HGS Bulletin
Houston Geological Society
Volume 67, Number 10
JUNE 2025

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The **Bulletin**
Houston Geological Society

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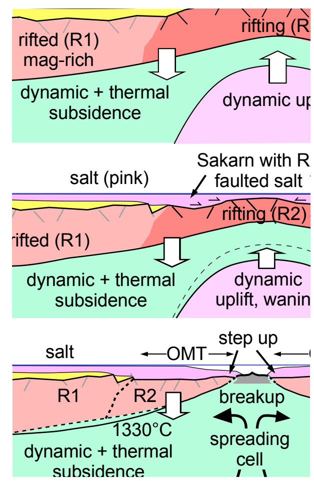

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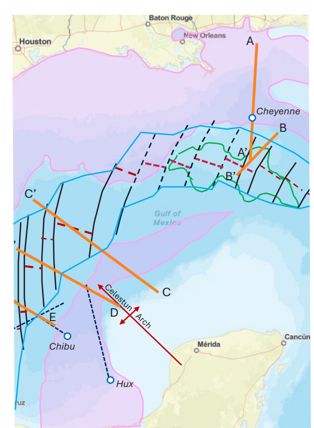

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About the Cover: *The cover photo displays several maps and an annotated log on the desk of an oil finder. The unrolled map highlights the dry holes and productive fields, which are colored according to reservoir age. See the feature article in this issue on "Oil Finders," a Collection of Opinions.*

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Penny Patterson, HGS President 2024-25
pennyp70@att.net

Reflect on the Past in Developing a Plan for a Successful Future

June has arrived, signaling the last month of my term as President of the Houston Geological Society. I am so honored to have served as President of HGS during this past year. It has been a wonderful experience in so many ways. My term as HGS's President has been filled with excitement, enthusiasm, unexpected challenges, and amazing outcomes. Through a united team effort, HGS has advanced in many incredible directions over the course of this year.

In this, my last letter as HGS President, I would like to reflect on the past for reference to help develop a plan for a successful future for the Houston Geological Society. In the September 2024 HGS Bulletin, I proposed an overarching goal for HGS for the upcoming year. The goal was to build HGS's reputation as a premier Houston-area geoscience organization that promotes innovative technologies, research, and education. To accomplish this goal, I identified three objectives to guide HGS activities throughout the year; they were: 1) grow HGS's membership; 2) build HGS as a geoscience resource and networking organization; and 3) strengthen HGS's financial sustainability.

Through a united team effort, HGS has advanced in many incredible directions over the course of this year.

REFLECTING ON HGS'S 2024 – 2025 GOALS

HGS membership has experienced an exceptional increase in active, emeritus, and student membership categories during this year. The significant increase in student memberships, in particular, may be precursor of a future sustained growth in HGS membership by actively engaged geoscientists in our community.

HGS has significantly expanded its position as a geoscience resource and networking organization. There have been numerous influential initiatives that have driven HGS to be the Houston-area geoscience resource organization. An initiative largely spearheaded by Catie Donohue, HGS Vice President, was innovative change to our technical meetings resulting in increased attendance and expanded networking opportunities. Catie organized speakers with diverse talks on pioneering technologies and current research in geoscience. Catie also reorganized HGS meeting formats to include panel discussions, and varied the meeting locations to provide a variety of settings for technology exchange. An initiative led by Ted Godo, HGS Editor, focused on strengthening HGS's technology exchange through innovative and informative articles in HGS's monthly Bulletin. The technical articles in the HGS Bulletin were well received by our members and initiated numerous stimulating discussions. Initiatives by Angel Callejon and Thom Tucker, Co-Charis of Continuing Education Committee (CEC) improved the diversity and content of HGS's short courses. This year, seven short courses were organized, providing critical state-of-the-art training opportunities for Houston-area geoscientists. Recruiting initiatives by the Student Expo committee, chaired by Andrew Sterns, brought together over 300 graduate students and 22 companies in a highly successful career networking event for our future geoscientists. HGS has benefited from numerous initiatives by HGS's committees for our social events, educational outreach programs, and social media programs. All these initiatives have positioned HGS as the go-to geoscience resource and networking organization for our geoscience community.

Strengthening HGS's financial sustainability as a goal has been a year-long effort taken on by the whole HGS team, which included Board members, committees, volunteers, and staff. In September, the HGS Board approved a budget that had been developed by working together as a team to put in place a financially sound budget of expenses and revenues for the fiscal year. I am thrilled to announce that HGS is, at this time, projected to have a positive cash flow for this 2024 – 2025 fiscal year, which will be the first time in several years! This is a truly inspirational example of HGS'S multi-year dedication to support and overcome financial challenges.

LOOKING FORWARD TO 2025 - 2026

I am excited to announce that the HGS Board has approved the proposal recommended by the HGS website committee to build a new HGS website! This new website will be greatly improved over our current antiquated system. It will be more interactive, and it should provide much easier navigation to HGS's various menus,

From the President *continued on page 9*

The Houston Geological Society

It's time to

Renew Your Membership

$40 for Active and Associate
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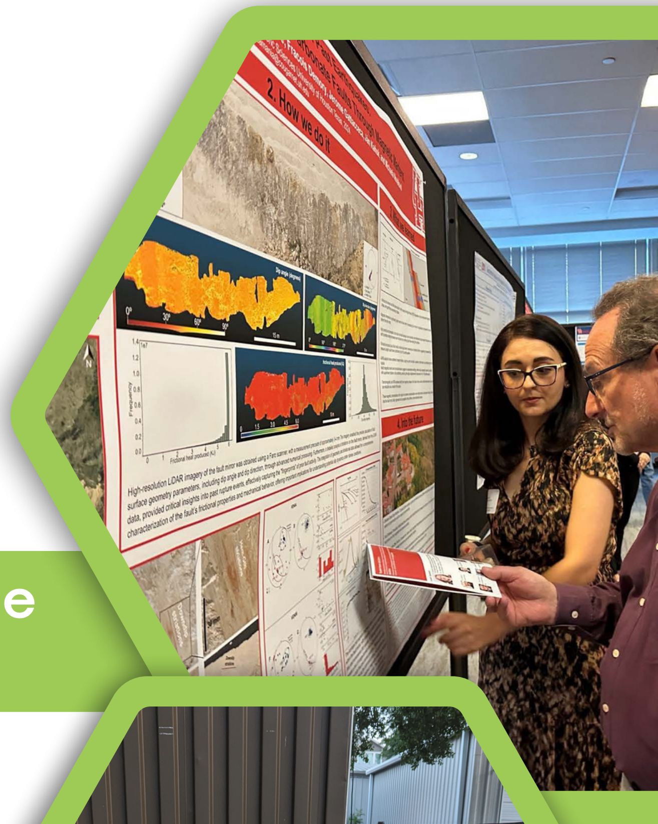

Why You Should Renew

- Free access to the monthly HGS Bulletin
- Discounted prices for meetings, social events, and short courses
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To pay by credit card, log into www.hgs.org using your existing username and password. Click on the Membership tab, then Renew Membership in the drop-down. For assistance, email office@hgs.org or call 713-463-9476.

RENEW NOW!

Please renew by JUNE 30, 2025!

Ted Godo, HGS editor 2024-25
editor@hgs.org

A Final Thanks for this Opportunity to Serve as your Editor

In my concluding "Letter from the Editor" for the 2024-2025 HGS Board Team, I want to express my gratitude to all HGS members who allowed me to serve in this role. This opportunity marked my first time as an editor, enabling me to learn about the various roles involved in producing the monthly *Bulletin*. One of the biggest challenges I faced was expanding my network to connect with individuals who might contribute technical or feature articles. I also learned that one barrier preventing contributors from submitting papers is that the *Bulletin* is not peer-reviewed; thus, authors needing peer-reviewed publications may feel hesitant to publish here. Therefore, I extend my heartfelt thanks to the individuals recognized as lead authors who did offer their technical articles for publication in the fiscal term of 2024-2025.

> *I extend my heartfelt thanks to the authors who offered their technical articles for publication in the fiscal term of 2024-2025*

October 2024 – Lorena Moscardelli

November 2024 – Joe Landry

December 2024 – (3 articles) Jamie Collard, Karen Carlson, and Craig Schiefelbein

January 2025 – Six technical abstracts from the University of Houston
- Kenneth Shipper -PhD candidate
- Daniel Maya -PhD candidate
- Estafani Ruiz Toro -MS candidate
- Jumoke Akinpelu -PhD candidate
- Ruth Beltran – PhD candidate
- Joshua Miller- MS candidate

February 2025 – (2 articles) Steven Naruk and L. Taras Bryndzia

March 2025- Wayne Camp

June 2025- (2 articles) James Pindell and Penny Patterson

The professional-quality look of the *Bulletin* results directly from the creative and consistent graphic designs of our graphic designer, Lisa Krueger. Year after year, Lisa acts as the essential glue that supports the ever-changing editors and staff of HGS. Lisa, I truly appreciate your suggestions and dedication. Andrea Peoples (Andi) has helped me immensely with organizational tips and the right contacts for the necessary information to perform my job. As the office manager, who has also been there for years, she takes calls from members and either answers them or redirects them to the appropriate contacts. Additionally, Andi knows where all the otherwise forgotten information lies and can help each new board member get "up the learning curve" faster. Beginning July 1, 2025, Lucia Torrado will assume the role of editor. I am confident that Lucia will excel in this role, especially since she has already made significant contributions this year by writing the "We Are HGS" column, which began mid-year. Each editor brings a distinct writing style and subject matter focus to the *Bulletin*, enriching it with a wide-ranging array of technical articles each year. Penny Patterson, as president, provided the leadership necessary for us to work together as a group on common goals. Catie Donahue, our VP, gathered an outstanding collection of speakers who covered diverse topics, and it showed by the increase in attendance.

This current *Bulletin* issue features three technical articles. The first article explores the recent stratigraphy uncovered along Buffalo Bayou in Houston. These articles conclude a two-part series, the first part of which appeared in the June 2024 *Bulletin*. Several authors contributed to both sections, and special thanks to Penny Patterson for leading the article in this *Bulletin*. The second article, by James Pindell and Teunis Heyn, focuses on the rapid early post-rift dynamo-thermal subsidence of the seafloor in the eastern Gulf of Mexico. My contribution, the third technical article, discusses the Gulf of Mexico's Differential Spreading and Subsidence, adding information to the Pindell and Heyn article. Finally, the "feature article" offers an engaging overview, sharing insights from experienced geologists and their managers on the "Characteristics of Oil Finders."

As a parting word, I am excited to see membership growth and interest in the Houston Geologic Society, especially with the new members and younger staff that hopefully portend a bright future for us all in the industry. And thank you again. ■

From the Editor

CALL FOR PAPERS

HGS MONTHLY BULLETIN

Would you like to share your groundbreaking research and insights with the Houston area geoscience community?

If so, submit your article to the HGS Bulletin, a high-quality journal published monthly by the Houston Geological Society.

Featured Articles

Technical Articles

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Submit your article »»» **editor@hgs.org**

From the President *continued from page 5*

links and sites. The new website is scheduled to be installed in mid-June to early July. So, please be patient during our transition to a new website! It's going to be great!

On July 1, 2025, the outgoing HGS Board members will hand over the reins to the 2025 - 2026 HGS Board. In discussions with the incoming HGS Board members, they are all excited to roll up their sleeves and move forward. President-Elect Patty Walker has worked alongside the current HGS Board and is already enthusiastically working on initiatives for the coming year.

THANK YOU TO HGS SPONSORS!

HGS extends a sincere and heartfelt thank you to all our sponsors that have contributed to our success over this past year! Your generous contributions have enabled HGS to host 24 technical lunch and dinner meetings, 2 conferences with joint geoscience societies, 7 short courses, 3 career networking programs, 4 outreach and STEM programs, and 14 social events. All these events have brought together our geoscience community to exchange innovative technologies and research and provide educational programs for our geoscientists.

In closing, again I would like to say that it has been a great honor to serve as HGS President this past year. I thank each of you for your support and encouragement during the course of my term. It has been an absolutely fantastic experience working with the HGS team, engaging with HGS members at the many venues and working with HGS's dedicated professional staff. Admittedly, it's taken a lot of work by a lot of people, but it's so satisfying to see the results of our hard work contributing to the growth of our understanding of our Earth! ■

I look forward to seeing you at our meetings this fall!

We Are The HGS

Kenneth Werner, HGS member since March 2025

A geologist with a rich international background, Ken grew up in Marin County, California, after his parents immigrated from Germany and Norway to San Francisco. Surrounded by linguistic diversity and inspired by a neighbor who worked at Chevron's refinery and spoke enthusiastically about the field, Ken's interest in geology began to take root early on. "I would babysit his kids," he recalls, "and he would talk about how much fun the geologists down the hall were having." Although he initially pursued biology in college, an aptitude test and a single, inspiring geology course in his junior year shifted his focus to a discipline that offered "the 3-dimensional aspect of problem solving, the ability to be outside in the field, and the never-ending opportunity to learn about related sciences."

Ken joined the HGS to connect with peers across the industry, stay informed on the latest developments in geoscience, and give back by supporting and mentoring early-career geoscientists.

Ken has enjoyed a diverse and fulfilling career in geology, starting with UNOCAL, where he developed deep technical expertise across several regions, including California, the Gulf Coast, and Indonesia's Kutei Basin—where he participated in the discovery of the Sadewa field. His role as a development and exploration geologist provided hands-on experience, from onshore rig site work to deep-water fields. After Chevron acquired UNOCAL, Ken embraced leadership opportunities while staying grounded in his technical roots, eventually leading teams in Thailand and the Gulf of Mexico. Now serving as Hub Leader for Deepwater and Conventional projects, Ken finds joy in collaboration and global engagement. "I get to learn so much while making a difference to the bottom line," he says, highlighting his passion for both learning and impact.

Outside of work, Ken enjoys spending time with his wife, Amy, and their five children—one of whom works for the Climate Leadership Council in Washington, D.C.—traveling, and playing board games. Having previously participated in the Southeastern Geological Society in Louisiana, joining the HGS seemed like a natural next step. ■

We Are The HGS is a series that highlights the careers and contributions of HGS members with the intention of building community. Would you like to be featured in We Are The HGS? Send a note to editor@hgs.org.

Characteristics of *Oil-Finders*, a Collection of Opinions

By Ted Godo

What is an *oil-finder*? Wallace Pratt defined it with a memorable and perhaps prescient summary in his 1952 paper. Pratt's statement reads: "Where oil is first found, in the final analysis, is in the minds of men. The undiscovered oil field exists only as an idea in the mind of some *oil-finder*. When no man any longer believes more oil is left to be found, no more oil fields will be discovered, but so long as a single oil-finder remains with a mental vision of a new oil field to cherish, along with freedom and incentive to explore, just so long new oil fields may continue to be discovered." (Pratt, 1952). What qualities constitute the mind of an *oil-finder* or that of a lithium or white hydrogen finder, or any other subsurface finder of natural resources? Let us explore how others perceive these qualities.

In this final feature article of my editor's term, I thought it would be helpful and at least interesting for readers to hear how other *oil-finders* and their managers characterize their most important traits or skills. My plan for this article was to contact potential participants, saying: "I plan to write an introduction to the feature article and then include yours and others' responses (verbatim), without identification or using any names." "The paper aims to help our readers, especially younger readers, learn more about exploration and what they may need to do to become better *oil-finders*."

Ten participants responded to the questionnaire, and their responses are listed below.

PARTICIPANT #1

Oil-finders are people who are optimistic skeptics. They approach the exploration of a potential trend with the courage to accept certain assumptions made by their peers while challenging others. They immerse themselves in the regional geology of the trend with the ability to visualize the analogous attributes of its hydrocarbon traps, sometimes tens of miles apart. They accept disappointment with humility but learn from their mistakes, and this tenacity eventually enables them to succeed in finding oil where others have failed. Also, prospects are most compelling when their generators can effectively convey the concept and the excitement of potential discovery to the "audience" (other professionals, deal screeners, investors, etc.). The ability to create compelling presentations is very important. The "steak" must have the "sizzle".

PARTICIPANT #2

Two special "traits" of my *oil-finder* are a "sense of curiosity" and the ability to assemble and communicate the story.

A trait common to many successful explorers is a "sense of curiosity"— the drive to learn more and ask questions. Exploration success often results from finding and effectively assembling a variety of data and information related to elements of the petroleum system and using these to identify opportunities/prospects.

The process of exploration can be likened to putting a puzzle together. As more pieces of the puzzle are assembled, the picture becomes clearer. Similarly, the more definitively each petroleum system element is characterized, the clearer the understanding of an exploration opportunity becomes. Often in exploration, there are some pieces of the puzzle missing or incomplete. Here, the successful explorer uses their knowledge, experience, models, and interpretations to fill the gaps. Then they need to effectively tell the story to characterize the opportunity, including the risks and potential rewards.

PARTICIPANT #3

What is the best part of being a geologist – the ability to use both the creative and analytical sides of our brains. This is what makes our science special. Nobody was around millions of years ago to see what was really going on at the time of deposition. We need to use our creativity and imagination to take the data we have and build a picture of the ancient world, and then fast-forward that timeline to today. Then we need to put thousands of feet of mud, salt, and water on top of it and deduce how hydrocarbons would enter and stay in a trapping configuration,

Once you have grasped this concept, it also requires ample optimism and conviction to understand the subsurface and convince yourself and others that this knowledge can be unlocked in the form of a future hydrocarbon field. But when you drill that idea and find hydrocarbons in a zone that has never been found before, the anticipation of which is like a child at Christmas, turns into an exhilaration that can rival any professional excitement found in any business.

PARTICIPANT #4

"The Explorer's Mindset, coined by Cindy Yeilding in her AAPG Distinguished Lecture, explains that with technical excellence, creativity, business acumen, an ability to tell a compelling story to bring your peers along on the journey of the prospect, and with tenacity paired with grace, any explorer can experience success in finding new resource. It may not be the next Thunder Horse - it may be the next Coral-Mamba, or Pikka-Horseshoe, or Zama. While the Explorer's Mindset traditionally focused on oil and gas,

Characteristics of *Oil-Finders* *continued on page 13*

it can be applied across the "new energies" spectrum and will be applicable for as long as humans need to explore the earth for resources."

"At the Denver Explorers Club last April, one of the lunch attendees asked, "If you had to sum up in one to two words, what distinguishes the most successful explorers, how would you describe them?" I'd never been asked that, to sum up years of studying successful explorers in 1-2 words, but it was an easy question to answer. I answered, "They listen." The best explorers listen to the data, the earth, their teams, even the quiet voice inside that guides them on the right path to find the next big field. They even listen to the thoughts that tell them, "This prospect will never work," and they find ways to test those alternative interpretations before drilling."

Characteristics of *Oil-Finders* continued on page 14

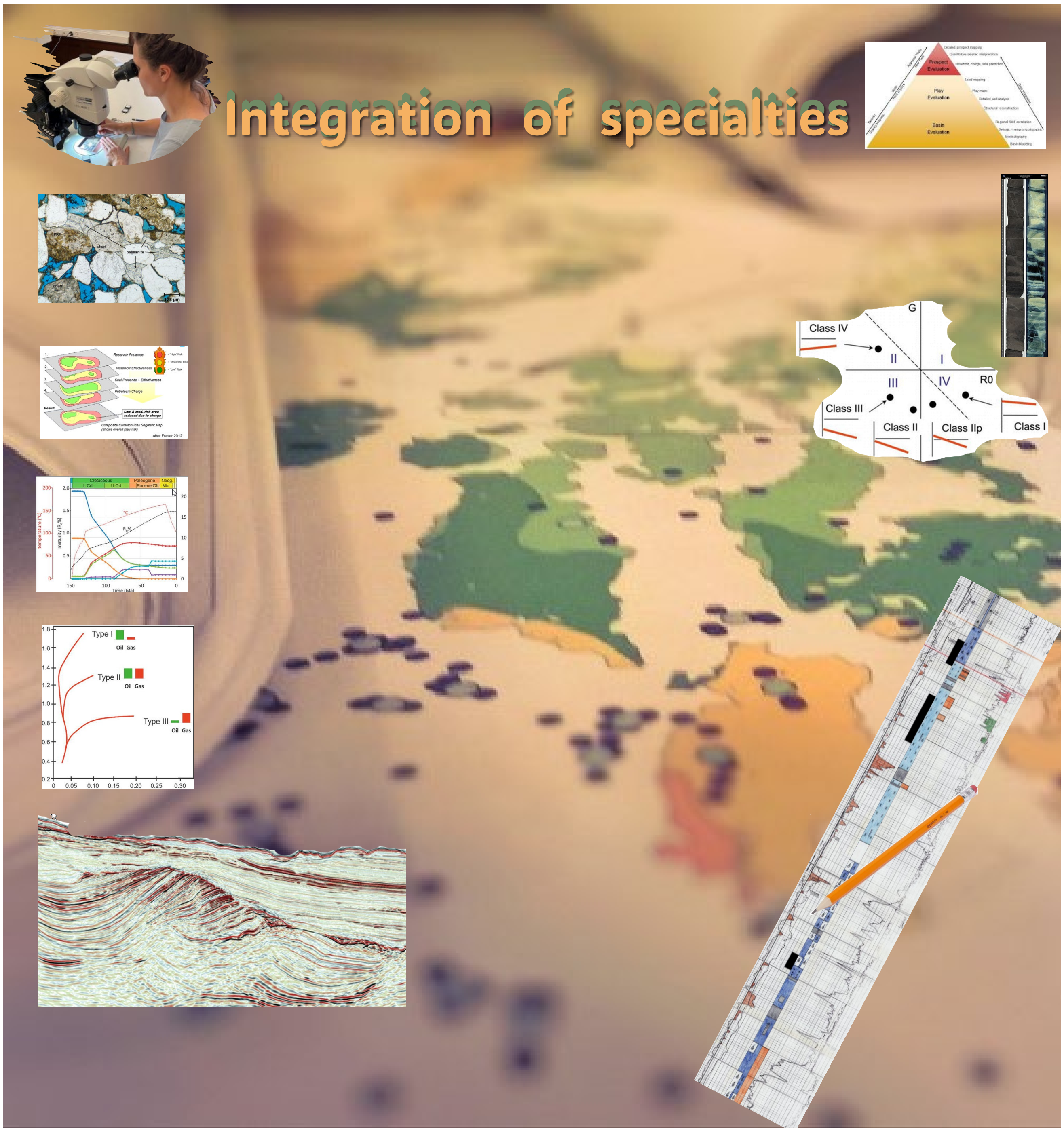

Figure 1 *is the same map used on the cover but enhanced with additional illustrations of other subsurface information, including the geochemistry of source rock types, basin modeling seismic, AvO, CRS (common risk segment mapping), and the play-based triangle of integration from regional to prospect maturation.*

Characteristics of *Oil-Finders* continued from page 13

PARTICIPANT #5

I think of Exploration as the most fun, high-stakes version of "connect the dots" that exists! To be successful, Explorers need to have a strong technical foundation that guides their insight while also preserving a curiosity to investigate discrepancies and conflicts in the data and models. They need to be able to fill the whitespace with constrained creativity while imagining what possible success looks like. The combination of disciplined application of technical expertise while challenging your own assumptions and dogmas takes a special type of person. So, my advice to the young explorers is develop and deepen your technical skills, and then question everything!

PARTICIPANT #6

Many of the responses in this article will likely involve a combination of being open-minded, being creative, questioning paradigms, climbing the technical learning curve, and being a good communicator, among others. While these traits are certainly partly true, context and luck play, a major role in determining who finds hydrocarbons and who does not. Luck can be based on technical skill and experience, but luck can also mean being in the right place at the right time – being on the right team with the right coworkers, being in the right company with the right strategic approach, or just serendipity.

In over 45 years of experience and having worked with hundreds of geoscientists, I can count on two hands the number of individuals who have actually found commercial oil and gas on their own or in a small team. Throughout my career, I have held many positions, ranging from junior geologist to regional geologist, exploration manager, vice president, and president, ultimately becoming CEO. Each of these roles enabled me to drill 19 exploration wells, over half of which resulted in discoveries. However, if you only have the opportunity to drill perhaps three wells in your career, you may come up empty, even though you have done everything right. Perhaps one of the most important tasks was not just finding hydrocarbons, but knowing when to tell management something won't work. I recommended against company acquisitions, new plays, acreage acquisitions, and exploration wells that I knew wouldn't work, and in some cases, they ended up costing tens of millions of dollars because I wasn't able to convince the higher-paid "help" not to move forward with them.

The plain truth is that this oil and gas business isn't the one I learned in and grew up in 45 years ago. It is fundamentally different, not just considering the great new software available, but also the task at hand, corporate structures, and staffing of the companies still looking for new resources. Regarding corporate strategies and staffing, first off, there were many more companies 45 years ago actively exploring for oil and gas. Secondly, more companies today, have broken up oil exploration into teams doing ILX, or infrastructure-led exploration. This limits you to doing step out work or new/deeper stratigraphic horizon stuff in a mature basin, compared to being a part of a new ventures team, that looks for truly new areas or revisiting once discarded plays in new basins.

Lastly, there is the issue of staffing. How many senior people are available to younger, less experienced geoscientists so they can ask those "old folks" simple, yet profound questions? Questions like, what am I missing? Or, am I wasting my time? Or, what's been done here before, by us or by others? Just those basic questions can improve the efficiency and speed of the exploration process by factors of ten or better.

Finally, is the old saying that "I'd rather be lucky than smart". It may work once. Maybe that's all it takes for some. However, being both smart and lucky can make you successful multiple times.

PARTICIPANT #7

This quote, by Jack Oliver (in the Incomplete Guide to the Art of Discovery), encapsulates the spirit of Discovery Thinking: "The way to enhance serendipity is to observe the process of discovery by others and to recognize patterns of behavior and activity that, while not guaranteeing discovery, can nevertheless improve one's chances for discovery significantly... To discover, act like a discoverer."

The best *oil-finders* have a mentor(s), and professional societies offer resources that can help mentor all of us. Immersion in economic analog discoveries, such as the AAPG Discovery Thinking program, communicates high bandwidth maps, cross sections, seismic images, and stories that stimulate thought patterns elsewhere with "lateral thinking."

Oil-finders can integrate aspects of the Exploration Pyramid at the basin, play, and prospect scale with creative partners that challenge and combine local and regional knowledge (geologists) with process-minded analysis (geophysicists and engineers).

