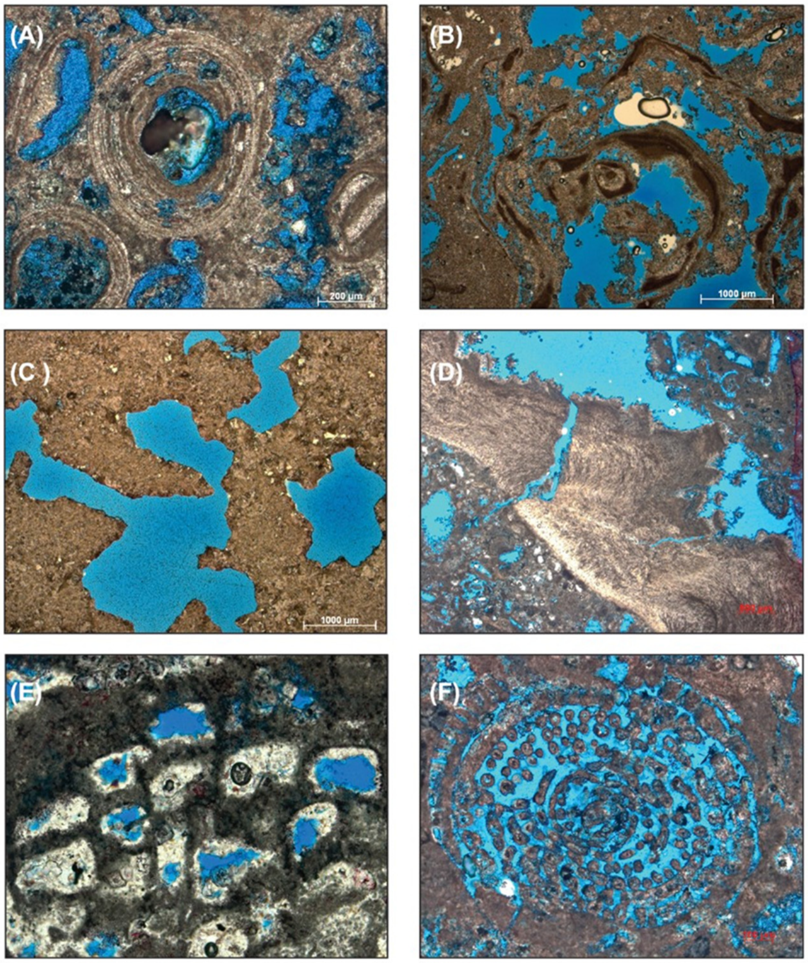

Sample illustration from Khaled S. Amrouni, Michael C. Pope, Ahmed S. El-Hawat, Ahmed M. A. Al-Alwani, Mohamed SH. Abdalla El-Jahmi, Hassan S. El-Bargathi, Adel A. Obeidi, Aimen Amer, Essa A. Elbileikia, and Salah S. El-Ekhfifi, "Analogues of Complex Carbonate Reservoirs from the Cyrenaican Miocene Carbonate Sequences, NE Libya" paper in the upcoming *SAGE Record* conference proceedings volume, showing photomicrographs of the porosity types observed in the Miocene carbonate sequences of northeastern Libya. (A) Oomoldic porosity in oolitic grainstone facies. (B) Biomoldic porosity in coralline red algal facies. (C) Fenestral porosity in microbial facies. (D) Fracture and biomoldic porosity oysters in coralline red algal facies. (E) Frame-growth porosity in bryozoan in coralline red algal facies. (F) Biomoldic porosity in forams in the coralline red algal facies.

Terry Lolan Mattalino

Lindsay Longman, Sr., P.E.

Harris Pantlik

A Primer on CCUS Regulation in Louisiana

Jeffrey D. Lieberman
Liskow & Lewis, Lafayette, Louisiana, USA

JEFFREY D. LIEBERMAN is an energy lawyer practicing in the Lafayette office of Liskow & Lewis. His practice includes title, conveyance, unitization, permitting, and regulatory issues involving oil and gas, renewables, and CCUS. Jeff regularly appears before the Louisiana Commissioner of Conservation and the State Mineral and Energy Board in Baton Rouge. He received his Law Degree, *magna cum laude*, from Louisiana State University in 2008, where he was a member of the *Louisiana Law Review*.

Carbon capture, utilization, and storage (CCUS) projects involve various legal issues. Like traditional exploration and development, CCUS projects require the operator to secure both the necessary private property rights from landowners as well as regulatory approval from the appropriate administrative agency in order to proceed. This article focuses on the latter.

Regulatory approval for CCUS falls under two broad categories—namely, agency approvals related to enhanced hydrocarbon recovery and those related to geologic sequestration. Both categories are regulated by the Office of Conservation within the Louisiana Department of Natural Resources.

Enhanced Recovery

Use of carbon dioxide for enhanced hydrocarbon recovery requires the creation of a unit by the Commissioner of Conservation for the purpose of secondary or tertiary recovery under La. R.S. 30:5(C)[1]. However, pilot programs can be available to allow the commencement of an enhanced recovery project prior to creation of the unit.

Any order approving such a unit operation shall be issued by the Commissioner only after notice and public hearing and shall be based on findings that: (a) the order is reasonably necessary to prevent waste and the drilling of unnecessary wells, and will appreciably increase the ultimate recovery of oil or gas; (b) the proposed unit is economically feasible; (c) the order will allocate to each separate tract within the unit a proportionate share of the unit production; and (d) at least three-fourths of the owners and three-fourths of the royalty owners have approved the plan and terms for unit operation. The order creating the unit will also name a unit operator and allocate unit costs in the same proportion that unit production is allocated.

In addition to the unit order, the operator must receive approval for its injection wells. Oil and gas related injection wells are considered Class II wells and are regulated by the Underground Injection Control (UIC) program within the Office of Conservation, which has achieved primary enforcement authority under the applicable federal guidelines. The pertinent regulations are in Statewide Order No. 29–B[2] and address permitting, construction, operations, monitoring, testing, reporting, and closure for Class II wells.

Geologic Sequestration

Geologic carbon sequestration requires approval of a storage facility under the Louisiana Geologic Sequestration of Carbon Dioxide Act (La. R.S. 30:1101–1111)[3]. Approval of a storage facility is not the creation of a unit. Rather, it is the approval to use a specific reservoir for injection and storage of carbon dioxide.

Approval of a storage facility by the Commissioner requires notice and public hearing and shall be based on findings that: (a) the reservoir is suitable and feasible for the project; (b) the reservoir is

(*Continued on Page 29*)

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[1] https://www.legis.la.gov/legis/Law.aspx?d=87579
[2] http://www.dnr.louisiana.gov/index.cfm/page/62
[3] https://www.legis.la.gov/legis/Law.aspx?d=670787

The Submergence of Fort Proctor

Chris McLindon
McLindon Geosciences, Mandeville, Louisiana, USA

Fort Proctor is a pre-civil war military installation on the shore of Lake Borgne, southeast of New Orleans (Figs. 1 and 2). Historical records state that the fort was constructed 150 feet inland from the shore of the lake just north of the mouth of Bayou Yscloskey. This was also the site of Proctorville, a rail depot at the terminus of the Shell Beach Branch of the New Orleans and Gulf Railroad, which ran along the east bank of the Mississippi River to the town of Poydras, then down the natural levees of Bayou Terre aux Boeufs, Bayou La Loutre, and Bayou Yscloskey to the shore of Lake Borgne. While it can logically be assumed that the original elevations of the fort and the railroad depot were necessarily at least a few feet above sea level, neither of the architectural studies of the fort conducted by Tulane Uiversity or Louisiana State University (LSU) appear to include any definitive values for the land elevation at the time of construction.

CHRIS MCLINDON was employed as an exploration geologist in the oil and gas industry between 1980 and 2020. He received a B.S. in Geology from the Louisiana State University in 1979. Chris has worked for several companies in the New Orleans area including Stone Energy, McMoRan Exploration, and Helis Oil, as well as being self-employed for several years. Chris is currently the manager/member of McLindon Geosciences, LLC in Mandeville, LA. He is a past-president of the New Orleans Geological Society and a member of the Geological Society of America, the American Geophysical Union, and the Society of Independent Professional Earth Scientists. Chris was named to an oversight position for the Louisiana Coastal Geohazards Atlas Project by Dr. Charles Groat of the Louisiana Geological Survey in 2018. In that same year, he was the recipient of the Gulf Coast Association of Geological Societies Statesmanship Award in recognition of work associated with the atlas project.

The fort is about 1000 feet from the Shell Beach Continuously Operating Reference Station (CORS) of the National Geodetic Survey (Fig. 3). This station is a part of the Global Navigational Satellite System that provides data for the 3D Global Positioning System (GPS) network. In addition to surface positioning data, this station provides a measurement of the vertical movement of the earth's surface, which in this case can be used to estimate a rate of subsidence.

Figure 1. Fort Proctor (photo credit, Marco Rasi).

Evaluation of data from the Shell Beach CORS by the LSU Center for GeoInformatics indicates a current rate of subsidence at this location of about 6.263 millimeters per year (mm/yr) or about 2.5 inches per decade (Fig. 4). The premise of the illustrations of the impacts of subsidence over time that follow is that this subsidence rate can be used to estimate the elevation of Fort Proctor at various points of time in the past relative to its current elevation. This relative approximation is made without knowledge of the absolute value of the elevation at any time. If data for the elevation of the fort at some point of time in the past were known, it could be used to calibrate the estimated relative rates of change based on current subsidence data.

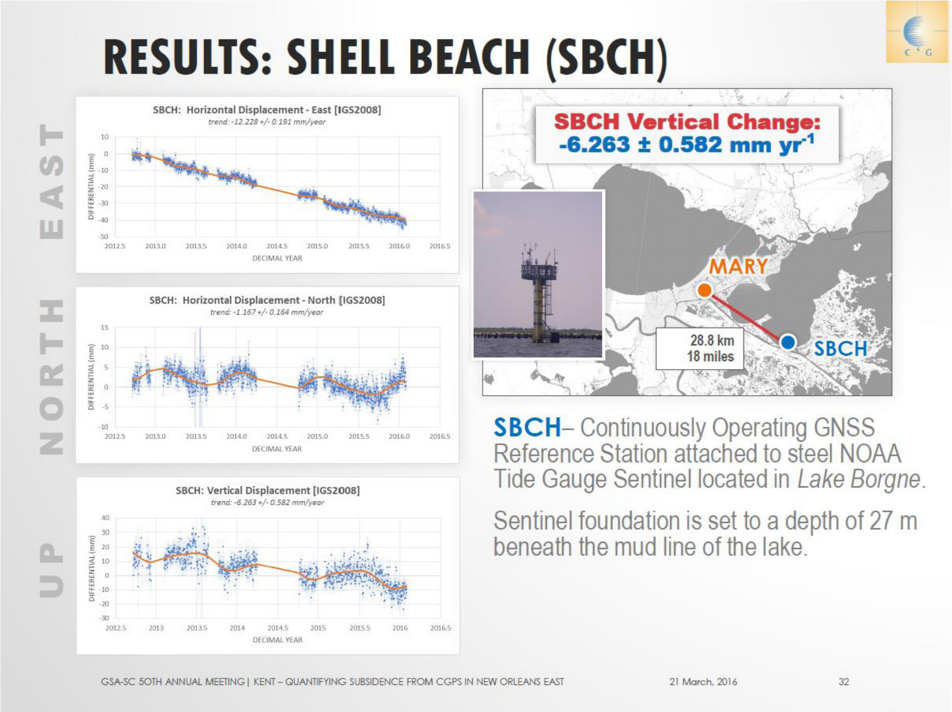
An elevation profile of the fort taken from a Historic American Building Survey published in the

Figure 2. Fort Proctor is located at the mouth of Bayou Yscloskey on the south shore of Lake Borgne.

report “Fort Proctor: A Conditional Preservation” by Ursula Emery McClure and Bradley Cantrell of the LSU Coastal Sustainability Studio in 2013 (McClure and Cantrell, 2013) is used as the basis for **Figure 5**. The profile has a proportional vertical scale and a reference for the elevation of “high tide,” but it is not otherwise referenced to a defined benchmark elevation. For the purposes of illustrating the relative effects of subsidence and sea level rise, the high tide level is taken to be current sea level.

