

HGS Bulletin

Volume 67, Number 6

Houston Geological Society

FEBRUARY 2025

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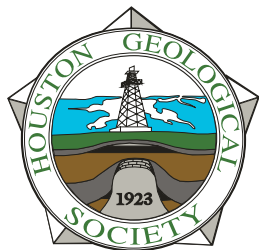
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Houston Geological Society

Volume 67, Number 6

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About the Cover: Photo Credit is to Haakon Fossen. These are conjugate cataclastic deformation bands, first described by Atolla Aydin during his PhD. The place is Molly's Castle, very close to Goblin Valley, S Utah.

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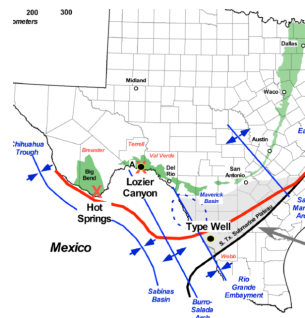
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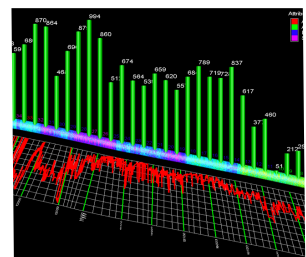
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Penny Patterson, HGS President 2024-25
pennyp70@att.net

Engage and Involve Our Young Geoscientists

The month of February for the Houston Geological Society strongly focuses on organizing and hosting events for our young, blossoming elementary-school and high-school science students and our emerging geoscientists studying at universities. Hence, this is a perfect time for our more experienced geoscientists of all ages to work with our Houston-area students to engage them and get them excited to learn about our earth and its many dynamic processes.

The first student-focused event to be held in February is the HGS Scholarship Night, which will take place on February 10, 2025, at the Norris Conference Center. The HGS Scholarship Night is a highlight of the year for HGS because HGS proudly presents two levels of scholarships. The HGS Undergraduate Fund awards scholarships to our winning undergraduate students. The Calvert Fund awards scholarships to our winning graduate students. Another highlight of this year's Scholarship Night will be hearing guest speakers Andrew Madof and Cody Miller's talk on "The Day the Dinosaurs Died."

The next student-focused event to be held in February is the Science and Engineering Fair of Houston (SEFH), scheduled for February 15, 2025, at the Fort Bend Epicenter in Rosenberg, Texas. Dorene West published an excellent article in the January 2025 HGS Bulletin, and I highly recommend reading her article to get detailed information. HGS's team of judges reviews projects related to earth sciences and presents Special Award certificates to winning student projects. Our Houston-area students work diligently and present extremely well-thought-out and informative earth science projects. This is an excellent opportunity to encourage and involve our young geoscientists. In addition, through HGS's membership with the Engineering, Science and Technology Council of Houston (ECH), HGS funds three summer internships for high school students at the Houston Museum of Natural Science (HMNS). HGS selects three top students from the SEFH competition to receive these coveted

HMNS summer internships. Both the science fair awards and internships help inspire our Houston-area students to pursue careers in the field of geoscience.

On March 22, 2025, HGS will be teaming up with the YMCA for a Volunteer Day at Camp Cullen to work on "sprucing up" the camp for this year's summer programs. Camp Cullen hosts children from across the greater Houston area and provides a wide variety of outdoor activities, including participating in geological field trips to a unique, onsite rock quarry, hands-on lessons with camp counselors to learn about rocks, minerals, and fossils from Camp Cullen's collection; and "gold" panning opportunities for younger children. Camp Cullen is looking for ways to improve the quality of its geoscience educational programs.

If you are interested in helping, please get in touch with HGS member John Adamick or see the page in this month's HGS Bulletin for more information.

Throughout the year, HGS members and volunteers organize and host numerous student-focused activities. I want to highlight and also thank all the members of HGS's Educational Outreach Committee who work tirelessly yearlong to bring excellent, hands-on learning to our young scientists. Educational Outreach Committee members Phil Caggino, Chuck Caghey, Keith Thies, Janet Combes, Letha Slagel, Debbie Caperton, and Steve Johansen are currently working on two programs: the "Bones in Schools" program, which includes hands-on learning about Pleistocene mammals and their environment; and STEM workshops, which are being held in Houston-area schools and institutions. If you would like to help with HGS's Educational Outreach programs, please contact any committee member. They will be glad to engage you!

In summary, HGS has many opportunities to engage with our

From the President continued on page 7



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

Challenging our Readers on New Thoughts and Ideas

Greetings, members, and I hope your 2025 new year is beginning well. I first want to thank Steve Naruk, a fellow HGS member and a colleague whom I worked with at Shell Oil. Steve writes an informative article in this *Bulletin* on deformation bands. Deformation bands in thick sandstone reservoirs are clearly at least baffles to flow and reservoir compartmentalization. My first experience, unlike Steve's broader knowledge, presented itself to me when we first discovered the Norphlet Appomattox field. To this day, it is not apparent if the deformation bands we found in wells at the structural crest seal the huge south flank oil column from the lesser column on the north flank. Without any apparent structural faults along parts of the crest, it can only be speculated if the reservoir fortuitously thins to a pinch-out ending permeability or whether only the presence of deformation bands that we know are present, seal these accumulations. So here is an invitation for anyone at Shell to write and update us!

Secondly, I want to thank another Shell colleague, L. Taras Bryndzia, for contributing an excellent technical article on the role of organic-rich source rocks (hydrocarbons) to cinnabar ore formation. Cinnabar is an elemental compound composed of mercury sulfide (HgS). While mercury, according to the USGS critical mineral list, is not currently on the list; however, some previous assessments have listed it as a potential critical mineral due to supply chain concerns and use in certain industries.

Lastly, I apologize for the length of the "feature article" – it doubles the length of past bulletin guidelines. The subject matter could have been broken into two parts, one in each month's bulletin. However, I decided to "let it rip" in this one, so to speak, because

I want to cover a few more subjects before the June issue. My excuse is simply a passion for asking questions, seeking colleagues challenging ideas, and, most importantly, serving our readers by offering or imparting some knowledge, observations, and mentoring for new geoscientists.

For example, the SAKARN section, as originally defined by Thierry Rivas in 2019, has been known and worked in the industry for 20 years since the first 3D surveys came out in the early 2000s. During various colleague meetings and interactions over the years, we found out that Anadarko, for example, referred to the Sakarn as the "Smackunder." At Shell, we referred to it as the "Mystery section." It has baffled me frankly that despite many oil companies that acquired leases with obvious objectives in the Sakarn, none was drilled. In addition, the fact that academia has not incorporated the potential for this older fill age of the sediments into the rifting models has also been surprising.

At Shell, we periodically discussed promoting the industry to petition the BOEM for a C.O.S.T. well 1 (Continental Offshore Stratigraphic Test) to drill this "mystery section" to see, for example, if there might be source rock (a first significant uncertainty) and second if there are reservoirs. Indeed, there are structures with rock closures that are present. In fact, one prospect at Shell, whom we referred to as "Five Forks," had similar major reflections to those of Appomattox.

Lastly, I encourage you to write your "letters to the editor" about any subject or challenge or correct things I may have

From the Editor continued on page 7

*I hope is to serve our
readers by offering
or imparting some
knowledge, observations
and help to mentor new
geoscientists*

WELCOME TO NEW MEMBERS, EFFECTIVE JANUARY 2024

Mike Schultz

Alison Macleod

Adam Haecker

Alice Dorsey

budding geoscientists of all ages. I invite everyone to get involved and nurture our next generation of geoscientists.

I will close with a quote from Benjamin Franklin: "Show me, and I forget; teach me, and I remember; involve me, and I learn." Let's work together to engage our young geoscientists and get them

excited to learn about our vibrant earth and its ever-changing dynamics! ■

I look forward to seeing you at HGS's student events!

From the Editor

continued from page 6

misrepresented or gotten wrong. We are transparent and are happy to interact and publish your letters "as is." So far in my term, we have only received one "letter to the editor," it appeared in the September issue (2024) correcting an article from a 2002 *Bulletin*. Thank you, Robert Leslie, for your letter on this subject. ■

See you next month

FOOTNOTE: (1)-A deep stratigraphic test, as defined in 30 CFR § 551.1, means, "drilling that involves the penetration into the sea bottom of more than 500 feet (152 meters)." These wells are sometimes known as Continental Offshore Stratigraphic

Test (COST) wells and are drilled primarily to gather geological information. Examples of information collected would be core samples and geochemical and geophysical data. COST wells have been drilled offshore in the Atlantic, Pacific, and Alaska regions.

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Photo courtesy of J.P. Brandenburg and taken in of an eroded remnant of sandstone with deformation bands taken in Kaibab Springs, Arizona in 2010

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We Are The HGS



MICHAEL BOIMAH JOHNSON, HGS member since November 2024

Michael's story begins in Brooklyn, New York, where he was born to Liberian parents. At an early age, he had the opportunity to live in Liberia, which sparked a deep connection to his roots. However, his childhood was dramatically altered in 1989 when Liberia's civil war erupted. "It was terrifying. Our lives were completely turned upside down," he recalls. His family was forced to leave their comfortable home and relocate to a small village for nearly two years. During this tumultuous time, his father, a computer programmer, ensured his education continued by giving him books to read. Despite the horrors of war, Michael found solace "...drawing up elaborate cityscapes... imagining them as whole cities with skyscrapers..". These formative experiences of resilience, education, and community shaped his worldview and would later influence his professional journey.

After returning to Monrovia, Michael was awarded a scholarship to study Mechanical Engineering at Southern University, where he worked on exciting projects, including drones and satellites. Michael had a job lined up with Pratt & Whitney, working on cutting-edge aerospace technology, when he met some Schlumberger engineers, whose stories of drilling wells around the world captivated him. "I was instantly hooked on the promise of adventure," Michael admits, marking the beginning of his journey into the oil and gas industry.

At Schlumberger, Michael's career flourished as he traveled the globe, learning about drilling operations in some of the most challenging environments. His experience there piqued his desire to contribute to Liberia's post-war recovery. Michael took on roles in the country's nascent oil and gas industry, where he coordinated drilling operations, and helped shape policies and regulations. This also led him to pursue a Master's degree in geoscience at Imperial College London, before ultimately becoming an entrepreneur. "The first pivotal moment was when I was working on a rig for a small company. During this time, he stumbled across T. Boone Pickens' autobiography where the author talks about striking out on his own and building his own empire... 'Maybe I could do that too,'" Michael says, reflecting on his decision to build his own business, Demus Exploration, where he focuses on finding new opportunities and making a positive impact on Liberia.

Now, as Managing Partner of Demus Exploration, Michael is dedicated to pushing the boundaries of the industry while ensuring that his work has a positive impact. "A major oil discovery can change a country, for better or worse. I want to make sure we're doing it right," he shares, underscoring his commitment to responsible business practices and his desire to give back to Liberia, which played such a crucial role in shaping his life and career.

Beyond his professional achievements, Michael values continuous learning, whether through reading about international relations or playing gospel piano. His membership with HGS, has reignited his passion for innovation and collaboration. "It feels like I've found my tribe again," he shares, emphasizing his desire to connect with others who share his vision for exploration and responsible business. ■

Michael's decision to join the HGS has reignited his passion for innovation and collaboration.

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.

Features in the Pre-Rift, Rift, and Sag Stages of the Gulf of Mexico – New Questions to Ask

By Ted Godo

This month's feature article poses a few questions about some of the structural features, sedimentary ages and lithologies formed during the early opening of the Gulf of Mexico (GOM). The article also hopes to raise some questions from our readers about potential new plays. One structural feature in the article is the Sabine High of Texas/Louisiana, in how its paleo alignment, and its structural similarity with the Celestun Arch of Yucatan, might be connected. Another interesting structural feature is the Yucatan's Hondo arch and whether it has any relation with the Middle Ground Arch or any of the other Jurassic paleo-high blocks of the EGOM. A third idea, and maybe the most provocative, would be the little-discussed formation of the SAKARN series (pre-Norphlet). Rivas (2019) chose the name SAKARN as an acronym from the favored concept of the lithologic sequence: salt -anhydrite – carbonate + Norphlet. A proposal is made in this article to consider whether the SAKARN facies presently identified in the EGOM could also be present on the current north side of the Yucatan Peninsula. Other questions posed throughout this article for example, ask about the remaining play potentials, such as the basal clastics of the Sarasota Arch or the Cretaceous carbonates which onlap it, or source rocks and reservoirs in the lower Paleozoic's originally deposited in West Africa, and now present in the subsalt of the EGOM.

Understanding the continental blocks that sutured to North America during the formation of Pangea (Permian), provides insight into the sediment provenances for the Mesozoic stratigraphy. This is especially important for Triassic and Jurassic stratigraphy, as the GOM began its extension by widening until the Oxfordian period, when the oceanic crust began to form. After the formation of Pangea, the various continental blocks of Gondwana with characteristic igneous and sediment terranes began spreading apart (Figure 1) to what we see today.

Several continental blocks that were either left attached to North America or spread to form the southern present-day GOM, are named the Florida-West Florida Terrace-Wiggins block, the Sabine, the Coahuila, the Yucatan, and the Maya blocks (Weber, 2012; Mueller, 2014; Erlich, 2020; Pindell, 2022; Tian, 2022). The Suwannee terrane that makes up the present-day greater Florida (West Florida Terrace (offshore)-Wiggins block is the most drilled with detailed descriptions. A summary description of terranes, starting in the central Appalachian and moving south through Florida, is found in Horton (1994). There are four sections in this article. Each will describe the terranes or blocks of continental crust that came together during the formation of Pangea. This then set the stage for some terranes that remained on the north and others that moved to the south as the GOM opened.

SUWANNEE TERRANE (FLORIDA WEST TO OFFSHORE AND INCLUDING THE WIGGINS ARCH)

The Suwannee-Wiggins suture marks a continent-continent collision of North America (Laurentia) with a piece of Africa left sutured (Thomas, 2010). Florida and the west Florida offshore area have both Lower Paleozoic sedimentary rocks and igneous rocks, characteristic of the separated part of Africa initially located in the greater Bove basin of Guinea (Klitgord, 1984; Dallmeyer, 1989; Christenson, 1990; Villeneuve, 1991; McHone, 2000).

Dallmeyer (1989) defines the Suwannee as being made up of four rock assemblages: 1) Cambrian aged Granite (aka Osceola Granite) ca 545-527Ma, 2) Cambrian aged high-grade metamorphic (St. Lucie) core complex, 3) weakly metamorphosed felsic calc-alkaline magmatic rock possibly of Lower Cambrian/Ediacaran (Upper Proterozoic) age, and 4) unaltered and fossiliferous Lower Ordovician-Middle Devonian clastic sedimentary rocks. All

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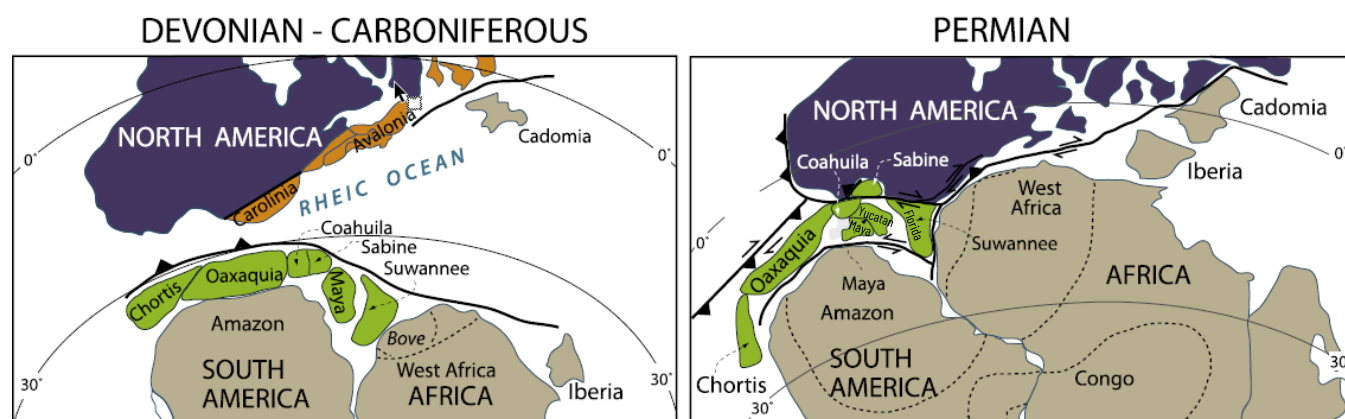


Figure 1. Modified from Mueller, 2014) Schematic depiction of relative plate motions associated with the sequential arrival of the Suwannee and other peri-Gondwanan terranes to Laurentia from Devonian to Permian times (large plate positions modified from Keppie et al., 2008)

these rock assemblages have been penetrated by the numerous wells in onshore Florida and offshore (Applin, 1951; Bass, 1969; Barnett, 1975; Smith, 1982, 1993; Klitgord, 1984; Applegate, 1985; Hetherington, 1991, 1996, 1999, 2003; Erlich, 2020, 2023a).

Generally, the sedimentary sequence consists of Lower Ordovician sandstone (or quartzite) followed by black or dark gray shale with

sandstone interbeds, ranging from Lower Ordovician to Mid-Devonian in age (**Figure 2**). The interpreted seismic calibrated with reasonable control (Arden, 1974) shows that the Lower Paleozoic section is mainly preserved in synclines, the folding and faulting that occurred after the Mid-Devonian was eroded or peneplained prior to the Upper Triassic (**Figure 3**). A question for our readers may be asked: Is there a hydrocarbon play to be pursued? A few wells have had geochemistry run with marginal to fair source rocks (1.1 – 2.5 %TOC). The maturity, however, is very mature. Though penetrations seldom exceeds several hundred feet, with most wells less than 100 feet.

Additional wells that penetrated rocks of the Suwannee terrane are found west of Florida in offshore federal waters. This supports the idea that the Suwannee terrane sequence extends from north Florida to west across the West Florida Shelf. Offshore in southwestern Florida, seven wells were drilled into the basement rock attributed to the Suwannee terrane (**Figure 4**). The exploration play common to all seven wells was to target the basal sandstone on top of the basement-cored Sarasota (aka Tampa) Arch. The basal sandstone was likely deposited as beach sand that incorporated granite clasts from the erosion of the granitic basement rock. This basal sandstone is likely time transgressive formed as sea level progressively onlapped the Arch. The axis of this large structural arch is southwest to northeast. Three wells defined the basement crest, with Shell #1 (Penny) encountering basement rock at 10,410 feet. The other two wells along the crest are the Odeco/Murphy #1 (CH 188) and Gulf #1 (CH144). The age of the carbonate that transgressed the basal sandstone in the crestal Shell well is Aptian Rodessa to Pine Hill formations. Despite all seven wells reaching TD in basement rock, the two wells on the north flank of the Sarasota Arch have been age-dated with consistencies of the Suwannee terrane. Mobil Oil drilled it's

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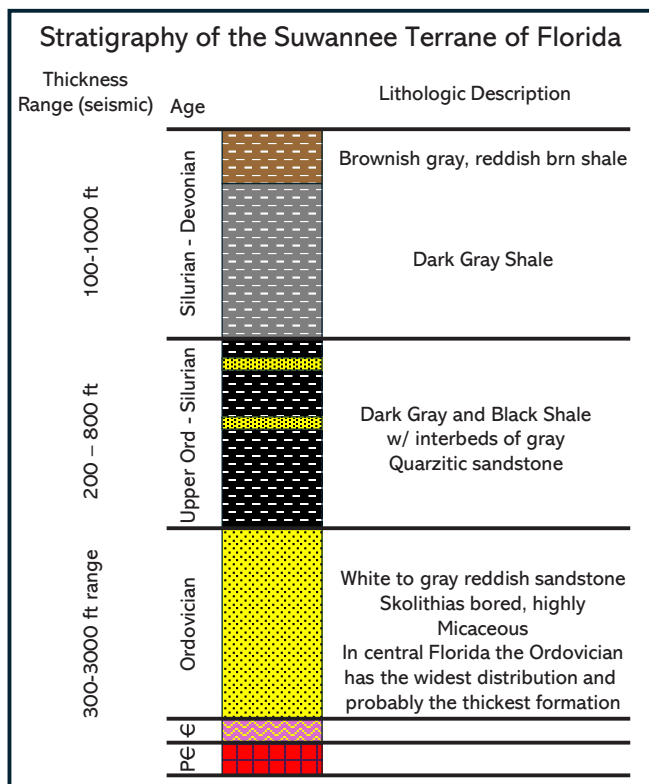


Figure 2. Stratigraphic column of Suwannee Terrane (Africa) In the Peninsula Florida and west into the offshore (eg, Middle Ground Arch and Desoto Salt Basin

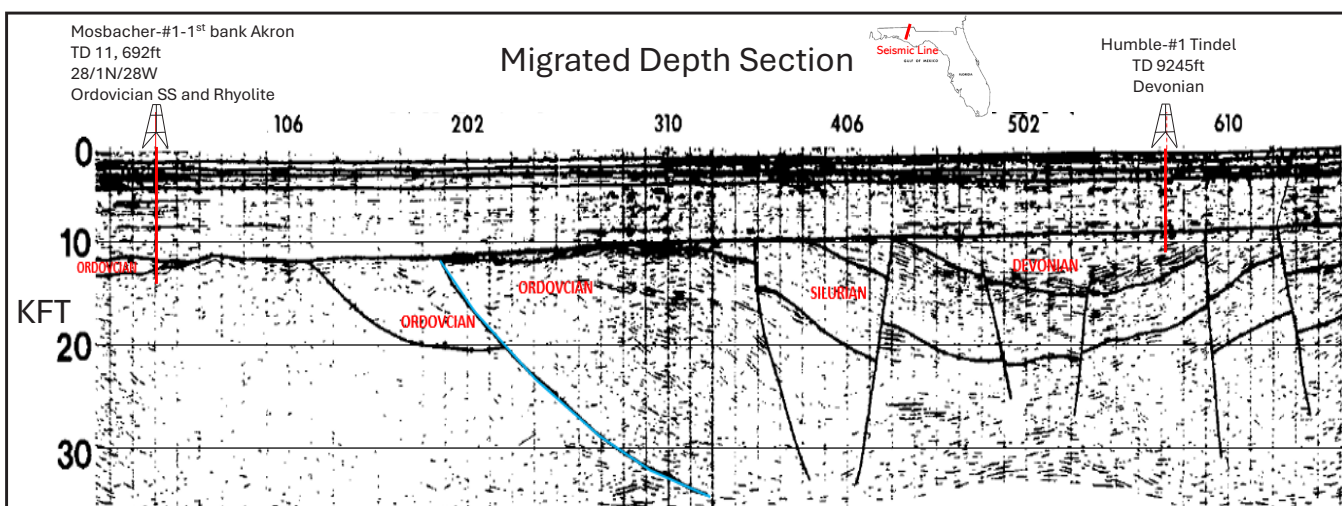


Figure 3. Modified from Arden (1974; fig 3). The seismic depth section shows the characteristic preserved synclinal folding of the lower paleozoic of the Suwannee Terrane.