Exploration is competitive, so defining a winning strategy and choosing the right area is essential. Exploring and following source rocks in proven petroleum systems is important. I have been involved in a portfolio of prospects with one main risk to improve chance factors while maintaining continuity of effort, play-based analysis, and continuous learning. Having the right fit-for-purpose team aligned by commercial goals is essential.

Here are some resources for the reader: https://www.aapg.org/resources/videos/dpa

PARTICIPANT #8

Looking at the term *oil-finder*, I see a split from the classic geophysicist, classic geologist, and a mixture of the two end members.

Characteristics of *Oil-Finders* *continued on page 15*

The classic geophysicist is a person who can handle the data from acquisition, processing, and interpretations. We sometimes forget that interpretation begins with processing and many early decisions affect the outcome of the data quality and interpretation. As we all know the ability to interpret, especially in the areas of low-quality data like subsalt or presalt, is really both artistic and interpretative. Sometimes, these high-quality interpreters "see" things that us normal people cannot.

The classic geologist understands the rock/reservoirs and quality, the migration tendencies from the source rock, the tank size likelihood of the reservoirs, and many other geologic and trap processes (such as pore pressure).

Most people are paired with each other to interpret the risks and outcomes of each opportunity.

The term *oil-finder* is usually misrepresented as the "team" is the *oil-finder* of our modern, very technical world. However, there have been a few people in my career who are really the *oil-finders* of old. There were people who had the ability to review an idea or find a prospect and intuitively could say to their boss, we need to drill this one. The person was immediately able to process all the variables. It was an amazing trait.

But the most important part of the capability is for these people to never be satisfied with the work, the quality of the data, and their interpretations. They continually do look-backs on everything to continually improve.

PARTICIPANT #9

Breadth of Geoscience Knowledge: A complete geoscientist with a broad understanding of all key geoscience competence areas and the ability to integrate into a regional, play, and prospect assessment.

- **Broad experience:** having worked in numerous basins and plays and in all parts or the business, Exploration, Development, and Production.
- **Curiosity and optimism:** Become a why person and keep challenging paradigms, looks for clues and signal from all data, even if subtle. Maintain a cautiously optimistic outlook of what could be possible in assessment and recommendations.
- **Technology:** identify the key risks and uncertainties and use available and new technologies to address, unlock, and derisk the potential prospects.
- **Risk taking:** With the team build the narrative to make bold recommendations to drill the exploration wells.
- **Continuous learning:** Be a "sponge" from all sources of data and information to build and rebuild your evaluation story with humility, realizing that our Exploration business is highly uncertain with multiple explanations for the same data.

PARTICIPANT #10

Try to learn something new every day. Learning not only involves your specialty craft but also encompasses some fundamentals of other specialties, which help you understand the "error bars" of your input assumptions better. Communication and iteration of the model with your colleagues result in a better-integrated model. Some examples of the related skills I am referring to include geochemistry, basin modeling, geophysics, rock properties, paleontology, mud logging descriptions and shows, carbonate and clastic facies, and stratigraphy.

Company policies may change, but geological fundamentals remain constant. Critical thinking and teamwork will help you secure your job and build a lasting career. Continue to ask questions and encourage coworkers to challenge you.

The two most important characteristics to develop are the desire to ask questions and the ability to tell stories. Natural probing curiosity often leads to those "ah-ha" moments when different observations come together to form a story. A natural storytelling ability integrates otherwise disparate observations, weaving them together to create a cohesive argument or pitch. Furthermore, it is the most effective form of understanding in communications.

SUMMARY

I want to express my gratitude to all the participants who shared their responses. It was fascinating to receive diverse comments from various companies and backgrounds. I noted several common traits in the WORD Search puzzle, but I encourage you to form your own conclusions. I believe this article serves as a fun concluding piece. Thank you.

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https://www.aapg.org/divisions/dpa/resources/currentpage/1

Wallace Everette Pratt (1885–1981) was a pioneering American petroleum geologist. In 1918, Pratt joined Humble Oil & Refining Co. as the company's first geologist. As one of the founders of AAPG, Pratt was elected its fourth president in 1920. Throughout his lifetime, many honors were bestowed upon Pratt. One of his legacies is the establishment of the Wallace E. Pratt Memorial Award in 1982, which is given to the best AAPG Bulletin article published each year.

Word Search

Oil Finder Characteristics

U	F	R	Y	C	B	V	R	Y	T	L	E	F	P	R	N	Z	M	U	O
P	W	C	L	B	Y	V	G	Q	A	Z	H	X	B	C	U	C	G	K	P
S	F	Y	D	W	N	G	F	A	Y	H	O	J	X	O	T	P	C	T	T
F	T	Q	M	H	S	A	K	N	P	B	F	P	L	M	C	B	K	D	I
R	I	Q	Y	B	N	V	X	V	X	X	N	U	O	M	W	T	O	G	M
F	N	N	U	K	C	P	D	Q	I	W	A	D	O	U	T	G	U	B	I
L	T	P	D	E	O	B	L	H	Q	L	G	Y	K	N	L	T	S	U	S
J	E	I	T	S	S	A	F	F	U	W	B	L	B	I	V	R	V	Z	T
U	G	X	I	L	N	T	T	D	A	F	A	X	A	C	E	R	H	X	I
L	R	M	Q	E	Q	L	I	S	D	K	W	O	C	A	A	Y	M	G	C
J	A	C	W	A	J	T	R	O	G	S	E	V	K	T	P	R	I	Q	V
H	T	M	F	R	K	D	R	X	N	U	O	O	S	I	A	V	Q	F	E
Z	I	L	Q	N	C	V	L	S	T	I	P	W	O	O	S	X	H	E	Q
Q	N	K	T	I	R	L	N	X	X	L	N	K	K	N	S	P	S	W	X
D	G	D	Y	N	E	H	T	F	S	K	R	G	A	F	I	K	J	G	A
J	A	C	X	G	A	S	C	Y	M	D	O	F	A	T	O	F	X	B	F
R	O	M	E	N	T	O	R	S	H	I	P	A	M	A	N	Q	J	E	O
H	H	C	U	R	I	O	S	I	T	Y	D	J	J	O	P	Z	D	W	P
F	J	J	R	H	V	Q	L	M	K	V	O	R	C	R	K	F	I	H	X
N	V	O	C	V	E	I	S	N	I	H	W	K	G	V	Y	R	Z	T	C

Communication
Questioning
Integrating
Mentorship
Curiosity
Creative
Learning
Optimistic
Lookbacks
Passion

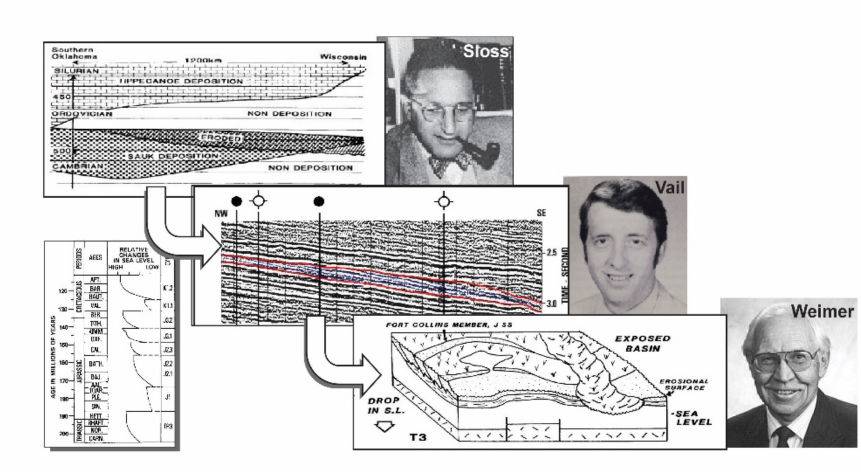
The GCSSEPM Foundation 41st Annual Perkins-Rosen Research Conference

17-19 November 2025 Houston, TX

Cycles and Sequences, So What?

A 21st century perspective in memory of Peter Vail, Bob Weimer, and Larry Sloss

Announcement and Call for Papers



With the recent passing of Pete Vail and Bob Weimer and the approaching 50th anniversary of the publication of AAPG Memoir 26, not to mention the recent retirements of the 1st generation that grew up with Memoir 26 and the rise of new generations of practitioners and innovative techniques, it is a propitious time to take stock of sequence stratigraphy in particular and applied stratigraphic analysis in general: where it came from, where's it going, and what's it good for…and to pass along hard-won practical lessons.

This year's conference features a hybrid program of short talks by practitioners who worked with Vail, Weimer, and Sloss, as well as those who have applied and expanded their concepts, hands-on exercises, discussions, case-study talks, and panel discussions that illustrate each of four focus areas:

- **Historical Perspectives** on the development of present-day integrated stratigraphic analysis since Sloss (e.g., incorporation of high-resolution age control and seismic, expansion to non-marine systems, etc.).
- **Regional- to basin-scale** concepts and applications (e.g., cycle chart uses and abuses, tectonic influences, systematic changes in reservoir-target age across a basin, etc.).
- **Play- to field-scale** concepts and applications (e.g., incised valleys, resource plays, sub-unconformity plays).
- **Practical applications** and tools for energy and other resources (groundwater, GCS/CCUS, H2 storage) and planets.

This program will offer opportunities to examine classic data sets in a series of collaborative exercises, affording a shared experience to focus discussion of foundational concepts…and assumptions…considering more than 50 years of application, experience, and innovation. We welcome industry and academic practitioners who have tested, applied, improved, and expanded these concepts, students and practitioners who would benefit from understanding their development and application, and researchers looking for new opportunities to advance these concepts.

We invite a diverse set of papers illuminating the history of integrated stratigraphic analysis and the near-term and long-range future, especially those that explore the practical application of such analyses to hydrocarbon and critical mineral exploration, groundwater, geothermal, and emerging resource exploitation, and the interpretation of the geological history of Earth and Mars. Student posters and presentations are encouraged.

Organizing Committee - Conveners

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Steve Sonnenberg: ssonenberg@mines.edu; Colorado School of Mines, Golden, Colorado

Important Dates and Deadlines Perkins-Rosen Research Conference 2025:

June 1, 2025	Expression of interest: Provide title of presentation and brief abstract
June 30, 2025	Preliminary Program Announced
August 4, 2025	Abstracts, Extended Abstracts and Full papers due
October 3, 2025	Final revised manuscript and illustrations due
November 17-19, 2025	Conference in Houston

Abstract submission opening soon at: https://sepm.org

Venue to be announced soon at: https://sepm.org

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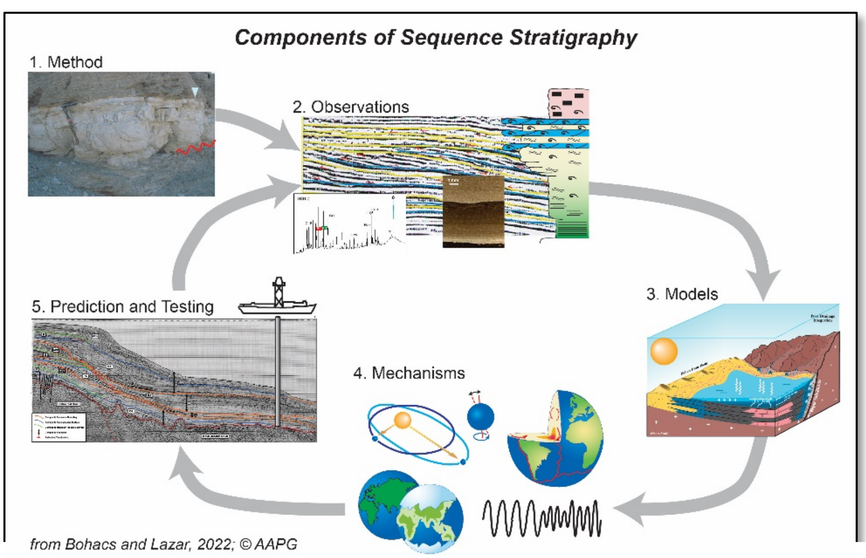
For more information, or to sponsor the Conference, contact John R. Suter, Executive Director, The GCSSEPM Foundation at gcssepm1@gmail.com.



Sedimentology, Sequence Stratigraphy, Diagenesis, and Paleogeographic Reconstruction of the Beaumont Formation, Late Pleistocene, Buffalo Bayou, Houston, Texas

By Penny Patterson, Jerry Kendall, Angela Schwartz, Joshua Novello, Will Gaston, Richard Lang, Dorene West, Justin Gosses, and Caroline Wachtman

INTRODUCTION

Laterally extensive outcrops of the Beaumont Formation, Late Pleistocene, are exposed along the embankments of Buffalo Bayou that transect the greater Houston area. These outcrops have been under studied, in part, because dense vegetation, wildlife, and treacherously steep embankments limit their access from the surface. However, with the use of kayaks, Beaumont strata can be observed during low-water stages of Buffalo Bayou (~1 foot height at the Shepherd Bridge Gage). This study of the Beaumont Formation, which was conducted by kayak, provides new information and interpretation on the stratigraphic setting and depositional history of the Houston area during the Late Pleistocene.

In 2024, a group of Houston area geologists formed the Buffalo Bayou Study Group and commenced an investigation on five Buffalo Bayou outcrops between the Woodway Boat Launch and Shepherd Bridge. The initial study focused on paleo-flow analysis and documented lineaments present along Buffalo Bayou (Kendall et al., 2024).

The Buffalo Bayou Study Group expanded the scope of their evaluation in 2025 to closely examine the Beaumont, which is characterized as "interdistributary mud facies" on United States Geological Survey (USGS) maps (Pope et al., 1990). Although this study supports that description, we further add to the understanding by documenting the spatial and temporal changes in depositional environments, the expression of sea level fluctuations on stratal architecture, and the extent of in situ diagenesis in Late Pleistocene sediments. In addition, we infer paleoshoreline positions for the last 130,000 years.

GEOLOGIC OVERVIEW

In this paper we use the Quaternary geologic formations as defined and mapped by the USGS in the publication "Quaternary Geologic Mapping of the White Lake 4 x 6 Quadrangle" by Pope et al. (1990). This geologic map encompasses the Gulf Coast region of Louisiana, Mississippi and Texas and is a detailed compilation

Sedimentology, Sequence Stratigraphy, Diagenesis *continued on page 20*

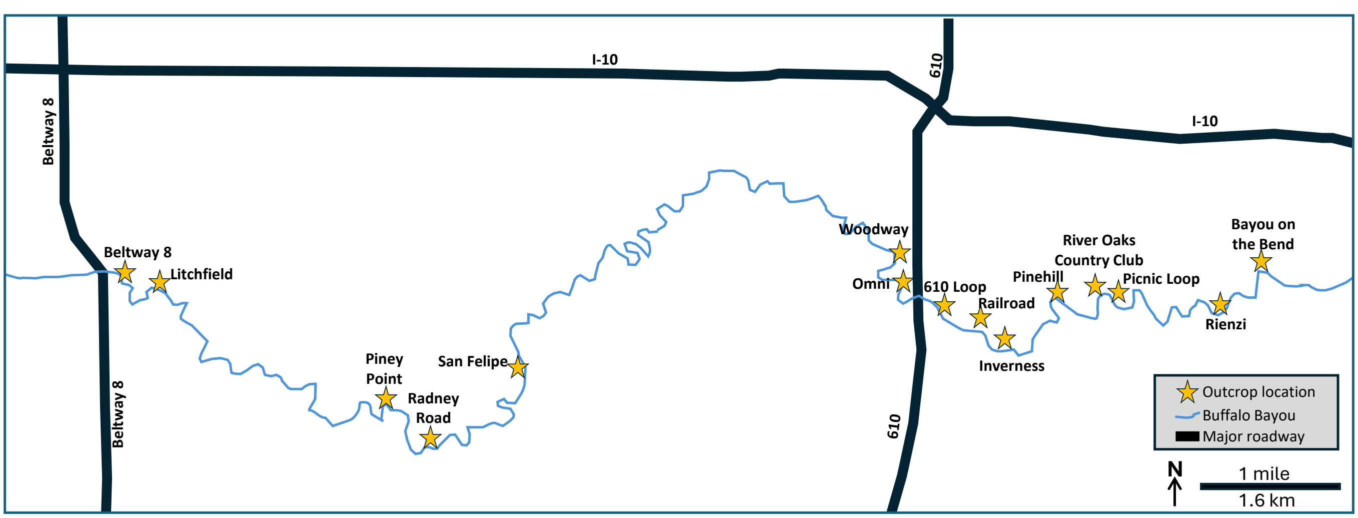


Figure 1. *Map of the study area and location of the 15 measured sections.*

of Quaternary units across the three-state region. The USGS completed this compilation in cooperation with the Louisiana Geological Survey, Mississippi Geological Survey, and the Texas Bureau of Economic Geology.

The Beaumont Formation is Late Pleistocene, ranging in age from 70 to 130 Kya (Winker, 1979; Baker, 1995; Blum, 1995; de la Garza, 2019). In the context of marine isotope stages, the Beaumont Formation is interpreted to have accumulated during Sangamon Interglacial Stage. This time period is interpreted to be the last interglacial period and is characterized by higher global temperatures and sea levels than in the present day (Shackleton et al., 2003). The Beaumont Formation is a mud-prone interval that is underlain by sand-prone clastic strata of the Lissie Formation (Pope et al., 1990; Baker, 1995). The Lissie Formation is Middle Pleistocene in age and is interpreted to have accumulated as an aggradational fluvial system dominated by sand-prone fluvial channels (Pope et al., 1990). Beaumont strata are overlain by alluvial terraces of a coastal-plain fluvial system (Blum, 1995).

STUDY AREA

The Beaumont Formation was examined along the embankments of Buffalo Bayou spanning ~20 km from Terry Hershey Park to the Shepherd Street Bridge, Houston, Texas (**Figure 1**). Outcrops of the Beaumont strata range from 1 to 5 meters in thickness. Because of the sinuosity of the Bayou, lateral correlations were limited to approximately 300 to 500 meters in length.

METHODS

Access to the Beaumont Formation outcrops was accomplished by kayaking down Buffalo Bayou, which enabled numerous relatively continuous views of the strata. Detailed facies analyses of lithofacies and lithofacies associations were conducted on 15 representative outcrops (**Figure 1**). Lithofacies are defined based on grain size, stratal color, composition, and sedimentary bedding. Stratal color was determined by use of the Munsell Soil Color Chart (Munsell, 1975). Post-depositional modifications were described within the context of lithofacies and include soft sediment deformation, bioturbation, rhizoliths, and pedogenic modifications. Stratal thickness was visually estimated. Samples were collected from four outcrops for petrographic analysis. Global Positioning System (GPS) locations for all the outcrops were obtained using Gaia and the Petroleum Experts Clino iPhone applications (**Figure 1**).

LITHOFACIES AND LITHOFACIES ASSOCIATIONS

Beaumont strata observed along Buffalo Bayou consist of four lithofacies: mudstones, sandstones, muddy conglomerates, and carbonates. A brief description of each lithofacies and their association is described below.

Mudstone Lithofacies

Mudstones are the most abundant (> 90%) lithofacies in the Beaumont Formation within the study area. The authors observe two mudstone lithofacies: moderately laminated reddish-brown mudstone lithofacies and moderately laminated gray mudstone lithofacies.

Moderately laminated reddish-brown mudstone lithofacies: Reddish-brown (2.5 YR 4/4), moderately laminated mudstones are the most commonly observed mudstone lithofacies (Figure 2). Laminations vary in thickness from approximately 1 to 10 cm and can be traced along the Bayou for ~100 meters. In some cases, laminated reddish-brown mudstones are underlain or overlain by massively bedded reddish-brown mudstones that contain dispersed nodules that are approximately 1 to 5 cm in diameter (**Figure 2**). The dispersed distribution of carbonate nodules within the mudstones differs from that of carbonate accumulations in soil profiles (Birkeland, 1999). Hence, they are not interpreted to have formed due to pedogenic processes. The carbonate nodules are interpreted to have formed within a shallow-water saline bay. The lithofacies association with the underlying laminated gray mudstone containing sand lenses interpreted to be starved current ripples is consistent with an interpretation that these lithofacies accumulated within a low-energy, mud-prone bay (**Figure 2**).

At some locations, the authors observe laminated reddish-brown mudstones, that are overlain by dark reddish-brown mudstones (2.5 YR 5/4) that possess pedogenic features including angular blocky pedogenic structures, filamentous rhizoliths (**Figure 3**) and rare vertical (~20 cm in length and ~5 in diameter), unlined calcareous burrows (**Figure 4**). These features are characteristic of early stages of argillic and carbonate accumulations and, hence, are interpreted as Inceptisols that developed on the reddish-brown mudstones (Birkeland, 1999; Soil Survey Staff, 1999).

Laminated gray mudstone lithofacies: Laminated gray (N5) mudstones are commonly interbedded with discrete lenses of current rippled sandstones distributed along mudstone bedding planes. (See the description of current rippled sandstone lithofacies below.) Laminated gray mudstones are sharply overlain by reddish-brown mudstones that contain dispersed carbonate nodules (**Figure 2**).

Sandstone Lithofacies

Sandstone lithofacies comprise a minor proportion (~ 5%) of the Beaumont Formation outcrop exposures along the transect of the study area. Sandstone lithofacies are light reddish-brown (5 YR 6/4) in color and are generally moderately sorted to well sorted. Four sandstone lithofacies are observed: scour-and-fill lithofacies, planar laminated lithofacies, trough cross-bedded lithofacies, and current rippled lithofacies.

Scour-and-fill lithofacies: A prevalent sandstone lithofacies is a

Sedimentology, Sequence Stratigraphy, Diagenesis continued on page 21

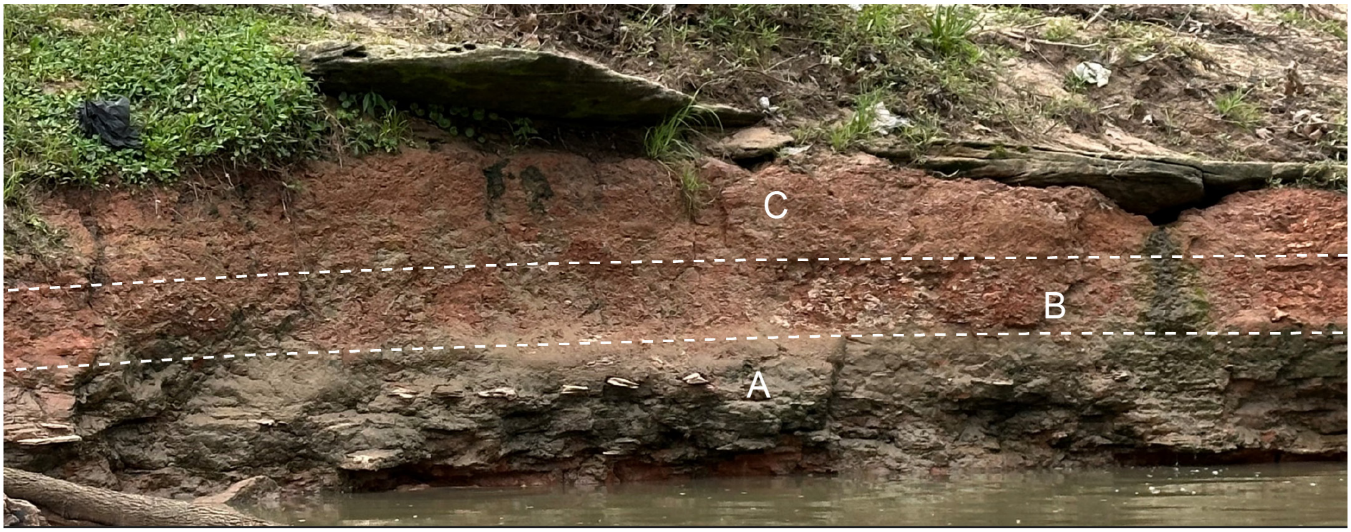


Figure 2. *Mudstone lithofacies: (A) laminated gray mudstone with starved current ripples, (B) reddish-brown mudstone containing carbonate nodules; and (C) weakly laminated reddish-brown mudstone.*

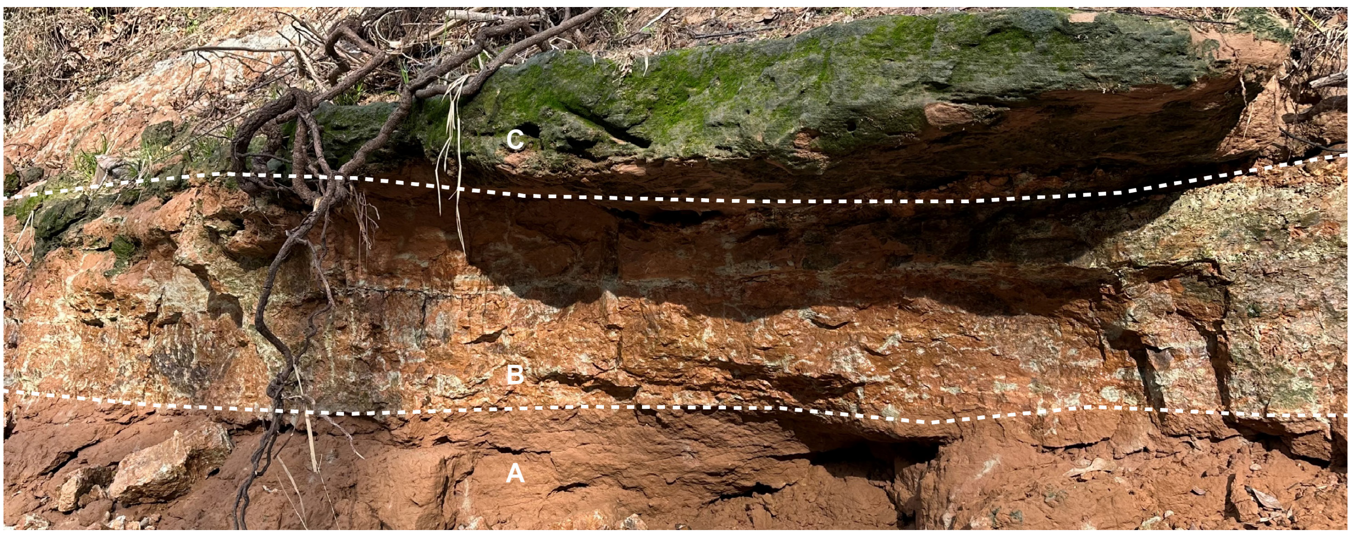


Figure 3. *Mudstone and sandstone lithofacies: (A) massive to weakly laminated reddish-brown mudstone, (B) Inceptisol characterized by thin filamentous rhizoliths, (C) trough cross-bedded sandstone.*

Figure 4. *Reddish-brown mudstone disrupted by vertical, unlined burrows.*

Sedimentology, Sequence Stratigraphy, Diagenesis *continued on page 22*

Figure 5. *Scour-and-fill sandstone lithofacies showing (A) thin laminae sets that onlap low-relief scours and (B) convex and concave laminae geometries of laminae sets.*

Figure 6. *Planar laminated sandstone lithofacies interpreted as low-concentration turbidite deposits.*

Sedimentology, Sequence Stratigraphy, Diagenesis continued on page 23

Figure 7. *Trough cross-bedded sandstone lithofacies.*

moderately well-sorted, lower fine-grained to upper fine-grained sandstone that possesses low-relief, curvilinear laminations. Curvilinear laminae occur as both convex and concave stratal geometries that onlap low-relief scours (**Figure 5**). These characteristics are unlike those of flat, horizontally laminated upper flow plane-bed sandstones that form under tractional depositional conditions. Rather, these lithofacies are interpreted to have formed from low-concentration sediment gravity flows. This lithofacies is referred to herein as a scour-and-fill lithofacies.