For the purposes of constructing **Figure 6** (and additional illustrations in McClindon [2020]), the rate of global sea level rise and the rate of local subsidence at Fort Proctor are assumed to be constant for the time period from 1856, when the fort was constructed, to the present. A constant subsidence rate of 6.263 mm/yr for this 160 time span results in a total elevation change at the site of the fort of 39.45 inches. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine and Atmospheric Research website published a graph of long-term sea levels showing an average rate of sea level rise of 1.7 mm/yr (CSIRO, 2014). This results in a change in global sea level of 10.71 inches during the same time period. This means that in 1856 the elevation of the foundation of the fort was about three and a half feet higher than it is today and sea level was almost a foot lower than it is today. The total combined “relative sea level rise” experienced at the site of Fort Proctor between 1856 and the present has been 50.16 inches based on the extrapolation of these data. In other words, the site of Fort Proctor was over four feet higher than it is today relative to sea level at the time of construction. For the purposes of constructing illustrations (**Fig. 6**; and in McClindon [2020]) of the relative changes of land elevation and sea level over time, the elevation of the “high tide” line on the architectural drawings of the fort that follow is assumed to be current sea level. This assumption is certainly not accurate, but it allows for tying relative changes in elevation to a scaled vertical elevation profile of the fort, and it is not intended to represent an actual elevation. It is also important to note that recent rates of sea level rise are greater than the 1.7 mm/yr long-term average used here. Recently published research by Applied Coastal Research and Engineering (ACRE) (2019) set the current rate of sea level rise in the Gulf of Mexico at 2.0 mm/yr. A gen-

Figure 3. The Shell Beach CORS station on the left and Fort Proctor as seen from the station on the right.



RESULTS: SHELL BEACH (SBCH)

SBCH Vertical Change:
-6.263 ± 0.582 mm yr^{-1}

SBCH– Continuously Operating GNSS Reference Station attached to steel NOAA Tide Gauge Sentinel located in *Lake Borgne*.

Sentinel foundation is set to a depth of 27 m beneath the mud line of the lake.

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Figure 4. A slide from the presentation given by Dr. Josh Kent of the LSU Center for GeoInformatics at the Geological Society of America South-Central meeting in 2016 (Kent, 2016). Data from the Shell Beach CORS station show a subsidence rate of 6.263 mm/yr or ~2.5 inches per decade.

erally accepted rate of sea level rise for the rest of the world since the 1990s is 3.0 mm/yr.

McClindon (2020) provided a link to a video progression of shoreline changes with time at Fort Proctor from 1856 to 2010 using maps, aerial photography, and depiction of elevation profile. **Figure 7** illustrates a dramatic aerial view comparison between circa 1959 and 2019.

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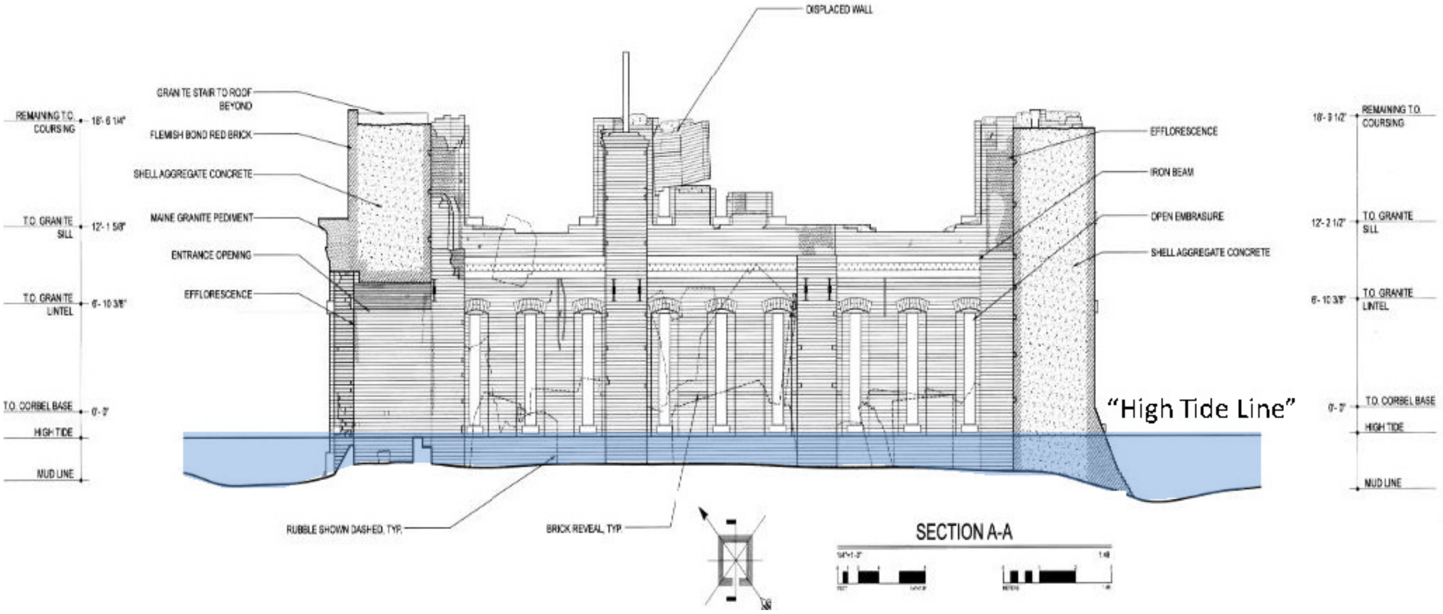

Figure 5. Elevation profile of Fort Proctor (modified after McLure and Cantrell [2013]).

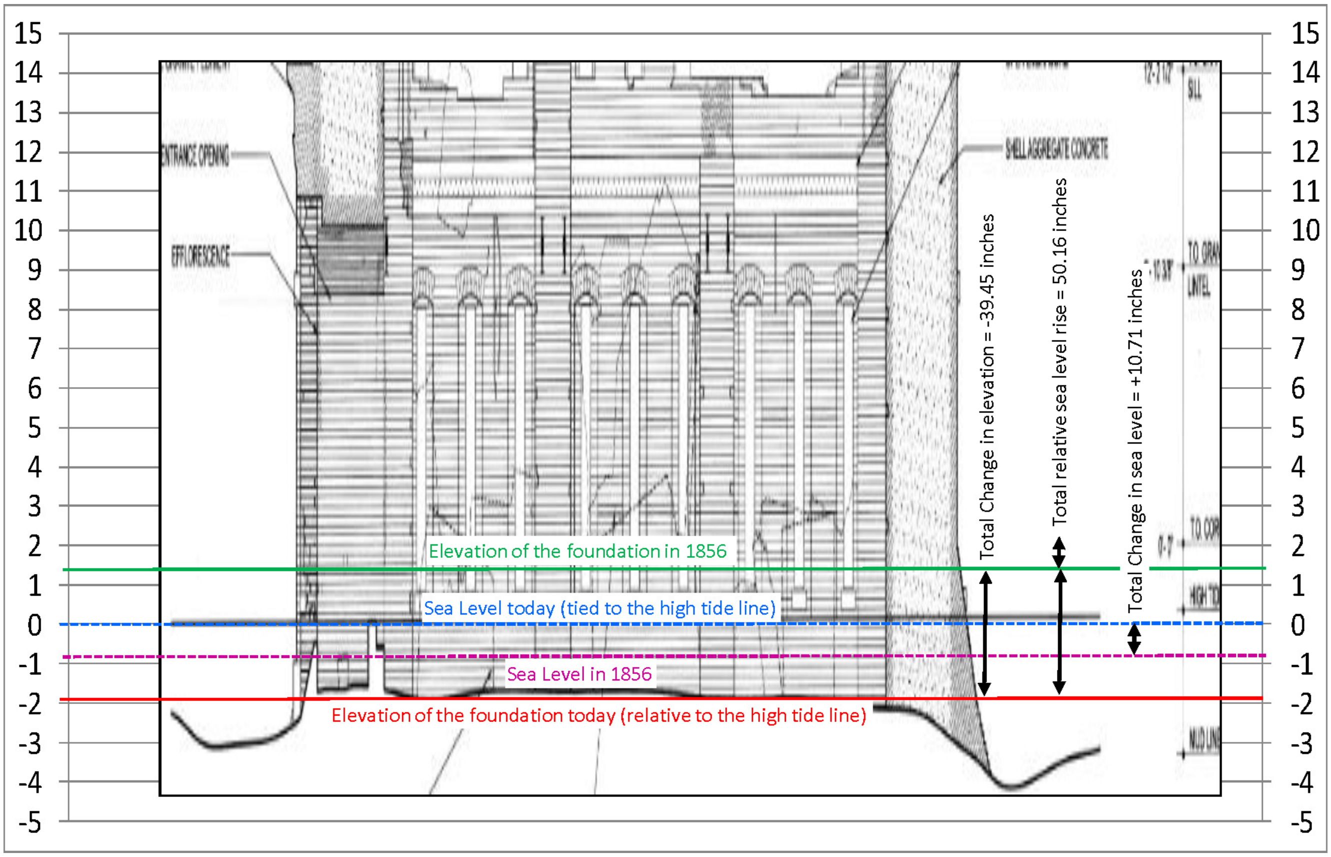

Figure 6. Vertically exaggerated elevation profile tied to a vertical scale (in feet) in which the "high tide line" is equal to current sea level.

Figure 7. A side by side comparison of an oblique aerial view of Fort Proctor circa 1959 and a recent perspective view from Google Earth.

