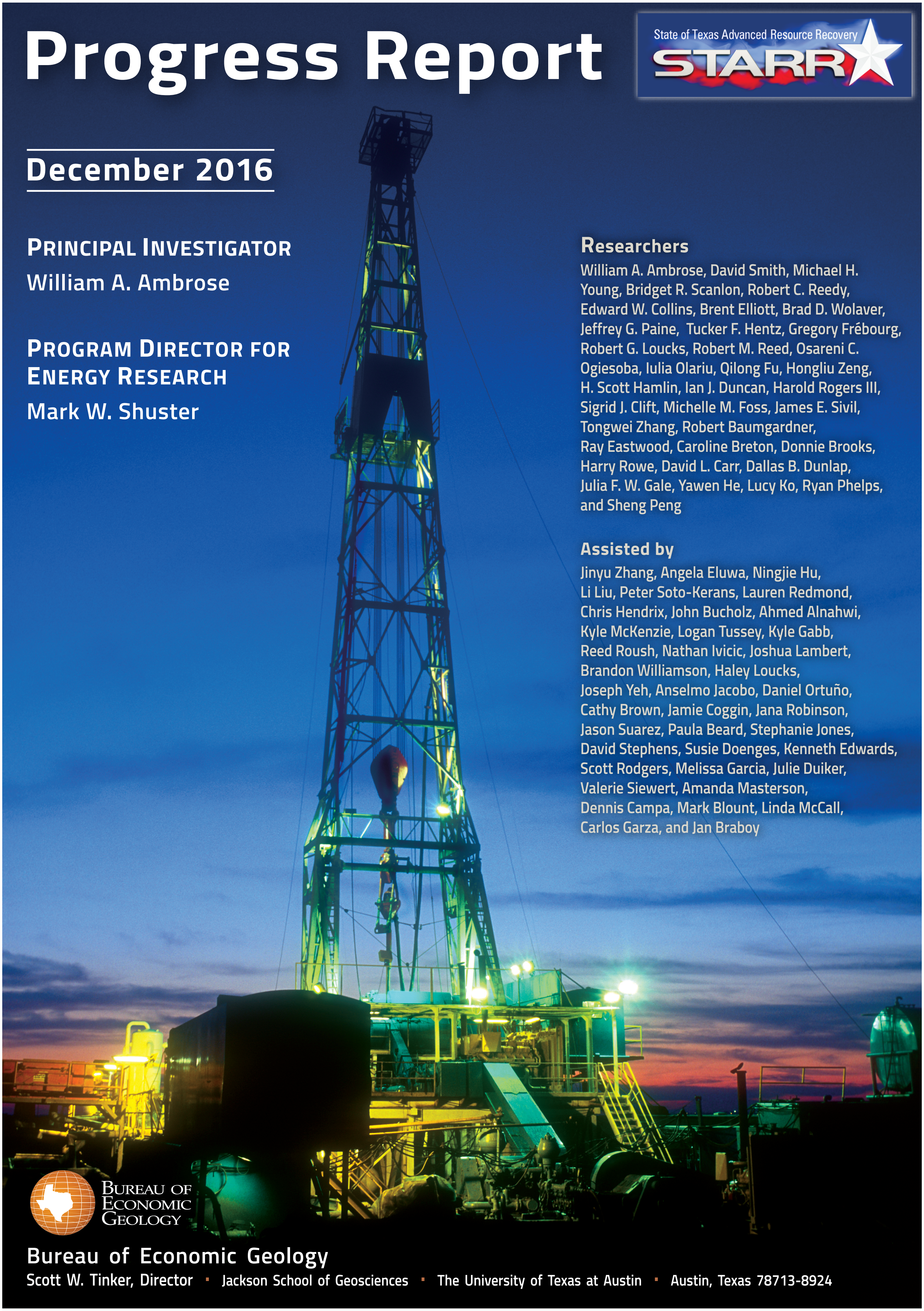

Progress Report

State of Texas Advanced Resource Recovery

STARR

December 2016

Principal Investigator

William A. Ambrose

Program Director for Energy Research

Mark W. Shuster

Researchers

William A. Ambrose, David Smith, Michael H. Young, Bridget R. Scanlon, Robert C. Reedy, Edward W. Collins, Brent Elliott, Brad D. Wolaver, Jeffrey G. Paine, Tucker F. Hentz, Gregory Frébourg, Robert G. Loucks, Robert M. Reed, Osareni C. Ogiesoba, Iulia Olariu, Qilong Fu, Hongliu Zeng, H. Scott Hamlin, Ian J. Duncan, Harold Rogers III, Sigrid J. Clift, Michelle M. Foss, James E. Sivil, Tongwei Zhang, Robert Baumgardner, Ray Eastwood, Caroline Breton, Donnie Brooks, Harry Rowe, David L. Carr, Dallas B. Dunlap, Julia F. W. Gale, Yawen He, Lucy Ko, Ryan Phelps, and Sheng Peng

Assisted by

Jinyu Zhang, Angela Eluwa, Ningjie Hu, Li Liu, Peter Soto-Kerans, Lauren Redmond, Chris Hendrix, John Bucholz, Ahmed Alnahwi, Kyle McKenzie, Logan Tussey, Kyle Gabb, Reed Roush, Nathan Ivicic, Joshua Lambert, Brandon Williamson, Haley Loucks, Joseph Yeh, Anselmo Jacobo, Daniel Ortuño, Cathy Brown, Jamie Coggin, Jana Robinson, Jason Suarez, Paula Beard, Stephanie Jones, David Stephens, Susie Doenges, Kenneth Edwards, Scott Rodgers, Melissa Garcia, Julie Duiker, Valerie Siewert, Amanda Masterson, Dennis Campa, Mark Blount, Linda McCall, Carlos Garza, and Jan Braboy

Bureau of Economic Geology

Bureau of Economic Geology

Scott W. Tinker, Director · Jackson School of Geosciences · The University of Texas at Austin · Austin, Texas 78713-8924

STATE OF TEXAS ADVANCED
RESOURCE RECOVERY PROGRAM
(STARR)

PROGRESS REPORT
DECEMBER 2016

PRINCIPAL INVESTIGATOR
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PROGRAM DIRECTOR FOR ENERGY RESEARCH
Mark W. Shuster

RESEARCHERS

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EXECUTIVE SUMMARY

The State of Texas Advanced Resource Recovery (STARR) program has been successful in its major objective to increase severance tax income for the State of Texas through research projects that promote the drilling of profitable oil and gas wells in the state. The Bureau of Economic Geology (BEG) receives funds from the State to conduct research that assists oil and gas operators in adding new or increasing existing production throughout Texas. STARR must be revenue neutral. Revenue associated with STARR projects must equal or exceed the amount appropriated to the program by the Legislature. This progress report summarizes accomplishments of Project STARR from September 1, 2014, to August 31, 2016.

Credit to the STARR program for the 2014–2016 biennium, in accordance with methodology approved by the State of Texas Comptroller's office, is $54,428,866.80 (Table 1). Relative to total income of $9.9 million over the current biennium, STARR is revenue positive by a factor of 5.5. To date, the STARR program has completed or is currently working on more than 60 field (reservoir characterization) studies (Fig. 1). Figure 2 shows the more than 20 new and completed field studies conducted during the 2014–2016 biennium. STARR has also been involved in 13 regional studies during the 2014–2016 biennium, many of them in the Permian Basin, which leads Texas in oil and gas production (Fig. 3).

Five additional program elements within STARR complement the Oil and Gas Resources program. Each of these program elements targets research that impacts key economic opportunities or challenges in Texas related to natural resources or geologic conditions. Program elements comprise geologic mapping and mineral/Earth resources of Texas, water/energy nexus issues, species, water, and landscape studies, managing water resources in times of droughts and floods, and hazards mapping and response issues. These program elements are summarized in pages 39-55 in this report.

Table 1. Summary of royalty and severance tax revenue from September 1, 2014, through July 31, 2016.
Credit to the STARR program is in accordance with methodology approved by the Texas State Comptroller's office.

Regional Studies	Condensate (BBL)	Oil Well Head Value ($)	Oil Severance Tax (4.6%)	Gas (MCF)	Gas well head value ($)	Gas Severance Tax (7.5%)	Oil Severance (25%)	Gas Severance (25%)	Total Oil ($)	Total Gas ($)	Well Count
Cleveland Marmaton Regional	1,263,460	51,263,440.47	2,306,854.82	11,441,377	25,272,408.88	1,895,430.67	576,713.71	473,857.67	576,713.71	473,857.67	68
Douglas Tonkawa Regional	999,858	41,991,532.93	1,889,618.98	7,880,799	17,917,755.58	1,343,831.67	472,404.75	335,957.92	472,404.75	335,957.92	38
Eagle Ford Regional	33,864,299	1,510,217,047.27	67,959,767.13	127,636,914	304,682,057.18	22,851,154.29	16,989,941.78	5,712,788.57	16,989,941.78	5,712,788.57	293
Frio	501,124	44,438,602.90	2,044,175.73	8,037,192	31,019,776.03	2,326,483.20	511,043.93	581,620.80	511,043.93	581,620.80	713
Marble Falls	655,761	42,191,023.08	1,940,787.06	10,704,078	34,859,649.45	2,614,473.71	485,196.77	653,618.43	485,196.77	653,618.43	268
Mississippian Bend Arch Regional	79,938	3,920,727.93	176,432.76	526,867	1,385,728.93	103,929.67	44,108.19	25,982.42	44,108.19	25,982.42	191
Spraberry Wolfcamp	16,809,233	1,486,988,702.75	68,401,480.33	53,695,970	207,048,737.25	15,528,655.29	17,100,370.08	3,882,163.82	17,100,370.08	3,882,163.82	2,133
Eastern Shelf	24,047	1,100,805.54	49,536.25	20,820	57,888.49	4,341.64	12,384.06	1,085.41	12,384.06	1,085.41	8
Wilcox Group Regional	150,470	6,380,145.77	287,106.56	2,058,286	4,814,730.20	361,104.77	71,776.64	90,276.19	71,776.64	90,276.19	21
Eaglebine	3,991,734	248,506,689.28	11,431,307.71	7,700,423	24,520,787.79	1,839,059.08	2,857,826.93	459,764.77	2,857,826.93	459,764.77	137
Wilcox Regional	1300469	67,785,874.10	3,050,364.33	19696096	53,860,702.72	4,039,552.70	762,591.08	1,009,888.18	762,591.08	1,009,888.18	65
									39,884,357.91	**13,227,004.17**	

Field Studies	Condensate (BBL)	Oil Well Head Value ($)	Oil Severance Tax (4.6%)	Gas (MCF)	Gas well head value ($)	Gas Severance Tax (7.5%)	Oil Severance (100%)	Gas Severance (100%)	Total Oil ($)	Total Gas ($)	Well Count
Marble Falls Atlas	137,246	8,420,582.80	378,926.23	2,192,763	6,267,030.59	470,027.29	378,926.23	470,027.29	378,926.23	470,027.29	26
Tonkawa Chesapeake	32,210	2,277,313.20	102,479.09	403,600	1,395,793.40	104,684.50	102,479.09	104,684.50	102,479.09	104,684.50	1
Douglas Tonkawa Cherokee Jones	75,900	3,757,818.57	169,101.84	243,872	651,916.07	48,893.71	169,101.84	48,893.71	169,101.84	48,893.71	4
Frio Refugio T-C Oil	682	59,481.38	2,676.66	12,117	46,399.68	3,479.98	2,676.66	3,479.98	2,676.66	3,479.98	2
Haimo Spraberry	16046	645715.79	29057.21055	30267	69205.72	5190.429	29057.21055	5190.429	29,057.21	5,190.43	1
Miocene	0	0	0	71666	159348.22	11951.1165	0	2987.779125	0.00	2,987.78	2
									682,241.03	**635,263.69**	
								Field Revenue ($)	1,317,504.72		
								Regional Revenue ($)	53,111,362.09		
								Total Revenue ($)	**54,428,866.80**		
								Biennium Funding ($)	9,900,000.00		

* WTI Cushing, Oklahoma

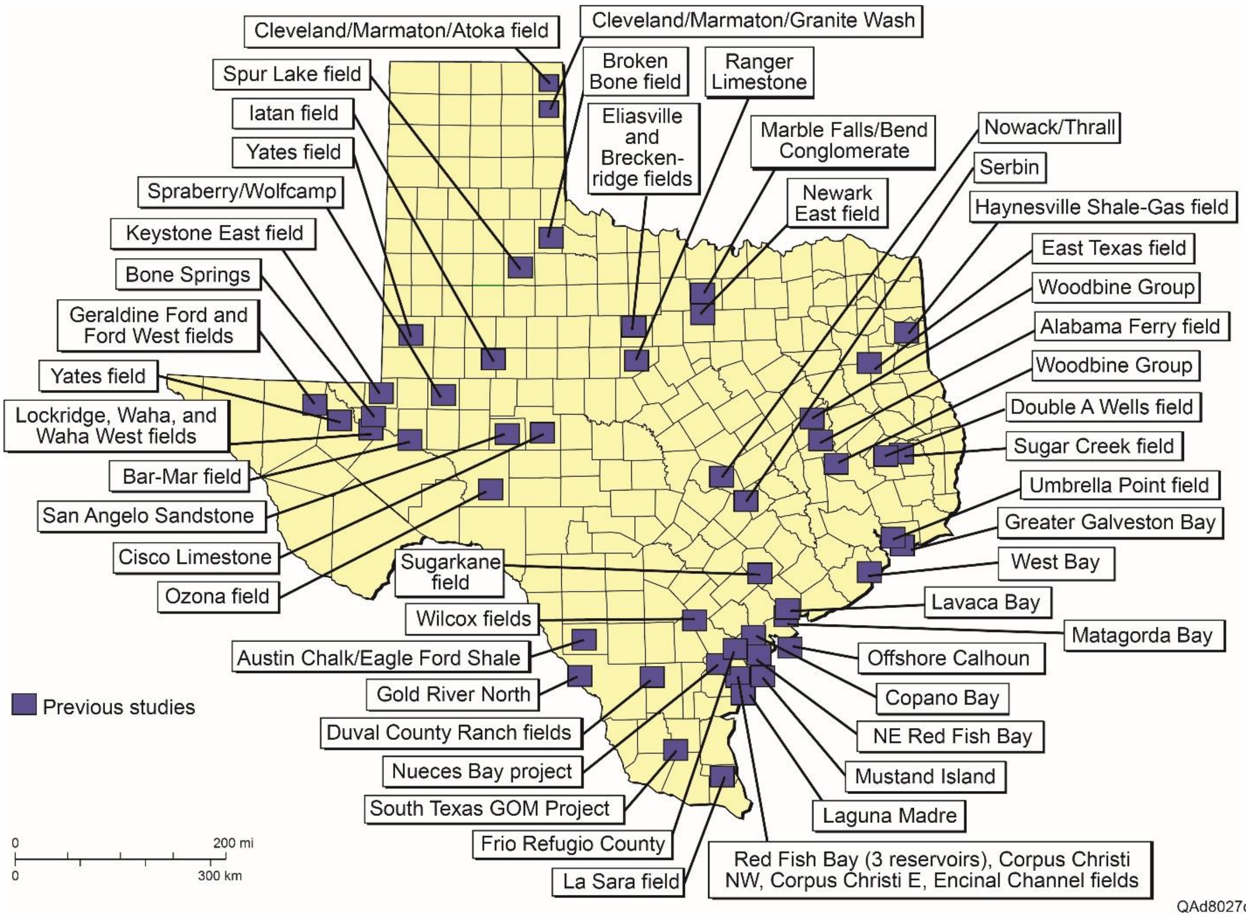


Figure 1. STARR field studies, cumulative to the 2014–2016 biennium.

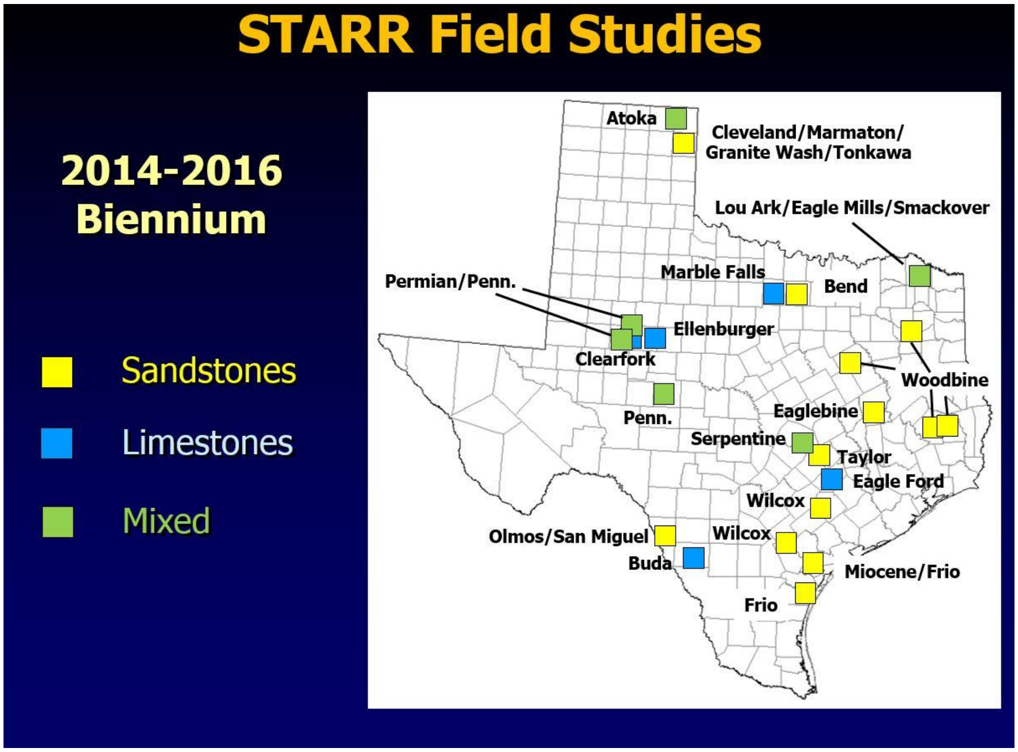


Figure 2. New and completed STARR field (reservoir characterization) studies in the 2014–2016 biennium.