Planar laminated lithofacies: The second prevalent sandstone lithofacies is a well-sorted, lower very fine-grained to upper very fine-grained planar laminated sandstone (**Figure 6**). This lithofacies is overlain by the scour-and-fill lithofacies and is underlain by reddish-brown laminated mudstones. This sandstone lithofacies is interpreted as finer grained, low-concentration sediment gravity flow deposits that accumulated downdip of the scour-and-fill lithofacies and, hence, are interpreted as low-concentration turbidites.

The lithofacies association of laminated mudstones overlain by finer-grained planar laminated sandstones that are overlain by scour-and-fill sandstones, which, in turn, are overlain by cross-bedded sandstone, is interpreted as deposits that accumulated from bayhead deltas that shed clastic detritus into marginal marine bays.

Trough cross-bedded lithofacies: Trough cross-bedded sandstone lithofacies is less commonly observed. Trough cross-bed thicknesses range from ~0.2 to 0.7 meters, and grain sizes range from upper fine to coarse sand (**Figure 7**). Trough cross-bedded sandstones that are underlain and overlain by pedogenically altered mudstones are interpreted as fluvial channel sandstones that accumulated on the delta plain. This trough cross-bedded lithofacies is also commonly associated with mudstones that possess burrows and rhizoliths (**Figures 3** and **4**). Trough cross-bedded sandstones that overlie the scour-and-fill lithofacies are interpreted to represent marginal marine fluvial channels situated near the shoreline and that transported sediment to the bayhead deltas.

Current-rippled lithofacies: The fourth sandstone lithofacies is composed of discrete lenses of lower very fine-grained current-ripple sandstones that are encased in laminated gray mudstones. The lenses of current-rippled sandstones are sparsely dispersed along mudstone bedding planes (**Figure 2**). In addition, these current ripples display bi-directional cross-bedding consistent with formation in a tidal environment characterized by relatively uniform, flood and ebb, low-flow conditions. Based on these sedimentary characteristics, the authors interpret this lithofacies as starved current ripples that accumulated within a low-energy tidally influenced bay.

Muddy Conglomerate Lithofacies

Muddy conglomerate lithofacies comprises a minor proportion (~ 1%) of the outcrop exposures observed along Buffalo Bayou and primarily occurs between the Woodway and Inverness outcrops. Two muddy conglomerate lithofacies are observed: mud-dominated conglomerate lithofacies and cross-bedded muddy conglomerate lithofacies.

Sedimentology, Sequence Stratigraphy, Diagenesis continued on page 24

Figure 8. *Muddy conglomerate lithofacies. (A) Massive, muddy conglomerates interbedded with cross-bedded muddy conglomerates (lower right) and (B) Cross-bedded muddy conglomerate.*

Mud-dominated conglomerate lithofacies: The mud-dominated conglomerate lithofacies is characterized by granule to pebble-sized carbonate and, to a lesser extent, mudstone rip-up clasts floating within a mudstone matrix (**Figure 8**). The mud-dominated conglomerate lithofacies is interpreted to have formed from the deposition of muddy debris flows.

Cross-bedded conglomerate lithofacies: The cross-bedded muddy conglomerate lithofacies is characterized by planar tabular cross-bedded to horizontally bedded granule to pebble carbonate clasts with abundant mud matrix (**Figure 8**). Detrital clasts are not matrix-supported and display grain-to-grain contacts, indicating tractional deposition of this lithofacies. Cross-bedded muddy conglomerate lithofacies occur in association with mud-dominated conglomerate lithofacies. Hence, the cross-bedded muddy conglomerates are interpreted to be locally reworked deposits of muddy debris flows. In some cases, muddy conglomerates are interbedded with scour-and-fill sandstone lithofacies.

Carbonate Lithofacies

Carbonate lithofacies constitute a very minor proportion of the Beaumont strata and are best observed at the Terry Hershey and Litchfield outcrop exposures (**Figure 9**). This lithofacies occurs as small (2-4 cm in diameter) nodules and as thinly bedded (<2 cm) micritic carbonate beds. Carbonate nodules and beds are commonly interbedded with reddish-brown, laminated mudstones that are underlain by gray mudstones and overlain by starved current-rippled sandstones. Hence, this lithofacies association suggests that the carbonate lithofacies accumulated within a saline, low-energy bay.

Sedimentology, Sequence Stratigraphy, Diagenesis *continued on page 25*

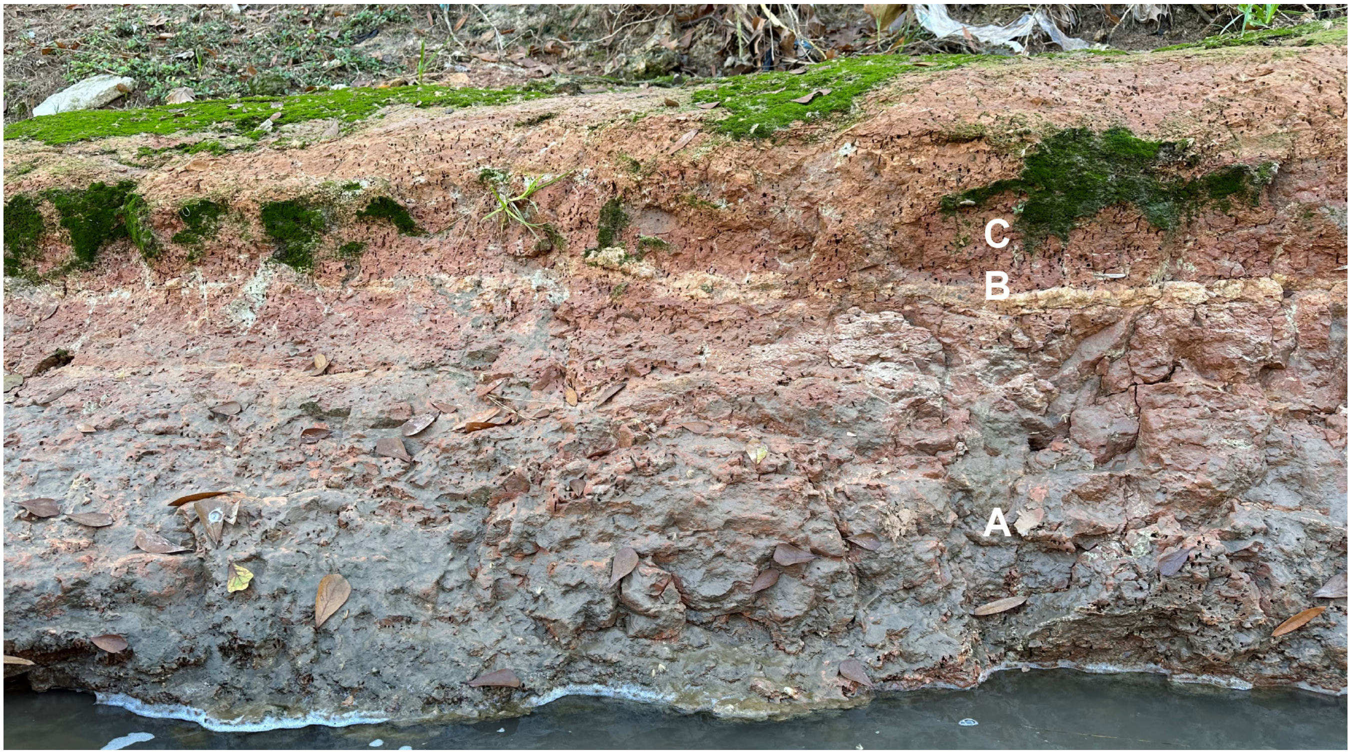


Figure 9. *Micritic carbonate lithofacies (B) underlain by gray mudstone containing starved current ripple sandstone lenses (A) and overlain by reddish-brown weakly laminated mudstone (C).*

INTERPRETATION OF DEPOSITIONAL ENVIRONMENT

Beaumont strata examined in this study area are interpreted to have accumulated within a deltaic environment characterized by marginal marine bays and an updip delta-plain alluvial system. Marginal marine bays formed landward of beach ridges as mapped by the USGS (Porter et al., 1990). Bay sediments initially accumulated in shallow-water regions that were influenced by low-energy tidal bores, resulting in the accumulation of laminated gray mudstones with dispersed bi-directional starved current rippled sandstones. Bay regions were periodically restricted from marine waters resulting in increased salinity conditions and accumulation of mud and carbonate sediments. Periodic drying of bay regions led to the development of incipient calcareous paleosols. Bayhead deltas formed inland along bay margins and received sediment from small, distributive delta-plain rivers. Clastic detritus transported to the bay region formed relatively small bayhead deltas roughly 2 to 4 meters in thickness and up to 500 meters in length (**Figure 10**). The transport of clastic sediment into the bay resulted in the progradation of bayhead deltas, characterized by coarsening upward and sand-prone stratal successions (**Figure 10**). In some cases, however, delta-plain mudstones proximal to the bay were eroded by delta-plain channels resulting in progradation of mud-prone bayhead delta stratal successions (**Figure 10**).

Sedimentology, Sequence Stratigraphy, Diagenesis *continued on page 26*

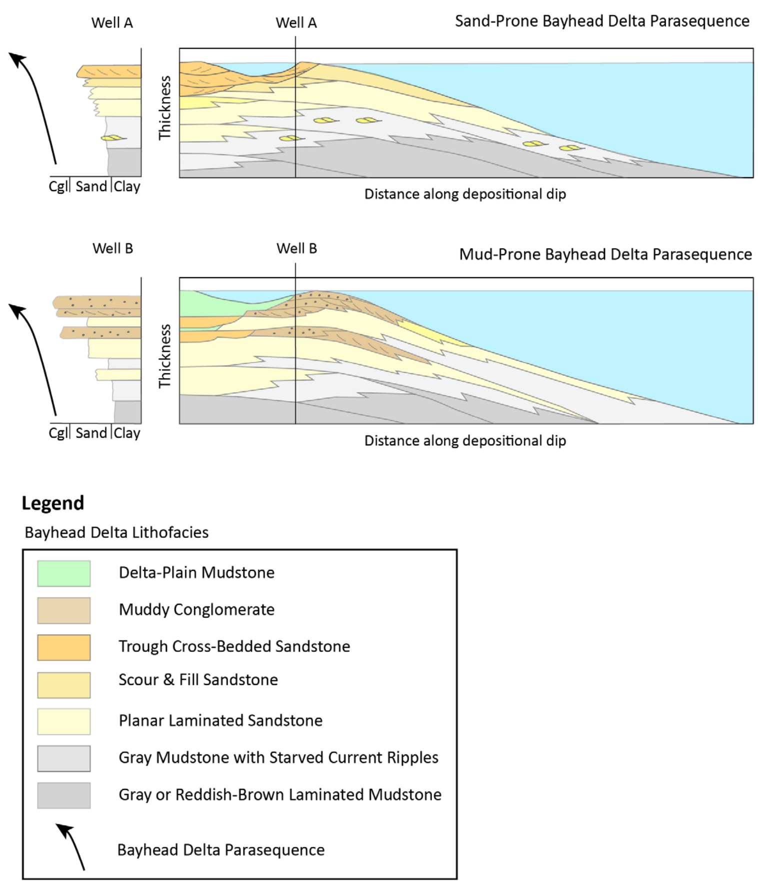


Figure 10. *Diagrammatic sketch of depositional dip cross-sections of a progradational sand-prone bayhead delta stratal succession (A) and a progradational mud-prone bayhead delta stratal succession (B).*

Sedimentology, Sequence Stratigraphy, Diagenesis

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PETROGRAPHIC ANALYSIS

Petrographic analysis of representative samples from the sandstone and carbonate lithofacies supports the outcrop observations of each lithofacies.

Sandstone Lithofacies

Scour-and-fill sandstone lithofacies vary from moderately sorted to moderately-well sorted, range in grain size from lower-fine to lower-medium sand and are litharenite to sublitharenite in composition (**Figures 11, 12A**). Lithic rock fragments are composed almost entirely of micritic calcite clasts and silty micritic calcite clasts (**Figure 12A**). Additional lithic detritus includes chert, biotite, hornblende, and polycrystalline grains composed of quartz, feldspar, and muscovite. Feldspar grains comprise a minor percentage of the framework grains and largely consist of potassium feldspar. Plagioclase grains have been extensively replaced by calcite.

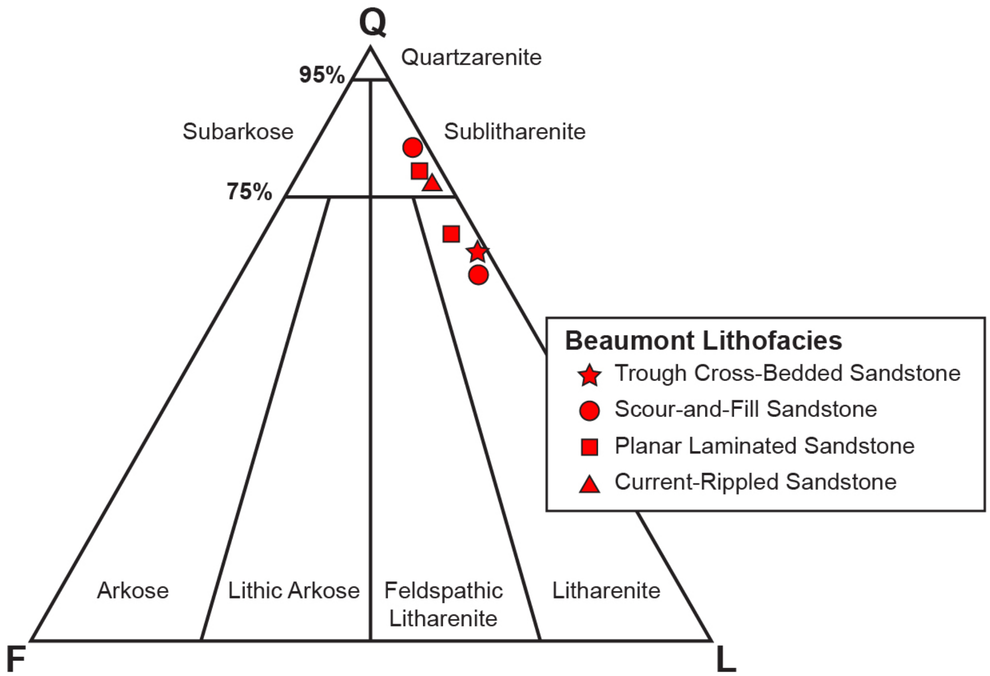

Figure 11. *Ternary diagram of quartz (Q), feldspar (F), and lithic detritus (L). Classification scheme after Folk (1980).*

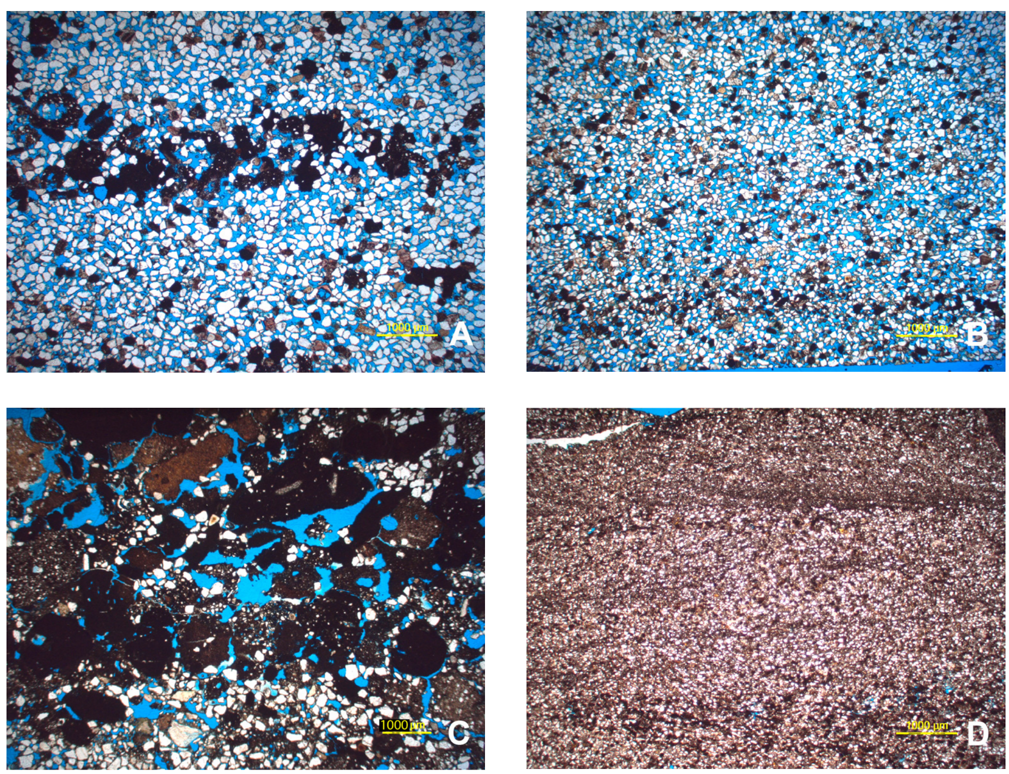

Figure 12. *Low-magnification photomicrographs of sandstone lithofacies: (A) Scour-and-fill sandstone with micritic calcite clasts along a laminae, 12.5x, Plane light; (B) Well-sorted planar laminated sandstone with micritic calcite clasts, 12.5x, Plane light; (C) Trough cross-bedded sandstone with abundant micritic calcite clasts, 12.5x, Plane light; (D) Current-ripple laminated sandstone. Current ripple laminae are well displayed in the upper portion of the photomicrograph, 12.5x, Plane light.*

In contrast, the laminated sandstone lithofacies is well sorted and ranges in grain size from upper very fine to lower fine sand (**Figures 11, 12B**). Laminated sandstones are classified as litharenite to sublitharenite. In comparison to the scour-and-fill sandstones, the planar laminated sandstones contain a lower percentage of reworked micritic clasts.

Trough cross-bedded sandstones are poorly to moderately sorted, lower fine to medium grained sand, and are litharenite in composition (**Figures 11, 12C**). Finally, current ripple laminated sandstone lithofacies are moderately sorted and possess the finest grain size, ranging in grain size from silt to lower very fine sand, and are sublitharenite in composition (**Figures 11, 12D**).

Diagenetic alteration of the sandstone lithofacies is surprisingly extensive, especially in light of the relatively young age of ~70

Sedimentology, Sequence Stratigraphy, Diagenesis *continued on page 27*

to 130 Kya of the sediments. Calcite cement is the most pervasive authigenic cement and it is present in all sandstone lithofacies. Paragenetic assessment of the in situ diagenesis reveals that fine-grained rhombohedral calcite crystals formed initially as grain coatings on detrital grains and micritic calcite clasts (**Figures 13A, 13B, 13C**). Energy Dispersive X-ray Spectroscopy (EDS) analysis reveals that authigenic calcite and micritic calcite clasts are calcium-rich and lack elemental impurities (**Figures 13C, 13D**). Subsequently, authigenic sparry calcite formed on the fine-grained rhombohedral calcite crystals (**Figures 14A, 14B**) and extensively filled pore spaces, resulting in occluded porosity (**Figures 14C, 14D**). Sparry calcite cement is most pervasive in the current rippled sandstone lithofacies (**Figures 14C, 14D**). Potassium feldspars have undergone minor dissolution but are relatively unaltered in the pervasively calcite cemented sandstones (**Figure 14C**). Incipient development of authigenic clay is observed on detrital grain surfaces and is interpreted to post-date calcite formation (**Figure 13C**).

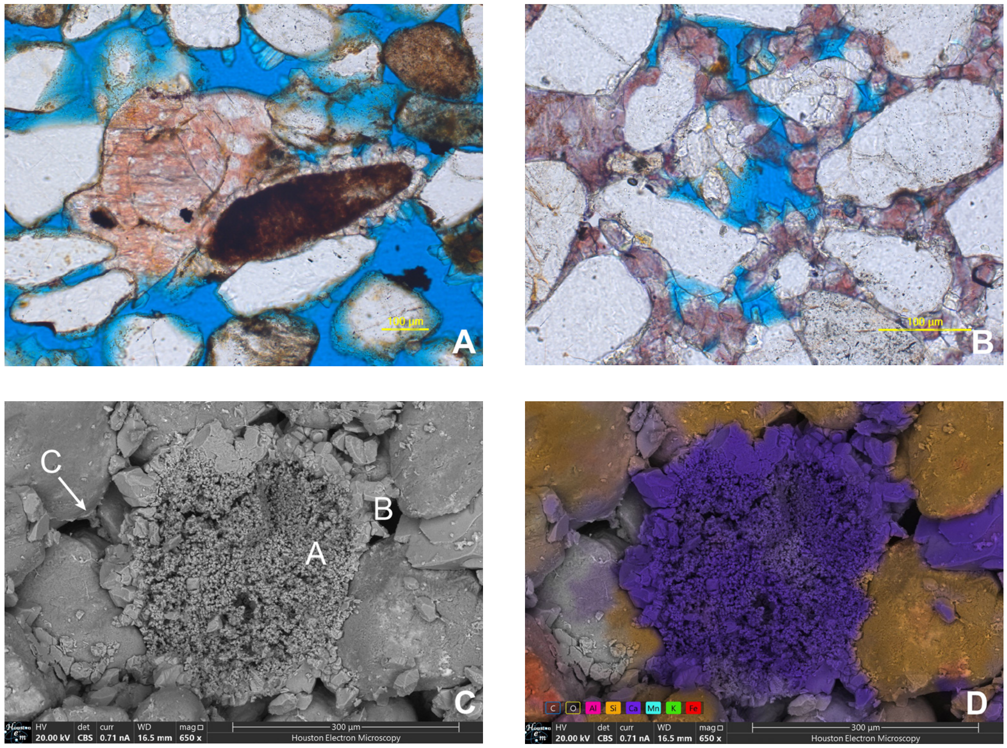

Figure 13. *Photomicrographs of authigenic calcite: (A) Small rhombohedral crystals coating a micritic clast and sparry calcite replacing a detrital grain and filling pore space, 100x, Plane light; (B) High magnification view of authigenic rhombohedral calcite crystals, 200x, Plane light; (C) SEM photograph of a micritic calcite clast with authigenic rhombohedral calcite crystals, 650x; (D) Energy Dispersive X-ray Spectroscopy of the micritic clast showing the calcium-rich chemical composition of the clast.*

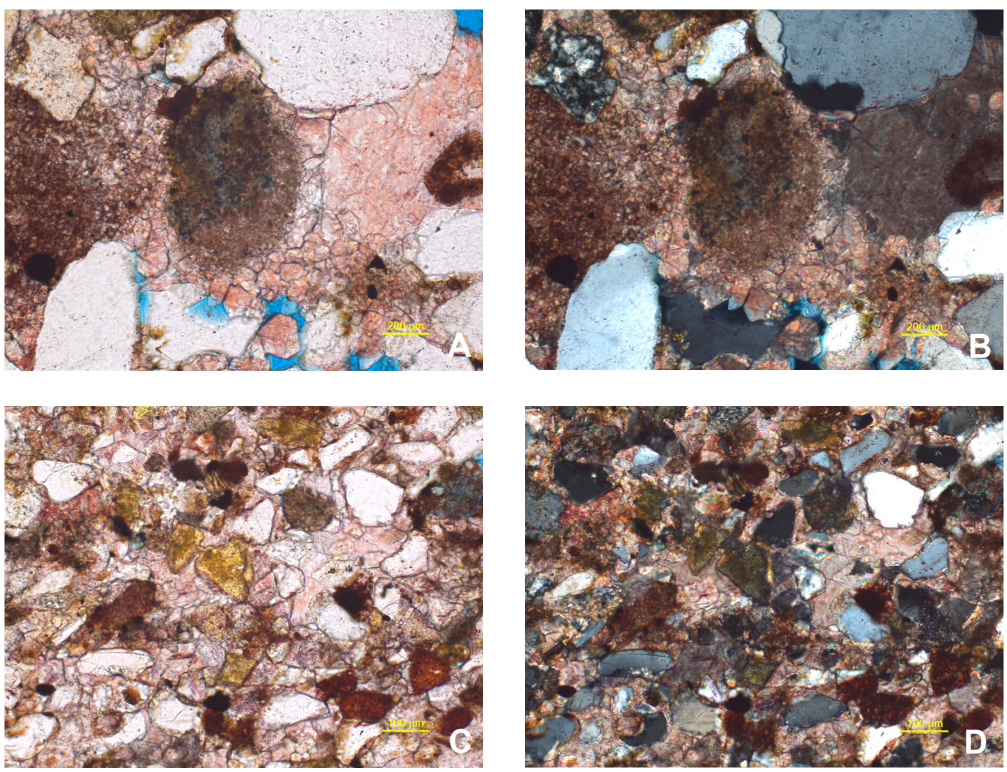

Figure 14. *Photomicrographs of: (A) Micritic clast coated by authigenic rhombohedral calcite crystals, which, in turn, are coated by sparry calcite 200x, Plane light; and (B) Crossed polarizers view of 14C, 200x, Crossed polarizers. (C) A current-rippled sandstone that has been extensively cemented by sparry calcite, Potassium feldspars (stained yellow) are unaltered. 100x, Plane light, (D) Crossed polarizers, 100x.*

Carbonate Lithofacies

The carbonate lithofacies is composed of micritic wackestone to packstone containing reworked micritic detritus. Petrographic observations revealed that some reworked clasts possess fenestral fabric indicative of an algal origin (**Figure 15A**). Micritic wackestones contain varying

Sedimentology, Sequence Stratigraphy, Diagenesis *continued on page 28*

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amounts of silt to medium grain-sized sand indicating close proximity of environments in which both sand and carbonate accumulated (**Figure 15B**). Aggradational banding of the clasts is indicative of their accretionary origin (**Figure 15B**). As in the sandstone lithofacies, authigenic rhombs of calcite have developed on micritic clast surfaces and void spaces.