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New Insights into Alaskan Permafrost via Rock Volatiles Stratigraphy: Linkages between Water and Hydrocarbon Gases that Control Micro-Ice Heaving Processes that Affect the Mechanical Strength of Rocks in Ice-Bearing Permafrost and Additional Observations of Biological Activity, Methane, and Carbon Dioxide in Permafrost and Transitions in Rock Properties and Volatiles at the Base of the Ice-Bearing Permafrost*

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Permafrost[1] is a subsurface feature of major importance in Alaska and other Arctic provinces. As a result of global warming, permafrost loss represents a risk in terms of both physical infrastructure and the large quantities of CO_2 and methane contained within it. Some reports have put the potential cost of damage to Arctic infrastructure in the billions of dollars; recently, it has been suggested that the rate of infrastructure degradation has likely been underestimated (Hjort et al., 2018; Kanevskiy et al., 2019; Mawad, 2021; Schneider Von Deimling et al., 2021). Other reports have pointed out the potential severe impacts to the global carbon cycle as the permafrost represents a massive reservoir of carbon that may have already transitioned from a net carbon sink to source (National Park Service, 2017; Koven et al., 2011; Natali et al., 2019; Schuur, 2019). At the same time, permafrost is also an area of where further study will assist in the potential exploration and development of methane gas hydrates as a future energy source.[2] In this context, measurements of the geochemistry and rock properties of rocks from permafrost containing strata can provide important insights.

To gain a better understanding of the geochemistry and the rock properties of the ice-bearing permafrost (IBP)[3], Advanced Hydrocarbon Stratigraphy (AHS) recently analyzed the entrained organic and inorganic volatiles of drill cuttings and the mechanical strength of those cuttings from the shallow section of four wells in the continuous permafrost zone[4] from the North Slope of Alaska (Jorgenson et al., 2008); see **Figure 1** for well locations.

The analyses were done using rock volatiles stratigraphy (RVS), a unique cryo trap-mass spectrometry technique developed by AHS, also known as Volatiles Analysis Service (VAS). This technique gently extracts, identifies, and quantifies entrained organic and inorganic volatiles; the ease with which these volatiles are extracted; and combined with physical measurements of rock strength[5], also allow the col-

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*This article is based on a September 2021 talk given at the Alaska Geological Society by Dr. Christopher Smith. Please direct all inquiries to Dr. Smith of Advanced Hydrocarbon Stratigraphy at christopher@advancedhydrocarbon.com.

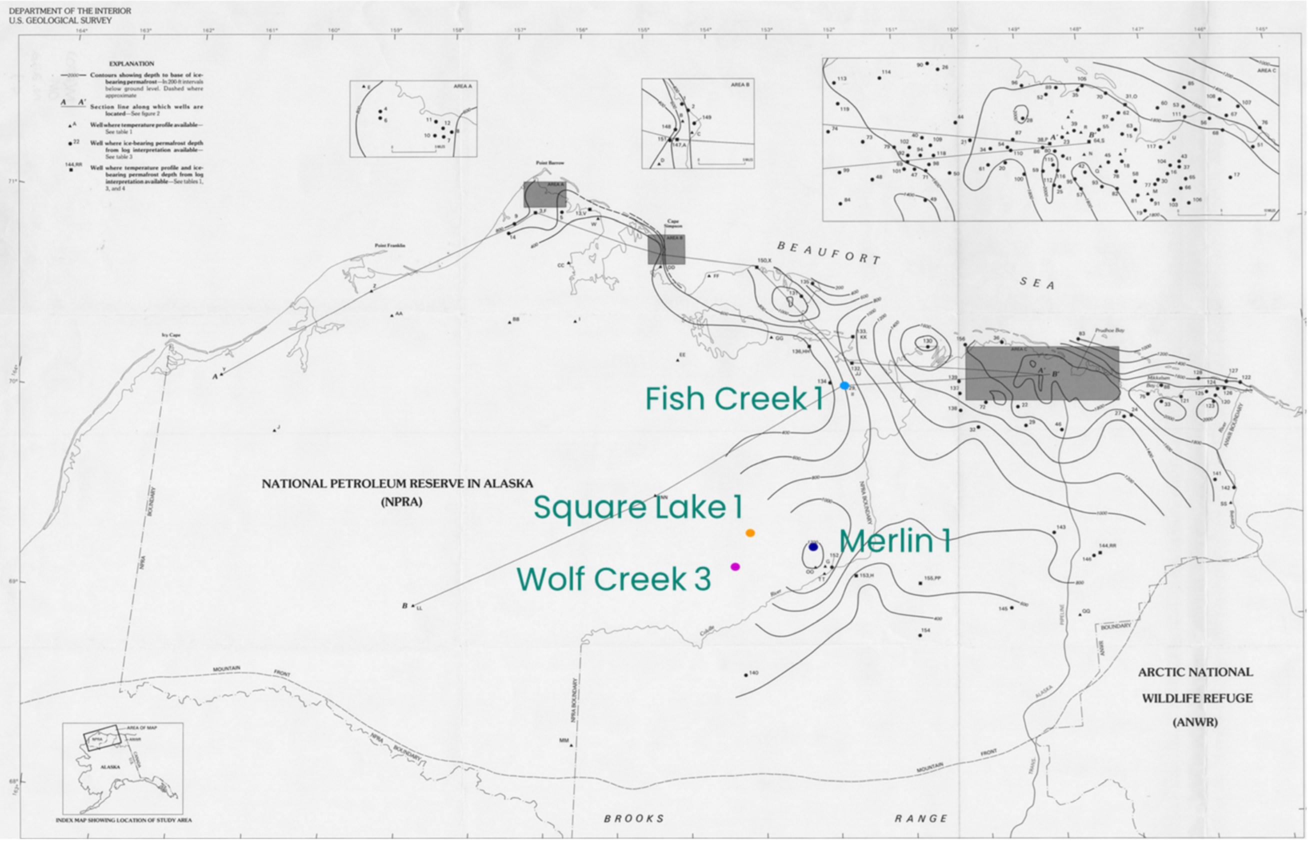
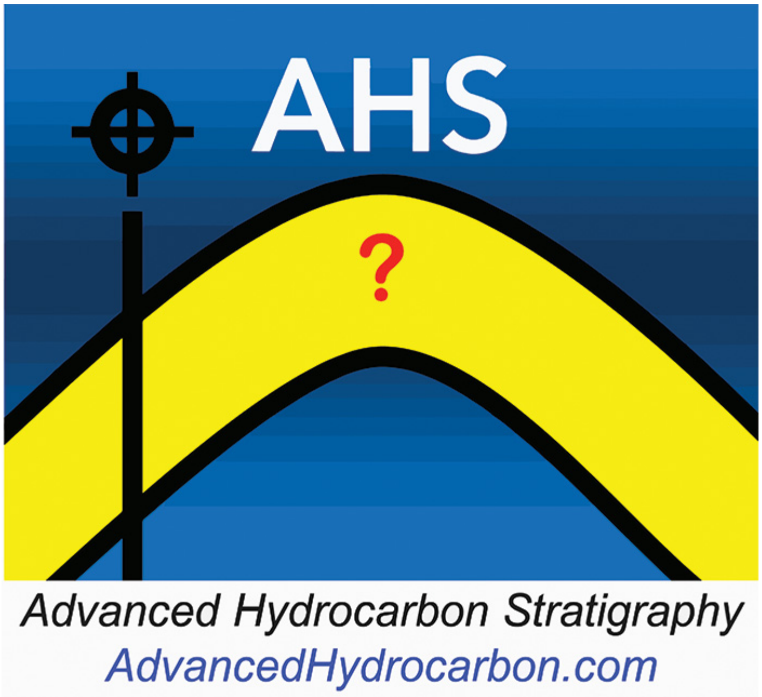


Figure 1. Contour map of base of ice-bearing permafrost based on well logs and indicating approximate positions of analyzed wells (modified after Collett et al. [1989]).

lection of rock properties data (M. Smith and Smith, 2020). The wells analyzed were Merlin 1 (Mer 1), Square Lake 1 (SL 1), Wolf Creek 3 (WC 3), and Fish Creek 1 (FC 1). SL 1, WC 3, and FC 1 were drilled in 1949–52 as part of a U.S. Navy exploration program; Mer 1 was drilled in 2021 by 88 Energy as part of Project Peregrine. The extreme sensitivity of RVS makes it well suited for working with legacy unpreserved rock samples that have received no special preservation treatment. For example, the volatiles in rock samples from a section of SL 1 containing a gas discovery pay zone (documented in 1952) correctly identify the pay zone as having low water content in addition to picking out an unconformity; see **Figure 2** (Collins, 1959; C. M. Smith and Smith, 2020; M. Smith and Smith, 2020). The analyses of these wells covered the shallowest depths where cuttings were collected to ≥~1200 ft; depth ranges analyzed in these wells included the base of IBP and several hundred additional



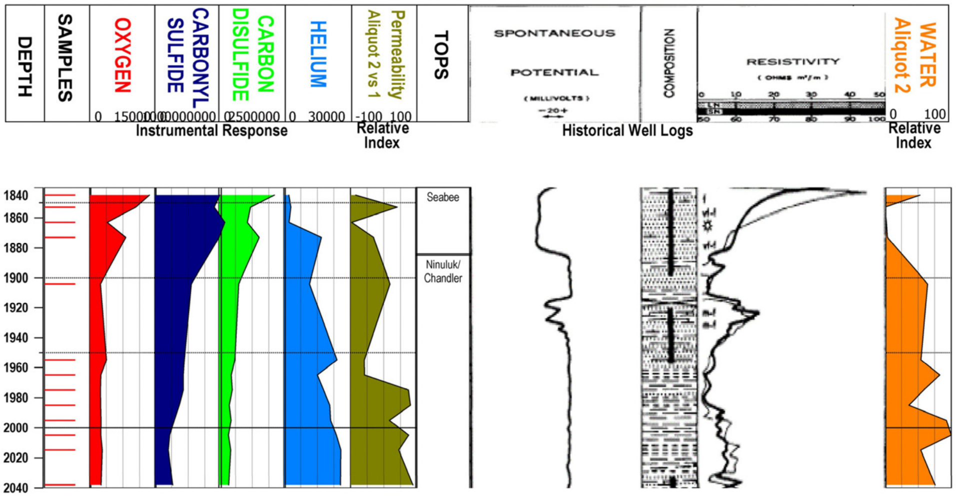


Figure 2. Selected Rock Volatiles Stratigraphy (RVS) data from washed cuttings and historical logs/descriptions from SL 1 (left) and core images of same section (right) used with permission of authors (C. M. Smith and Smith, 2020; M. Smith and Smith, 2020). Core image provided courtesy of State of Alaska's Geological Materials Center. The historical logs and description suggest the presence of a gas pay zone, which was confirmed by subsequent formation tests; a test from 1847–1879 ft produced gas and some water and a deeper test from 1878–1897 ft produced only water (Collins, 1959). This is consistent with the RVS water data shown in the orange log track. An unconformity occurs at ~1886 ft as indicated on the core image by the red box. In the RVS data, the unconformity is at approximately the contact of the Seabee and Ninuluk/Chandler; while the spacing of the samples and the log plotting software give the impression of a smooth transition there is an abrupt change in the concentration of molecular oxygen, carbonyl sulfide, carbon disulfide, and molecular nitrogen (not shown) above and below the unconformity. Both the water content and unconformity relationships demonstrate RVS's capability to relate present day entrained volatiles to subsurface conditions present at the time of drilling.

feet of ice-free strata (FC 1 and Mer 1), or a range that could be expected to encompass these features based the work from Collett et al. in 1989 (WC 3 and SL 1) (Collins, 1959; Collett et al., 1989). Using FC 1 and Mer 1, where the base of the IBP was known (see Collett et al. [1989] for FC 1 base of IBP, which was determined from logs; Mer 1 base of permafrost was provided by 88 Energy—assumed to be base of IBP from discussions with operator), volatiles and rock properties relationships within the IBP were investigated. Some relationships, including changes in mechanical strength, permeability, apparent salinity, and gas content, described further below, appear to identify the base of the IBP.

