

BULLETIN

Corpus Christi Geological Society



and

Coastal Bend Geophysical Society



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2020-2021

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2020-2021

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**Visit the geological
web site at
www.ccgeo.org**

CCGS/CBGS JOINT MEETING SCHEDULE 2020-2021

September 2019							October 2019							November 2019						
S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S
		1	2	3	4	5					1	2	3	1	2	3	4	5	6	7
6	7	8	9	10	11	12	4	5	6	7	8	9	10	8	9	10	11	12	13	14
13	14	15	16	17	18	19	11	12	13	14	15	16	17	15	16	17	18	19	20	21
20	21	22	23	24	25	26	18	19	20	21	22	23	24	22	23	24	25	26	27	28
27	28	29	30				25	26	27	28	29	30	31	29	30					

Virtual Meeting Sept 16, 2020
At 11:00 am
Honoring Ray Govett

Oct 21 Virtual Meeting at
11:00 am
Presenter Dr. Osareni
Ogiesoba from the BEG

December 2019							January 2020							February 2020							
S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	
		1	2	3	4	5						1	2			1	2	3	4	5	6
6	7	8	9	10	11	12	3	4	5	6	7	8	9	7	8	9	10	11	12	13	
13	14	15	16	17	18	19	10	11	12	13	14	15	16	14	15	16	17	18	19	20	
20	21	22	23	24	25	26	17	18	19	20	21	22	23	21	22	23	24	25	26	27	
27	28	29	30	31			24	25	26	27	28	29	30	28							
							31														



CCGS/CBGS Joint Meeting Schedule 2020-2021

March 2020							April 2020							May 2020						
S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S
	1	2	3	4	5	6					1	2	3							1
7	8	9	10	11	12	13	4	5	6	7	8	9	10	2	3	4	5	6	7	8
14	15	16	17	18	19	20	11	12	13	14	15	16	17	9	10	11	12	13	14	15
21	22	23	24	25	26	27	18	19	20	21	22	23	24	16	17	18	19	20	21	22
28	29	30	31				25	26	27	28	29	30		23	24	25	26	27	28	29
														30	31					

Calendar of Meetings and Events

Calendar of Area Monthly Meetings

Corpus Christi Geological/Geophysical Society.....	Third Wed.—11:30a.m.
SIPES Corpus Christi Luncheons.....	Last Tues.—11:30a.m.
South Texas Geological Society Luncheons.....	Second Wed—noon San Antonio
San Antonio Geophysical Society Meetings.....	Fourth Tuesday
Austin Geological Society.....	First Monday
Houston Geological Society Luncheons.....	Last Wednesday
Central Texas Section of Society of Mining, Metallurgy & Exp.....	2 nd Tues every other month in San Antonio

Corpus Christi Geological Society Dues Renewal

Dear CCGS Members,

Success with our CENSUS helped us design a template for collecting dues via email this year. Please take a few minutes to work through this renewal process. Then you can pay dues via check or via the SquareUp site using your credit card.

If you have questions, please contact us at membership@ccgeo.org or send me a personal email, randyb@headingtonenergy.com

THANK YOU SO MUCH!

We so look forward to seeing you at our first Society meeting on September 16th, 2020, at 11 am via ZOOM.

Sincerely,

Randy Bissell
Membership Chairman

CCGS c/o Headington Energy Partners, Suite 902 N, 500 North Shoreline Blvd., Corpus Christi, TX 78401



From the President's Desk

A New Season Begins, the Pandemic Continues

By Rick Paige

Living in a 'State of Change'

Unexpected changes, big and small. That sums up 2020 well, and we're only 2/3 through! Big changes include economic lockdown, self-isolation, job loss, entire industries shut down. Smaller changes include social distancing, mask wearing, curbside pickup, grocery shortages, coin shortages, parades of Amazon deliveries. Nothing feels normal in the 2020 Covid "new normal".

Another of these unexpected changes is a shift in the Presidency of your CCGS. Austin Nye had to forgo his attempt at an unprecedented 3rd Presidential term due to complications from the pandemic. No, not the disease itself (thank goodness), but the ramifications of the changes brought by the disease.

Running his company from home, while home-schooling two little ones, left no time to properly steward your CCGS. So, he asked me to take over. I accept. So, allow me to welcome you to the inaugural Bulletin issue of the 2020-2021 season.

Most of you know me, but for a refresher, I was President in 2010-11, and have served as Counselor since. I've been a member for 30 years and have held every board position except Secretary and Treasurer. This President's job really is pretty easy because of the dedicated board members that

surround me. They, and the stalwart committee chairs, really do all the work. I just have to make sure they have access to the resources they need, when they need them. Oh, and maybe discuss future directions and programs we sponsor. If any of this sounds appealing, it's not too late to give me a call. We're flexible and always looking for new voices.

Taking over my Counselor duties is Past-Past President (Benevolent Overlord as he preferred) Frank Cornish. Thank you, Oh Great One, for making our board changes complete .

At this time, I want to give a special shout-out to VP and Membership Chair Randy Bissell for constructing and sending out the online Society census you received recently. The information gathered from that has been critical to our planning a path forward during this "year of change". Many thanks to all who replied.

Covid-19 pandemic, the saga continues....

Ready or not, willing or not, the changes brought about by this insidious disease still prevail in our community and our nation. Cancellations are the norm, in-person meetings are replaced virtually, no social events, living AND working from home, social distancing, mask-wearing, when will it all end? Sadly, though the pandemic will surely end, no one can predict when.

Faced with this reality, your board has discussed how we can provide the services you've grown to expect while under such limitations. **I'm happy to report we have a solution!** It will, however, require our membership embrace some of the changes mentioned above, particularly attending technical (or social) meetings virtually, for at least the near-term. As I write this the board is busy lining up educational, informative material that include lunchtime technical presentations and longer webinar-based workshops.

The Zoom platform will be our media vehicle of choice. For many, that will not be an issue. **For those unfamiliar, or unsure, of Zoom, fear not!** Randy Bissell, our Membership Chair, and VP, is offering a tutorial for all members who wish to get more comfortable with Zoom. He did it for me a couple weeks

ago, and trust me, it is easy! Your first chance to learn from Randy will be September 16, when we are hosting, via Zoom, a CCGS meeting to honor long-time member Ray Govett with the Distinguished Service Award. Randy will open up the Zoom window ½ hour before the meeting commences to allow anyone logging in for the first time, or just wanting some familiarization, the chance to go over the process. Stay tuned, an email announcement will be sent out with more detail. By the way, it was responses from the census that convinced us we can, and should, go forward with virtual offerings.

On a personal note, I must confess I entered this season feeling there was little the Society could offer in the face of the growing pandemic. We've been forced to cancel every planned event since March, including technical, social, and charitable gatherings. That set up a very gloomy forecast in my mind. But after our most recent board meeting, wherein we discussed what we could offer and how we could do it, AND seeing firsthand how easy it is to function within the "ZoomVerse", I am actually optimistic this could wind up being a very fruitful season.

Think about it, we aren't limited to only those speakers who can travel here. The door is now open to a much larger pool of excellent lecturers, covering a broader arena of expertise. Also, since we can't gather in person, we don't have to contract with a restaurant (saving money) for any specific day each month. This means we can offer technical meetings anytime that best fits our and the speaker's schedule (although we will continue to aim for the 3rd Wednesday of the month, noon hour, for meetings. Tradition, if nothing else). And, the virtual meetings are free! **But you must be a member to join the Zoom meeting,** so please, renew your membership promptly.

Our Secretary, Emily Olson recently attended the virtual URTeC convention. She reports that listening to a talk was actually enhanced in the virtual setting, because there were no difficulties with vantage point, following the laser pointer, or poor audio.

Lastly, since we aren't locked into a contracted restaurant date, we could have multiple virtual technical talks, or workshops, per month, at minimal to no cost to members! This option may be a little overly ambitious at this time. We'll see how the first few virtual meetings go, **but I hope you're getting the idea that cancellations are over, and we can now look forward to a productive, meaningful season.**

Just in a different format - the 2020 "new normal" format.

For those who long for some face to face activities (myself included), we are considering outdoor events, requiring masks and social distancing. The census Randy sent out indicated a sufficient number of members would appreciate such a gathering. Possibly an outdoor "what's new", or alternatively "cry in our beer" happy hour somewhere with an outdoor venue, such as Nueces Brewpub, Dos Comales, or our old standby, the Surf Club. But rest assured, we will NOT host any gathering unless we are confident that protocols are more than sufficient, and the threat of exposure is nil. So, be patient, we may have to wait a few more months for that happy day, but it will come! And you can be certain, once a vaccine has been widely distributed, we WILL return to catered technical luncheons, pub crawls, fish, and golf tournaments, and all the other activities we love about our Society. Just don't be surprised if some of these new virtual events remain as regular features.

This year membership renewals were sent via email to save money (it is surprisingly expensive to mail out printed renewals to 220 people). You should have received one in August. If not, please check your spam filter, then contact Randy Bissell at randyb@headingtonenergy.com, (361) 885-0110. For added convenience payment can be made online with credit card, or mail-in check.

Summing up,

2020: Making Lemonade from the Pandemic Lemon. We Can Do This!

Rick Paige

CCGS President, 2020-2021

**Join us for upcoming
Society Meetings via -**

ZOOM

CCGS Virtual Meetings

***WATCH your email, you will receive notifications & invitations a
week in advance for these planned events.***

September 16, 2020 at 11:00 am

**Honoring Ray Govett, 2020 GCAGS Distinguished Service Award
Recipient. This short meeting will allow you to test the Zoom
meeting format.**

October 21, 2020 at 11:00 am

Presenter, Dr. Osareni Ogiesoba from the BEG –

**DIAPYRIC SHALE, COAST-ORTHOGONAL AND COAST-
PARALLEL FAULTS, OBSERVED IN THE VICINITY OF THE
SAN MARCOS ARCH, REFUGIO AND CALHOUN COUNTIES,
SOUTH TEXAS GULF COAST**

Announcements, then presentation. Followed by Q&A.

Future meetings are being planned.

Did YOU get an email from the CCGS regarding your Membership Renewal?



If YES, did you renew your dues via the instructions in the email? If YES, did you pay your dues via the SquareUp link? Or – Did you send us a check?




PLEASE PLEASE PLEASE RENEW VIA THAT EMAIL LINK!!!

If NO, please check your SPAM mail, look back through your inbox. If still NO, please send Randy an email, randyb@headingtonenergy.com.

We will not be sending and handling paper renewals this year. So PLEASE help us get our dues collected.

THANK YOU SO MUCH!

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CBGS President's Letter

CBGS Board 2019-2020

President- Dr. Subbarao Yelisetti

Vice President- Samara Omar

Secretary/ Treasurer-

Scholarship Chair- Matt Hammer

Golf Chair- Mark Wiley

Education – Dr. Robert Schneider

TAMUK student representative- Monica Estrada

TAMUCC student representative- Ryan Turner

CBGS Scholarships

The Coastal Bend Geophysical Society (CBGS) has donated \$10,000 to the Department of Physics and Geosciences, Texas A&M University-Kingsville in support of the multidisciplinary Petrophysics Graduate Program that has been requested. These funds will be used as scholarships in attracting quality graduate students.

The board awarded three scholarships of \$2,000 each to undergraduate geophysics majors from Texas A&M University-College Station, University of Houston and Texas A&M University-Kingsville. We will be awarding the scholarships again this year.

Scholarship Requirements

Criteria for awarding the Scholarship from Coastal Bend Geophysical Society of Corpus Christi, Texas:

1. Scholarships are open to undergraduate or graduate students.
2. Must have declared major in Geophysics, or Geology with a concentration in Geophysics or Petrophysics.
3. Preference is given to students attending Coastal Bend schools (TAMU-K, TAMU-CC and Del Mar College), then to Coastal Bend natives attending other universities.
4. Must have a GPA of at least 3.0 and be in good standing with the school.
5. Must make effort to attend a Coastal Bend Geophysical Society Meeting in Corpus Christi Texas after being awarded a scholarship to be recognized by the society.

News

- According to data from Baker Hughes, the U.S. oil and gas rig count dropped to an all-time low of 244 at the time of writing this report. This is 74% less compared to last year's rig count at this time, as reported by Scott DiSavino on reuters.com.
- According to the U.S. Energy Information Administration, U.S. crude oil output is expected to drop by 990,000 barrels per day (bpd) this year to 11.26 million bpd as producers reduce drilling activity after oil prices plunged.

- Crude oil prices increased to \$42 a barrel in the second week of August as the governments lift lockdowns imposed due to corona virus pandemic. This reflects 123% increase over the past four months.

CBGS Business

CBGS currently has 43 active members, 4 honorary members, and 40 student members. Raised \$1,450 towards student scholarships through membership revenue.

CBGS workshops/talks

CBGS organized **2020 SEG Distinguished Lecture** entitled “*Automating seismic data analysis and interpretation*” by Sergey Fomel on February, 11th, 2020, from 11:30 am -12:30 pm.

Sergey’s biography and abstract can be found at

<https://seg.org/Education/Lectures/Distinguished-Lectures/2020-DL-Fomel>

CBGS has also hosted another lecture entitled “*Spectral Extrapolation and Acoustic Inversion for the Characterization of An Ultra-thin Reservoir*” by Charles Puryear on March 4th, 12-1 pm.

CBGS is looking forward to offer workshops/talks in the future. Topic/speaker suggestions are welcome. Email your suggestions to Subbarao.Yelisetti@tamuk.edu or

Samara_Omar@eogresources.com

Golf Tournament

CBGS organized its annual **Golf Tournament** to fund its scholarship program in the first week of October, 2019 at Northshore Country Club. Raised ~\$1,600 for the scholarship fund.

If you are interested in our next Golf Tournament, please contact Mark Wiley at

Mark_Wiley@eogresources.com

New Degree Tracks at TAMUK and Graduate Scholarships

- Texas A&M University-Kingsville (TAMUK) started its first cohort of MS Petrophysics program in Fall 2018. If you are interested in joining this program in Fall/Spring 2020, please contact the graduate coordinator for MS in Petrophysics, Dr. Subbarao Yelisetti at Subbarao.Yelisetti@tamuk.edu.
- Texas A&M University-Kingsville is offering **\$1000 scholarships** to TAMUK graduates who plan to join a graduate program at TAMUK in Fall, 2020, including the M.S. in Petrophysics in the Department of Physics and Geosciences. It is not just for May graduates but any graduate of TAMUK is eligible for this award if they join the Petrophysics program in the Fall, 2020. It will automatically be applied to the student’s account – so you do not need to apply or anything to get it. The Department of Physics and Geosciences also has other scholarships. For additional details about the program and scholarships, please visit the website:

<https://www.tamuk.edu/artsci/departments/phge/phys/academics/gp.html>

- **BS degree in Geophysics, Minor in Geophysics and Certification in Geophysics** offered at Texas A&M University-Kingsville since Fall 2017. Interested students can contact Dr. Subbarao Yelisetti (Subbarao.Yelisetti@tamuk.edu) for additional information.

Education/Events

-SEG

SEG 2020 annual meeting will be held in Houston, TX from Oct 11-16th. See <https://seg.org/AM/2020/> for additional details.

See <https://seg.org/Education/Lectures/Distinguished-Lectures> for information about upcoming SEG distinguished lecture in Houston and other locations.

See <https://seg.org/Education/Lectures/Honorary-Lectures> for SEG honorary lecture locations in Texas.

-AGU

2020 Fall AGU annual meeting will be held in San Francisco, CA from December 7-11th, 2020. <https://fallmeeting.agu.org/2018/future-meetings/>

Monthly Saying"Drill for oil? You mean drill into the ground to try and find oil? You're crazy." Drillers who Drake tried to enlist for his project in 1859 (Quoted from HPC Newsletter).

Monthly Summary

Texas Oil and Gas Info	Current Month	Last Month	Difference	
Texas Production	MMBO/BCF	MMBO/BCF	MMBO/BCF	
Oil	134.3	150.0	-15.7	April
Condensate	20.9	22.4	-1.5	April
Gas	821.2	885.0	-63.8	April
	Current Month	Yr to date - 2020	Yr to date - 2019	
Texas Drilling Permits	351	4136	7369	July
Oil wells	70	997	1973	July
Gas wells	27	241	565	July
Oil and Gas wells	232	2681	4260	July
Other	13	49	69	July
Total Completions	2102	13607	10814	July
Oil Completions	1684	10536	8442	July
Gas Completions	418	3071	2372	July
New Field Discoveries	0	2	25	July
Other	614	4670	3992	July

Subbarao Yelisetti
President, CBGS



COMPARISON OF STRUCTURAL STYLES OBSERVED IN UPPER EOCENE (JACKSON GROUP) AND OLIGOCENE (VICKSBURG GROUP) STRATA WITHIN THE RIO GRANDE AND HOUSTON EMBAYMENTS SOUTHWEST AND NORTHEAST OF THE SAN MARCOS ARCH, REFUGIO AND CALHOUN COUNTIES, SOUTH TEXAS GULF COAST

Osareni C. Ogiesoba and Angela K. Eluwa

Bureau of Economic Geology, University of Texas at Austin, 10100 Burnet Rd., Austin, Texas 78759, U.S.A.

ABSTRACT

This paper presents structural styles associated with the upper Eocene (Jackson Group) and lower Oligocene (Vicksburg Group) located in the Rio Grande and Houston embayments southwest and northeast of the San Marcos Arch of the South Texas Gulf Coast, respectively. Previous studies that focused on the Rio Grande Embayment documented structural styles that include unusual coast-perpendicular faults, diapiric shale, and subbasins.

Present work involves mapping the structural styles in the Houston Embayment and comparing the deformational pattern in both basins using 3D seismic data from four different surveys. Two of the seismic surveys (surveys #1 and #2) are located in Refugio County in the Rio Grande Embayment. The other two are located in the Houston Embayment—one (survey #3) within Calhoun County and the other (survey #4) straddling Calhoun and Jackson counties and Matagorda Bay. Methods of investigation consist of seismic interpretation, 3D visualization, and seismic-attribute extraction.

Our map at the top of the Vicksburg in the vicinity of the San Marcos Arch shows that: (1) although the prevailing mechanism of deformation during the deposition of the Eocene (Jackson Group) and Oligocene (Vicksburg Group) in the Rio Grande and Houston embayments was extensional tectonics, stratal deformational patterns are different in each basin; (2) in the Rio Grande Embayment, the dominant structural styles are mostly coast-orthogonal faults and shale ridges, prominent northeast-southwest-southeast trending curvilinear anticlines, and coast-parallel synthetic and antithetic faults; whereas in the Houston Embayment, the dominant structural styles consist of coast-parallel synthetic growth faults and shale diapirs; (3) the Houston Embayment is about 3050 m (10,015 ft) deeper than the Rio Grande Embayment; (4) the remnant erosional anticlinal structure within the Houston Embayment constitutes a potential hydrocarbon prospect; and (5) the diapiric structure along COCORP line TX4 in the Houston Embayment is interpreted to be composed mostly of overpressured shale.