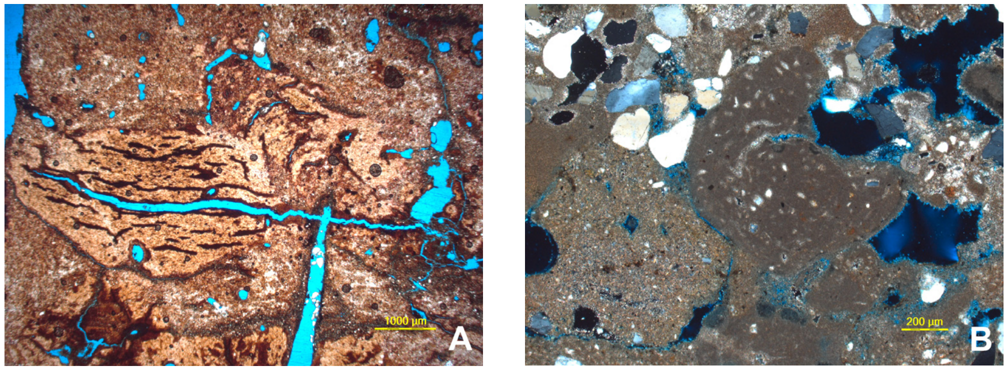

Figure 15. *Photomicrographs of the carbonate lithofacies: (A) A reworked clast that possesses algal fenestral fabric, 12.5x, Plane light; and (B) Packstone composed of rounded reworked micritic clasts that have accretionary banding of micritic laminae and sandstone detritus, 12.5x, Plane light.*

SEQUENCE STRATIGRAPHIC INTERPRETATIONS

The long distance between the relatively thin stratigraphic intervals of each measured section poses a challenge for correlation of the lithofacies associations and their interpreted depositional environments. Moreover, there is no single, unique interval that can be correlated across the entire lateral stratal succession to enable a datum to be defined. Hence, the measured sections were compiled using two methods. The first cross-section was compiled using elevation above mean sea level (MSL) obtained from GPS data and projected onto a west-to-east line (**Figure 16**). The second cross-section was compiled using a fence diagram method, in which the measured sections are plotted based on their geographic location along Buffalo Bayou.

The cross-section based on elevation above MSL reveals distinct regions of lithofacies associations and their interpreted depositional environments. Correlation of the measured sections on a fence diagram (**Figure 17**) supports the depositional environment and stratigraphic interpretations proposed in the MSL section.

Bayou on the Bend to Woodway outcrops

The lowermost stratigraphic interval is located at Bayou on the Bend, which is the eastern end of outcrop exposures. The strata at this locality are interpreted to have accumulated as a single coarsening upward bayhead delta parasequence. This parasequence is composed of the same lower to upper fine sand grain size as bayhead parasequences to the West. However, it contains several recumbently folded beds consistent with high

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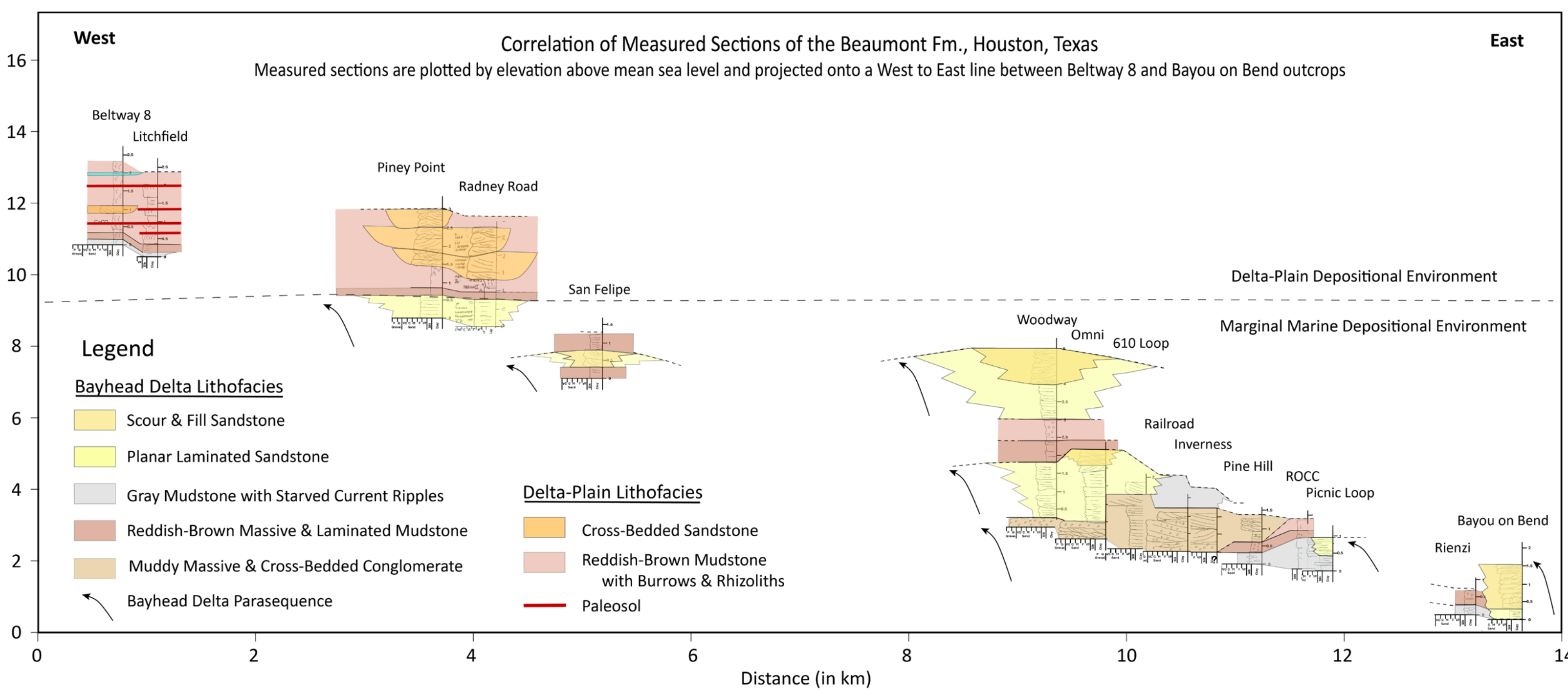

Figure 16. *West to East cross-section of the 15 measured sections described in this study. The cross-section was compiled using elevation above mean sea level (MSL) obtained from Global Positioning System (GPS) and projected onto a West to East line.*

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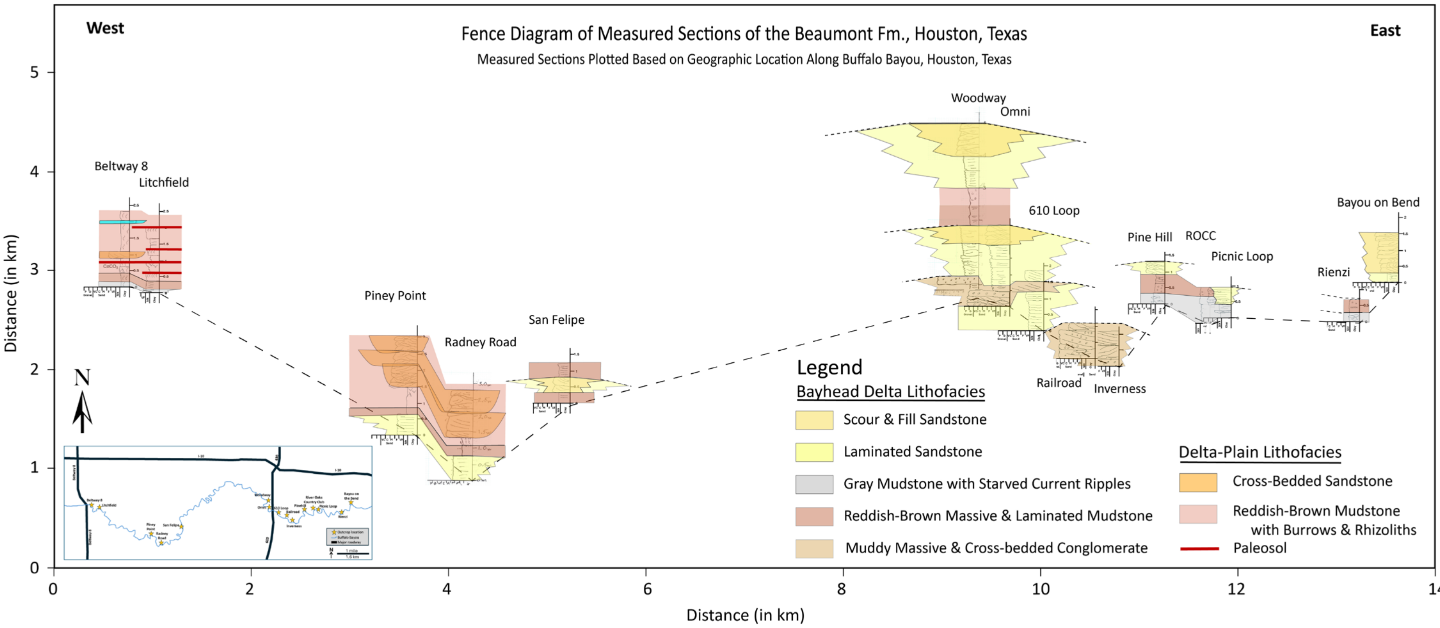

Figure 17. *Fence diagram cross-section compiled based on their geographic location along Buffalo Bayou.*

shear flow velocities during its deposition. These recumbently folded beds are not observed in outcrops to the West of this locality. Hence, the provenance of sediments deposited at this location is interpreted to be from the East, possibly from a San Jacinto drainage area.

To the West of Bayou on the Bend outcrop, the authors observed a cluster of eight outcrops, which are interpreted as four bayhead delta parasequences extending from Picnic Loop to Woodway (**Figure 16**). The lowermost parasequence is a thin, coarsening upward parasequence located at Picnic Loop. This parasequence is finer grained than the Bayou on the Bend parasequence and is composed of laminated gray mudstones with starved current ripple laminae overlain by planar laminated turbidite deposits. To the West and stratigraphically above the Picnic Loop outcrop is the second parasequence, which is dominated by muddy debris flow and reworked debris flow deposits.

The basal interval of the second parasequence is interpreted to have accumulated within a restricted shallow bay characterized by high salinity resulting in the deposition of micritic algal detritus interbedded with weakly laminated mudstones (**Figures 9** and **15**). These mudstones are overlain by planar laminated turbidite beds that, in turn, are overlain by reworked debris flows and capped by massive debris flow deposits. The clasts within the muddy debris flow lithofacies are predominantly composed of reworked micrite. Hence, this second bayhead delta parasequence is interpreted to have formed from a channel system that eroded into muddy micritic deposits and transported the muddy detritus into the bay. This muddy bayhead delta is overlain by two sand-prone, coarsening upward bayhead deltas, as described at the Omni outcrop (**Figure 16**). The sand-prone bayhead delta at the Omni outcrop is correlative to the lower bayhead delta parasequence at the Woodway outcrop. Finally, the fourth bayhead delta parasequence is composed of a basal interval of laminated mudstones overlain by micritic mudstone that are overlain by planar laminated turbidite beds and capped by trough cross-bedded fluvial channel deposits. These four parasequences form a progradational parasequence set with each parasequence possessing more proximal facies.

San Felipe to Beltway 8

There is a gap of approximately 5 km between the measured section at Woodway and the measured section immediately to the West at San Felipe. The San Felipe outcrop is interpreted as a thin bayhead delta interval that is approximately correlative with the bayhead parasequence interpreted at Radney Road (to the East) and Piney Point (to the West) outcrops. The bayhead delta strata at Radney Road and Piney Point are overlain by deltaic-plain facies that include bayhead mudstones that have been modified by pedogenesis and burrowing, which in turn, are overlain by amalgamated fluvial channels. The lower interval of the Beaumont Formation is interpreted as bayhead delta and bay mudstones that are overlain by marginal marine deposits that formed in a delta plain. All outcrops observed in Buffalo Bayou are interpreted to represent an overall progradational parasequence set with progradational bayhead parasequences overlain by delta-plain deposits.

Additional information gleaned from the fence diagram is that the parasequence set of the Beaumont strata is more strongly progradational than previously inferred in the first cross-

Sedimentology, Sequence Stratigraphy, Diagenesis *continued on page 30*

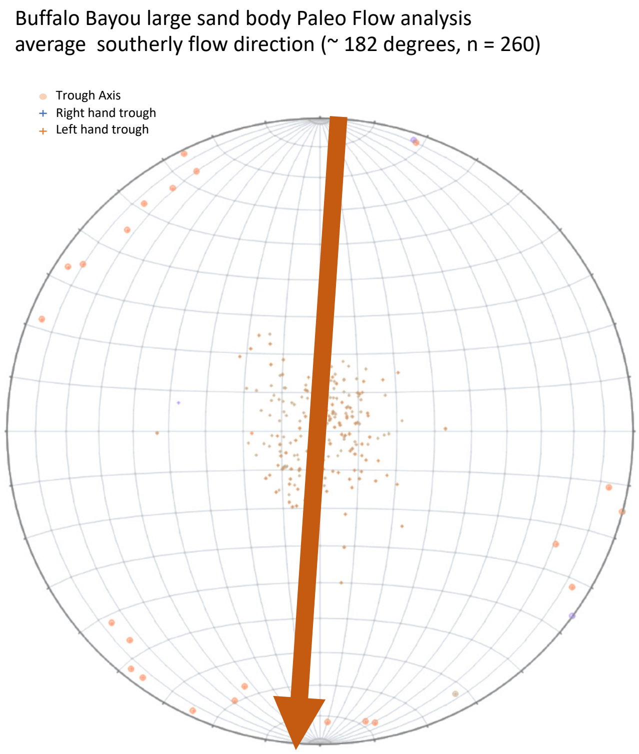

Figure 18. *Summary of paleo flow analysis using the trough cross-stratification paleo-flow-direction method of Decelles et al., (1983) of larger (10 m2) sandstone outcrops along Buffalo Bayou. The interpreted southerly flow is also consistent with the North to South trend of the larger sand bodies that extend into and across Buffalo Bayou.*

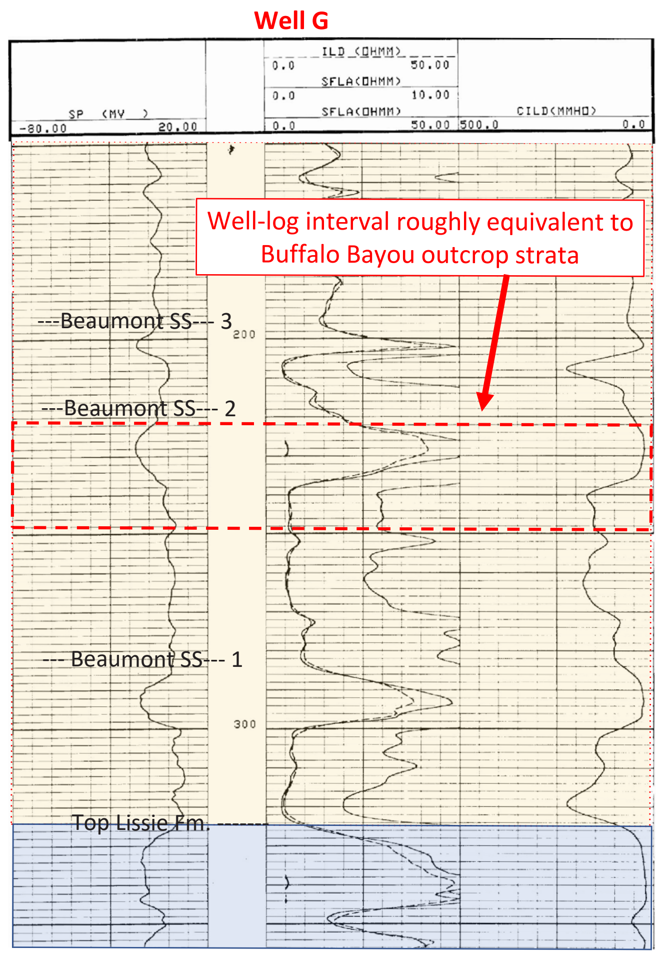

Figure 19. *Enlarged view of Well G from Figure 20. The dashed red box highlights an interval analogous to the stacked sands observed in the outcrops (Figure 17).*

section. The fluvial channels are situated farther basinward than the underlying deltaic parasequences documenting a strong progradational stratal stacking pattern of the parasequence set. This progradational stacking pattern is further supported by a study of the regional Quaternary geology of the Gulf Coast by Winker (1979).

PALEO-FLOW ANALYSIS

The paleo-flow analysis reported by Kendall et al. (2024) was expanded and confirmed with the addition of measurements from Beltway 8, Litchfield, and Piney Point. The ~1 meter scale of the sand bodies is consistent with the previous outcrops studied and implies these systems were smaller than present day Buffalo Bayou. **Figure 18** combines all 260 measurements using the trough cross-stratification paleo-flow-direction method of Decelles et al. (1983). The analysis implies these systems were small and generally southerly flowing.

CORRELATION OF OUTCROP TO SHALLOW WELLS

Using the composite stratal thicknesses and interpreted depositional environments described in the measured sections, the authors correlated the Buffalo Bayou outcrops to a nearby shallow well log, referred to herein as Well G (**Figure 19**). The authors interpret that the outcrops observed along Buffalo Bayou are equivalent to the stratigraphy approximately 20 meters above the top of the Lissie Formation (**Figure 19**). This interval is informally referred to as the "Beaumont 2" sandstones. The Beaumont 2 is comprised of two coarsening upward well-log signatures (each 2 to 4 meters thick) that are of comparable thickness and inferred well-log character to that observed in outcrops. These well-log signatures are also comparable to the progradational bayhead deltaic stratal successions observed at Woodway and Omni outcrops.

The Quaternary strata dip South at approximately 1-degree, based on a correlation of Well G with other wells in a northwest-southeast well log cross-section (**Figure 20**). Lithostratigraphic correlation of the Buffalo Bayou outcrops and mapped Quaternary units by the USGS (Pope et al., 1990) indicates that the Buffalo Bayou outcrops examined in this study are part of the lower mud-prone stratigraphic interval of the Beaumont Formation. The underlying amalgamated sandstones of the Lissie Formation are projected to lie ~20 meters below the outcrops observed in the Buffalo Bayou study area. The Lissie Formation is described by the

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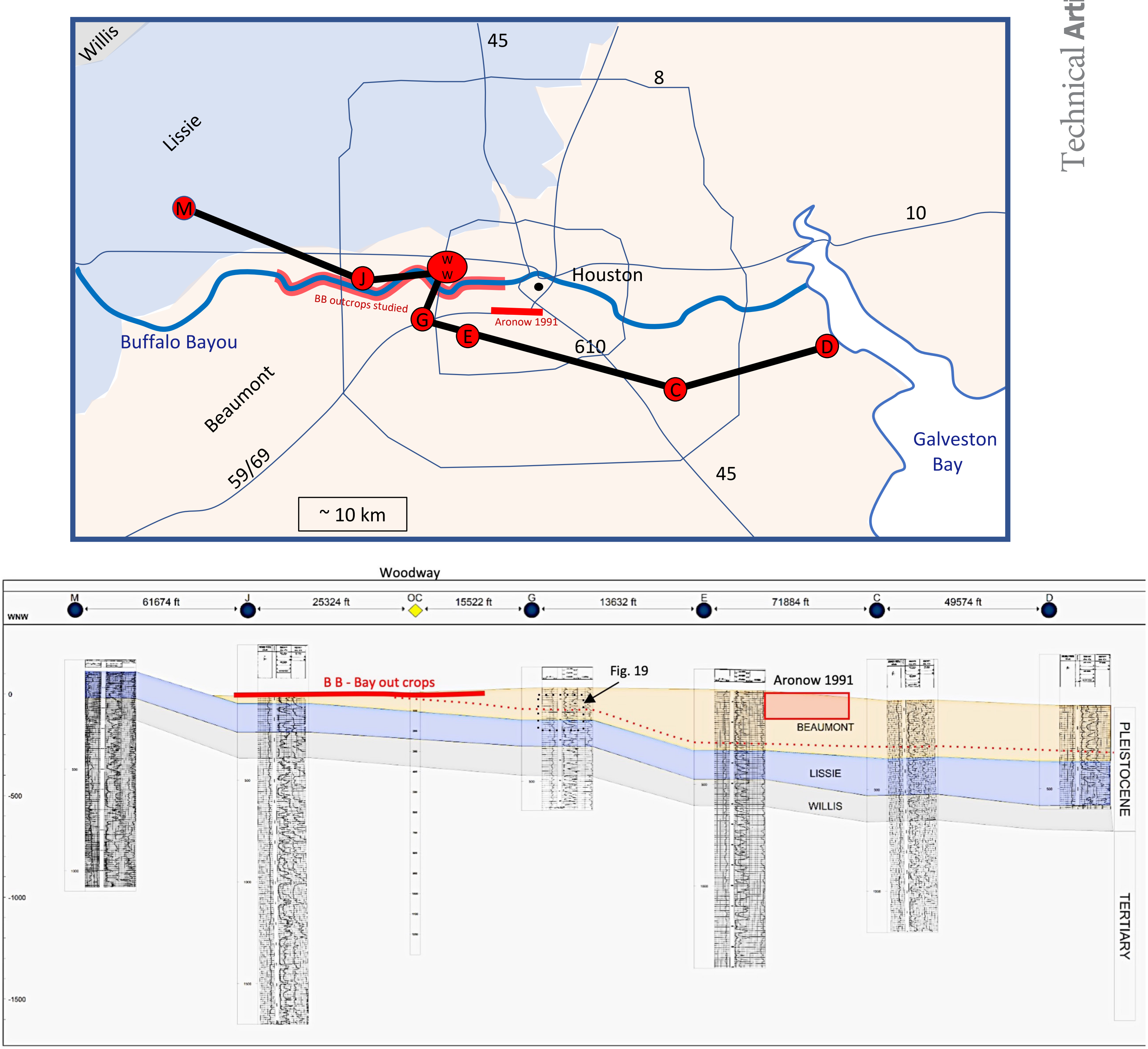

Figure 20. *Well log cross-section. Map showing: 1) the generalized geologic map of the Quaternary formations (Pope et al., 1990); 2) location of the well on the well log cross-section (black line with wells shown by red circles), Buffalo Bayou (blue line and red line shows outcrops studied), and Aronow (1991) core study (red line). Well section tied to surface geology and outcrops (WW= Woodway) examined in this study. Red dotted line shows dip to the southeast of lower Beaumont fine grained bay sediments studied along Buffalo Bayou. Figure 19 is an enlarged view of Well G. Wells: M=Ricewood MUD #1, J=City of Bunker Hill #3, G=City of Houston SW #3sb, E=City of W University #8, C= City of South Houston 65-23-709, D= Air Products and Chemicals #2. (TCEQ, 2023)*

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USGS as "channel facies" of Middle Pleistocene age (Pope, 1990). Within a sequence stratigraphic context, the fluvial deposits of the Lissie Formation constitute a lowstand interval, and the overlying bay and delta-plain deposits of the Beaumont Formation comprise the transgressive and possibly early highstand intervals.

PALEOGEOGRAPHIC MAP RECONSTRUCTIONS

The authors constructed paleogeographic maps (**Figure 21**) for five time intervals spanning from 140 Kya to present using interpreted stratal and sequence-stratigraphic interpretations from this study and from published studies on Quaternary geology of the Houston area (Winker, 1979; Aronow et al., 1991; Pope et al., 1990; Anderson et al., 2004; Anderson et al., 2008) and sea level data from Marine Isotope Stages (MIS) (Shackleton and Opdyke, 1973; Shackelton et al., 2003). Because of the lack of biostratigraphic age control, the authors interpret shoreline position based solely on basinward and landward shifts in depositional environments. The maps relate observations in the study area (blue dotted line) to the sea level curve (red highlighted interval on sea level curve in lower left) and the shoreline position.

The Beaumont Formation examined in this study is interpreted to have accumulated during the Sangamon, MIS Stage 5e spanning 130 to ~110 Kya (**Figure 21B**). The Beaumont Formation is underlain by the Lissie Formation, which is interpreted to be fluvial deposits. The mud-prone Beaumont strata are interpreted in this study, as marginal-marine deposits. This stratal architecture suggests that the Lissie strata constitute lowstand deposits and the overlying marginal-marine strata of the Beaumont were deposited during rising sea level between 130 to 110 Kya and comprise the transgressive systems tract to early highstand systems tract. This interpretation places deposition of the Beaumont Formation during the onset of the last full interglacial period of the Sangamon age.

~140 Kya, Illinoian Glacial Stage: Lowstand Systems Tract

During this time, the Buffalo Bayou study area is interpreted to have been an alluvial plain. The shoreline was located 100's of kilometers to the southeast (**Figure 21A**) and the Colorado, Brazos, San Jacinto, and Trinity Rivers may have been prograding to the coast.