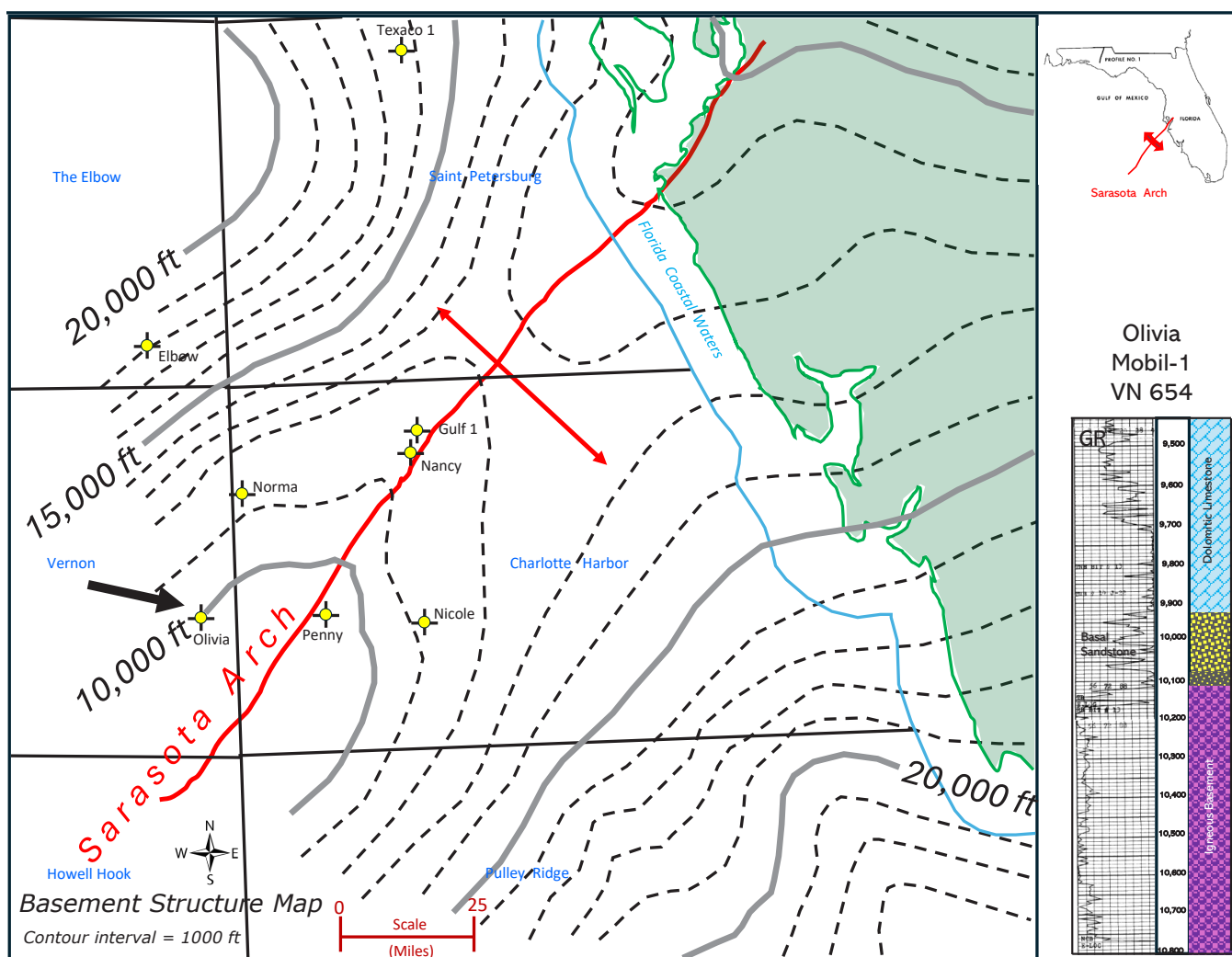


Figure 4. Basement Structure Map on the Sarasota arch with the location of the eight well control points. Prospect Olivia at the right shows the basal conglomeratic sandstone eroded from and deposited atop the basement and is then overlain with Cretaceous (Sligo) dolomitic limestones. The granite is Cambrian aged dated at 492 ± 17 Ma.

Olivia prospect in Vernon Block 654. That well found the basal sandstone at 9,930 feet below Sligo carbonate and sits on eroded Cambrian granite at 10,070 feet, dated as 492 ± 17 Ma (Figure 4). The well continued to be drilled to a total depth of 10,763 feet. The other well was Shell Oil's prospect, Norma. The well found the basal sandstone immediately below the Sligo carbonates at 11,300 feet. The thickness of this basal sandstone is about 130 feet thick and rests directly on granite basement rock of Early Cambrian to Ediacaran age dated at 543 ± 10 Ma by the Rb/Sr method.

Although not currently available for leasing offshore, and with seven wells encountering wet basal sandstone reservoirs, the play might be considered to have been tested. However, an alternative play might have stratigraphic trapping components as porous Albian and Aptian carbonates are interbedded with anhydrite potential seals. A couple of these seven wells described oil shows having cut fluorescence in vuggy carbonates with additional potential source rock intervals. Maturity at the base of the wells

is in the early oil window. The onlap of the normally prolific Tithonian age source rock is down-dip of the Sarasota crest as seen in the Elbow 915 well; however, the facies are of very shallow waters and not highly prospective. Also, the Sarasota Arch marks the southeast depositional boundary of the Tithonian in the GOM. However, mature source rocks in the Cretaceous Formation will be found in deeper positions, especially on the structure's south side, including the Lower Cretaceous Sunniland Formation equivalent source rocks. Even though the Arch was a major topographic high in the Jurassic, the southern side of the arch would have access to Jurassic (Tithonian) deposited from the opening of the Atlantic in the Florida Straits. Speaking of the Florida Straits area, several wells between northern Cuba, eastern Florida, and Little Bahama Bank reached their total depths in basement rocks. Based on zircon analyses, they are also of the African Suwannee terrane (Erlach, 2020).

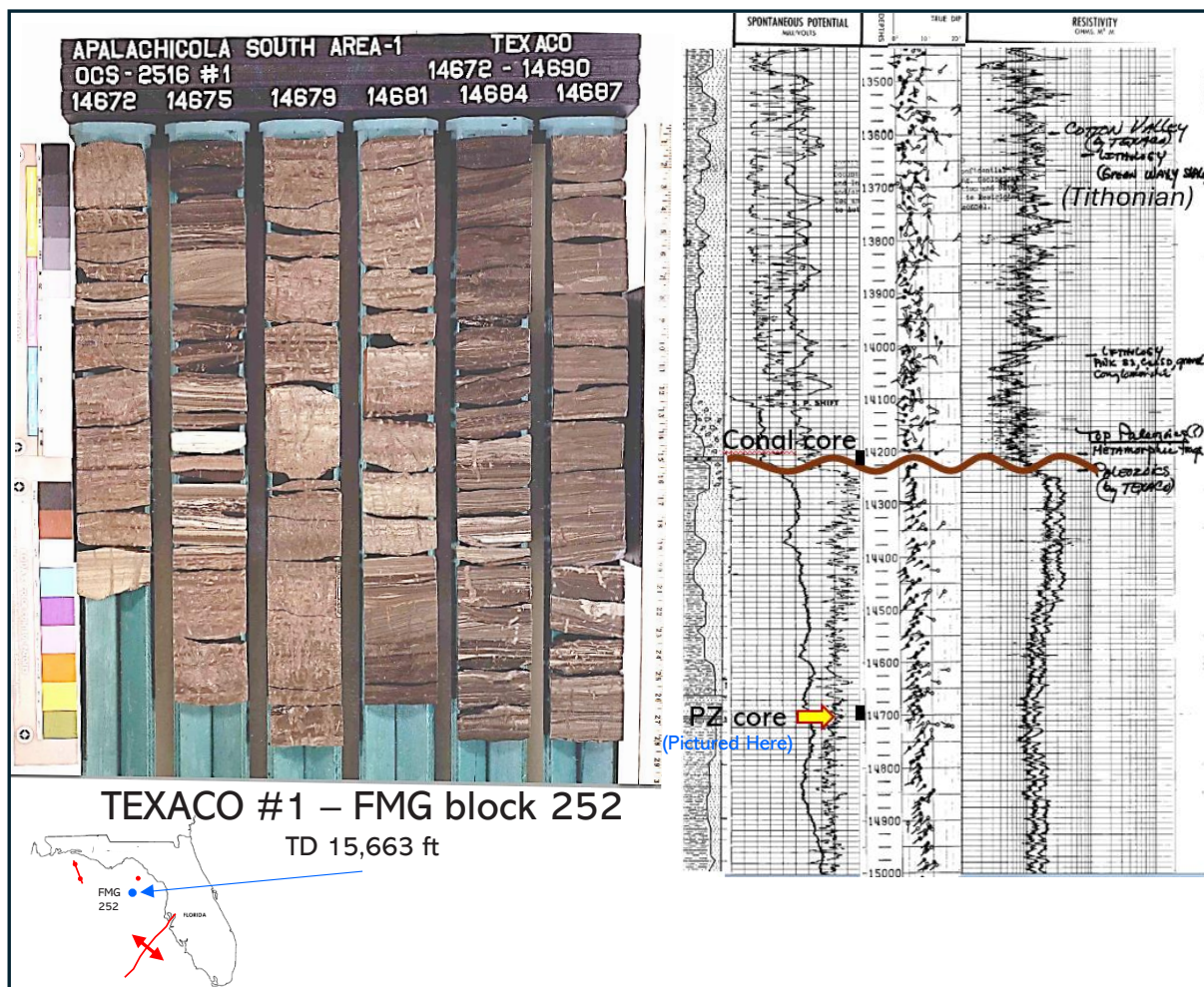


Figure 5. Annotated well log and dipmeter of the Texaco #1 well that drilled nearly 450 meters (1,470 ft) of Paleozoic aged siltstone and sandstone. The well took three cores in the Paleozoic section at the top, middle, and base of the well. The core photo on the left is taken from core#2 in the middle of the penetrated Paleozoic section.

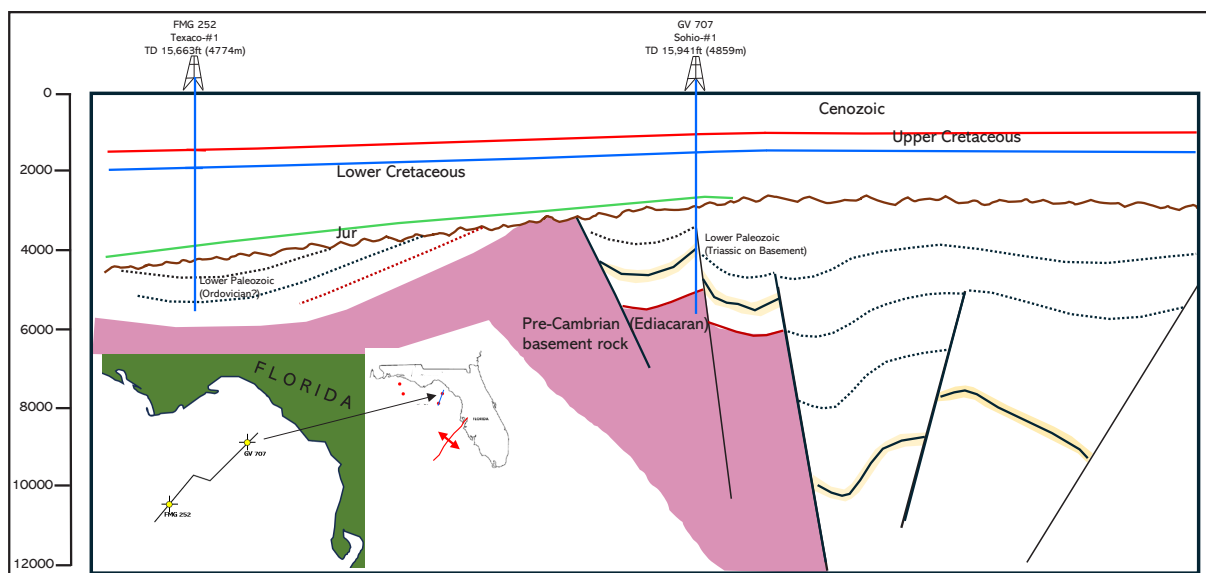


Figure 6. Seismic line drawing between two wells (FMG 252 and GV 707) that penetrated the two types of sub-Mesozoic basement rock types of the Suwannee Terrane (Lower Paleozoic and Upper Precambrian igneous rock)

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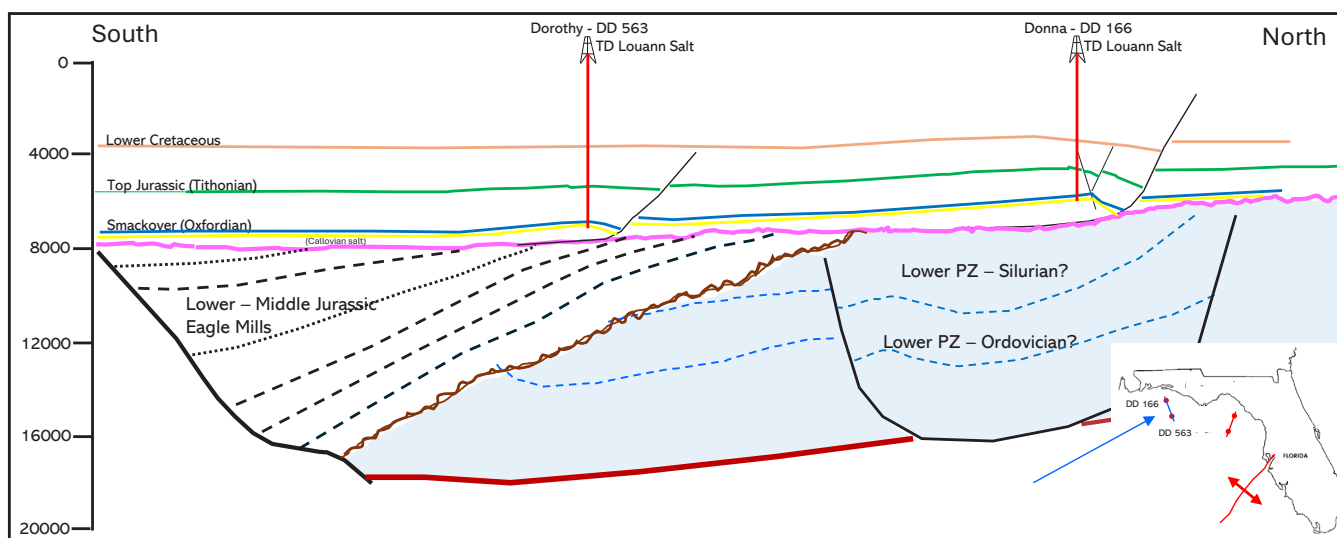


Figure 7. Seismic line drawing in the Desoto Salt basin between two wells (DD 563 and DD 166) that reach total depth in Louann salt. Beneath the salt detachment are dipping bedforms that would appear to be consistent with the Triassic half-graben fill and the preserved dominantly synclinal features of the Lower Paleozoic as described onshore Florida by Arden 1974 and by the two offshore wells shown in Figure 6. The “scooped shaped fault below the salt is a strike line cut of the interpreted Lower Paleozoic fold.

Working back up the west side of the Florida federal waters and north of the Sarasota Arch is the Middle Ground Arch. Texaco drilled its prospect Iris in Florida Middle Ground (FMG) block 252 (**Figure 5**). This well encountered about 450 meters (1,470 ft) of Lower Paleozoic age of highly silty and sandy sedimentary rocks without drilling into the crystalline basement (see also Applegate, 1985; Christenson, 1990). Two cores were taken in this interval, and in sample descriptions from 14,440ft, it was reported in sample logs that a few Acritarch fossils were found. Acritarch fossils greatly declined at the end of the Devonian (Strother, 2008), suggesting that the highly silty and sand interval may be equivalent to the Ordovician/Silurian section.

Another offshore well further north of the Iris well is the Sohio #1 well drilled in Gainesville block (GV) 707 (**Figure 6**) (see also Storey, 2020). After drilling shallow water Albian age carbonate to 5,460 feet, the well began drilling continental “redbeds” shale, silt and sandstone of likely Aptian to Valanginian/Berriasian (near “Knowles” seismic correlation) before crossing a major unconformity. The unconformity was the eroded top of a Triassic-filled graben consisting of volcanoclastics, continental clastics of red shale, and sandstone with interbedded tuffs and ash layers. This interval includes a basalt layer from 11,500 to 12,800 feet dated at 244 ± 10 Ma. (mid-Triassic) from a whole core taken at 12,340 feet. Another unconformity was crossed near total depth at 15,460 into Pre-Cambrian (Ediacaran) basement rock. Two core samples were taken in this basement rock at 15,483 feet and 15,937 feet. The rock is described as a rhyolite porphyry dated 576 Ma. The total depth of the well is 15,941 feet. A more recent seismic line (**Figure 7**) acquired in the Desoto Salt Basin over two wells that reached total depth in the Louann Salt displays the typical synclinal shape of Paleozoic rocks versus the half-graben

basins filled with Triassic Eagle Mills (Storey, 2020).

Finally, in 2013, Anadarko drilled the furthest west control point for Suwannee terrane rocks in deep water. The well penetrated below the Louann salt, reaching TD in Lower Cambrian. The well is Prospect Raptor, which tagged subsalt basement rock of Mid-Cambrian age dated at 509 Ma (Mallis, 2024; see also the feature article in the November 2024 HGS Bull).

WIGGINS ARCH (ALABAMA/MISSISSIPPI)

The Wiggins Arch is considered a westward extension of the Suwannee terrane of Florida and the west Florida offshore region. The Wiggins is a cored basement high along the west end of a trend or chain of basement highs that extend offshore into Florida State and Federal waters, also known as the “Pensacola Archipelago.” The offshore trend of these basement cored highs is clearly seen on seismic but not yet drilled. Regarding the Wiggins Arch (or block), Thomas (2010) states that it has a full thickness of continental crust beneath it. The depth to the top of the basement is ~20,000 feet. The Wiggins Arch was exposed in the Upper Jurassic during Norphlet and Smackover deposition (Cagle, 1983; Rhodes, 1994; Montgomery, 2005). Several wells have been drilled into Wiggins Arch basement, which is thought to be of the Suwannee terrane. Rock types of granite, gneiss, amphibolite (calc-alkaline), and low-grade metamorphics (phyllites) have been described. However, the age dating of these rocks is younger than the age dates of the Suwannee terrane, but Dallmeyer (1989) has an explanation. Dallmeyer (1989) reports that the ~300 to 320 Ma post-metamorphic cooling ages are likely due to a reset related to the heating of the Wiggins Arch near the suture zone of Laurentia and Gondwana. (Dallmeyer, 1989; Thomas, 2010).

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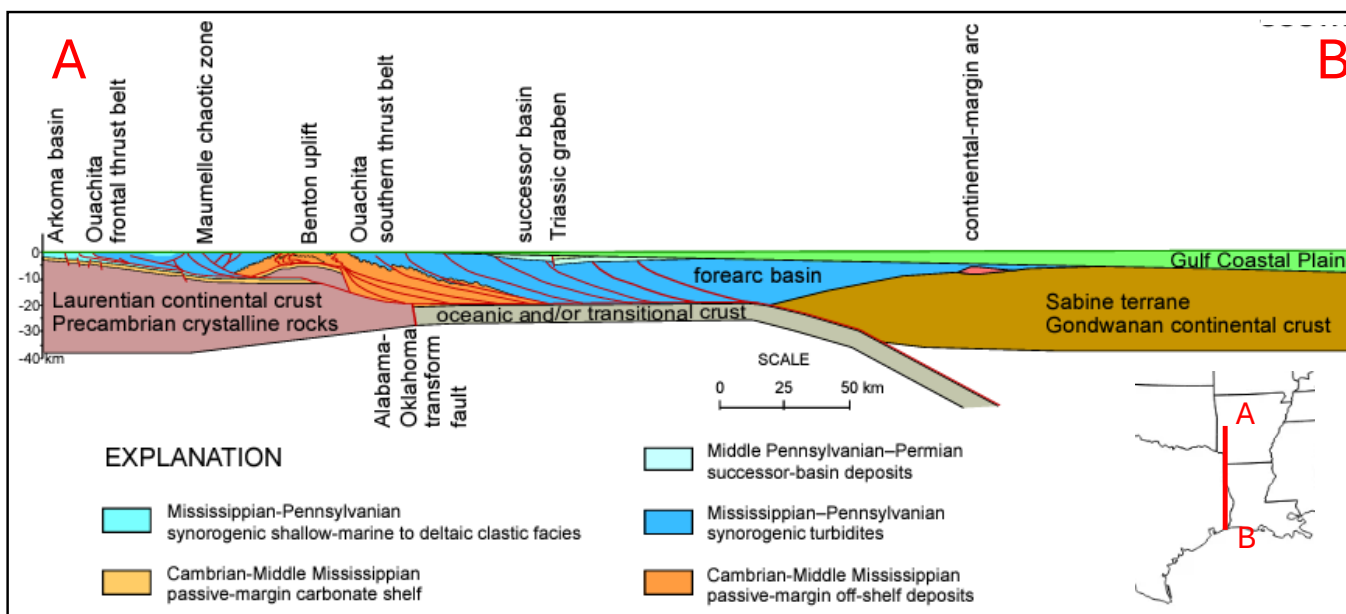


Figure 8. modified figure from Thomas 2021. This generalized cross-section illustrates the components of the Ouachita and the Sabine by an interpreted “gap” (oceanic crust?)