INTRODUCTION

Although much work has been conducted in the Rio Grande and Houston embayments (e.g., Halbouty, 1966; Galloway et al., 1982; Culotta et al., 1992; Galloway et al., 2000; Ogiesoba and Hammes, 2012; Ogiesoba and Hernandez, 2015), a comparison of structural styles within these basins in the vicinity (southwest

and northeast) of the San Marcos Arch has yet to be published. The Rio Grande Embayment is bordered to the southwest by the northwest-trending frontal folds of a Late Mesozoic–Cenozoic fold-thrust belt in Mexico (Sierra Madre Oriental) and to the northeast by the San Marcos Arch. The Houston Embayment is bordered to the northeast by the Belton High and the Sabine Arch (Halbouty, 1966), with the San Marcos Arch forming its southwestern boundary. Both the Houston and Rio Grande embayments are bordered to the northwest by the Ouachita Tectonic Belt (Halbouty, 1966). Because of tectonic activities associated with the intermittent motion of the San Marcos and Sabine arches during the waning phases of the Laramide compression, and because of the onset of volcanism and magmatism in the early Oligocene during deposition of the Vicksburg Group (continuing into the Miocene and ending at about 17 Ma) (Henry and

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GCAGS Journal, v. 8 (2019), p. 170–190.

DOI: pending

McDowell, 1986), the two arches have played a key role in the control of sediment deposition and deformation in the Rio Grande and Houston embayments.

Angular unconformity and thinning of stratigraphic units over these arches indicate that both the San Marcos and Sabine arches were intermittently positive areas in the Late Cretaceous and early Paleogene (Murray, 1961). A second Paleocene episode of motion between the Sabine Arch and adjacent basins is marked by thickening of the Wilcox Group delta-plain sediments in the East Texas Basin and thinning across the arch (Laubach and Jackson, 1990). A Halbouty (1966) diagrammatic geologic section showed that the Vicksburg Group thins considerably (~165 m [-540 ft]) over the San Marcos Arch compared to its thickness in the Rio Grande (~680 m [-2240 ft]) and Houston (~890 m [-2920 ft]) embayments, which suggests that the arch was in motion during the Oligocene. According to Halbouty (1966), the San Marcos Arch played a key role in influencing the stratigraphic and structural attitudes of strata in adjacent basins from the Jurassic to early Neogene.

Objective

Three previously published works played very pertinent roles in defining the objectives of this current project. Culotta et al. (1992) discussed the results of the Consortium for Continental Reflection Profiling (COCORP) seismic survey along the San Marcos Arch. The survey line consists of three line segments (TX4, TX5, and TX6) covering a distance of 250 km (~156 mi) from Port Lavaca on the central Texas coast to the southeastern side of the Llano Uplift (Fig. 1A). Based on the authors' interpretation of this line (Fig. 1B), the Vicksburg and Jackson groups at the extreme southeastern end of the survey have not been penetrated by any well. Well 11, located at the southeastern end of TX4, was drilled to depths of about 2300 m (~7550 ft) but did not encounter the Vicksburg, suggesting that the strata are located at a depth greater than 2300 m (7550 ft). In fact, it appears that the Vicksburg and Jackson were faulted down thousands of meters by a couple of major synthetic and antithetic faults (Fig. 1B). Thus, the depths at which the tops of these strata occur in the Houston Embayment at this location are not certain. Furthermore, directly below the total depth of well 11, Culotta et al. (1992) tentatively interpreted a diapiric structure (Fig. 1B), suggesting doubts about the actual composition of the structure; whether it is composed of shale or salt is yet to be resolved. The remaining wells to the northwest penetrated the top and base of the Vicksburg and Jackson, with the exception of wells 9 and 10, which penetrated only the top of the Vicksburg. At the southeastern end of TX6, the authors interpreted the outline of the Luling Uplift (Fig. 1B), a Precambrian rock that is closely associated with the San Marcos Arch (Fig. 1A).

The second influential paper is Coleman and Galloway (1990), which discusses oil and gas field distribution within the Vicksburg in the Rio Grande and Houston embayments and in the vicinity of the San Marcos Arch (Fig. 2). In Figure 2, we have superimposed the COCORP line (TX4, TX5, and TX6 [bold magenta line segments]). As shown, the southeastern part of TX4 is completely on the downthrown side of fault B, where information about the Vicksburg is scanty—no oil or gas field has been identified in this area of Calhoun County in the Houston Embayment. Thus, the area needs further investigation and constitutes part of our study area. The third influential paper, Ogiesoba and Hernandez (2015), shows that, in addition to synthetic and antithetic growth faults, the dominant structural features in the Rio Grande in the vicinity of the San Marcos Arch are coast-orthogonal shale ridges, subbasins, and coast-orthogonal faults.

Based on the foregoing discussion, the objectives of this project are to (1) determine the lithological composition of the diapiric structure that sits directly below well 11 along line TX4,

(2) determine the similarity between the deformational pattern in the Vicksburg Group within the Rio Grande and the Houston embayments in the vicinity of the San Marcos Arch, and (3) identify any structurally and stratigraphically trapped hydrocarbon play within the Vicksburg in the Houston Embayment. Our current effort builds on the results of Ogiesoba and Hernandez (2015) by extending the previous interpretation into Victoria County using additional 3D seismic volume and by mapping the top of the Vicksburg in the Houston Embayment in the vicinity of the San Marcos Arch.

LOCATION AND GEOLOGY OF STUDY AREA

The study area is located partly in the Rio Grande Embayment, straddling Refugio and Victoria counties, and partly in the Houston Embayment, straddling Calhoun and Jackson counties and Matagorda Bay about 30–40 km (~19–25 mi) northeast of the San Marcos Arch axis (Fig. 3). The stratigraphic section of interest stretches from the Eocene Jackson Group to the late Oligocene Anahuac Shale, with particular emphasis on the Vicksburg Group (Fig. 3). In the Rio Grande Embayment southwest of the San Marcos Arch axis, stratal thicknesses (isopachs) are thinner than in the Houston Embayment northeast of the arch. In fact, although the top of the Vicksburg has not been penetrated by any well in our study area in the Houston Embayment, the Frio Formation is up to 2440 m (~8000 ft) thick at some locations, such as in the Damstrom #1 well in the Appling Field in the Carancahua Bay area.

DATABASE

The database consists of four 3D seismic surveys, #1 through #4. The first two surveys are located in the Rio Grande Embayment. Survey #1 consists of a 25 x 25 m (~80 x 80 ft) stacking-bin size covering an area of ~125 km² (~48 mi²), with a sampling interval of 4 ms. Survey #2, directly southeast of survey #1, has a 25 x 25 m (~80 x 80 ft) stacking-bin size with an area of ~260 km² (~104 mi²). The sampling interval is also 4 ms. Both surveys have a record length of ~6 s each. Surveys #3 and #4 are located in the Houston Embayment northeast of the San Marcos Arch (Fig. 4). Survey #3 is located entirely in Calhoun County and covers an area of 130 km² (~50 mi²). It has a stacking-bin size of 34 x 34 m (~110 x 110 ft), with a sampling interval of 2 ms and a record length of 6 s. Survey #4 straddles Calhoun and Jackson counties and Matagorda Bay, covering an area of ~196 km² (~76 mi²). It has a stacking-bin size of 34 x 34 m (~110 x 110 ft), with a 4 ms sampling interval and a record length of 6 s.

In the Houston Embayment, although more than 100 wells have been drilled in the area covered by surveys #3 and #4, none penetrated the top of the Vicksburg. The average depth of these wells ranges from ~2135–2740 m (~7000–9000 ft), although a few have been drilled up to 3960–5200 m (~13,000–17,000 ft). In survey #1, located in the Rio Grande Embayment, only one available well (well J, Fig. 4) has penetrated the top of the Vicksburg (at ~1990 m [-6520 ft]) down to near the base of the Eocene Jackson Shale. The total depth of well J is ~3554 m (~11,660 ft). Wireline-log suites consist of sonic, gamma ray, resistivity, and spontaneous potential curves.

METHODS

The first step, beginning with survey #1 in the Rio Grande Embayment, was to tie the wells to the seismic data. We identified the tops and bases of the Oligocene (Anahuac, Vicksburg, and Frio) and Eocene (Jackson Group). These tops were interpreted throughout the entire survey and across the down-to-the-southeast synthetic faults into survey #2 (Fig. 5). Five surfaces plus two detachment surfaces (detachment surfaces 1 and 2,

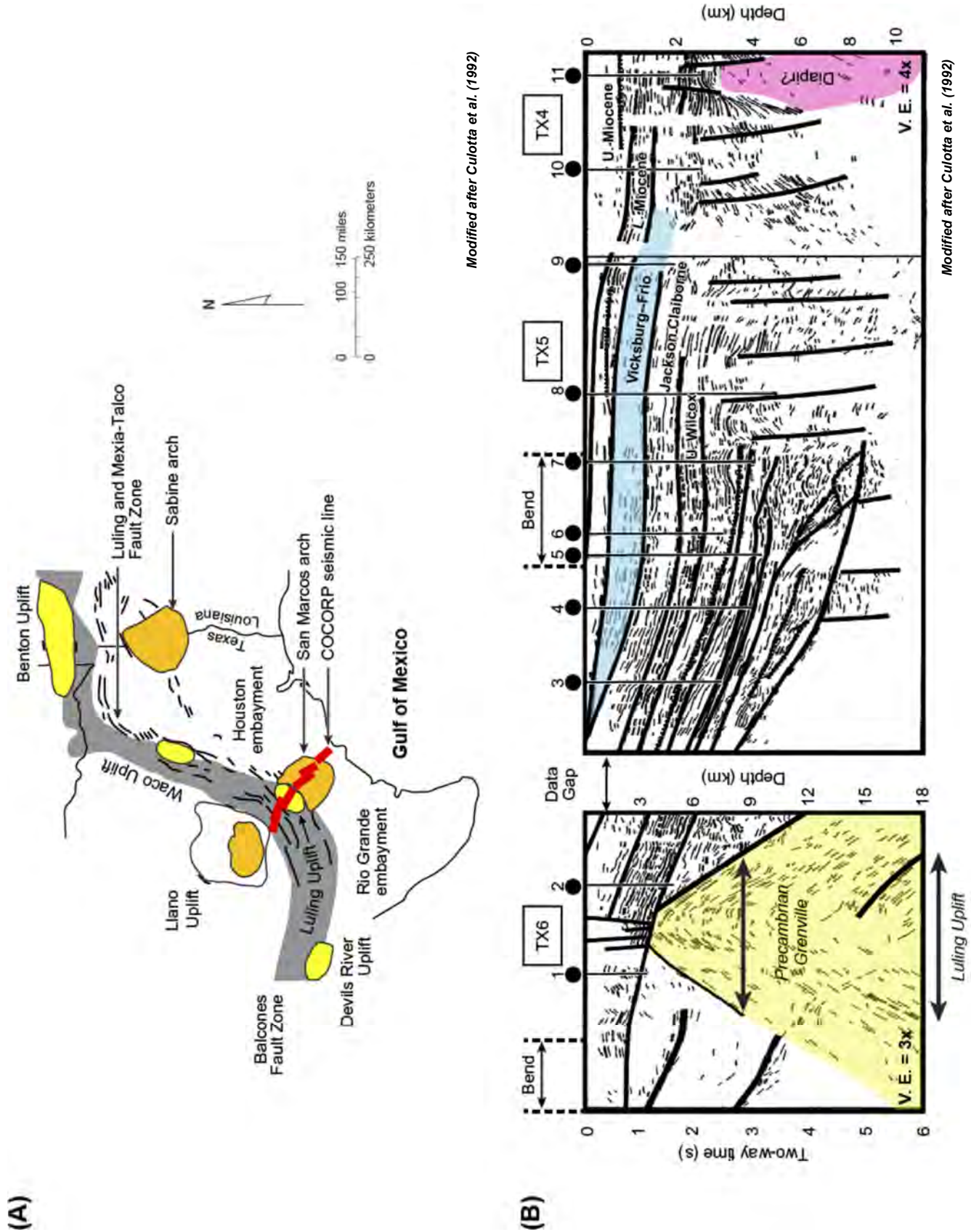


Figure 1. (A) Map of South Texas showing Precambrian arches and uplifts, and location of COCORP seismic line (modified after Culotta et al., 1992). (B) COCORP's minimal interpretation of line segments TX4, TX5, and TX6 (modified after Culotta et al., 1992). 1 km = ~0.62 mi.

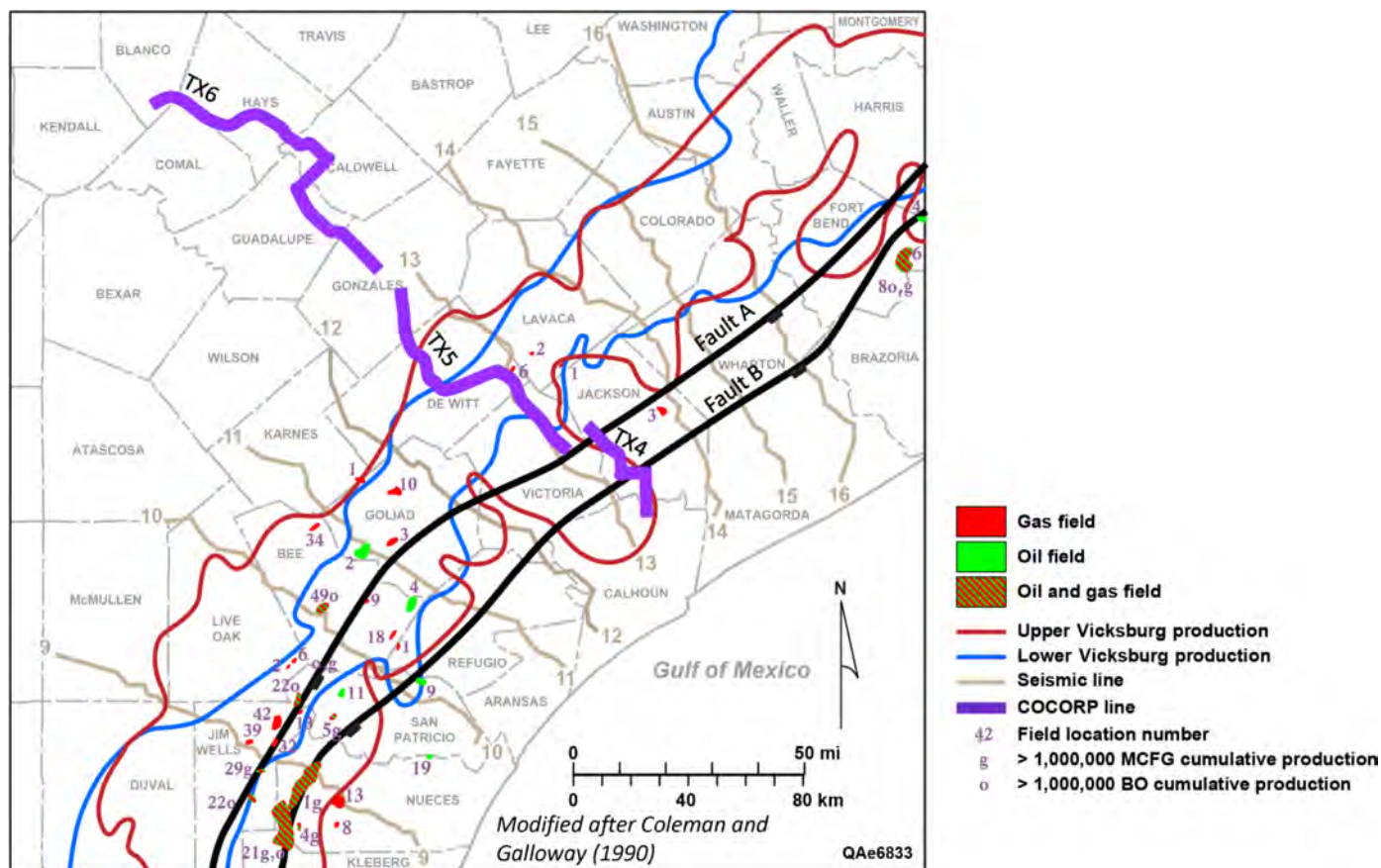


Figure 2. Distribution of oil and gas fields of San Marcos Arch area with superimposed COCORP TX4, TX5, and TX6 line segments (magenta color) (modified after Coleman and Galloway, 1990). Wells are numbered 1 through 11.

Fig. 5) were interpreted in survey #1. Detachment surface 1 (cyan surface) occurs just below the base of the Jackson, while detachment surface 2 (yellow surface) occurs at much greater depth. These two surfaces were not identified in the other three surveys. Although five surfaces were interpreted, because the focus is on the Vicksburg, only the map at the top of the Vicksburg is discussed. In surveys #3 and #4 in the Houston Embayment, because the Vicksburg and the Jackson are located at much deeper depths than those in the Rio Grande Embayment, none of the available wells has penetrated the tops of these stratigraphic units, making interpretation of the tops of these two units difficult. However, after tying one of the deep wells (well K, Fig. 4) to seismic data in survey #4, we interpreted the top of the Vicksburg as a major detachment surface onto which fault A soles out. It appears as an unconformity surface at the base of the lower Frio (seismic line B-B', Fig. 6). The base of well K is in shale at a total depth of 4500 m (14,780 ft). The top of the Vicksburg is characterized as a surface onto which the lower Frio strata structurally rotated. In some cases, it truncates underlying beds and also serves as a decollement surface for lower Frio shale-rich strata (dashed black arrow, Figs. 6, 7, and 8).

In survey #3, difficulty in recognizing the top of the Vicksburg is compounded by severe structural deformation. The closer one approaches the San Marcos Arch from the northeast direction, the greater the structural deformation. However, by carefully comparing parallel seismic lines C-C' and D-D', E-E' and F-F', and F-F' and H-H' from both surveys #3 and #4, we interpret the top of the Vicksburg in survey #3 (Figs. 7, 8, and 9). In this area, the top of the Vicksburg also appears as an unconformity (yellow surface, Fig. 6A) onto which lower Frio sediments down-

lap (red arrows, Fig. 9A). However, because of the limited areal extent of this surface, we mapped the green surface (Fig. 9A). Having identified the top of the Vicksburg in both surveys, we also interpreted the top and base of the Anahuac Shale. The top and base of the Jackson Shale were not interpreted because of the absence of penetrations.