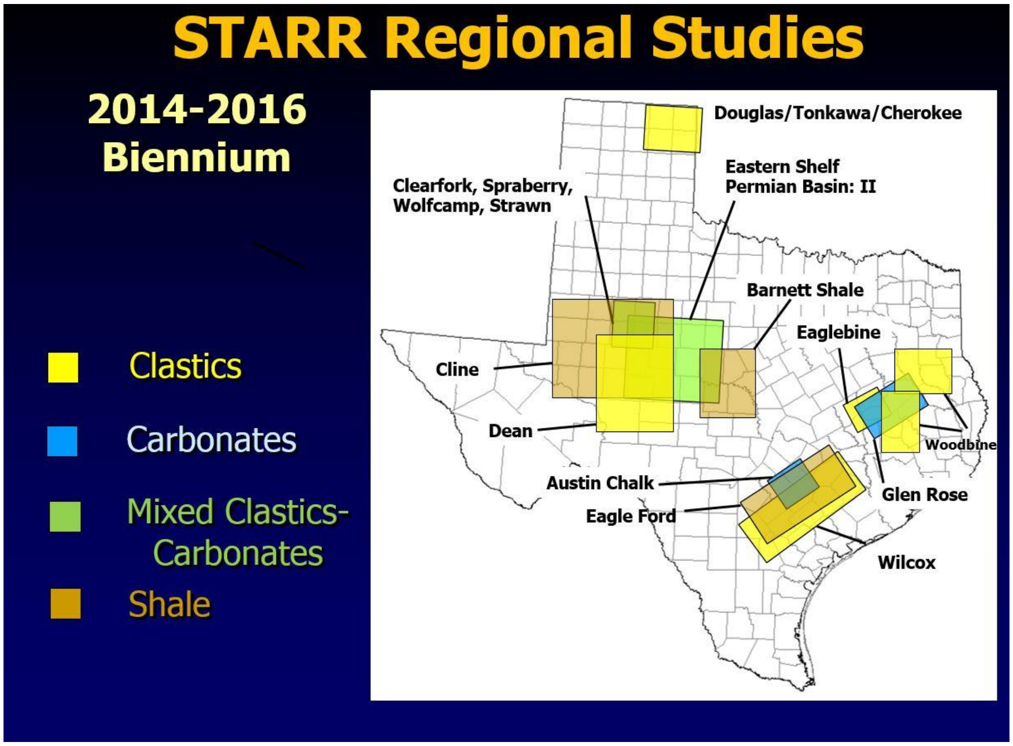


Figure 3. New and completed STARR regional studies in the 2014–2016 biennium.

INTRODUCTION

Texas has produced more oil and natural gas than any other state and has been the largest daily producer, with 2.0 MMbbl/d (million barrels per day) of oil and 21.9 Bcf/d (billion cubic feet per day) of gas in 2013, although these production rates have fallen with recent declines in oil prices. No other state, or other region worldwide, has been as heavily explored or drilled for oil and natural gas as Texas. As of the beginning of 2014, 293,595 active oil wells and 125,157 active gas wells were producing oil and natural gas in the state (Fig. 4).

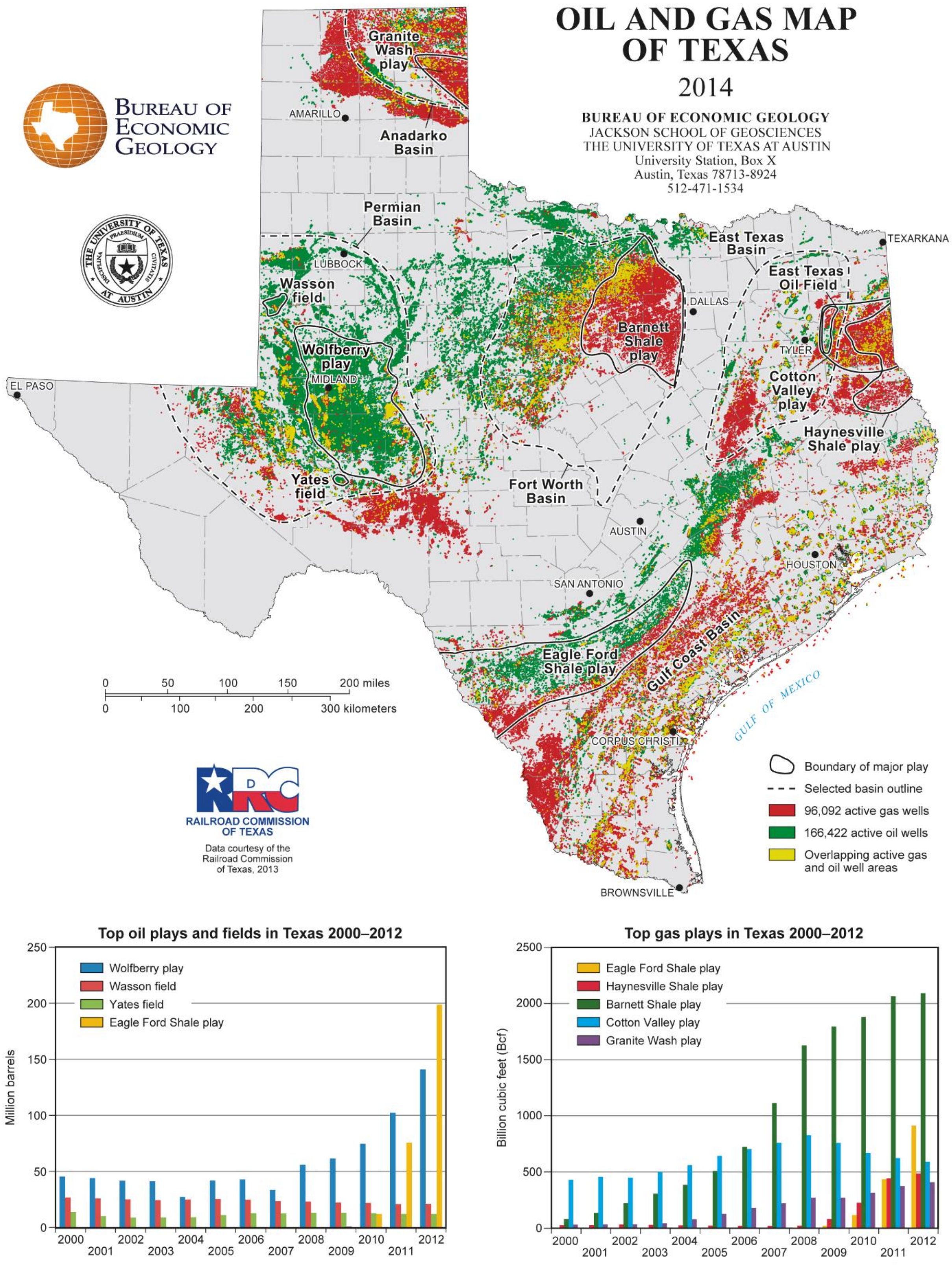


Figure 4. Oil and gas production in Texas as of January 2014, showing distribution and relative rank of top 10 oil and gas plays to the end of 2012.

A variety of oil and gas companies request reservoir characterization and exploration assistance from STARR (see Letters of Cooperation, Appendix A). The Bureau of Economic Geology (BEG), with STARR funding from the State of Texas, provides technical support, identifying opportunities for increased production and associated reserves; these areas are then drilled by cooperating companies. STARR personnel provide assistance and advice to numerous operators on optimal development strategies, appropriate well-log suites, styles of reservoir heterogeneity and their effects on oil and gas recovery, and evaluation of exploration targets, as well as regional geology and unconventional resources. STARR's revenue-neutrality calculations are typically conducted for the trailing two-year period at the time of reporting. For this report, calculations cover the period from September 1, 2014, through July 31, 2016.

STARR has a technology-transfer approach that includes workshops, presentations, and publications. Through technology transfer, we envision that many remaining oil and gas reserves in Texas will be explored and developed in future decades. STARR personnel have provided the public with numerous publications, workshops, and lectures. Since the last biennium report, STARR personnel have produced 43 professional papers, 20 abstracts, 7 BEG publications and reports, 56 presentations, and 8 workshops and guidebook chapters. These items are summarized in Appendix C at the end of this report.

During the 2014–2016 biennium, STARR personnel gave a variety of presentations and conducted reviews of core data for industry partners, including Anadarko Petroleum, Arête Resources, Devon Resources, Endeavor Natural Gas LP, Five Star Energy, Haimo America, Inc., Imagine Resources, Jones Energy, Riley Exploration, Inc., U.S. Enercorp, Winchester Energy Limited, LLC, and Zone Energy. A list of other operators who have worked with STARR is in Table 2.

To date, the STARR program has generated more than 60 field studies (Fig. 1; Table 2). More than 50 Texas oil and gas operators have been, or are currently, involved in the STARR program (Table 2). Over the project's 24-year duration, STARR studies have been used to recommend more than 300 infill and step-out wells, as well as many recompletions (Tyler et al., 1998; Hardage et al., 2000; Loucks et al., 2002, 2004, 2006; Hammes et al., 2008; Ambrose et al., 2010, 2014; Ambrose and Potter, 2012).

Highlights of the present biennium (September 2014–August 2016):

- STARR is revenue positive by a net factor of 5.5. Credit to the STARR program for the 2014–2016 biennium, in accordance with methodology approved by the Texas State Comptroller's office, is $54,428,866.80. The high positive revenue factor is chiefly because of several thousand successful wells drilled in the highly productive, unconventional Spraberry-Wolfcamp (Wolfberry) play in the Permian Basin, as well as other active plays such as the Eagle Ford Trend in south Texas, the Eaglebine Trend in southeast Texas, and Pennsylvanian reservoirs in the Anadarko Basin.

- A wide variety of new reservoir characterization projects (field studies) (Fig. 2) and 13 ongoing or recently completed regional studies (Fig. 3) contributed to the successful completion of new wells and improved oil- and gas-recovery strategies. A partial list of examples of reservoir characterization studies includes the Woodbine Group in Anderson, Houston, Tyler, Polk, and Navarro Counties; the Marble Falls Formation in Jack County; the Wolfcamp and Spraberry Formations in Howard and Glasscock Counties; and the Eaglebine Trend in Leon, Madison, and Fayette Counties (Table 2). Some examples of important regional studies are the Clear Fork, Spraberry, Strawn, and Wolfcamp Formations in the Permian Basin, the Eastern Shelf of the Permian Basin, the Wilcox Group in the Texas Gulf Coast, and the Barnett Shale south of the Fort Worth Basin (Fig. 3).

- STARR's regional study of the Spraberry and Wolfcamp Formations in the Permian Basin provided a detailed and comprehensive framework for continued successful drilling of tight-oil reservoirs in one of the most productive unconventional trends in Texas. Results were published in the Bureau of Economic Geology Report of Investigations No. 277.

- A regional study of the Eaglebine Trend in southeast Texas focused on a play where recent horizontal wells have produced oil and gas in heterogeneous, low-permeability distal-deltaic deposits in the Woodbine Group. Results were released in the December 2014 issue of the *AAPG Bulletin.*

Table 2. STARR field studies, 1995 to present.

Field	Operator	Period of Project STARR Interaction
Keystone East field	Bass Enterprises, Hallwood Energy, Pioneer Natural Resources, Vista Resources	1995–1999
Geraldine Ford and Ford West fields (primary funding by U.S. Department of Energy)	Conoco, Incorporated	1995–1997
Lockridge, Waha, and Waha West fields (primary funding by U.S. Department of Energy and Gas Research Institute)	Shell Oil and Mobil Oil (now ExxonMobil)	1996–1998
Bar Mar field	Hanson Corporation	1997–1998
	Union Pacific Resources (now Anadarko)	1996–1998
Ozona field	Cross Timbers Oil Co.	1998–1999
Duval County Ranch field	Killam Oil	1998–1999
Umbrella Point field	Panaco, Incorporated	1995–1999
Red Fish Bay field (shallow Frio)	Pi Energy	1996–1997
Corpus Christi East field (Frio)	Sabco Oil and Gas, Royal Exploration	1998–2000
Corpus Christi NW field (Frio)	Sabco Oil and Gas, Royal Exploration	1998–2000
Encinal Channel field (Frio)	Sabco Oil and Gas, Royal Exploration	1999–2000
Mustang Island 889 field (Frio)	Sabco Oil and Gas	2000–2001
Red Fish Bay field (Middle Frio)	IBC Petroleum, Cinco	2001–2008
Red Fish Bay field (Deep Frio)	Boss Exploration, Cinco	2003–2008
Mustang Island Offshore (Frio)	Cabot Oil and Gas	2003
Northeast Red Fish Bay project (Frio)	Cabot Oil and Gas	2003
Laguna Madre (Frio)	Novus	2004–2005
Yates field EOR (Permian)	Kinder Morgan	2004–2006
Galveston Bay Shelf area study (Frio)	Santos USA Corp	2004–2006
Carancahua and Matagorda Bay projects (Frio, Miocene)	Brigham Exploration Company	2004–2008
West Bay area study (Alligator Point field; Frio, Miocene)	Gulf Energy Exploration	2005–2007
LaSalle, Calhoun offshore (Frio)	Gulf Energy Exploration	2005–2007
Gold River North field (Olmos)	Huber	2006
Gold River North field (Olmos)	St. Mary's Land and Exploration	2007–2009
East Texas field (Woodbine)	Various operators	2006–2008
North Newark field (Barnett)	Various operators	2007–2009
Spur Lake and Broken Bone fields	Gunn Oil Co.	2007–2009
Mustang Island (Frio)	Sabco Operating Co.	2006–2008
Copano Bay	MPG Petroleum	2007–2009
East Texas field (Moncrief lease)	Danmark Energy	2007–2009
Sugarkane field	Texas Crude	2006–2008
Cleveland/Marmaton/Atoka field	Jones Energy, Ltd.	2008–2010
Lavaca Bay field	Neumin Production Company	2008–2010
Alabama Ferry field	Antioch Energy LLC	2009–2011
Haynesville	Petrohawk, Common Resources, BP	2009–2011
Spraberry/Wolfcamp (Midland County)	Pioneer Resources	2010–2012
Lavaca Bay field (Frio)	Neumin Production Co.	2010–2012
Eliasville/Breckinridge fields (Caddo Limestone)	BASA Resources	2011–2013
Dismukes field (Dimmit County: Austin Chalk/Eagle Ford Shale)	CML Exploration	2011-2013

Sugar Creek field (Austin Chalk/Woodbine)	**BBX Operating**	**2011–2013**
Double A Wells field (Woodbine)	**Vision Resources**	**2011–2013**
K-R-S field (Marble Falls Limestone)	**Cobra Oil and Gas, Stalker Energy**	**2011–2013**
Bend Conglomerate (Wise County)	**Devon Energy**	**2011–2013**
La Sara field (Frio)	**Risco La Sara Operations**	**2011–2013**
Ranger Limestone (Eastland County)	**Stalker Energy**	**2011–2013**
Austin Chalk (Dimmit County)	**Newfield Exploration Company**	**2011–2013**
Frio Formation (Refugio County)	**T-C Oil Company**	**2012–2014**
Cleveland/Marmaton/Granite Wash (Hemphill County)	**Devon Resources, Arête Resources,**	**2012–2014**
Woodbine Group (Leon County)	**Risco La Sara Operations, Chesapeake Energy**	**2012–2014**
Woodbine Group (Walker County)	**Chesapeake Energy**	**2012–2014**
Cisco Limestone (Tom Green County)	**AEATX**	**2012–2014**
Pearsall Formation (McMullen, Dimmit Counties)	**Valence, Devon**	**2012–2014**
San Angelo Sandstone (Irion County)	**Renda Energy**	**2012–2014**
Atoka/Cherokee Group (Ochiltree, Lipscomb, Hemphill Counties)	**Arête Resources**	**2012–2014**
Mississippian Lime (Shackelford, Stephens, Throckmorton, Young Counties)	**Tracker Resources**	**2012–2014**
Glorieta Group (Ward County)	**Whiting Resources**	**2012–2014**
Harkey, Swastika, Cline Woodbine/Eagle Ford (Polk County)	**BP**	**2012–-2014**
Woodbine Group (Tyler County)	**BP**	**2012–2014**
ClearFork Formation (Iatan field)	**BASA Resources**	**2013–2015**
Buda Limestone (Dimmit County)	**US Enercorp**	**2013–2015**
Tonkawa, Douglas Formations (Hemphill County)	**Chesapeake Energy**	**2013–2015**
Woodbine Group (AA Wells, Hortense fields)	**Apache Corporation**	**2013–2015**
Pettet Limestone (Anderson County)	**Arête Resources**	**2013–2015**
Woodbine Group (East Texas field)	**Zone Energy**	**2013–2015**
Woodbine Group (Kerens, South field)	**Five Star Energy**	**2013–2015**
Wilcox Group (Bee, Goliad Counties)	**Excellong**	**2013–2015**
Wolfcamp Formation (Howard County)	**Excellong**	**2013–2015**
Eaglebine Trend (Fayette County)	**Devon Resources**	
Marble Falls Formation (Jack County)	**Atlas Resource Partners**	**2014–2016**
ClearFork/Spraberry/Wolfcamp		**2014–2016**
(Howard, Borden, Scurry Counties)	**Harmonia**	
Wilcox Group (Bee County)	**Formosa Petrochemical**	**2014–2016**
Douglas/Tonkawa Formations		**2014–2016**
(Lipscomb County)	**Jones Energy**	
Wilcox Group (Lavaca County)	**Imagine Resources LLC**	**2014–2016**
Spraberry/Dean/Wolfcamp		**2014–2016**
(Howard County)	**Haimo America Inc.**	**2015–2017**
Nowack/Thrall (Williamson County)	**Trinity Brothers**	**2015–2017**
Serbin (Bastrop/Lee Counties)	**Riley Exploration**	**2015–2017**
Wolfcamp Formation (Howard County)	**Anadarko Petroleum**	**2016–2018**
Thrall (Williamson County)	**Patriot Operating Co.**	**2016–2018**
Ellenburger (Nolan County)	**Winchester Energy Limited**	**2016-2018**
San Miguel/Olmos (Maverick County)	**Endeavor Natural Gas LP**	**2016–2018**
		2016–2018

STARR REVENUE-NEUTRALITY METRICS

An important goal of the STARR program is to demonstrate revenue neutrality for the Texas State Comptroller's office, with each reporting biennium to be considered for funding in the next biennium. STARR's revenue neutrality is calculated for two years. For the 2014–2016 biennium, we calculated our revenue neutrality from September 1, 2014, through July 31, 2016. This two-year interval was chosen because our progress report is typically submitted before the end of the current legislative biennium. Royalties for the State and severance taxes are accounted for in revenue-neutrality calculations (Table 3). This metrics table was developed in conjunction with the Texas State Comptroller's office in 2004 and slightly modified following discussion with the Comptroller's office in 2006. Six major types of projects are noted in Table 3.