A key finding was a complex set of systematic relationships in the IBP between the mechanical strength of the cuttings (disaggregated grain strength), water content in the cuttings, the size of the pores which the measured water occupied, and gas content (**Figs. 3** and **4**)[6]. (Core bled gas shows in **Figure 3**, and subsequent figures for FC 1, come from Hayba et al. [2002].) Briefly, the relationships show (1) different regimes of mechanical strength vs. water content in the IBP vs. deeper ice-free strata, (2) water content in "macro"[7] pores is inverse to gas content, and (3) the proportion of water present in "macro" pores appears to alter the mechanical strength of the rock in the IBP strata in comparisons between different wells (**Figs. 3–5**). These relationships appear to be related to micro ice-heaving; when large quantities of water in the "macro" pore spaces froze, micro ice-heaving occurred damaging the microfabric of the rock grains. When there was significant hydrocarbon (HC) gas content, the "macro" water was displaced; subsequently, either micro ice-heaving did not occur as greatly or the mechanical strength of the cuttings may have increased because of ice induced compaction of the gas filled pores (see **Figures 3–5**). The effects of lithology and porosity have not been fully investigated, in part because of a lack of data, but it is worth noting the identified systematic relationships are apparent in all four wells and most of the cuttings, in and below the IBP in the section of FC 1 shown in **Figure 3**, are "clay shale"; see **Figure 6** (Robinson and Collins, 1959).

Several features common across all four wells were identified,

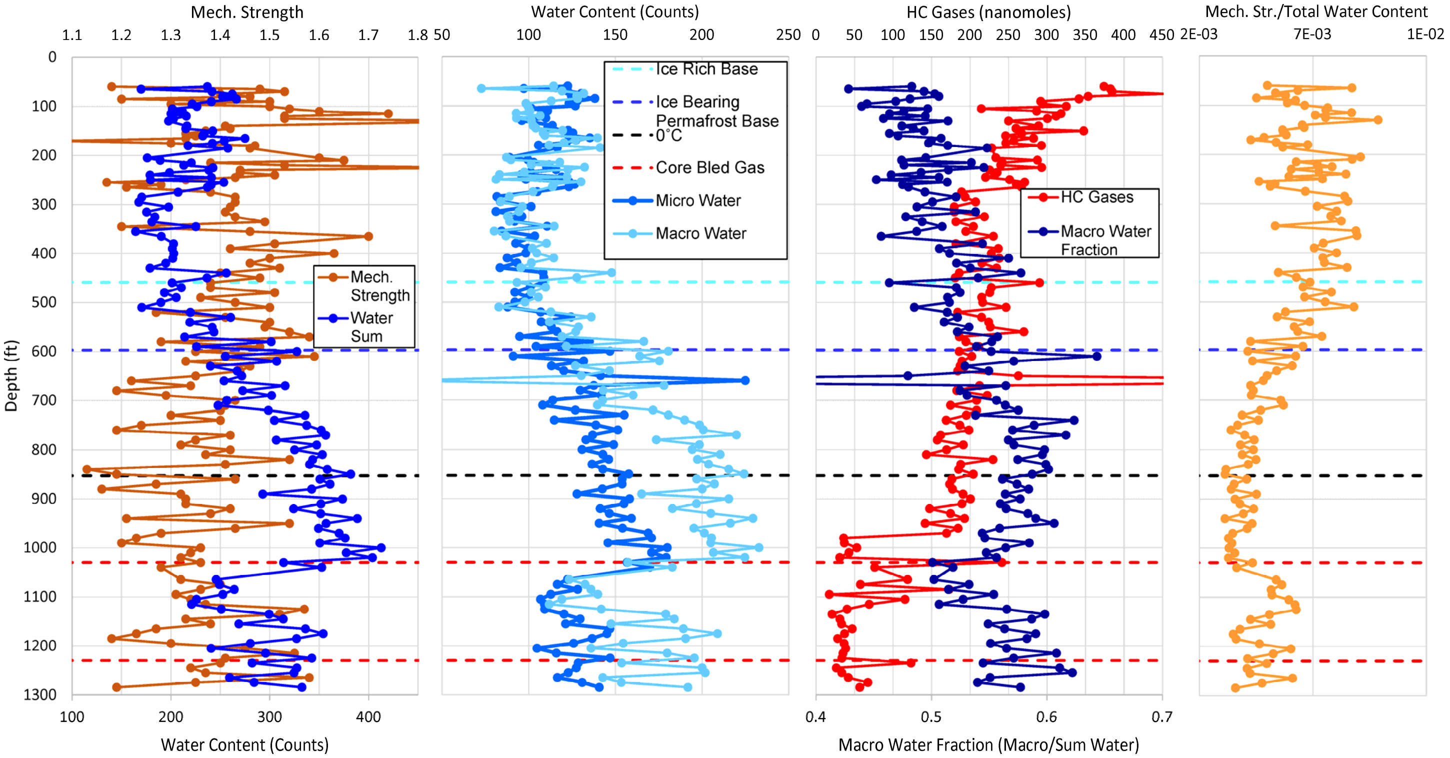


Figure 3. FC 1 RVS data vs. depth for total water content and mechanical strength (far left), "macro" and "micro" water content (water extracted from the rock samples and measured by RVS at the 20 vs. 2 mbar vacuum extraction conditions) (center left), the proportion of the water present in "macro" pore spaces vs. HC gas content (center right), and the ratio of mechanical strength vs. water content (far right). In addition to the relationships that show a change at the base of the IBP, the water and HC gas responses in relation to the gas shows in the core add further confidence that the data in these legacy materials relate to subsurface conditions present at the time of drilling.

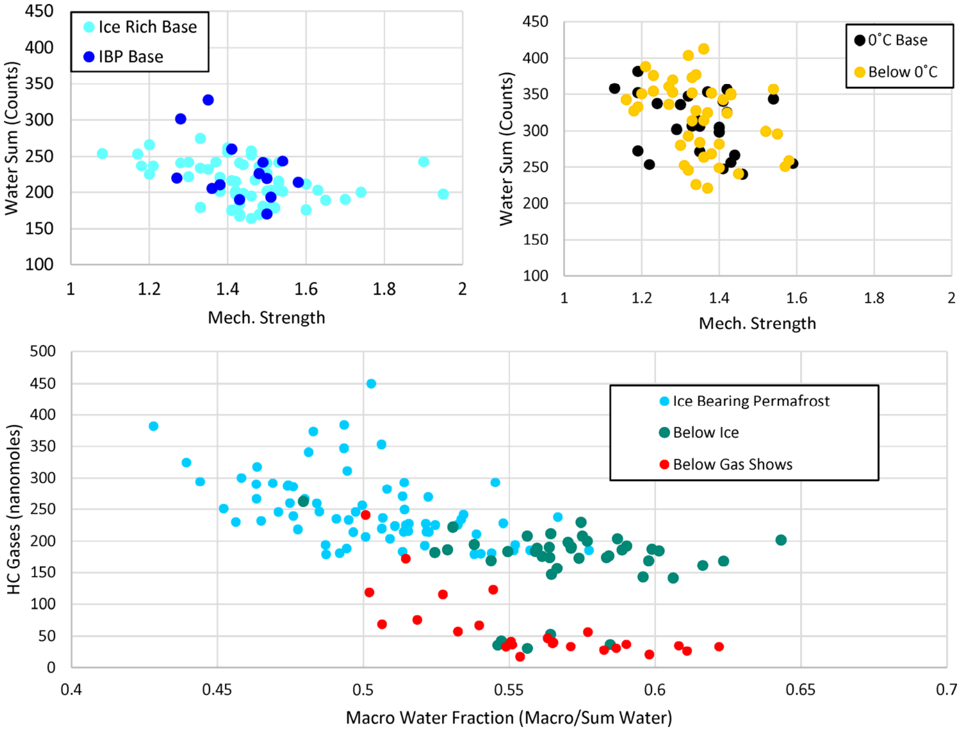


Figure 4. (Top) Total water content vs. mechanical strength in FC 1 with data from below the IBP (right) showing increased mechanical strength at the same water content compared to depths in the IBP (left). While difficult to visually resolve, data suggest an inverse relationship between water content and mechanical strength with different regimes in the IBP and ice-free strata. (Bottom) HC gas content vs. the water fraction present in "macro" spaces. There appears to be a notable inverse relationship in the IBP. The ice-free strata may be in the same regime as the IBP; the relationship is likely not unique to the IBP, but the HC gas content, specifically methane content, is unique to the IBP. These cross plots and different regimes reinforce apparent stratigraphic relationships in Figure 3.

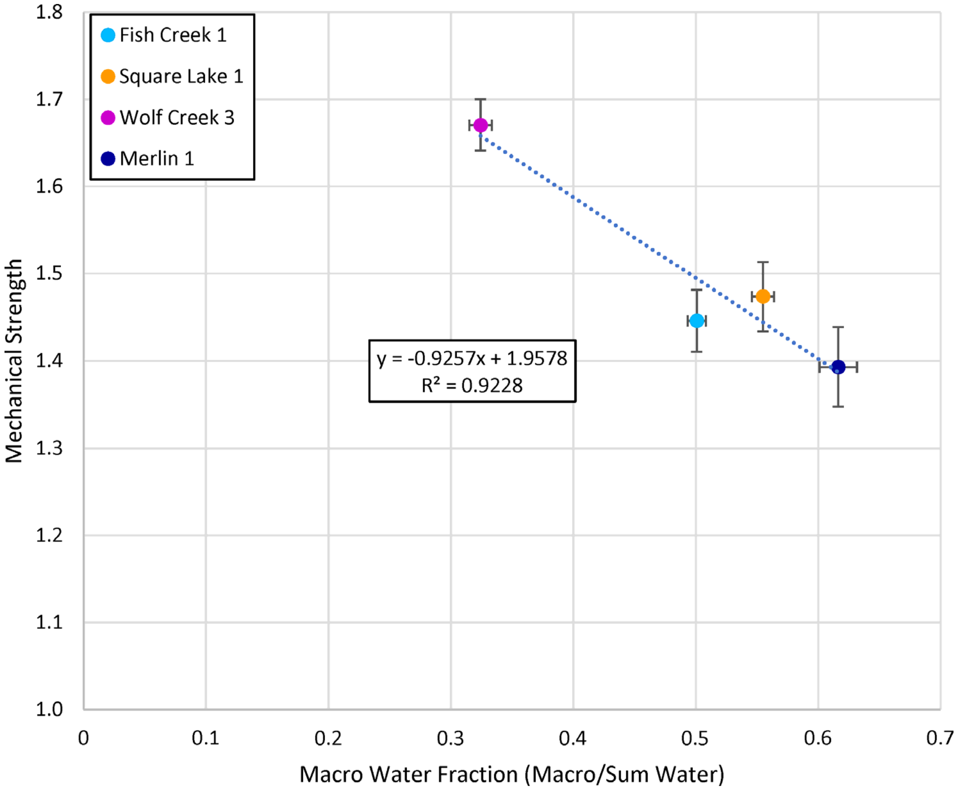


Figure 5. Cross plot of the mechanical strength vs. proportion of the water content in the residing in "macro" pore spaces; these values are the averaged values of each parameter in the IBP. In the case of WC 3 and SL 1, the various signatures that respond to the base of the IBP in FC 1 and Mer 1 were used to define the IBP. The error bases represent 95% confidence intervals from the data across all depths included in the IBP.