RESULTS

This section presents the map at the top of the Vicksburg in surveys #1 to #4. Only the dominant structural features in each survey are discussed, starting with survey #1 in the Rio Grande Embayment.

Rio Grande Embayment: Survey #1

The main structural elements in this acreage are the down-to-the-basin, coast-parallel, synthetic growth faults (Figs. 5 and 9). Although the map at the top of the Vicksburg in this acreage is of small areal extent, being ~125 km² (~48 mi²), it nevertheless presents some unique structural features that include a curvilinear anticlinal structure. The anticline at first trends northeast-southwest, then to the southeast, where it becomes a coast-orthogonal structure (Fig. 10). It is broken into two unequal halves by a down-to-the-southeast, crestal, synthetic fault (fault CV). The fault is also curvilinear, trending along the length of the anticline from northeast to southwest, then to the southeast, where it assumes a coast-orthogonal attitude (Fig. 10). The fault cuts well J at the top of the Vicksburg (Figs. 5 and 10). In addition to fault CV, a combination of three other faults—faults CV-

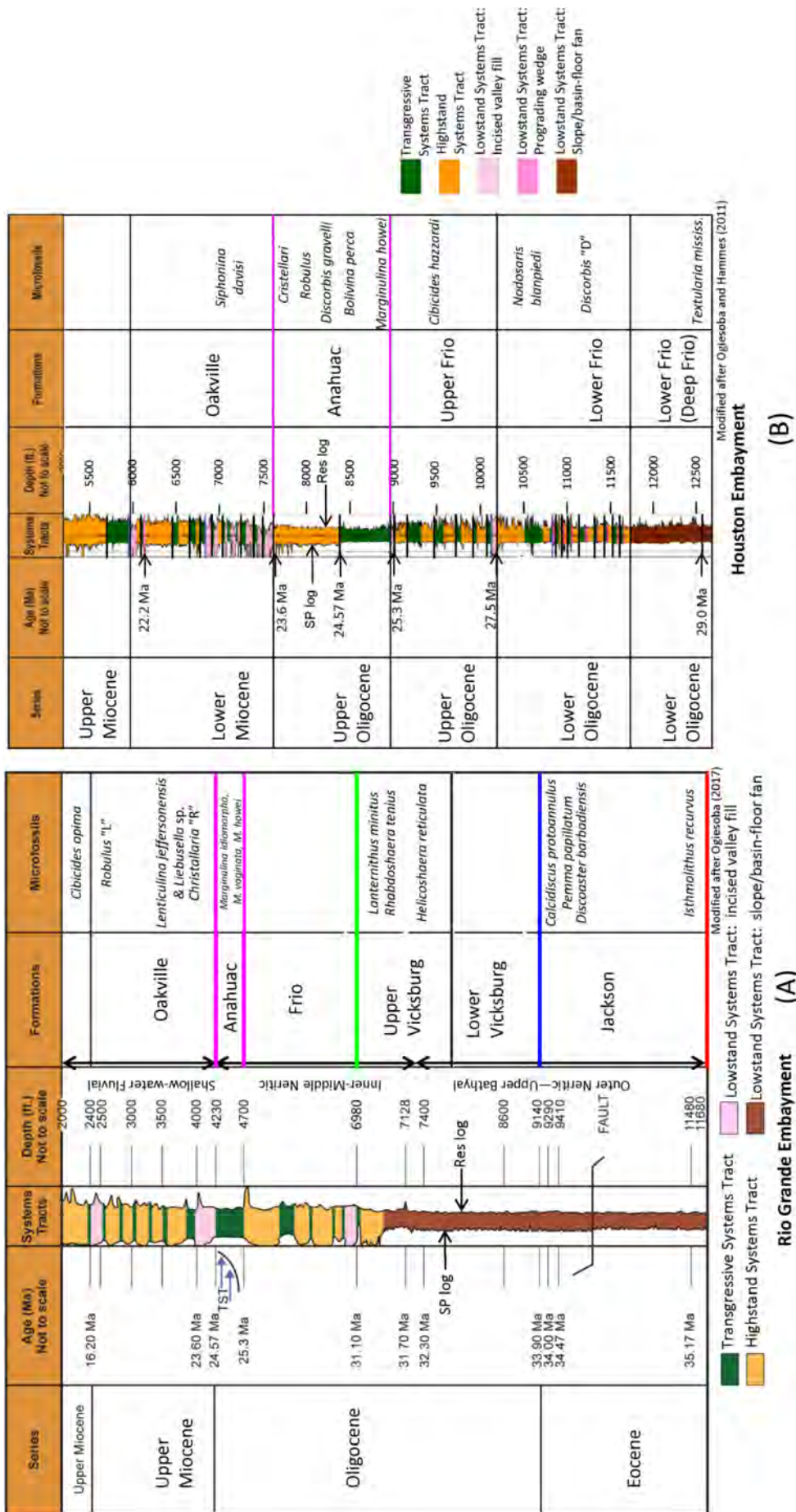


Figure 3. Stratigraphic columns from (A) southwest side of San Marcos Arch in the Rio Grande Embayment showing interpreted horizons—top and base Anahuac (magenta), top Vicksburg (green), and top Jackson (deep blue). (B) Northeast side of San Marcos Arch in the Houston Embayment showing only top and base Anahuac (magenta); top Vicksburg and top Jackson are not seen. 1000 ft = ~304.8 m.

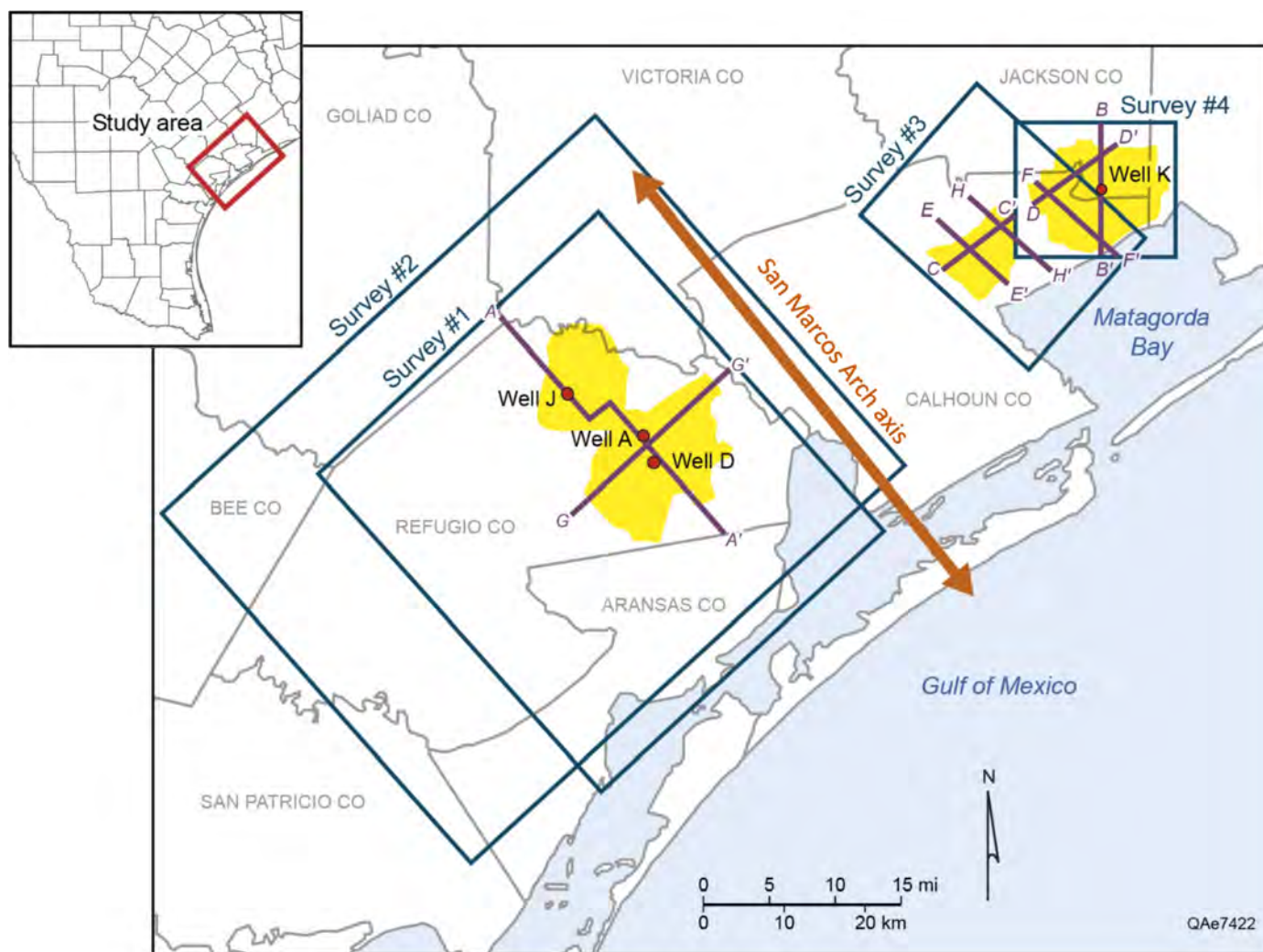


Figure 4. (A) Map of South Texas showing study area (red rectangle). (B) Enlarged version of red rectangle showing Refugio, Calhoun, Victoria, and Jackson counties; Matagorda Bay; and San Marcos Arch axis. Blue rectangular outlines = 3D survey boundaries for surveys #1 to #4; yellow outlines = area where seismic data is available in each survey; solid red circles = well locations; magenta lines = seismic lines discussed in text.

1, CV-2, and CV-3—separate the northwestern part of the anticline, which is also curvilinear (magenta arrow), from the southeastern part (red arrow) (Fig. 10). Apart from fault CV, all other faults are coast-parallel synthetic faults.

Although the mechanism responsible for the curvilinear anticline is not clear, deposition occurred during extension (Galloway et al., 2000).

Rio Grande Embayment: Survey #2

The main structural elements in survey #2 consist of coast-orthogonal faults, subbasins, shale ridges, and coast-parallel synthetic and antithetic faults. The entire survey #2 area is located in a minibasin that is bound on the northeast by the San Marcos Arch, being ~10 km (~6 mi) from the arch. The top of the Vicksburg interpreted surface in this survey is separated from the top of the Vicksburg surface in survey #1 by a down-to-the-southeast synthetic fault HB (Fig. 5). The map in survey #2 illustrates four alternating coast-orthogonal shale ridges (SD 1 to SD 4) and subbasins (SB 1 to SB 4) (Fig. 11). Within the subbasins are coast-parallel synthetic faults located in the northern part and coast-parallel antithetic faults located in the southern part. At the flanks of the shale ridges, the coast-parallel synthetic and anti-

thetic faults merge to form three coast-orthogonal, down-to-the-southwest faults (Ogiesoba and Hernandez, 2015) (Fig. 11). Along seismic line G-G' (Fig. 12), alternating shale diapirs and subbasins are highly pronounced.

Houston Embayment: Survey #3

The dominant structural elements in this survey consist of coast-parallel synthetic faults and shale ridges. The survey is located on the northeast side of the San Marcos Arch, ~30 km (~19 mi) from its axis. Because of the complex faulting and shale diapirism prevalent in this acreage, the mappable area of the top of the Vicksburg is very limited, particularly in the southeastern part. To gain better insights into structural styles in this area, we mapped another surface (green surface) ~300 ms deeper than the top of the Vicksburg (yellow surface) (Fig. 7A). This green surface covers a larger area and also addresses the structural picture in the southeastern part of the area. The map shows that although there are some minor coast-orthogonal faults, the main structural elements are down-to-the-southeast synthetic faults and shale diapirs (Figs. 7, 8, and 13A). Along the fault plane of one of the major synthetic faults, folded fault blocks (bold, dashed red arrow) are rafted downslope basinward, having

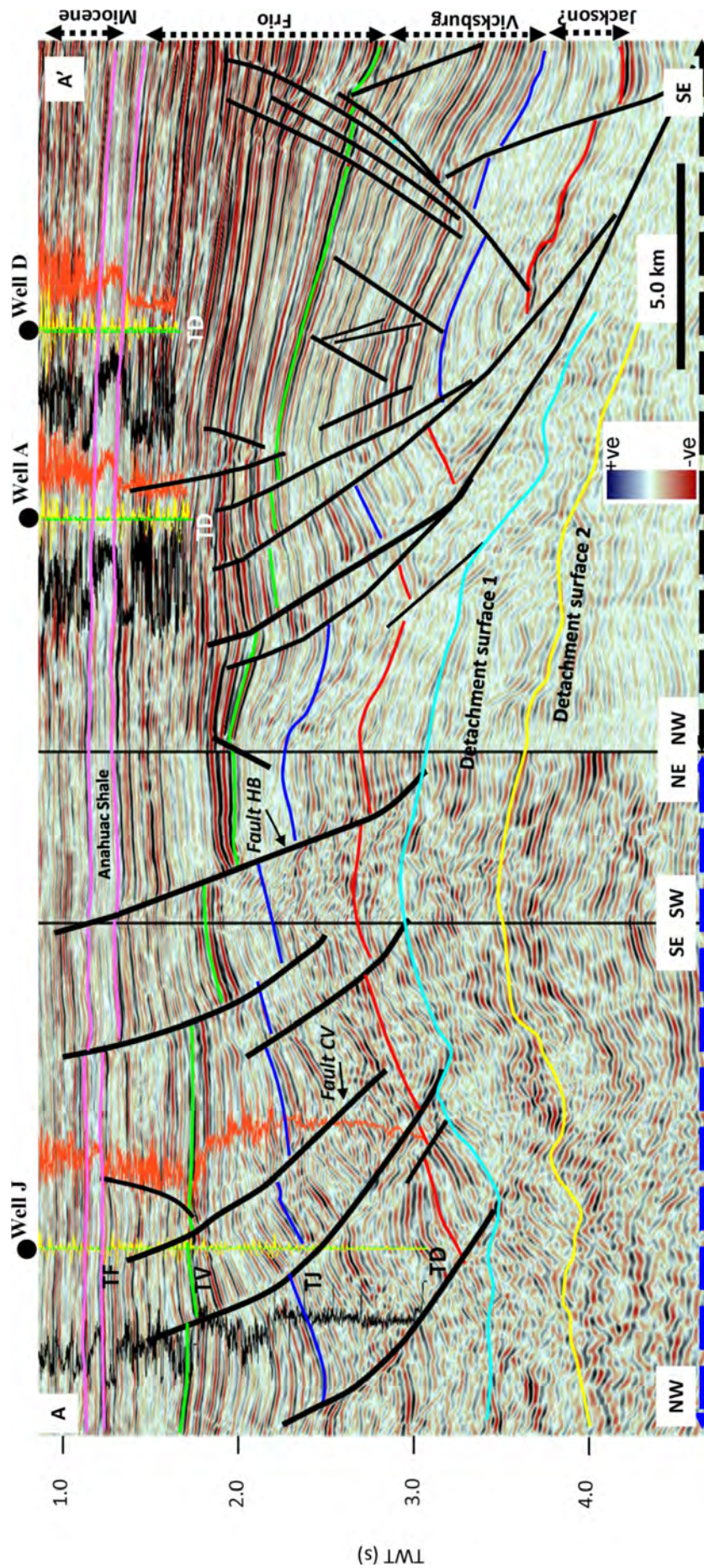


Figure 5. Seismic line A-A' through wells J, A, and D. Displayed log curves are gamma ray (black) and sonic (red) logs. Sonic log deflection to right = increasing sonic values (i.e., decreasing velocity); deflection to left = decreasing sonic values (i.e., increasing velocity). Note: sonic scaling is reversed from standard scaling. Deflection of gamma ray log to right = increasing shale content; deflection to left = decreasing shale content. Yellow curve = synthetic trace. Double-headed, dashed blue arrow = seismic data from survey #1; double-headed, dashed black arrow = seismic data from survey #2. 5 km = ~3.1 mi.

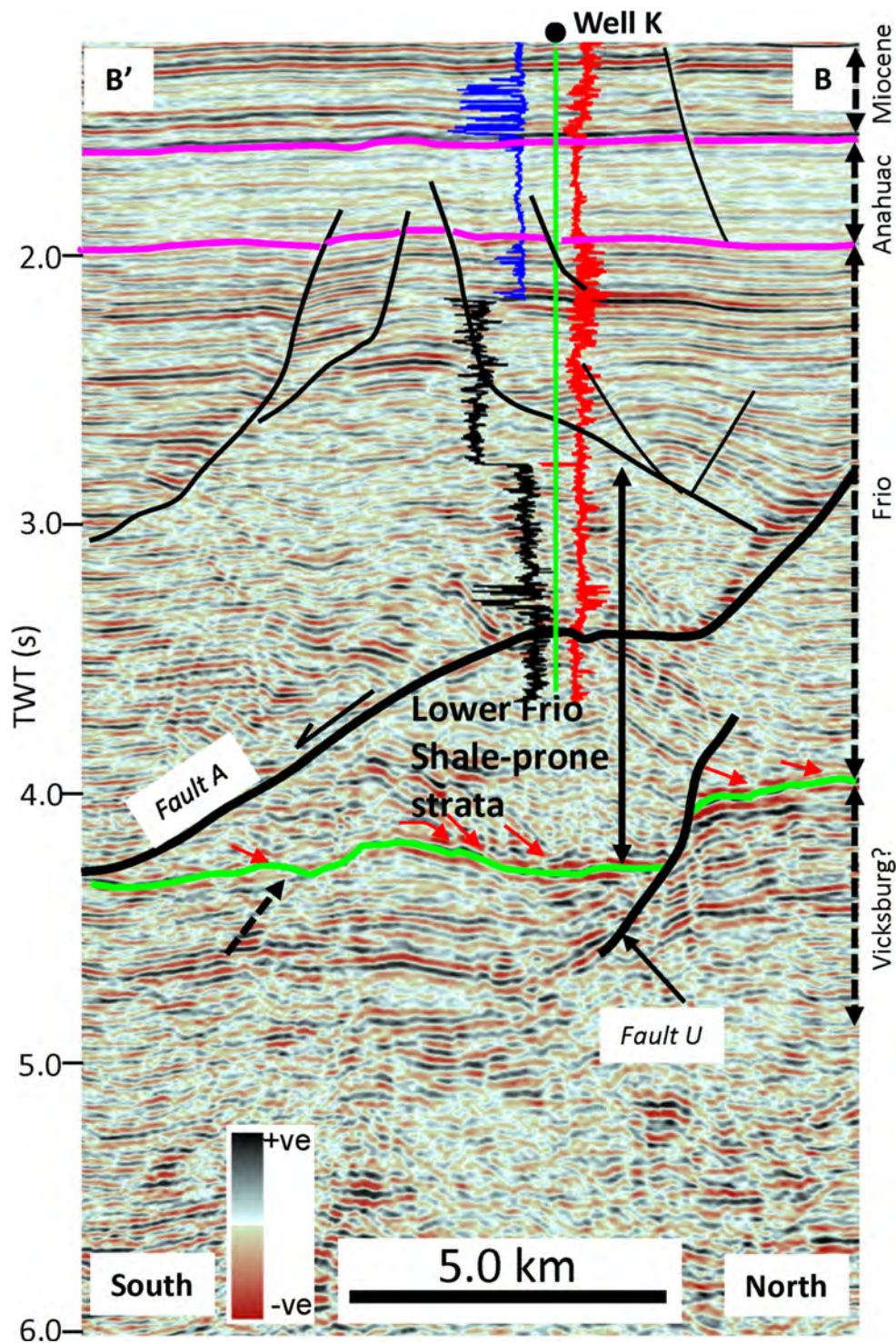


Figure 6. Seismic line B-B' through well K showing seismic data and interpreted horizons from survey #4. Top and base Anahuac Shale shown in magenta color; top of Vicksburg Formation shown in green; and small red arrows indicate direction of downlap of lower Frio strata on top Vicksburg surface. Blue log curve = spontaneous potential log; black log curve = gamma ray log; and red log curve = resistivity log. Upper Frio Formation is sand dominated, and lower Frio Formation is shale dominated. Note unconformable nature of Vicksburg surface (dashed black arrow). 5 km = ~3.1 mi.

travelled 1.0 km (~0.62 mi) (Fig. 8A). The minor coast-orthogonal faults are antithetic faults whose northeast arms extend northward to form coast-orthogonal faults (Fig. 13A). These antithetic faults occur at the flank of a shale-cored anticline. Although seismic data in the northern part of survey #3 is of fair to poor quality, based on well information, we confirmed the presence of a shale ridge in the northwestern part of the area as discussed below. Based on the trend interpreted from the seismic data, the shale was inferred to trend southwest-northeast, parallel to the coast (Fig. 13A).