Table 3. Project STARR revenue-neutrality metrics

Type of STARR recommendation	Expiration period following recommendation (Initial/incremental production must begin before recommendation expires)	Time period for credit following initial production	Royalty credit	Severance tax credit
1. Drilling new infill or step-out well in established field	4 years	2 years	100%	100%
2. Drilling new infill or step-out well in established field with multiple reservoir intervals	4 years	2 years following completion of each additional reservoir interval	100%	100%
3. Recompletion—missed pay well in established field	4 years	2 years	100%	100%
4. Enhanced oil recovery (EOR) field project	4 years	2 years following date selected by STARR within a 5-year period from initial operator action	100% of incremental production	100% of incremental production
5. Exploration well	4 years	2 years	100%	100%
5.a. Subsequent development wells following discovery of new field	2 years following initial production from exploration well	2 years	100%	100%
5.b. Copycat wells following discovery of new field	2 years following initial production from exploration well	2 years	25%	25%
6. Wells drilled on basis of influence of regional trend studies	4 years starting 6 months after releasing study	2 years	25%	25%

Note: Royalty credit accrues only from production on State GLO (General Land Office) Lands. Severance tax credit accrues from production anywhere in Texas.

SELECTED PROJECTS IN THE 2014–2016 BIENNIUM

REGIONAL STUDIES

Eastern Shelf Permian Basin

STARR's regional study of the southern part of the Eastern Shelf of the Permian Basin, an extension of a previous study by Brown et al. (1987, 1990) encompasses parts of 18 counties in West Texas (Fig. 5). The primary objective of this study, which focuses on Upper Pennsylvanian and Lower Permian (upper Missourian, Virgilian, and Wolfcampian) strata, is to provide a regional stratigraphic and depositional framework to guide future investigations of this large portion of the West Texas Permian Basin. The Eastern Shelf has long produced oil and natural gas from numerous stratigraphic zones in the Canyon and Cisco Groups. Reservoir facies include both limestone and sandstone that were deposited in a variety of depositional settings, including siliciclastic highstand deltaic, barrier/strandplain, and shelf systems; lowstand fluvial and shelf-edge deltaic systems; and carbonate-bank, transgressive shelf-carbonate, carbonate-platform, and shelf-edge reef-bank systems. These facies are well documented in outcrop studies of the Canyon and Cisco successions in North-Central Texas (Brown, 1960, 1969; Galloway, 1971; Brown et al., 1973; Erxleben, 1974; Hentz, 1988) and in the subsurface north of our study area (Van Siclen, 1969; Galloway and Brown, 1973; Brown et al., 1987, 1990). Brown et al. (1987, 1990) correlated all the primary Canyon and Cisco lithostratigraphic units from the outcrop to the subsurface. Our regional chronostratigraphic synthesis extends the work of these earlier workers by documenting the shelf, shelf-margin, slope, and basinal depositional-facies characteristics, stratigraphic variations, and sedimentation trends of the Missourian Canyon Group and Virgilian-Wolfcampian Cisco Group across the southern Eastern Shelf and, to a lesser extent, the adjacent Midland Basin.

Incised-valley-fill sandstone reservoirs occur on the Eastern Shelf in Concho County. An example from this study is the Lower Hope Sand, also known as the King Sand. It is oil-productive in Agaritta, Lonesome Dove II, and Brady Creek fields in Concho County (Powers and Watters, 1992; Saunders et al., 1993). These fields occur within a southwest-trending belt of thick (as much as 40 ft [12 m]) sandstone bodies having blocky and upward-fining wireline-log responses. The Lower Hope Sand locally truncates limestone beds in Lonesome Dove field, where it is interpreted as fluvial point-bar deposits, although distributary-channel deposits are also inferred (Powers and Watters, 1992). Core data from the field indicate that the Lower Hope Sand has an erosional base and is composed of an aggradational section of cross-stratified, fine- to medium-grained sandstone beds (Figs. 6 and 7). These sandstone beds represent bedload fluvial-channel deposits in a braided-stream system within a valley-fill succession. Recognition criteria for bedload fluvial, braided-stream deposits of lowstand origin in these cores include (1) abrupt juxtaposition of predominantly medium- and coarse-grained sandstone beds onto outer-ramp and slope carbonates, (2) absence of marine burrows, and (3) aggradational stacking patterns having an overall blocky vertical grain-size profile consistent with bedload fluvial systems lacking well-defined point bars that record lateral channel migration (Galloway, 1977; Schumm, 1981).

Slope deposits in the Wolfcamp Formation in Howard County, which grade westward into basin-floor-fan deposits, are composed of multiple, 10- to 20-ft (3- to 6-m) sections of fine- to medium-grained sandstone interbedded with mudstone with thin (1- to 2-ft [0.3- to 0.6-m]) beds of very fine to fine-grained sandstone (Fig. 8). Most of these 10- to 20-ft (3- to 6-m) sandstone bodies, with the exception of the upward-coarsening one from 7,835 to 7,842 ft (2,388.7 to 2,390.9 m), have a blocky to slightly upward-fining vertical grain-size profile and are composed of individual 1- to 3-ft (0.3- to 0.9-m) beds of predominantly massive and weakly planar-stratified, and fine- to medium-grained sandstone (Figs. 9a and 9b). Sections of planar-stratified sandstone in the core are commonly capped by thin (<1-inch [<2.5-cm]) beds of fine-grained sandstone with ripple stratification (Fig. 9b). Accessory features in these sandstone bodies include elongate clay clasts (Fig. 9a) and organic fragments. Muddy sections are composed of discontinuous and distorted, millimeter- and centimeter-scale beds of very fine grained sandstone and sideritic mudstone (Fig. 9c). Deepwater slope deposits in the Texaco No. 1-D Sterling well, which contain multiple and thin (commonly <30 ft [<9 m]) composite channel-fill facies, are composed of poorly connected, areally limited and narrow, sinuous channels in a muddy slope system. The stratal architecture of the sandy framework facies in the Texaco No. 1-D Sterling well is similar to that described by Galloway and Hobday (1996), Gardner (1997), Dutton et al. (2003), and Prather (2003) for slope depositional systems, with a point-sourced, elongate and sinuous channel-feeder system with shoestring plan geometries. Reservoir development in such muddy slope systems is challenging because of thin and narrow channel-fill sandstones and a high degree of interbedded sandstone and shale beds (Kendrick, 2000).

Wolfcamp carbonate debris-flow deposits are also locally productive westward of carbonate-ramp margins in the eastern Permian Basin. The Amerada Hess No. 1 Robinson core in Howard County consists of a 66-ft (20.1-m) section of heterolithic, coarse-grained and conglomeratic detrital carbonate beds having an overall aggradational, blocky grain-size trend (Fig. 10). Individual beds, 0.5 to 2 ft (0.15 to 0.6 m) thick, range in grain size from dark calcareous mudstone to poorly sorted conglomerate (Fig. 11a). Clasts occur in a wide variety of types, including brachiopod, sponge, mollusk, and crinoid fragments, as well as light- to dark-gray carbonate mudstone and wackestone fragments. Crinoid fragments compose the most common type of bioclast in the section (Figs. 11a and 11b). Other features include 1- to 2-inch (2.5- to 5.1-cm) zones of stylolites and both open and closed vertical factures (Fig. 11b). Vuggy porosity is also present within numerous 1- to 3-ft (0.3- to 0.9-m) zones throughout the section (Figs. 10 and 11c).

Hamlin and Baumgardner (2012) and Baumgardner et al. (2016), in a study of the Wolfcamp Formation in the southern part of the Midland Basin, reported that a major sea-level fall during deposition of the middle Wolfcamp caused subaerial exposure and erosion of emergent shelves (Mazzullo and Reid, 1989; Candelaria et al., 1992; Wahlman and Tasker, 2013). Sediment density flows carried shelf-derived carbonate debris as far as 25 mi (40 km) from the toe-of-slope along the Eastern Shelf (Morgan et al., 1996). Hobson et al. (1985) described packages of thin-bedded allochthonous carbonate in the lower Leonard and upper Wolfcamp with bioclast-lithoclast grainstone deposits that are developed >20 mi (>36 km) basinward of the Central Basin Platform. These carbonates become cleaner and thicker shelfward, merging into thick-bedded, pebbly lithoclast floatstone/rudstones around the platform. These deposits of shelf-derived carbonate have been described as cyclic and episodic in nature (Hobson et al., 1985; Sivils and Stoudt, 2001).

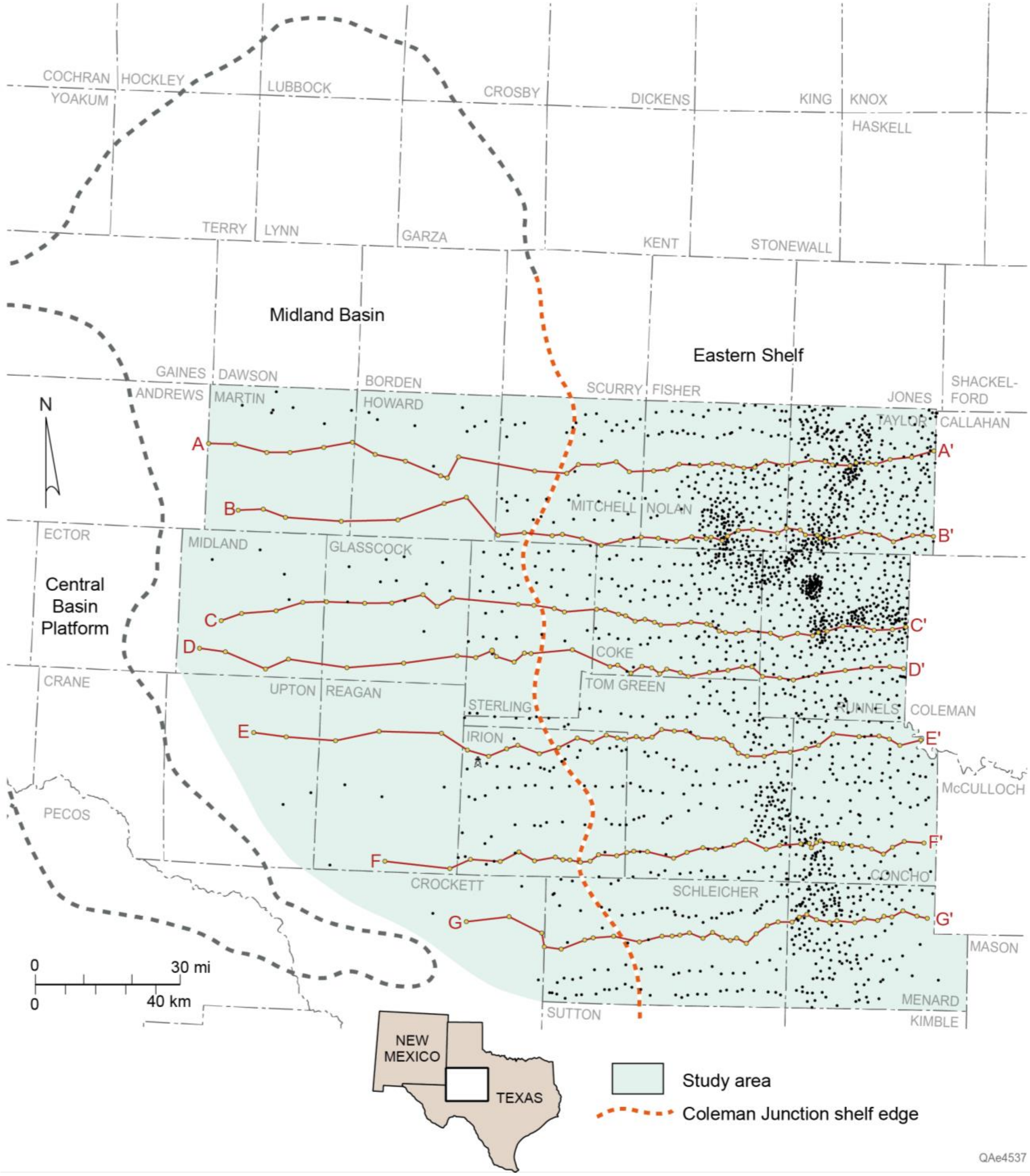


Figure 5. Study area, Eastern Shelf Permian Basin regional project.

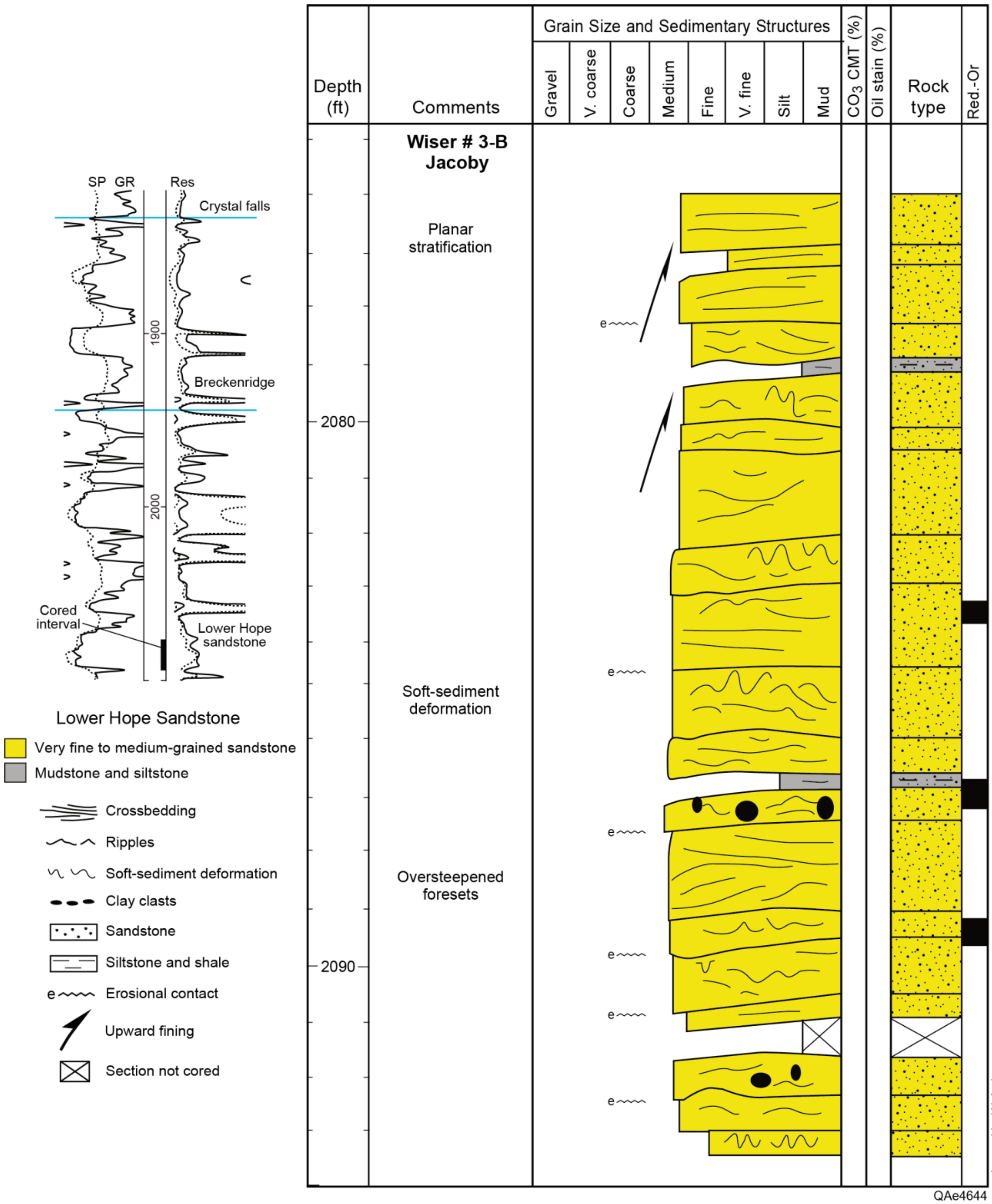


Figure 6. Core description of the Hope Sand in the Wiser No. 3-B Jacoby well from 2,076 to 2,093.5 ft (632.9 to 638.3 m). SP: spontaneous potential; GR (gamma ray); Res: resistivity; CO_3 CMT: carbonate cement; Rd.-Or.: red-orange color. Core photographs are shown in Fig. 7.

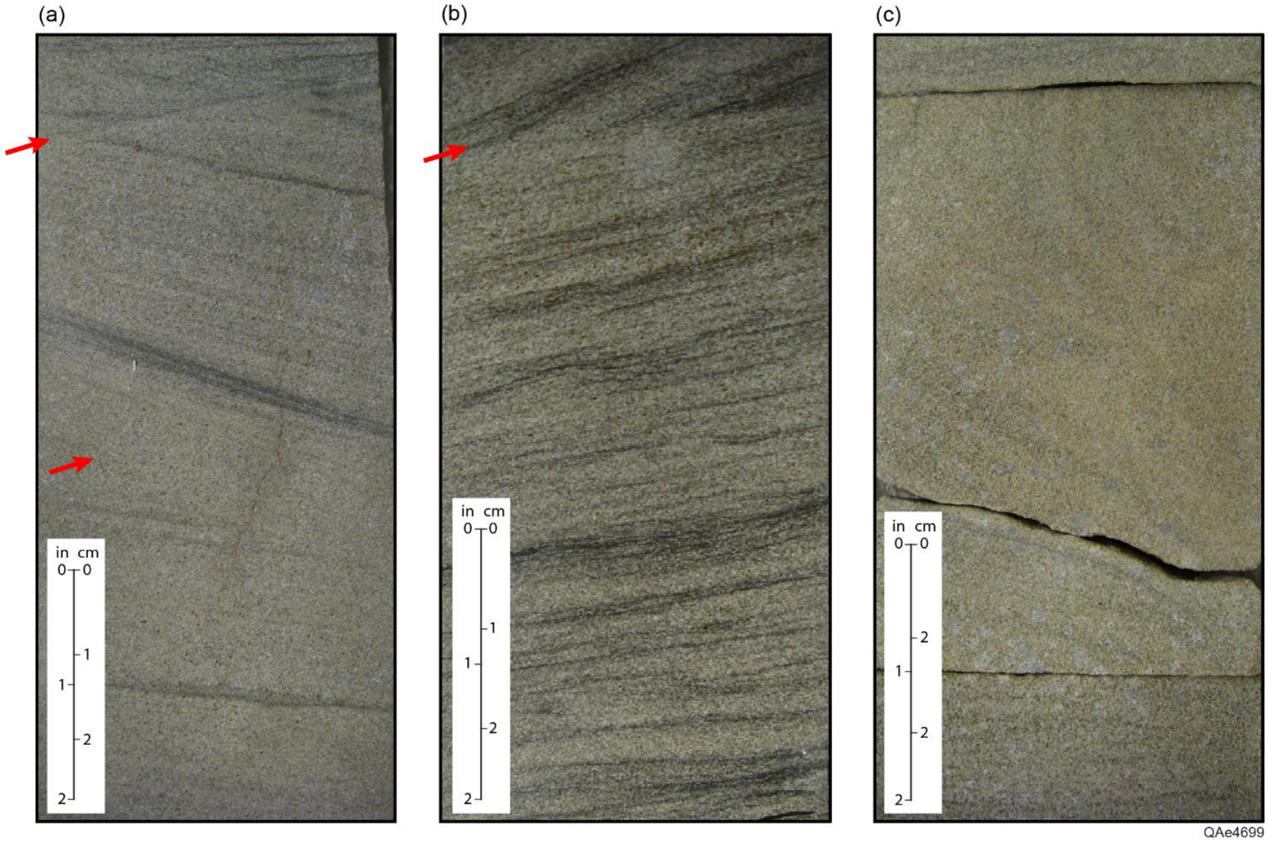
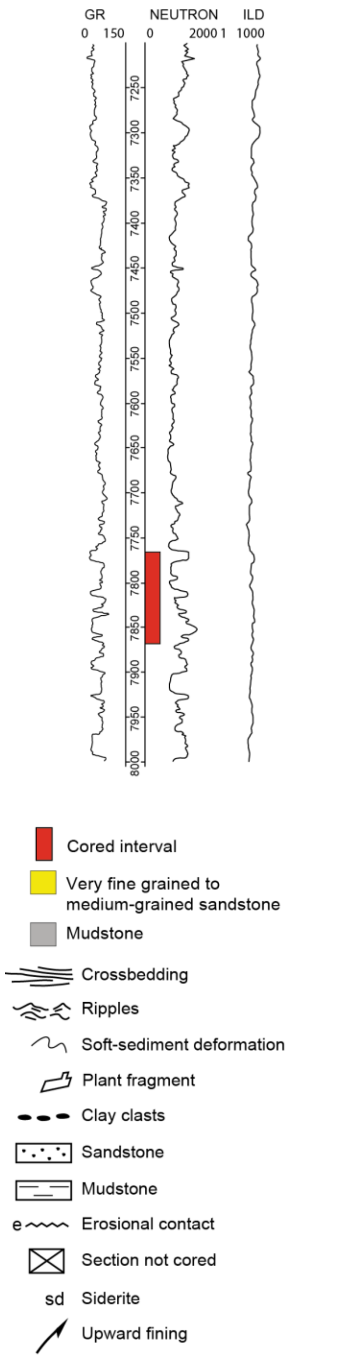


Figure 7. Core photographs from the Wiser No. 3-B Jacoby well. (a) Crossbedded, fine- to medium-grained sandstone at 2,078.4 ft (633.7 m). Arrows indicate erosional surfaces. (b) Medium-grained sandstone with low-angle, planar stratification at 2,077.9 ft (633.5 m). Arrow indicates erosional surface. (c) Medium-grained sandstone with oversteepened and deformed stratification at 2,082.1 ft (634.8 m). Core description is shown in Fig. 6.