SABINE BLOCK (TEXAS-LOUISIANA)

Farther west along the Texas-Louisiana border, the Sabine terrane (block) is a geophysically defined segment of continental crust lying below the cover of the Gulf Coastal plain and along the internal part of the Ouachita orogenic belt (Keller, 1989; Viele, 1989; Mickus, 1992; Thomas, 2004; Fig. 1). The Sabine Terrane/Block is 600 to 800 km wide (Mickus 1992-fig 1; Thomas, 2010). The origin of the Sabine Block has been controversial in the literature. Mickus (1992) interprets the Sabine as an accreted “micro-continent” of unspecified affinity. More recent workers using radiometric dating and Zircon provenance work describe the Sabine Block as accreted to the current Ouachita Mountains created by the closing of the Rheic Ocean, which closed around 250 million years ago, forming Pangea during the Permian. Pangea is assumed to have been a continent-continent collision of the Laurentian (N. America) with the S. American sector of Gondwana. However, geophysical models indicate an unclosed gap of ~100 km between Laurentia (N. America) and the Sabine block (Lillie, 1983; Nelson, 1982; Mickus, 1992; Dunn, 2009; Thomas, 2010 and Calignano, 2017) (also see the November HGS *Bulletin* feature article on “Rockhounding and Treasure seeking” Fig 3). To explain this “gap,” Thomas (2010, 2021) suggests that the Ouachita orogeny was a soft collision of a forearc sedimentary complex with the margin of the Laurentian crust (Figure 8) (see also Viele and Thomas, 1989).

As the GOM opened, the Sabine block tapered in thickness toward the present-day coast (Hales, 1970; Mickus, 1992). The crustal thickness, apparently changing from ~35 km to ~15 km, may be explained by the stretching increase toward the present-day

coastline before the continental breakup (Hales, 1970; Mickus, 1992). Van Avendonk (2015) interprets that as the GOM basin stretched to open, the North American continental crust thinned and showed normal block faulting all the way to the present oceanic crust (Van Avendonk, 2015 fig 3).

The Sabine block has six deep wells that penetrated four different aged strata beneath likely Haynesville with no Smackover or salt before penetrating four Paleozoic rock types: 1) “Carboniferous-aged flysch,” 2) Rhyolite porphyry, 3) Pennsylvanian limestone and 4) Lower Permian limestone and shale) Nicholas and Wadell, 1989; Ewing, 2001; Hames, 2009). Only one of the two wells that penetrated the rhyolite porphyry had been dated with a single ~255 Ma Rb-Sr age (Mueller, 2014). This 255my age would coincide with the timing of the collision and heating of Gondwana with Laurasia. As the collision of the plates neared, volcanism was associated with southward subduction beneath the Sabine terrane. The Hatton tuff of the Mississippian Stanley formation exposed in the Ouachita Mountains has been attributed to this volcanism (Viele, 1989; Loomis, 1994; Thomas, 2004; Shaulis, 2012). U-Pb ages of zircons from these tuffs indicate an initial eruption at ~325 Ma. However, the tuffs have two distinct ages, with the older zircons dating from 400 to 2000Ma. (Mueller, 2014). The older age of zircons found in the Hatton tuff may more likely be xenocrysts from the Sabine basement rock incorporated in the magmas (Mueller, 2014). Perhaps the Sabine terrane is likely a Gondwana terrane rather than a piece of Laurentian basement? Several other authors contend that the origin of the Sabine is either an exotic terrane, possibly even an oceanic island arc formed in an ancient ocean basin (*although usually, arc terranes*

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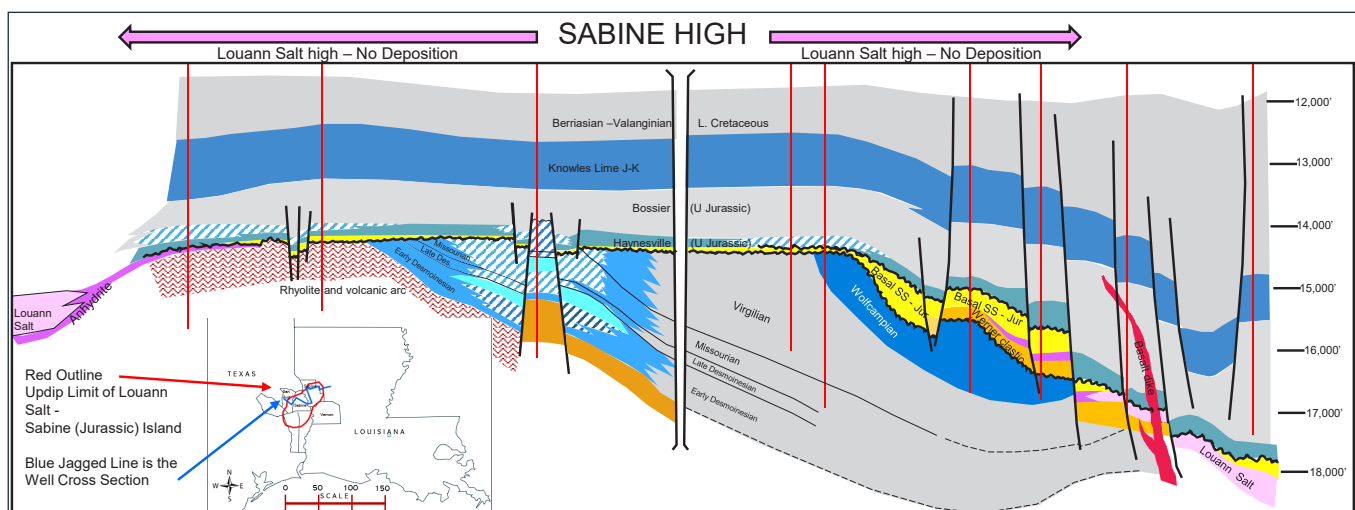


Figure 9. Well Cross Section over the “Sabine Island,” where Louann Salt through Oxfordian Smackover onlaps this paleo high. The Carboniferous package of rocks was developed in a successor basin on the backside of the Ouachita Orogeny, which occurred in the late Paleozoic ~300Ma.

are not granitoid) or rifted from another continental block and then subsequently accreted against North America as the Iapetus Ocean closed (Viele, 1989; Griffin, 2011). Whatever the origin of the Sabine Block is, the widely accepted view is that the Sabine Block was juxtaposed against the Yucatan Block before the Gulf of Mexico Basin opened, and that is where this article begins, with the opening of the present GOM.

A cross-section over the deepest wells shows that the Sabine high was a paleo-high. Mid to upper Jurassic formations all onlap the east and west flanks (Figure 9). Over a portion of the Sabine block, the absence of Louann salt indicates that it was an exposed paleo-high that remained as such, beyond Smackover deposition. Ages dates of exposure would extend from Aalenian/Bajocian past Late Oxfordian (ages by Curry, 2024; Pindell, 2021, and Erlich, 2023b). Other play potentials around the Sabine paleo high have been proven, such as the Gilmer (Kimmeridgian) oolite facies that pinch out against this high (see the HGS November 2024 feature article). There are also Norphlet sandstones or other basal clastic sandstones shown on the cross-section on the east flank of the Sabine. While tested as wet in a couple of these wells, they might be productive in other pinch-out or truncation traps on either side of this uplift.

MAYA BLOCK / YUCATAN PENINSULA

The Yucatan Peninsula is defined today by the exposed area of the peninsula and its extension outward to the continental shelf margin. The Yucatan Peninsula also overlies and in the southern portion, is part of the Maya Block (Lawton, 2021). The remaining part of the block includes a narrow portion of the coastal plain to the west of the Yucatan, including the Tehuantepec Isthmus, the Mexican state of Chiapas, and northern Guatemala. The Yucatan block on its southern boundary is separated from the

Caribbean plate by the Motagua–Plochic fault system (M–P, Fig. 1, Dengo, 1969; Donnelly, 1990; Weber, 2012). Along the southern margin of the Yucatan and north of the Motagua–Plochic fault system, igneous and metamorphic basement rocks are exposed (Weber, 2008, 2009; Solari, 2009; Martens, 2010). Based on zircon provenance, the southern portion of the total Yucatan block was likely an amalgamation with the Maya block as accretion to the southern Laurentia in the late Paleozoic (Mueller, 2014). In the southern Yucatan (Maya block portion), there is a paucity of Silurian-aged (Pan African-Brazilian, aka Suwanee terrane) zircon signatures (Weber, 2012). Although, Dengo (1969) reports that Maya-Chuacus metamorphics are “undoubtedly of pre Pennsylvanian age.” More recent radiometric determination indicates that some of these rocks are probably Devonian age (Gomberg, 1968). Back now to the northern Yucatan, an Early Cambrian granitic basement is present and thought to be a Suwanee terrane (545±5 Ma; Keppie, 2011). In summary, a hypothesis of blocks accreted to Laurentia forming Gondwana would include northern Florida, the Wiggins (Alabama-Miss), Sabine (Texas), Coahuila (S Texas-N Mexico), Yucatan and Maya block (Mueller, 2014).

Physiographically, the emergent Yucatan Peninsula and the salt basins of Campeche Platform and northern Yucatan comprise the dominant recognizable features (Figure 10). Figure 10 illustrates the salt basin of the Yucatan coast with a pink outline. In a gray shade is the oceanic crust, and in a light tan shade is the area thought to be exposed as a paleohigh during the Jurassic time on the Peninsula. Also highlighted are three published seismic lines (red, blue and orange), a seismic line tracing (green), and a well cross-section over the Hondo Arch (blue). The light blue line is the Cretaceous shelf margin, but where dashed, the margin is largely

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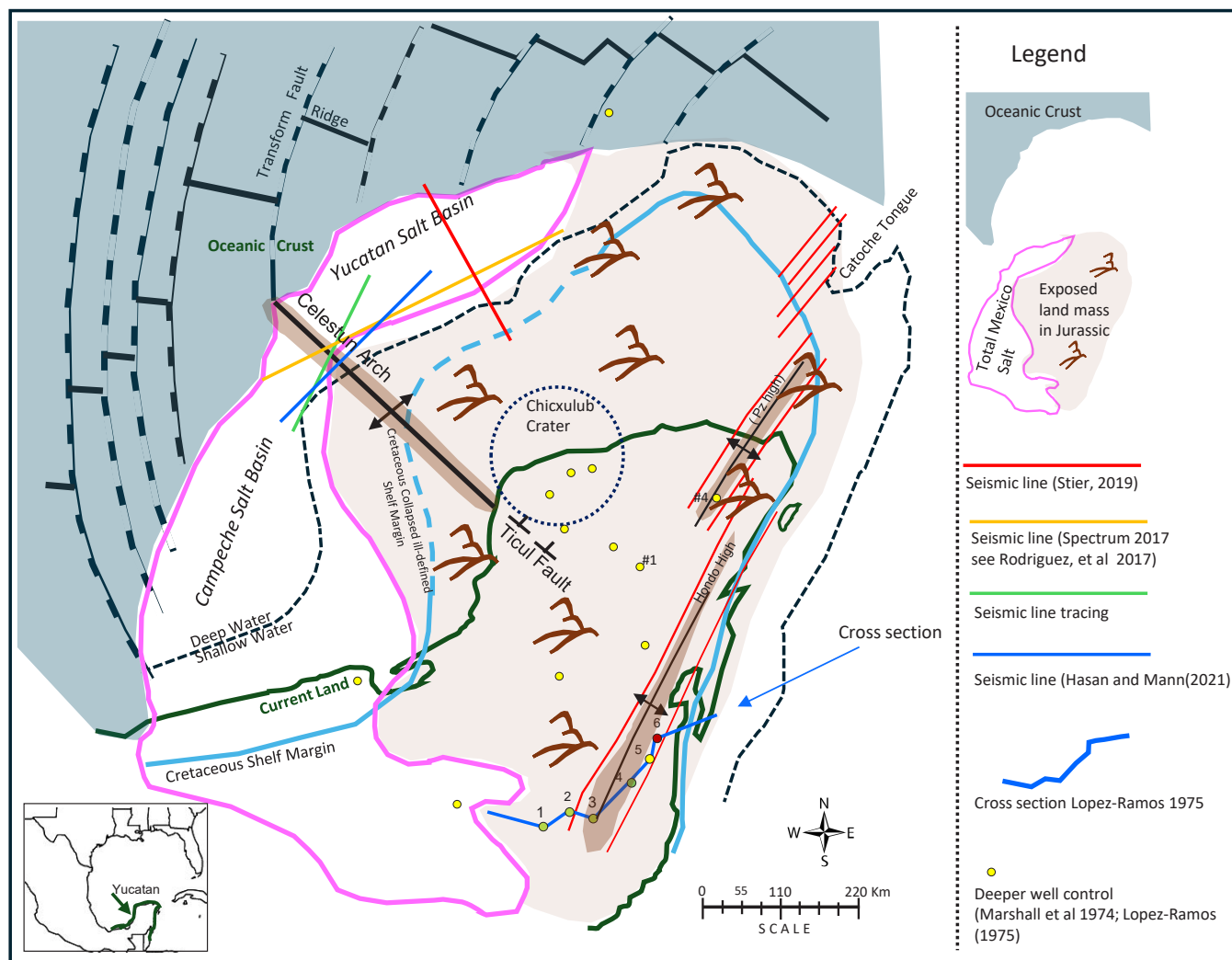
destroyed or collapsed due to the K/T event of the Chicxulub meteor strike (annotated dashed circle)(see next month's HGS feature article). The yellow circles are the relatively deep wells (Marshall, 1974; Lopez-Ramos, 1975a).

During the early to middle Jurassic, shallow marine deposition lay further west and north in the salt basin. At the same time, thin terrestrial sediments were deposited over topographically exposed Lower Paleozoic metasediments and igneous rocks (Viniegra, 1971; Marshall, 1974). The basement rock in Yucatan #1 has been dated on a rhyolite using Rb-Sr, suggesting an age of 410Ma (Silurian) with a probable metamorphic event of about 300Ma. (Lopez-Ramos, 1975b). In Yucatan #4, the basement rock consisted of 8 meters of light gray, slightly metamorphosed quartzite with yellowish-brown weathering (Weide, 1978). The basement rocks have been highly weathered, suggesting a significant exposure period (Lopez-Ramos, 1975a). The eroded highlands have thin colluvial and fluvial sediments deposited unconformably on the eroded Paleozoic basement. In the Yucatan #1

and Yucatan #4 wells, this likely Jurassic age sediment is 30 – 40m thick and overlies the Paleozoic basement (Viniegra, 1971-Fig 7, Weide, 1978). This thin red sediment covering is referred to in some literature as Capas Rojas (Red Layers) (Lopez-Ramos, 1975a). No major rivers likely existed over this drainage area, especially during an arid climate. In other literature, this thin red sub-aerially deposited sediment has been suggested to correlate with much thicker and more well-developed facies of the Todos Santos Formation of Chiapas and Guatemala (Viniegra, 1971; Godinez-Urban, 2011; Guzman, 2021).

The Yucatan has two distinct structural trends: the Hondo Arch complex on the peninsula's eastern side and the Celestun Arch that runs perpendicular to the Hondo complex, from southeast to northwest (Steier, 2019; Hasan, 2021). The Hondo Arch complex extends from Belize northward, closely trending along the eastern coast and extending offshore, bounding both sides of the Catoche Tongue (Figures 10 and 11) (Lopez-Ramos, 1975; Dengo, 1975;

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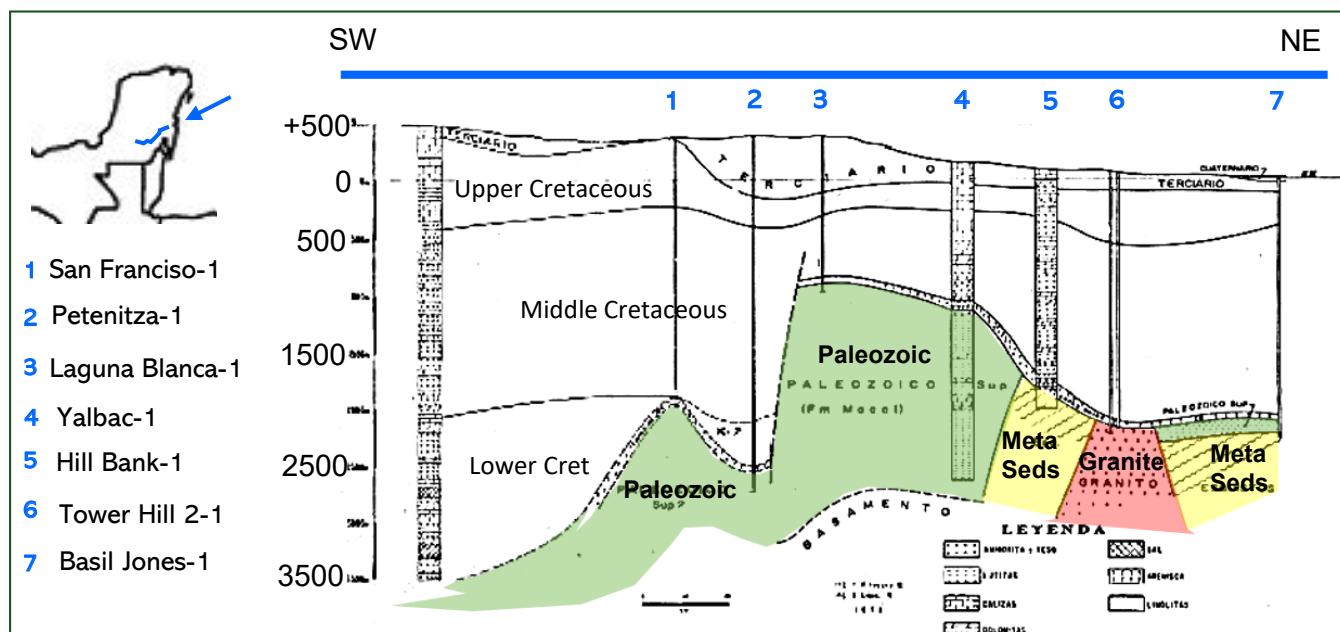


Figure 11. Structural Well Cross Section over the Hondo Arch, illustrating the Paleozoic (lower?) and metasediments of the pre-Mesozoic basement, shown here overlain by Cretaceous in by a significant unconformity. See also a better location map in Figure 10.

Weide, 1985). The island of Cozumel is a horst block bounded by normal faults on its west and east sides (Weide, 1985). The Catoche tongue originated as block faulted graben with the upthrown sides underlain by Paleozoic continental blocks (Schaub, 1983). The Catoche Basin (graben) is interpreted by seismic to be filled with talus from Paleozoic and Jurassic red beds (Schaub, 1983). Just east of the Island of Cozumel is a southwest-to-northeast alignment of subsea high blocks and tiny islands that are likely the marginal ridges of the faulting. Dredged samples taken offshore near these marginal ridges, recovered Paleozoic age rocks that “fell off the adjacent continental margin of Yucatan” along the Caribbean strike-slip faulting toward Cuba (Vedder, 1973; Ramos, 2023).

Returning to the Celestun arch, it is likely an analogue for a depositional paleo arch like the Middle Ground Arch in the EGOM; but connecting structurally to the Sabine Arch. A paleo arch has been shown to lessen the subsidence typically found in off-arch areas. With less rapid subsidence, aeolian dunes forming over the ridge are characteristically “drier” dunes having a deeper groundwater. This further allows more time and distance for the downward percolation of rainwater through the dune to the water table. Repeated percolations are more effective in thoroughly coating sand grains, thus reducing quartz cementation with burial (Godo, 2017, 2019). This large regional arch structure might also be a major charge-focusing high for potentially attractive Norphlet/Bacab play opportunities (Godo, 2023). The Norphlet/Bacab potential around the Celestun Arch may be very good given that the productive “belt” can extend out 50 to 60 miles from the depositional up-dip limit (Godo, 2017-fig 1; Godo, 2023). There are also mappable corridors of likely Norphlet/Bacab sandstone

trending basinward off the Celestun. Two recent Shell wells tested the Bacab in the Campeche salt basin (Max-1 and Alux-1). Neither was a discovery, but there are different (better?) types of potential prospects with potentially better critical success factors present than in these two wells.

The burial depth is the primary difference between the two arches (middle Ground and Celestun). In the GOM, the Tertiary sediments from the Mississippi drainage buried the Smackover source rock to a depth to be mature. The Celestun Arch is shallower over the crest, but the Norphlet/Bacab play would extend further basinward off the arch and the Smackover source rock would likely become more thermally mature (Williams-Rojas, 2012; Kenning, 2020). In addition, other plays like the Smackover or Kimmeridgian Gilmer oolitic pinch-out play, as established on the Sabine block flanks, might also have merit on the Celestun flanks.