Houston Embayment: Survey #4

The main structural elements in this acreage are coast-parallel synthetic faults and erosional anticlines. In this survey, the top of the Vicksburg is less deformed than it is in survey #3. Here, the interpreted surface appears as a prominent detachment (decollement) surface, on top of which the lower Frio shale-prone strata appear to be structurally rotated (Figs. 6, 7B, and 8B). In map view, the surface is composed of two erosional anticlinal structures separated by a saddle and a down-to-the-southeast,

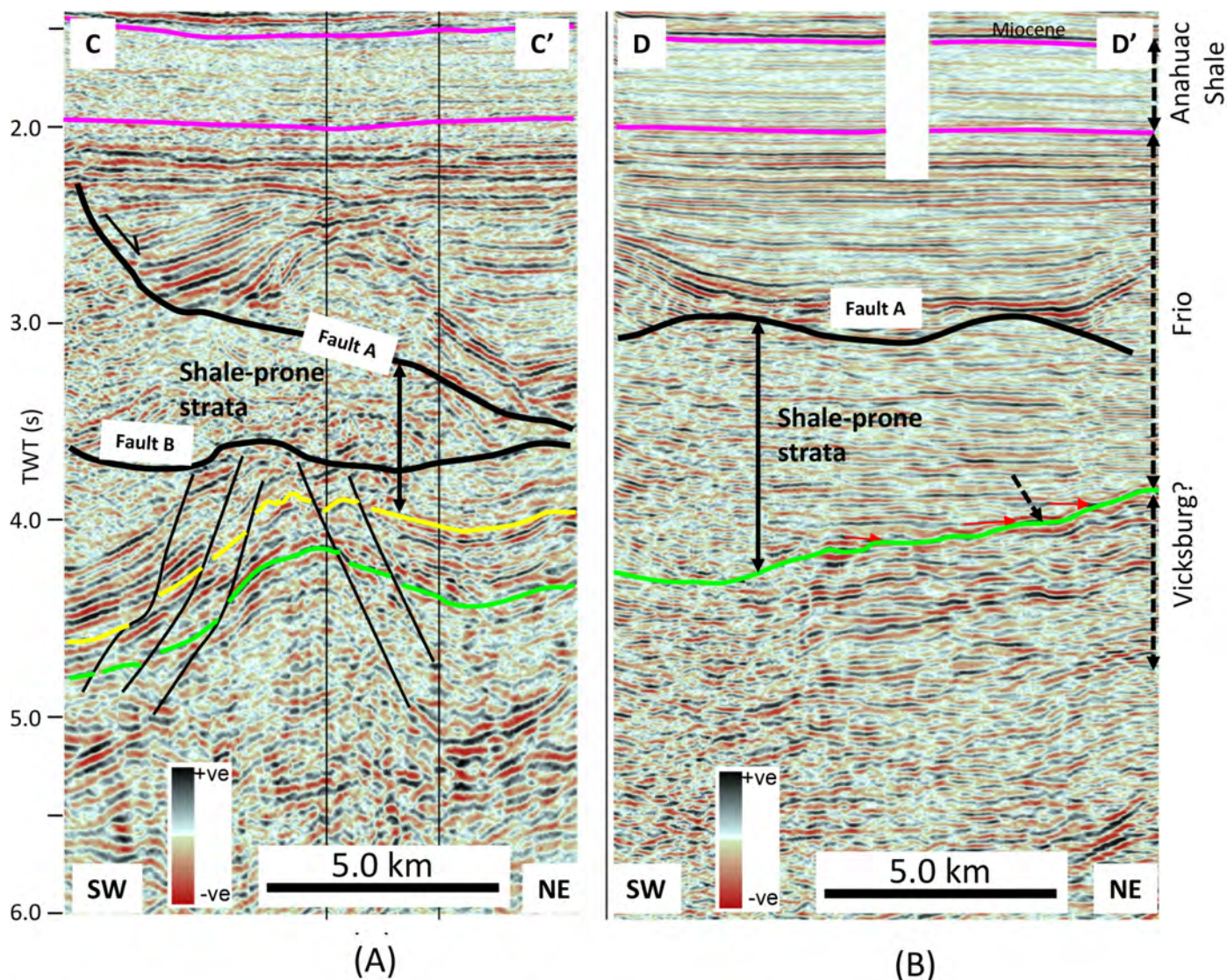


Figure 7. (A) Seismic line C–C' from survey #3 showing inferred top Vicksburg Formation (yellow horizon). Green horizon, 300 ms deeper than yellow, was mapped instead of yellow horizon (see text). Note lower Frio shale-prone sediments atop fault B and small-scale faults at flanks of shale-cored anticline. (B) Seismic line D–D' from survey #4 showing interpreted top Vicksburg (green horizon). Note: Small red arrows = onlap direction of lower Frio sediments atop Vicksburg surface; and top and base Anahuac Shale shown in magenta color. Note unconformable nature of top Vicksburg horizon. 5 km = ~3.1 mi.

southwest-northeast trending fault U (Figs. 4 and 13B). The anticlinal structure is bounded on the southeast by the down-to-the-southeast synthetic fault (fault A), but the fault actually soles out along the surface (Figs. 6, 8, and 13B). Situated on top of the anticline are low-amplitude and high-frequency lower Frio sediments. Although well K did not test the entire lower Frio section, the penetrated section of it is shale-prone compared to the sandstone-rich upper Frio strata (Fig. 6) and may serve as a seal for possible hydrocarbons trapped by the anticline. However, there are some zones, such as the dashed magenta outline (Figs. 8B and 9B), within the lower Frio interval that may be sand-prone.

Although surveys #3 and #4 are separated by ~4 km (~2.5 mi), we observed that the erosional gully (coast-parallel valley) in survey #3 appears to continue into survey #4 (broad magenta arrow, Figs. 12A and 12B). Furthermore, the anticlinal structure in the southeastern part of survey #3 appears to correspond to the structural high in survey #4 (Figs. 12A and 12B); fault A in survey #3 also appears to correlate to fault A in survey #4. These

correlations suggest that at the top of the Vicksburg, the structure in survey #4 is a continuation of the structural pattern in survey #3.

Evidence of Existence of Southwest-Northeast Trending Shale Ridge in Survey #3

The evidence confirming that the structure at the top Vicksburg strata in survey #3 is bounded by a southwest-northeast trending shale ridge in the north can be seen in well M located along line K–K' (red line, Fig. 14). In Figure 14A, the location of well M together with lines K–K' (red line), H–H' (green line), and the COCORP TX4 (dashed cyan line) are shown. Along line K–K', we interpreted the outlines of two shale-prone zones (Fig. 14B). Based on spontaneous potential and resistivity-log curves, the last 230 m (~750 ft) of the wellbore, starting from the blue arrow to the end of the well, is composed of very low

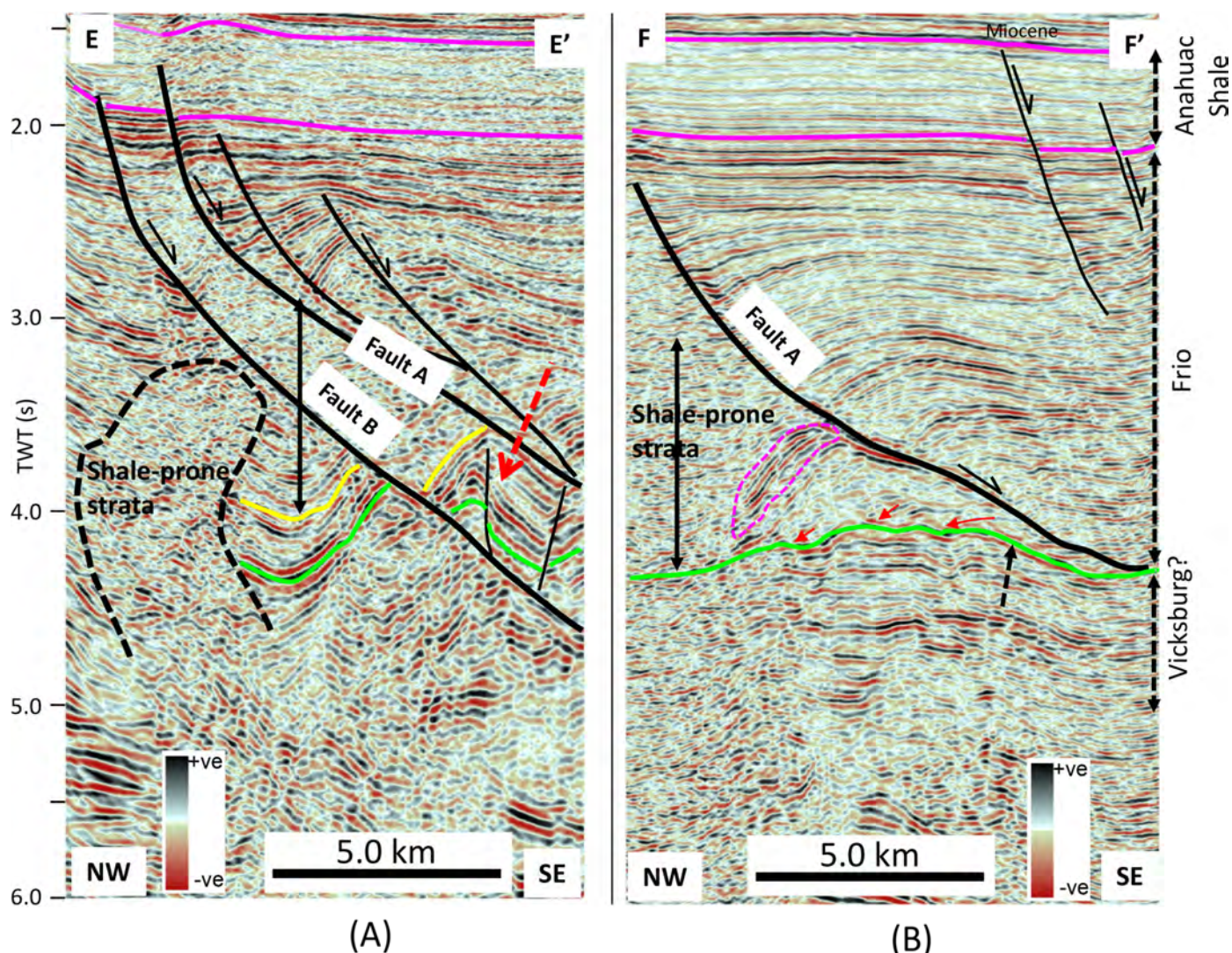


Figure 8. (A) Seismic lines E–E’ from survey # 3 showing inferred top Vicksburg and interpreted shale diapir (dashed black outline). Green horizon, 300 ms deeper than yellow, was mapped instead of yellow horizon (see text). Note: Bold, dashed red arrow indicates folded and faulted block being rafted down fault plane. (B) Seismic lines F–F’ from survey # 4 showing interpreted top Vicksburg Formation. Small red arrows = downlap direction of lower Frio sediments atop Vicksburg surface; and magenta horizons = top and base Anahuac Shale. Dashed magenta outline = possible sand-prone zone. 5 km = ~3.1 mi.

resistivity shale (Fig. 14B). From the blue arrow to the end of the well, formation resistivity decreases rapidly to almost zero ohm, while the conductivity increases rapidly to the maximum value of 2000 mmho (2000 millisiemens), suggesting that the shale-prone zone is overpressured (Fig. 14C).

Comparison of COCORP Line TX4 and 3D Seismic Line H–H’

In this section, we compare the COCORP TX4 line and line H–H’ from our 3D survey #3 (Figs. 15A and 15B), whose locations are shown in Figure 14A. COCORP interpretation of TX4 shows the presence of a diapiric structure, albeit with a question mark that suggests uncertainty about the nature of the diapir (Fig. 15A). By comparing the interpretation of lines TX4 and H–H’, we show that the questionable diapir in TX4 corresponds to the shale-prone zone delineated in H–H’ (Fig. 14B). Note that line TX4 terminated within the diapir (Fig. 14A), where it almost merged with line H–H’, and thus did not encounter the south-dipping flank of the diapir. Had line TX4 continued along line H–H’ (Fig. 14A), it would have encountered the south-dipping

flank of the diapir at the location where we have interpreted the shale-prone outline along line H–H’. However, the north-dipping flank of the shale-prone diapir along lines H–H’ and K–K’ was not defined because the lines did not extend to the northern part covered by line TX4 (Fig. 14). Had line H–H’ continued along line TX4 (Fig. 14A), it would have found the north-dipping flank and would have been the same as the one encountered by line TX4. Based on these deductions, we interpret the diapir along line TX4 to be the same as the one along lines H–H’ and K–K’, which has been confirmed by well M to be composed of overpressured shale (Figs. 14B and 14C). Hence we interpret the south-dipping flank in TX4 and H–H’ to be the same (Figs. 14 and 15). Therefore, we conclude that the questionable diapir in TX4 is an overpressured shale penetrated by well M, with the south-dipping flank being the same as the south-dipping flank along lines H–H’ and K–K’ (Fig. 14).

We interpret the age of the diapir in the Rio Grande Embayment (survey #2) to be late Eocene–early Oligocene, when the uprising shale terminated just about the top of the Vicksburg—and in some cases penetrated a little bit into the lower Frio

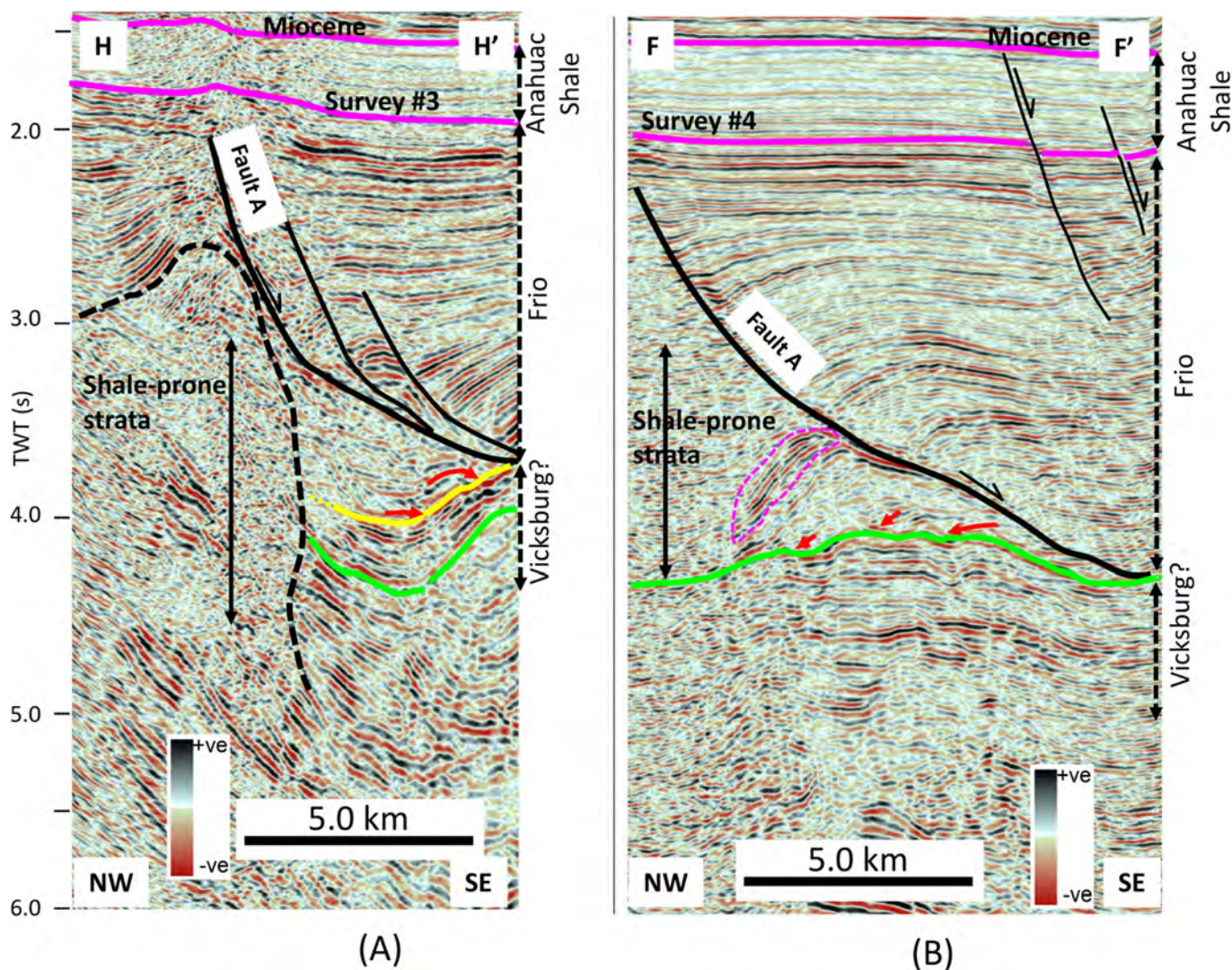


Figure 9. (A) Seismic lines H–H' from survey # 3 showing inferred top Vicksburg and interpreted shale diapir (dashed black outline). Green horizon, 300 ms deeper than yellow, was mapped instead of yellow horizon (see text). Note unconformable nature of yellow horizon. (B) Seismic lines F–F' from survey # 4 showing interpreted top Vicksburg Formation. In (A) and (B), small red arrows = downlap direction of lower Frio sediments atop Vicksburg surface; and magenta horizons = top and base Anahuac Shale. Dashed magenta outline = possible sand-prone zone. 5 km = ~3.1 mi.