~130-110 Kya, Sangamon Interglacial Stage: Transgressive to Early Highstand Systems Tract

The Buffalo Bayou outcrops examined in this study are interpreted to have been deposited during the Sangamon Interglacial Stage. During this time, the shoreline is inferred to have transgressed over 100 km to the northeast (**Figure 21B**). The Buffalo Bayou study area (dotted blue line) consisted of a bay with bayhead deltas and marginal marine fluvial channels. **Figure 21B** is drawn

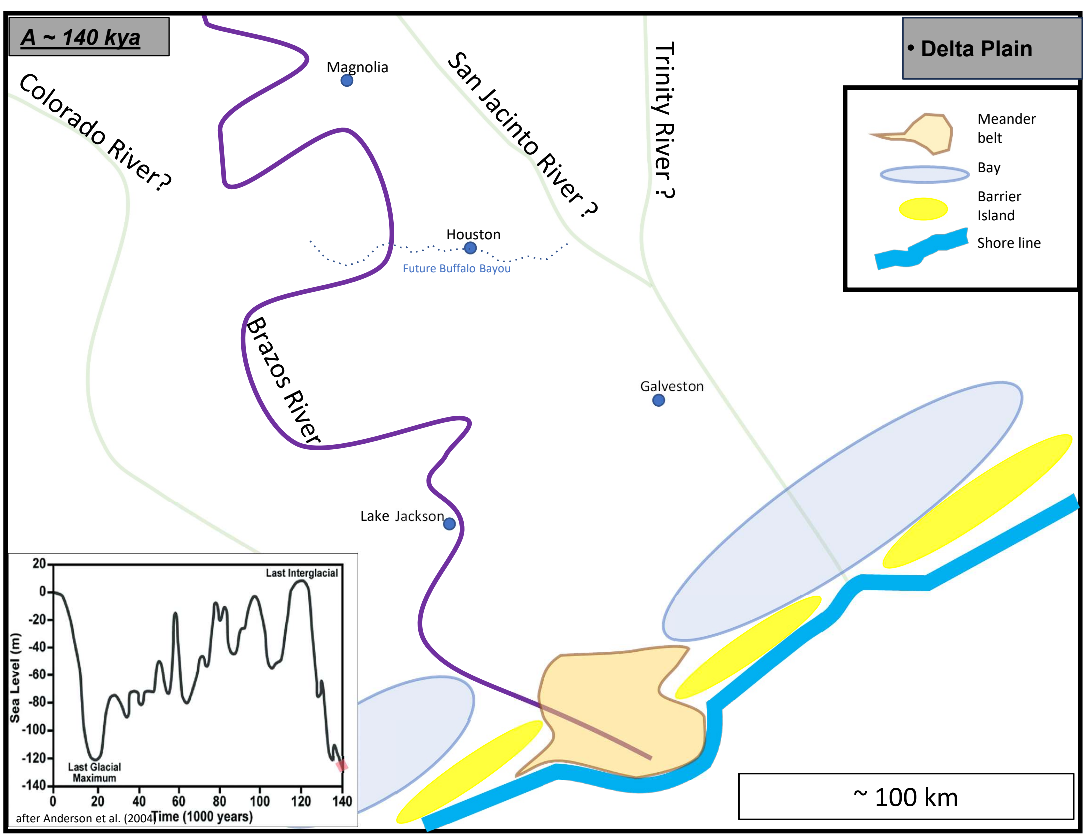

Figure 21. *Paleogeographic reconstruction maps of the Late Quaternary.* ***Map A*** *represents the paleogeography at ~140 Kya (Illinoian Glacial Stage) during a period of low sea level. The future Buffalo Bayou (dotted blue line) is located in the upper reaches of a delta plain.*

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at the time of rapid sea level during the transgression to early highstand. This rapid sea level rise resulted in a landward shift of the shoreline. The streams shown are modified from Van Siclen (1985, 1991), and the Brazos River (purple line) is interpreted to be the source of the sediments. However, the bayhead deltas along the eastern edge of the study area (**Figure 16**) represent possible sediment contributions from the San Jacinto River (red line). The Colorado River (light green line) is interpreted to have be active to the West and may have modified the Brazos River delta plain. The shoreline on the figure is modified after the Stage 5 shoreline from Simms et al. (2013).

~110 - 20 Kya, Sangamon Interglacial and Wisconsin Glacial Stages: Late Highstand and Lowstand Systems Tract

During this time, the shoreline is inferred to have migrated over 100 km offshore (**Figure 21C**) extending the paleo Brazos River southward to create a series of fluvial-deltaic depositional lobes (Van Siclen 1985, 1991, Dupré, 2019). In the Buffalo Bayou study area, two depositional lobes filled the former bay. The depositional lobes are inferred to include east-to-west oriented meander ridges. To the West, the Colorado River modified the depositional lobes of the Brazos River. While the Brazos River prograded basinward, the smaller San Jacinto/Trinity River system could not keep up with falling sea level, downcut, and was entrenched (Anderson et al., 2008). **Figure 21C** shows an early Buffalo Bayou drainage system as a tributary that formed by the westward nick point migration from the San Jacinto River. The east-to-west strike of Buffalo Bayou is inferred to be the result of the east-to-west orientated meander ridge topographic fabric.

~20 - 10 Kya, Late Wisconsin Glacial Stage: Transgressive Systems Tract

As sea level rose, the San Jacinto River system expanded, and Buffalo Bayou continued to erode headward to the West, capturing small drainage basins (Kendall et al., 2024, **Figure 21D**). The Clinton Salt Dome (CD) may have been a positive topographic feature at this time, which could have contributed to the observed deviation in the orientation of Buffalo Bayou.

~5 - 0 Kya, Present: Holocene Interglacial: Highstand Systems Tract

Buffalo Bayou continued to entrench and expand to the West as sea level continued to rise. Active faults like the Long Point (LP) and Eureka Heights (EH) faults (Tolman, 2018; Kendall et al., 2024) deflected and changed the gradient of Buffalo Bayou (**Figure 21E**).

SUMMARY

This study documents observations and interpretations of

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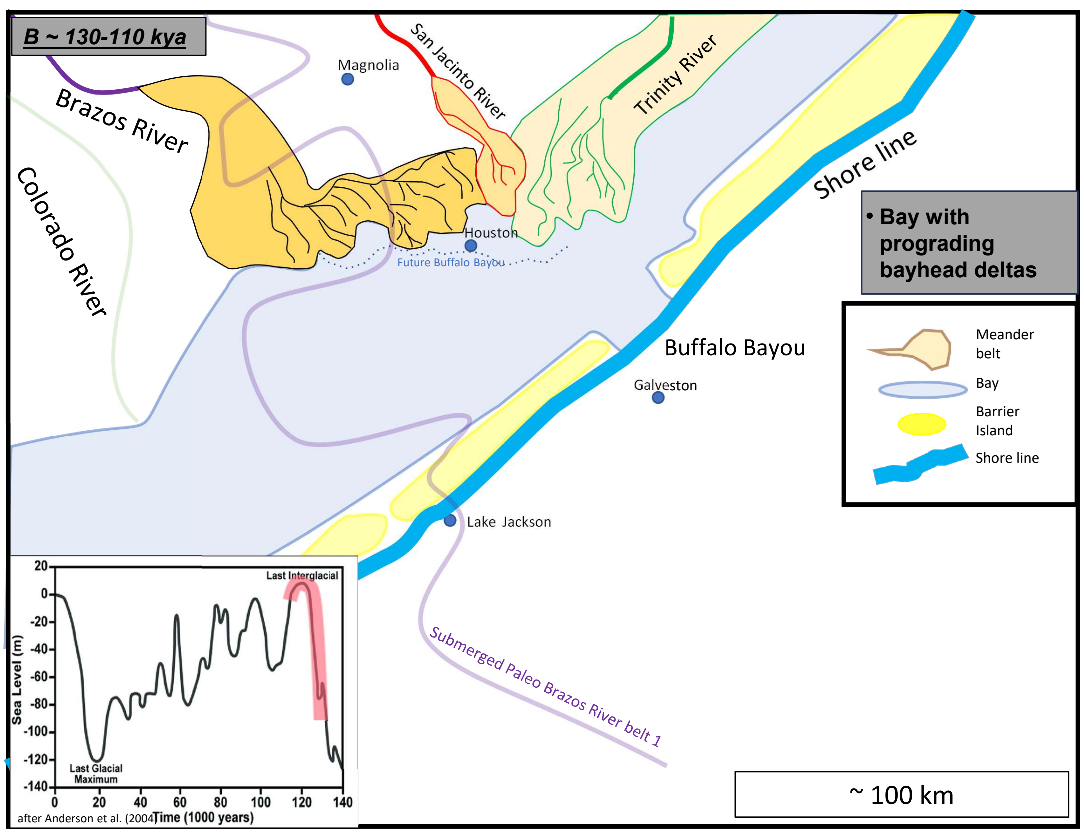

Map B *represents ~130-110 Kya (Sangamon Interglacial Stage) during rapid sea level rise. At this time, the shoreline position moved landward and the future Buffalo Bayou study area is interpreted to have been a bay receiving deltaic sediment from the Brazos River.*

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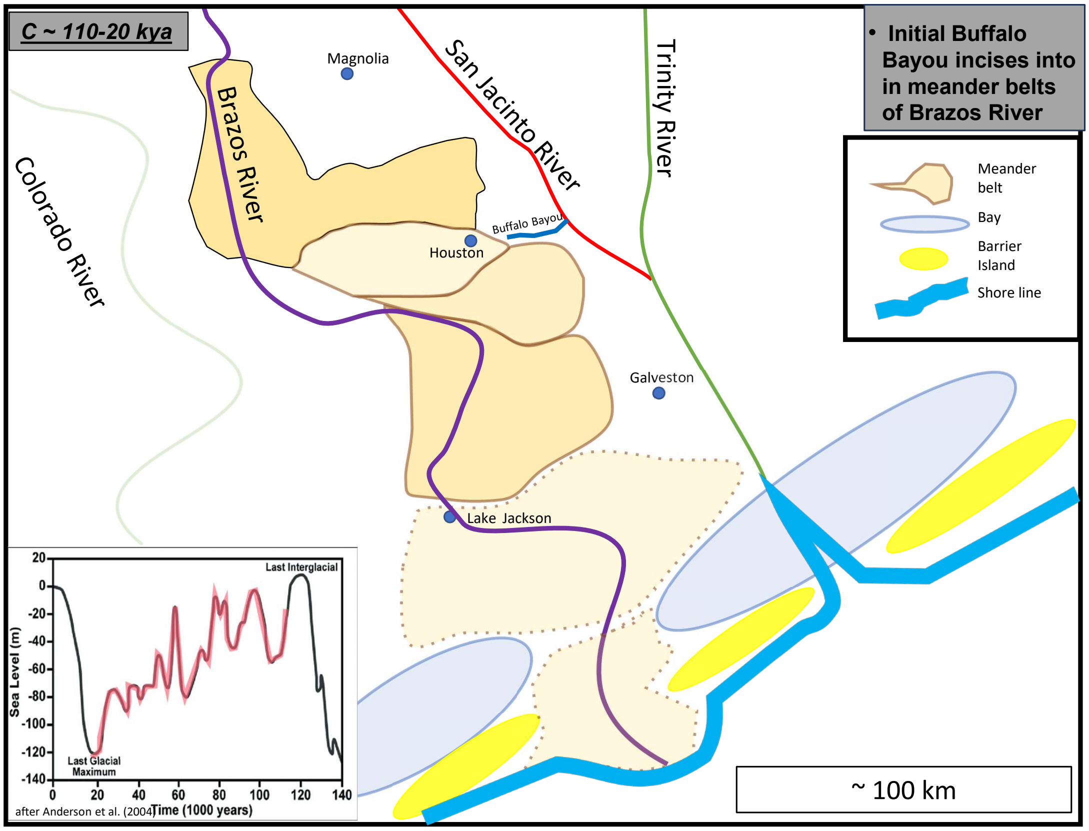
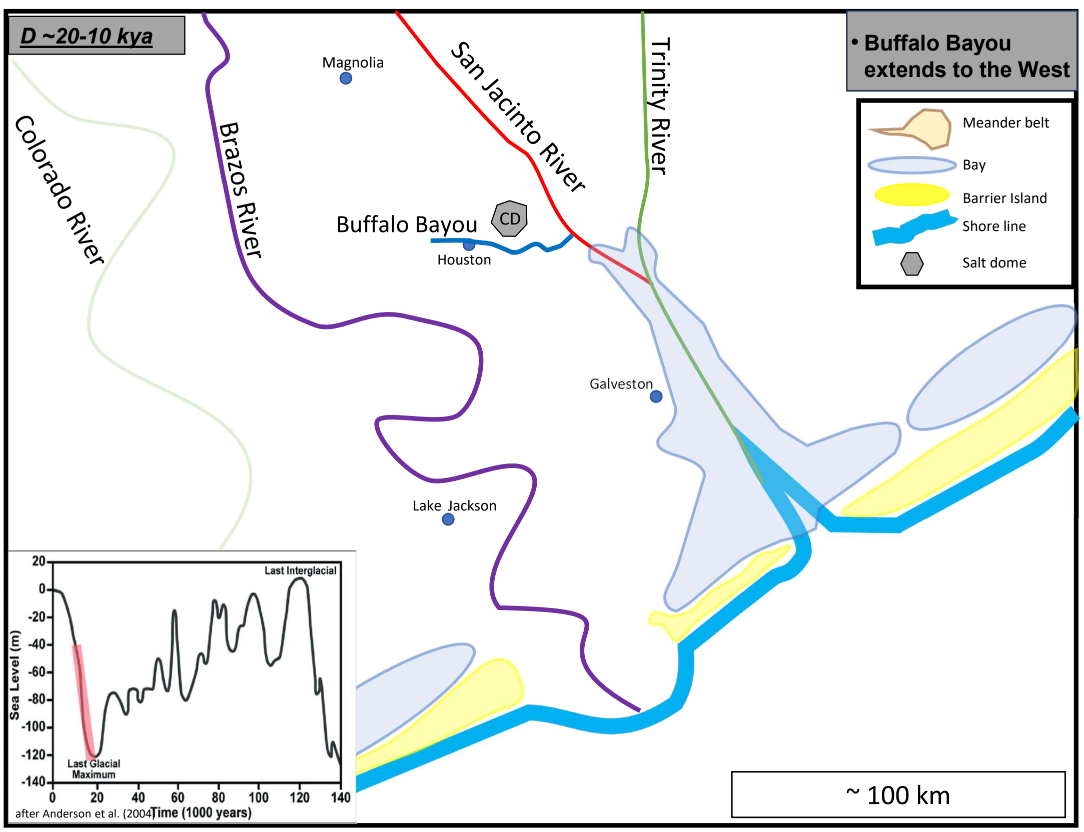
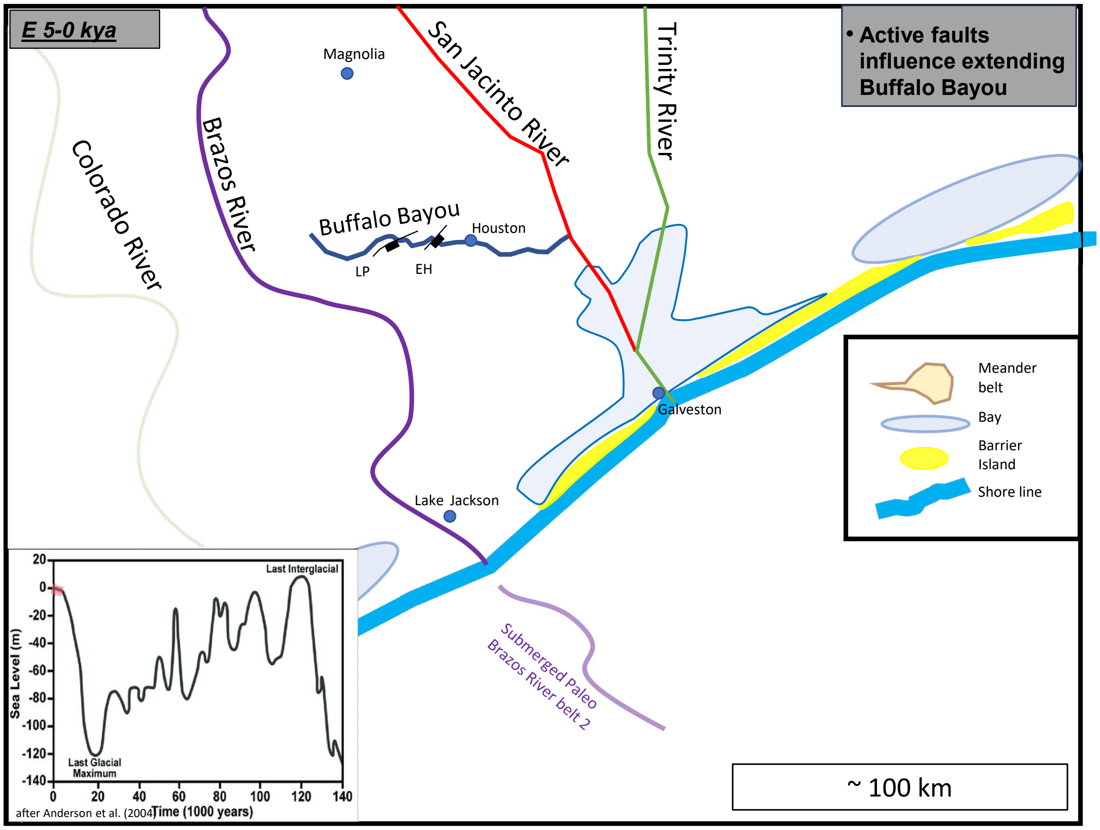


Map C *represents ~110-20 Kya (Sangamon Interglacial and Wisconsin Glacial Stage) during a period of falling sea level. The Brazos River formed a series of east-to-west oriented deltaic lobes while the San Jacinto River incised. Buffalo Bayou is inferred to initiate as an east-to-west tributary from the San Jacinto River.*



Map D *represents ~20 - 10 Kya (Late Wisconsin Glacial Stage) during a period of rising sea level representative of a transgressive systems tract. During this time, Buffalo Bayou continued to erode headward and captured drainages from the Brazos River system.*

Sedimentology, Sequence Stratigraphy, Diagenesis *continued on page 35*



Map E *represents ~0-5 Kya (Present, Holocene Interglacial) during a period of high sea level representing a highstand systems tract. During this time, Buffalo Bayou continued to erode westward, its growth was likely influenced by the active faults.*

lithofacies, lithofacies associations, and petrography from 15 outcrops of the Beaumont Formation encountered along Buffalo Bayou, Houston, Texas. The Buffalo Bayou Study Group authors interpret a sequence stratigraphic framework and paleogeographic reconstructions based on data from these outcrops. Although the Beaumont Formation is commonly regarded as a homogeneous mud-dominated interval, it contains a wealth of information regarding depositional environments, sediment transport, stratal architecture, pedogenic and diagenetic alterations, and shifts in depositional environments over the last 130,000 years.

The Beaumont strata examined along a ~20 km transect of Buffalo Bayou are interpreted to have formed in marginal marine deltaic and delta-plain environments. The lower two-thirds of the stratigraphic interval is interpreted to have been deposited in a marginal marine bay environment during the Sangamon highstand (~70-130 Kya). Bayhead deltaic deposits prograded into the bay, forming mud-prone and sand-prone parasequences (~90 Kya). During the formation of these parasequences the bay region was periodically restricted forming a closed saline basin in which micritic algal carbonates formed. Bayhead deltaic parasequences are overlain by delta-plain mudstone and channel sandstone deposits that were variably altered by pedogenic processes.

Within a sequence stratigraphic context, the Beaumont Formation is a progradational parasequence set that accumulated within the transgressive system tract of OIS 5 (75 to 130 Kya). The Beaumont Formation is underlain by sand-prone channel deposits of the Lissie Formation (Pope, 1990) that are interpreted as lowstand deposits, and accumulated during the Illinoian glacial period.

Sandstones in the Beaumont Formation have undergone a surprisingly high degree of diagenetic alteration. Authigenic calcite formed as small rhombohedral crystals coating detrital grain surfaces and subsequently developed as a relatively pervasive sparry cement that indurated the sandstones. Scour-and-fill sandstones that were extensively cemented by authigenic calcite became sufficiently indurated to serve as land bridges across Buffalo Bayou. Formation of authigenic clay coatings on detrital grain surfaces marks the most recent phase of diagenesis.

The modern-day Buffalo Bayou formed during a period of falling sea level. The orientation of the Bayou is influenced by the East-West topographic fabric of the pre-existing Brazos River depositional lobes. As Buffalo Bayou incised to the West, it cut into the previously deposited marginal marine sediments exposing those sediments along its banks.

Sedimentology, Sequence Stratigraphy, Diagenesis *continued on page 36*

Sedimentology, Sequence Stratigraphy, Diagenesis *continued from page 35*

FUTURE WORK

The Buffalo Bayou Study Group is interested in collecting data to further constrain the age of outcrops exposed in the channel and to continue investigating early diagenetic events. Furthermore, the Study Group plans to incorporate the results into educational projects, such as the AAPG Geoscience Educators program (Bourgue, 2025), and digitally archive the data in a publicly accessible GIS database.

This is an ongoing effort. If you want to participate and/or have any information on definitive age dates, samples for dating, well control, or other data, please contact editor@hgs.org

SPECIAL THANKS

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Sedimentology, Sequence Stratigraphy, Diagenesis *continued on page 37*

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Jurassic Paleoenvironmental Data Support Syn-Rift Dynamic Elevation and Subsequent Dynamo-Thermal Subsidence from near Sea Level in the Eastern Offshore Rifted Margins of the Gulf of Mexico

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INTRODUCTION

Controversy persists over how and when accommodation is produced for thick, rapidly accumulated, sag and layered evaporite sequences (sag/salt sections), such as those in the rifted margins of the Gulf of Mexico, central South Atlantic, and northern Central Atlantic. Where present, sag sections in these margins are well known for their paucity of large offset basement-related faults, and the large areas of regionally planar base-salt surfaces in rift basins attests to little basement-related fault control on salt deposition in those areas, too. Taken together, local active tectonic faulting does not appear to accommodate these sections. Yet, the thicknesses and apparent depositional rates of sag/salt sections are hard to explain by thermal subsidence (plus sediment loading) alone, suggesting other mechanisms are at play. In the search for an explanation, an important question is, "what was the absolute initial elevation or depth, relative to average global sea level, of the basin surface at the onset of sag/salt deposition"? The question is important because the former depths of these pre-sag/salt surfaces have significant implications for what might be expected within undrilled portions of pre-sag/salt stratigraphy (source and reservoir). The question is hard to answer because of the generally non-marine nature, where drilled, of pre-sag/salt strata.

ALTERNATIVE VIEWPOINTS

The great thicknesses and apparent limited depositional timespans of sag/salt sections (known for the central South Atlantic) have been explained in at least three ways. One way is that much of the accommodation for the sag/salt sections was created prior to sag/salt deposition in geographically isolated, mainly non-marine depressions 1–2.5 km below global sea level (e.g., Burke, 1975; Rowan, 2015; 2018; 2022; Hudec and Peel, 2019; Curry et al., 2024; Lundin et al., 2025). These envisaged depressions carry the requirement that they formed behind barriers to the world's oceans while remaining relatively sediment starved. Subsequently, they then began to fill rapidly with fluvio-lacustrine sag and, eventually, evaporitic strata in depressions where the accommodation already existed.

A second way to explain thick, rapidly deposited sag/salt sections is that they were deposited across depositional flats within a few hundred meters below average global sea level, and that much of the sag/salt accommodation was created by rapid, syn-depositional basement subsidence (Pindell et al., 2014; 2018). The challenge for this type of model is that basement subsidence rates during sag/salt deposition must exceed normal rates of thermal (plus sedimentary load) subsidence. Pindell et al. (2014) referred to this envisaged phase of rapid subsidence as "outer marginal collapse" and posited the idea that outer margins rotate basinward as they are sloughed off the upper mantle during its rise to become the site of initial seafloor spreading between the conjugate margins. This form of crustal scale, low-angle tectonic detachment involving simple shear along the Moho is in some ways akin to the non-uniform stretching concept of Driscoll and Karner (1998), but near the Moho. However, outer marginal collapse, where outer margins rapidly become deep if sag/salt deposition does not keep pace with collapse, appears to be inconsistent with the very shallow paleoenvironmental data for the Upper Jurassic section off northwest Florida (Godo (2025a,b and as discussed further below).

A third way to explain these thick, rapidly accumulated sections acknowledges that the Gulf of Mexico, central South Atlantic, and northern Central Atlantic salt basins overlie magma-rich rifted margins. If we look at today's analogues, magma-rich rift settings have positive average dynamic elevations up to 2.5 km above isostatic compensation levels, due to lying above mantle plumes or thermally buoyant mantle below the rifted lithosphere. Pindell and Heyn (2022) compiled magmatic chronological data to infer that the Gulf of Mexico and central South Atlantic magma-rich rifted margins likely had positive paleo-dynamic elevation at the time of rifting. They further built a case that sag/salt deposition occurred while applicable parts of the margins of these basins moved off the underlying magmatic plumes responsible for the magma-rich rifting (**Figure 1**). Pindell and Heyn (2022) thus argued that the time of sag/salt deposition corresponds to the period when syn-rift dynamic elevation dissipates, and that the dissipation of dynamic elevation is a form of dynamic subsidence. They further proposed that the concurrence of this dynamic subsidence and initial thermal subsidence, which they called "dynamo-thermal subsidence", can create accommodation rapidly enough to explain the deposition of sag/salt sections near sea level.