The Celestun Arch, when reconstructed to pre-rifting of the GOM, shows that both the Celestun and Sabine highs were either on trend or slightly offset (Clift, 2018-fig1; Pindell, 2021-fig13; Lawton, 2021-fig1; Pindell, 2022-fig8) (see also reconstructions by Maarten, 2010; Mueller, 2014; Nance, 2009; Weber, 2012; Hudec, 2019; Erlich, 2020; Lawton, 2021; Pindell, 2021; and Tian, 2022). In these restorations, notice the characteristic shape of the Yucatan block with a prominent salient point or outline of the Yucatan coastline (Figure 12). Based on reconstructions shown in Figure 12, that salient point lines up with the Sabine high. You ask, why is that significant? This salient Yucatan coastline point directly

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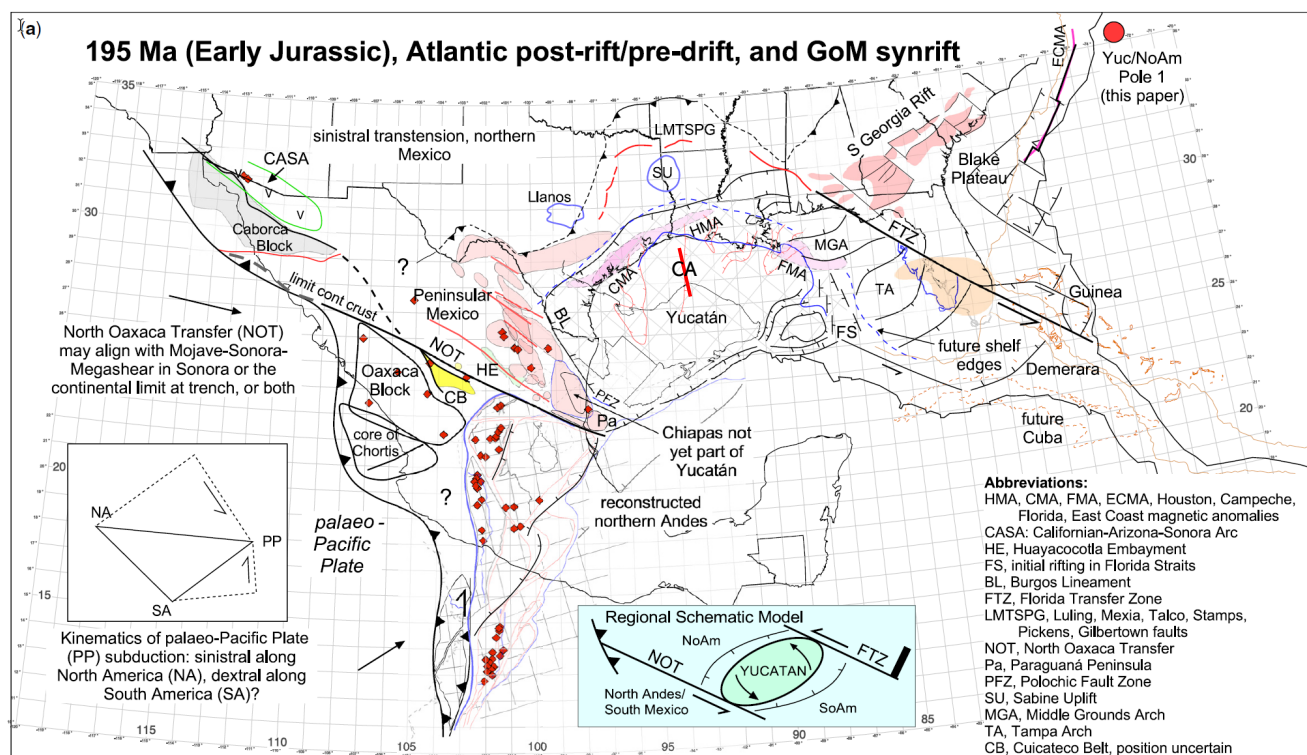


Figure 12. Modified from Pindell et al. 2012 (fig 13): In this restoration, notice the characteristic shape of the Yucatan peninsula, shows a prominent salient point by the outline of the Yucatan coastline highlighted by the red line. Notice that this red line, which also marks the axis of the Celestun arch, lines up or points directly to the Sabine uplift (SU). Did this alignment of paleo high that restricted deposition of Louann through Oxfordian restrict seawater that entered the GOM from the west and filled eastward?

aligns with the paleo-high called the Celestun Arch (Steier, 2019; Hudec, 2019; Hasan, 2021). Hudec (2019 Fig 2) shows the line up with the Celestun Arch but does not refer to this name but rather an “axis” [line] of basement high separating subbasins” [Campeche salt basin and the Yucatan subbasin]. Hudec (2019) describes the Campeche subbasin as having a much higher density of salt diapirs, suggesting thicker salt. The Celestun and the Sabine are also defined by magnetic highs (Pearson, 2006; Ewing, 2009; Steier, 2019; Hasan, 2021). Again, you ask why this alignment might be significant. Well, seawater constriction across these high blocks might have occurred if the Celestun and Sabine paleo high were connected or closely aligned during earlier salt deposition and might be one reason for thicker salt on the Campeche (west) side versus the Yucatan salt basin (east side). **Figure 13** is a seismic line drawing acquired over the axis of the Celestun arch. Notice how the salt (pink) thins and is likely not present over the crest of the arch (see **Figure 9** for line location). **Figure 14** (Hasan, 2021) is a larger view of the Celestun arch that shows that most of the Mesozoic and pre-salt stratigraphy also thin across the crest of the arch (**Figure 9** for line location).

No wells have been drilled offshore and east of the Celestun Arch. Andrew Steier was the first to work on Spectrum’s offshore Mexico Campeche-Yucatan 2D regional multi-client program, earning his master’s degree. He published his work with Dr. Paul Mann (Steier, 2019). I was also present at his defense but have recently

thought more about the ages and sediment fill. Other workers at Spectrum (Sanders, 2016; Rodriquez, 2017) have had similar correlations as Steier (2019). They all used the well tops from a USGOM deepwater well named Cheyenne (LL399; this well will be a feature article in the HGS *Bulletin*, likely in the April issue. A problem with correlating from Cheyenne is the separation of oceanic crust from the Yucatan continental block (see Saunders, 2016 fig 3). Also, the top Jurassic (Tithonian) laps onto oceanic crust before it reaches the Yucatan continental block. Interpreting seismic in Mexico and correlations from the Campeche over the Celestun arch has led me to question myself and the traditional tops and fill ages that have been published.

Only two papers, Thierry Rivas and others (2019) and Vernon Moore and others (2024), have detailed the subject of the SAKARN. In their paper, the SAKARN is more likely an equivalent to the “entire” Louann salt, meaning in part, the oldest Louann(?). This article is already too long to describe and do justice to the SAKARN fill but summarizing the thinking of Rivas (2019) and what he describes as up to 8,000 feet of thickness might be as follows: The lower SAKARN, based on the seismic reflection character, would be consistent with anhydrite and/or carbonate. The Upper SAKARN, which has low contrast seismic reflection, indicates the “inclusion of clastic sediments.” In my opinion, this could be “dirty salt” by the inclusion of clastics (sand, silt,

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volcaniclastics) in a halite matrix.

Do we have other drilled examples of “dirty salt” in the GOM? Interestingly, there has been a well located onshore in the East Texas Basin drilled by Exxon (Fina L.V. Ray Gas Unit #1-2), which penetrated below the Louann, drilling 4800 feet of subsalt sediment and 800 feet of salt named the Rosewood evaporites (White, 1999; Snedden, 2019). The other dominant blocked lithologies described by White (1999) are 1800 feet interbedded igneous and clastic rocks with another 1800 feet interval of red and gray shales and white to pink sandstones with minor limestones. No age determinations were made, and the possibility exists that it is the Eagle Mills section, except that Eagle Mills has nowhere else described evaporates, indicating that water was present. Snedden (2019, see pg.59-60) shows a newer reprocessed seismic line, describing the sub-Louann salt section as not deposited in a half-graben-rift structure. Instead, he favors deposition in a successor basin, as defined by Nicholas and Wadell (1989). Snedden (2019) also describes the Rosewood evaporite section as made of interbedded anhydrite and gray silt. Structurally, the SAKARN series appears to have been deposited in strike-slip polygonal “pull-apart” basins related to the Phase 1 GOM opening before the Phase 2 rotation phase. Normal faults bound the deeper SAKARN section, but as offset decreases upward and faulting dies out, the mid to upper SAKARN is somewhat conformable to the bedding

of the uppermost Louann salt.

Another example of a well that drilled “dirty salt” in a halite basin of Kimmeridgian age is in Clark County, Alabama. It is the Champion-Klepac #1 (Eustice, 1994). This thick evaporite section, cored by the Klepac well, lies in an area of the Mobile graben where local subsidence created shallow saline lakes, salinas, and salt pans, interbedded with terrigenous clastic mudstones and organic-rich cumulate halite (Eustice, 1994 their fig.3). This type of lithology might likely also represent some of the SAKARN section. By the way, the Clark County area might be interesting for lithium and bromine-rich brines, similar to the description in the September 2024 HGS feature article on lithium from oil field brines.

Returning to the idea that the northern Yucatan salt basin, in part, would contain the SAKARN facies, I offer some alternate interpretations on two published lines by Rodriquez (2017) and Steier (2019). First, to acknowledge that interpretation on the northern Yucatan is without well control, so previous interpretations and my questioning of them are merely an exercise of presenting alternatives until a well is drilled. All interpretations are wrong in detail, it is just how close to reality we can make them. After mapping the Mesozoic for over four years on the

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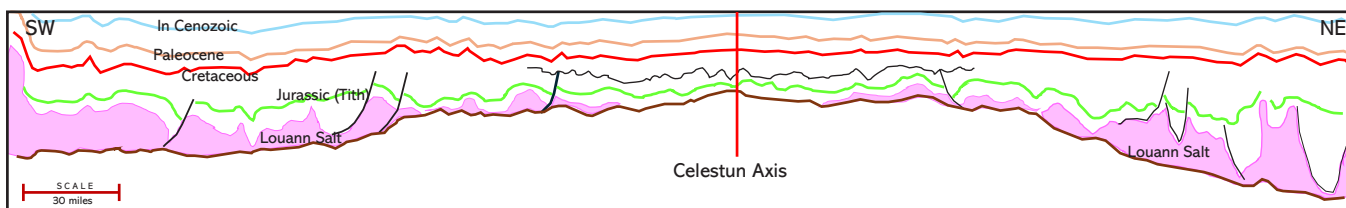


Figure 13. Seismic line interpretation over the Celestun arch's axis. A strike view orientation over the Celestun arch that separates the Campeche Salt Basin from the northern Yucatan Salt Basin. Notice the marked thinning of the Mesozoic and the likely absence of the Louann Salt (pink) across the arch. See Figure 6 (this article) for location map (green line)

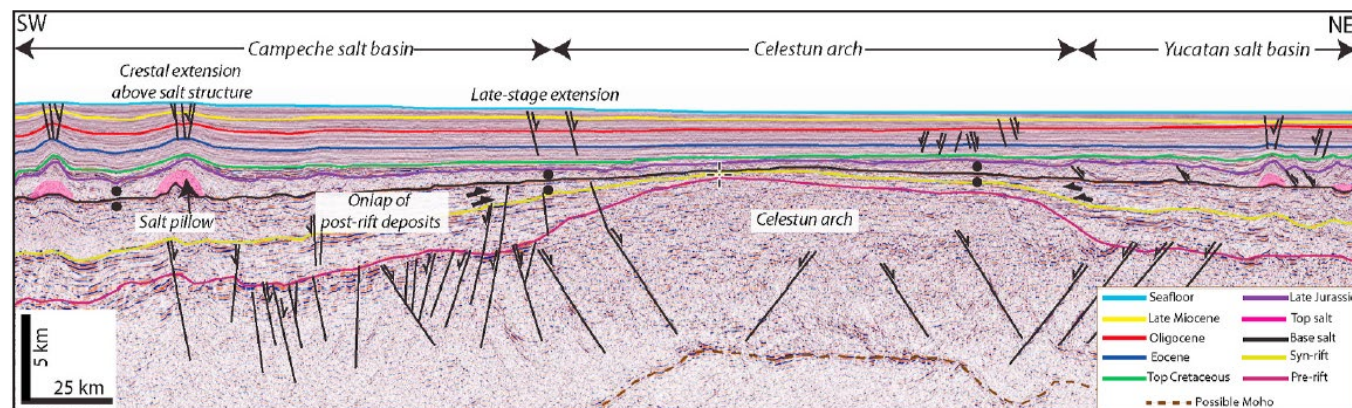


Figure 14. Modified from Hasan and Mann 2021 (fig 7): A larger strike view orientation over the Celestun arch separating the Campeche Salt Basin from the northern Yucatan Salt Basin. Onlap of pre-salt and thinning Mesozoic strata demonstrate that the arch was a positive feature before Bajocian-early Callovian salt deposition. Seismic data courtesy of Geox MCG. See Figure 6 (this article) for location map (blue line)

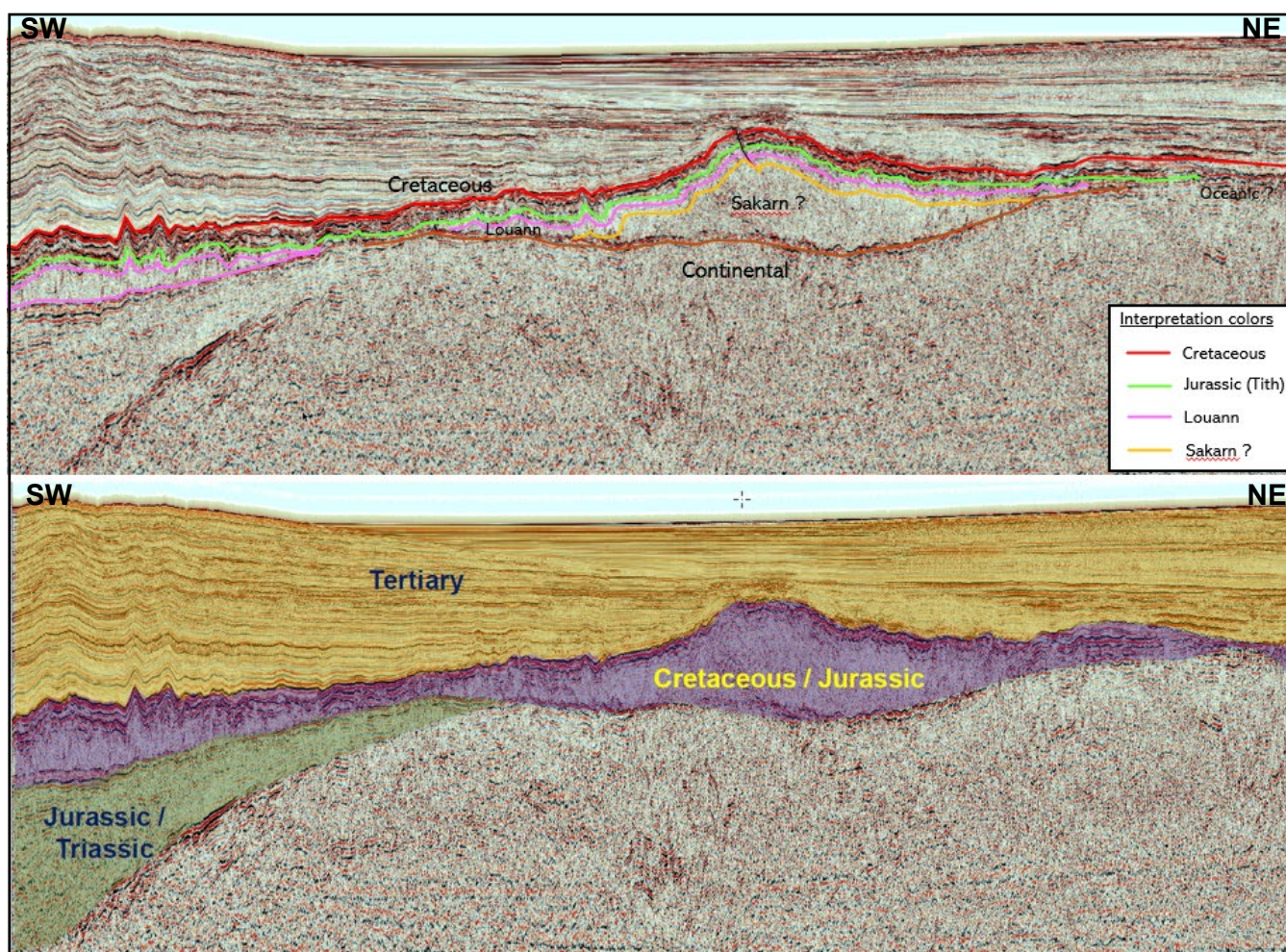


Figure 15. Interpretation on the lower Seismic profile is from Rodriguez, 2017. The upper seismic line interpretation is the interpreted Sakarn facies as questioned in this article (Godo). The index map is shown in Figure 10 as the “yellow” line. Data is from Spectrum

Campeche side, where substantial well control is present, the Mesozoic thickness (Cretaceous to Oxfordian) is commonly in the 500 to 600-meter range with a maximum of about 1000 meters. Correlation of the Mesozoic over the Celestun arch can be done, but closer to the arch, the thickness of the Mesozoic reduces to the smaller range of thickness of the Campeche Basin. The alternative correlation is to come south from the USGOM side at the Cheyenne well. But one must explain how such a huge thickness difference of Cretaceous through Oxfordian (from Cheyenne) appears only in a part of the northern Yucatan Salt Basin. Either the correlation stays “high,” as in **Figure 15** and **16**, or a correlation decision is made to go low on the highly rotated dip profile line (**Figure 16**), which then makes anomalous thicknesses in the Kimmeridgian or Tithonian. The issue would be that these anomalous thicknesses of either Kimmeridgian or Tithonian would be very localized on a portion of the paleo-Yucatan coastline. This is difficult to explain because only a small, exposed sediment area is present on Jurassic Yucatan for sediment runoff. Plus there is no obvious anomalous basement subsidence for sediments to accumulate anomalous

thickness. Referring to Kenning (2020), he writes, “as a result of the variable thickness of growth strata, the near Jurassic horizon can only be inferred within this package”. I would agree with the growth faulting, but think about this: growth faulting in the Jurassic on the USGOM side is often fed a sediment supply from the large ancestral drainage from the North American continent, including the Appalachians/Ouachita mountains. The only landmass during the Jurassic off the northern Yucatan would be a much smaller area of exposed basement with likely limited river drainage. Therefore, if no significant subsidence can account for the thick, then it is also unlikely that big river systems delivered sediment northward of the Yucatan Peninsula while at the same time delivering much less to the Campeche side of the Yucatan.

Finally, as mentioned earlier, deposition of the SAKARN series may have likely formed along polygonal-shaped basins that line up, resulting from a strike-slip motion during Phase I of the initial gulf opening. Rivas (2019) also describes the SAKARN series that thickens in polygonal-shaped minibasins elongated in

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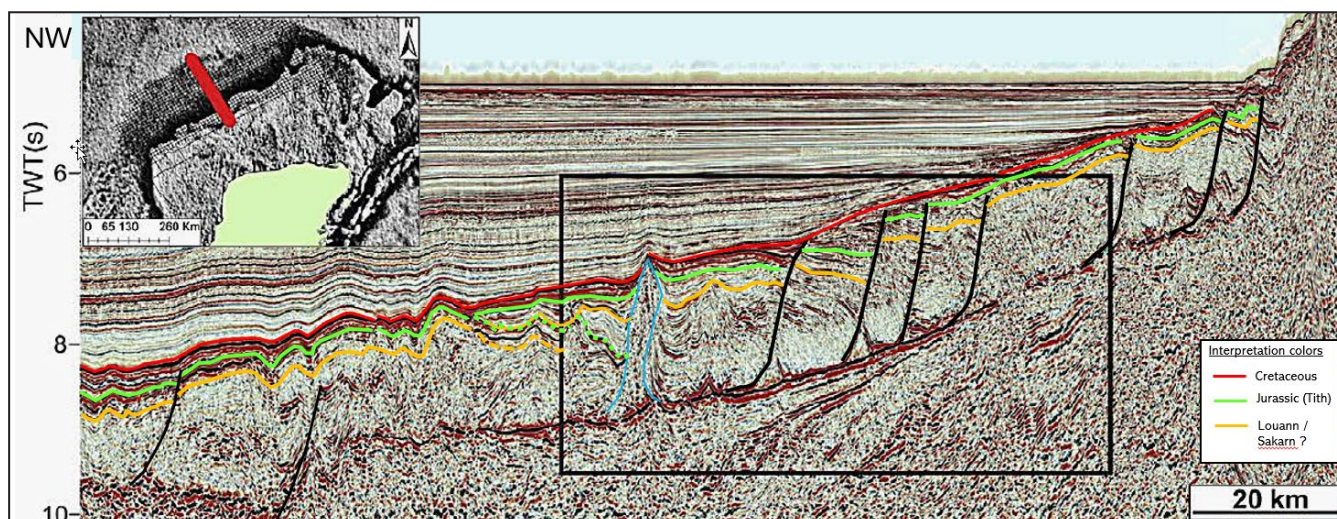


Figure 16. This interpretation is made on the same line shown in Steir (2019), courtesy of Mike Saunders and Spectrum Geo. The difference in this interpretation compared to Steir's (fig 7c) is that below the orange horizon on this interpretation, Steir would suggest the rotated events would be in the Jurassic above the bottom most couple seismic events thought to be Norphlet equivalents. Correlating the Top Jurassic from the Campeche, the Mesozoic thickness (Cretaceous through Oxfordian) would be represented on this line as between the red and orange event. The orange event would represent the top Louann / Sakarn. If the interpretation of the units is nearly correct, then the thick mass of sub-orange would be like the 8000 feet of Sakarn equivalent in the USGOM as described/defined by Rivas (2019)

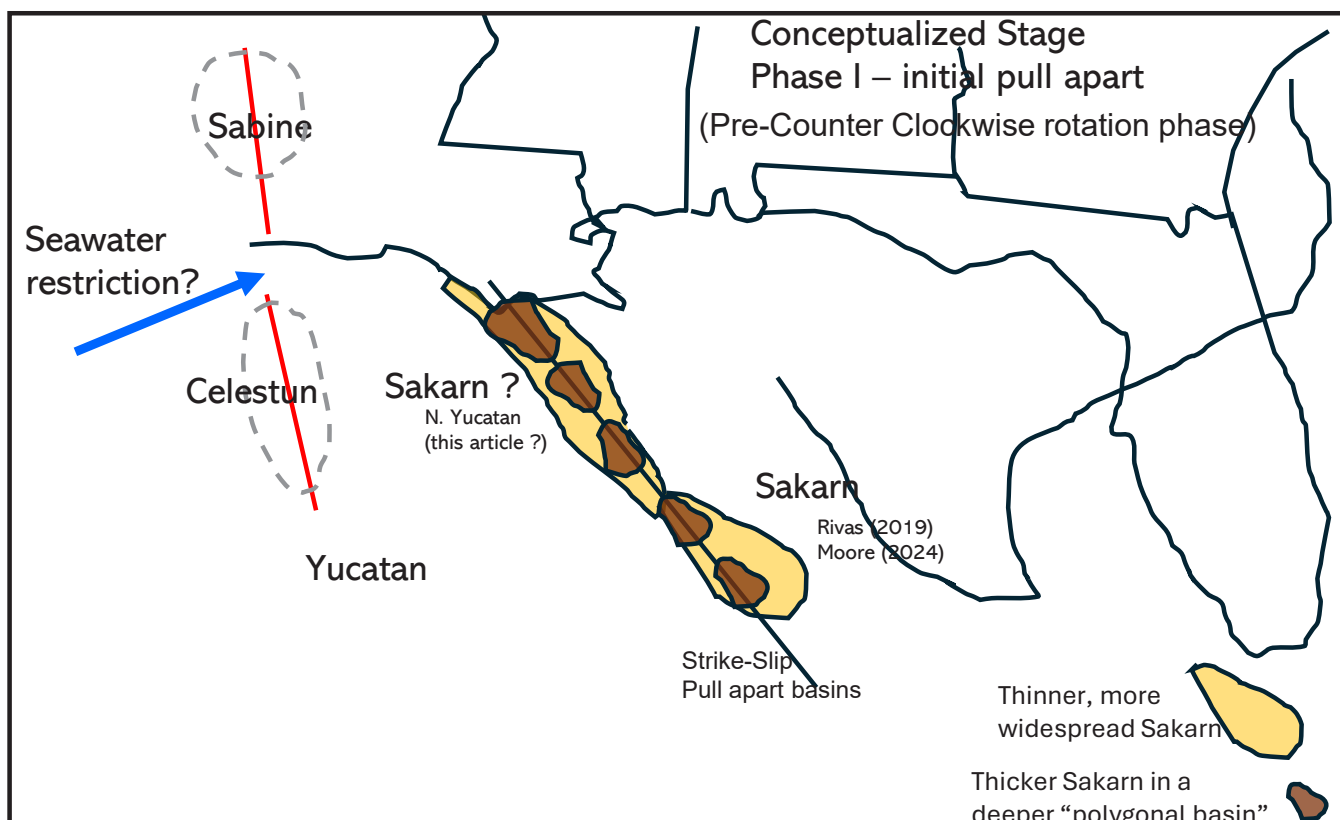


Figure 17. This is a rough "sketch map" of what the early pull apart or separation of Yucatan from the US might have appeared with local deposition of the Sakarn series in polygonal-shaped basins aligning with a strike-slip motion. At the end of Phase I, rotation of the Yucatan block occurs, and some of the Sakarn series is left attached to the Northern Yucatan "Salt Basin."