(Fig. 12). As noted by Ogiesoba and Hernandez (2015), the diapir stopped rising when the pressure within the overpressured shale had substantially bled off because both the small- and large-scale faults that served as pressure-release valves cut into the diapirs. In the Houston Embayment, because the diapir continued into the lower and middle Frio (Figs. 9 and 15), we interpret the age of the diapir in this basin to be early-middle Oligocene. Although the possible causative mechanisms of the shale diapirs have already been discussed by Ogiesoba and Hernandez (2015), we note that while the possible cause of diapirism in the Rio Grande may be due to a combination of vertical loading and local lateral compression of the rapidly deposited sediments, in the Houston Embayment the possible causative mechanism may be due to vertical loading only.

3D Visualization of Mapped Surfaces, Shale Ridges, and Diapirs

This section presents 3D visualization of the mapped surfaces in surveys #1 through #4 (Fig. 16). Figure 16 clearly shows the curvilinear faults in survey #1 and the curvilinear appearance

of SB 1 in survey #2. These features are better displayed in Figure 17, where the stepping fault pattern of the curvilinear faults in survey #1 and the nature of the subbasins, shale ridges, and diapirs in survey #2 are clearly highlighted. A more accentuated view of the structures identified in surveys #3 and #4 are shown in Figures 18A and 18B, respectively. Figure 18A shows without any doubt a high-rise southwest-northeast trending shale ridge penetrated by well M to the north and bounding a southwest-northeast trending deep valley. In Figure 18B, the erosional anticlines in survey #4 are prominently differentiated from the synclines. Although more seismic data would be required to firm up the areal extent of these anticlines, they nevertheless constitute potential hydrocarbon targets.

HYDROCARBON POTENTIAL

This section focuses on the hydrocarbon potential of the Vicksburg within the study area by examining the structural closures, caprock, and possible sandstone richness/distribution in each survey area. In survey #1, the curvilinear anticlines are strongly defined and, as revealed by well J (Fig. 19), the struc-

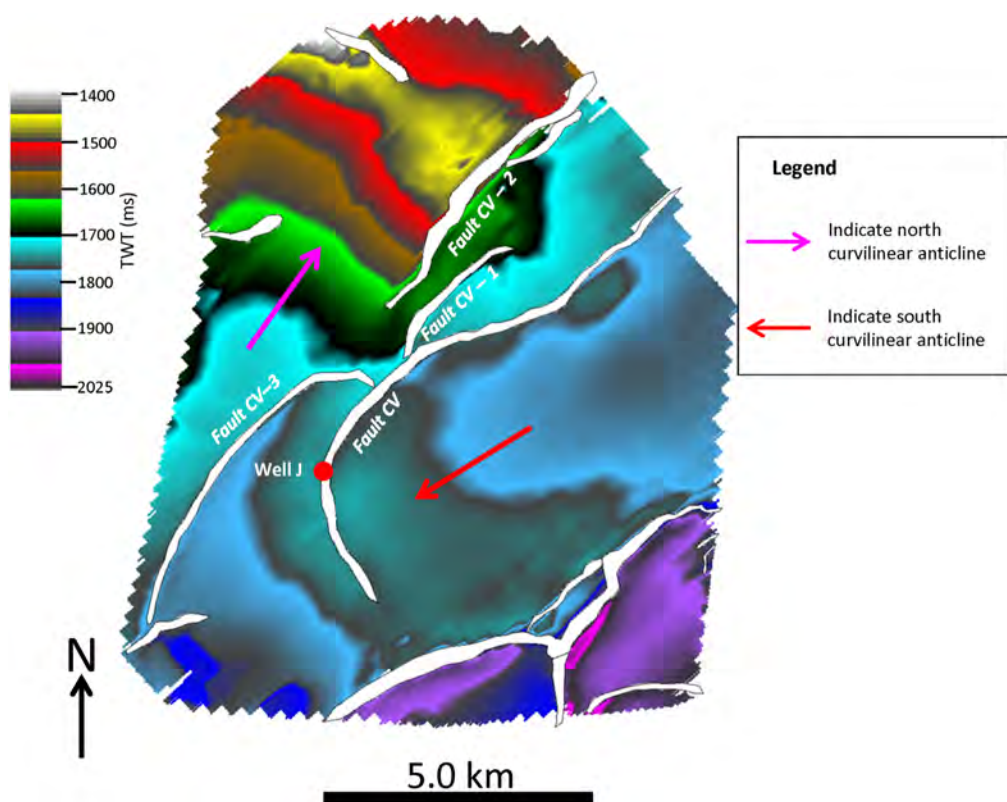


Figure 10. Map of top Vicksburg Formation in survey #1 showing faulted northwest-southeast trending curvilinear anticline. Dominant structural styles are down-to-southeast synthetic growth faults. 5 km = ~3.1 mi.

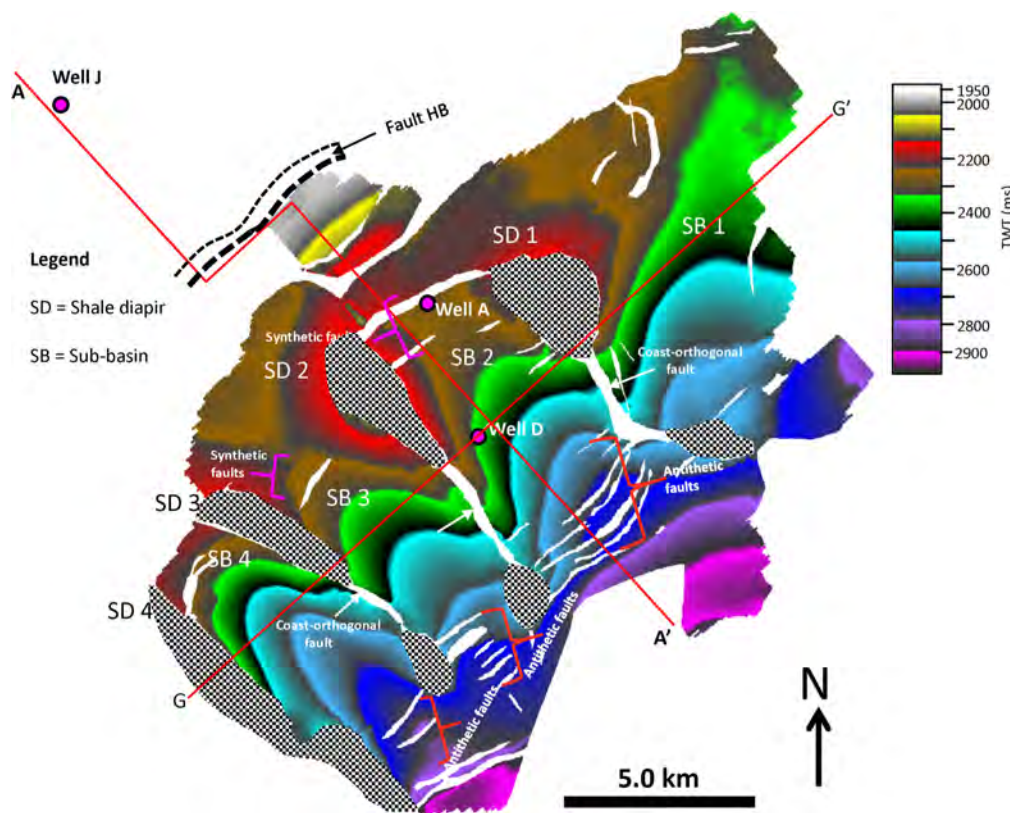


Figure 11. Map of top Vicksburg Formation in survey #2 showing four coast-orthogonal shale ridges, four coast-orthogonal shale subbasins, and three coast-orthogonal faults, as well as coast-parallel synthetic and antithetic faults. 5 km = ~3.1 mi.

tures at the Vicksburg surface have a gross reservoir sandstone thickness of about 30 m (~100 ft). However, the caprock integrity is in question. As shown by well J (Fig. 19), the top of the Vicksburg is in the middle of a sand-prone interval, suggesting

that the unconformity surface separating the upper Vicksburg and the lower Frio is a sand-on-sand contact. The placement of the top Vicksburg surface at this depth (~2130 m [~6980 ft]) is supported by paleoanalysis. The surface is identified by *Lanter-*

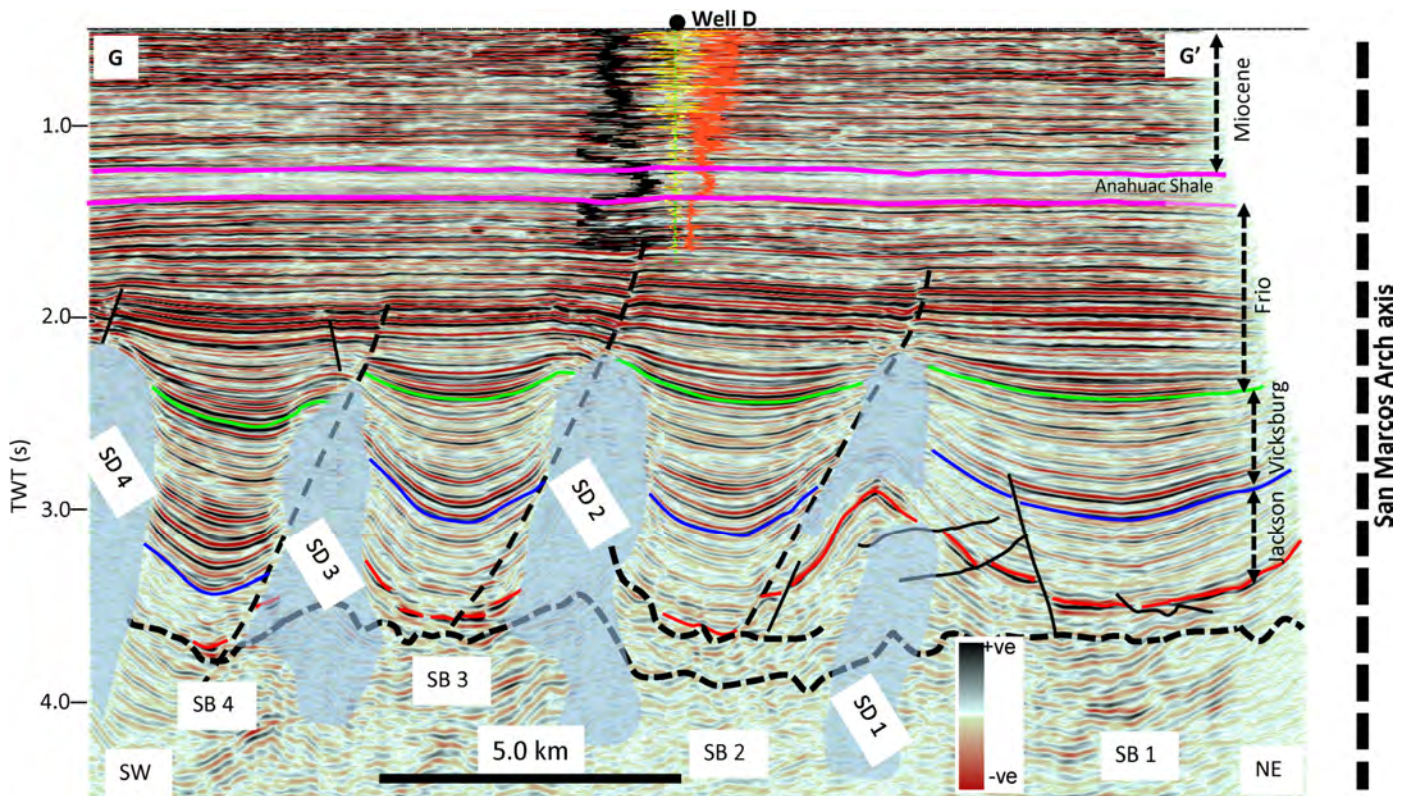


Figure 12. Seismic lines G–G' from survey # 4 through well D showing top Vicksburg (green horizon), top Jackson (blue horizon), top Frio (lower magenta horizon), and top Anahuac Shale (upper magenta horizon). Note alternating shale diapirs (SD 1 to SD 4) and subbasins (SB 1 to SB 4). Approximate location of San Marcos Arch axis is shown on right side of this figure (see actual location in Figure 1). Red horizon = near base Jackson. Black log curve = gamma ray log; and red log curve = sonic log. 5 km = ~3.1 mi.

nithus minutus (31.10 Ma) and *Rhabdosphaera tenuis* (31.70 Ma) nanofossils that are characteristic of the upper Vicksburg, whereas the lower Frio is characterized by *Helicosphaera wilcoxonii* (30.0 Ma) and *Helicosphaera compacta* (30.0 Ma) nanofossils. In Figure 19, the last 100 m (~300 ft) of the lower Frio shale that caps the curvilinear anticlines is composed of interbedded sandstones and shale beds. The thickness of each shale bed ranges from about 6–20 m (~20–60 ft), while the thickness of sandstone beds ranges from about 3–12 m (~10–40 ft). Because this lower Frio shale is not composed of 100 percent shale, it cannot be regarded as a good caprock with good sealing properties. Thus, the lack of hydrocarbons in well J can be attributed to either the poor sealing properties of the caprock overlying the curvilinear anticlines at this location or because it was drilled too far downdip of the structural crest and potentially outside of closure as suggested by Figure 5, or due to a combination of both.

In the survey #2 area, the structures are essentially fault closures with many crestal faults. Because this area is more distally located basinward, the caprock could be shalier than in survey #1. However, the presence of many crestal faults and the poor rollover character reduced the hydrocarbon trapping potential of these fault closures.

In contrast, as evidenced by the bottom part of well M (that is, the last 230 m [~750 ft] of the wellbore), the lower Frio shale capping the faulted erosional anticlines in survey areas #3 and #4 is composed of almost 100 percent continuous shale (Fig. 14C). These sediments are characterized by low-amplitude and high-frequency events. These events extend from the bottom of the borehole to the top of the faulted erosional anticlines—from ~3.0–4.1 s (Fig. 14B). Because these seismic events are very similar to those that characterize the bottom part of well M suggests that

the interval from 3.0–4.1 s would be mostly shale, albeit there are some zones such as the dashed magenta outline that may be sand-prone (Figs. 8B and 9B). Therefore, the caprock overlying the faulted erosional anticlines can be regarded as very competent with good sealing properties.

In these two survey areas, the main concern with respect to hydrocarbon trapping potential is whether there will be reservoir sandstones. To address this issue, we extracted sweetness and instantaneous frequency attributes. These two attributes have been shown to be very effective in the identification of sandstone-rich zones in shale-dominated depositional environments (Ogiesoba, 2017; Ogiesoba et al., 2018). The relationship between sandstone richness and the sweetness attribute shows that the sweetness value increases as sandstone richness increases (Ogiesoba, 2017). In addition, instantaneous frequency values increase as shale content increases; that is, low values of instantaneous frequency suggest an increase in sandstone richness (Robertson and Fisher, 1988; Taner, 2003; Ogiesoba et al., 2018). On the basis of these deductions, we extracted sweetness and instantaneous frequency along the Vicksburg surface and identified sandstone-rich zones in surveys #3 and #4. In Figure 20, we show the sweetness attribute map that was extracted in these two surveys. As can be seen in Figure 20A, the high sweetness values (green to red to yellow color) indicative of sandstone-rich zones are enclosed by the dotted-black outline. On transferring this outline onto the instantaneous frequency map (Fig. 20B), we find that the outline is coincident with the outline of the low-frequency zone. Values within the low-frequency zone range from ~5–15 Hz (magenta to deep blue, Fig. 20B), whereas values within the high-frequency (shale-rich) zones range from ~20–45 Hz (cyan to yellow, Fig. 20B). By transferring sandstone-rich

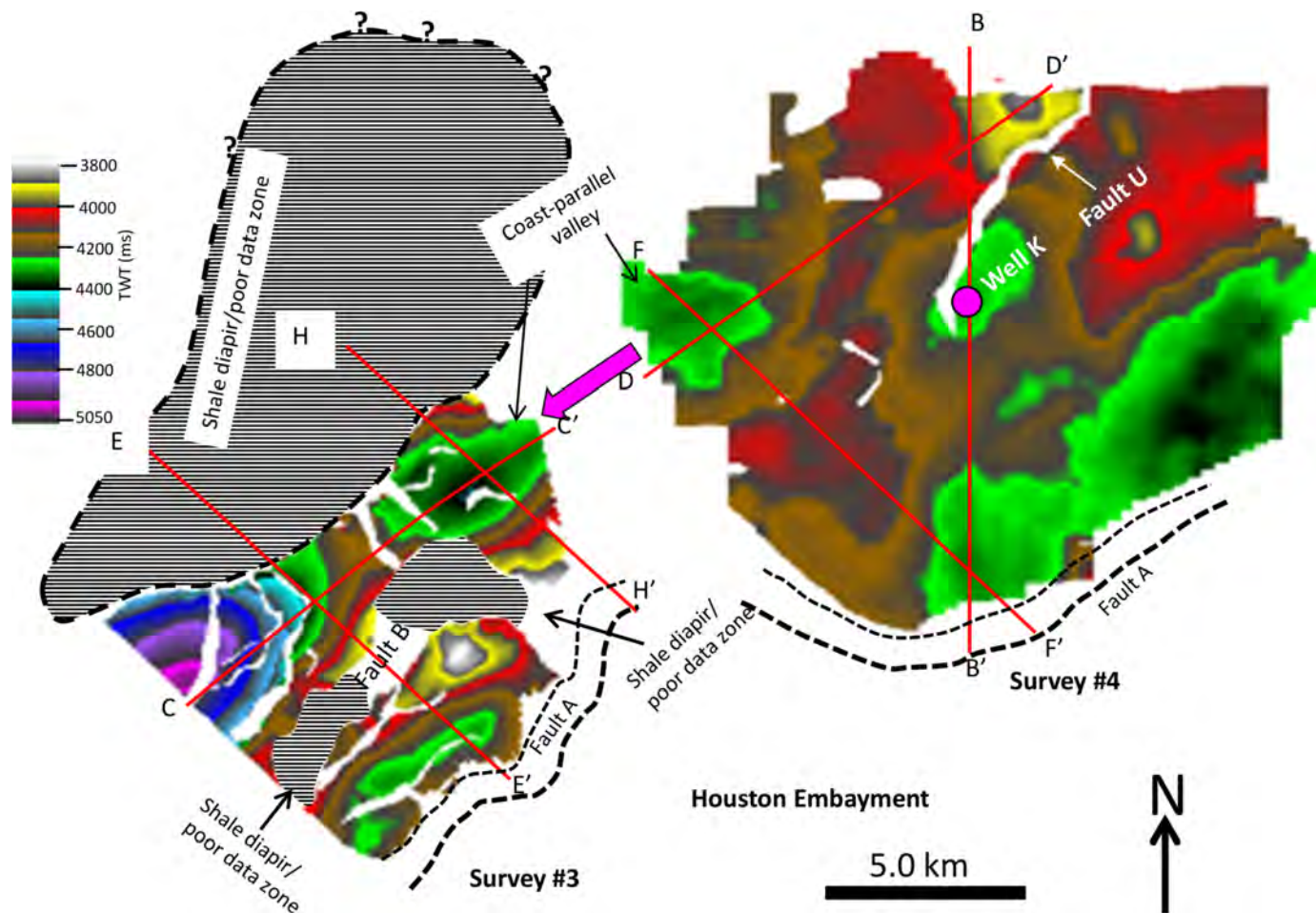


Figure 13. (A) Map of top Vicksburg Formation in survey #3 showing southwest-northeast trending faulted anticline, southwest-northeast trending interpreted shale diapir/poor data zone, minor antithetic faults, and minor coast-orthogonal faults. (B) Map of top Vicksburg Formation in survey #4 showing three lines of sections discussed in text and erosional anticline having two culminations. Note question marks along dashed black line suggesting uncertainty in diapir boundary. 5 km = ~3.1 mi.

outlines on the structure map, it can be seen that the structurally high areas fall within the sandstone-rich zones (Figs. 21A and 21B). In the southwestern part of survey #4, the sandstone-rich outline coincides with the closing contour (4200 ms, yellow outline). It appears that almost all the erosional highs in survey #4 are sandstone-rich, suggesting that the highs are remnant sandstone beds resistant to erosion. We consider these erosional highs to be prospective because the structures have both vertical and lateral seal. However, in survey #3, apart from the central structural fault closure to the northwest along line E–E', all other highs are shale-prone. Some other areas that appear to be sandstone-rich, such as in the southeast along line E–E', are in a low.