DYNAMIC ELEVATION AT MAGMA-RICH CONTINENTAL RIFT SETTINGS

Today's active continental-scale rift settings (East African, Afar–

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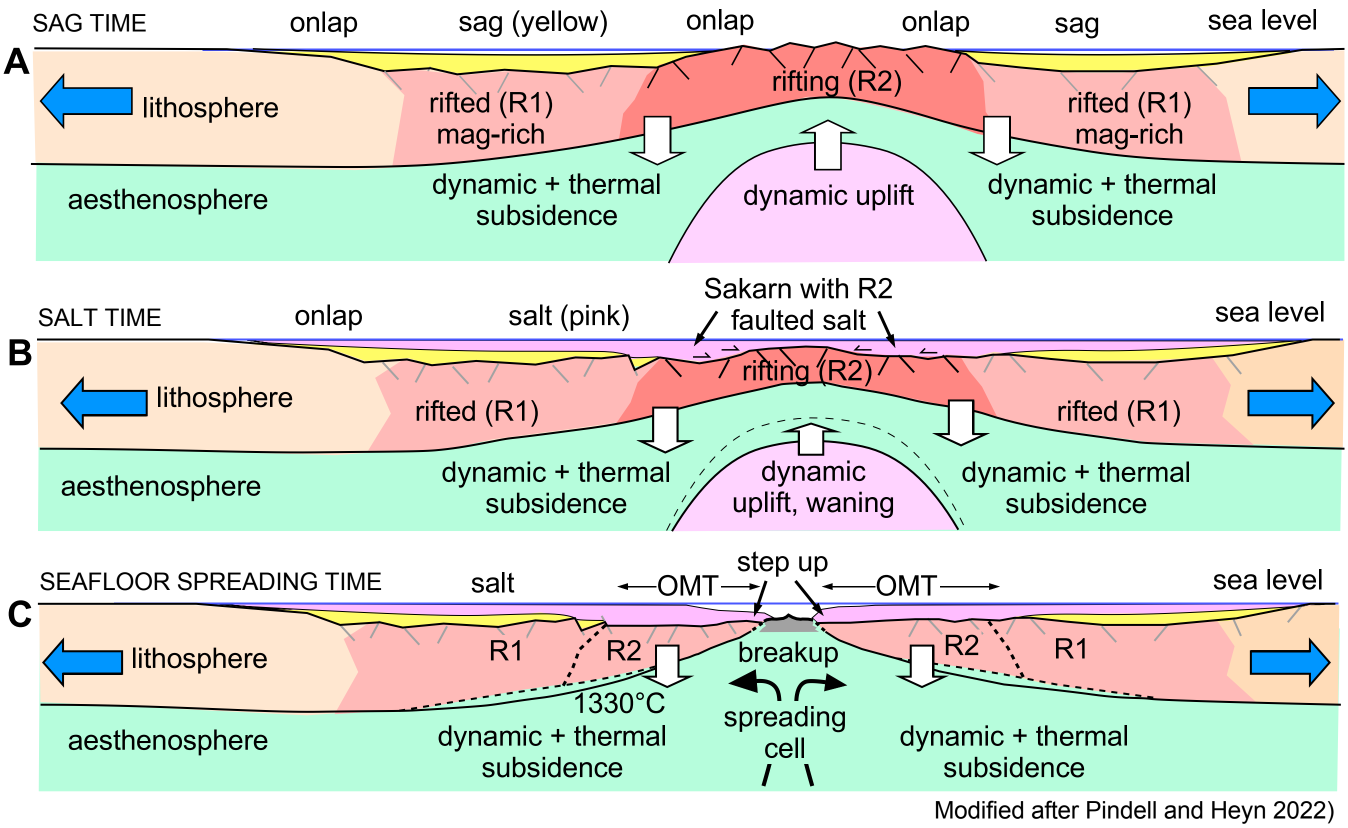

Figure 1. *Envisaged cross-sectional settings for subaerial magma-rich intra-continental rift margins above a plume. At least one side must move off the plume, such that dynamo-thermal subsidence ensues and leads to sag and possibly salt deposition (climate dependent) from near sea level (modified after Pindell and Heyn, 2022). A) Time of sag deposition as R1 rifted and/or magmatically accreted crust focusses and continues as R2 rifting along the outer marginal troughs. Accommodation for sag is driven by dynamo-thermal subsidence of "rifted" crust after moving off the active zone of magma-rich "rifting". B) Time of salt deposition, meaning that sea water has been able to enter the basin, now definitely at or slightly below global sea level. Salt precipitation can keep pace with dynamo-thermal subsidence in both R1 and R2 areas. However, accommodation is created by R2 tectonic extension along outer marginal troughs near the eventual site of seafloor spreading. C) Time of initial seafloor spreading, with some spilling of salt onto oceanic crust if the step-up buttress is not well developed (left side), or salt inflation within the outer marginal troughs (OMT) if a step-up buttress is well developed (right side). Juvenile oceanic crust sits shallower than 2.6 km as plume continues to wane.*

Red Sea, Río Grande) have magma-rich rift character and are also elevated well above isostatically balanced levels (Roberts et al., 2012; Karlstrom et al., 2012; Faccenna et al., 2013). Rising mantle plumes, and flow within excessively warm and buoyant sub-lithospheric mantle, relative to the surrounding mantle, cause dynamically elevated lithospheric swells 800 km and more in diameter (Winterbourne et al., 2014). Active rift flanks lie up to 2.5 km average elevation above sea level, most of that due to dynamic elevation, and central rift grabens and areas of continental crust thinned to less than 20 km occur well above sea level, too (Karlstrom et al., 2012; Faccenna et al., 2013; Sembroni et al., 2016). Today's magma-rich rifts look nothing like the isostatically balanced, passive rift model of McKenzie (1978) in which the rift never rises above sea level, and which has, perhaps inappropriately, formed the basis of much of our basin modelling for magma-rich margins, when the model applies to passive, magma-poor, rifts. McKenzie, in Crosby and McKenzie (2009) for example, acknowledges dynamically driven elevations exceeding 1.5 km.

Similarly, areas of newly accreted, lightly sedimented, oceanic crust within dynamic highs, such as in the Red Sea, have subsea depths of only about 1 km, and as little as 700 meters (Delaunay et al., 2023; Baby et al., 2024). These non-loaded crustal accretion depths amidst northeast Africa's dynamic swell are nearly 2 km shallower than the typical 2.6 km average depth of juvenile oceanic crust formed at spreading ridges far from plumes. Moreover, oceanic crust at 1 km depth subsea would lie at only about 700 meters below global sea level were it not for the load of seawater. Such levels are only marginally deeper than the subaerial Afar triangle, whose basement is mostly igneous and sits some 2 km higher than it would if it were isostatically balanced (Faccenna et al., 2013).

The link between magma-rich rifting and dynamic elevation of associated tectonic environments is clear. It is important, however, to distinguish between dynamic elevation and actual elevation. Carrying on with the example above, an area of juvenile oceanic

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crust with an actual elevation/depth of negative 1 km subsea will have a dynamic elevation of about positive 1.6 km. Likewise, continental crust that would be isostatically balanced at 500 meters above sea level but that lies at 2 km actual elevation would have a dynamic elevation of 1.5 km.

Extending these principles to ancient continental margins, there is clear spatial and temporal association between magma-rich rift character and the former presence of tracked mantle plumes and/or excessively hot sub-lithospheric mantle beneath the site of continental breakup. This is true for the central South Atlantic (Quirk et al., 2013; Morgan et al., 2020 and references cited therein), and it applies to the Gulf of Mexico rift, too (Imbert and Phillipe, 2005; Pindell et al., 2011, 2014, 2018; Izquierdo-Llavall et al., 2022; Pindell and Heyn, 2022; Lundin et al., 2025), as discussed further below.

DYNAMIC ELEVATION AND SUBSIDENCE IN THE GULF OF MEXICO RIFT MARGINS

Following today's magma-rich rift analogues, Pindell and Heyn (2022) pursued the suggestion of Pindell et al. (2019, their Fig. 5b) and argued that positive dynamic elevation in the early Gulf rift basin (today's Gulf of Mexico rifted margins) kept the region above isostatically balanced elevations during Late Triassic and Lower Jurassic rifting. Plume-related magmatic activity and intra-continental rifting intensified across the region by 200 Ma (time of the Central Atlantic Magmatic Province, CAMP). Magma-rich rifting along Gulf rift margins continued through the Early Jurassic to about 175 Ma, a phase of Gulf evolution commonly known as "Gulf stage 1" that was dominated by NW-SE crustal extension due to North America's flight from Gondwana. This stage 1 rifting, including the formation of areas of magmatic crust off northwest Yucatan (Pindell and Heyn, 2022, Pindell et al., 2024) and probably most of the northern Gulf (Mickus et al., 2009; Pindell et al., 2024; Lundin et al., 2025), can be referred to as "R1" rifts or magmatic accretions, whereas "Gulf stage 2", or "R2" rifting, pertains mainly to the outer marginal troughs along today's Penrose oceanic crust of the Gulf of Mexico. R2 rifting began just before (Pindell et al., 2020) and continued during salt deposition, as Yucatan began to rotate CCW from North America, thereby creating the outer marginal troughs along the Penrose oceanic crust. **Figure 2** is drawn for 167 Ma, during R2 rifting. Although

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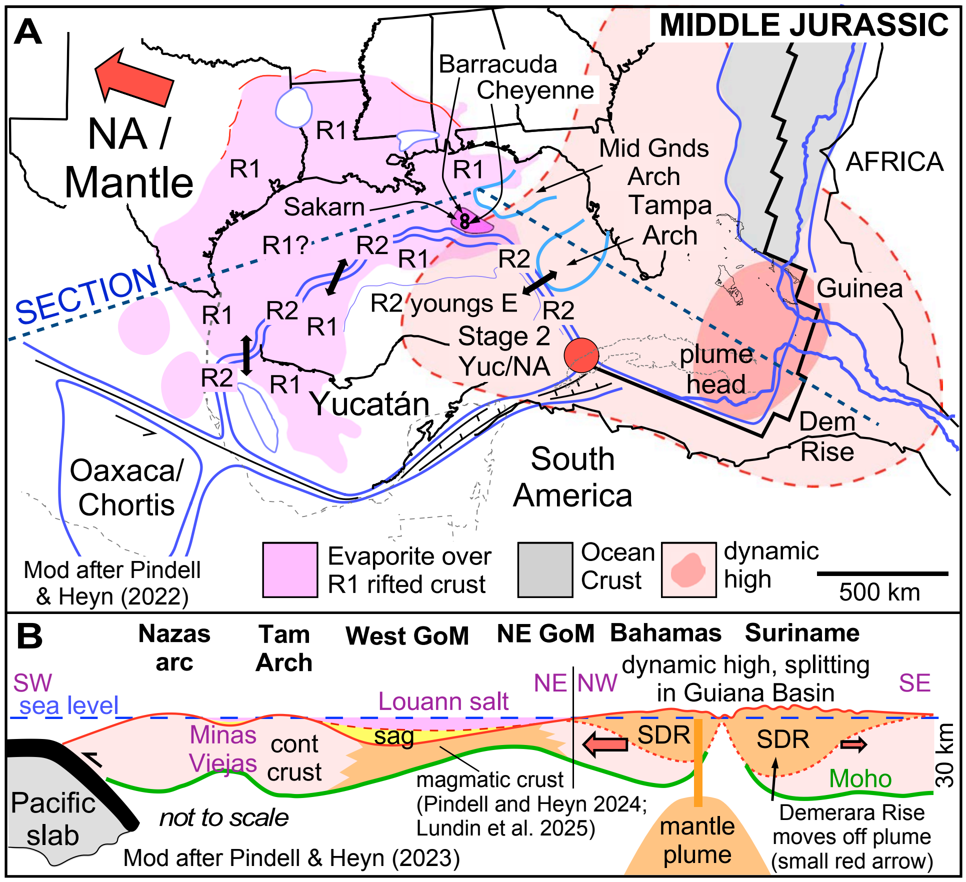

Figure 2. *A) Late Middle Jurassic (~Bathonian, 167 Ma) reconstruction of the greater Gulf of Mexico–southern Central Atlantic region, as "Stage 2" of Gulf evolution was getting underway (rotation of Yucatan with respect to North America around the red pole, from Pindell et al., 2020). Earlier regional CAMP magmatism was becoming focussed on an Iceland-style hot spot beneath the reconstructed Bahamas, Demerara Rise and Guinea Plateau. Inferred area of dynamic elevation as indicated by the occurrence of ongoing Middle Jurassic igneous activity (see Pindell and Heyn, 2022) is shown in pink. Area of salt deposition (rose) to the west (R1 rifted crust) has moved off the plume and is undergoing dynamo-thermal subsidence as recorded by sag/salt deposition. Positions of the distal Cheyenne and Barracuda wells, with paleo-depositional surfaces at global sea level, are shown along with the area of the Sakarn Series. Modified after Pindell and Heyn (2022). B) Regional section, position shown in A, portraying continental and magmatic crusts including SDR piles beneath Demerara Rise (becoming dormant) and the Bahamas (still active), which were being separated by more normal seafloor spreading at this time. Demerara Rise and Guinea Plateau have been displaced from the plume center presumably by small eastward drift over the mantle, while North America was drifting northwest over the mantle much faster, as recorded by the continued development of the Bahamas hot spot track. The area of salt deposition across the reconstructed Gulf of Mexico is generally underlain by sag section and covers the area of R1 rifted crust (Late Triassic to early Middle Jurassic rifting), the two halves of which are now being separated by syn-salt, late Middle Jurassic R2 rifting (with no sag section) in the conjugate outer marginal troughs which include the Sakarn Series. Modified after Pindell and Heyn (2023) with the clarification of magmatic crust beneath the northern Gulf margin following Pindell and Heyn (2024) and Lundin et al. (2025).*

stage 1 rifting continued to develop through the Early Jurassic, by ~175 Ma most igneous activity had shifted east and become focussed on the Bahamas-Demerara Rise-Guinea Plateau area, with peripheral magmatism persisting in the eastern Gulf margins (Florida, Georgia, and northern Yucatan). The eastward migration of magmatism, relative to the Gulf rift basin, is consistent with the absolute north-westward migration of North America in the mantle reference frame (Molina-Garza et al., 2019), such that the central and western Gulf rifts had moved off the mantle plume by the Middle Jurassic. The interpreted area of ongoing dynamic uplift in the Middle Jurassic as judged by the area of known continuing magmatism included these easterly areas of the Gulf rift basin (**Figure 2**).

The dissipation of dynamic elevation (dynamic subsidence) is generally thought to be slow (essentially thermal; Nadin and Kusznir, 1996). However, Pindell and Heyn (2022) reasoned that if a juvenile plate margin can be shown to have moved off the plume after rifting, then that margin would lie in a setting where the former dynamic elevation could dissipate relatively quickly (**Figures 1, 2**). Moreover, such a setting would also be where thermal subsidence begins, and the combination of thermal subsidence plus the dissipation of syn-rift dynamic elevation (i.e., thermo-dynamic subsidence) can significantly outpace thermal subsidence alone as a driving subsidence for accommodation, depending on the rate the margin moves off the plume. Because of 1) North America's flight from Gondwana and hence the mantle-based plume center, and 2) the presence of sag/salt section above R1 rifted/accreted crust, the margins of the Gulf of Mexico are prime examples for judging the effects of dynamic elevation and subsidence at magma-rich rifts.

As postulated by Pindell and Heyn (2022), when the effect of sediment loading is added to feasible amounts and rates of dynamo-thermal subsidence, up to 8 to 9 km of sediment may accumulate on a rifted margin over the timespan of sag/salt sections, starting from near sea level, even if R1 faulting is no longer occurring beneath areas of sag/salt deposition. These depositional rates easily account for the thicknesses of timespans of known sag/salt sections, including those in the Gulf of Mexico, the central South Atlantic, and Nova Scotia (Hudec and Norton, 2019; Snedden and Galloway, 2019; Rowan, 2023; Pindell and Heyn, 2022; Decalf and Heyn, 2023).

PALEODEPTH DATA FROM THE DISTAL SLOPE OF NORTHWEST FLORIDA (EASTERN GULF RIFT)

Recently published paleoenvironmental data for the Upper Jurassic section at the Barracuda, Cheyenne (**Figure 2**) and other neighbouring wells (Godo, 2025a,b) in today's deepwater slope setting off northwest Florida shed light upon our controversy, at least for the eastern part of the Gulf rift basin. The Barracuda and Cheyenne wells are the most distal and overlie hyper-extended magma-rich crust (<10 km), or purely magmatic crust, very near the mapped limit of the Penrose oceanic crust (Fig. 2; Pindell et al., 2011; 2014; Rowan, 2018; Rives et al., 2019; Pindell and Heyn, 2022; Izquierdo-Llavall et al., 2022; Moore et al., 2024; Lundin et al., 2025). Godo (2025a,b) presents paleontological and palynological calls for these wells that indicate bay (estuarine) to inner neritic paleoenvironments for initial post-salt deposition (Smackover Formation), deepening slightly up section to middle neritic (<100 m subsea) for the Tithonian, before becoming outer neritic and then bathyal in the Cretaceous. Thus, even if the 20 km of mainly Kimmeridgian downslope gravity sliding of the Oxfordian section in this area measured by Pilcher et al. (2019) is acknowledged, the entire Upper Jurassic section including the Tithonian was deposited in very shallow water (<100 m). In addition, the Gulf of Mexico was open to the world's seas for the entire Late Jurassic, Smackover time included, judging from the similar maximum onlap limits of the salt, the Smackover, the Haynesville, and the Cotton Valley (e.g., Dobson and Buffler, 1997; Snedden and Galloway, 2019). This negates any chance that the shallow paleoenvironments in the eastern Gulf's distal wells result from a Late Jurassic persistence of a hypothetical air-filled, sub-sea level depression. The shallow water environments at Barracuda, Cheyenne and other neighbouring wells were effectively at global sea level.

The noted paleoenvironments in this distal margin are surprising from the perspective of isostasy, given the proximity of the wells to the limit of ocean crust and the thinness of the underlying crust of the outer margin. One way to explain this would be if great thicknesses of sag/salt section were present. However, Pindell et al. (2011, 2014) and Izquierdos-Llavall et al. (2022) noted that the sag is thin to non-existent along most of the west Florida margin, in contrast to that in the central and western Gulf, if one accepts the Yucatan margin as representative of the whole. Likewise, the average salt thickness off west Florida (Pindell et al., 2011; 2014; Rowan, 2018; Izquierdo-Llavall et al., 2022; Pindell and Heyn, 2022; Lundin et al., 2025) appears to be less than that in the central and western Gulf with enormous and widespread diapirs, walls, stocks, and stacked canopies rising to the Pleistocene (Hudec et al., 2013; Horn et al., 2017; Snedden and Galloway, 2019; Hudec and Norton, 2019; Godo, 2025c). **Figure 3** compares salt habitats across the basin from west to east.

One area off Florida where evaporite may be relatively thick is the Sakarn Series within the outer marginal trough (**Figures 2A, 3C, 4**), which comprises an uncertain stratigraphy with a basal salt that is together up to 2.5 km thick (Rives et al., 2019; Moore et al., 2024). Heyn, in Pindell et al. (2023) and Heyn et al. (2024) interpreted the entire Sakarn as a layered evaporite sequence thicker than the evaporites in adjacent R1 areas. Cheyenne tagged salt beneath the Oxfordian Smackover (Godo 2025a,b),

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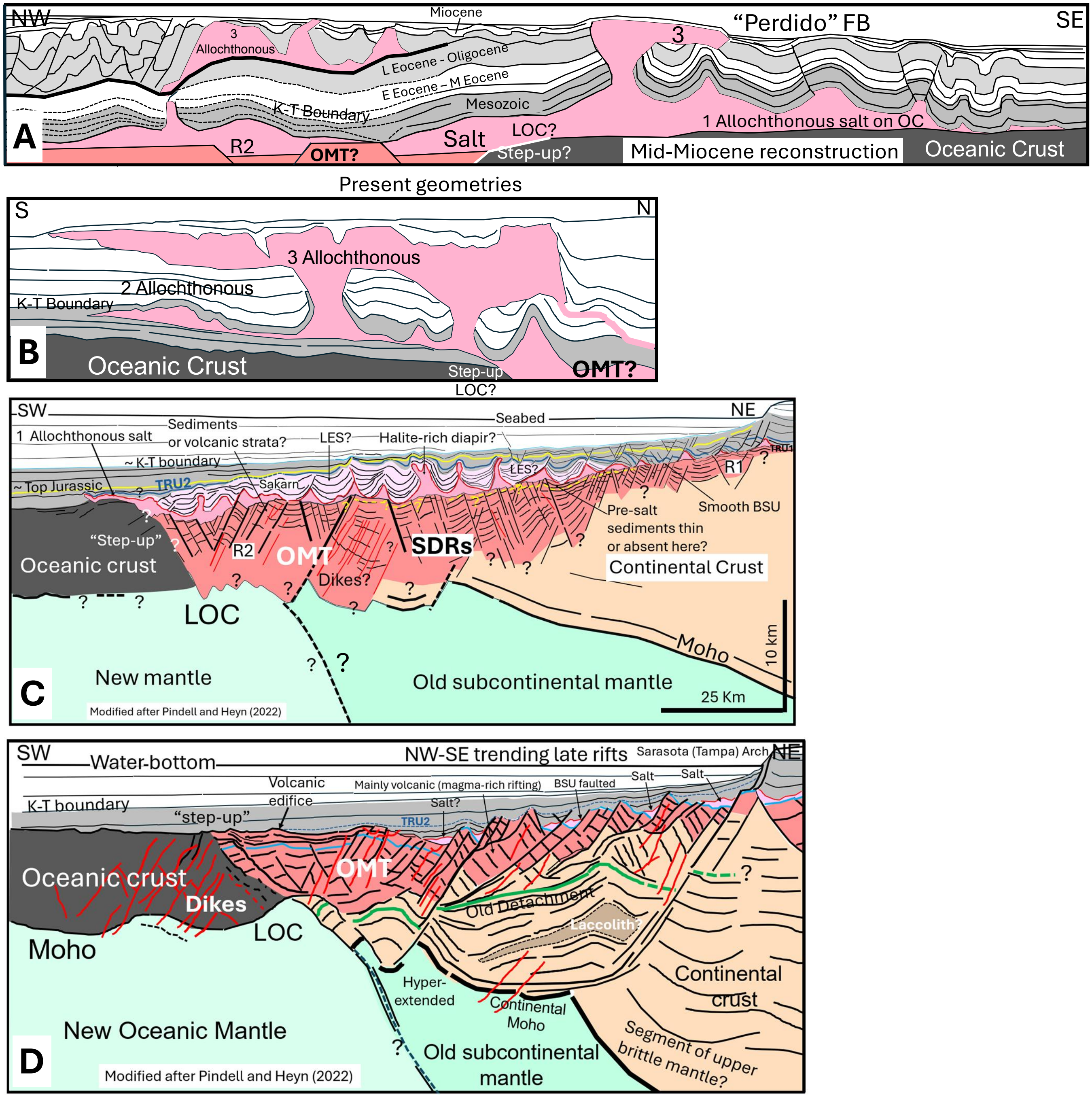

Figure 3. *Drawings of seismic lines A-D comparing salt volume (light rose), from west to east. Line A is a Miocene reconstruction of the salt from Heyn et al. (2017). Lines B, C and D are present day geometries. Line A is in East Breaks to Keathley Canyon. Line B crosses the limit of oceanic crust (LOC) in southern Green Canyon and extends across oceanic crust in Walker Ridge. Line C is in northwestern Lloyd Ridge protraction area adjacent to the western flank of the Middle ground Arch crustal ribbon. The upper part of the Sakarn Series in Line C probably represents layered evaporites (light pink), above dominantly halite diapirs (light rose). Line D is located off the western flank of the Tampa Arch (Vernon Basin to Florida Plain protraction areas). Line D is closest to the pole of rotation for the counterclockwise rotation of the Yucatan relative to North America and has an outer marginal trough (OMT) filled with volcanic strata. The amount of salt supplied by the northern half of the split Louann salt (initially a basin-wide salt) appears to decrease towards the east, towards the pole of rotation. The outer marginal trough likely deepens toward the west because the area was already off the plume by salt time, and it could also be the widest in the west due to being farther from the pole of rotation. In D, the outer marginal trough is filled with the youngest SDRs and volcanics (Tithonian?), and salt is limited to small R2 rift basins. Lines C and D are modified from Pindell and Heyn (2022). Salt labelled allochthonous salt 1 represents salt flow onto oceanic crust as observed in the Red Sea (Mitchell et al., 2010). Salt labelled allochthonous salt 2 represents a salt that climbed up section during the Mesozoic. Salt labelled allochthonous salt 3 represents a canopy that developed during the Cenozoic. R2 faults offset base salt but the inception of these faults is likely older in the west (~Oxfordian) than in the east (Lower Cretaceous). R1 faults occur beneath thick pre-salt sag landward from the OMTs. Line C shows R1 faults beneath relatively smooth base salt directly flanking the Middle Ground Arch. Next to the LOC, R2 faults are superimposed on R1 faults along the most strained segment of the outer marginal trough. Scale in C represents all the sections shown.*

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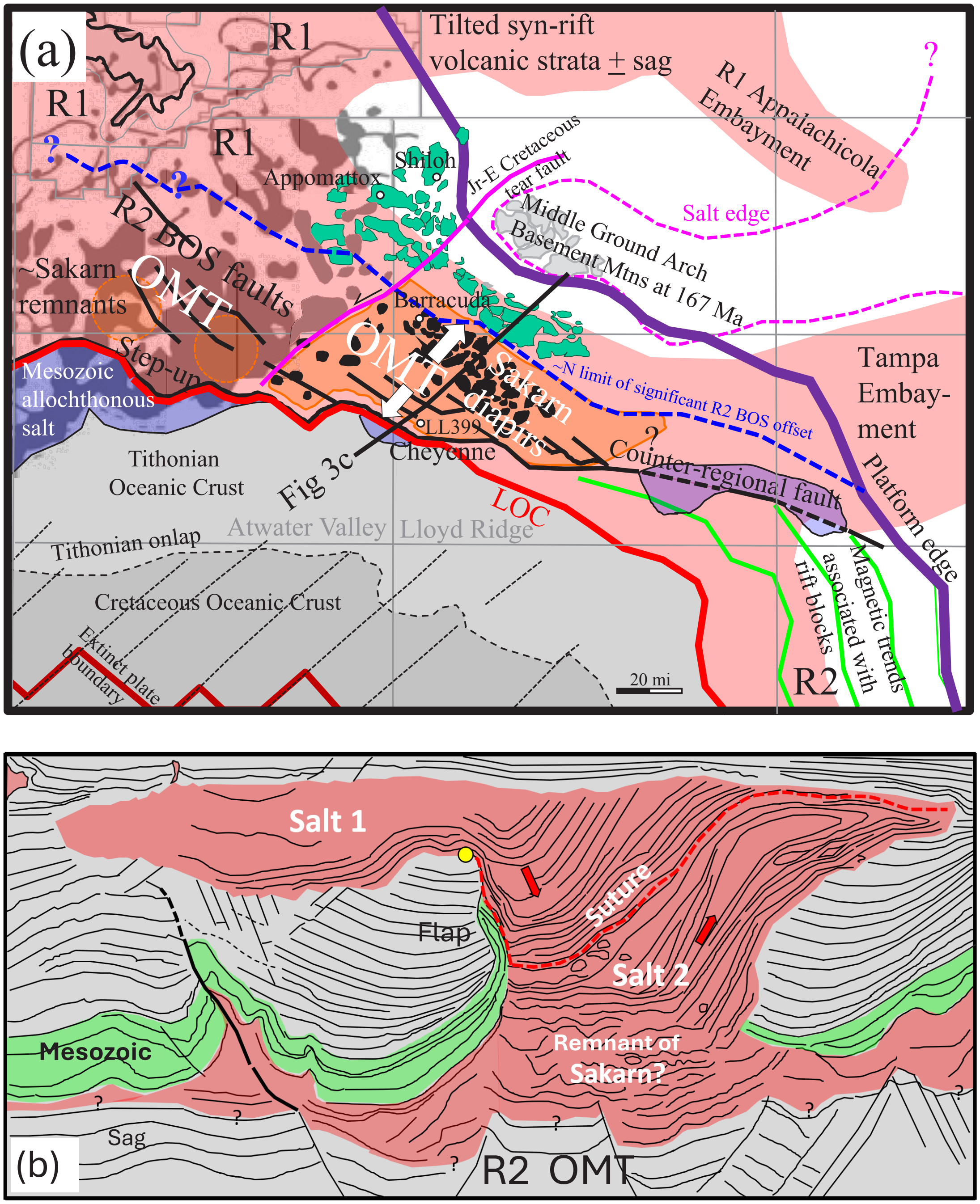

Interpreted long-offset FWI seismic data courtesy of TGS

Figure 4. *(a) Location map of the Sakarn (orange area), Middle Grounds Arch, Apalachicola and Tampa embayments, and Penrose oceanic crust. (b) Drawing of a 3d seismic line of a deformed remnant of Sakarn (west of pink tear fault in a). Heyn, in Pindell et al. (2023) and Heyn et al. (2024) interpreted the entire Sakarn as a layered evaporite sequence (LES) in the eastern Gulf of Mexico. The line is located northwest of the fault (pink line) identified by Rives et al. (2019) which they represent as the northwest limit of the Sakarn domain. This structure is probably a tear fault above base of salt rather than a transform. Sakarn remnants are displaced to the southwest due to Late Jurassic and Early Cretaceous climb of allochthonous salt (plus cover) outwards over newly deposited sediments on new Tithonian Penrose oceanic crust (light grey) to the south of the LOC. The outer marginal trough (OMT) occurs between the dashed blue line and LOC (red line). The Apalachicola Basin provided a larger fetch for salt supply into the Mesozoic allochthonous sheet (blue) west of the tear fault (pink line). Orange circles representing Sakarn remnants are NOT exactly located. The drawing shows Sakarn (salt 2) connected into a diapir stem and folded shapes where LES deformed within the canopy. The Sakarn is predicted to be interlayered with other salts and perhaps even a few shale or sand layers. The green unit of the line drawing represents condensed Mesozoic section. The faults at/below base of salt in the line drawing are R2 faults typical of the OMT. The yellow dot of the drawing represents a base of salt suture point, and the red dashed line is a suture between two salts. Figure 3C is indicated with a black line in the map (a). Dark grey represents Cenozoic diapirs and canopy from Rowan and Vendeville (2006). Green areas represent Norphlet rafts from Pilcher et al. (2014). The Tithonian sedimentary onlap is labelled with a thin dashed black line.*

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supporting Heyn's interpretation. However, the Sakarn fills the outer marginal trough where R2 rift faulting provided tectonic accommodation for Sakarn deposition (**Figures 3C, 4**), unlike R1 areas. Ultimately, evaporite deposition kept the eastern Gulf rift basin's depositional surface near global sea level, including the Sakarn outer marginal trough. Such was the setting while evaporite was continuous across the reconstructed conjugate margins, and while R2 extension beneath the evaporite section formed the outer marginal troughs that were ultimately separated by sea floor spreading.