such as changes in permeability at the base of the IBP, and a general trend of increasing sulfate proxy content/concentration in the IBP that plateaus at or near its base (**Fig. 7**). Other RVS observations include linkages between biodegradation products (organic acids) and microbial feed stocks (n–butane) (Hunt, 1995; Skaare et al., 2011). In some wells (FC 1 and WC 3) enhanced methane content and high concentrations of CO_2 (FC 1, WC 3, and Mer 1) are observed in the IBP (**Fig. 8**). High CO_2 content is observed in the IBP, but it is not possible to identify the base of the IBP from these data. Methane appears to undergo a stepwise increase in the IBP compared to the deeper ice-free strata. Such a stepwise change is not observed in the other HC gases. Concentrations of CO_2 in Mer 1 and FC 1 IBP are typically high enough that if the measured CO_2 were immediately aerosolized, its gaseous volume would be ≥50% of the volume of the rock sample (0.4 cc).[8] This last point is especially surprising as the highest calibrated CO_2 response was observed in cuttings from FC 1, which was

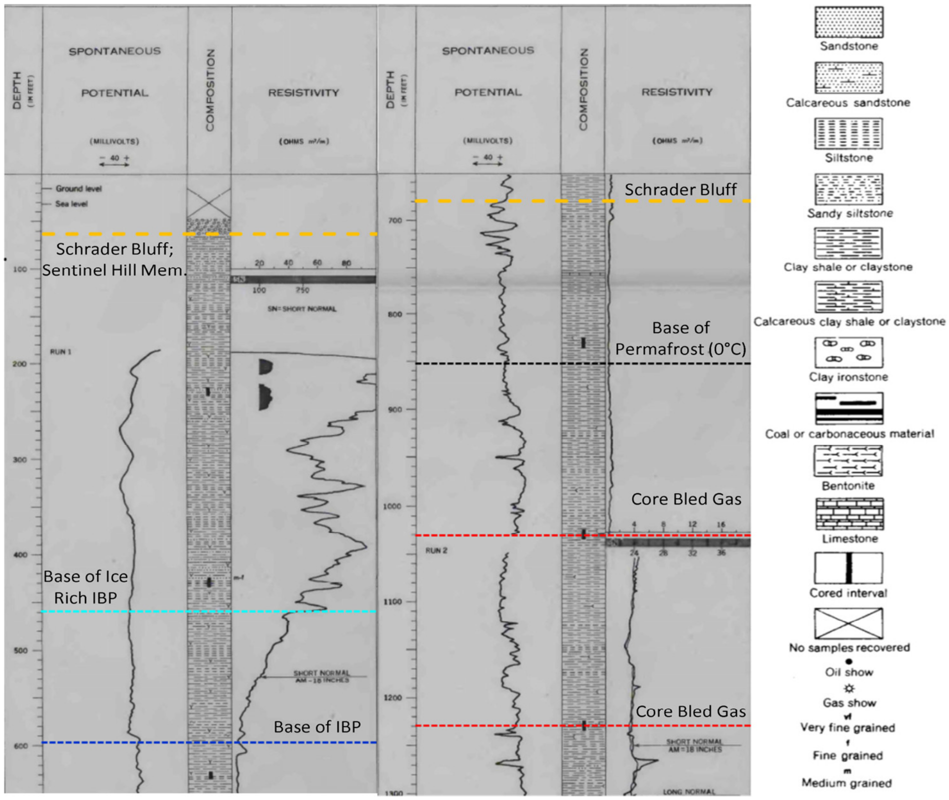


Figure 6. Historical spontaneous potential, resistivity, and lithology composition logs and key from FC 1 (modified after Robinson and Collins [1959] to include TOPS and identified features in Figure 3). The features that allowed for the identification of the base of the ice-rich IBP and the IBP in the logs can be observed. While there are some fine scale changes in lithology, broadly the borehole encountered mainly clay shale and some siltstone. There are no obvious changes in lithology that account for the water, gas, or mechanical strength behavior/content discussed in relation to the IBP or changes that occur at its base.

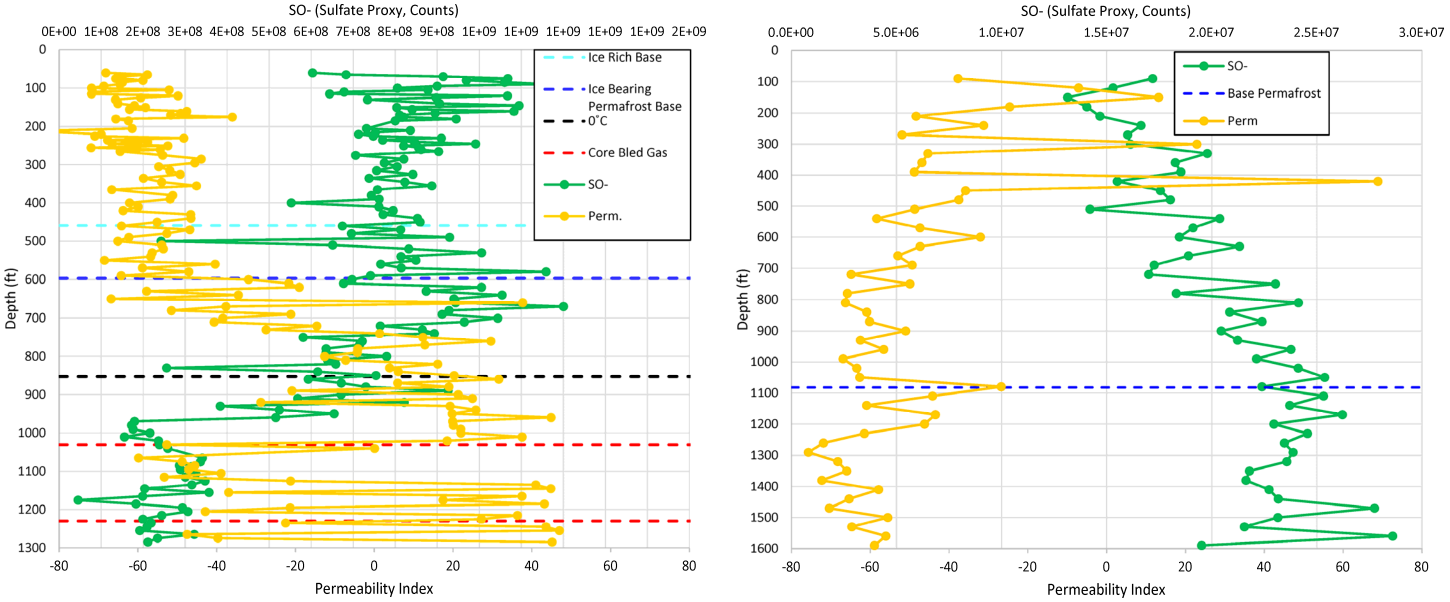


Figure 7. Permeability index and SO- (molecular fragment used as proxy for sulfate in RVS) vs. depth in FC 1 (left) and Mer 1 (right). Base of permafrost was provided by 88 Energy. A general trend of increasing SO- content/concertation can be observed as the base of the IBP is approached before a plateau is reached proximal to this base. Permeability can be keyed to a variety of molecules in RVS, where the trend shown for FC 1 uses hexanes and the trend shown in Mer 1 uses benzene. Immediately below the base of the IBP, the permeability is relatively high before transitioning to lower index values in the IBP.

drilled in 1949. These observations suggest that the CO_2 being measured is likely very strongly sorbed to the IBP sediments to still be present in such large quantities.

In FC 1, the enhanced methane content in the IBP (**Fig. 8**) is a likely explanation why both the mechanical strength of the cuttings and the mechanical strength vs. water content regime are higher in the IBP than the deeper ice-free strata, even though the cross plot in **Figure 4** suggests that there is no change in the gas vs. proportion of "macro" water content behavior that is unique to the IBP.

The behavior in FC 1 can be contrasted with WC 3 where stratigraphically micro ice-heaving appears to have occurred; the mechanical strength and the mechanical strength vs. water content regime of the deeper ice-free strata are greater compared to the IBP (see **Figure 9**). It is worth noting in WC 3 that there are greater variations in lithology in the analyzed section than in FC 1, which may explain some of the apparent variance in the mechanical strength vs. water content regime in the IBP; but, there are no significant lithology transitions/regimes that can explain the transition observed at approximately 900–920 ft, likely the base of IBP (based on similar features as those noted at the base of the IBP in FC 1 and Mer 1) (**Fig. 10**) (Collins, 1959). **Figure 11** shows the mechanical strength in the Chandler formation for WC 3 for those cuttings described as being "clay shale"; there is a clear shift in the mechanical strength at the likely base of the IBP around 900 ft.

The greater variations of lithology in WC 3 than in FC 1 allow for the interrogation of how various lithologies effect some of the parameters discussed; see **Table 1**, which contains tabulated values by formation, lithology, and likely IBP status. Lithology clearly plays a role in mechanical strength; for example, sandstone is observed to be stronger than clay shale. In the Ninuluk formation, based on the Student's T–Test (Harris, 2010), the average mechanical strength of the two lithologies is statistically significantly different at the 95% confidence level. Similarly, when comparing all listed parameters in **Table 1** for the clay shale sections of the Chandler formation that likely contain IBP vs. those that do not, except for macro water fraction, they are all significantly different at the 99.5% confidence level (macro water fraction shows a difference at the 90% confidence level). While there are a smaller number of samples with the sandstone lithology type, the difference in the mechanical strength is statistically significant at the 98% confidence level as well. These results show that in the same formation and lithology type the presence of the IBP does impact the mechanical strength of the rocks.