SUMMARY AND CONCLUSIONS

The results of the above investigations are summarized in Figures 16 and 22 (2D version of Figure 16). In the Rio Grande Embayment, the surface of detachment occurs just below the base of the Jackson Group (Fig. 5); in the Houston Embayment, the top of the Vicksburg Group is interpreted to be the detachment surface.

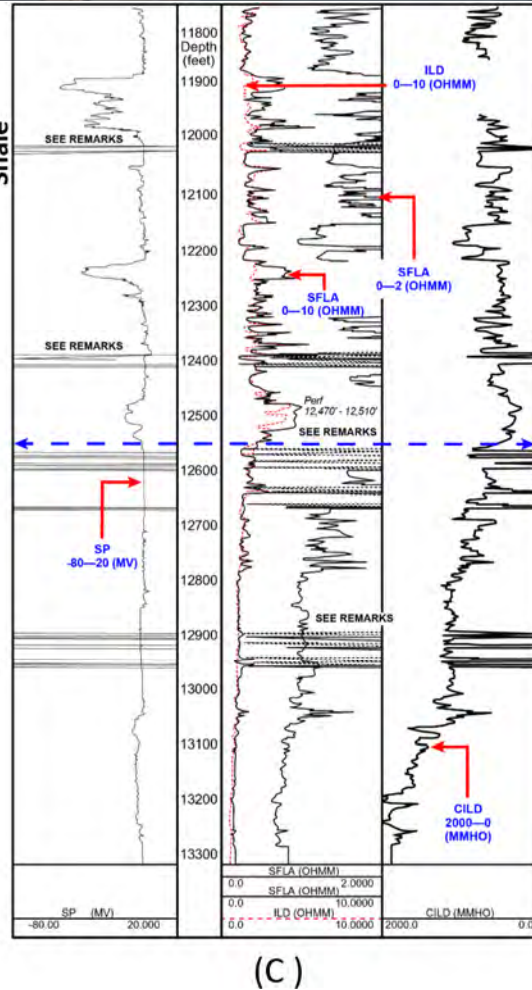
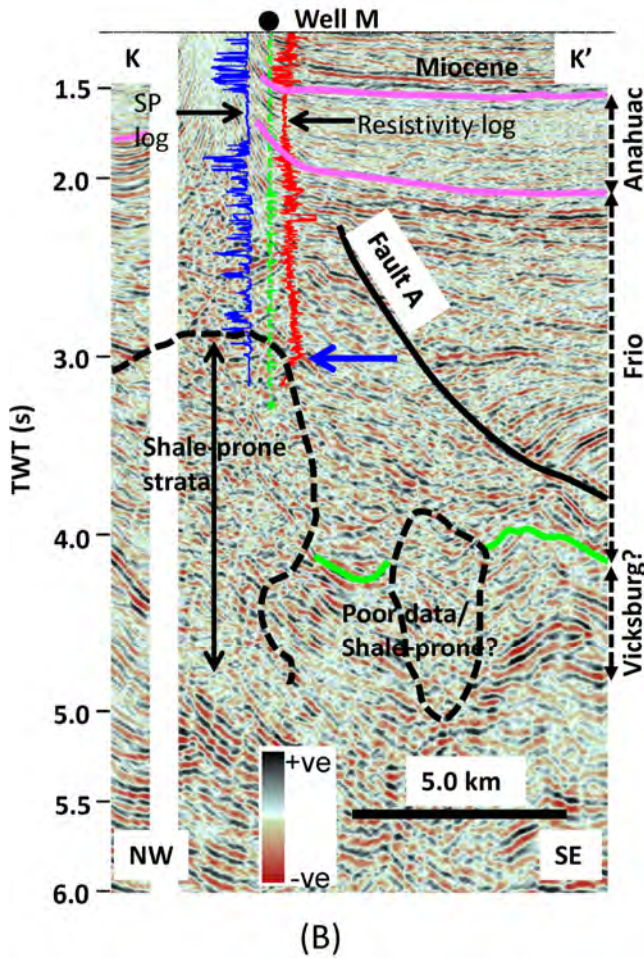
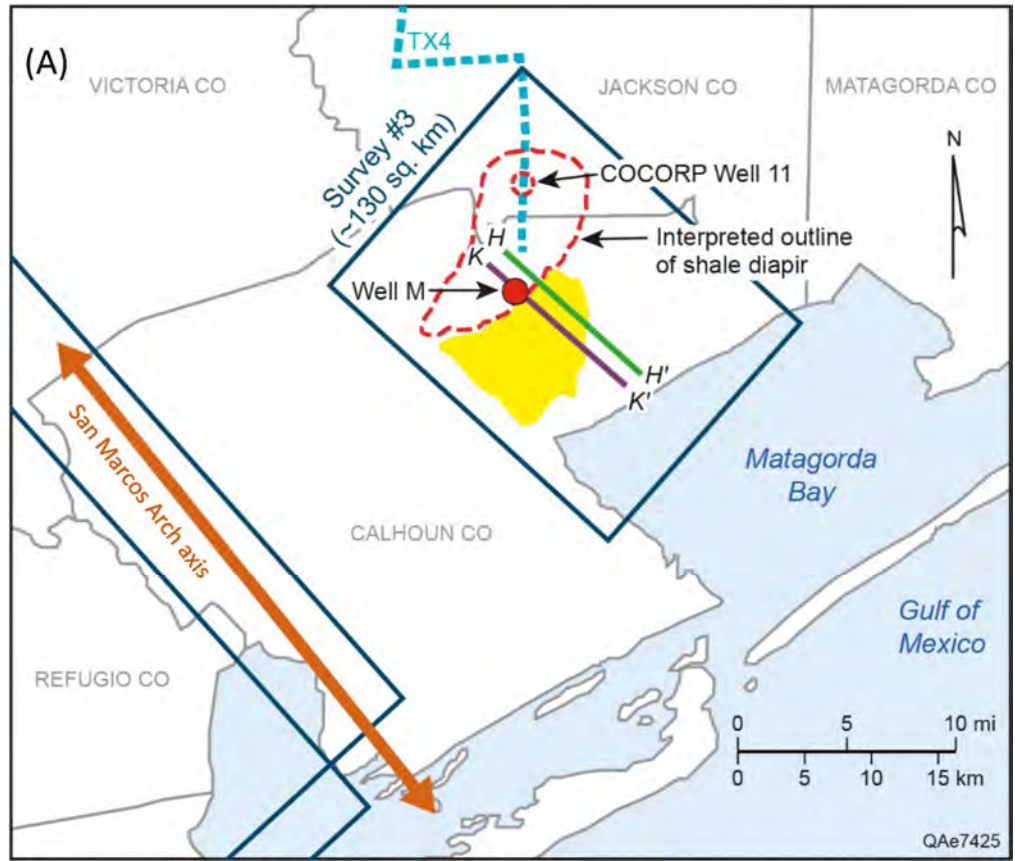
In the Rio Grande Embayment, in addition to the coast-parallel synthetic and antithetic faults, the pattern of deformation includes prominent alternating coast-orthogonal shale ridges, subbasins, and coast-orthogonal faults that suggest local lateral compression and vertical loading. Furthermore, structural ele-

ments also exhibit northwest-southeast trending curvilinear anticlines. In the Houston Embayment, the dominant structural elements are coast-parallel synthetic faults and coast-parallel shale ridges.

Deformation in the Houston Embayment is more severe than in the Rio Grande Embayment and increases with nearness to the axis of the San Marcos Arch. In the Rio Grande Embayment, the subsea elevation of the top of the Vicksburg Group ranges from a seismic two-way time of ~1380–3000 ms (~1550–3380 m [~5085–11,100 ft]); in the Houston Embayment, it ranges from ~3770–5050 ms (~4600–5850 m [~15,100–19,200 ft]).

Based on the map at the top of the Vicksburg in the vicinity of the San Marcos Arch, we conclude the following: (1) although the prevailing mechanism of deformation during the deposition of the Eocene (Jackson Group) and Oligocene (Vicksburg Group) in the Rio Grande and Houston embayments was extensional tectonics, stratal deformational patterns are different in each basin; (2) the Houston Embayment is deeper than the Rio Grande; (3) the geometry of the San Marcos Arch must have influenced the shape and depths of the basins and, thus, the stratal deformational patterns; and (4) on the basis of sweetness and instantaneous frequency attributes, the remnant erosional anticlinal structure within the Houston Embayment, which is capped by more than 1000 m (~3200 ft) thick shale and has a vertical closure of ~180–250 m (~590–820 ft) in survey #4, constitutes a potential hydrocarbon prospect. However, more 3D seismic data

Figure 14. (A) Base map showing locations of well M, lines H–H' (green), K–K' (magenta), interpreted outline of shale diapir (dashed red line), location of COCORP well 11, and COCORP TX4 (cyan). (B) Line K–K' through well M. Note that well M bottomed within shale-prone diapir. 5 km = ~3.1 mi. (C) Log responses in well M. Note rapid decrease of resistivity (ILD) from the dashed blue, double-headed arrow to near zero ohm-m at end of well, and rapid increase of conductivity (CILD), the double-headed arrow to 2000 mmho (2000 millisiemens) at end of well. Note: "See Remarks" indicates tight hole where drilling-tool string is pulling intermittently, induction and spontaneous potential curves appear to fail, and caliper is being closed/opened to free the tool—suggesting sticky and swelling shale zones. 100 ft = ~30.5 m.



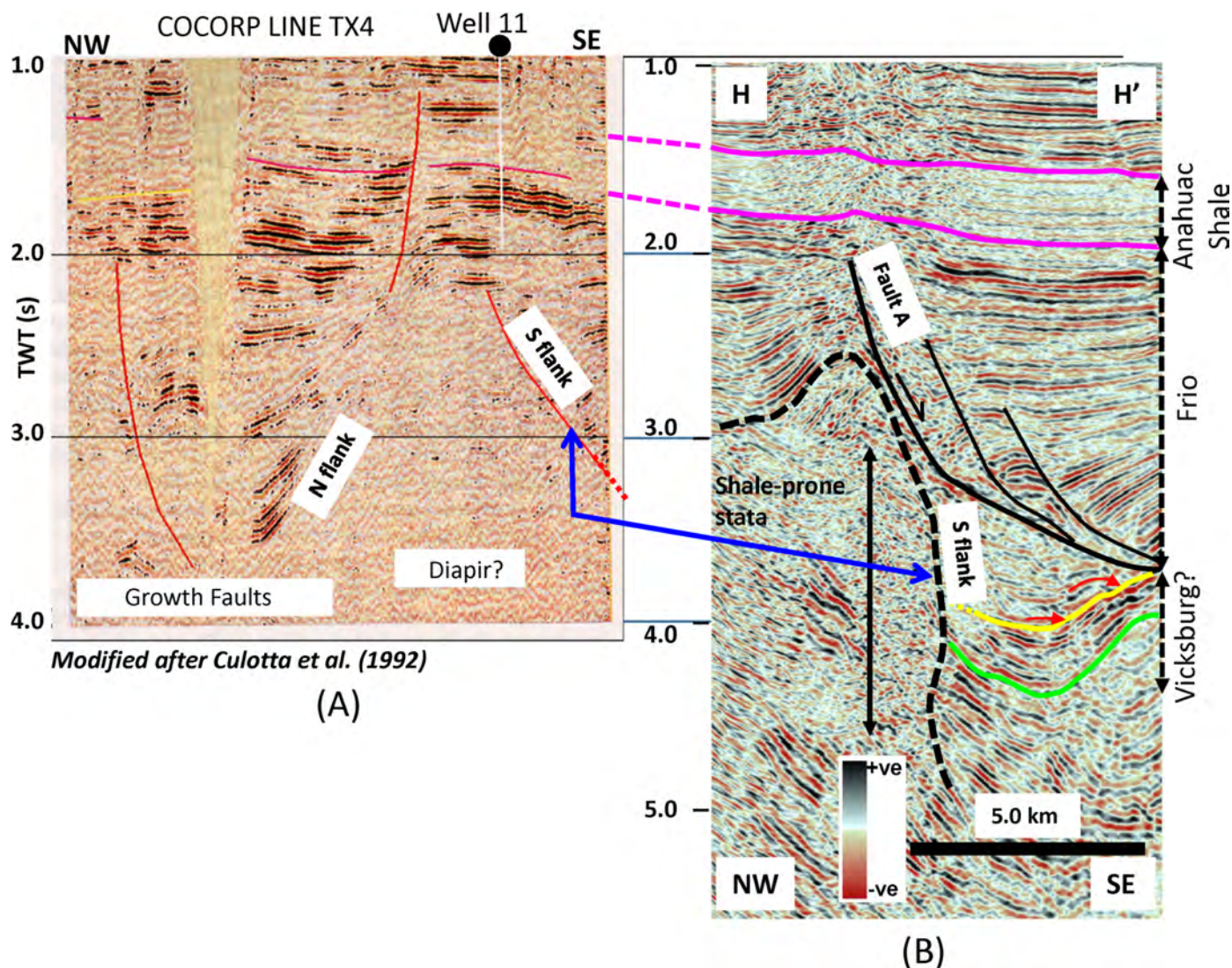


Figure 15. Comparison between (A) COCORP interpreted line TX4 (modified after Culotta et al., 1992) and (B) 3D line H-H'. Note that diapir with a question mark in TX4 corresponds to shale-prone diapir identified in H-H'. See text for more details. 5 km = ~3.1 mi.

are needed to determine the full areal extent of these structures to the northeast.

ACKNOWLEDGMENTS

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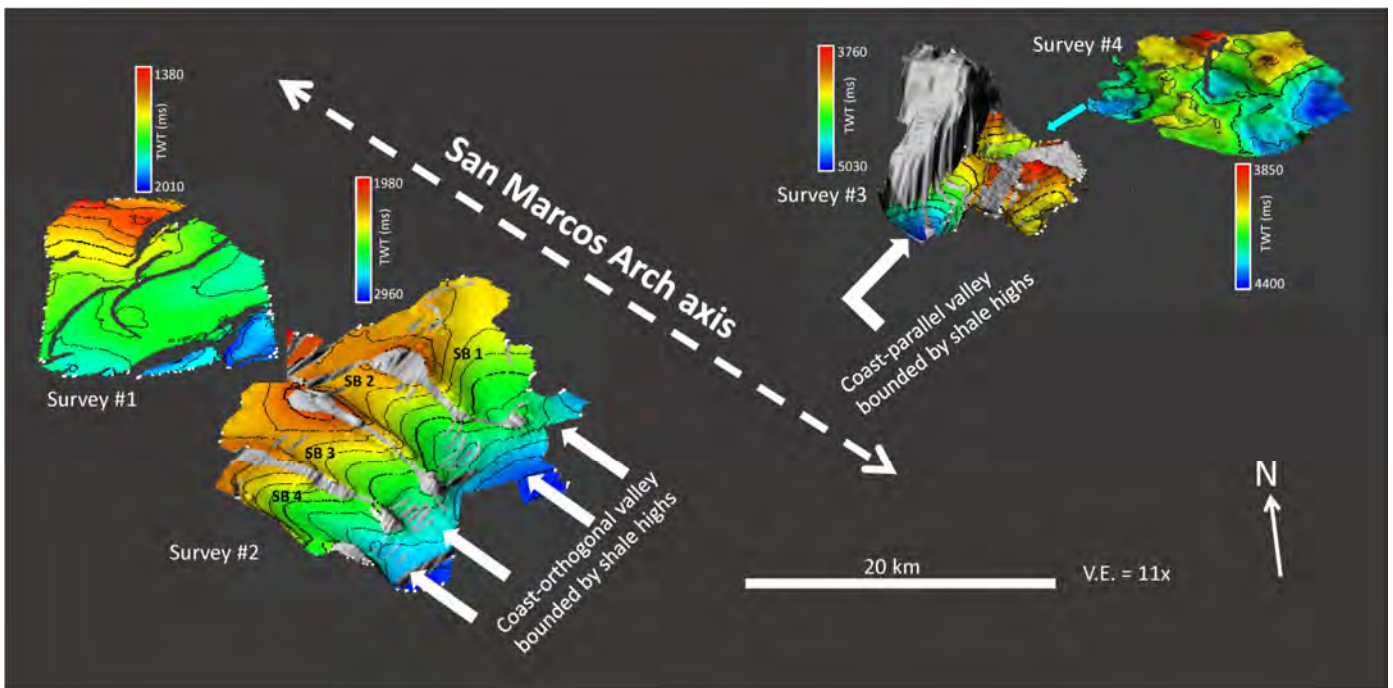


Figure 16. 3D display of top Vicksburg map in surveys #1 through #4. Note enhanced curvilinear faults in survey #1 and coast-orthogonal faults, subbasins, shale ridges, and curvilinear subbasin SB 1 in survey #2. 20 km = ~12.4 mi.