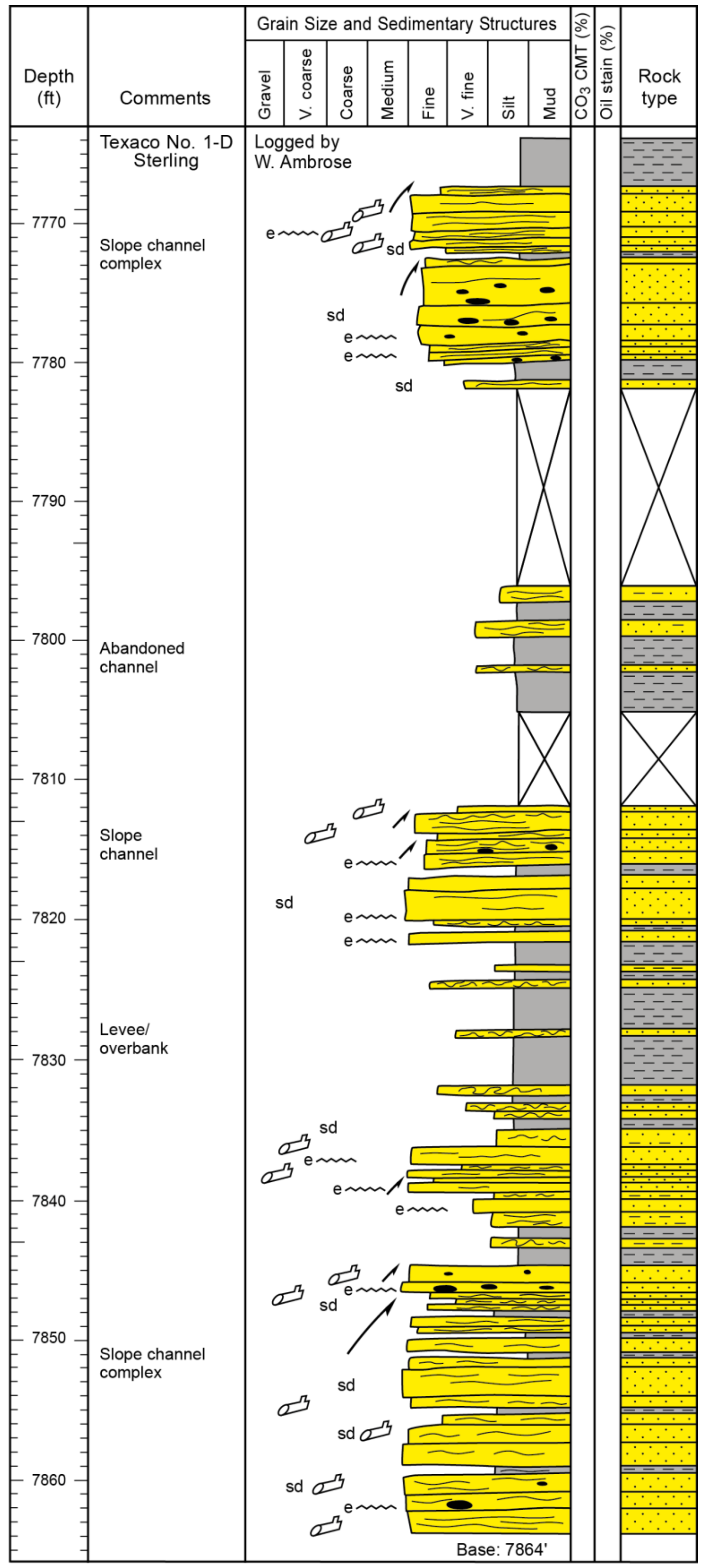


Figure 8. Core description of middle Wolfcamp slope channel-fill and levee deposits in the Texaco No. 1-D Sterling well from 7,764 to 7,864 ft (2,367.1 to 2,397.6 m). GR: gamma ray; ILD: intermediate, dual-induction resistivity; CO_3 CMT: carbonate cement. Core photographs are shown in Fig. 9.

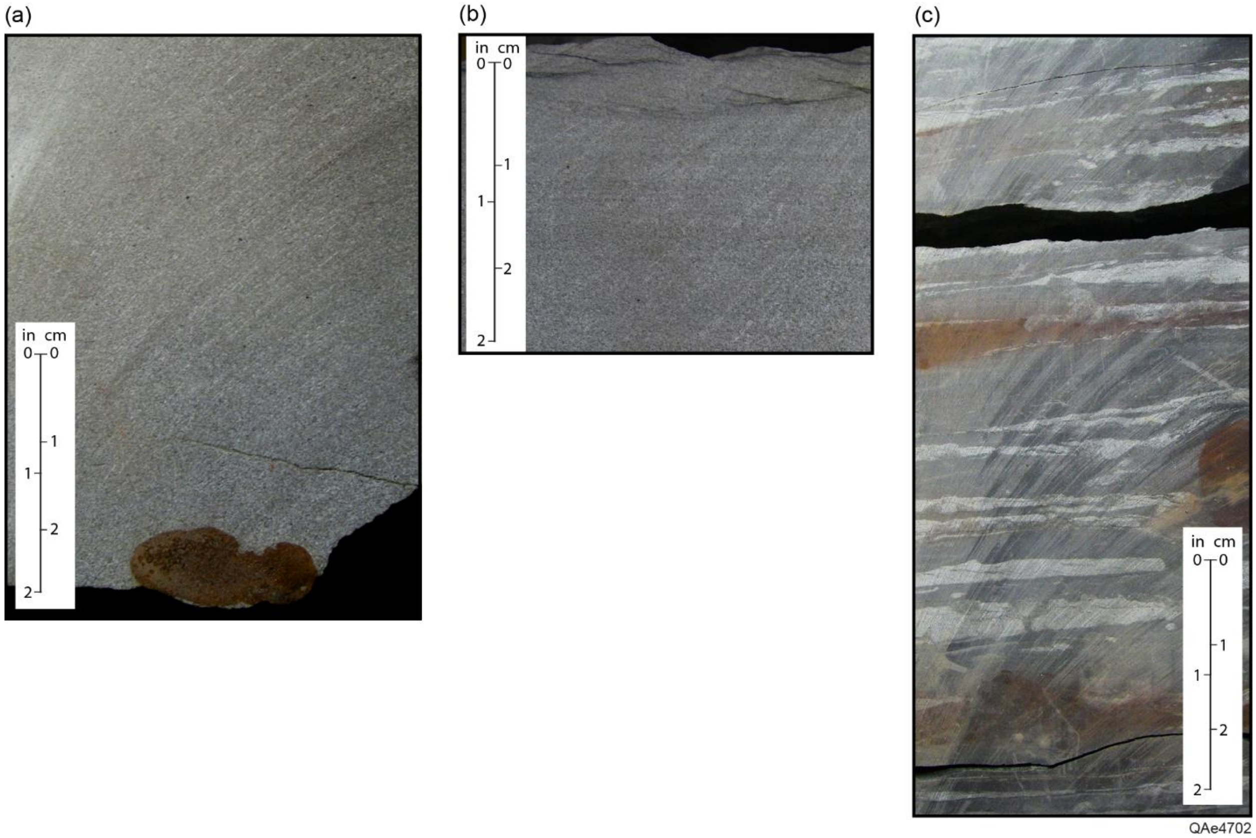


Figure 9. Core photographs of clastic slope deposits in the Texaco No. 1-D Sterling well. (a) Fine- to medium-grained, massively bedded sandstone with large clay clasts in channel-fill facies at 7,861.7 ft (2,396.9 m). (b) Fine-grained sandstone with planar stratification overlain by climbing-ripple bedding in upper-channel-fill facies at 7,812.9 (2,382.0 m). (c) Discontinuous beds of very fine grained sandstone and sideritic mudstone in levee-overbank facies at 7,834.8 ft (2,388.7 m). Core description is shown in Fig. 8.

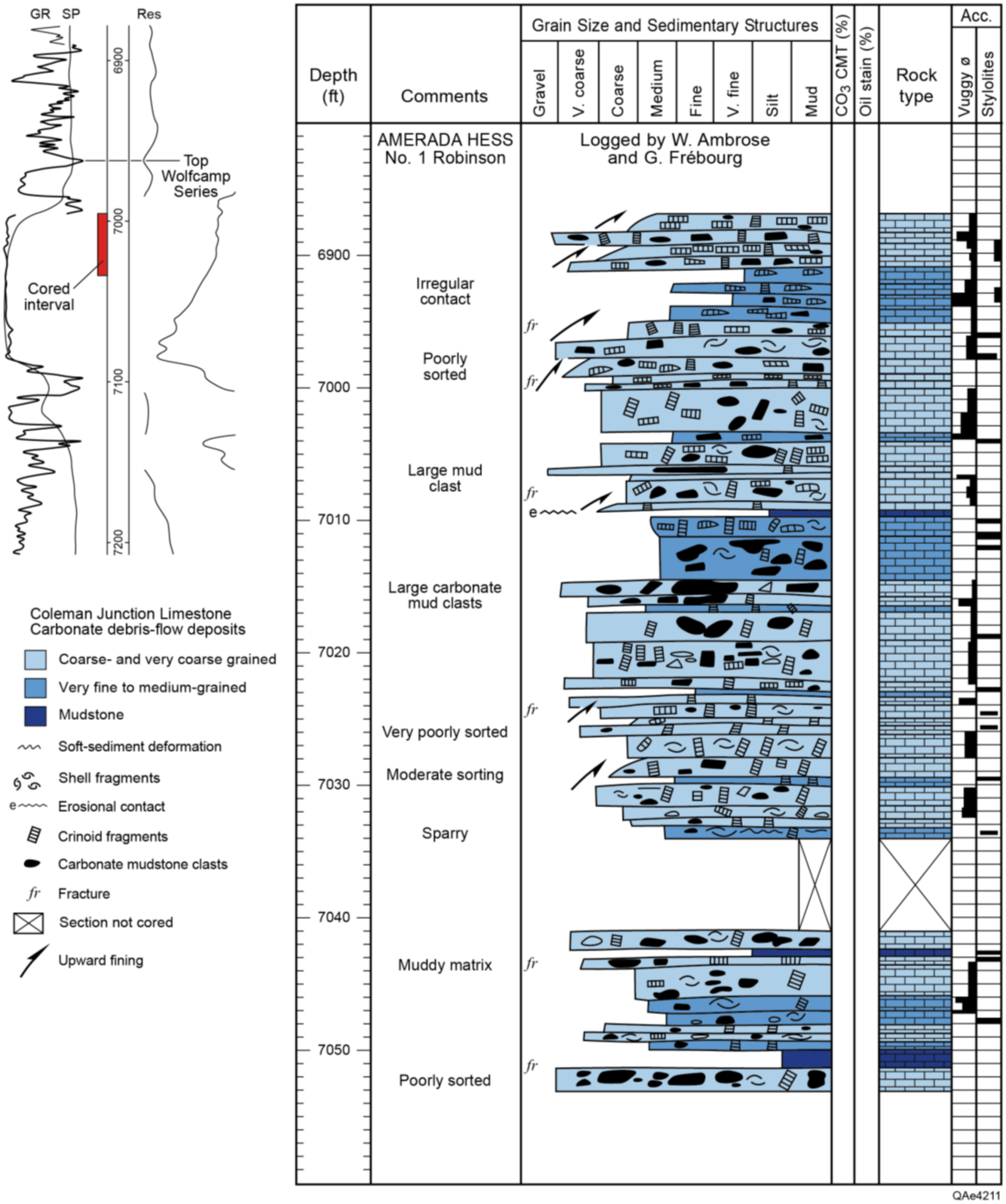


Figure 10. Core description of deepwater slope carbonate debris-flow deposits in the Amerada Hess No. 1 Robinson well from 6,987 to 7,053 ft (2,130.2 to 2,150.3 m). GR: gamma ray; ILD: intermediate, dual-induction resistivity; CO_3 CMT: carbonate cement; ACC: accessory features. Core photographs are shown in Fig. 11.

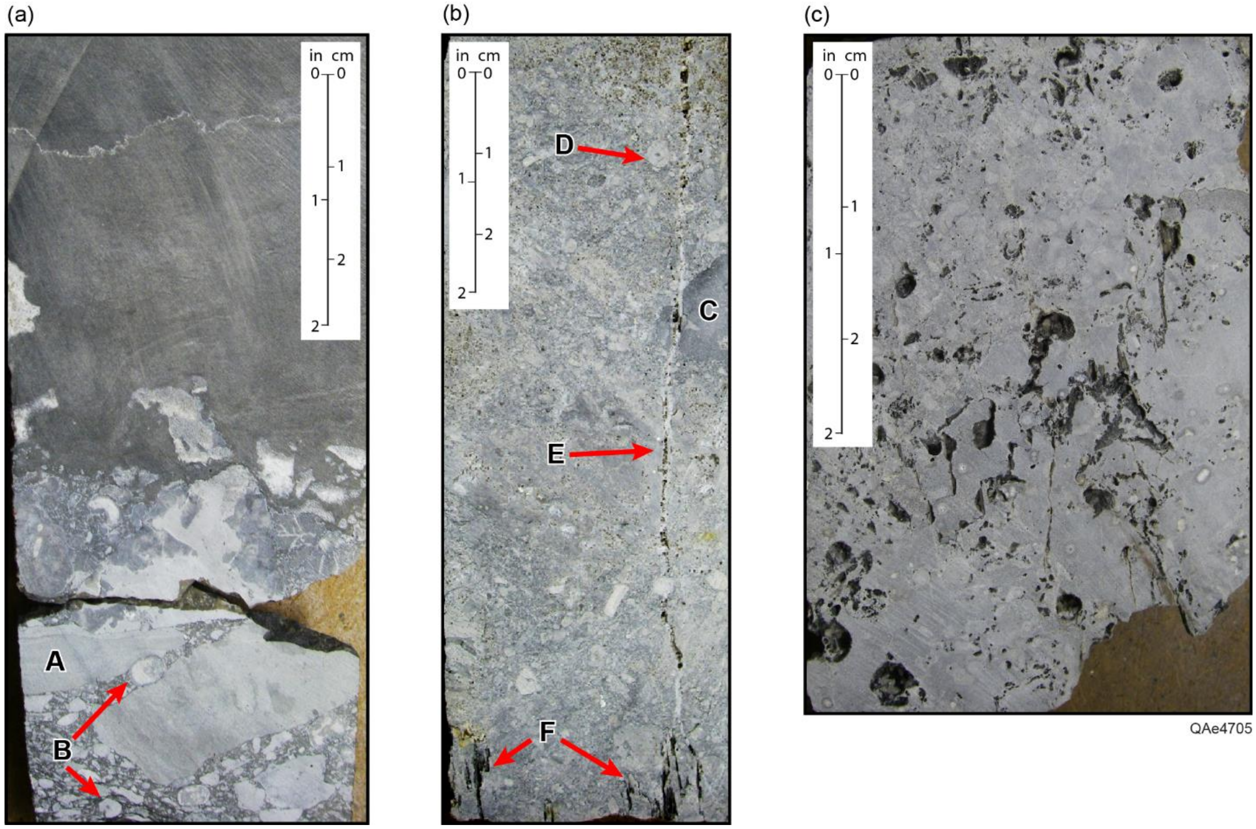


Figure 11. Core photographs of deepwater carbonate debris-flow deposits in the Amerada Hess No. 1 Robinson well. (a) Dark, calcareous mudstone overlying 2-inch (5.1-cm) zone of coarse-grained, conglomeratic carbonate debris-flow deposit at 7,050.8 ft (2,149.6 m). A: Carbonate clast composed of laminated mudstone. B: Crinoid fragment. (b) Poorly sorted, coarse-grained carbonate debris-flow deposit at 6,995.0 ft (2,132.6 m). C: Dark carbonate mudstone clast. D: Crinoid fragment. E: Partly open, crosscutting vertical fracture. F: Stylolites. (c) Fine-grained, poorly sorted carbonate debris-flow deposit with extensive vuggy porosity at 6,992.0 ft (2,131.7 m). Core description is shown in Fig. 10.