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a northwest-southeast orientation. I have sketched a map of what that might look like (**Figure 17**).

CONCLUSION/SUMMARY

In this article, several features on both the US and Mexico sides of the GOM were presented. Questions were asked, such as the relationship between the Sabine Arch (Texas and Louisiana) and the Celestun Arch (Yucatan, Mexico). A second question posed to the readers is whether the SAKARN (pre-Smackover) as originally defined by Rivas (2019) is also present off northern Yucatan. Other items that may be of interest are a description of the offshore Sarasota basal clastic play, a couple of key basement test wells in the west Florida terrace, a Sabine arch cross section, and features on the Yucatan Peninsula such as the Hondo arch and basement descriptions. Once again, I apologize for the rather lengthy article, but I want to share other information in other areas in the upcoming *Bulletin's*. Thank you for your patience and look forward to next months shorter article on Chicxulub. ■

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Deformation Bands

By Dr. Stephen Naruk

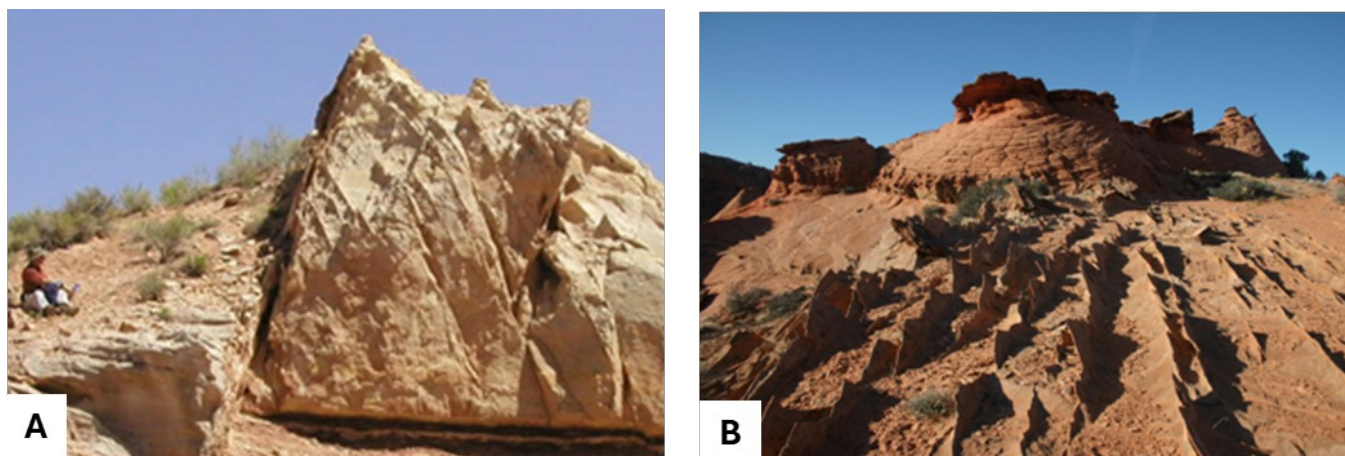


Figure 1. Outcrop examples of deformation bands in sandstones, showing the two most common modes of occurrence. A) In a fault-damage zone adjacent to meter-scale (or larger) displacement fault. B) In a rotated fold limb of a trishear fault-propagation fold.

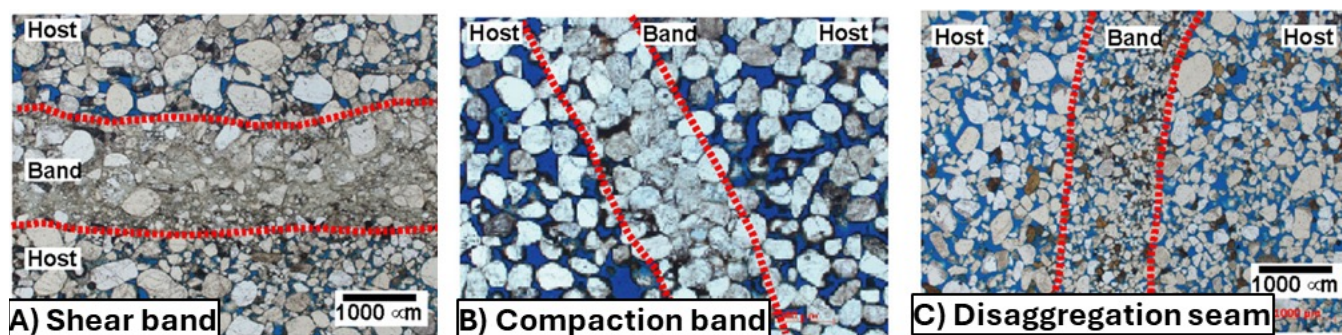


Figure 2. Petrographic images of deformation bands A) Cataclastic shear band. B) Compaction band. C) Noncataclastic shear band or disaggregation seam.

Deformation bands are essentially cm-scale faults in very high porosity, medium- to coarse-grained sandstones and carbonate grain stones which essentially no phyllosilicates (**Figures 1 and 2**) (Aydin, 1978; Fossen et al., 2007; Cilona et al., 2012). The two main habitats of deformation bands are (A) in the damage zones adjacent to faults, and (B) within rotated fold limbs, particularly the deformation zones of trishear fault-propagation folds such as the Colorado Plateau monoclines, which are the type locality of deformation bands (e.g., Davis, 1999). In both cases, the deformation within the bands typically involves grain-size reduction through cataclasis. Displacement may occur either sub-parallel to the plane of the bands, in which case they are called shear bands (**Figure 2A**), or perpendicular to the plane of the bands, in which case they are termed compaction bands (**Figure 2B**). A subset of bands that do not involve cataclasis are termed disaggregation bands (**Figure 2C**).

In fault damage zones, the bands occur as conjugate sets with one set sub-parallel and synthetic to the main fault. In this case they are confined to the meter-scale-width damage zone immediately adjacent to the main fault. In the deformed fold limbs, the bands occur as synthetic-antithetic conjugate pairs oriented at acute

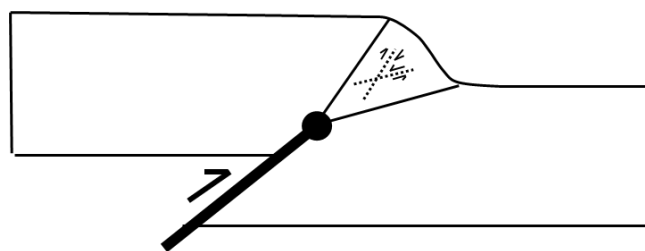


Figure 3. Schematic of trishear fault propagation fold. Conjugate sets of deformation bands (dotted lines) occur in the triangular zone of shear and folding in front of the fault tip.

angles to the main shortening direction within the trishear zone, (**Figure 3**) and may extend over hundreds of meters depending on the strains and the scale of the fold limb (Brandenburg et al., 2012). The most spectacular examples of this type of deformation band occur in the Mesozoic aeolian sandstones of the Colorado Plateau and the Valley of Fire northeast of Las Vegas (Flodin and Aydin, 2004).

In the subsurface of the Gulf of Mexico, extensive conjugate sets of deformation bands have been noted in core from the Jurassic

Deformation Bands continued on page 30

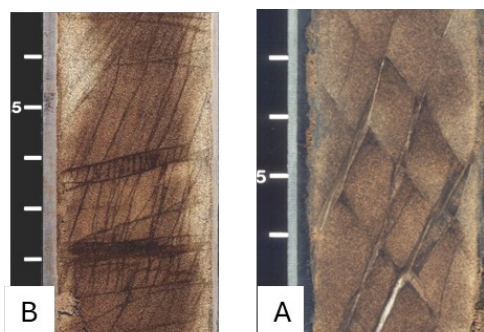


Figure 4. Deformation bands in core from Gulf of Mexico fields. The deformation bands in (A) reduce the bulk permeability of the reservoir by 10-20%. In contrast, the deformation bands in (B) reduce the bulk permeability of the reservoir by only 75-85%.

Norphlet Sandstone (Godo, 2019), Pliocene reservoirs in the Holstein Field (Wilkins et al., 2019) and Miocene reservoirs in moderately dipping to overturned sandstones adjacent to salt walls in Green Canyon (Figure 4) (Wilkins et al., 2022).

Individual deformation bands in both outcrops and the subsurface may have several orders-of-magnitude less permeability than the host reservoir rock (Figure 5). However, the bands' impact on reservoir performance depends on the bands thickness and spacing in addition to their permeability. Where the deformation band intensity is low (~1-1 total millimeters of deformation bands per meter of reservoir) and their permeability is ~ 1/10th the host

reservoir permeability, the bands reduce the bulk permeability of the reservoir by only 10-20% (e.g., Figure 4A). In contrast, where the deformation band intensity is relatively high (30-50 total millimeters of deformation bands per meter of reservoir) and their permeability is ~ 1/100th – 1/1000th the host reservoir permeability, the bands reduce the bulk permeability of the reservoir by 75-85% (e.g., Figure 4B). Thus, once deformation bands have been encountered in core, it is critical to reservoir development to estimate the intensity of band development elsewhere in the reservoir. Where the deformation bands are limited to fault damage zones, their impacts on sealing and baffling are relatively minor compared to the main fault. For the deformation bands which occur over hundreds of meters in fold limbs, outcrop-based studies show that the deformation band intensity correlates with the finite strain, such that once deformation bands are positively identified from core in a folded reservoir, finite strains can be calculated and used as a proxy to estimate the distribution and intensity of deformation bands elsewhere in the reservoir (Brandenburg et al., 2012). On the positive side, despite decreasing reservoirs' bulk permeability in both damage zones, and fold limbs, the deformation bands may increase overall oil recovery in water injection scenarios by increasing fluid flow tortuosity and sweep efficiency (Zuluaga et al., 2016).

Deformation Bands continued on page 31

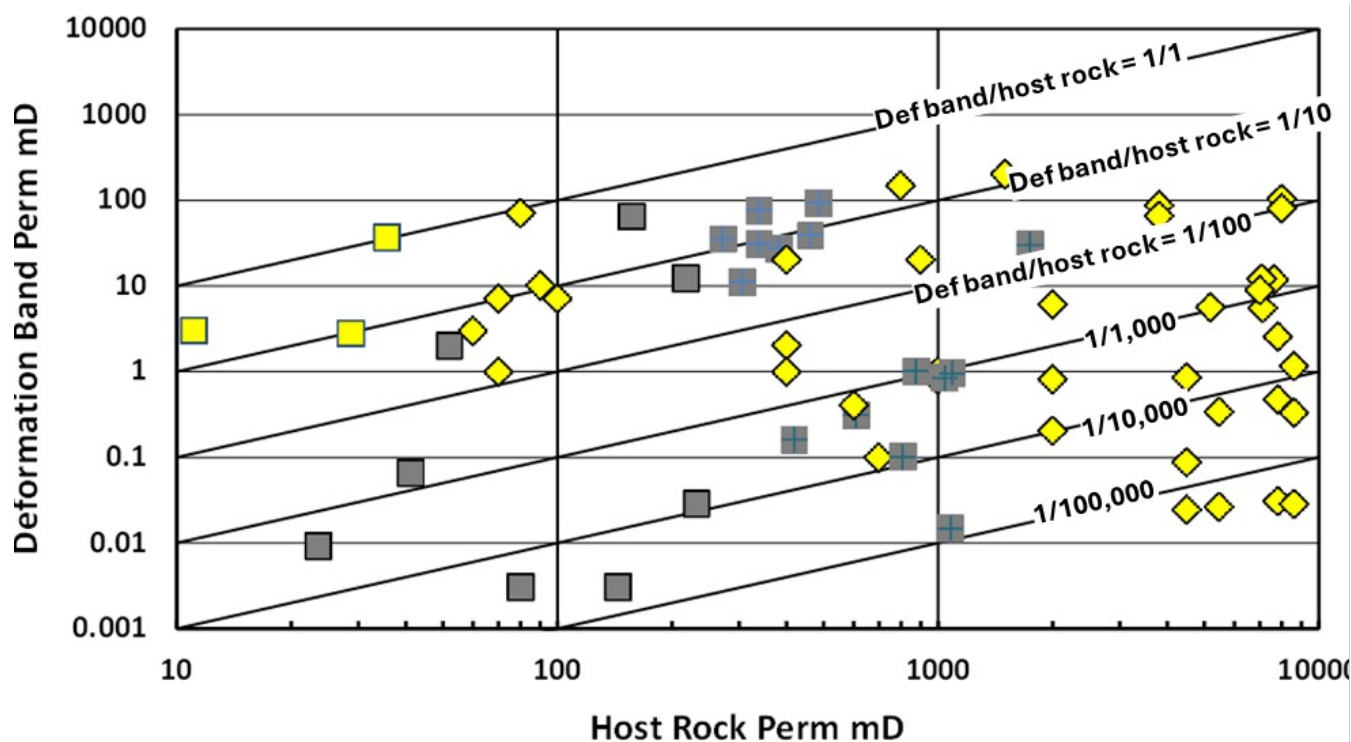


Figure 5. Comparison of deformation band permeabilities with their host rock permeabilities. Each point represents two core plug measurements; one of the host rock, and one of the deformation band itself. Yellow diamonds are from outcropping deformation bands on the Colorado Plateau. Gray squares are from deformation bands in core from the Gulf of Mexico. The deformation bands' reduction in permeability ranges up to six orders of magnitude

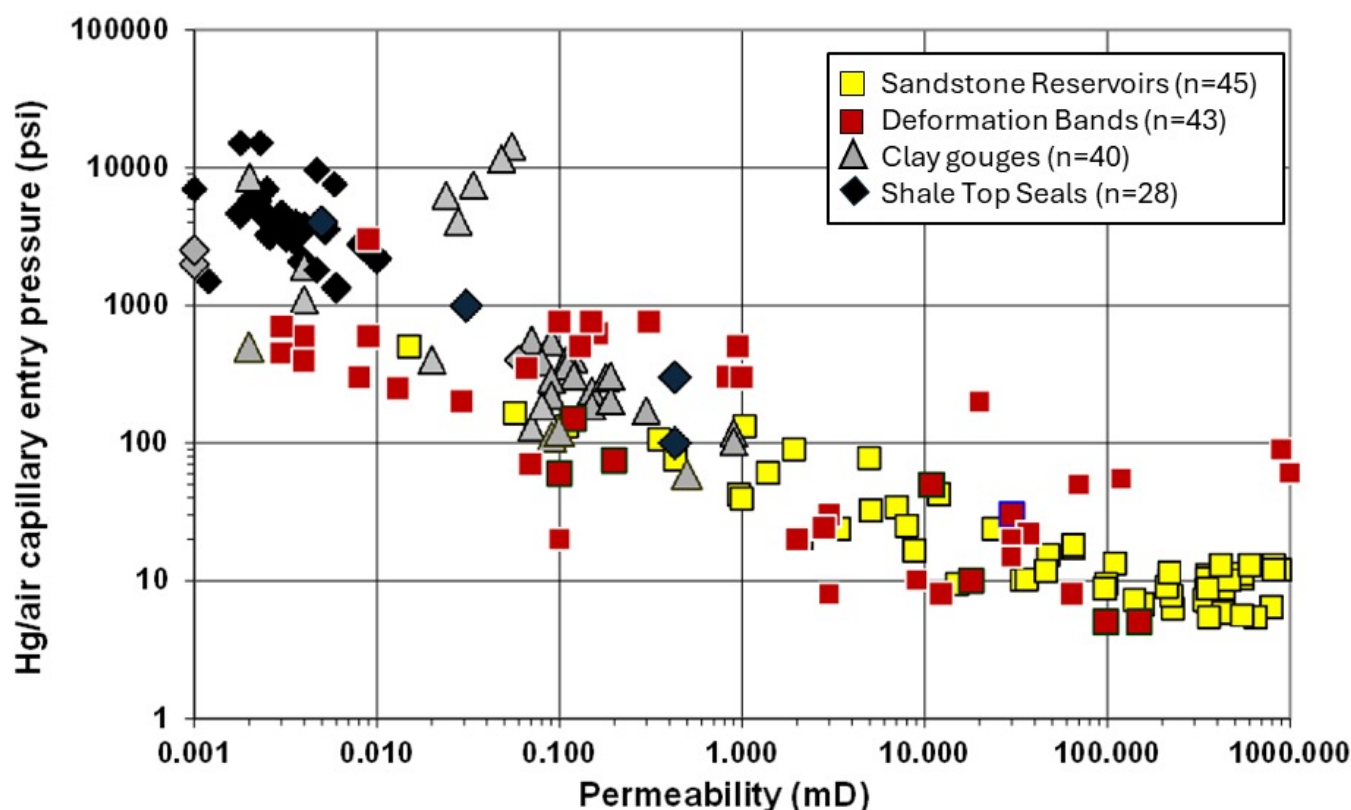


Figure 6. Comparison of capillary entry pressure and permeability measurements of reservoirs (yellow squares), deformation bands (brown squares), top seals (black diamonds) and fault gouges (gray triangles). The seal capacities of deformation bands range from that of reservoirs (negligible) to top seals (high).

The trapping capacity of deformation bands, like that of any rock, depends on capillary entry pressure rather than permeability (Schowalter, 1976). Consequently, many deformation bands have limited trapping capacity despite their large reduction in permeability relative to their host rocks. The capillary entry pressures of deformation bands range from that of top seals and fault gouges, to that of reservoir rocks (**Figure 6**). Thus, it is only deformation bands with permeabilities less than ~0.5–1.0 mD that have capillary entry pressures and trapping capacities equivalent to top seals and fault gouges.