Some features were identified in the comparisons between **Figures 9** and **10** for WC 3 that should be called out. First, the presence of discrete coal shows correlates with discrete decreases in mechanical strength. Second, several sandstones have lower water content; to an extent this is also observed in **Table 1**. These depths correlate with increased resistivity in the historical wireline logs and frequently correlate with increased gas content in the RVS analysis (not

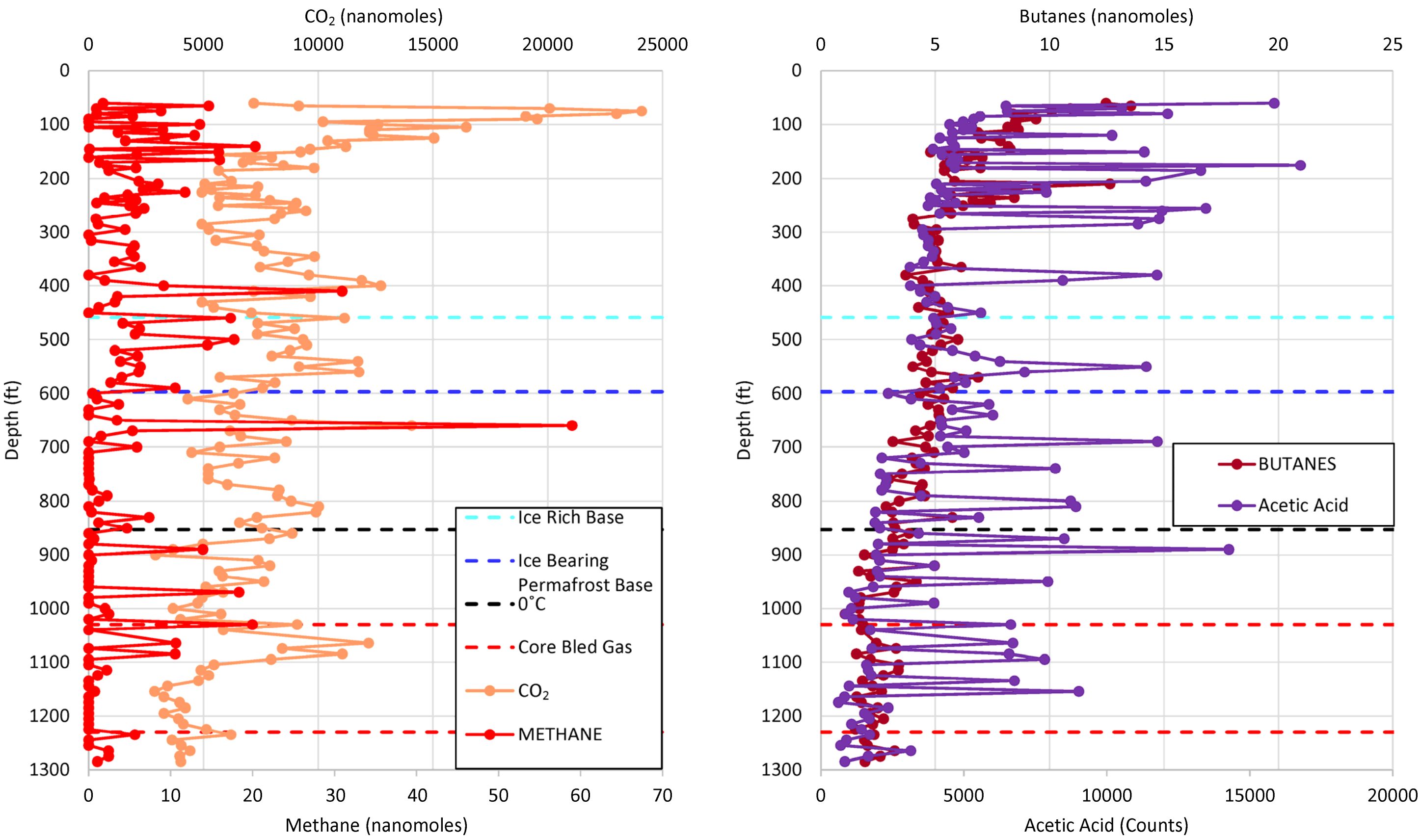


Figure 8. Methane and carbon dioxide (left) vs. depth for FC 1. Enhanced methane content is observed throughout the IBP compared to deeper ice-free strata. While high CO_2 can be observed in relation to the historical gas shows, high concentrations, including the highest concentration, are observed in the IBP. Acetic acid and butanes (right) vs. depth for FC 1. n–butane can serve as a feedstock for subsurface micro-organisms. Organic acids, such as acetic acid, can commonly be produced by subsurface microbial activity. The strong correlation between the two tracks suggests that biological activity (represented by acetic acid) is tracking with the availability of its feedstocks (butanes; includes both isomers). There are some depths with disproportionately high acetic acid vs. the typical butanes/acetic acid trend; examples of these high acetic acids to butanes responses in the IBP are at 185, 275, 380, and 550 ft. At these depths, the butanes concentration also appears to decreases. These types of responses are likely indicative of biological activity being so prolific that it has begun to significantly deplete its feedstocks, transitioning from a direct to an inverse relationship.

shown); these sandstones are likely serving as shallow gas reservoirs where water has been displaced. A comparison of **Figures 9** and **10** at approximately 260 ft reveals an excellent example of this.

Another aspect that should be considered is that while the ice-free lithologies (clay shale and sandstone) have statistically significant higher mechanical strength than their IBP counterparts in the Chandler formation of WC 3, this could potentially be due to greater compaction as a function of depth. Such a relationship has previously been observed by RVS in the Marcellus liquids fairway in West Virginia (WV) when comparing the same shale formations over increasing depth ranges when moving from west to east (Smith et al., 2021). It is unlikely that potential compaction explains the differences in mechanical strength observed here. No such linear trend is observed, rather, considering **Figure 11**, the transition in the mechanical strength of the clay shale lithology in the Chandler appears abrupt. Also, in the case of FC 1, the opposite trend was observed, where mechanical strength decreased below the base of the IBP, a phenomenon that cannot be ascribed to compaction.

In FC 1, the mechanical strength is greater in the IBP than in the ice-free strata below it. This is the opposite of what is observed in WC 3 and would seem to be a contradiction in the proposed model as both wells have enhanced methane content present in the IBP and a resulting lower macro water fraction in the IBP. Considering only the data in the IBP, the model does hold; less water is observed where greater gas content is present and resultingly the rock is stronger, especially when the trends are compared across the IBP of the four wells. Considering the ice-free strata below the base of the IBP, it is important to consider what the mechanical strength of the rock may be regardless of the presence of the overlying IBP. While there are likely a variety of factors that could influence the mechanical strength of the rock below the IBP, such as formation and mineralogy, a potentially straight forward explanation is arrived at by considering the mechanical strength of cuttings from the same lithology immediately below the IBP as a function of depth; see **Figure 12**. Considering the 100 ft below the base of the IBP, a linear trend similar to the compaction trend described from the WV study is observed in the mechanical strength of cuttings described as having the same lithology. That the mechanical strength of the rock in the ice-free strata may be a function of compaction (i.e., depth) and not related to the presence of the IBP is a plausible explanation that addresses this potential contradiction.

Further study of IBP related processes is needed. The current study of these four wells has only considered unsealed/unpreserved cuttings samples with limited available data in terms of lithology or porosity, which may be key variables in completely elucidating the apparent interplay between mechanical strength of the rock samples, water content, pore size that water occupies, and gas content in the IBP. Collecting cuttings from modern wells drilled with access to these measurements in the IBP could address the roles of these potential variables. The collection of sealed at well cuttings would better preserve hydrocarbon gas content as well as other gases that may play a role (e.g., molecular nitrogen, mo-

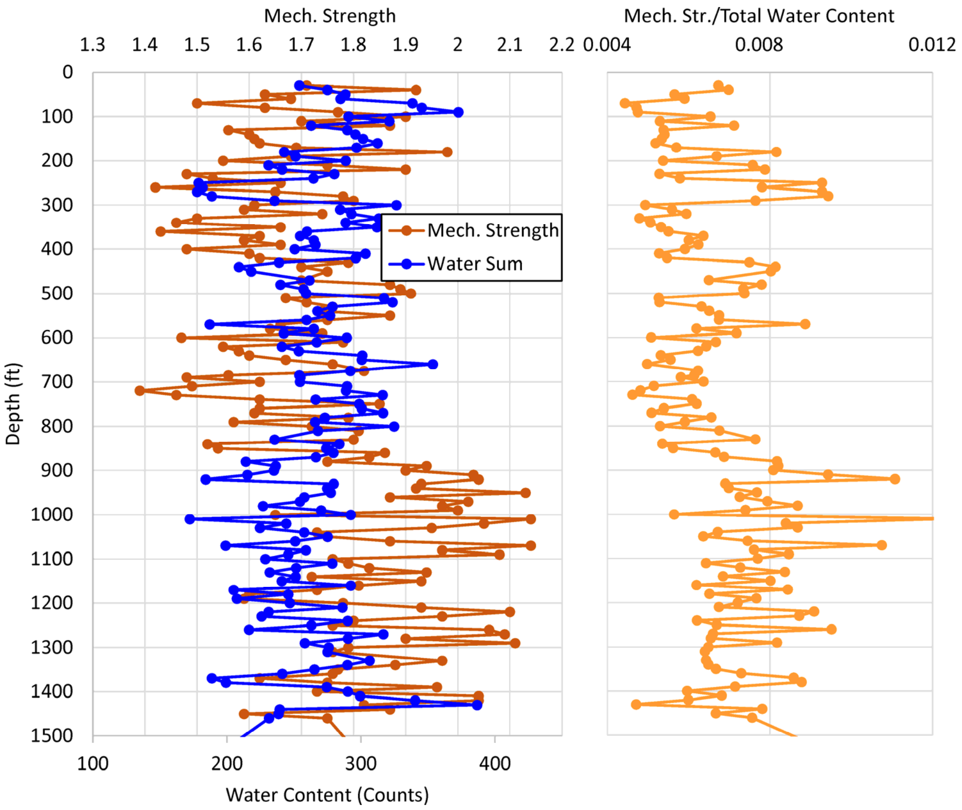


Figure 9. WC 3 RVS data vs. depth for total water content and mechanical strength (left) and the ratio of mechanical strength vs. water content (right). Unlike FC 1, these data suggest that the mechanical strength of the cuttings as a function of water content are stronger below the likely base of the IBP than in the IBP.

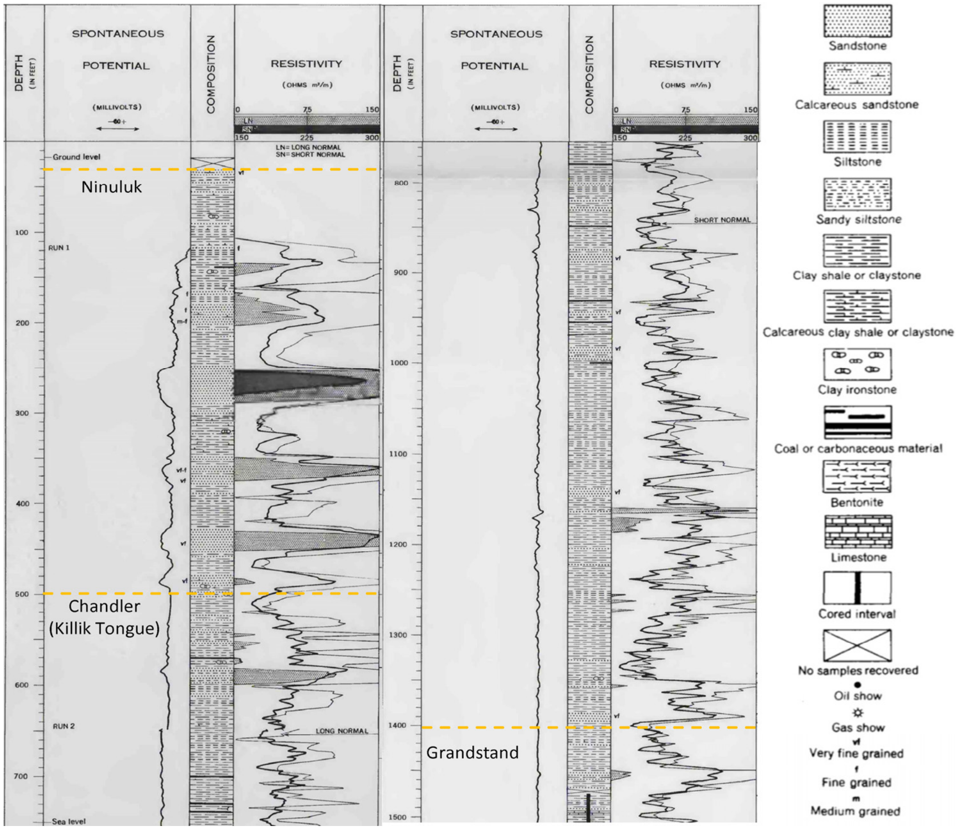


Figure 10. Historical spontaneous potential, resistivity, and lithology composition logs and key from WC 3 (modified after Collins [1959] to include TOPS). The lithology is significantly more complicated than FC 1, although the majority of the considered section is described as clay shale.

lecular oxygen, and/or argon); such samples can only be collected from an actively drilling well. The collection of sealed at well cuttings samples would allow for a better appreciation of subsurface CO_2, methane, and biological processes in the IBP which can have important implications in understanding the role IBP plays in the global carbon cycle.