Lower Wilcox Group, South-Central Texas

The Wilcox stratigraphic section has long been recognized as an important petroleum resource in southeast Texas, producing primarily gas from fluvial, deltaic, and shallow-marine sandstone reservoirs. Oil and gas accumulation in the lower Wilcox Group is closely controlled by distribution of deltaic-lobe complexes in the Rockdale Delta System (Fisher and McGowen, 1967) with principal reservoirs occurring in delta-front sandstones and proximal-deltaic facies (distributary–mouth bar and channel deposits). The lower Wilcox Group in DeWitt County is especially attractive because it is an active gas-producing stratigraphic unit (Billingsley, 1982).

The lower Wilcox Group in Lavaca, DeWitt, and Karnes Counties is a 10,000-ft-thick (3,000-m-thick), fault-bounded succession of hydrocarbon-producing, clastic deposits that accumulated along a series of growth faults (Fig. 12). This regional study of the lower Wilcox Group integrates wireline-log, seismic, and core data to document the sedimentology and stratigraphy of the lower Wilcox Guadalupe Delta (Fig. 13) and to provide a framework for oil and gas exploration. Growth faults within the lower Wilcox control expanded thickness of sedimentary units (up to 4 times) on the downdip sides of faults (Fig. 14). Increased local accommodation because of fault subsidence favored a stronger wave regime on the outer shelf owing to unrestricted fetch and water depth. As the shoreline advanced during deltaic progradation, successively more sediment was deposited in downthrown depocenters and reworked alongshore by wave processes, resulting in thick sedimentary units characterized by repeated stacking of shoreface sequences. Thick and laterally continuous, clean sandstone successions in the downthrown compartments represent attractive hydrocarbon reservoirs. As a consequence of wave dominance and increased accommodation, thick (tens of meters) sandstone bodies having increased homogeneity and vertical permeability within the stacked shoreface successions were deposited, thereby increasing sandstone-body and potential reservoir continuity. However, these wave-dominated deltas are also associated with a slow progradation rate and therefore less sediment having been supplied per unit time (Olariu and Olariu, 2015). In addition, growth faults control reservoir partitioning and may contribute to hydrocarbon trapping. Autocyclic processes involving delta lobe switching also control discontinuities in sandstone-body geometry (Ainsworth et al., 2011; Olariu, 2014).

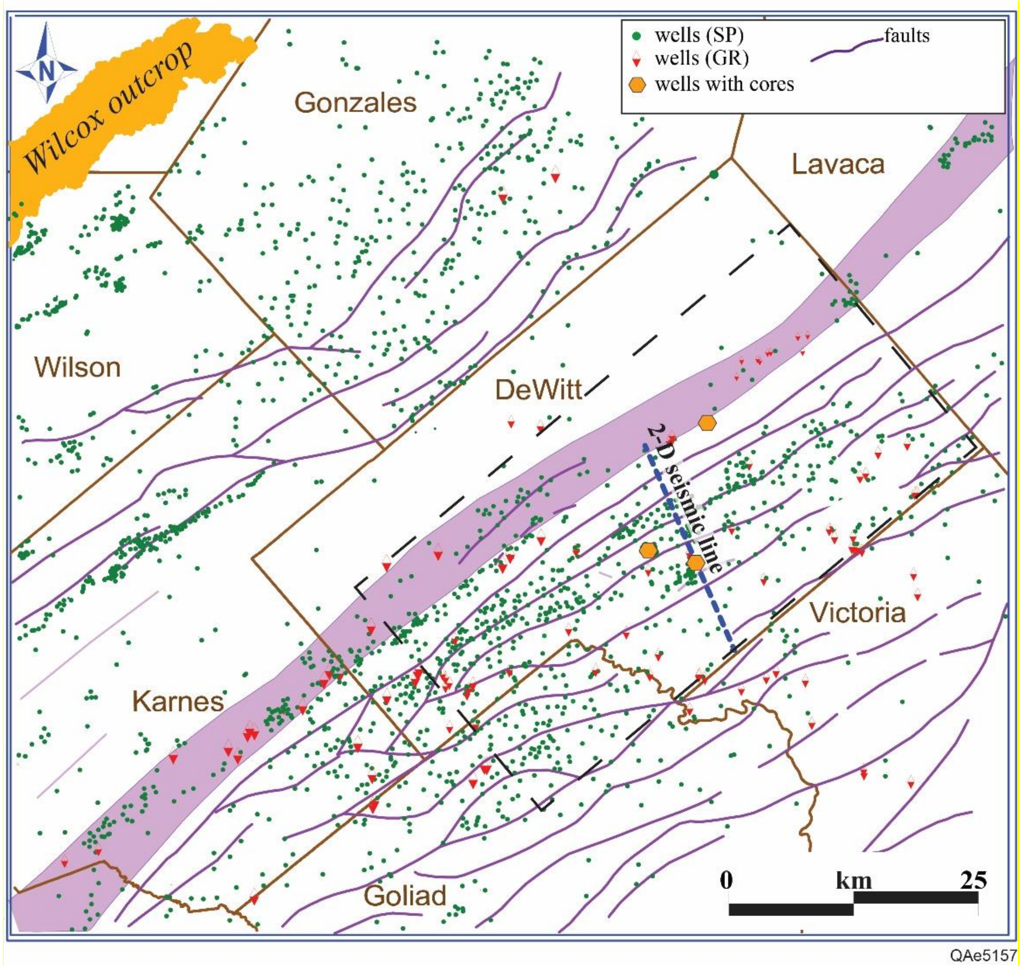


Figure 12. Study area of the lower Wilcox Group in south-central Texas. Purple band coincides with areas of closely spaced normal faults. Other significant faults associated with down-to-the-coast thickening of lower Wilcox strata are depicted in northeast-trending purple segments. SP: spontaneous potential; GR: gamma ray. From Olariu and Ambrose (2016).

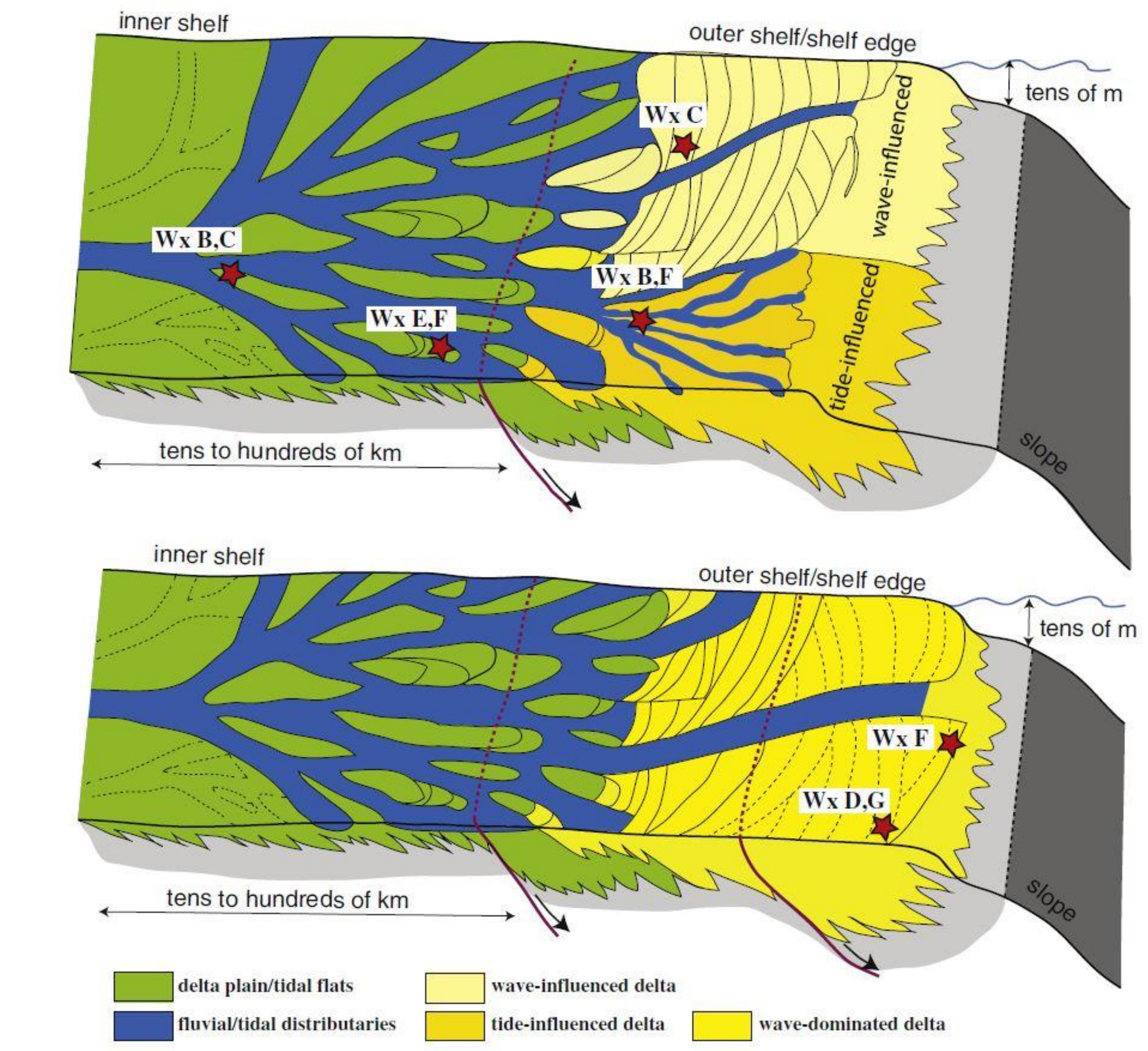


Figure 13. Evolution of lower Wilcox deltas in Lavaca, DeWitt, and Karnes Counties. Wave- and tidal-influenced, fluvial-dominated deltas were subsequently followed by wave-dominated deltas during periods of decreased sediment supply and increase of wave energy relative to tidal or fluvial energy because of changes in water depth. From Olariu and Ambrose (2016).

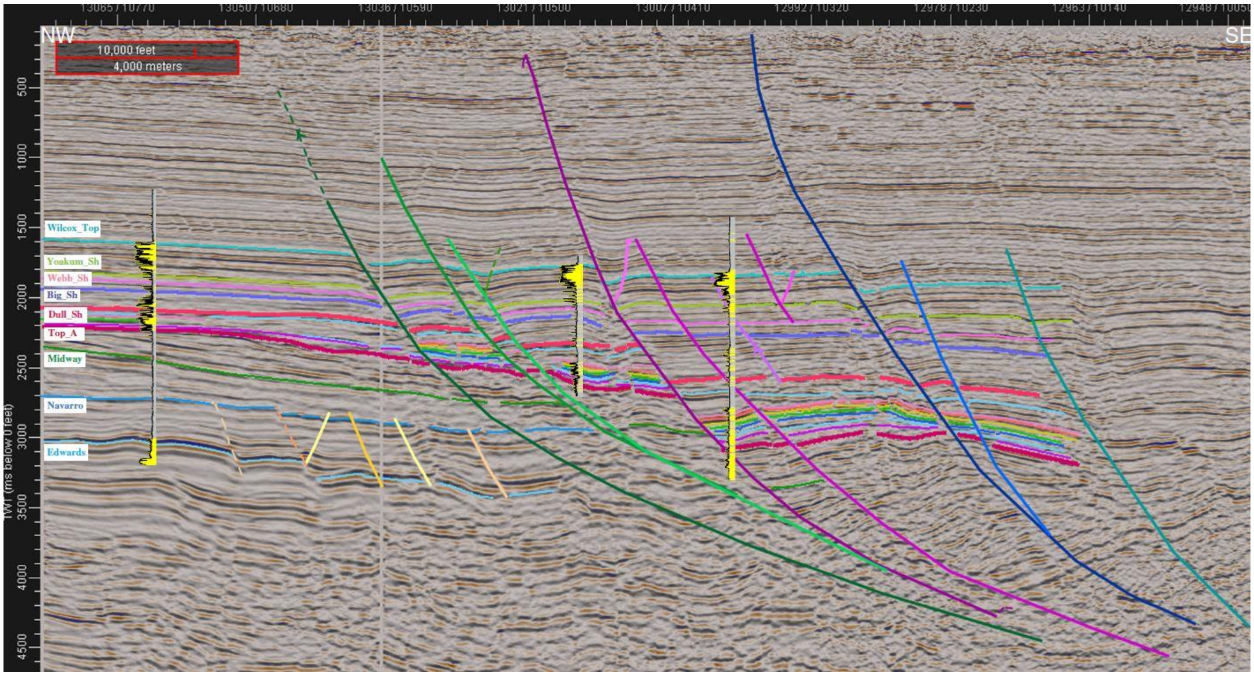


Figure 14. Dip-oriented seismic profile illustrating expanded Wilcox section across series of growth faults. From Olariu and Ambrose (2016).

RESERVOIR CHARACTERIZATION STUDIES

Sugar Creek and Big Cypress Fields (Tyler County)

Following its reservoir characterization of the Woodbine Group in East Texas field (Ambrose et al., 2009), the STARR group focused on downdip (southward) Woodbine oil and gas trends in Polk County (Ambrose and Hentz, 2012), Madison and Leon Counties (Hentz et al., 2014), and Tyler County (Ambrose et al., 2014). The goals of the study in Tyler County were to characterize the shelf-to-slope transition in the Woodbine Group and to evaluate the potential impact on reservoir heterogeneity and reservoir quality in shelf-edge and slope depositional reservoir facies in the area.

The Upper Cretaceous Woodbine Group is a major oil- and gas-producing stratigraphic unit in the U.S. Gulf Coast. It has produced >5.42 BSTB (billion stock-tank barrels) of oil from East Texas field in the updip Woodbine Trend in northeast Texas (Wang, 2010). The productive Woodbine Group extends southward to the Lower Cretaceous Edwards Reef Trend in southeast Texas (Fig. 15), where it produces gas, condensate, and lesser amounts of oil along the downdip Woodbine shelf-edge trend in Double A Wells and Sugar Creek fields in Polk and Tyler Counties, respectively (Figs. 16 and 17). Double A Wells field, discovered in 1985, produces oil and gas mainly from sandy fluvial-dominated and wave-modified deltaic deposits (Ambrose and Hentz, 2012) and has an expected ultimate recovery of ~0.5 Tcf (trillion cubic feet) of gas and 20 MMbbl (million barrels) of condensate (Stricklin, 2002; Adams and Carr, 2010). Cumulative production in the field is >450 Bcfe (billion cubic feet of gas equivalent) (Bunge, 2011). Ultimate production from these and other extensively drilled Woodbine fields along the Edwards Reef Trend is estimated to exceed 1 Tcf of gas and 30 MMbbl of oil and condensate (Byther, 2006). In contrast, Woodbine slope facies south of the Edwards Reef Trend are less productive, having limited production mainly from slope-channel and levee facies (Siemers, 1978). Permeability and limited porosity data from core plugs indicate that primary reservoir-quality sandstones in Woodbine shallow-marine systems occur in distributary-channel and proximal-delta-front facies (Fig. 18), although original porosity has been modified by diagenesis. In contrast, Woodbine slope facies in western Tyler County (Fig. 18) have low reservoir quality and are nonproductive, although channelized-levee deposits are locally productive. Even though the porosity and permeability of these facies decrease with depth, reservoir quality also varies between and within both shallow-marine and deepwater facies, as a function of sedimentary facies that control grain size and stratification.

Proximal shallow-marine systems in northern Tyler County are represented by the Cities Service No. B-1 Sutton well (Fig. 19). This well produced ~36,400 bbl of oil and condensate, as well as >1.96 Bcf of gas from 1976 to 1984. The Woodbine Group in the Cities Service No. B-1 Sutton is composed of two sandstone-rich, upward-coarsening progradational cycles containing *Palaeophycus* burrows, interbedded with mudstone-rich zones dominated by *Planolites* burrows. The lower sandstone-rich section, from 11,292 to 11,323 ft (3,442.7 to 3,452.1 m), has an overall blocky vertical grain-size profile, although the lower 6 ft (1.8 m) coarsens upward (Fig. 19).

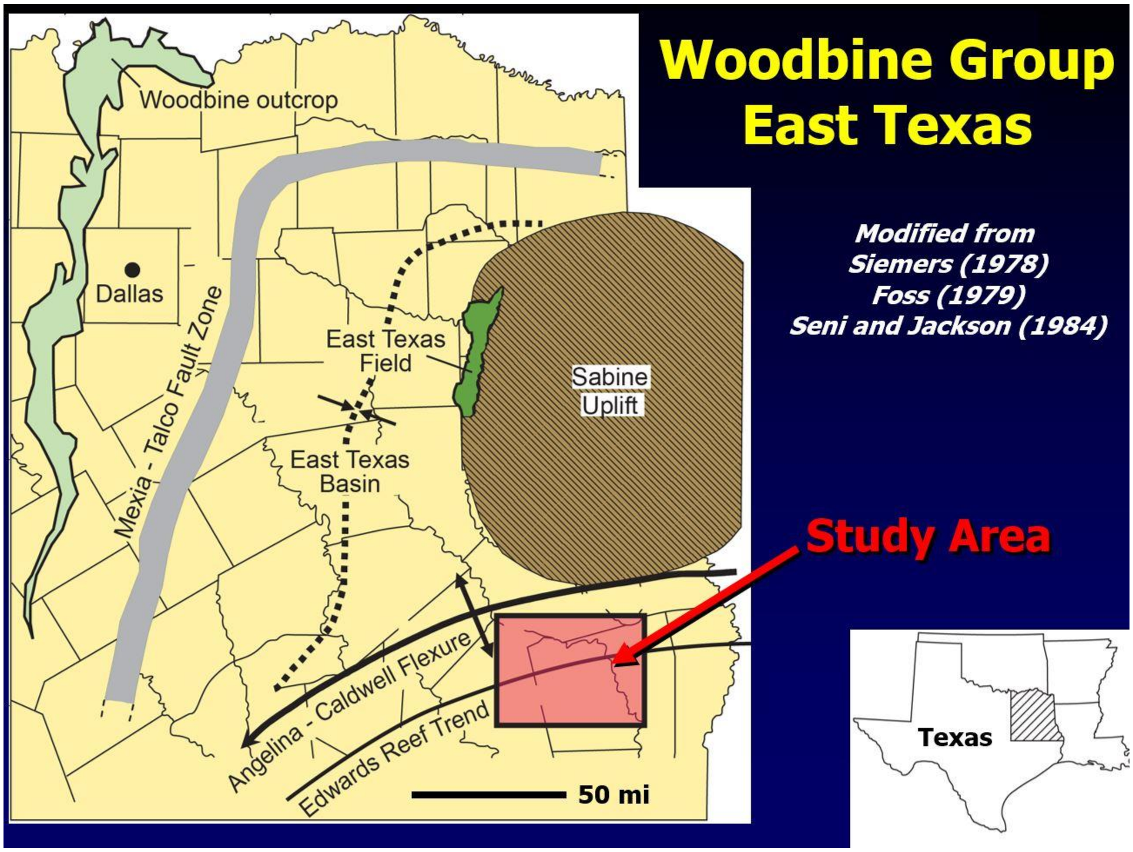


Figure 15. Structural setting of the Woodbine Group in East Texas and study area of Woodbine shelf-edge trend. From Ambrose et al. (2014), modified from Siemers (1978), Foss (1979), and Seni and Jackson (1984).