In summary, deformation bands are essentially cm-scale-displacement faults in medium- to coarse-grained high porosity, high net/gross sandstones and carbonate grainstones. The bands can be subdivided into cataclastic and noncataclastic bands depending on the degree of grain-size reduction. They can be further subdivided into shear bands or compaction bands depending on the sense of displacement. The two main habitats of deformation bands are in fault damage zones, and in widespread zones of deformation in fold limbs, particularly the limbs of trishear fault-propagation folds. Individual bands can have up to six orders of magnitude less permeability than their host reservoir rock. However, their impact on bulk reservoir permeability is a function of their thickness and spacing in addition to their individual band permeability. In Gulf of Mexico reservoirs, they

have been documented to reduce the bulk reservoir permeability from 10–20% up to 75–85%. Their trapping potential depends on their capillary entry pressure rather than their permeability. Only deformation bands with very low permeabilities (less than ~0.5–1.0 mD) have capillary entry pressures and trapping capacities equivalent to top seals and fault gouges. ■

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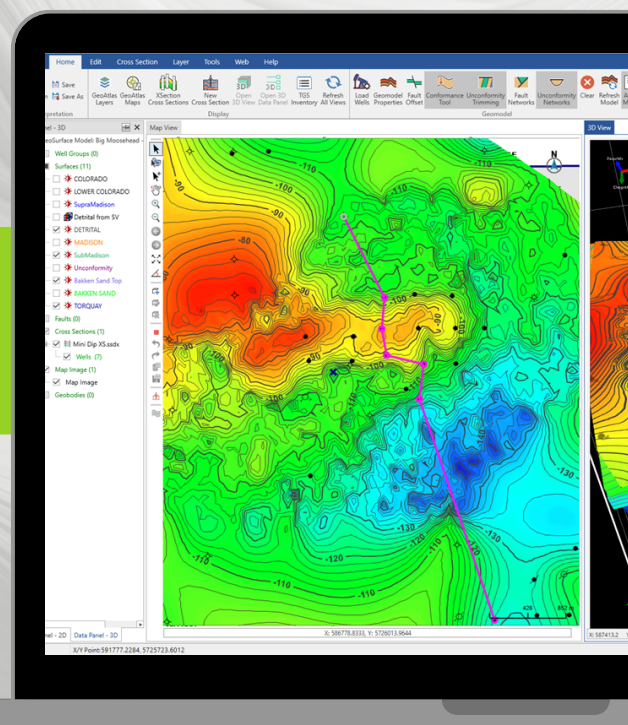
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OAE-2 and the Role of Hydrocarbons in Cinnabar (HgS) Mineralization in Terlingua, SW Texas

By L. Taras Bryndzia, Independent Geoscientist, Houston, Texas Corresponding author e-mail: ltbryndzia@gmail.com

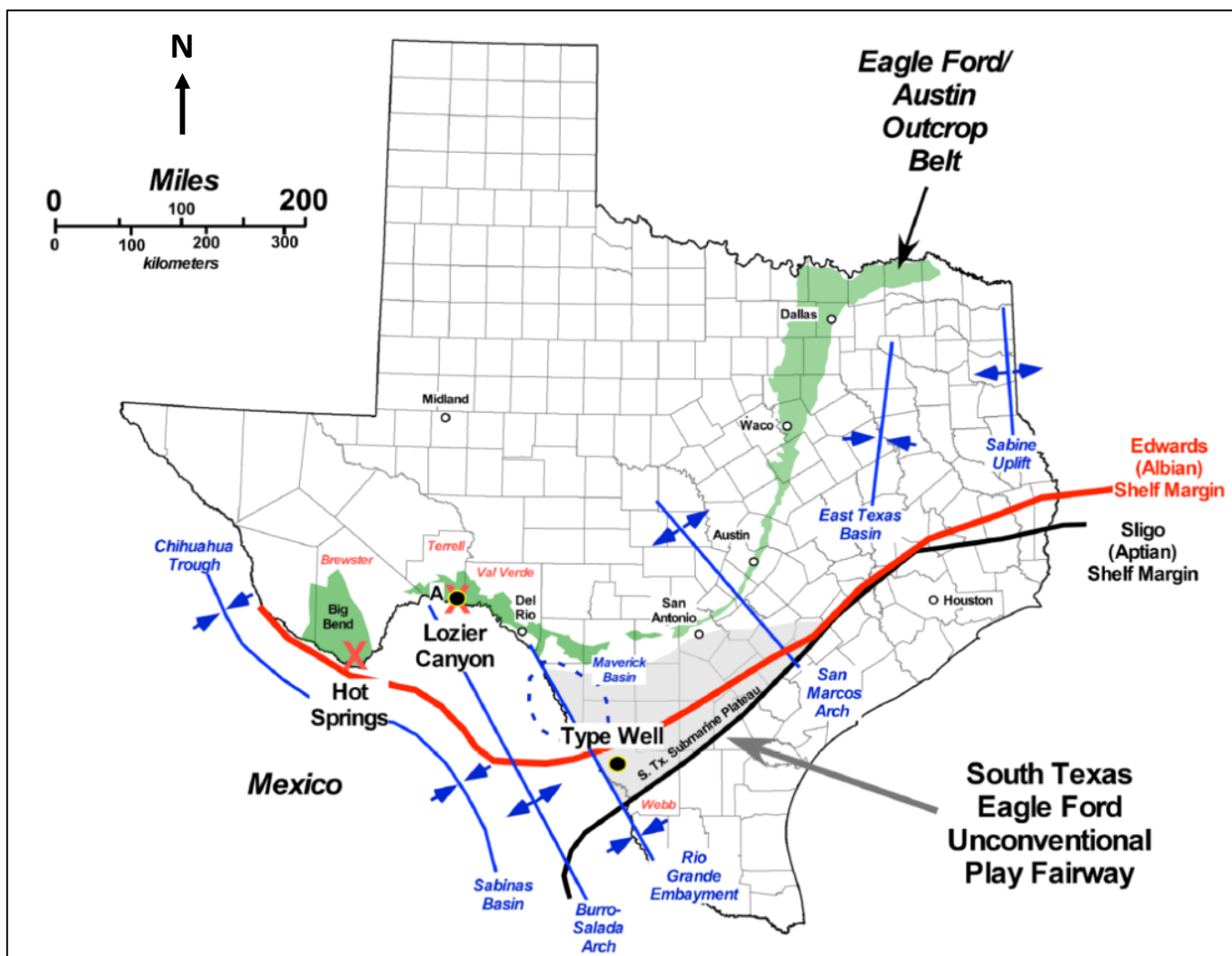


Figure 1. Map of Texas showing the location of Big Bend National Park (BBNP). The green areas represent the outcrop belt of Eagle Ford and Austin groups in Texas. The bold red X is the Hot Springs location used by Wehner et al. (2017) to correlate the Cretaceous stratigraphy in BBNP to the type well locality in Lozier Canyon. The blue lines mark the axes of prominent arches/uplifts and basins/troughs during the Late Cretaceous. The red line marks the edge of the Edwards (Albian age) shelf margin and the black line marks the older Aptian Sligo reef margin. The Terlingua mining district (mapped area in Figure 2), is located ~30 miles to the W-NW of the Hot Springs location. This map is from Wehner et al. (2017), reproduced with permission of the Gulf Coast Association of Geological Societies Journal.

INTRODUCTION

The source of Hg in most sediment-hosted Hg deposits was, until recently, the subject of considerable debate (Bryndzia, 2023). In a recent paper published by HGS member Taras Bryndzia, he showed that the formation of Hg mineralization in the Terlingua mining district of SW Texas was a consequence of the thermal maturation of organic-rich, Lower Cretaceous source rocks formed during the global Oceanic Anoxic Event-2 (OAE-2 LIP event). In this contribution, I share Hg isotope data from Terlingua that demonstrates a genetic relationship between the organic-rich source rocks of the lower Eagle Ford Fm to the global OAE-2 LIP

and the role that hydrocarbons play in forming sediment-hosted Hg deposits in Terlingua.

BACKGROUND

Cinnabar (HgS) was first discovered in the Terlingua district of SW Texas (Figure 1) around 1894 (Philips, 1906). Commercial production began in 1900 and continued until 1947, with sporadic production through 1973, when economic extraction of Hg ceased (Sharp, 1980; Avery et al., 1996). Total production from this region exceeded ~5,100 metric tonnes of total Hg⁰ (Yates &

OAE-2 and the Role of Hydrocarbons in Cinnabar continued on page 35

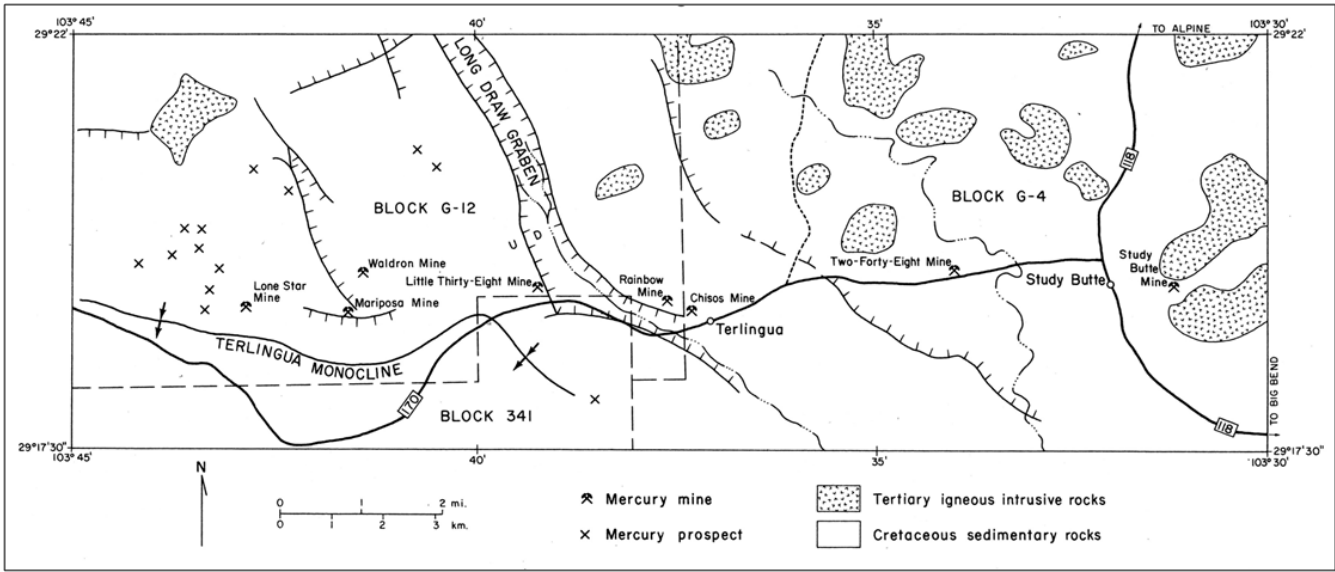


Figure 2. Location of mercury mines and structural features of the Terlingua mining district. Figure is from Sharpe (1980), reproduced with permission of the Bureau of Economic Geology.

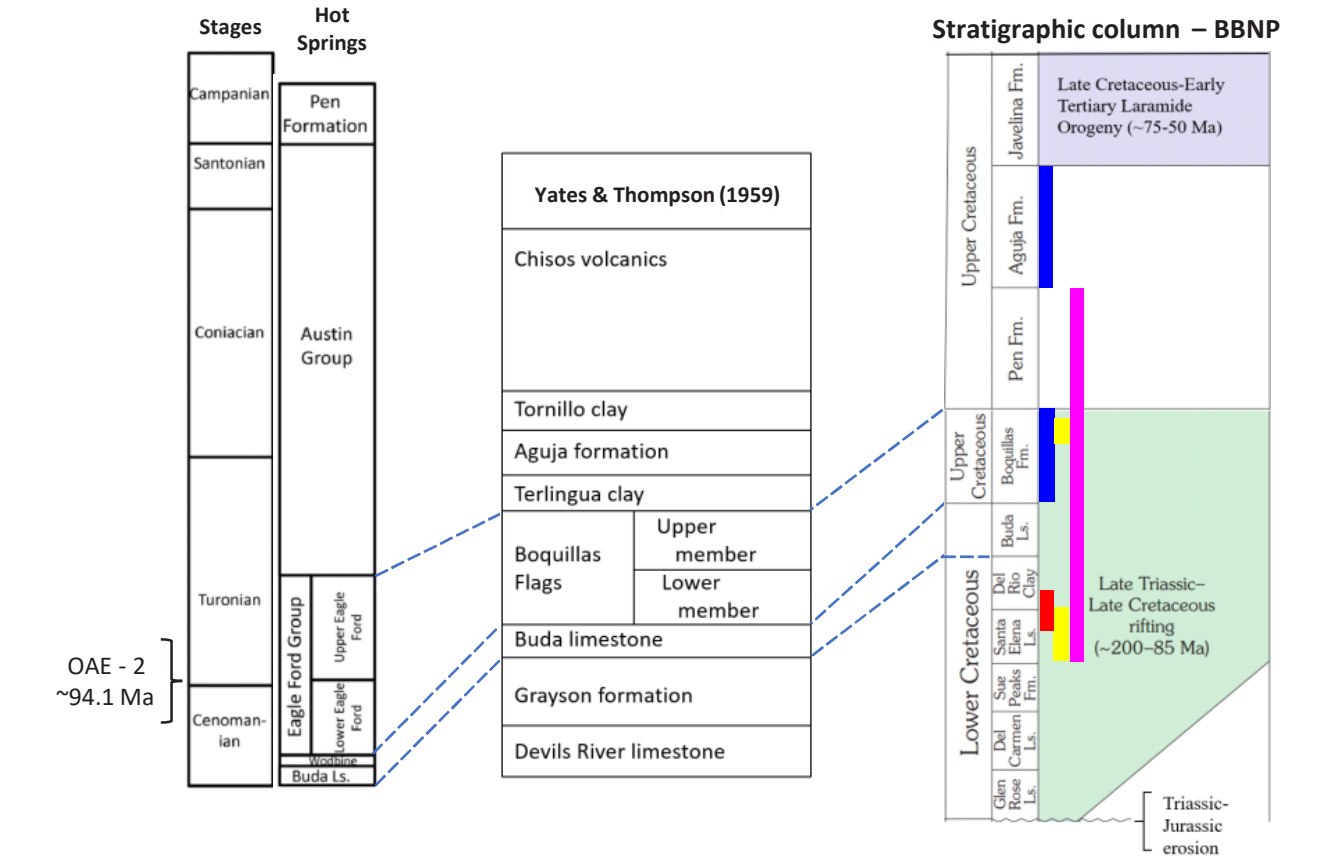


Figure 3. Recently established Cretaceous stratigraphy in the Hot Springs area in Big Bend National Park (BBNP) from Wehner et al. (2017), showing the boundary between the Cenomanian and Turonian stages (left), and the age of the OAE-2 event determined by Eldrett et al. (2015). The original stratigraphic framework for the Terlingua mining district (center), is from Yates and Thompson (1959). In the Hot Springs location, the Woodbine formation disconformably overlies the Buda limestone, as shown in the second panel from left. Right panel shows the stratigraphic column, geologic rock units, major tectonic episodes, and present-day nomenclature of stratigraphic units underlying the Buda limestone (Page et al. 2008). Stratigraphic distribution of major cinnabar ore types is shown by vertical bold colored bars. Blue: Clay matrix-hosted cinnabar in breccia pipes; Yellow: Calcite vein-hosted cinnabar; Red: Limestone-clay contact hosted cinnabar deposits; Pink: Cinnabar hosted in fractures in intrusive igneous rocks (Sharpe, 1980).

Thompson, 1959). Consequently, the Terlingua district ranks as the third largest mercury-producing region in the United States; only mercury mines in the California Coast Ranges (100,000 t of mercury) and McDermitt, Nevada (10,000 t of mercury) were larger (Rytuba, 2000; Gray et al., 2002). Metallic mercury (Hg^0) was produced by retorting primary cinnabar ore.

Relatively little has been published on the source of Hg and the geochemical conditions that produced the Terlingua Hg ores. Early work by Ross (1941) surmised that the deposits were low temperature, low pressure, and shallow. He also noted the association of bitumen and its spatial relationship to HgS ore formation but could not explain their coexistence. A common characteristic of most sediment-hosted Hg deposits, including the largest Hg deposits in the California Coast Ranges (New Idria and New Almaden), is the ubiquitous presence of hydrocarbons, both liquid oil and solid bitumens. The crucial role that the hydrocarbons have in Hg ore formation had not previously been well understood. In most of these deposits, liquid hydrocarbons (and associated formation brines) are the dominant ore-forming fluid that concentrates and transports Hg^0 from source rocks to the site of mineral deposition (Bryndzia, 2023).

GEOLOGICAL SETTING

The Terlingua mining district is located in Brewster County, Trans-Pecos Texas, proximal to Big Bend National Park (BBNP) **Figure 1**. It is ~22.4 km long and 6 km wide and broadly reflects the dimensions of the underlying igneous intrusive bodies (Fig. 2; Ross, 1941).

Recent geologic correlations by Wehner et al. (2017) established that the Cretaceous stratigraphy in the BBNP is correlative to the type locality of the Eagle Ford Formation in the Maverick basin of SW Texas. This area is notable for its prodigious production of unconventional hydrocarbons from the Eagle Ford Formation (Fig. 1; Driskill et al., 2012; Bryndzia & Braunsdorf, 2014). The type well is in Lozier Canyon (Donovan et al., 2012) and is also correlative to the PU-79 core at Pueblo Anticline, near the Global Boundary Stratotype Section and Point (GSSP) near Pueblo, Colorado. This is the location in North America of the “type section” in which the OAE-2 event, defined by a positive $\delta^{13}C$ isotope anomaly, establishes the boundary between Lower Cretaceous Cenomanian limestones, tuffs and marls and the Upper Cretaceous Turonian interval (Kennedy et al., 2005). The age of this boundary and the OAE-2 event have been dated at ~94.1 Ma using high-resolution U/Pb age-dating on zircons recovered from interlayered tuffs in the Lower Eagle Ford Fm (Eldrett et al., 2015). **Figure 3** summarizes the main stratigraphic relationships of the Cretaceous stratigraphy in the Terlingua district.

The dominant structural element in the Terlingua district is the Terlingua monocline, an east-west trending feature dominated by

the outcrop characteristics of the Buda limestone (**Figure 2**). Yates and Thompson (1959) attribute the formation of the Terlingua monocline to the intrusion of sills and laccoliths that uplifted the local stratigraphy upon intrusion, resulting in monoclinical flexures over the margins of sills and laccolith domes. The Terlingua mining district is in a province of alkalic igneous rocks that range in composition from rhyolite through analcite syenite to olivine basalt. Most of the igneous units were deposited about 31 to 37 Ma (McDowell, 1979).

Many of the major faults of the Terlingua district are steeply dipping graben bounding normal faults. As major structures, the grabens die out along the Terlingua monocline, which thus serves as a hinge line for the graben faults. Almost all the ore bodies are associated with fractures that range in trend from N. 20°E. to N. 85° E., consequently the cinnabar deposits form a zone of en-echelon northeasterly trending veins. The most productive mercury mines are in a zone of southward-dipping fractures and faults near the Terlingua monocline and Long Draw graben (**Figure 2**). The cinnabar deposits are not on the monocline itself but are up-dip from it.

Relationship between mineralization and sedimentary rocks

Yates and Thompson (1959) classified the cinnabar deposits of the Terlingua district into four classes:

1. Limestone-clay contact deposits that formed along the contact between the Devils River limestone and the Grayson Formation, (Chisos, Rainbow, Mariposa, and Fresno mines);
2. Cinnabar occurring in calcite veins in the in the Boquillas flags of the Lower Eagle Ford Formation, (Chisos mine);
3. Breccia-pipe cinnabar deposits in the Lower Eagle Ford Formation, Buda limestone, and Aguja Formation, (Chisos mine, Maggie Sink), and
4. Mineralized fractures in intrusive igneous rocks and adjacent baked clays (Study Butte mine)

Figure 2 shows the distribution of important mines in the Terlingua district, and **Figure 3** shows their relative stratigraphic distribution. Detailed descriptions of individual mines can be found in Yates and Thompson (1959) and Sharpe (1980).

Mineralogy

A consistent spatial association exists among cinnabar, pyrite, calcite, kaolinite, and hydrocarbons, indicating that these minerals share a common origin and are a direct result of the processes of cinnabar mineralization (Yates & Thompson, 1959).

Hydrocarbons in the form of bituminous matter constitute a

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minor, albeit ubiquitous phase, in all the cinnabar deposits. Yates and Thompson (1959) describe in considerable detail the formation of calcite with cinnabar, often discolored by the presence of liquid hydrocarbon inclusions contained within fluid inclusions on growth zones within the calcite. The calcite + cinnabar assemblages described in the Terlingua deposits confirm that the Hg forming the cinnabar was sourced directly from the petroleum trapped by fluid inclusions in calcite, which formed contemporaneously with cinnabar ore. Calcite growth would have required a coexisting aqueous phase necessary to sustain calcite mineral growth. The ore-forming fluid, therefore, likely had the properties of a hydrodynamically buoyant emulsion, consisting of liquid hydrocarbons and formation brine.

The results of organic geochemical analyses performed on three samples of bitumen from the Two-Forty-Eight mine, a single sample of bituminous calcite from the Study Butte mine, and one sample of carbonaceous black shale from the Boquillas flags (Lower Eagle Ford Fm), showed that their sulfur contents ranged from 1.32 to 1.61 wt.% S. These sulfur abundances are similar to those reported for organic matter in the Lower Eagle Ford by Bryndzia and Macaulay (2018), consistent with their being products of relatively low maturity, asphaltene-rich oils, typical of the low pressure sour black oils produced in the low maturity part of the Eagle Ford shale oil play (Bryndzia & Braunsdorf, 2014).

Model for the formation of cinnabar ore in the Terlingua mining district

Details of the thermodynamic model developed for the formation of cinnabar deposits in the Terlingua mining district and the conditions of ore formation may be found in Bryndzia (2023) and will not be repeated here.

Cinnabar was deposited as a result of H₂S oxidation through mixing and cooling with local meteoric water. Both Hg⁰_(org) and Hg⁰_(aq) species were likely important in cinnabar ore formation. However, recent studies on the solubility of Hg⁰ in hydrocarbons shows that at cinnabar saturation, Hg⁰ is more than an order of magnitude more soluble in hydrocarbons (Hg⁰_(org) = 163 mg/kg) than is Hg⁰ in water (Hg⁰_(aq) = 10.8 mg/kg).

DISCUSSION

Organic-rich source rocks as potential sources of Hg for cinnabar ore deposits

Some of the most persistent questions concerning the genesis of Hg deposits concerns the ultimate source of Hg, how is it transported to the site of deposition, and the reason for the ubiquitous presence of hydrocarbons?

The thesis developed by Bryndzia (2023) is that the source of Hg in most sedimentary-hosted Hg deposits are organic-rich black shales, together with associated marls, ash and tuffs, which may

be chrono-stratigraphically related to significant global volcanic events such as prolonged volcanism typical of a large igneous province (LIP) event. In the black oil producing zone of the Eagle Ford shale play in Maverick basin, Scaife et al. (2017) report values of ~200 to 750 µg/kg Hg in smectite-rich marls and organic-rich black shales from cores in this low maturity part of the Eagle Ford shale play. These rocks are significantly enriched in Hg relative to normal marine sediments (~62.4 µg/kg Hg; Grasby et al., 2019). There remains some debate as to which LIP event contributed to the volcanic ash and tuffs that dominate the organic-rich facies of the Lower Eagle Fm (Bergman et al., 2021), but they are geochemically and chrono-stratigraphically highly correlated to the global OAE-2 event that defines the boundary between Cenomanian-Turonian rocks of lower Cretaceous age (Fig. 3; Eldrett et al., 2015).