Given the west Florida margin's highly thinned crust, thin to non-existent sag section, and a thinner salt section than that to the west, it is very likely that dynamic elevation was required for the depositional surface to be at global sea level at the end of salt deposition (Smackover age; Godo, 2025a,b). Moreover, the Sakarn Series within the outer marginal trough thins to the southeast, toward Yucatan's pole of rotation. West of Tampa Arch, there is no sag, and salt is found only in isolated rift grabens (Izquierdo-Llavall et al., 2022; Pindell and Heyn, 2022). This salt was likely deposited near sea level like the salt off northwest Florida: if so, the outer marginal trough itself must have been near global sea level toward the southeast in the Middle and Late Jurassic. Pindell and Heyn (2022) attributed this surprisingly shallow Jurassic paleo-tectonic setting to a regional (>1000 km diameter) dynamic swell up to 2 km above isostatic compensation levels due to a mantle plume below the reconstructed lithospheres of Florida, northeast Yucatan, the western Bahamas, and the Demerara Rise/Guinea Plateau (**Figure 2**). This high migrated to the southeast, relative to North America, as North America continued to migrate to the northwest in the mantle reference frame, thereby progressively displacing the Gulf rift from the plume.

The above reasoning, along with Godo's (2025a,b) paleoenvironmental data, touches upon another controversial issue, namely whether salt filled the entire Gulf rift basin to sea level. Rowan (2015, 2018) appears to have assumed 1) thinner salt in the east, and 2) typical 2.6 km depths for the accretion of the Penrose oceanic crust across the Gulf, and he thus concluded that the top-salt surface formed a basinward- and eastward-deepening, submarine slope. Rowan in turn invoked deep-water salt precipitation models (e.g., Roveri et al., 2014; Konstantineau et al., 2024) in the distal and the eastern Gulf rift margins. In contrast, Pindell and Heyn (2022; 2023) explained the eastward-thinning salt isopach as due to eastwardly shallowing basement at the time of salt deposition, due to eastwardly increasing dynamic elevation at the time of salt deposition, with a top salt surface near global sea level (Fig. 2). Given the paleoenvironmental data from the eastern Gulf wells (Godo 2025a,b), the idea of top-salt submarine relief and deep-water salt deposition in the east is not supported. Having said the above, it is only fair to note that Pindell and Kennan (2007) also assumed a 2.6 km depth of oceanic plate accretion in the eastern Gulf. Our transition to our present views on syn-rift dynamic elevation and shallow seafloor spreading is a function of the enormous gains made in recent years about the significance of dynamic topography.

CONCLUSIONS AND IMPLICATIONS

The paleoenvironmental data provided by Godo (2025a,b) combined with the thinness of the sag/salt section in the R1 rifted margin of western Florida pose an obstacle for giant, deep, air-filled depression rift models, for the eastern Gulf of Mexico at least. Magma-rich R1 rifting is also clear for the central and western Gulf rift margins (Pindell and Heyn, 2022; Lundin et al., 2025), suggesting significant R1 syn-rift dynamic elevation of former tectonic environments in those areas, too, especially if there were magmatic outer highs prior to basin splitting. Accepting significant, positive, R1 dynamic elevations toward the west, thereby keeping actual elevations closer to or near global sea level as we infer for the eastern Gulf, the fact that the post-tectonic sag/salt section is much thicker in the central and western Gulf (Hudec and Norton, 2019; Pindell and Heyn, 2022) suggests that the dissipation of syn-rift elevation (dynamo-thermal subsidence) began earlier there than in the eastern Gulf. The anticipated earlier beginning of dynamo-thermal subsidence in the west accords with North America (including the Gulf rift basin) moving progressively to the northwest off the plume. In other words, the eastern Gulf remained close enough to the plume during the time of sag/salt deposition that much of the dissipation of the dynamic elevation occurred in Late Jurassic and into Early Cretaceous time. This is supported by the paleoenvironmental data (distal ramp/early slope remained middle neritic through the end of the Jurassic; Godo, 2025a,b), and, in our opinion, by the subsidence analysis for the northwest Florida shelf by Curry et al. (2024).

The foregoing reasoning suggests that a pre-sag/salt, air-filled depression(s) deeper than a few hundred meters may never have existed anywhere within the Gulf of Mexico rift margins. This supposition carries implications for the construction of pre-salt facies, paleo-depth, and paleoenvironmental maps. It also implies that deep-water salt precipitation models may be overapplied to ancient margins where basement had been dynamically elevated during rifting, as with the eastern Gulf of Mexico. However, we acknowledge that, for areas that might have subsided to depths greater than a few hundred meters, the depositional surface could have returned to global sea level during salt precipitation with either deep-water or episodic-spill types of models, or perhaps even syn-salt lateral flow. The discussion herein has not eliminated these models, and we must remember that nothing can ever be proved. ■

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Gulf of Mexico Differential Spreading and Subsidence

By Ted Godo

INTRODUCTION

This article explores the varying degrees of lateral spreading of the oceanic crust and its subsidence history in the Gulf of Mexico (GOM). It presents five regional interpretations of seismic line tracings that extend basinward from well control. The lines start on the continental crust and continue onto the interpreted oceanic basement crust of the Gulf of Mexico (GOM). These interpretations have been developed over the past five to ten years. This study concludes that the differential spreading and subsidence rates of the Penrose oceanic crust have resulted in changes to the presence and thickness of the Upper Jurassic (post-salt) sediments.

The most striking observation is that in the eastern GOM, the interpreted oceanic crust appears to have been somehow "propped up," causing the Knowles and older events to onlap the basement crust in an area outlined in dark green in Figure 1. In contrast, in the central and western GOM, the thick Upper Jurassic strata of the Knowles and Kimmeridgian extend across the spreading center. Additionally, in the western and central regions, older interpreted horizons, including the Oxfordian, have thicker sections above the oceanic crust on either side of the spreading center.

METHODOLOGY

Seismic reflectivity of sedimentary events above the oceanic crust is easily correlated with good reflectivity and structurally low dip. There are no well penetrations, however, of the oceanic crust itself. The deepest well control only reaches the salt above the thin, magma-rich crust or near the outer trough of the oceanic crust (Pindell, 2025-this issue; Lundin, 2025). Three of these wells fully penetrated the entire Mesozoic section, reaching a total depth within the Louann salt (Cheyenne, LL399, Hux-1, and Chibu-1). The fourth well, Triton-1, reached total depth after penetrating the Knowles/Tithonian. These wells, or "tie-points," provided the age correlation for correlating events onto the oceanic crust. The well ties to seismic data and the actual 2D or 3D seismic lines will not be presented.

The end of the seafloor spreading occurred at approximately 135 mmybp in the Valanginian (approximate Knowles limestone-US name) (Lin et al, 2019; Pindel et al, 2020). The primary focus of the events depicted in the figures is the Knowles limestone, Kimmeridgian, Oxfordian, and "in Oxfordian" events. The Green event, or Knowles limestone, closely approximates the top of the Jurassic, as the Tithonian paleo pick occurs a few hundred feet

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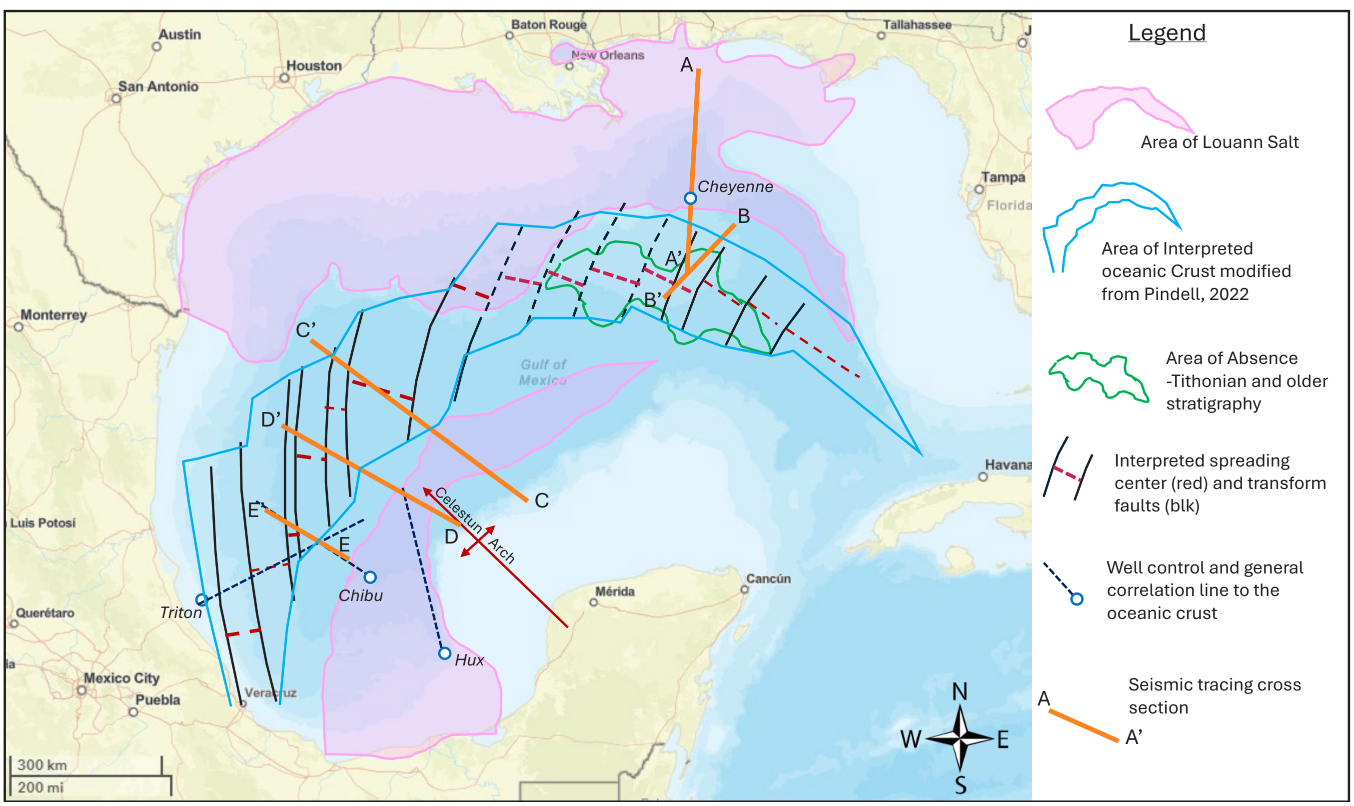

Figure 1. The map shows the interpreted spreading center and transform faults of the formation of oceanic crust during the opening of the Gulf of Mexico. The orange lines represent seismic tracings that extend from the continental crust into the oceanic crust. In the dark green polygon is a high area where the Knowles and older Upper Jurassic events terminate by onlap onto basement rock.

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below the Knowles. Four wells on both sides of the Gulf were used to link the 2D seismic lines shown in the examples (**Figure 1**). Seismic correlation of these events involved utilizing additional seismic data to extend the interpretations around salt domes or areas with poor data, which were meticulously guided to extend the interpretation onto the flat area of the oceanic crust. Confidence is high in these interpretations, especially of the Knowles limestone event, and event correlations from these widespread data points were free of seismic "mis-ties" over the oceanic crustal area.

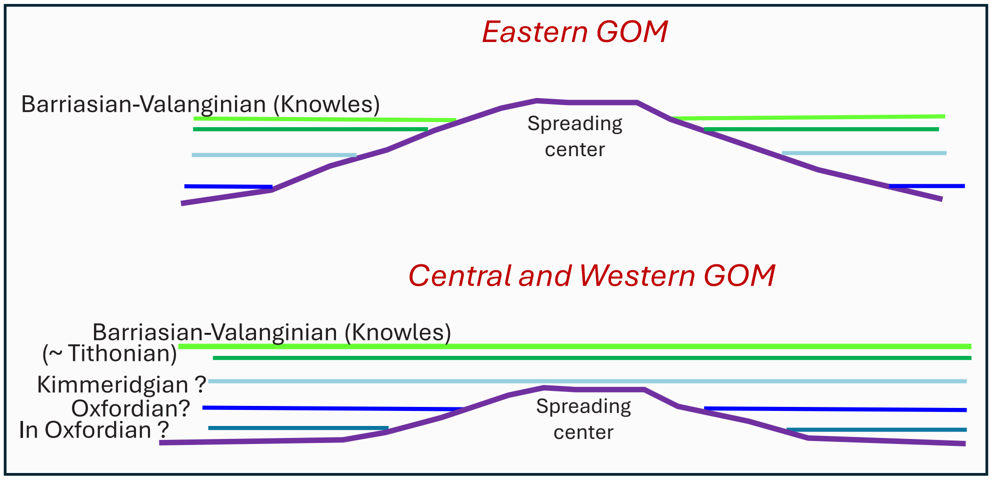

Figure 2. *Example comparisons of the seismic events that were of Upper Jurassic, deposited during seafloor spreading. In the EGOM area, this "taller" spreading center appears to have been "buoyed up" for a more extended period than the central and western GOM. In the west and central Gulf of Mexico (GOM), the Knowles through Kimmeridgian extends across the oceanic crust from Mexico to the US side. Additionally, in the west and central Gulf of Mexico (GOM), the Oxfordian and older "In Oxfordian?" area is deposited over larger areas compared to the eastern Gulf of Mexico (EGOM).*

OBSERVATIONS AND INTERPRETATIONS

The oceanic crust in the GOM exhibits two significant differences in the post-salt sedimentary fill (**Figure 2**). The first type, found in the western and central Gulf, has Tithonian and nearly all Kimmeridgian rocks extending from the U.S. to the Mexican side, well above the spreading center. In contrast, in the eastern GOM, the Upper Jurassic events associated with the Cheyenne well terminate on oceanic crust surrounding the green polygon in **Figure 1**. The preferred model explaining the differing burials of the oceanic spreading centers is partly the "dynamo-thermal subsidence" model proposed by Pindell and Heyn (2022). In the eastern Gulf, where lateral spreading was minimal, the model suggests that an underlying hotspot generated by a mantle plume raised the area above sea level, leading to the onlap of Oxfordian through Tithonian. In contrast, the western and central GOM began a counterclockwise rotation of the Yucatan block around the rotational pole near the eastern Gulf of Mexico's volcanic plume. The lateral spreading likely began in the Oxfordian and created the subsidence needed for the deposition of the Oxfordian through the Tithonian. The Oxfordian was only deposited in lower areas of the spreading ridge axis, but subsequent Kimmeridgian

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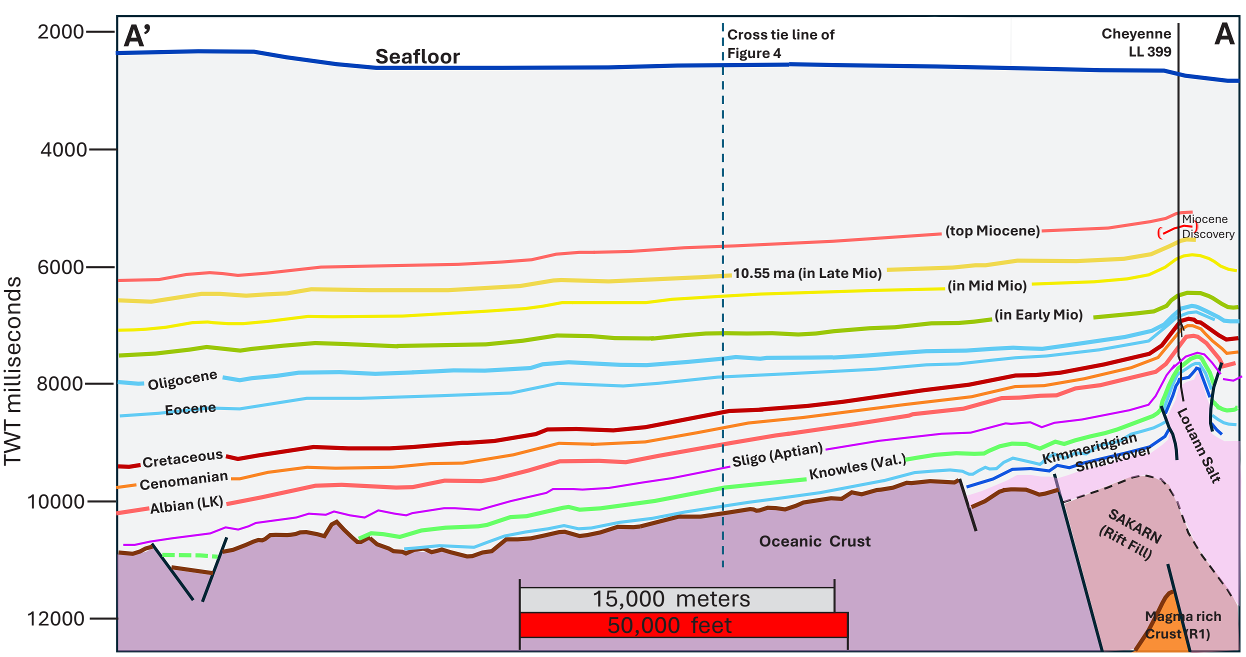

Figure 3. *The seismic tracing is a key line that ties the Mesozoic events to the Cheyenne well and events older than the Knowles onlap the basement (oceanic crust). The crust colored in orange is interpreted as magma-rich crust formed during the R1 rift stage.*

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sediment nearly covered the spreading center, while the Tithonian completely blanketed the oceanic crust.

Seismic cross-section A-A' (**Figure 3**) connects to the Cheyenne-1 well in Lloyd Ridge (**Figure 1**). The paleo-bathymetries of the paleontologic tops in the well suggest that water depths ranged from bay (estuarine) to inner neritic, deepening only to middle neritic during Tithonian time (Godo, 2025a, b). These horizons extend southward from the well and onlap against the oceanic crust (**Figure 4**). The intersecting line in **Figure 3** is shown in **Figure 4**, which crosses onto a structurally higher portion of the oceanic basement, where even Lower Cretaceous events onlap or are truncated against smaller areas of the high. Line C-C' traverses the North Yucatan salt basin (**Figure 5**), covering a central part of the Gulf of Mexico. On the right side of the line is

Gulf of Mexico Differential Spreading and Subsidence *continued on page 53*

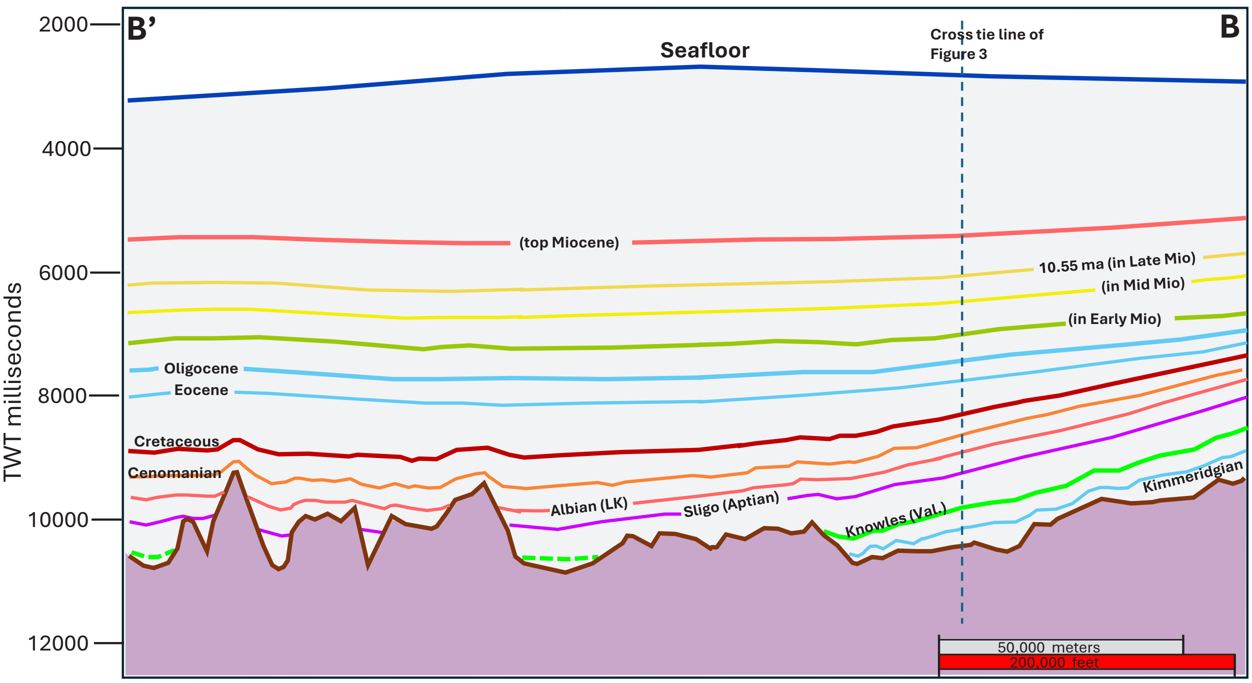

Figure 4. *The seismic tracing intersects the line in Figure 1 (dashed vertical line) and then this line extends further to the southwest, where even younger events in the Lower Cretaceous onlap the oceanic crust basement. This structural high in the oceanic crust, where there is an occurrence of onlapping/truncations of seismic events, is shown as the green polygon area in Figure 1.*

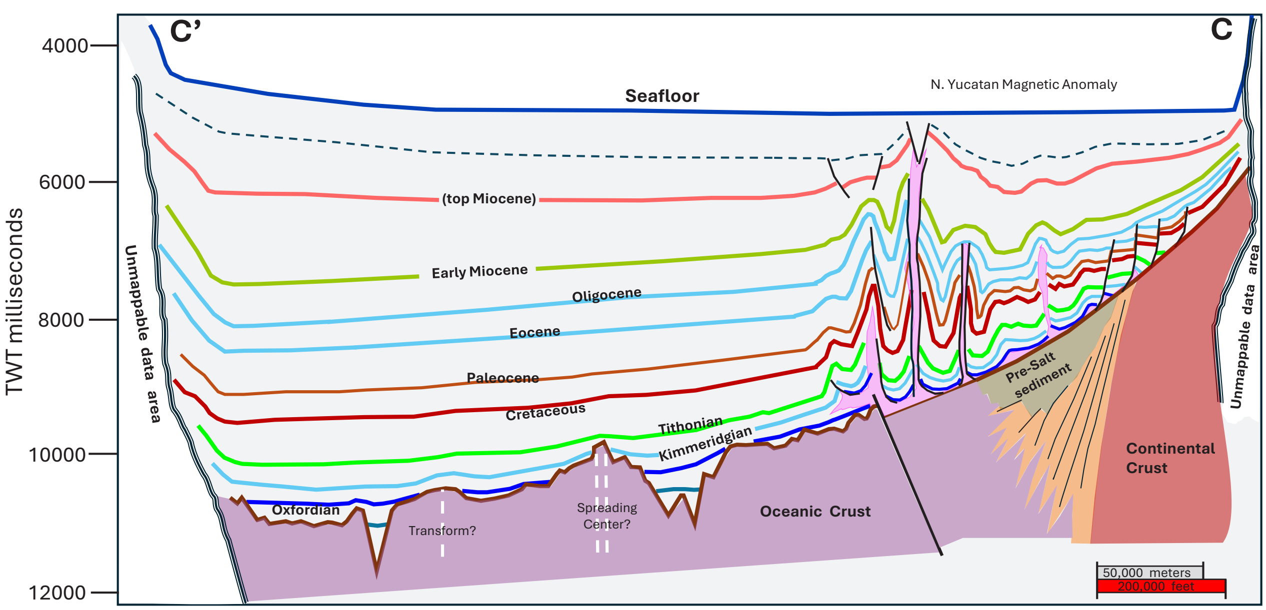

Figure 5. *The seismic tracing of a line is taken as an example line from a grid where all interpreted events are tied in the oceanic crust area. Also annotated in the oceanic crust are vertical dashed lines across basement highs that could be the spreading center and transform faults. The line is in the Yucatan Salt basin northeast of the Celestun Arch, which separates the Sureste Basin from the North Yucatan basin. Notice the somewhat limited thickness of salt, as the mobility is only expressed as diapirs (no complex salt geometries)*