The Humble No. 1 Howell well, representing Woodbine slope deposits in northwestern Tyler County is located in Big Cypress field, east of Double A Wells field (Fig. 16). The Humble No. 1 Howell well produced only ~5,220 bbl of oil and condensate, as well as 147.7 MMcf (million cubic feet) of gas from 1965 to 1967. Two cored sections are within a 40-ft (12-m), upward-coarsening interval inferred from SP and resistivity log responses, as well as an overall vertical grain-size profile (Fig. 20). The lower cored interval from 14,797 to 14,807 ft (4,511.3 to 4,514.3 m) is composed of mudstone interbedded with thin (<0.5-inch [<1.3-cm]) beds of very fine grained sandstone. Permeability values in this lower cored section are low, ranging from 0.1 to 0.5 md (Fig. 20). The upper cored interval from 14,766 to 14,784 ft (4,501.8 to 4,507.3 m) features an upward-coarsening succession of very fine and fine-grained sandstone that truncates a muddy interval at 14,780 ft (4,506.1 m). This muddy interval is inferred to be part of the same fine-grained succession below a 15-ft (4.6-m) uncored section (Fig. 20). In contrast to the lower cored interval, the upper cored interval features greater permeability values that range from 0.4 md to as much as 4.5 md, with a median value of 1.6 md. Although these permeability values are low, they are an order of magnitude greater than those in the lower muddy section. Core-plug porosity values increase upward, approximately corresponding to an upward increase in overall grain size (Fig. 20).

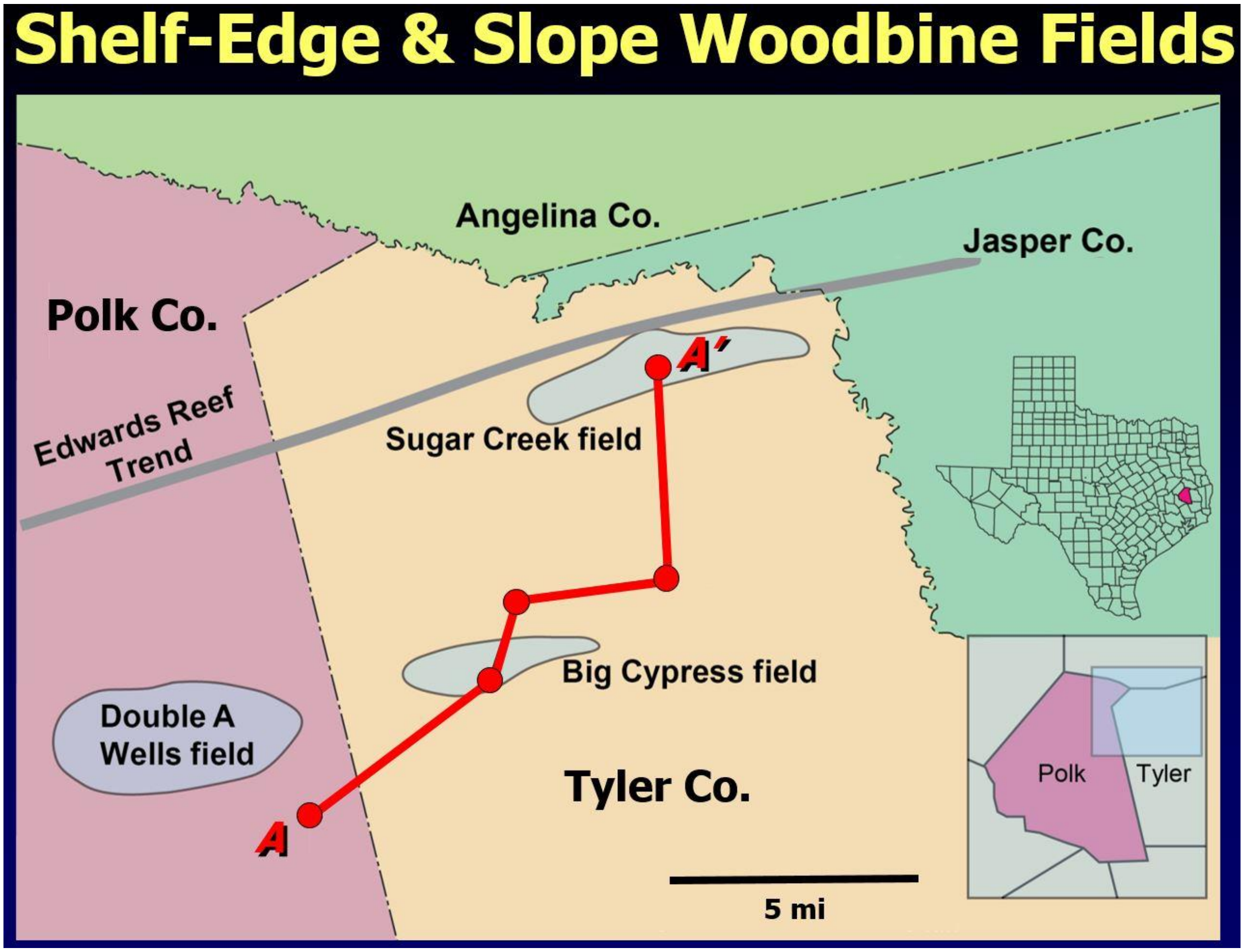


Figure 16. Location of downdip Woodbine fields in eastern Polk and northern Tyler Counties. Stratigraphic cross section A-A’ is shown in Fig. 17. Modified from Ambrose et al. (2014).

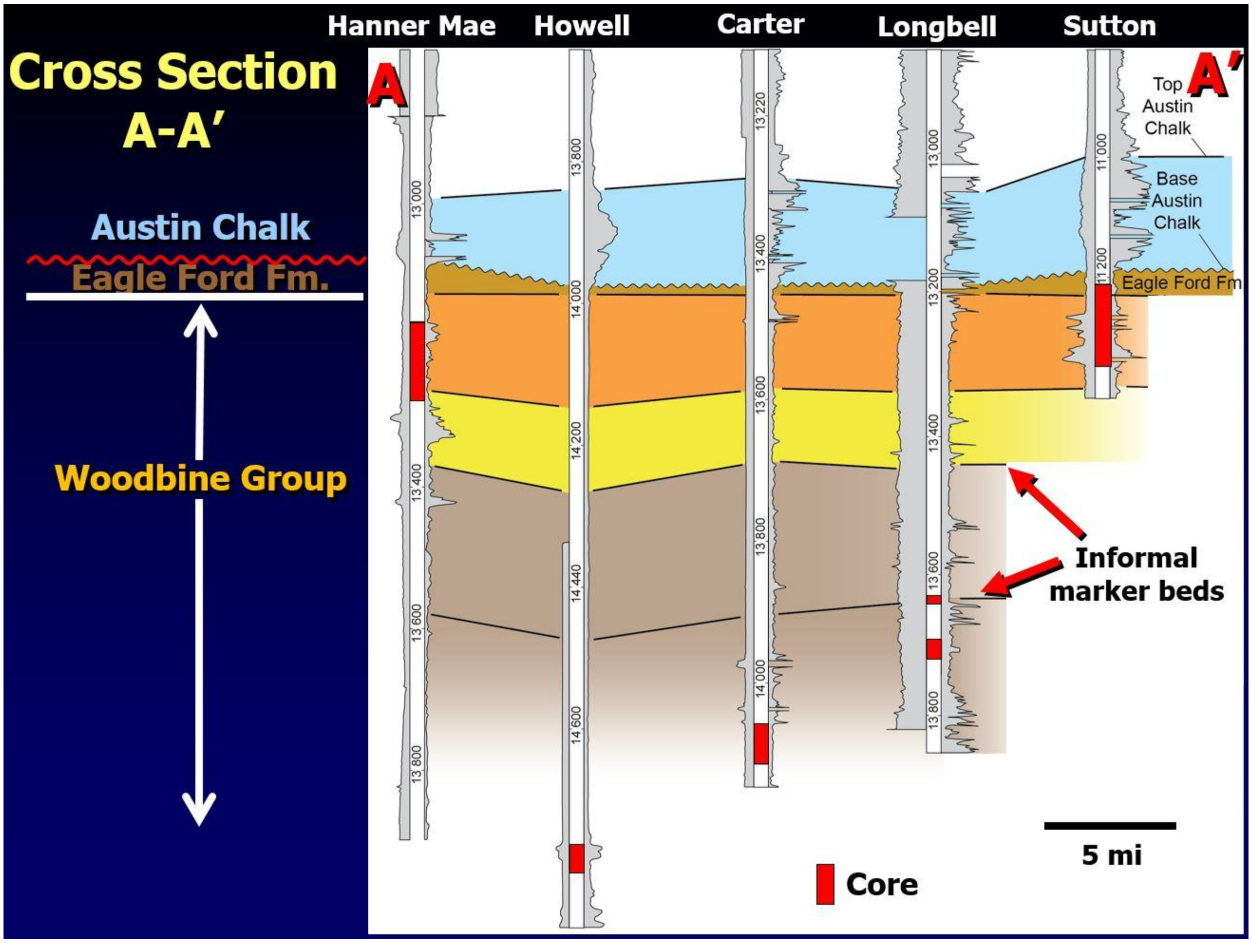


Figure 17. Stratigraphic cross section A-A' in eastern Polk and northern Tyler Counties, illustrating upper Cretaceous stratigraphy in the Woodbine Group, Eagle Ford Formation, and Austin Chalk. Cross section is located in Fig. 16. Modified from Ambrose et al. (2014).

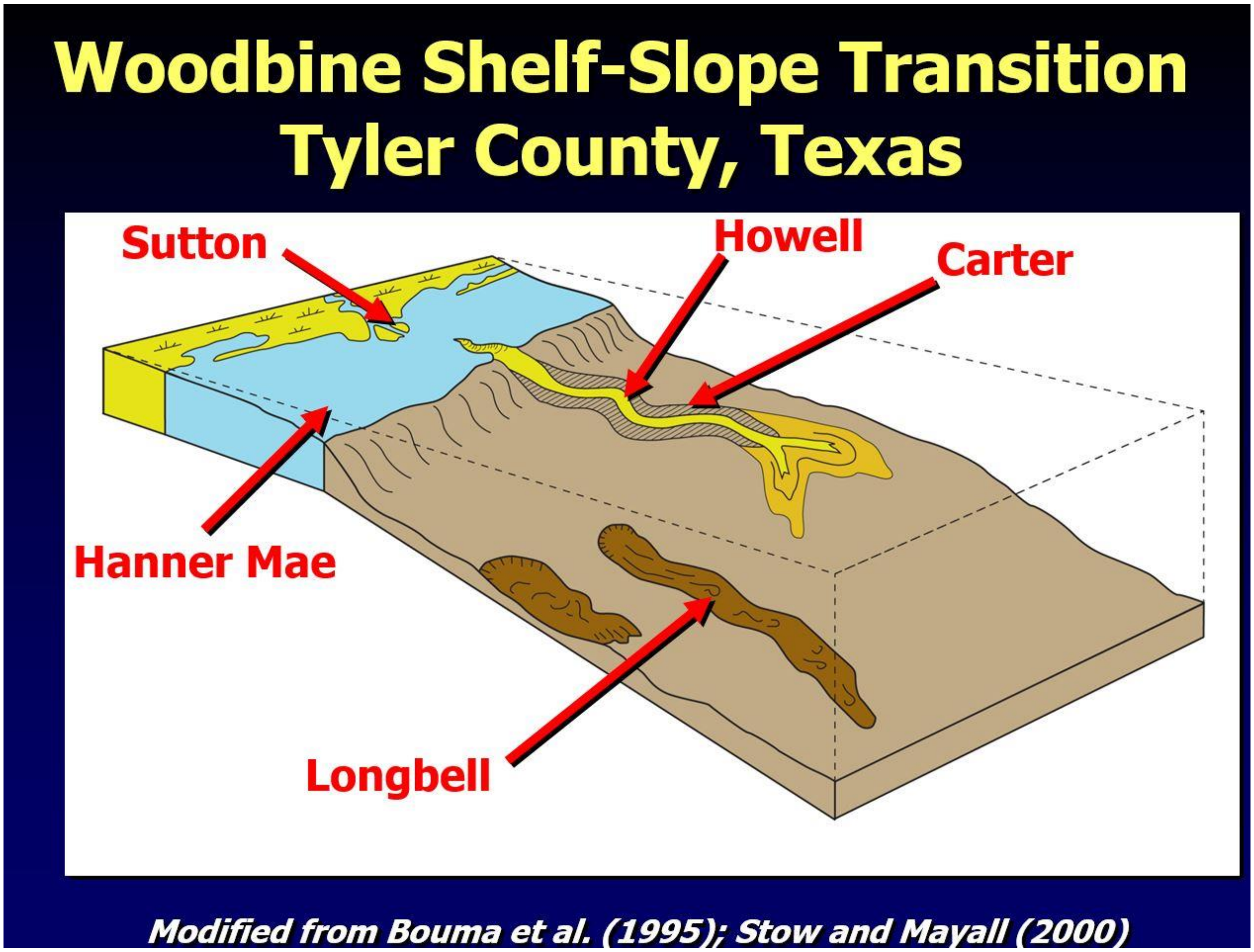


Figure 18. Schematic block diagram summarizing depositional setting for five cored wells shown in Figs. 16 and 17. From Ambrose et al. (2014), modified from Bouma et al. (1995) and Stow and Mayall (2000).

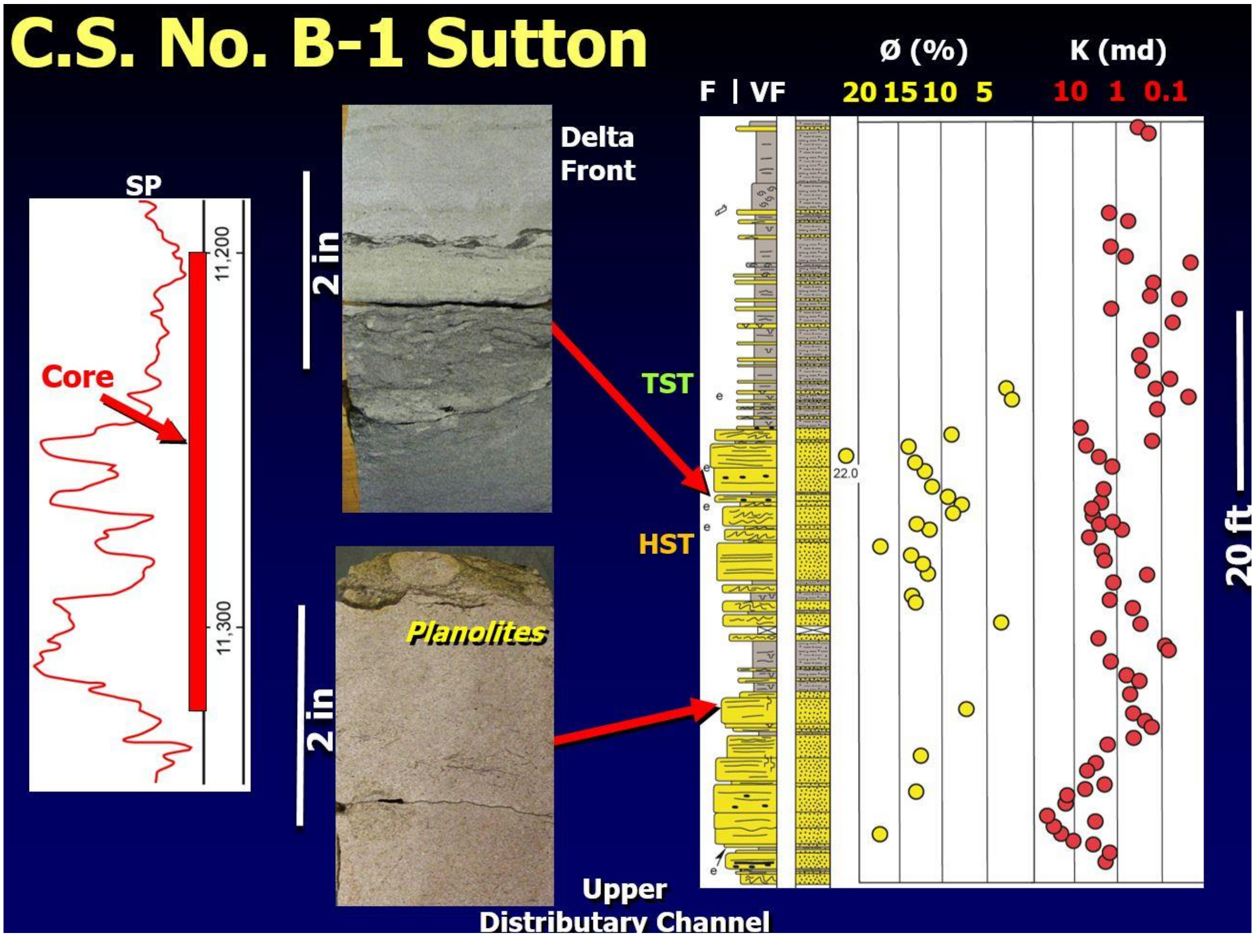


Figure 19. Wireline log, core photographs, core description, facies interpretation, core-plug porosity, and permeability data for the Cities Service No. B-1 Sutton well in northern Tyler County. SP: spontaneous potential; Res.: resistivity; F: fine-grained; VF: very fine grained. Ø: porosity in percent; K (md): permeability in milldarcies. Well located in Fig. 16. Schematic block diagram summarizing depositional setting is shown in Fig. 18. Modified from Ambrose et al. (2014).