Solubility and transport of Hg

Bryndzia et al. (2022) demonstrated that hydrocarbons are a very effective means of transporting Hg⁰_(org) in the subsurface. In the case of organic-rich Lower Eagle Ford source rocks containing up to 750 µg/kg Hg (Scaife et al., 2017), the generation of hydrocarbons during maturation would almost certainly result in enrichment of Hg⁰_(org) in the generated hydrocarbon phase, and rapidly reach levels in the 100s of mg/kg range at cinnabar saturation due simply to oxidation of H₂S, as indicated by the generalized cinnabar ore-forming reaction shown by Equation 1 (Bryndzia et al., 2022).



Immature marine Type II source rocks often contain several weight percent sulfur, which, on thermal maturation of the organic matter, readily generates labile H₂S, as observed in areas of sour black oil production in the Eagle Ford shale of SW Texas.

The intrusive igneous bodies that resulted in uplift of overlying strata and formed the Terlingua monocline were the obvious source of heat that drove maturation of organic matter in the Lower Eagle Ford source rocks. A significant volume of hydrocarbon liquids must have been generated as a result of the thermal perturbations from this intrusive igneous activity, and present day there are still numerous active thermal springs in BBNP, such as at Hot Springs, for example (Figure 1).

Hg isotopes as a fingerprint for potential source of Hg in the Terlingua district

A characteristic of Hg isotopes is that odd mass number isotopes of Hg are observed to follow mass-independent fractionation (MIF), while even mass number isotopes of Hg follow mass-dependent fractionation (MDF). The MDF and MIF Hg Isotopic data reported by Stetson et al. (2009) for Hg minerals from the

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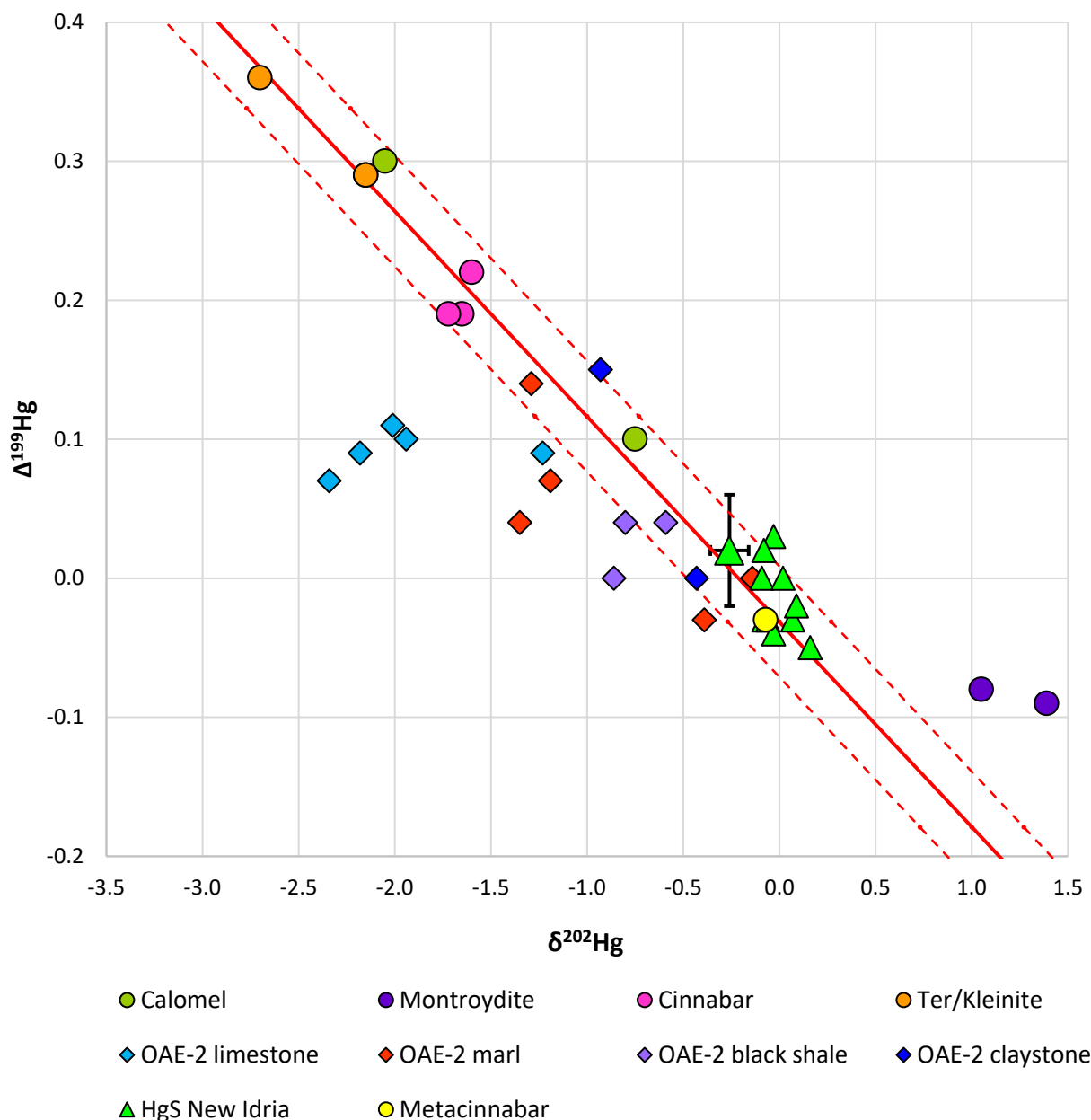


Figure 4. Plot of MDF ($\delta^{202}\text{Hg}$) versus MIF ($\Delta^{199}\text{Hg}$) data for Hg minerals in the Terlingua mining district (Stetson et al., 2009), together with Hg isotope data from OAE-2 rocks, including limestone, marl, black shale and claystone from the Rehkogelgraben location, Austria (Yao et al., 2022). Also plotted is the Hg isotopic composition of primary cinnabar ore and unroasted ore waste from the New Idria mine, California (Wiederhold et al., 2013). Solid red line is best fit to the Hg mineral data from Terlingua, excluding the two Hg^0 (montroydite) samples. Dashed red lines represent $\pm 2\sigma$ analytical uncertainty in $\delta^{202}\text{Hg}$ as reported by Stetson et al. (2009). Error bars are $\pm 2\sigma$.

Terlingua district are shown in **Figure 4**. The observed range in $\delta^{202}\text{Hg}$ for cinnabar ore was -1.60 to -1.72‰. The $\delta^{202}\text{Hg}$ of other Hg-bearing ore minerals from Terlingua (montroydite, kleinite, terlinguaite, metacinnabar, and calomel) range from -2.70 to 1.39‰, a variation of 4.09‰ and a much wider variation than observed for cinnabar. The observed MIF in these Hg minerals have $\Delta^{199}\text{Hg}$ values ranging from -0.09 to 0.36‰, which is statistically significant. It is the application of two-dimensional isotope plots such as $\Delta^{199}\text{Hg}$ versus $\delta^{202}\text{Hg}$ that enables the use of Hg isotope data as an isotopic fingerprint (Moynier et al., 2021).

Also plotted in **Figure 4** are Hg isotopic data for a suite of OAE-2 rocks from the type locality in Austria. Rocks typical of OAE-2 sediments at this location are similar to those that have been described for the organic-rich Lower Eagle Ford facies in SW Texas, and consist of limestone, marl, black shale, and claystone. There is a paucity of Hg isotopic data for any of the OAE-2 rocks in either the Maverick basin or the Terlingua mining district. However, since the OAE-2 event is a global phenomenon in which mercury enrichment is derived from an atmospherically distributed Hg pool (Yin et al., 2022), it is assumed that the OAE-2

Hg isotopic composition is also globally uniform in composition. There is no other local source of Hg in the Terlingua district except for the Lower Eagle Ford Fm. Therefore, the data are considered relevant to the discussion concerning the source of Hg in the Terlingua Hg deposits.

The solid red line in **Figure 4** is a best fit to the mineral data (excluding the Hg oxide mineral montroydite, HgO). The dashed red lines represent average $\pm 2\sigma$ analytical uncertainty in $\delta^{202}\text{Hg}$, which is ± 0.27 (Stetson et al., 2009). This analytical uncertainty is larger than the $\pm 2\sigma$ analytical uncertainty in $\Delta^{199}\text{Hg}$ which is ± 0.08 . It is assumed that similar analytical uncertainties also pertain to the OAE-2 rock data from the Rehkogelgraben location in Austria. The linear array of data in **Figure 4** provides compelling evidence for a genetic link between Hg minerals in the Terlingua mining district and organic-rich OAE-2 source rocks, not just by their provenance, but also through whatever process(es) they experienced during ore formation. The limestones do not appear to contribute Hg in any meaningful way to the suite of Hg minerals shown in **Figure 4**.

Studies of mercury ore and mine waste from the second largest producer of mercury in the United States, the New Idria mercury deposits in the California Coast Range, provide additional Hg isotope data relevant to this study (Wiederhold et al., 2013; Smith et al., 2014). These data are also plotted in **Figure 4**. Within analytical uncertainty, the New Idria cinnabar ore and untreated ore waste samples plot on the same linear array as do all of the Terlingua samples (excluding montroydite), and OAE-2 sediments from the type locality in Austria.

The conformity of New Idria cinnabar ores with the Hg isotope data from Terlingua is not a coincidence. The New Idria Hg mines are located proximal to the New Idria serpentinite protrusion (Coleman et al., 2022), on the eastern side of the San Andreas fault and proximal to several producing oil fields, including the Vallecitos and Coalinga oil fields located ~20 and ~25 km respectively, from the New Idria Hg mine. Oil in some of the Vallecitos fields is known to be sourced from the upper Cretaceous Moreno Formation (He et al., 2014), while Coalinga oils are found within Cretaceous-age reservoir rocks that are underlain by lower Cretaceous marine shales of the Panoche Formation. The Cretaceous marine shales of the Lower Panoche Formation are age-equivalent to the OAE-2 Lower Eagle Ford shales (Coleman et al., 2022; their Figure 3), and are therefore potential candidates for being the source of mercury in the New Idria Hg deposits. Most of these sediments are missing in the local stratigraphy around the New Idria district so their presence at that location cannot be confirmed.

The New Almaden Hg mining district, located ~90 miles (~140 km) to the north west of New Idria, was by far the largest Hg

producer of all the Hg mines in the California Coast Range. Bailey and Everhart (1964) report the presence of a sequence of intercalated limestone and tuffaceous and calcareous shales, described by them to “have a strong fetid odor, due to petroliferous material and hydrogen sulfide”. The interbedded tuffaceous limy shales contain Foraminifera that have been correlated to Cenomanian age rocks in Europe and Africa (Bailey and Everhart, 1964). It is tempting to speculate, therefore, that these organic-rich shales, tuffs and marls are the OAE-2 age-equivalent sediments typical of the Lower Eagle Ford Formation in the Terlingua district. This would explain why the New Idria Hg isotope data are so consistent with other OAE-2 sediments and the isotopic composition of Hg minerals from Terlingua. Unfortunately, no Hg isotope data could be found for either Hg ore minerals or sediments in the New Almaden mining district.

Role of petroleum as an agent of Hg transport

It has been speculated that a genetic link might exist between crude oils and oil field brines being agents of transport for Hg deposits in the Parkfield mercury district of the California Coast Range (Bailey et al., 1961). This was based on the observation that in many of the California Hg mines both liquid and solid hydrocarbons were commonly more abundant than cinnabar ore, and that crude oil from the Cymric field in the San Joaquin Valley contained elevated levels of Hg⁰. Bailey et al. (1961) reported values of ~2 to 21 ppm (mg/kg) Hg⁰ in crude oils, and values of 0.17 to 0.45 ppm (mg/kg) in associated oil field brines, from two different oil-producing zones in the Cymric oil field (Bailey et al., 1961; Table 398.2 and 398.3). Oils from the Cymric oil field are enriched by one to two orders of magnitude above what is commonly observed in natural hydrocarbons (Bryndzia et al., 2022). These oils and brines therefore represent a significant resource of Hg⁰ that could be transported over considerable distances by migrating flows of oil and brine and are therefore capable of transporting a significant amount of Hg⁰ from their respective source rock and reservoirs to sites of cinnabar deposition.

Model for cinnabar formation in the Terlingua district

The Terlingua monocline formed by a relatively shallow intrusion of tabular igneous rocks which resulted in thinning of sediments on the southern limb of the monocline, dipping steeply to the south for ~2 km. Labile Hg was almost certainly concentrated in the organic-rich marls and black shales of the Lower Eagle Ford Formation, and also in the smectite-rich clays in the altered ash and tuff layers. The Terlingua cinnabar ores were deposited just to the north of the hinge line defining the axis of the monocline. The most labile form of Hg was Hg⁰_(org), associated with H₂S in liquid hydrocarbons generated by thermal maturation of the organic-rich Lower Eagle Ford sediments. Magmatic intrusions provided the heat for maturation of organic matter and also hydrothermal

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Table 1. Model results for mass of Hg⁰ which could have been produced from the Lower Eagle Ford Fm, in the Terlingua mining district. Source of Hg data for wells Iona-1, Innes-1 and Chittim-2H are from Scaife et al. (2017).

Well	Hg concentration		Density 2800 kg/m ³	Volume (m ³)	Hg ⁰ (kg)
	(ppb)	(ppm)			
Iona-1 Innes-1 Terlingua Chittim-2H	10	0.01	0.000028	5.50E+09	1.54E+05
	100	0.1	0.00028	5.50E+09	1.54E+06
	1000	1	0.0028	5.50E+09	1.54E+07
	200	0.2	0.00056	5.50E+09	3.08E+06
	250	0.25	0.0007	5.50E+09	3.85E+06
					5.10E+06
	750	0.75	0.0021	5.50E+09	1.16E+07

convection of local meteoric waters around the margins of the intrusive bodies. The model presented here is that the generated hydrocarbons and H₂S-saturated formation brines, concentrated the Hg⁰ and migrated up-dip along permeable pathways towards the hinge line of the monocline where the H₂S was oxidized (Equation 1), and Hg subsequently deposited in pre-existing solution caverns and pipes.

Mass balance model

To test whether migrating hydrocarbons could produce the Terlingua cinnabar deposits, a mass balance calculation was performed to determine if the rocks in the Terlingua district were capable of generating the mass of Hg⁰ that was ultimately produced from mining operations. Details of the mass balance calculation are discussed in Bryndzia (2023), and summarized in Table 1. Model results of the mass balance calculation show that 1.54*10⁵ to 1.54*10⁷ kg Hg⁰ could have been produced from the Lower Eagle Ford Formation, for an initial Hg concentrations of 10 to 1000 µg/kg, respectively. Also included in Table 1 are the reported ranges of Hg concentration for the Lower Eagle Ford Formation from three wells in the Maverick basin from Scaife et al. (2017). The Iona-1 and Innes-1 wells are from the lowest maturity part of the Maverick basin, while the Chittim-2H well is from the black oil production area of the Eagle Ford shale play. The mass of Hg⁰ which could be produced based on these reported concentrations ranges from 3.08*10⁶ to 1.16*10⁷ kg of Hg⁰, which closely brackets the 5.10*10⁶ kg of reported Hg⁰ production from the Terlingua district shown in Table 1.

CONCLUSIONS

The Terlingua cinnabar ores were deposited as a result of H₂S oxidation through mixing and cooling with local meteoric water. Both Hg⁰_(org) and Hg⁰_(aq) species were important in cinnabar ore formation. However, recent studies on the solubility of Hg⁰ in hydrocarbons shows that Hg⁰_(org) is more than an order of magnitude more soluble in hydrocarbons (163 mg/kg) than it is Hg⁰_(aq) in water (10.8 mg/kg) at cinnabar saturation.

Hg isotope data for a suite of Hg minerals from the Terlingua mining district and cinnabar ores from the New Idria mine provide compelling evidence for a genetic link to Hg concentrated in Cretaceous sediments of OAE-2 age. The intrusive igneous rocks that formed the Terlingua monocline were principally a source of heat that drove maturation of organic matter, hydrothermal activity, and fluid migration.

Hydrocarbon liquids are viable ore-forming fluids, and thermal maturation and migration of liquid hydrocarbons are very effective means of concentrating and mobilizing Hg⁰. Mass balance calculations based on the known concentration of Hg in OAE-2 organic-rich source rocks in SW Texas show that they contain more Hg than is required to account for historic Hg⁰ production in the Terlingua district.

The ubiquitous presence and vital role of hydrocarbons associated

with most sediment-hosted cinnabar deposits globally is now understood in the context of organic-rich source rocks being the source of Hg in these deposits, and were likely the result of global LIP events. ■

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Photo courtesy of J.P. Brandenburg and taken of deformation bands in the Buckskin Mountains of the Kaibab Plateau, Utah.

Rock Matters, Who Would Have Thought

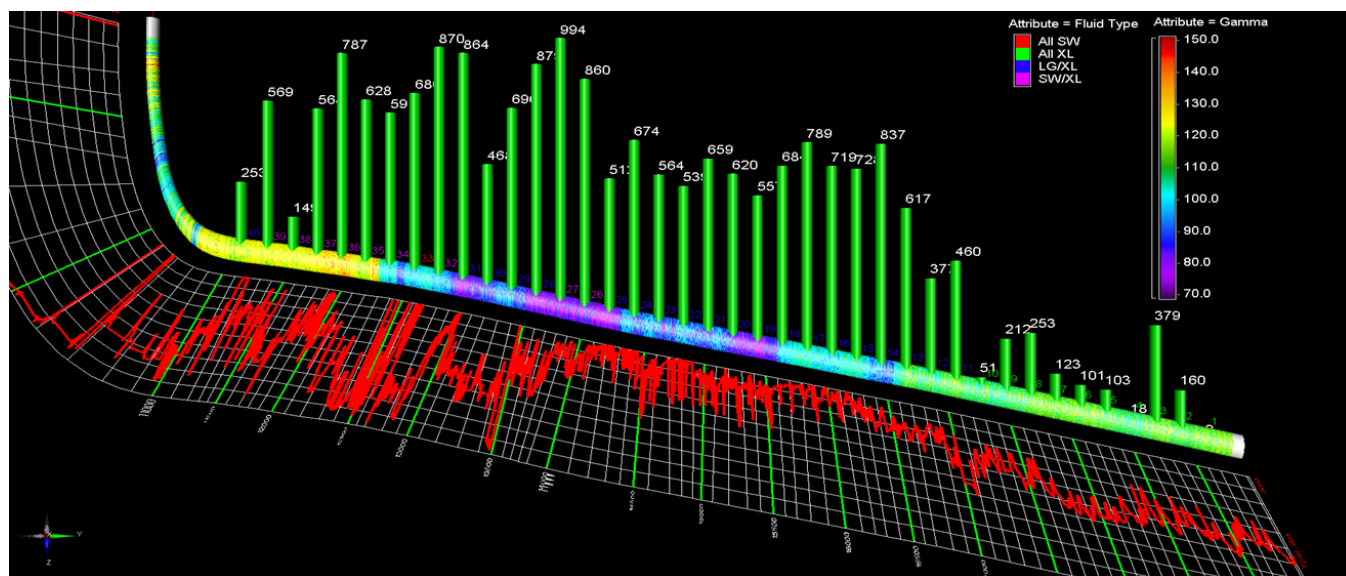
In today's competitive exploration and production market, Optimization has taken the front seat by managing cost, driving productivity, and increasing the return on investment to the shareholders. The correct wellbore location as well as understanding the reservoirs interactions with the completions can greatly affect a wells economic performance. The ability to measure and quantify the specific phases of production over time in conventional and unconventional wells both in the short and long term provides the link to geology, rock properties, completions, and the ultimate wells recovery.

This presentation utilizing real case studies will demonstrate the value of correlating production to the subsurface geology as well as showing the management of production using this information. ■

BIOGRAPHICAL SKETCH



SHOYNE JORDAN has worked in the oil & gas industry for over 18 years+ with companies such as Wood Group, GE Oil & Gas and Southern Petroleum Labs. He joined Tracerco in 2023 as Business Development Manager here in Houston. He has MBA in Business Management and mostly worked in Commercial/ Business Development roles in multiple plays around North America. Shoyne is now focused on working with operators in North America to help them to gain production efficiencies through the better understanding of the relationship between reservoir characteristics, completions and productions.



NeoGoes HAPPY HOUR
Thursday, February 20th, 2025, 6:00-9:00 PM
Location TBD
Sponsored By UH AAPG WILDCATTERS

Small-Scale, Near-Site CCS: A Catalyst for Scaling Up Carbon Capture Projects

This presentation delves into the challenges and opportunities of launching CCS projects, addressing key economic barriers, infrastructure requirements, public perception concerns, and competition from emerging technologies. Drawing on the Harvestone Blue Flint CCS project as a real-world case study, it illustrates how smaller-scale, near-site CCS projects can provide a practical and impactful entry point for meeting emissions reduction targets. The session also emphasizes the importance of innovation in overcoming technical and regulatory hurdles, the need for strategic investment to unlock scalability, and the crucial role of public engagement in building support for CCS initiatives. Ultimately, it advocates for leveraging small-scale projects as a stepping stone to accelerate the broader deployment of carbon capture technologies and realize global decarbonization goals. ■

CORE VIEWING SESSION:

The whole core of the project will be on display at the event! The Blue Flint core is the third well to ever undergo CO₂ injection

in the US. Currently, there are only four CO₂ injection projects across the US.

BIOGRAPHICAL SKETCH



ZACH LIU, PE, PG, CGA, is the Director of Subsurface CCUS at Harvestone Low Carbon Partners, where he oversees one of the few active Class VI CO₂ injection operations at the Blue Flint CCS site in North Dakota. With over 25 years of experience in oil and gas, including 15 years focused on CCUS at Kinder Morgan and Harvestone, Zach has built a strong track record of success, having drilled more than 100 CO₂ wells.