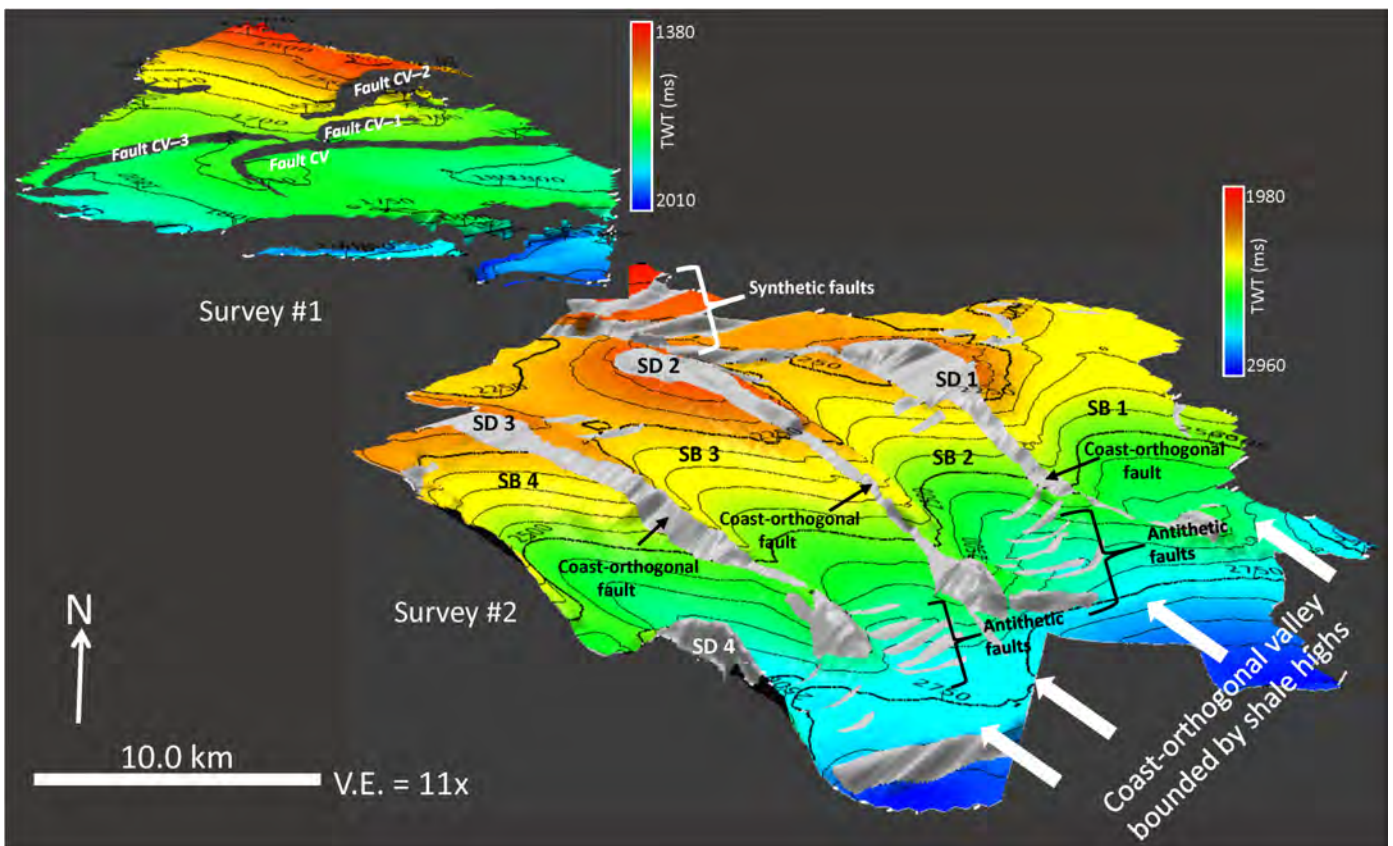


Figure 17. 3D display of top Vicksburg map in surveys #1 and #2. Note accentuated curvilinear faults in survey #1 and accentuated coast-orthogonal faults, subbasins, shale ridges, and curvilinear subbasin SB 1 in survey #2. 10 km = ~6.2 mi.

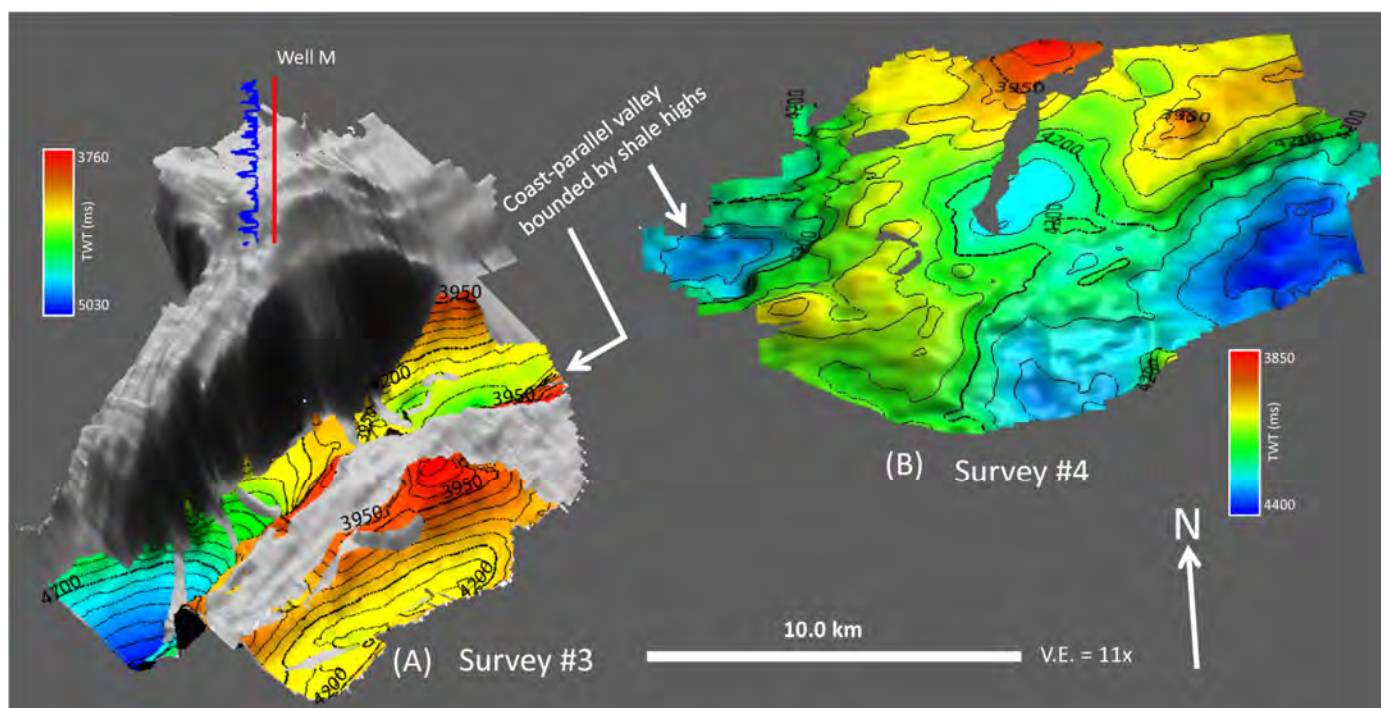


Figure 18. 3D display of top Vicksburg map in (A) survey #3 showing well M penetration into shale mass (note accentuated coast-parallel shale ridges and valleys) and (B) survey #4. Note accentuated erosional anticlines. Displayed log curve in well M = spontaneous potential log. 10 km = ~6.2 mi.

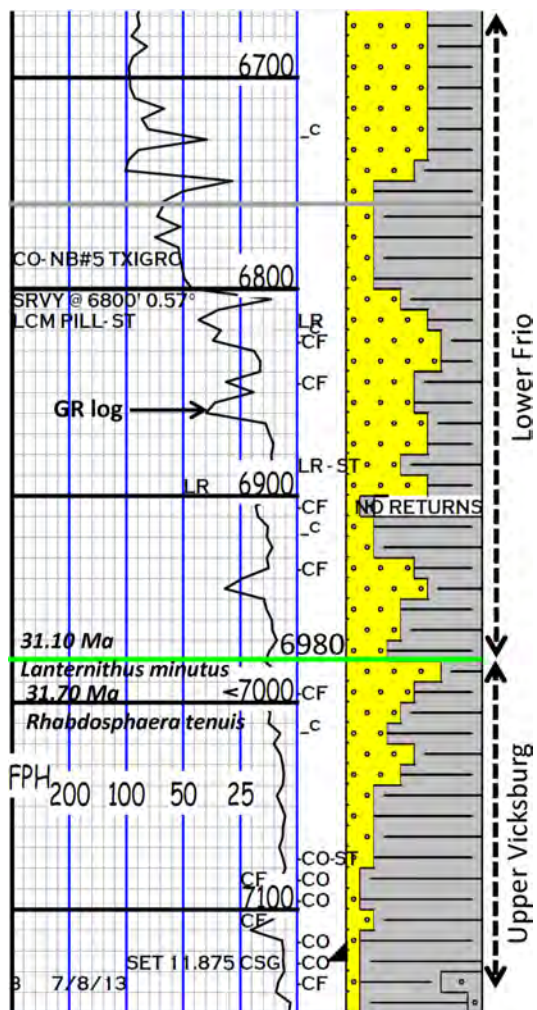


Figure 19. Gamma ray log (GR log) from well J showing depth intervals between ~2040–2180 m (~6700–7150 ft) and depths to top Vicksburg (~2130 m [~6980 ft]). Note Frio strata overlying top Vicksburg are composed of sandstone and shale beds, suggesting shales with poor sealing properties—weak caprock. 100 ft = ~30.5 m.

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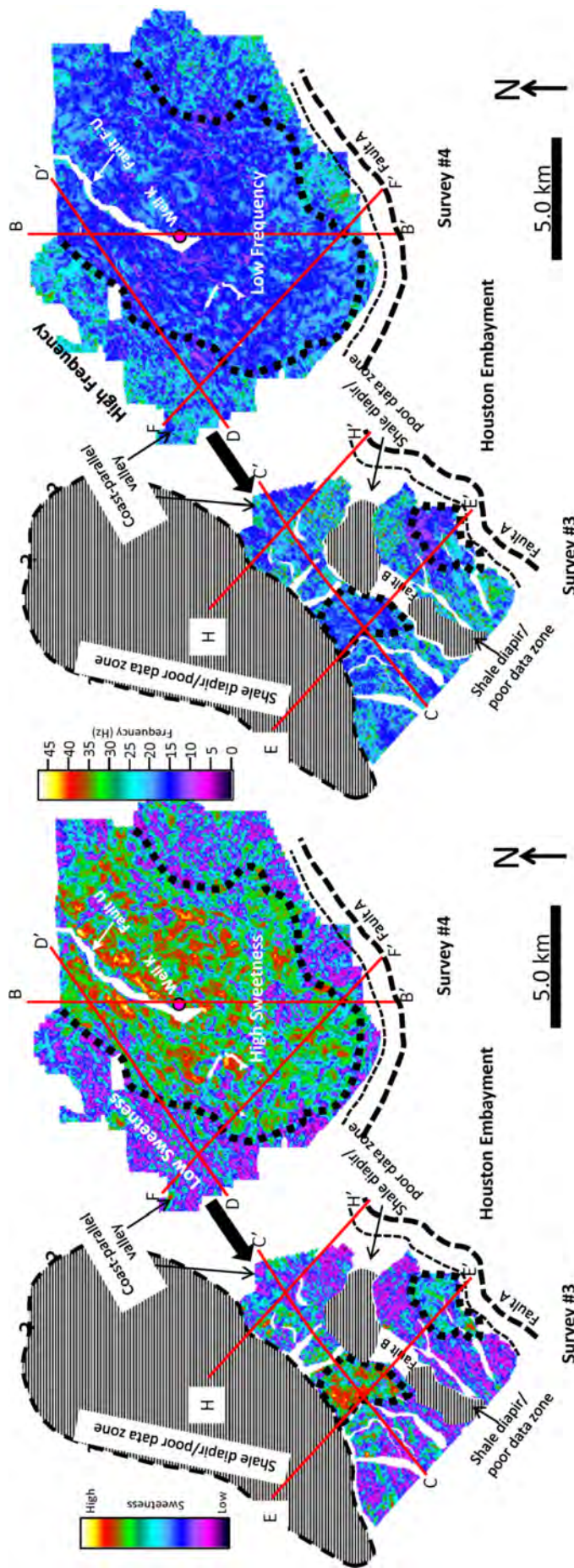
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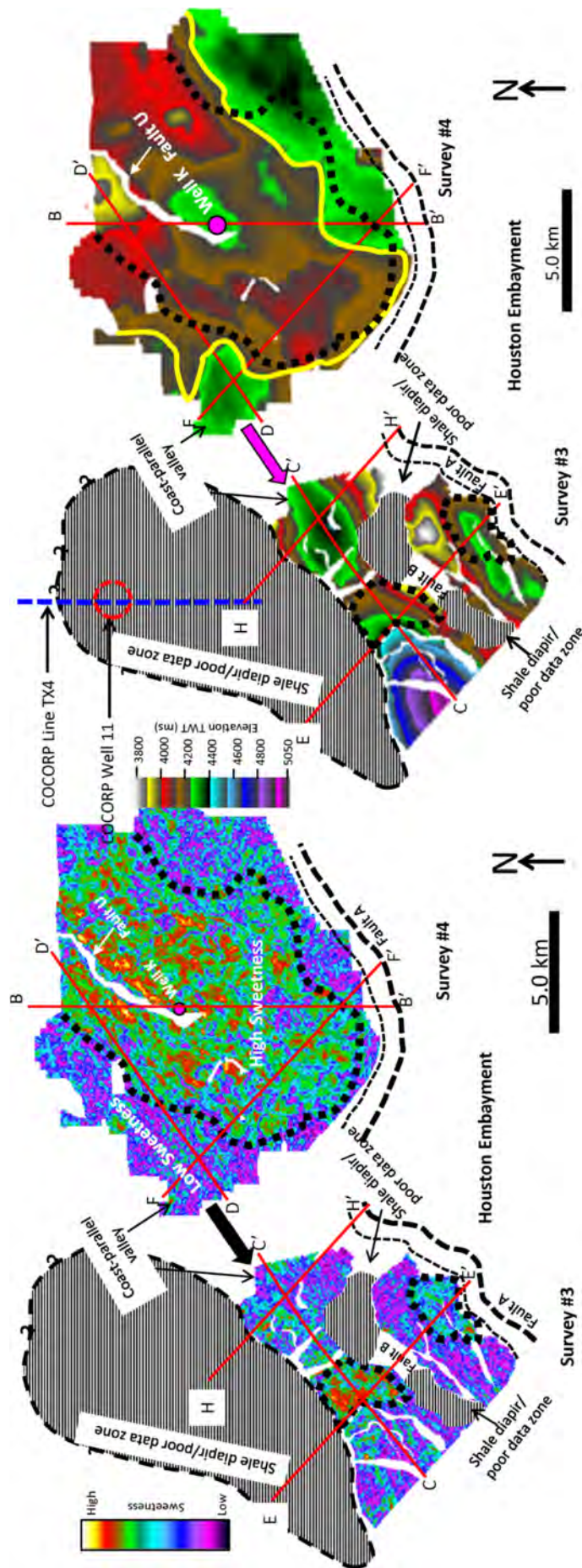
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(A) (B) Figure 20. Maps showing extracted attributes along top Vicksburg horizon in surveys #3 and #4. (A) Sweetness map and (B) instantaneous frequency map. Note south-west-northeast trending shale diapir. Note question marks along dashed black line suggesting uncertainty in diapiir boundary. 5 km = ~3.1 mi.



(A) (B)

Figure 21. Maps showing outlines of high sweetness value areas (dotted black lines) overlain on top Vicksburg structure map in surveys #3 and #4. Note that high sweetness values suggest sandstone-rich zones. Yellow line = ~1280 m (~4200 ft) contour line. Note southwest-northeast trending shale diapir. Note question marks along dashed black line suggesting uncertainty in diapir boundary. 5 km = ~3.1 mi.