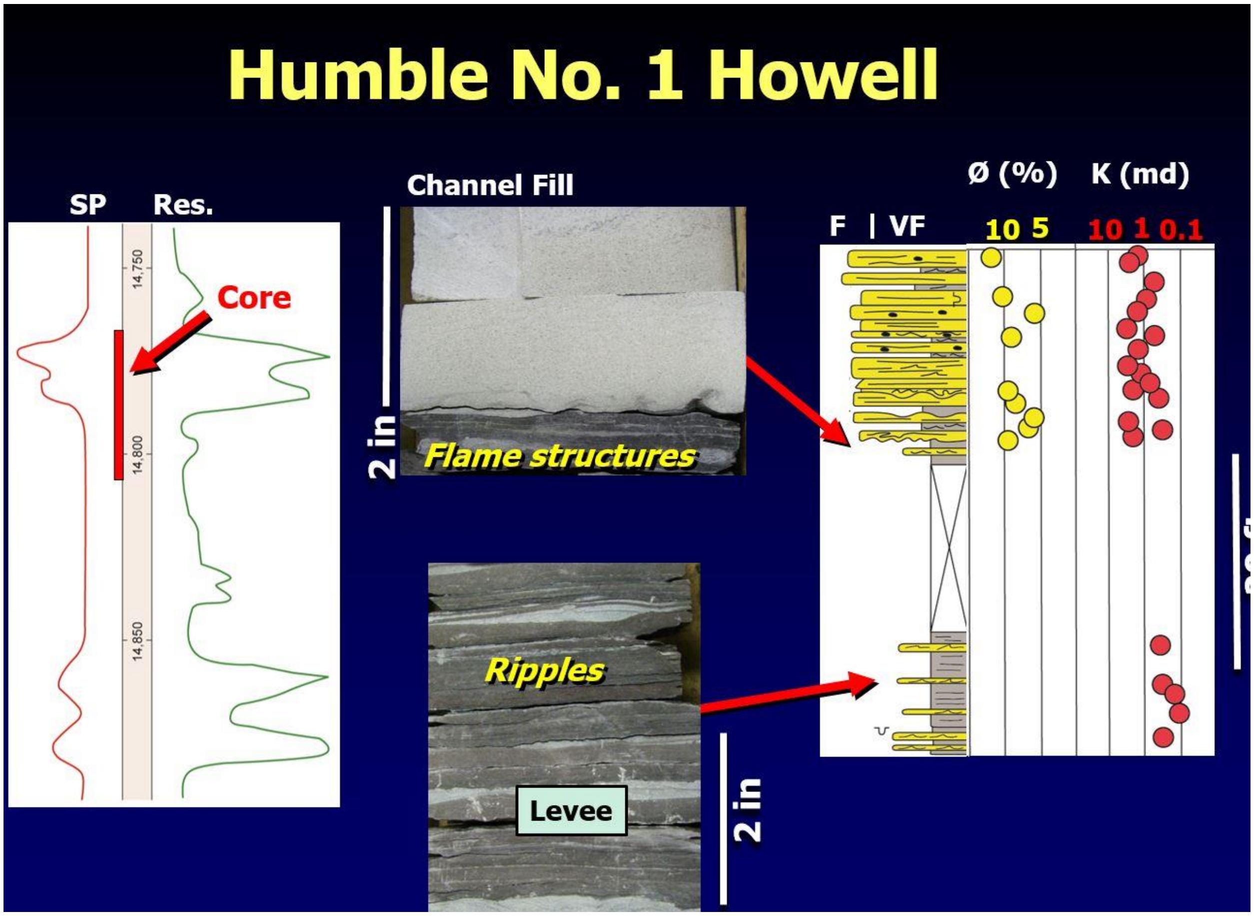


Figure 20. Wireline log, core photographs, core description, facies interpretation, core-plug porosity, and permeability data for the Humble No. 1 Howell well in northwestern Tyler County. Well located in Fig. 16. Schematic block diagram summarizing depositional setting is shown in Fig. 18. SP: spontaneous potential; Res.: resistivity; F: fine-grained; VF: very fine grained. Ø: porosity in percent; K (md): permeability in milldarcies. Modified from Ambrose et al. (2014).

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ADDITIONAL PROGRAM ELEMENTS

1. STARR WATER/ENERGY NEXUS

Overview and Goals of Project

In 2014, Texas was experiencing a severe hydrologic drought that resulted in significant shortages of water resources stored in reservoirs, especially west of the I-35 corridor. Precipitation in 2015 rebounded—mostly through two storm events around Memorial Day and Halloween—leading to record flooding in some areas. At the same time, oil and gas prices fell, leading to reduced water demand in the energy sector. Though water availability appeared to increase and water needs reduced, water handling in the energy sector (including sourcing water for exploration, management of flowback, and produced water) continued to be an area of concern for various stakeholders, and an area where research and data analysis can reduce impacts to water resources and reduce risks of shortages or impacts to water quality. Perhaps no issue related to water resources and the state's energy industry has garnered more attention than the potential for wastewater disposal to induce earthquakes, often call induced seismicity. The STARR Water/Energy project has provided support to initiate an in-depth assessment of statewide risk of earthquakes, including the leveraging of resources to create an industry-funded research program known as the Center for Integrated Seismicity Research (CISR), which has led to an increase in external (non-State) funding of $750,000, or leveraging at more than 3:1 for this project alone. Another important consideration involves potential for oil and gas infrastructure to impact land resources and long-term productivity through increased risk of erosion and flooding, fragmentation of ecosystems, or introduction of invasive species. STARR helped match funding from JPMorgan Chase Bank (in New York) to study potential landscape impacts across the 27-county footprint of the Eagle Ford play in South Texas. STARR funds have supported these scientifically focused tasks to improve our understanding of this complex water/land/energy nexus.

Description of Results and Findings

Water/Energy

Significant effort was expended on creating an externally (industry-based) funded research program to understand overall earthquake potential in Texas, including those potentially caused by disposal of wastewater from oil and gas operations.

Water injection rates in the Fort Worth Basin are being compiled from 1983 to the present (graph at right [modified from Lemons et al., unpublished]

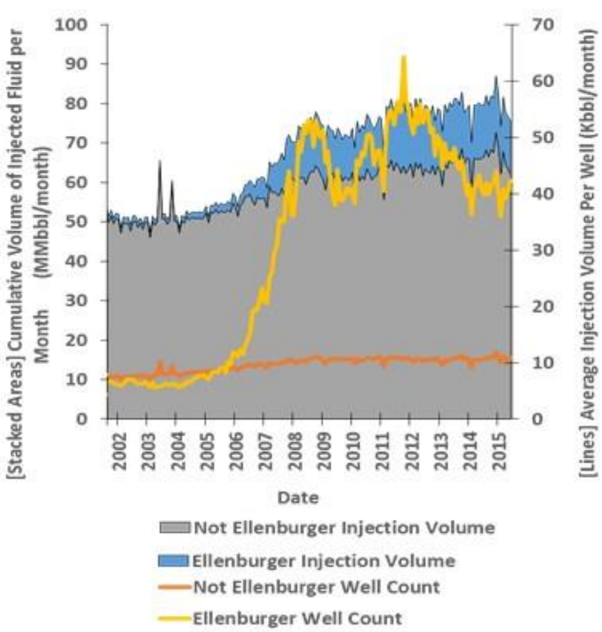

Figure 21. Water injection rates in the Fort Worth Basin compiled from 2002 to the present.

shows only 2002–present) using data from the Railroad Commission of Texas and other sources. Disposal volumes have increased in the Ellenburger Group, which is located above faulted basement formations.

A complete geologic and reservoir analysis is under way, with a goal of improving our ability to make causative connections between wastewater disposal and seismic activity in the Fort Worth Basin. The impacts of earthquakes on infrastructure in Texas are funded by the CISR consortium.

Similar analysis in other basins will be completed in the future.

Land/Energy

The 27-county footprint of the Eagle Ford play was assessed for land use changes. Changes in land classification were based on pipeline and drill pad locations beginning in 2006, before the onset of significant Eagle Ford activity.

Substantial variability of impacts was observed across the play, as measured by the area of land altered in the county. Highest alteration was Webb County (42.2 km^2), and lowest alteration was Bastrop County (0.1 km^2).

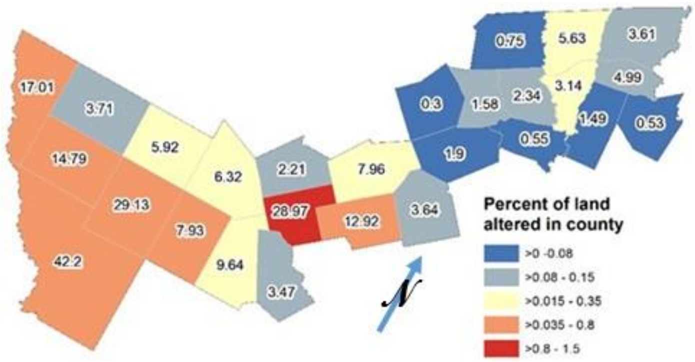

Figure 22. 27-county footprint of land alteration in the Eagle Ford play.

Pad and pipeline infrastructure required more than 200 km^2 of land area across all 27 counties, with just over 70 km^2 of area intersecting core landscape areas (>2 km^2) that could be considered habitats for different species (e.g., terrestrial and aquatic based).

Results suggest that reducing set-asides and coordinating field infrastructure could reduce land impacts, potentially reducing erosion and flooding risks, and preserving habitats.

Products and Outcomes (partial list)

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Connection to Neutrality and Value to Texas

Funds have been used to match external grants in two different programs: the water/energy program, where 10 companies each have sponsored the CISR consortium at a total of $750,000 per year, and the land/energy program, where JPMorgan Chase Bank underwrote a study at $100,000 to assess potential impacts to land resources from infrastructure to support oil and gas activity in the Eagle Ford play. In the water/energy research, the Bureau of Economic Geology has focused on both water resource sustainability in Texas, vital for maintaining the quality of this resource for the state for current and future citizens, and the issues of induced seismicity

2. SPECIES, WATER, AND LANDSCAPE STUDIES

Overview and Goals of Project

To enable Texas to continue economic growth and facilitate conservation of species, we are studying how aquatic and terrestrial habitats, some of which may be protected by State and/or Federal programs, intersect with economically important water, energy, and land resources. Our goals are to conduct unbiased, scientifically rigorous research that provides stakeholders with the information and assistance they need to develop strategies for a potential listing of threatened or endangered species or to navigate a previous Federal listing. Our collaborators include State and Federal agencies, nongovernmental organizations, and industry.

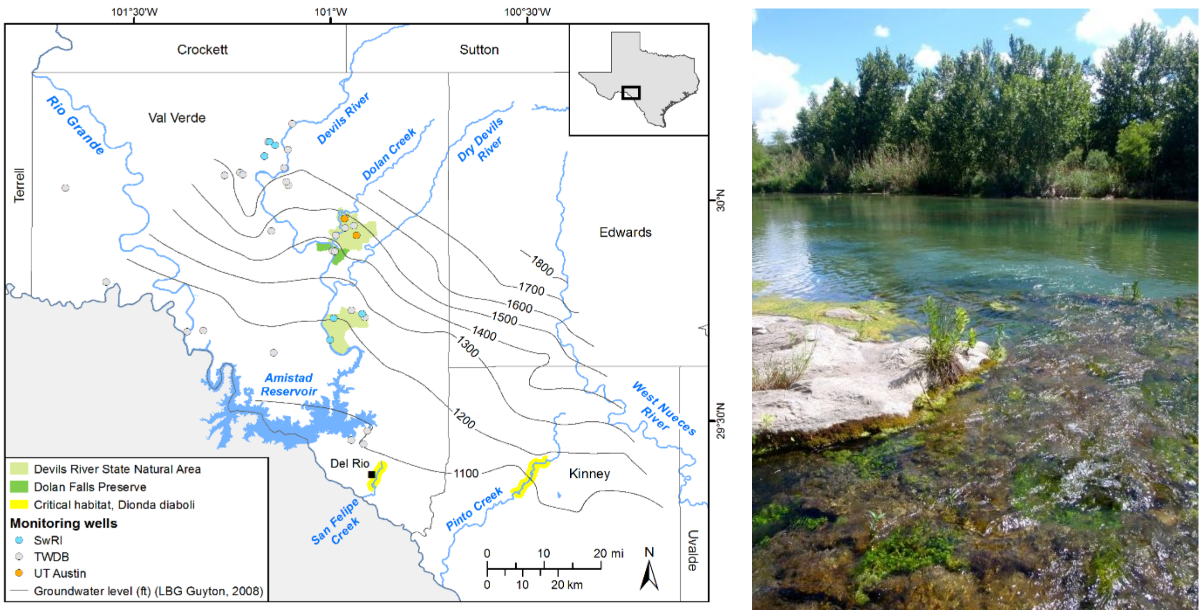

Figure 23. Devils River, including groundwater monitoring. Springs and the river were also monitored.

One study partially funded under the STARR program is an ongoing program to monitor the effects of groundwater levels on spring and stream discharge, stream temperature, and habitat for the Devils River minnow. The federally threatened Devils River minnow *(Dionda diaboli)* was historically found in spring-fed Rio Grande tributaries, but its modern range is substantially reduced by anthropogenic development. Now, proposed unregulated groundwater development in the Devils River watershed threatens to reduce streamflow and aquatic habitats for ~50 percent of the current known range. Of economic importance to Texas is that flows from the Devils River account for 10 to 15 percent of inflows to Amistad Reservoir. Thus, understanding how possible groundwater development may affect this fish may also assure that Rio Grande flows to the Valley are maintained, which could reduce the cost of future water development projects in the Valley.

Description of Results and Findings

We have completed year 1 of a two-year project for which STARR was used for cost share:

1. Water conductivity (e.g., salinity) and temperature were collected in two springs and two stream locations to understand how rainfall-runoff and spring-flow relationships affect streamflow and how habitat quality changes in response to the mixing of various inputs including groundwater, stream water, and precipitation.
2. Meteorological parameters were measured to understand how climate affects spring flows.
3. We installed two new stream gauges to understand how streamflow fluctuates in response to changing groundwater levels and climatic conditions. These gauges also fill gaps on the Devils River, allowing us to quantify how much spring discharge contributes to stream flow.
4. Groundwater levels were measured in two wells to understand groundwater variability before possible onset of groundwater pumping projects; we found that shallow groundwater must be managed to limit overuse, which could reduce spring discharge and flows to the Amistad Reservoir.

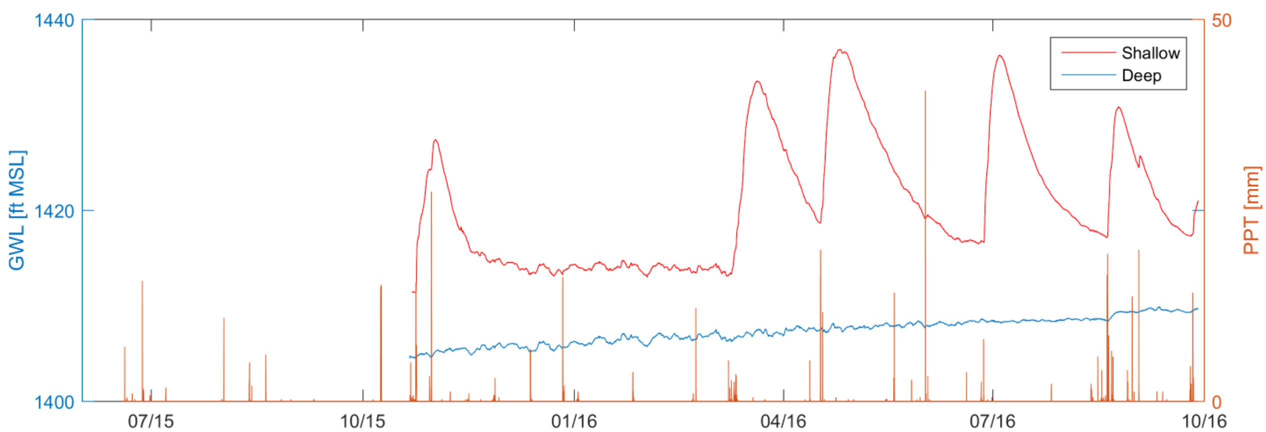

Figure 24. Groundwater levels at two groundwater monitoring wells shown with precipitation.

Products

- Presentation at 2016 Geological Society of America conference, Denver, Colorado
- Report on one-year, interim monitoring results of groundwater levels, spring and stream discharge, temperature, and salinity for the Devils River minnow
- Paper to follow upon completion of Devils River minnow study in early 2018

Connection to Neutrality and Value to Texas

The potential Federal listing of threatened or endangered species may add regulations to private property owners; use of water, energy, and land resources; and economic development across Texas. Studies of species of State and Federal interest benefit Texans by highlighting areas of heightened risk and assessing risks to the Texas economy. Understanding how aquatic and terrestrial habitats intersect with economically important water, energy, and land resources helps to proactively identify and mitigate possible economic effects of changes in water, energy, and land management following Federal listing of species under the Endangered Species Act protection. STARR Species, Water, and Landscape Studies funds ($5,585) were used as a cost share to augment Federal funds to support this study ($149,594.33 total project).

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3. STARR HAZARDS MAPPING AND RESPONSE

Overview and Goals

Multiple geologic hazards impact Texas citizens, infrastructure, and economic development. Principal among these are coastal erosion, tropical-cyclone impact, sinkhole development, and landslides. Goals of the STARR Hazards program are to prepare the state to respond to hazards by understanding their location and severity, assessing the threat they pose, and ultimately producing an atlas of geologic hazards that is accessible to emergency responders, planners, and citizens.

Description of Results and Findings

Efforts in this biennium are focused on coastal-hazard mapping and sinkhole assessment. Major activities fully or partly supported by STARR Hazards include

- A geophysical and geodetic survey of the Wink sinkhole area in Winkler County, West Texas, to assess collapse risk associated with current and historical subsidence that has led to formation of two large sinkholes since 1980 and continues to pose a threat to public safety, roads, pipelines, utilities, and oilfield infrastructure. The geophysical and geodetic survey, located in subsiding areas identified in a 2013 STARR-supported airborne lidar survey, was completed in May 2015, and data have been processed to indicate ground subsidence along county roads (Fig. 1). STARR support leverages funds donated by industry to enable ongoing sinkhole studies. Winkler County officials have helped support the studies to the extent possible. STARR support also enabled rapid response actions on behalf of the state in other sinkhole-prone areas, including the Corpus Christi area.