For example, on Great Bear Pantheon's Talitha A well, both sealed at well and unsealed cuttings were collected and analyzed across the pay zone intervals; see **Figure 13** for the CO_2 data from the different sample types. The quantities of CO_2 observed in the unsealed cuttings of Talitha A were typically an order of magnitude less than what was observed in the IBP of FC 1, and the sealed cuttings of Talitha A also contain significantly less CO_2 than in the IBP in FC 1 (**Fig. 8**). However, comparing the ratio of the unsealed to sealed CO_2 in Talitha A, there is typically 2.3 times more CO_2 in the sealed samples, though there are a wide range of ratios between these two sample types. This broad range is likely due to multiple factors, such as pressure, temperature, salinity, phase, and surface chemistry to name a few, encountered at different depths sampled in Talitha A.

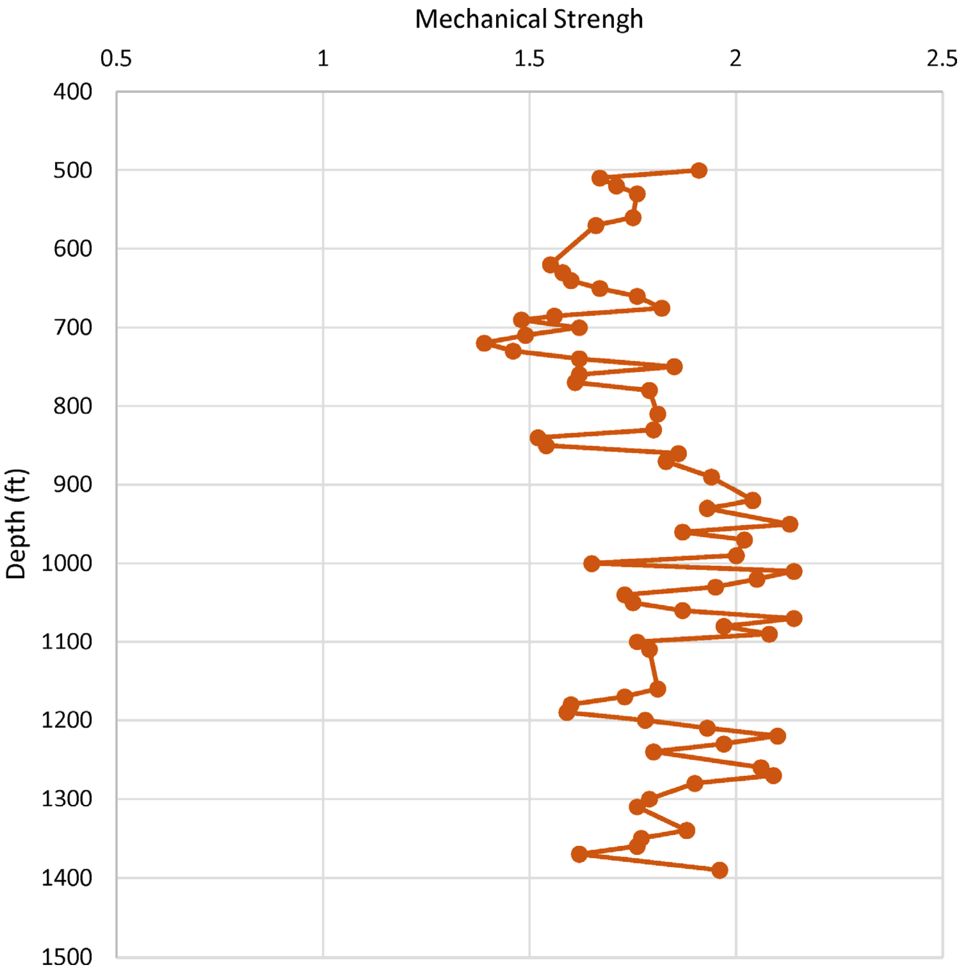


Figure 11. Mechanical strength measurement from WC 3, showing only those described as a clay shale lithology by Collins [1959] in the Chandler (Killik Tongue) formation. Note the abrupt shift and apparent establishment of a new baseline around 900 ft.

Table 1. Mechanical strength, sum water content, the ratio of the two, and macro water fraction values tabulated by formation, lithology, and likelihood of containing IBP. Data are displayed as average plus/minus the standard deviation. The last column indicates the number of depths/cuttings samples analyzed for a given combination of formation, lithology, and likelihood of containing IBP. The mechanical strength of the clay shale and sandstone lithologies in the Chandler above and below the likely base of the IBP at 920 ft are statistically significantly different at the 99.5% and 98% confidence levels, respectively.

Formation	Lithology	IBP Likely?	Mech Str	Water Sum	Mech Str/Water Sum	Macro Water Fraction	Cutting Depths of This Type, n=
Ninuluk	Clay Shale	Yes	1.59±0.071	300±33	0.0053±0.00053	0.32±0.021	8
	Claystone	Yes	1.6±0.13	290±19	0.0055±0.00063	0.32±0.029	10
	Sandstone	Yes	1.7±0.15	240±36	0.007±0.0013	0.29±0.035	21
	Silstone	Yes	1.7±0.12	300±36	0.0059±0.00081	0.33±0.034	7
Chandler (Killik Tongue)	Clay Shale	Yes	1.7±0.14	280±33	0.006±0.0010	0.35±0.042	30
		No	1.9±0.16	250±35	0.007±0.0015	0.36±0.033	37
	Sandstone	Yes	1.72±0.060	270±45	0.007±0.0012	0.35±0.037	4
		No	1.9±0.11	250±38	0.008±0.0010	0.37±0.046	6
	Siltstone	Yes	1.8±0.19	260±26	0.007±0.0014	0.32±0.014	7
		No	1.9±0.15	253±9.6	0.0075±0.00069	0.37±0.024	4
Grandstand	Clay Shale	No	1.8±0.18	300±58	0.006±0.0010	0.41±0.059	6

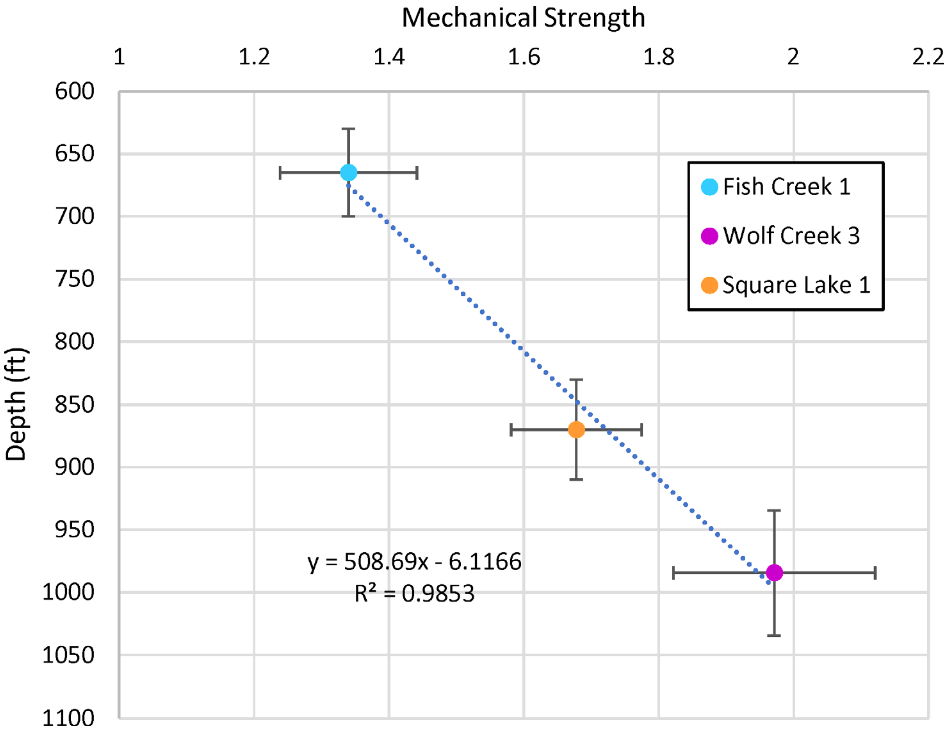


Figure 12. Cross plots of average mechanical strength of the cuttings from depths with clay shale lithology in the 100 ft below the documented base or likely base of the IBP. Mer 1 is not included as a lithology description for the different depths analyzed is not available. Historical lithology description for FC 1 (Robinson and Collins, 1959) does not significantly differentiate clay shale from claystone at several depths; those depths are treated as clay shale. Vertical error bars indicate the vertical depth range utilized for the average mechanical strength value. The horizontal error bars are the standard deviation of the average mechanical strength of the cuttings. While upon visual inspection the standard deviation may appear large, in all cases the relative standard deviation is less than 8% of the average mechanical strength.

While using relationships from data like that of Talitha A may allow for some appreciation of how much CO_2 may have originally been present in the IBP, sealed cuttings will allow for a more accurate measurement of the CO_2 present in the IBP given the range of ratio values observed between the two sample types in Talitha A. A comparison of the two sample types from a North Slope well in IBP containing strata would also importantly allow for an appreciation of how strongly associated the CO_2 may be with the IBP sediments. Given the large quantities of CO_2 being measured in FC 1 and the nature and age of the samples, around 70 years old at time of analysis, these point towards potentially a very strong set of interactions between CO_2 and the sediments of the IBP. It is important to better understand these interactions to appreciate potential CO_2 release as the IBP melts, especially as the highest CO_2 responses in the FC 1 IBP strata were encountered within the first 100 ft of the borehole. Similar relationships could be investigated for other compounds such as methane.