He is a licensed Petroleum Engineer, Professional Geologist in Texas, and a CFA charter holder. In 2018, he served as President of SPWLA International. Zach enjoys golf outside work and once hit a 202-yard hole-in-one with a 5-iron.



Aerial photograph of the Blue Flint Ethanol Plant with a CO₂ Capture Facility.

FEBRUARY 2025

SUNDAY

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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).

Science and Engineering Fair of Houston: Join Us in Making a Difference in 2025!

By Dorene West, Chair, Science and Engineering Fair Committee,

Are you enthusiastic about earth sciences? Do you enjoy listening to students talk about geology? If so, share your love of geology by joining the HGS Special Awards Agency team of volunteer judges at the annual Science and Engineering Fair of Houston (SEFH) on Saturday, February 15, 2025, at the Fort Bend Epicenter, 28505 Southwest Fwy., Rosenberg, TX 77471.

HGS SPECIAL AWARDS

The HGS team reviews Earth science-related projects in the Junior and Senior Divisions at the SEFH. Phase II and Special Awarding Agency Judging is from 1:15 PM—4:15 PM Saturday afternoon. We give two types of awards: rank and internships. HGS Special Awards are meant to encourage students to pursue Earth science-related careers.

RANK AWARDS

A top project is chosen for each division, and 2nd and 3rd place projects are chosen for the Senior Division. After judging ends, HGS presents these winners with a certificate, and congratulation letters are sent to parents and teachers. Winners are recognized at Guest Night (if held in June).

INTERNSHIPS

Through our membership in The Engineering, Science, and Technology Council of Houston (ECH), HGS funds three summer interns at the Houston Museum of Natural Sciences (HMNS). These Finalist HMNS Summer Intern Awards are nominated by HGS but awarded to three Senior Division finalists by ECH. Students must meet work requirements (so they are not necessarily the top-ranked project winners). The awardees are invited to an ECH awards banquet (or Zoom meeting), where the students showcase their projects.

CHALLENGES IN JUDGING

An effort has been made to remove “community bias” from our judgment. Students are judged on their individual efforts; those with fewer resources cannot compete with student projects from areas with more resources/community support. We are charged with encouraging students to participate in STEM and not penalizing students from schools/communities with fewer resources.

SEFH PLACE JUDGING

There are also opportunities for HGS members to volunteer in the Saturday morning SEFH Place Judging session. Some Place Award Judges are assigned to review projects that have advanced to Phase II on Saturday afternoon (if you volunteer to be a Place Award Judge, you may not be able to serve as a Special Award Judge for HGS). Judging ends at 4:00 PM; the public can view projects from 4:30 PM to 6:30 PM.

To volunteer as a Place Award Judge (in any category), register on the SEFH 2025 website at <https://sefhouston.org/for-judges/#Signup>.

HGS members can volunteer to be an HGS Special Awards judge on Saturday afternoon; please email Dorene West (dbwesthou@earthlink.net); please put ‘SEFH Special Awards judging’ in the subject line).

Additional info: <https://sefhouston.org/general-information/> or <https://sefhouston.org/for-volunteers/>. ■

DHI Class Draws Record Attendance

A record-setting snowstorm was no match for the record turnout for the one-day Continuing Education Class held on January 23, "Prospect Evaluation Methods Using DHIs", taught by world-famous DHI experts Henry Pettingill and Rocky Roden. The sold-out event, held at the Core Lab facility in Northwest Houston, attracted over 60 geoscientists. Ticketmaster reports scalpers were hawking tickets for over \$1,000 – just kidding!

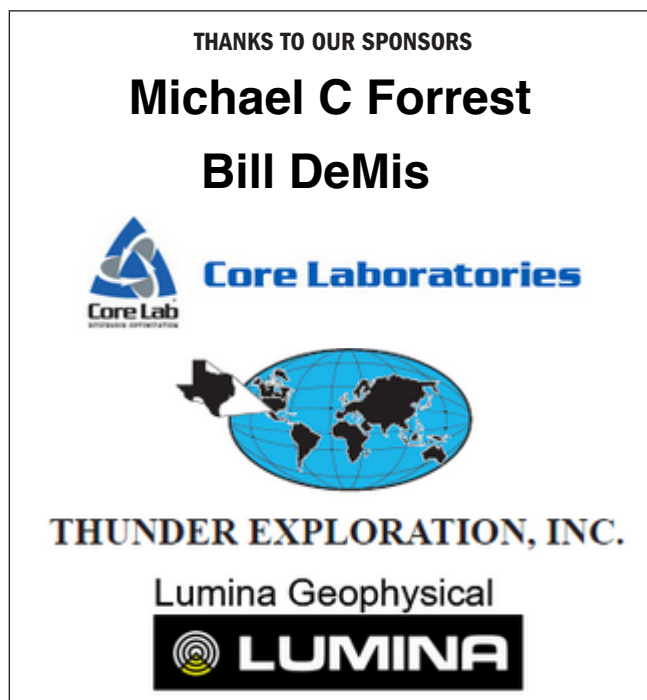
The instructors are Principals of the Rose and Associates DHI consortium which has the largest inventory of DHI case studies on the planet. The instructors drew from their years of experience and hundreds of real-life Case Studies of DHIs to show students through their methodology of pre-drilling evaluation of seismic-supported prospects using DHIs attributes to reduce risk and to better constrain the probability distribution of reserves.

The class included a review of various types of DHIs such as AVO, flat spots, and bright spots. The instructors showed how to rank DHIs attributes for their quality and showed that by properly ranking them, companies can increase, or decrease, Pg for a prospect significantly.

The DHI class attracted geoscientists from HGS, the Geophysical Society of Houston, and geoscientists from our-of-town. Out-of-town participants came from Oklahoma City, Alabama, and Denver. The class had great appeal to many companies. Four Companies sent 3 to 4 geoscientists, and one Major company sent 8 geoscientists to the event.

Core Lab provided a beautiful meeting room for the event. Generous financial support from individuals and companies kept the price of this continuing education class low as well as allow 9 students to attend the class for free.

All of us at the Houston Geological Society give an enormous "Thank You" to Core Lab, our financial sponsors, and to Henry and Rocky for making this class "the Woodstock of training courses." ■



HGS president Penny Patterson (from right to left) with instructors Rocky Roden and Henry Pettingill, and 4 out-of-town participants.

Houston Museum of Natural Science Volunteer Activities Associated with the Houston Geological Society Committee

By Janet Combes, Ken Williams

The HGS museum committee has members who are volunteers active in multiple halls at the Houston Museum of Natural Science. The Wiess Energy Hall is a comprehensive and exciting overview of the petroleum industry from exploration including geology and geophysics, through onshore and offshore engineering (from drilling and completion through development and production). Refining, pipelining and transportation are highlighted. There are videos and interactive displays that are extremely informative as are the Energy City and the two “rides” that take you down into a wellbore to show hydraulic fracturing and discuss hydrocarbon trapping, oil generation and migration. Both the Gem and Mineral Hall and the Morian Hall of Paleontology are fascinating and can reward the geologist who gets a chance to examine the displays.

Training for those of us who are lucky enough to have time volunteer is varied – from museum wide processes to further information on specific displays within specific halls. Recently there have been training sessions related to various displays in Wiess: power grid and renewables, oil and gas well construction, and the basics of oil and gas data. A special part of the trainings are presentations by invited speakers on areas of interest related to the energy transition. These sessions are often hybrid – including

in-person attendees and virtual via ZOOM presenters and/or attendees. One of the topics over the past year included climate change through time, and a panel discussion on various aspects of climate change. Other topics with invited speakers included: Deep Water Facilities, Geothermal Energy, Fracking Hall Tour & Panel Discussion, Understanding the Louann Salt, The Energy Transition and Salt Tectonics, Energy Transition at Port Houston, The Future of Energy in Texas, and CO2 Recovery Efficiency.

The museum provides volunteers as tour guides for groups of school kids, adults from companies or organizations, friend or family groups, and for special events like family nights and sensory friendly days. Volunteers also frequently staff “touch carts” in various halls in the museum, or pick a favorite area and discuss the exhibits with visitors passing through.

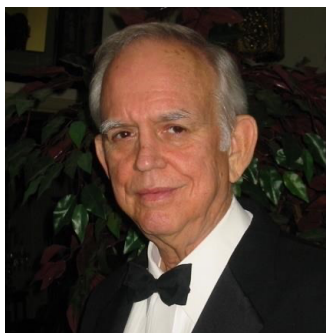
Volunteers are responsible for “touch cart” contents – keeping the stock in good condition and replacing when needed and adding items as new technologies and discoveries expand the scope of the science. Volunteers are also the source of ideas for special topics to be presented in special training sessions and they also provide suggestions for the speakers. ■



Remembrance

CAMERON HERSCHEL GATES

12/03/1937 – 12/15/2024



CAMERON HERSCHEL GATES passed peacefully on December 15, 2024. He was born in Houston, Texas, to Edith and Herschel Gates on December 3, 1937. He grew up in Baytown, Texas, where he attended Robert E. Lee High School and was a star football player for the Ganders. Cameron excelled as a running back and linebacker and was recognized as a high school all-American football player. He was recruited by the University of Texas, among other universities, and he received a scholarship to play football at the University. While at the University of Texas, he earned both a bachelor's and master's degree in geological sciences and courted his future wife, Elaine Bruce. He married Elaine and they had three children: Bruce, Brock, and Lynne. Before his marriage to Elaine, he had a daughter, Sheila, who gave Bruce the joy of having an older sister.

Prior to starting his business career, he served as a second lieutenant in the US Army. Cameron went on to have a successful career as a petroleum geologist and businessman. He started his career with Exxon. Later, he joined up with his college roommate, Jim Bob Moffet and helped build McMoran into a preeminent offshore exploration and production company. He was a member of HGS from 2008-2014.

Cameron remarried, and their union brought them his youngest child, Cameron H. Gates Jr. Cameron spent the last 13 years in the loving arms of Linda Solook, whom he loved dearly and who made his later years a blessing. Cameron is preceded in death by his mother and father, his brother, Buddy Gates, and his son, Brock Gates. He is survived by his children, Sheila Alloway, Bruce Gates, Lynne DiFrancesco, and Cameron Gates Jr., eight grandchildren, his sister, Yslita Brewer, and many nephews and nieces, as well as his loving partner, Linda Solook. Cameron lived a full life always keeping his children close to him, teaching us most of what we know. He worked hard, played hard, and got the most out of life, and in the end, he simply ran out of juice. Rest in peace, Dad. WE LOVE YOU.

Remembrance

DAVID M. ORCHARD

1952-2025



PAST HGS BULLETIN EDITOR, GEOLOGIST, POET, WRITER, AND BUSINESS ENTREPRENEUR — Remembered by Linda Sternbach

We want to take this time to remember one of HGS's most dedicated volunteers, Dave Orchard (1952-2025), who made a lasting mark on HGS history by becoming Editor from 1996-1997 and then continuing to publish the print magazine as the owner of Manzanita Alliances from the mid-1995 to mid-2000s. Dave served HGS as a long-term committee member on publications, including the *Bulletin*, and was Guest Night chair in 2018. He is fondly remembered for his sense of humor, wit, and creative writing, including poetry.

On a personal note, Dave and his wife, Marie Orchard, have lived in Houston for 45 years, raised three children, enjoyed ten grandchildren, and sponsored two young men from Liberia who became beloved family members, college graduates, and US citizens.

Dave grew up in California and earned a BA in Anthropology at Stanford University in 1974. During college summers, he fought fires for the California Division of Forestry. His interest turned to petroleum geology, and he attended the University of Texas at Austin, graduating with an MA in geology in 1979.

When Dave got involved with HGS, he was a geologist and exploration manager at BHP in Houston. When the oil industry suffered a downturn in 1995, Dave pivoted away from geoscience and started his own publishing and translation business called Manzanita Alliances. He kept his hand in the petroleum news by acting as HGS *Bulletin* volunteer editor, supervising layout, and taking charge of the print and mailing issues. Linda Sternbach followed Dave as editor and worked closely with him and his staff at Manzanita from 1995 to 1998. Dave had a vision for the HGS *Bulletin* that included improving the cover design, adding better graphics, and using color printing. Before Dave, the HGS *Bulletin* was all black and white and looked like it was typed out by hand. After Dave's improvement, the HGS *Bulletin* became what it looks like today.

Dave was beloved by many because of his keen interest in any type of geology, his sharp mind, his analytic ability, and his sense of humor. When things went wrong, Dave would always see the humorous side of magazine publishing problems and management snafus. Then, he would crack a joke and let everybody know the situation's absurdity. In one of his Editor columns Dave mused on "Nine Easy Steps to Longer Sentences." One suggestion: Use weasel words as often as possible. For more effective weaseling, replace "will" and "would" with "can" and "could".

Dave's love of geology drew him back into the petroleum business in 2006. He left Manzanita Alliances and became a staff geologist at Conoco Phillips in Houston. Dave trained himself to be an expert in carbonate petrophysics. He was in charge of well operations and development in the Permian basin. In 2016, Dave joined Layline Energy. His interest was in developing shallow oil production from Pennsylvanian (Cisco, Canyon) clastic and carbonate reservoirs in two thousand active and shut-in wells on the Red River Arch, north Texas.

In 2017, Dave fulfilled a dream to purchase country property (with a pond!) near New Ulm, Texas, as a family retreat. At the same time, he renewed his interest in firefighting and joined the New Ulm Volunteer Fire Department.

Dave was diagnosed with Alzheimer's in 2022 and passed away on January 7, 2025. A funeral service is planned for February 21st at St. Bartholomew Catholic Church in Katy, Texas, at 10:30 am. Friends can contact Marie Orchard at marie.orchard@gmail.com.

Obituary at <https://www.schmidtfuneralhome.net/obituaries/David-Merle-Orchard?obId=34358241>

David M. Orchard continued on page 51

Clever and Capable Men

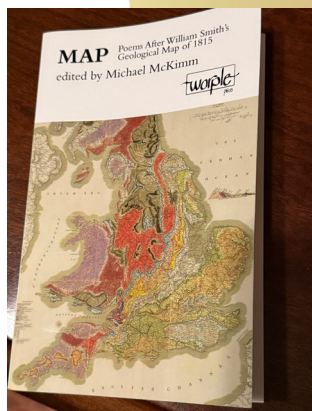
*It is the first geologic map – tattered and torn papyri
pieces lost, drawn by a Scribe-of-the-Tomb, servant of Rameses,
collected by a Napoleonic diplomat, preserved in Turin,*

*depicting in approximate scale with lain-flat hills the
Valley of Many Baths, the road, the mine, the behken-stone
quarry, and settlements and temples of importance*

*with alluvium, graywacke, granite, serpentinite, volcanics
and gold veins patterned and colored by occurrence, all
with hieratic annotations in the script of the inventor.*

*Clever and capable man that Amennakhte, son of Ipyu.
Clever and capable man that Willian Smith, ignoble-born.
who re-invented geologic maps, whose magnificent re-invention.
blossomed with invented biostratigraphic correlations.*

David M. Orchard



Poem in the book after William Smith's Geologic Map of 1815

Remembrance

DR. PETER R. VAIL

1930-2024

IN MEMORY *by Jack Neal*

Who in the Houston Geological Society hasn't heard of **PETER VAIL**, the Father of Sequence Stratigraphy? The man who pioneered the integration of sedimentary geology and reflection seismology left a lasting mark, truly to be counted among the greats in geological science history. We are deeply saddened by his passing on December 28, 2024, at 94, but we are so lucky to be living in a world graced by his presence. When you ask almost anyone who knew him, the universal sentiment would be "He has made amazing contributions, but he was an even better person". What could be a better remembrance?

A man of Peter's stature has had his biography told on many occasions as he garnered prestigious recognition for his achievements. The Benjamin Franklin Institute Award, The Geologic Society of America's Penrose Medal, and an amusing citation to Peter on his reception of SEPM's Twenhofel Award from his thesis advisor at Northwestern, Larry Sloss, are just a few examples. Peter Vail's journey to scientific greatness is well-documented, but his greatness as a person can never be shared too much.

Peter Vail was my thesis advisor at Rice University in the early 90's. When I visited Rice to tour the Geology Department, Pete, as he was known to his many friends, greeted me at the airport as if I were family already. The Department was vibrant in Stratigraphy, with students from around the world coming to work with Bert Bally, John Anderson, André Droxler, and, of course, Vail. These professors attracted and acquired incredible datasets for stratigraphic study. Pete could not have been happier as students brought him new seismic lines in diverse settings that he somehow knew immediately what they were showing him. "Here is the Mid-Oligocene unconformity," "Look at that Valanginian lowland," or "This stacking pattern in Norway is the same thing we see in the Gulf Coast." He would share his interpretation genius and mentor those students so they could run with his guidance. His office at Rice was a chaos of scattered seismic lines and colored pencils, but he never turned away a student seeking help, and those interactions often had an impact for a lifetime.

While he had unparalleled stratigraphy knowledge and confidence in his models, he could be convinced to change his thinking in the face of new or contrary data. After vigorous debate when a change seemed to win, Pete would pause and say, "It's even better!" and embrace a new model incorporating the change. He would then proceed to take the new models and apply them to other problems around the world – always giving credit to the person whose work convinced him to change. "It's even better" is a lesson for open-mindedness and inclusivity that Pete taught naturally, something that was even more valuable than sequence stratigraphy to me in my career.

Those times at Rice were incredibly special because we did not know what was to come. In 1993, while teaching in Europe, Pete hit his head when a chair collapsed and suffered a brain injury that would change his life forever. Although he lost mobility that would limit his teaching and time in the field, he worked hard to come back from the effects of his injury, always remaining upbeat, kind, curious, and generous with his time and insights. Above all, he was devoted to his family and would light up whenever talking to them or sharing news about them. He was passionate about birdwatching, Houston professional sports, and occasional pinot noir. His former students and colleagues would regularly gather with him for "Friends of Pete" meals, celebrations or outings, and we always felt like the lucky ones who got to share him with his family.

Pete fundamentally changed stratigraphy and subsurface data interpretation for the better. That contribution and the countless lives he influenced is a legacy that will last forever. I, and so many others whose lives were touched by this remarkable man, will never forget his spirit, humor, kindness, generosity and genius. We are so grateful for every moment we got to spend with him and will cherish those memories. May he rest in peace and may the love so many had for him bring comfort to his family and friends in their loss. ■

Dr. Peter R. Vail *continued on page 53*

AWARDS GIVEN:

- Hollis D. Hedberg Award, Energy Institute for the Study Earth and Man, Southern Methodist University (2005)
- Benjamin Franklin Medal for Earth Science (2005)
- Legendary Geoscientist Award, American Geological Institute (2004)
- Penrose Medal, The Geological Society of America, Inc. (2003)
- Sidney Powers Memorial Medal, American Association of Petroleum Geologists (2003)
- Distinguished Educator Award, American Association of Petroleum Geologists (1999)
- T. Neville George Medal, Geological Society of Glasgow (1995)
- Northwestern Alumni Merit Award (1994)
- Honorary Medal, University of Burgundy, France (1993)
- Geological Society of France Award, European Union of Geosciences Meeting, Strasbourg, France (1993)
- Twinhofel Award, Society for Sedimentary Geology (1992)
- Honorary Degree, Ghent University, Belgium (1989)
- William Smith Medal, Geological Society of London (1986)
- Distinguished Achievement Award for Individuals, Offshore Technology Conference (1983)
- Best Paper Award, Houston Geological Society (1983)
- Matson Award, Author of Best Paper, American Association of Petroleum Geologists Convention (1981)
- President's Award, Best Published Paper, American Association of Petroleum Geologists (1977)
- Virgil Kauffman Gold Medal, Advancement of the Science of Geophysical Exploration Society of Exploration Geophysicists, Annual Meeting (1976)

- A) Peter in an Alabama quarry containing the mid-Oligocene sequence
- B) Three center pictures showing Peter leading small groups in seismic sequence interpretation
- C) Guadalupe Mountains trip in 1987

A



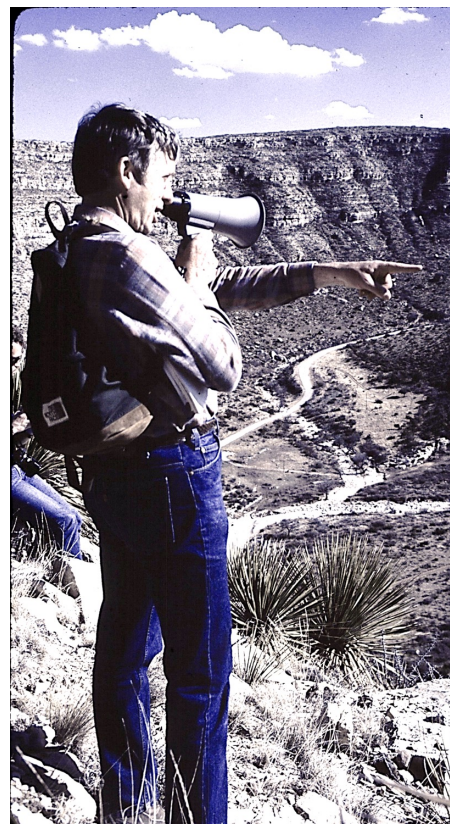
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B-3





HGS Membership Application

Houston Geological Society
14811 St Mary's Lane Suite 250 Houston
TX 77079

Phone: (713) 463-9476

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** _____

Student **\$0.00** _____

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

Total remittance _____

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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 _____

City (Work) _____ **State** (Work) _____ **Postal Code** (Work) _____

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.

AAPG Member Number _____ OR

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Signature: _____ **Date:** _____

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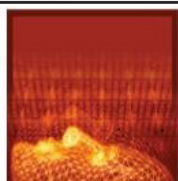
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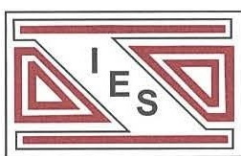
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Photo Courtesy of J.P. Brandenburg taken from Kaibab Springs, near the Grand Canyon National Park. Note the confinement of the deformation band to the thicker sandstone beds