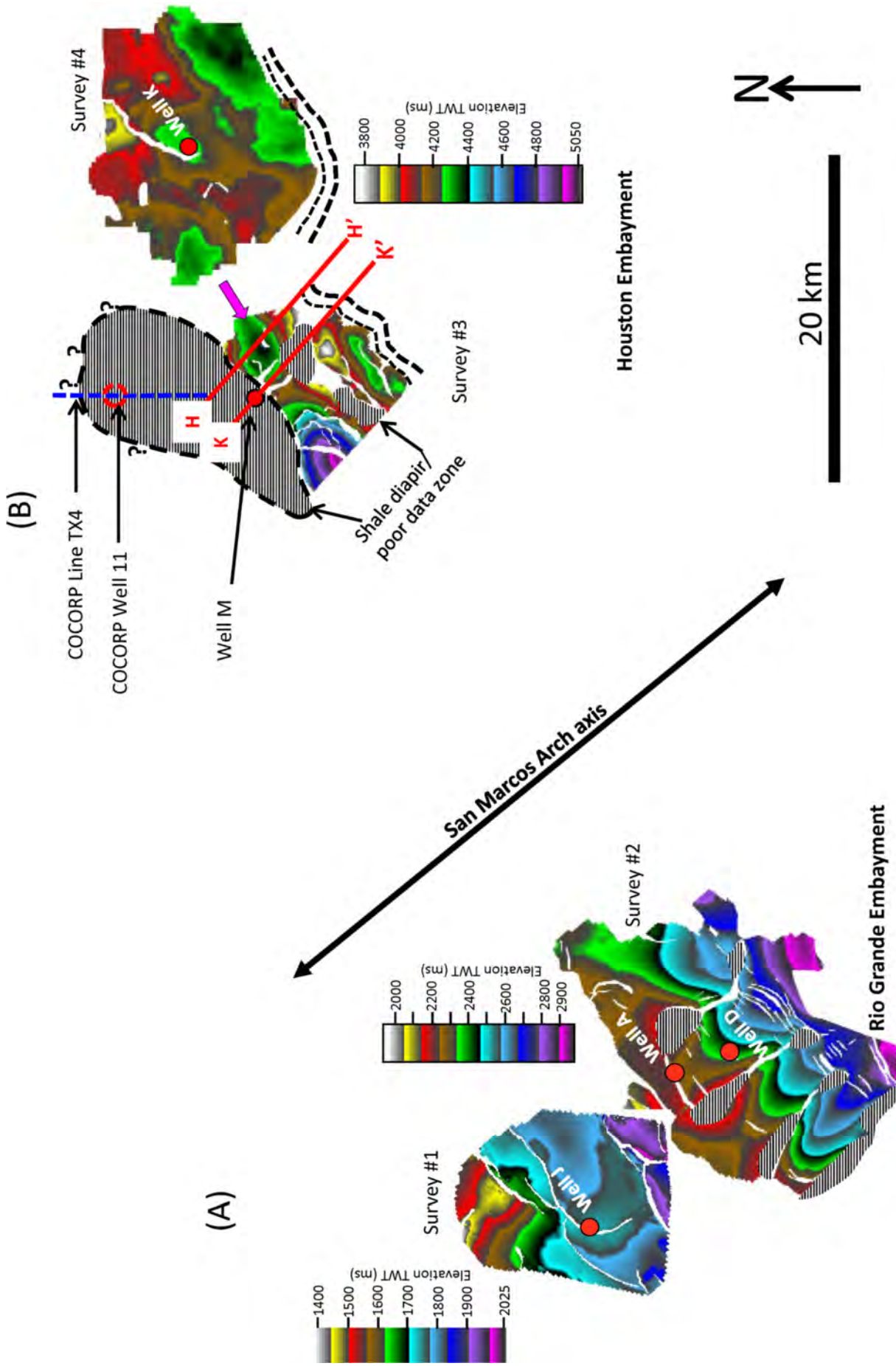


Figure 22. Map of top Vicksburg in surveys #1 through #4 showing location of San Marcos Arch axis and combined maps in surveys #1 and #2. Note that combined top Vicksburg map in surveys #1 and #2 have different color values, ranging from 1380 to ~2980 ms and from 1980 to ~2980 ms, respectively. Maps in surveys #3 and #4 have the same color values, ranging from 3770 to 5050 ms. Note southwest-northeast trending shale diapir, a segment of COCORP line TX4, and COCORP well 11. Note question marks along dashed black line suggesting uncertainty in diapir boundary. 20 km = ~12.4 mi.



Remembering James Albert Knupke



James Albert Knupke

-

Corpus Christi - James Albert Knupke, long time former Corpus Christi resident, passed away peacefully in Boerne, Texas on July 8, 2020 at the age of 93.

-

James was born near Clyde, Ohio on May 17, 1927 to Reverend Arthur Andrew Knupke and Anna Azalea (Albert) Knupke. He graduated from high school in Payne, Ohio. He enlisted in the U.S. Navy in 1945 and served at Corpus Christi Naval Air Station. After his discharge from the Navy, he attended Capital University, Columbus, Ohio and Miami University, Oxford, Ohio where he received B.A. and M.S. degrees in Geology. He started his career in petroleum and uranium exploration with Continental Oil Company and continued in that business for 50 years. A lifelong Lutheran, he served faithfully in his church as elder, Bible class teacher and choir member at Trinity Lutheran, Corpus Christi where he was a member for 56 years.

-

Jim was an active member of the Corpus Christi Geological Society, Coastal Bend Gem and Mineral Society, the Energy Minerals Division of the American Association of Petroleum Geologists and the Coastal Bend Geological Library. He enjoyed meeting at these gatherings with his friends and associates. He helped organize the Corpus Christi International Seamen's Center in 1971 and supported this institution for many years. He loved the National Parks and took the family camping at many of them. He climbed Guadalupe Peak, with some fellow Midland, Texas geologists in the late 1950's before the area was declared a National Park in 1972.

-

Jim is survived by his loving wife, Ruth, of 62 years, his daughter Sarah Ruddock of Katy, Texas, and daughter Kathryn Rutherford of Boerne, Texas, their husbands Michael Ruddock and Scott Rutherford, their grandchildren, Mitchell and Sydney Ruddock, Frances Kay and R.J. Rutherford, as well as his sisters Marian Kuehnert of Woodburn, Indiana and Joan Hartwig of Fort Wayne, Indiana, his brother in law Robert Pomerence of Mesa, Arizona and numerous nieces and nephews.

-

Jim loved geology as it highlighted the beauty of God's creation. He put trust in his Lord Jesus and is most certainly in the serenity of God's glorious presence in heaven.

-

Friends and family may send cards and condolences to the family to the attention of Mrs. James A. Knupke, [1100 Grand Blvd., Apt. 328, Boerne, Texas 78006](mailto:1100GrandBlvdApt328@BoerneTexas78006). If desired, memorial donations may be made to the Lutheran Hour Ministries.

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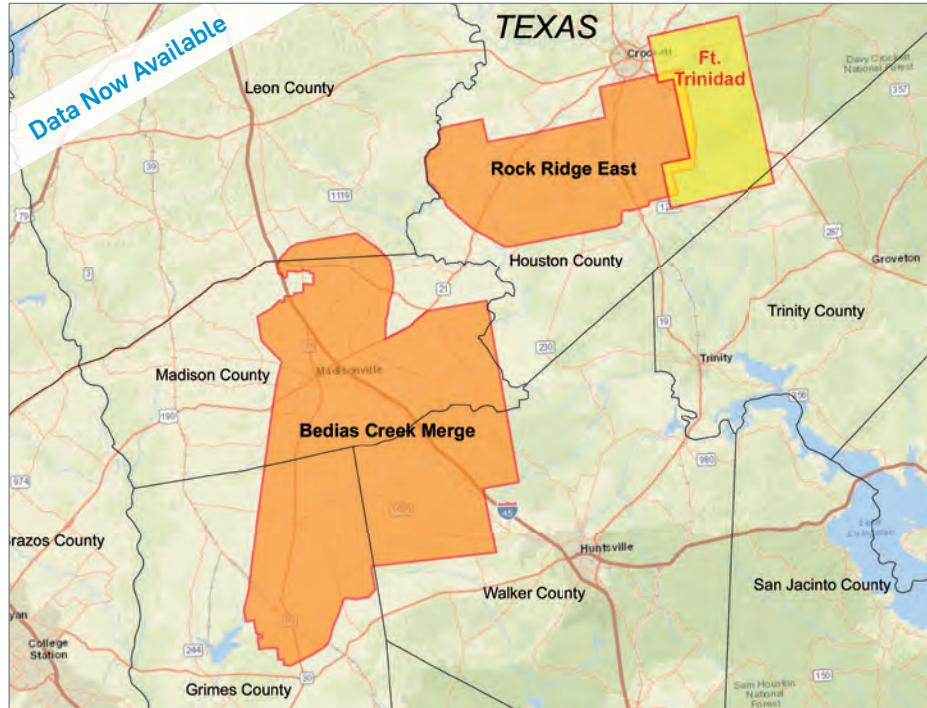
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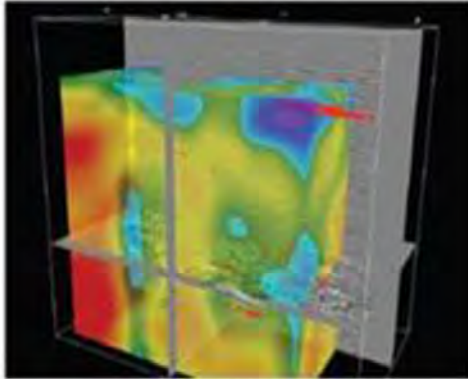
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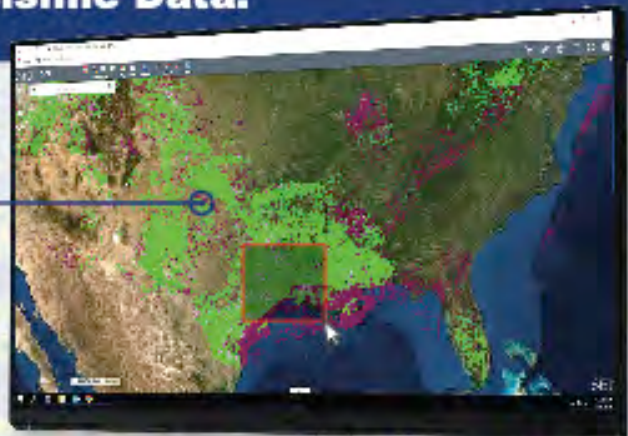
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Geology of the Llano Uplift, Central Texas, and Geological Features in the Uvalde Area. Corpus Christi Geological Society Annual Spring Field Conference, May 7-9, 1982. Various paginated. 115 p., 53 p.
[CCGS 110G](#) \$15.00

Structure and Mesozoic Stratigraphy of Northeast Mexico, prepared by numerous authors, variously paginated. 76 p., 38 p., 1984.
[CCGS 111G](#) \$15.00

Geology of the Big Bend National Park, Texas, by C. A. Berkebille. 26 p., 1984.
[CCGS 112G](#) \$12.00

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<http://www.lib.utexas.edu/books/landsapes/index.php> Free service. Rare, fragile, hard-to-find, public domain documents covering various topics about the landscape of Texas. Includes the Texas Geological Survey from 1887 until 1894.

USGS TAPESTRY OF TIME AND TERRAIN <http://tapestry.usgs.gov> The CCGS is donating to all of the 5th and 6th grade schools in the Coastal Bend. Check it out--it is a spectacular map. You might want to frame one for your own office. The one in my office has glass and a metal frame, and It cost \$400 and it does not look as good as the ones we are giving to the schools.

FREE TEXAS TOPOS'S <http://www.tnris.state.tx.us/digital.htm> these are TIFF files from your state government that can be downloaded and printed. You can ad them to SMT by converting them first in Globalmapper. Other digital data as well.

FREE NATIONAL TOPO'S [http://store.usgs.gov/b2c_usgs/b2c/start/\(xcm=r3standardpitrex_prd\)/do](http://store.usgs.gov/b2c_usgs/b2c/start/(xcm=r3standardpitrex_prd)/do) go to this webpage and look on the extreme right side to the box titled TOPO MAPS DOWNLOAD TOPO MAPS FREE.

<http://www.geographynetwork.com/> Go here and try their top 5 map services. My favorite is 'USGS Elevation Date.' Zoom in on your favorite places and see great shaded relief images. One of my favorites is the Great Sand Dunes National Park in south central Colorado. Nice Dunes.

<http://antwrp.gsfc.nasa.gov/apod/asropix.html> Astronomy picture of the day--awesome. I click this page everyday.

<http://www.spacimaging.com/gallery/ioweek/iow.htm> Amazing satellite images. Check out the gallery.

<http://www.ngdc.noaa.gov/seg/topo/globegal.shtml> More great maps to share with kids and students.

www.ccgeo.org Don't forget we have our own we page.

<http://terra.nasa.gov/gallery/> Great satellite images of Earth.

www.ermaper.com They have a great free downloadable viewer for TIFF and other graphic files called ER Viewer.

<http://terrasrver.com> Go here to download free aerial photo images that can be plotted under your digital land and well data. Images down to 1 meter resolution, searchable by Lat Long coordinate. Useful for resolving well location questions.

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Copano Bay, South
Estes Cove
Fulton Beach
Goose Island
Half Moon Reef
Nine Mile Point
Rockport, West
St. Charles
Tally Island
Tract 831-G.O.M. (offshore)
Virginia

BEE COUNTY

Caesar
Mosca
Nomanna
Orangedale(2)
Ray-Wilcox
San Domingo

Tulsita Wilcox

Strauch_Wilcox

BROOKS COUNTY

Ann Mag
Boedecker
Cage Ranch
Encintas
ERF

Gyp Hill
Gyp Hill West

Loma Blanca

Mariposa

Mills Bennett

Pita

Tio Ayola

Tres Encinos

CALHOUN COUNTY

Appling
Coloma Creek, North
Heyser

Lavaca Bay

Long Mott

Magnolia Beach

Mosquito Point

Olivia

Panther Reef

Powderhorn

Seadrift, N.W.

Steamboat Pass

Webb Point

S.E. Zoller

CAMERON COUNTY

Holly Beach

Luffles

San Martin (2)

Three Islands, East

Vista Del Mar

COLORADO COUNTY

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Graceland N. Fault Blk
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Anna Barre

Cook

Nordheim

Smith Creek

Warmesley

Yorktown, South

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Four Seasons

Good Friday

Hagist Ranch

Herbst

Loma Novia

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Seven Sisters

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Berclair

North Blanconia

Bombs

Boyce

Cabeza Creek, South

Goliad, West

St Armo

Terrell Point

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Donna

Edinburg, West

Flores-Jeffress

Foy

Hidalgo

LA Blanca

McAllen& Pharr

McAllen Ranch

Mercedes

Monte Christo, North

Penitas

San Fordyce

San Carlos

San Salvador

S. Santallana

Shary

Tabasco

Weslaco, North

Weslaco, South

JACKSON COUNTY

Carancahua Creek

Francitas

Ganado & Ganado Deep

LaWard, North

Little Kentucky

lost now found

Maurbro

StewartSwan Lake

Swan Lake, East

Texana, North

West Ranch

JIM HOGG COUNTY

Chaparosa

Thompsonville,N.E.

JIM WELLS COUNTY

Freeborn

Hoelscher

Palito Blanco

Wade City

KARNES COUNTY

Burnell

Coy City

Person

Runge

KENEDY COUNTY

Candelaria

Julian

Julian, North

Laguna Madre

Rita

Stillman

KLEBERG COUNTY

Alazan

Alazan, North

Big Caesar

Borregos

Chevron (offshore)

Laguna Larga

Seeligson

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LA SALLE COUNTY

Pearsall

HAWKVILLE:EAGLEFORD

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Hallettsville

Hope

Southwest Speaks

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LIVE OAK COUNTY

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Braslau

Chapa

Clayton

Dunn

Harris

Houdman

Kittie West-Salt Creek

Lucille

Sierra Vista

Tom Lyne

White Creek

White Creek, East

MATAGORDA COUNTY

Collegeport

MCMULLEN COUNTY

Arnold-Weldon

Brazil

Devil's Waterhole

Hostetter

Hostetter, North

NUECES COUNTY

Agua Dulce (3)

Arnold-David

Arnold-David, North

Baldwin Deep

Calallen

Chapman Ranch

Corpus Christi, N.W.

Corpus Christi West C.C.

Encinal Channel

Flour Bluff/Flour Bluff, East

GOM St 9045(offshore)

Indian Point

Mustang Island

Mustang Island, West

Mustang Island St.

889S(offshore)

Nueces Bay/Nueces Bay

West

Perro Rojo

Pita Island

Ramada

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Riverside

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Saxet

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Turkey Creek

REFUGIO COUNTY

Bonnieview/Packery Flats

Greta

La Rosa

Lake Pasture

Refugio, New

Tom O'Connor

SAN PATRICIO COUNTY

Angelita East

Commonwealth

Encino

Enos Cooper

Geronimo

Harvey

Hiberia

Hodges

Mathis, East

McC Campbell Deep/Aransas Pass

Midway

Midway, North

Odem

Plymouth

Portilla (2)

Taft

Taft, East

White Point, East

STARR COUNTY

El Tanque

Garcia

Hinde

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Ricaby

Rincon

Rincon, North

Ross

San Roman

Sun

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VICTORIA COUNTY

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Keeran, North

Marcado Creek

McFaddin

Meyersville

Placedo

WEBB COUNTY

Aquilares/Glen Martin

Big Cowboy

Bruni, S.E.

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Black Owl

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Benavides

Davis, South

Jennings/Jennings, West

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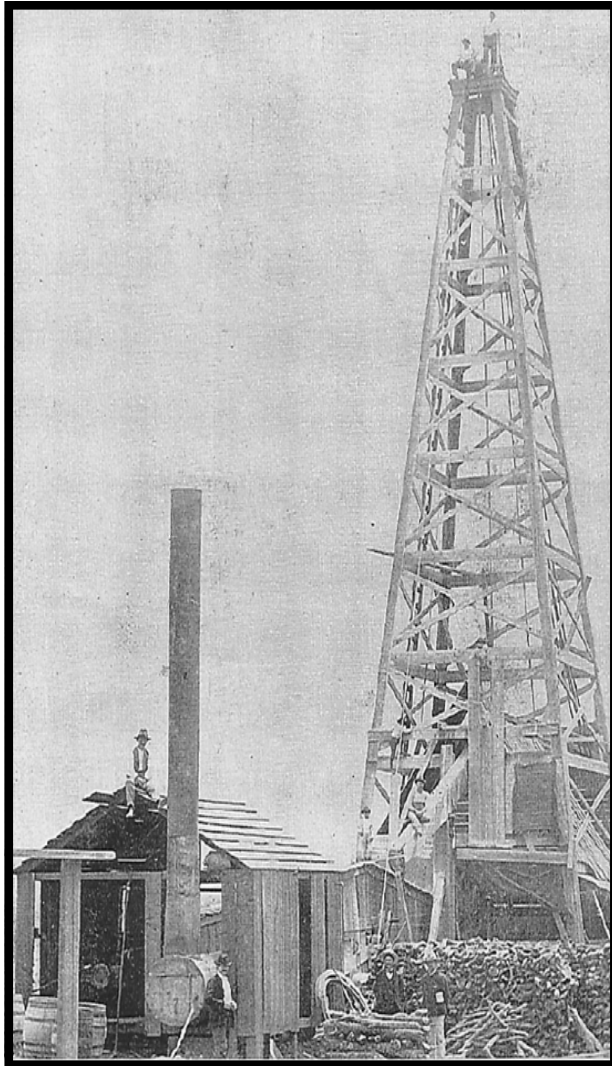
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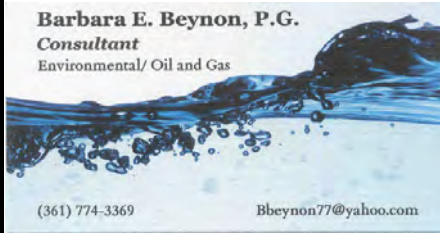
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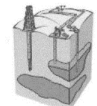
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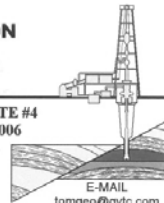
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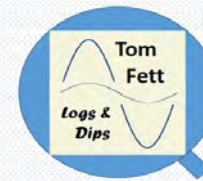
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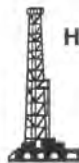


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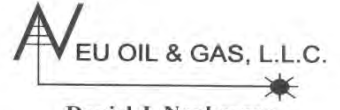
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