Furthermore, the current set of wells studied represents a limited number and geographical area. SL 1, WC 3, and Mer 1 are all relatively tightly clustered within a diameter of approximately 28 mi in and about the foothills of the Brooks Range, while FC 1 is roughly 70 mi away from this cluster and 7–8 mi from the coast of the Beaufort Sea. Beyond the stratigraphic trends of individual wells, the greater potential of these observations likely will come from comparison of the IBP of different wells across a greater extent of the North Slope. The potential for greater understanding of these processes in a geographical context can be seen when comparing **Figures 5** and **14**. **Figure 5** suggests there are overall trends in the data, whereas **Figure 14** clearly demonstrates geographical relationships are present in the IBP data. WC 3, SL 1, and Mer 1, have very apparent linear relationships between mechanical strength and water content in the IBP; FC 1, which is spatially significantly removed from these other wells, does not participate in these trends, nor does it contain the same formations (Robinson and Collins, 1959; Collins, 1959; Hayba et al., 2002).

Why some wells contain enhanced methane throughout the IBP and enhanced high CO_2 in the IBP and others do not is also unclear. FC 1 and WC 3 contain methane that appears to be enhanced throughout the IBP and undergoes a stepwise transition to lower values at the base of the IBP in the deeper ice-free strata, whereas Mer 1 and SL 1 show no such apparent behavior. FC 1 and Mer 1 have very high concentrations of CO_2 present in the IBP (and WC 3 likely does too), but SL 1 very clearly does not. RVS data of cuttings from deeper depths than discussed here may offer clues to these distributions in a potential future study.

While this study did not focus on methane hydrates, the demonstrated ability of RVS to evaluate a large range of chemicals and changes in rock properties and methane associated with the ice, as well as transitions at the base of the IBP, would potentially make RVS a powerful tool in the evaluation of subsurface methane hydrates.

This preliminary study of the shallow section in four North Slope of Alaska wells demonstrates the need for further study of IBP to better appreciate changes that may occur from warming Arctic climate. Taken together, these observations and findings offer the potential for significant new understandings of

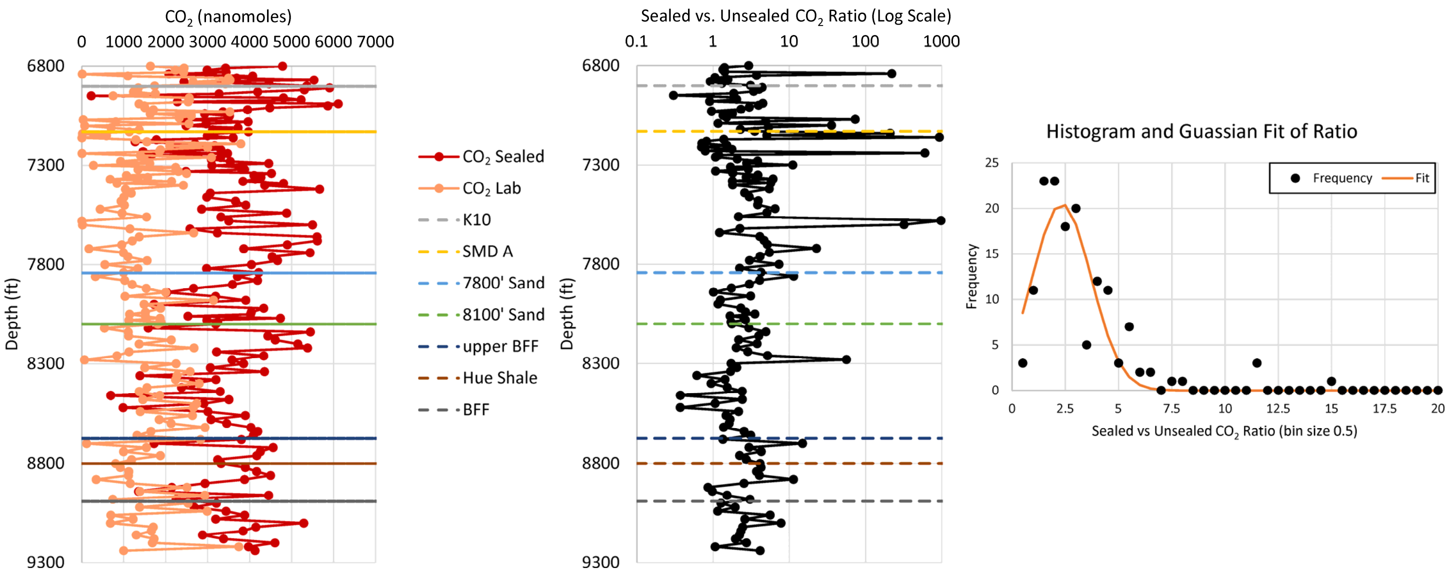


Figure 13. Talitha A RVS CO$_2$ data for sealed at well (sealed) vs. unsealed (lab) cuttings (left). Ratio of the CO$_2$ measured in the sealed vs. unsealed cuttings samples (center) presented in a log scale. Histogram of the ratio data from sealed vs. unsealed cuttings CO$_2$ content. Histogram was fit to a Gaussian curve to identify the most common ratio.

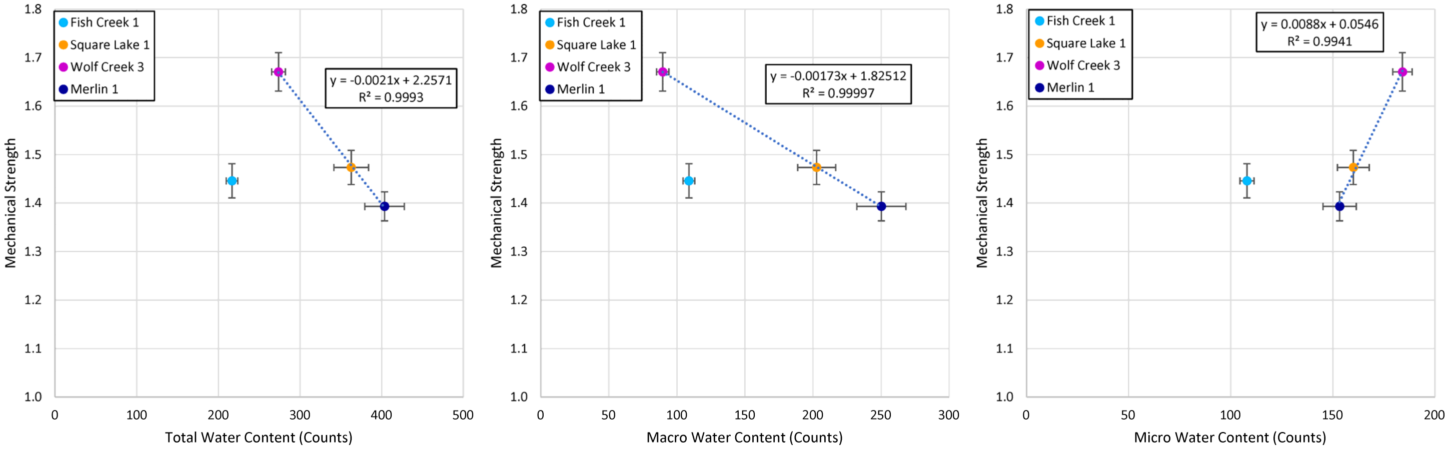


Figure 14. Cross plots of average mechanical strength of the cuttings in the IBP vs. total (left), macro (center), and micro water content (right); error bars are 95% confidence intervals. Regardless of which water measurements are used a remarkable linearity of the geographically clustered WC3, SL 1, and Mer 1 data are observed in contrast to FC 1, strongly suggesting local geographical regimes likely due to the similarity of the local sediments.

IBP in terms of geophysics/rock mechanics, entrained gases (especially methane and carbon dioxide), and subsurface biological processes. These findings could have important societal impacts in terms of understanding the risk of damage to physical infrastructure and the role permafrost plays in the global carbon cycle in addition to possibly providing important insights for the exploration and development of methane hydrates as an energy source.

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ENDNOTES

[1] There are multiple common and scientific definitions of permafrost. For this article, the definition from Brown and Kupsch (1974) is used: "Permafrost is defined as the thermal condition in soil or rock having temperatures below 0°C which persist over at least two consecutive winters and the intervening summer."

[2] Please see the U.S. Department of Energy's "Fire in the Ice" publication: <https://www.netl.doe.gov/advsearch?tid=113>.

[3] Ice bearing permafrost (IBP) is a subset of permafrost, soil, or rock that contains detectable ice (Collett et al., 1989). Most discussions of permafrost tend to conflate the two; herein, IBP refers specifically to the presence of ice in the permafrost. Some controls that define the base of the IBP, besides subsurface temperature gradients, are pressure (liquid water is denser than ice) and salinity. Lithology and porosity of the rocks in the zone are also thought to play roles. These cause a disconnect between the base of permafrost, 0°C, and the base of ice.

[4] Permafrost is present across 90% or more of the surface area of this region (Jorgenson et al., 2008).

[5] The mechanical strength of the cuttings is measured by their ability to resist a 2 ton uniaxial crushing force applied over a ¼ inch^2 surface area when cuttings are held in a standardized consumable kit. The reported value is the resulting thickness of the container holding the cuttings following the crushing protocol.

[6] When discussing water content, it is important to understand that what is effectively being measured is the volume of water physically present in the cuttings at the time of analysis; given that these cuttings have had no special preservation, this water could have been present as an ice or an aqueous phase at the time of drilling. A significant portion of the water extracted from cuttings in the IBP strata is presumed to have existed as ice at the time of drilling.

[7] "Micro" water is water tightly associated with the rock and likely residing in pores with diameters of approximately 4 nm to 1.5 nm. "Macro" water is water that resides in pores larger than 4 nm. See M. Smith and Smith (2020) for more details.

[8] WC 3 CO_2 data were not calibrated at time of analysis in such a way as to allow conversion to volume at standard temperature and pressure (STP).

(*Continued from Page 4*)

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(*Continued from Page 12*)

depleted of hydrocarbons or that a certain percentage of mineral owners have consented to the use of the reservoir if it is not depleted; (c) use of the reservoir will not contaminate other fresh water formations or other oil, gas, or mineral formations; and (d) use of the reservoir will not endanger human lives or cause a hazardous condition to the property. Unlike enhanced recovery unit hearings that are held in Baton Rouge, hearings to approve geologic storage facilities must be held in the parish where the facility is located. Beyond approval of the storage facility itself, the Louisiana Geologic Sequestration of Carbon Dioxide Act provides for expropriation authority, a trust fund, and a liability release upon cessation of storage operations under certain conditions.

In addition to approval of the storage facility, the operator must also receive approval for its injection wells. Injection wells used for geologic sequestration of carbon dioxide are considered Class VI wells. Unlike Class II wells, Louisiana's application for primary enforcement authority for Class VI wells remains pending. It is anticipated that primacy for Louisiana will be granted in early 2022. The State regulations that will govern Class VI wells once primacy is achieved are in Statewide Order No. 29–N–6[4], which addresses permitting, construction, operations, monitoring, testing, reporting, and closure for Class VI wells.

The reader is directed to the referenced statutes and statewide orders for more detail on the particular requirements discussed above. The author would also be happy to assist with any legal issues or questions that may arise in your CCUS endeavors and can be reached at jdlieberman@liskow.com or (337) 232–7424.

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[4] http://www.dnr.louisiana.gov/index.cfm/page/62

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