Gulf of Mexico Differential Spreading and Subsidence *continued from page 52*

the Yucatan continental block. The Louann salt thins and pinches out along with the Oxfordian through Tithonian events on this line. The Yucatan was an exposed paleohigh during these periods (Godo, 2025c). Below the salt detachment lies an area of pre-salt stratigraphy, likely composed of continental clastics. Further down, the orange is interpreted as a magma-rich complex accreted to the continental crust during the R1 phase of the Yucatan and North American separation (Pindell, 2022, 2025; Lundin, 2025). A magnetic signature over the orange area likely indicates a magma-rich basement that may have originally been connected with the Houston Magnetic anomaly (Pindell, 2020; Lundin, 2025). The main observation of this report is that the Tithonian and most of the Kimmeridgian events extend across the oceanic crust that spread during the R2 phase. The Oxfordian event is also significantly more widespread across the Gulf's oceanic crust. Seismic line tracing D-D' is located off the northwest Yucatan near the axis of the Celestun arch (**Figure 6**). Very thin salt in this area facilitates straightforward seismic correlation, as seismic events from the Hux-1 well south of the dashed vertical line were brought north to tie this dip line. This line also demonstrates increased subsidence over the oceanic crust, leading to thicker Upper Jurassic sections. The last seismic line tracing is labeled E-E' (**Figure 7**). This line is a depth line flattened on the Knowles horizon. The seismic event correlations come from all four wells tied onto the oceanic crust, but this line is part of the line running northwest from the Chibu-1 well. The Oxfordian event (dark blue) extends across the entire line, while a deeper horizon labeled "In

Gulf of Mexico Differential Spreading and Subsidence *continued on page 54*

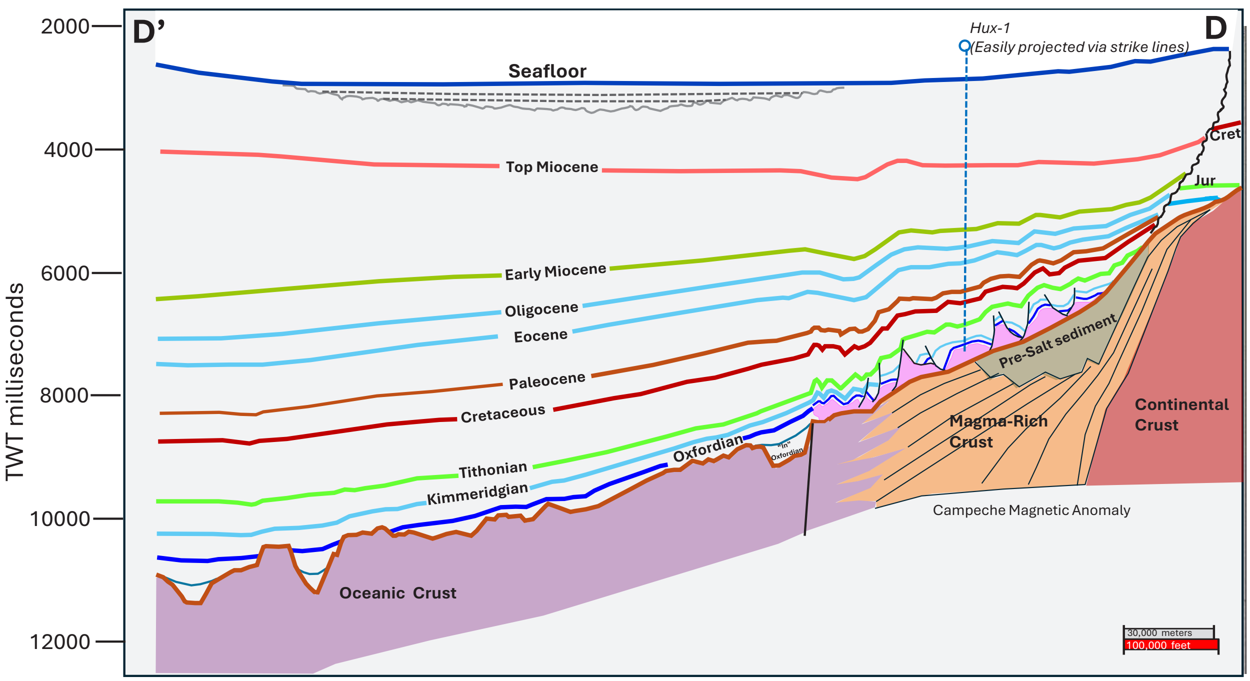

Figure 6. *The seismic tracing is a key line to more confidently bring well ties (such as the Hux-1) in areas of thin salt near the Celestun arch that separates two thicker salt basin areas of the Sureste and North Yucatan basins.*

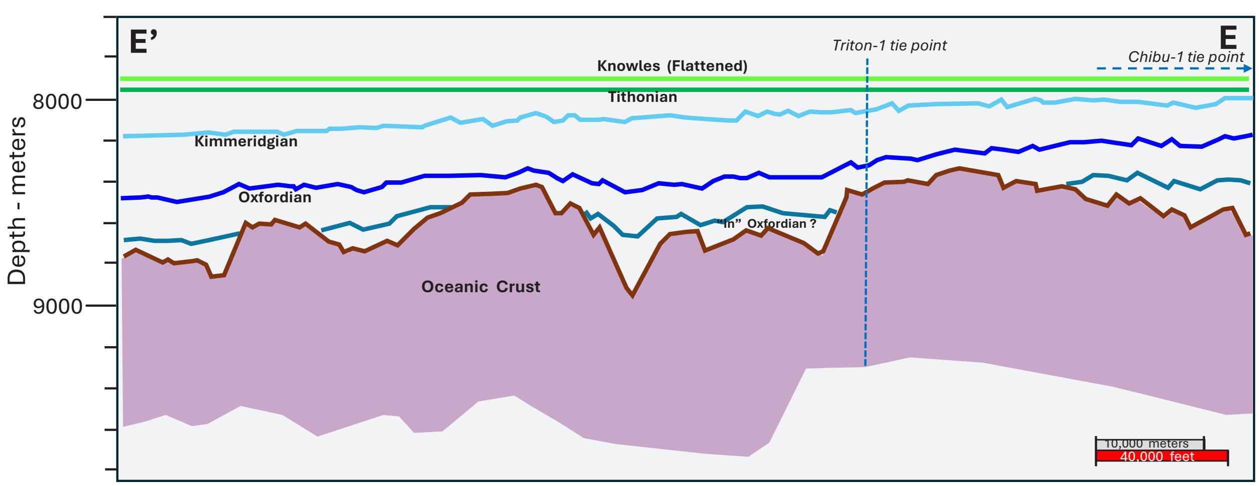

Figure 7. *The seismic tracing is the most southwesternly located line. The thickness of the Tithonian, Kimmeridgian, and Oxfordian sections is much thicker than the same stratigraphy in the EGOM and in some wells.*

 continued from page 53

Oxfordian" cannot be tied to any well, as the event likely occupies grabens or otherwise local depressions in the oceanic crust.

Lastly, reconstructing thick, present-day, deformed salt that forms complex salt canopies, welds, and diapirs to determine the original salt thickness can seem like an exercise in futility. However, based on the post-salt Oxfordian through Tithonian presence and thickness, it suggests that the original salt deposition was thicker in the west and thinned toward the eastern GOM. A qualitative evaluation of salt structures and local thickness across the Gulf indicates that the west-to-east thinning of salt is the most likely scenario. For example, on the Yucatan side of the GOM, two salt basins have been identified on either side of the Celestun arch, initially proposed by Hudec (2013) and now named the Celestun arch (Steier, 2019; Hasan, 2021; Godo, 2025c). The Campeche salt basin lies west of the arch, while the Yucatan salt basin lies to the east. Any seismic line in the Campeche basin reveals much more mobilized, thicker salt with complex geometries compared to the Yucatan salt basin, where only a few simple salt diapirs are present. Further east of the Yucatan, a reconstruction shows that on the present US GOM side, a narrowing of the salt basin limits is marked by mostly salt detachments and very few diapirs. Additionally, the US portion of the salt basin contains mainly salt detachments with rotated sediment blocks and simple diapir structures, such as those found at Cheyenne and Barracuda wells (Godo, 2025a).

SUMMARY

The main observation detailed in this paper is the difference in Upper Jurassic seismic reflections over the oceanic basement. In the eastern Gulf of Mexico near the Cheyenne-1 well, all of these horizons thin and onlap the basement. In contrast, the same reflections in the western and central Gulf of Mexico demonstrate greater subsidence of the oceanic crust, permitting a continuous section of Tithonian and primarily Kimmeridgian strata across the entire oceanic crust from Mexico to the US. Furthermore, sufficient subsidence occurred in this region for Oxfordian rocks to be found over a large portion of this crust. These observations were made while exploring to determine if Tithonian rocks were present in at least some areas off the coast of Mexico, supporting the existence of petroleum source rocks. After Cheyenne was drilled in 2004, it became clear that in the east, the Tithonian was absent in certain areas, as it onlapped the oceanic crust. It was not until the "dynamo-thermal subsidence" model proposed by Pindell and Heyn (2022, 2025) that the EGOM area could be placed in a more consistent regional tectonic context. ■

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JUNE 2025

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
1	2	3	4	5	6	7
8	9 **URTEC** *https://www.hgs.org/civicrm/event/info?id=2655* (→ through 11)	10	11	12	13	14
15	16	17	18	19 **HGS NeoGeos Happy Hour Intern Night** *https://www.hgs.org/civicrm/event/info?id=2644*	20	21
22	23	24	25	26	27	28
29	30					

Make your reservations online at hgs.org

RESERVATIONS The HGS prefers that you make your reservations online through the HGS website at WWW.HGS.ORG. If you have no internet access, you can e-mail OFFICE@HGS.ORG, or call the office at 713-463-9476. **Reservations for HGS meetings must be made or cancelled by the date shown on the HGS website calendar, normally that is 24 hours before hand or on the last business day before the event.** If you make your reservation on the website or by email, an email confirmation will be sent to you. If you do not receive a confirmation, contact the HGS office at OFFICE@HGS.ORG. Once the meals are ordered and name tags and lists are prepared, no more reservations can be added even if they are sent. **No-shows will be billed.**

INSTRUCTIONS TO AUTHORS

Materials are due by the first of the month for consideration to appear in the next month's publication. Submissions should be emailed to editor@hgs.org. The Editor reserves the right to reject submissions or defer submissions for future editions.

Text should be submitted as a Word file. Figures or photos may be embedded in the document or submitted separately. The following image formats are accepted: tif, .jpg, .png, .psd, .pdf.

Feature submissions, e.g., Rock Record, should be approximately 600 words. Technical papers should be approximately 2000 words or less (excluding references).

NeoGeos 2025 Happy Hours

NeoGeos HGS

FEB 20 — **UH AAPG WILDCATTERS NIGHT**
Kirby Ice House (3333 Eastside St.)

MARCH 20 — **IMPAC - EXPLORATION SERVICES**
Corn Hole Tournament
Eleven Below (Spring, TX)

APRIL 17 — **INTERTEK**
Trivia Night
Location TBD

MAY 22 — **CORE GEOLOGIC**
Members Drink Free
Kirby Ice House (1015 Gessner Rd.)

JUNE 19 — **CO-SPONSORSHIP AVAILABLE***
Intern Night
Cottonwood

JULY 17 — **SPONSORPSHIP AVAILABLE**
Location TBD

AUG 21 — **SABATA ENERGY CONSULTANTS**
Platypus Brewing

SEPT 18 — **GVERSE-GEOGRAPHICS**
Trivia Night
Location TBD

OCT 16 — **GEOMARK & PETRICORE**
Pickleball Tournament
PKL Social

NOV 13 — **SPONSORSHIP AVAILABLE**
End of Year Celebration
Location TBD

ALL EVENTS 6-9PM

WWW.HGS.ORG

*Seeking Multiple Sponsors

SEFH Awards Banquet 5/20/25

The SEFH Awards Banquet was held, May 20, 2025, at the University of Houston, MD Anderson Library, Elizabeth Rockwell Pavilion, 2nd Floor. The banquet celebrated scientific achievements of students competing in three competitions as well as the students who received Houston Museum of Natural Science (HMNS) summer internships. The Science and Engineering Fair Houston (SEFH) was held February 15, 2025, at the Fort Bend Epicenter. Top students in the SEFH competition went to Texas Science and Engineering Fair (TSEF), March 28-29, 2025, at Texas A&M. Top students in the SEFH competition also advanced to Regeneron International Science and Engineering Fair (ISEF), May 10-16, 2025, Columbus, Ohio. Winners were celebrated as well as local teachers who encouraged and supported them.

Prachi Natoo (HGS 2024 sponsored summer intern) won 1st Place Senior Division Chemistry at SEFH as well as 3rd Place at ISEF. She will be an HGS sponsored intern again this summer. Prachi also received a special award from HMNS (Dr. Carolyn Sumners) for her work last summer. When Penny Patterson and I went for a short visit with Prachi last summer, we ended up spending 3 ½ hours with her in the Open Space lab.

HGS sponsors 3 internships each summer; this year HGS will again support 2 full internships and 2 half internships. This was final week at most Houston Metropolitan area schools and many students were not able to attend the banquet. Not present were 2025 HGS sponsored interns Ram Magathala, Shri Chada, and Heba Badat (we supported them last summer as well).

The keynote speaker was, Girish Prabhu (CEO imaginX). His opening quote was, "We will be the last generation to manage only humans!" Girish described the three prior Industrial Revolutions and stated that the fourth will demand a new kind of literacy 'AI FLUENCY'. The mission he wants us to join is to ensure that AI is used to promote discovery and empowerment; allowing students with disabilities to be independent and ensuring that all students (and their advisors) can easily monitor course requirements to complete degree programs on time. ■

From left to right: Parag Natoo (Prachi's proud father), Dorene West (HGS Science Fair Chair), and Prachi Natoo (HGS 1st Place Senior Division and sponsored summer intern) pose in front of Prachi's project board.

Celebrated students and proud parents taking pictures. Far left Dr. Lionnel Ronduen (Associate Fair Director SEFH, with gray sports coat) and Dr. Heather Domjan (Executive Director of UH STEM Center and Executive Director of SEFH, with red jacket) and Prachi Natoo (second from left front row).

Remembrance

Denise Maureen Stone

1957-2025

Denise Stone, passed on to heaven at her home on May 3, 2025, in Centennial, Colorado. She was born in Summit, NJ on Sept. 2, 1957, to parents Clara Adele Vandenberg Stone and Joseph John Stone who predeceased her. She was their fourth daughter, and she is survived by her sisters Muriel Marie Stone Manning of Encinitas, CA, and Karen Ann Stone Silver of Neenah, WI, in addition to several cousins, nieces, and nephews. She was predeceased in 2020 by a sister, Andra Lynn Stone of Houston, TX.

Even though Denise's first home with Clara and Joseph and her sisters was in Springfield, NJ, she moved internationally while growing up. During her high school years, she attended the Overseas School of Rome, Italy, initiating her interest in languages and the study of ancient Roman history. She graduated from Valdez (AK) High School (1975) and went on to Texas Christian University (B. S. in Geology, 1979), Memphis State University (M.S. Geology, 1981) and Rice University Jones School of Business ("The Management Program", 1997).

She entered the oil business as a summer geological hire at Unocal in Houston, TX in 1978. After graduation in 1981, she went to work as a petroleum exploration geologist in Houston, TX with Superior Oil before moving on to Mobil, Amoco, and BP. After BP she worked as a Houston- and Denver-based independent consulting geologist focusing on Trinidad, the North Sea, and Alaska until she retired in 2012. She moved to Colorado in 2017 and became very active in the Rocky Mountain Association of Geologists (RMAG) with the On The Rocks (OTR) fieldtrip committee.

Denise loved geological field work, well site work, and exploring for oil and gas in frontier areas around the world. In addition to long hours in the office and in partner meetings, she spent time on the ground in Burundi, Tanzania, Kenya, Egypt, and Colombia. She also authored or co-authored more than 20 peer-reviewed publications and presentations on international and domestic topics on oil and natural gas exploration and production including significant works on Alaska and Kenya.

She held many leadership positions in civil and professional societies including the American Association of Petroleum Geologists (AAPG), the Society of Independent Professional Earth Scientists (SIPES), and the Houston Geological Society (HGS) including President.

She loved several dogs over her lifetime. Her favorite hobby was lap swimming where she made life-long friends. Piano playing and cooking Italian food were also two of her favorite activities.

At the time of her death, she was an active member of St. Mark Catholic Church, Highlands Ranch, CO. She thanks the parishioners of St. Mark and Father Greg Bierbaum for their prayers and attention during her illness. She also thanks all her friends and family for their loving concern and visits during her illness.

A funeral mass in celebration of her life will be held at St. Mark Catholic Church, Highland Ranch, CO, May 16, 2025, and followed at a later date by a memorial service at St. John Vianney Catholic Church chapel, 625 Nottingham Oaks Trail, Houston, TX 77079; https://www.stjohnvianney.org. In lieu of flowers please donate to the (Rocky Mountain Association of Geologists [RMAG] Denise M. Stone Memorial Scholarship Fund for Geology Field Trips (730 17th St., B1, Denver, CO 80202 or https://www.rmag.org/index.php?src=forms&ref=Donations) or the Cholangiocarcenoma Foundation (5526 West 13400 South, #510, Herriman, Utah 84096 or https://www.cholangiocarcinoma.org/donate/).

3RD ANNUAL HGS SPORTING CLAYS SHOOT

HOUSTON GEOLOGICAL SOCIETY

FRIDAY, NOVEMBER 21, 2025
7:30AM - 1:30PM
WESTSIDE SPORTING GROUNDS
10120 PATTISON RD., KATY, TX 77493

Gun Raffle, Mulligans, Silent Auction items for purchase Door Prizes, breakfast 7:45am - 8:45am, lunch 11:30am - 1:30pm, drinks included

Sponsorship Opportunities Available!
www.hgs.org

Registration & Sponsorship Info: www.hgs.org
or call 713-463-9476

3rd Annual HGS Sporting Clays Shoot

Friday, November 21, 2025
Westside Sporting Grounds
10120 Pattison Rd., Katy, TX 77493

Individual and Team Entry Form

This 100-sporting clay target event will provide a 4-person team with a cart and ammo, both 12 and / or 20 gauge. **Participants must provide and wear eye and ear protection.** Westside Sporting Grounds and National Sporting Clay Association safety rules will be strictly enforced. Each attendee will receive one door prize ticket with additional tickets available for purchase at $5.00 each. Prizes will be awarded by blind drawing after the conclusion of shooting. Participants must be present at the time of the drawing to win a prize.

Registration opens at 7:30AM
Breakfast – 7:45am - 8:45am.
Mandatory Safety Briefing for all Attendees 8:45am
Lunch will be provided from 11:30am - 1:30pm.
Refreshments will be available throughout the day.
Non-shooting guests are welcome to enjoy lunch and refreshments at a cost of $35 per guest.

Entry fee is $900.00 per 4-person team or $225.00 per individual shooter, for registrations received by *MONDAY SEPTEMBER 17th*. After 09/17/25 online and walk-up registration is $950.00 per team and $245.00 per individual. Individual shooters will be squadded with a team. Lunch only, $35.00.

Register early, it will fill up fast!!

Houston geological Society 3rd Annual Sporting Clay Shoot Tournament 2025

For more information, contact: Andrea Peoples at (713)463-9476 or andrea@hgs.org For directions to the club, visit www.wsgclays.com

To Register online please go to www.hgs.org / Please send form to Andrea@hgs.org

To pay by check, mail this form with a check made out to HGS to:
Houston Geological Society, 14811 St. Mary's Lane, Ste. 250, Houston, TX 77079

To pay by Zelle or credit card, please call the HGS office: (713) 463-9476.

Name: ______________________________Company: _________________________

Email:_______________________________Phone:____________________________

CC: _________________________________Exp:_________________ CVC:______

Ammo: (circle one) 12 gauge 20 gauge

Entry Fees: $______ + Guest Fees: $______ + Mulligan Fees: $______ +
Door Prize tickets : $_________
Sponsor Contribution: $______ = Total: $______

If you wish to register as a squad, please return forms for all squad members together.

ALL SHOOTERS WILL BE REQUIRED TO SIGN A WAIVER OF RESPONSIBILTY BEFORE THEY WILL BE ALLOWED TO SHOOT!

Team Member Name	Email Address	Phone	Ammo Guage
1			
2			
3			
4			

Houston geological Society 3rd Annual Sporting Clay Shoot Tournament 2025

Available Sponsorship Opportunities

Ammo Corporate Sponsor - $3,000
This Sponsor will be provided with one 4-person shooting team including team mulligans, cart and ammo. The Sponsor company logo will be recognized as a corporate sponsor and be displayed on the website, printed advertisements, HGS newsletter and sponsor board.

Trophy Sponsor - $3,000.00 This Sponsor will be provided with one 4-person shooting team including team mulligans, cart and ammo. Your company logo will be recognized as a corporate sponsor and be displayed on the website, printed advertisements, HGS newsletter and sponsor board.

Hat Sponsor - $2,500
This Sponsor will be provided with one 4-person shooting team including team mulligans, cart and ammo. Your company logo will be recognized as the Hat sponsor and be displayed on the hat, website, newsletter and sponsor board. **(Need logo by Oct. 1st, 2025, for this sponsorship) No Mulligans included.**

Lunch Sponsor - $2,000
This Sponsor will be provided with 2 shooter registrations, cart and ammo. Your company logo will be recognized as a lunch sponsor and be displayed on the website, printed advertisement and sponsor Board.

Breakfast Sponsor - $1,000
This Sponsor will be provided with one team member registration with ammo. Pay for three more team registrations and get the cart with your

Houston geological Society 3rd Annual Sporting Clay Shoot Tournament 2025

package. Your company logo will be recognized as a breakfast sponsor and will be displayed on the website, printed advertisements.

Beverage Sponsor - $750

Your company logo will be recognized as a beverage sponsor and will be displayed on the website, printed advertisement.

Door Prize or Silent Auction sponsor- $500

Company Logo will be displayed on the HGS website and printed advertisement.

Gun Cleaning Station- $300

The sponsoring company will provide gun cleaning materials, spray, brushes & a table.

Station Sponsor - $100

The company will be able to set up on any of the available station and provide give away items, food, and drinks (non-Alcoholic on the course).

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HGS Membership Application

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Email: office@hgs.org

Active Membership

In order to qualify for Active Membership you must have a degree in geology or an allied geoscience from an accredited college or university or, have a degree in science or engineering from an accredited college or university and have been engaged in the professional study or practice of earth science for at least 5 years. Active Members shall be entitled to vote, stand for election, and serve as an officer in the Society. Active Members pay $36.00 in dues.

Associate Membership

Associate Members do not have a degree in geology or allied geoscience, but are engaged in the application of the earth sciences. Associate Members are not entitled to vote, stand for elections or serve as an officer in the Society. Associate Members pay $36.00 in dues.

Student Membership

Student membership is for full-time students enrolled in geology or an allied geoscience. Student Members are not entitled to vote, stand for elections or serve as an officer in the Society. Student Member dues are currently waived (free) but applications must be filled out to its entirety. Student applicants must provide University Dean or Advisor Name to be approved for membership.

Membership Benefits

Digital HGS Bulletin

The HGS Bulletin is a high-quality journal digitally published monthly by the HGS (with the exception of July and August). The journal provides feature articles, meeting abstracts, and information about upcoming and past events. As a member of the HGS, you'll receive a digital copy of the journal on the HGS website. Membership also comes with access to the online archives,with records dating back to 1958.

Discount prices for meetings and short courses

Throughout the year, the various committees of the HGS organize lunch/dinner meetings centered around technical topics of interest to the diverse membership of the organization. An average of 6 meetings a month is common for the HGS (with the exception of July and August). Short courses on a variety of topics are also planned throughout the year by the Continuing Education Committee. These meetings and courses are fantastic opportunities to keep up with technology, network, and expand your education beyond your own specialty. Prices for these events fluctuate depending on the venue and type of event; however, with membership in the HGS you ensure you will always have the opportunity to get the lowest registration fee available.

Networking

The HGS is a dynamic organization, with a membership diverse in experience, education, and career specialties. As the largest local geological society, the HGS offers unprecedented opportunities to network and grow within the Gulf Coast geological community.

Please fill out this application in its entirety to expedite the approval process to become an Active/Associate member of Houston Geological Society.

Full Name ____ Type *(Choose one)*: Active Associate Student

Current Email *(for digital Bulletin & email newsletter)*______________________

Phone _______________

Preferred Address for HGS mail____

This is my home address ______ business address _____

Employer *(required)*___________________________ Job Title *(required)*____________________ Will you volunteer? ____ (Y/N) Committee choice: ____________________

Annual dues Active & Assoc. for the one year *(July 1st-June 30th)* **$36.00**______

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OPTIONAL Scholarship Contributions- Calvert/HGS Foundation-Undergraduate **$5.00**______

Total remittance______

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CVV code (req'd): ______ Expiration: ______ (mm/yy)

Signature: ___________________________ Date: __________

To the Executive Board: I hereby apply for membership in the Houston Geological Society and pledge to abide by its Constitution & Bylaws.

Company*(required, mark 'in transition' if unemployed)*____

Company Address ______________________

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School *(required)*____

Major *(required)*____________________________________ **Degree** *(required)*_________________________

Year Graduated __________________

School *(optional)*____

Major *(optional)*____________________________________ **Degree** *(optional)*_________________________

Year Graduated _____________________

Years Work Experience *(required)*_________________

Please submit a brief statement regarding your work experience in the practice or application of earth science or an allied science.

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HGS Sponsor's Name _________________

Signature: __________________________ **Date:**_________

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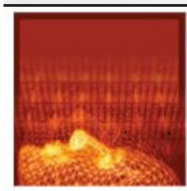

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The image features Hidden Lake, with Bearhat Mountain positioned at the top center. This photo was taken with a zoom lens from the Hidden Lake trailhead on "Going-to-the-Sun" road in Glacier National Park, Montana. Photo courtesy of Ted Godo (taken in 2009).