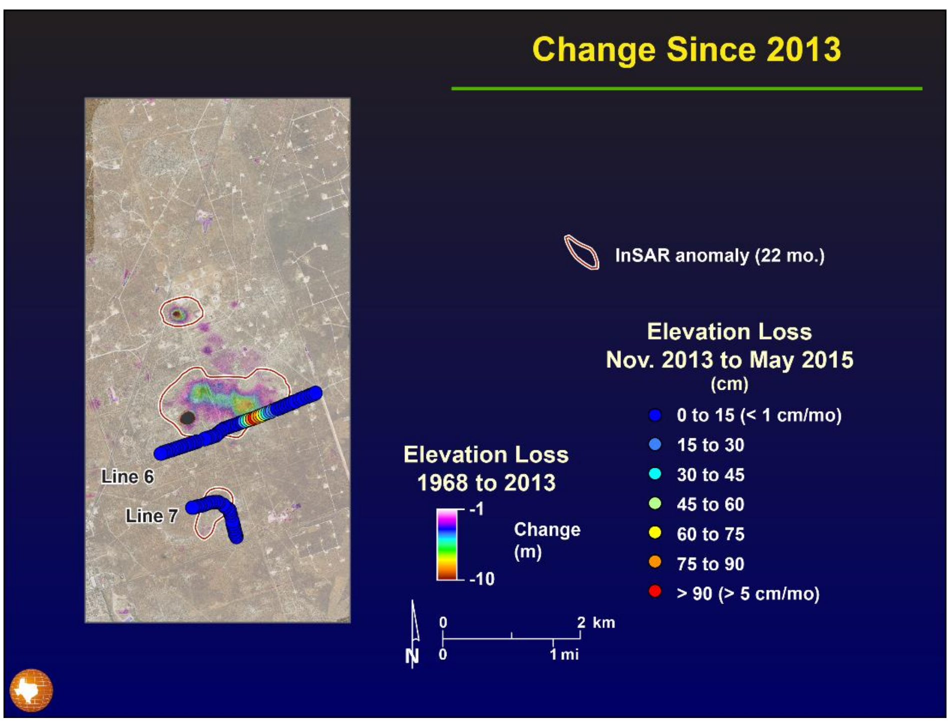

Figure 25. Elevation loss along Winkler County roads near Wink Sinks 1 and 2 between November 2013 (from airborne lidar) and May 2015 (from geodetic and gravity survey) superimposed on map showing elevation loss between 1968 and 2013.

- Airborne lidar and ground mapping on the Texas coastal plain to assess onshore sand resources that will be needed to support coastal resilience and restoration projects in response to sea-level rise, tropical cyclone impacts, and shoreline erosion. STARR funds supplement externally funded projects, allowing us to conduct airborne lidar and ground-based investigations that complement project objectives in the Copano and Matagorda Bay areas on the central Texas coast. Sand deposits are potential resources for future energy extraction, beach nourishment, and coastal habitat restoration. In addition, STARR-supported surveys have identified previously unknown surface faults and enhanced subsidence areas on the central Texas coast and are being used to conduct geoenvironmental mapping associated with the development of Powderhorn Ranch, a 17,000+ acre parcel of land recently purchased for the State of Texas for development as a State Park and Wildlife Management Area.

Products

Principal products from STARR-supported activities include presentations at conferences and stakeholder meetings, maps available to the public, interviews, reports, articles, and interactive websites showing historical coastal erosion rates on the Texas Gulf and bay shorelines.

- Four quadrangle-scale maps showing sand distribution in one quadrangle adjacent to Matagorda Bay, one quadrangle along Espiritu Santo Bay, and two quadrangles in the Copano Bay area. These maps are jointly produced from STATEMAP, STARR mapping, and General Land Office projects and are listed in the STARR Mapping section.

- Fourteen presentations on sinkholes and coastal geologic hazards at the following venues:
    - Wink sinkholes to San Antonio Geophysical Society, San Antonio, Texas.
    - Wink sinkholes to AAPG International Conference and Exhibition.
    - Coastal erosion hazards to Texas Beaches and Dunes Science and Management Forum, Corpus Christi, Texas.
    - Coastal mapping and sand resources to Gulf Coast Association of Geological Societies, Houston, Texas.
    - Coastal mapping and sand resources to Gulf Coast Association of Geological Societies, Corpus Christi, Texas.
    - Coastal mapping and sand resources to Symposium on the Application of Geophysics to Engineering and Environmental Problems, Denver, Colorado.
    - Coastal mapping and sand resources to Texas Mining and Reclamation Association, Bastrop, Texas.
    - Texas geologic hazards to Earth Science Week, Austin, Texas.

- Twenty-seven reports, articles, and maps on coastal and geologic hazards:
    - Journal of Coastal Research article on coastal erosion hazards and trends, Texas Gulf shoreline.
    - Two articles on coastal mapping and sand resources for Gulf Coast Association of Geological Societies and Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP).

    - Nine abstracts on sinkhole hazard assessment and coastal hazards and sand-resource mapping at national and international conferences (Gulf Coast Association of Geological Societies, Geological Society of America, SAGEEP, and American Association of Petroleum Geologists).
    - Two contract reports to the Texas General Land Office (GLO) on coastal erosion and mapping and two to the U.S. Geological Survey on coastal mapping in the Copano Bay and Matagorda Bay areas.
    - Four quadrangle-scale maps in the Copano and Matagorda Bay areas that include the distribution of sand-prone surficial strata.
    - Seven posters available to the public that depict coastal erosion hazards for the seven Texas Gulf shoreline segments.

- Three interactive websites on coastal erosion hazards:
    - Texas Gulf Shoreline Change Project (http://coastal.beg.utexas.edu/shorelinechange/)
    - Shoreline Change and Beach/Dune Morphodynamics (http://www.beg.utexas.edu/research/programs/coastal/shoreline-change-and-beach-dune-morphodynamics-along-the-gulf-coast)
    - Measurement and Characterization of Bay Shoreline Change (http://www.beg.utexas.edu/research/programs/coastal/measurement-and-characterization-of-bay-shoreline-change)

Connection to Neutrality and Value to Texas

Coastal hazards, sinkholes, and active faults threaten citizens, infrastructure, and economic development across Texas. Studies of geologic hazards benefit Texans by highlighting areas of heightened risk and assessing risk and magnitude of future events. Knowing the context and distribution of geologic hazards helps maximize effective response when an event does occur and minimize its impact through better planning and avoidance of high-risk areas. STARR hazards funds supplement industry sources of funds that are being used to conduct sinkhole hazard studies in West Texas, and numerous State and Federal grants (GLO and National Oceanic and Atmospheric Administration primarily) that support coastal erosion studies on the Texas coast.

Sand resources on the Texas coastal plain will become an increasingly valuable commodity as offshore and dredged-channel sources are consumed in current and planned coastal restoration projects intended to offset chronic coastal erosion and land loss. STARR Hazards funds help supplement existing projects, allowing sand-resource assessments to be conducted in association with other funded coastal projects, leveraging both STARR and project funds.

4. MAPPING AND MINERAL/EARTH RESOURCES OF TEXAS

Overview and Goals of Project

This project produces geologic maps to support the development and management of Texas' resources. The diverse geologic formations of Texas provide many industrial rocks and minerals used by Texas' industries and society. Mineral production exists throughout Texas and is mostly related to construction and industrial activities. Demand for earth materials that are used for construction materials, minerals used in the chemical industries, as well as earth materials used in the hydrocarbon exploration/production industry, increases with population and economic growth. Geologic maps are one of the most basic data sets used by professionals to aid in exploration and evaluation of earth resources. Maps and their related materials foster economic development and support the ability to locate and develop mineral and water resources, to identify and plan for potential hazards, to assess changes in sensitive coastal environments, and to properly plan and permit major construction projects. This project supports the development and management of Texas' mineral/earth resources by providing basic geologic information, such as geologic maps, to the public.

The STARR Geologic Mapping and Mineral/Earth Resources of Texas project complements the STARR Hazards Mapping and Response project and Texas STATEMAP project, which is partially supported by the National Geologic Mapping Cooperative Program administered by the U.S. Geological Survey. Possible mapping study areas in Texas are prioritized by a mapping advisory committee composed of representatives from the Texas Water Development Board, Texas Natural Resources Information System, Railroad Commission of Texas, Texas General Land Office, and Texas Parks and Wildlife Department, with coordination from the Bureau of Economic Geology.

Description of Results and Findings

Two geologic maps produced for the Central Texas area with geologic units of potential industrial and/or hydraulic fracturing sand resources. One additional map scheduled for completion in June 2017 (**B. Elliott**). Co-mapping for Texas STATEMAP Program and STARR.
Two geologic maps produced for West Texas areas with geologic units of potential rare earth elements, uranium, precious and base metals (**B. Elliott**). Co-mapping for Texas STATEMAP Program and STARR.

Two geologic maps produced for North-Central Texas area with geologic units of potential industrial and/or hydraulic fracturing sand resources and limestone aggregate resources, and for geologic data applicable to earth and water resources and engineering projects of transportation corridor (**E. Collins**). Co-mapping for Texas STATEMAP Program and STARR.

Four geologic maps produced for middle Texas Gulf of Mexico Coast area of sensitive coastal environments, potential sand resources, and ongoing evaluation of coastal erosion. Two additional maps scheduled for completion in June 2017 (**J. Paine and E. Collins**). Co-mapping for Texas STATEMAP Program and STARR.

Three geologic maps for the Central Texas area produced for geologic data applicable to earth and water resources and engineering projects of population corridors. Two additional maps scheduled for completion in June 2017 **(E. Collins and C. Woodruff**). Co-mapping for Texas STATEMAP Program and STARR.

Continued development and update to the mineral resources map of Texas through the Bureau of Economic Geology website http://igor.beg.utexas.edu/txmineralresources/ (**B. Elliott**).

Promoted industry connections and fostered relationships with organizations and agencies that maintain valuable resource-related data. Organizations include U.S. Geological Survey, Department of Energy, Department of Interior, Texas Mining and Reclamation Association, Texas Aggregate and Concrete Association, Texas Cement Association, Texas Water Development Board, Texas Department of Transportation, Texas Railroad Commission, Texas Commission on Environmental Quality, and Texas Workforce Commission (**B. Elliott**).

Provided information and assistance with inquiries concerning engineering geology and geologic hazards in Central Texas (**C. Woodruff**).

Provided information and assistance by responding to more than 90 inquiries on mineral occurrences, deposits, data, and available publications. Inquiries ranged from public questions on rocks and minerals, regional and local geology, to resource-specific questions concerning uranium, sand and gravel, hydraulic fracturing sand and high-quality industrial sands, natural clay materials, and rare earth elements (**B. Elliott**).

List of Products

Collins, E.W., 2016, Geologic map of the Bee Cave quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Collins, E.W., 2015, Geologic map of the Gainesville South quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Collins, E.W., 2015, Geologic map of the Muenster West quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Collins, E.W., in progress for 2017, Geologic map of the Shingle Hills–Dripping Springs–Driftwood–Rough Hollow–Henly–Hammett Crossing area, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:50,000.

Elliott, B.A., 2016, Geologic map of the Fredonia quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Elliott, B.A., 2016, Geologic map of the White Hills quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Elliott, B.A., Verma, R., and Kyle, J.R., 2016, Prospectivity modeling for Cambrian-Ordovician hydraulic fracturing sand resources around the Llano Uplift, Central Texas: Natural Resources Research, v. 25, no. 4, p. 389–415, http://doi.org/10.1007/s11053-016-9291-6.

Elliott, B.A., 2015, Geologic map of the Spice Rock quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Elliott, B.A., 2015, Geologic map of the Gunsight Hills South quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Elliott, B.A., and Verma, R., 2015, Identifying new resource prospects and resource assessment with geospatial modeling techniques: The Central Texas Frac Sand District, Society for Mining, Metallurgy and Exploration, Open File Report, v. 16, no. 2, Minneapolis, Minn., 13 p.

Paine, J.G., and Collins, E.W., 2016, Geologic map of the Port O'Connor quadrangle, Texas Gulf of Mexico Coast: Sheet 1: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Paine, J.G., and Collins, E.W., 2016, Geologic map of the Port O'Connor quadrangle, Texas Gulf of Mexico Coast: Sheet 2, Geophysical logs and time-domain electromagnetic induction soundings: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Paine, J.G., and Collins, E.W., 2016, Geologic map of the Saint Charles Bay quadrangle, Texas Gulf of Mexico Coast: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Paine, J.G., Collins, E.W., and Costard, L., 2015, Geologic map of the Rincon Bend quadrangle, Aransas River, and Copano Bay area, Texas Gulf of Mexico Coast: Sheet 1: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Paine, J.G., Collins, E.W., and Costard, L., 2015, Geologic map of the Woodsboro quadrangle, Aransas River, and Copano Bay area, Texas Gulf of Mexico Coast: Sheet 1: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Verma, R., and Elliott, B. A., submitted, Transportation economics and applicability of Central Texas hydraulic fracturing sand to regional oil and gas production: Journal of Unconventional Oil and Gas Resources.

Woodruff, C.M., Jr., and Collins, E.W., 2016, Geologic map of the upper Lake Travis area, Texas: The University of Texas at Austin, Bureau of Economic Geology, Miscellaneous Map No. 52, scale 1:50,000.

Woodruff, C.M., Jr., and Collins, E.W., 2015, Geologic map of the Pace Bend quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Woodruff, C.M., Jr., in progress for 2017, Geologic map of the Mansfield Dam quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Connection to Neutrality and Value to Texas

STARR Mapping and Earth/Mineral Resources of Texas work integrates much of its effort with the ongoing BEG Texas STATEMAP program, an established, ongoing geologic mapping program that began in 1992. Integrating work for this program allows for some State dollars to be matched with Federal dollars, increasing the productivity (and budgets) of the programs. The Texas STATEMAP program also complements ongoing studies of geologic hazards affecting Texas and studies of the status and trends of wetland environments and aquatic habitats.

STARR funds accounted for most of the required cost share for Federal funds awarded in the amount of $433,664 for the STATEMAP Program.
STARR funds accounted for most of the required cost share for the awarded Federal funds ($49,351 Federal) for the Department of Interior Office of Surface Mining Reclamation and Enforcement (OSMRE) Texas Sub-surface Coal Mine Inventory Program.

Geologic maps and related charts, diagrams, and texts, are a type of product that has been documented to have immense economic and societal value (Bhagwat and Ipe, 2000; GSA Geology & Public Policy Committee, 2012). For example, one analysis calculated the value of the geologic maps to be 25 to 30 times the cost of map preparation. Geologic maps and their related materials foster economic development and support the ability to locate and develop mineral and water resources, to identify and plan for potential hazards, to assess changes in sensitive coastal environments, and to properly plan and permit major construction projects.

References

Bhagwat, S.B., and Ipe, V.C., 2000, Economic benefits of detailed geologic mapping to Kentucky: Illinois State Geological Survey, Special Report No. 3, 48 p. http://library.isgs.illinois.edu/Pubs/pdfs/specialreports/sp-03.pdf ; http://isgs.illinois.edu/kentucky-geologic-mapping-program

GSA Geology & Public Policy Committee, 2012, The value of geologic mapping: The Geological Society of America, Position Statement, http://www.geosociety.org/positions/pos3_mapping.pdf .

5. MANAGING WATER RESOURCES IN TIMES OF DROUGHTS AND FLOODS

Overview and Goals of Project:

Texas is continually subjected to droughts and floods, such as the extreme drought in 2011 through 2014 that was broken by floods in 2015. Managing these extremes is challenging because of water supply variability with either too much or too little water being available. The goals of this study were to

(1) conduct detailed analysis of the 2011–2014 drought,

(2) examine the use of satellite data to track changes in water storage in Texas in response to droughts and floods, and

(3) assess the potential of managed aquifer recharge or aquifer storage and recovery to even out water supply variability related to droughts and floods.

Because of water scarcity concerns related to droughts in Texas it is important to understand as much as possible the conditions that led to the 2011 drought and others in the past, the persistence of various droughts in the historical record, and the processes that were related to end droughts. This analysis is intended for us to be better prepared for future droughts and to assess whether we can predict the beginning, length, and end of droughts in the future.

There is increasing interest in using satellites to track droughts and to provide an early warning system for droughts. The National Aeronautics and Space Administration (NASA) has been promoting the use of the Gravity Recovery and Climate Experiment (GRACE) satellites to monitor droughts in the United States and also provides input to the National Drought Monitor. We wanted to assess the capabilities of GRACE data specifically for Texas and to evaluate the reliability of the results in this region through evaluation of different GRACE products and ground-validation within the state. Because the University of Texas Center for Space Research is one of three developers of the NASA GRACE satellite mission, we have a unique opportunity to evaluate different GRACE products and optimize applications for the state.

It is important to develop adaptive strategies to cope with droughts and floods. One of the primary approaches is to store water to resolve the temporal disconnect between having too much or too little water. Whereas traditional water storage approaches focus on surface reservoirs, we wanted to examine the potential for use of storage in aquifers through programs variously termed aquifer storage and recovery (ASR) or managed aquifer recharge (MAR). Because these programs are relatively new to Texas, we looked at long-term programs in the southwestern United States, specifically California and Arizona, to determine how they were able to expand managed aquifer recharge programs in these states and evaluate the legal and regulatory aspects of application of these types of storage programs.

Description of Results and Findings:

The analysis of droughts in Texas identified eight major droughts on the basis of the six-month standardized precipitation index (SPI): 1901–1902, 1910–1911, 1917–1918, 1924–1925, 1954–1955, 1956–1957, 1996, and 2011. Texas is in moderate drought (-1.5<SPI<-1) 32 percent of the time, severe drought (-2<SPI<-1.5) 9 percent, and extreme drought (SPI<-2) 7 percent. Although many studies suggest that droughts have been icreasing recently, six out of the eight extended droughts occurred before 1960. Extreme hydrologic drought conditions were recorded in Texas six times over the historical record, with the lowest recorded in 2011, followed by 1971, 1996, 1955–1956, 1966, and 2013. La Niña preceded six of the eight major Texas droughts, while negative Pacific Decadal Oscillation and positive Atlantic Multidecadal Oscillation preceded five of the droughts. Most droughts in Texas end in floods. A key finding is that drought-breaking rainfall in Texas is generally a result of a southward shift in the polar jet stream or a low-pressure trough over central North America. Improved knowledge of the climate mechanisms controlling the onset and termination of drought periods should enhance drought forecasts and improve drought management practices.

GRACE satellite data are valuable for continuously tracking total water storage in the state. We evaluated a number of new GRACE products and found consistency among the results, increasing confidence in water storage changes from GRACE. Gradual increases in GRACE total water storage and increases in vegetation wetness from satellite data in fall 2014 and spring 2015 showed that the system was gradually recovering from the four-year drought and was preconditioned, with increasing soil moisture, for the flooding that occurred in spring 2015. A key strategy for managing water supply variability related to droughts and floods is to store more water in aquifers. House Bill 655 (HB 655), enacted by the 84th Texas Legislature in 2015, greatly facilitates ASR in the state. Major elements of HB 655 were implemented, and revisions to Texas Commission on Environmental Quality (TCEQ) regulations were made. For example, a water right holder may undertake an ASR project without obtaining any additional authorization, and ASR projects no longer require continuous availability of historical normal stream flow. Furthermore, previously implied groundwater conservation district jurisdictional authority over ASR projects is now explicitly repealed. The TCEQ has sole regulatory authority over the issuance of Class V injection well permits for ASR. Analysis of MAR systems in California and Arizona showed how storing water in partially depleted aquifers was very favorable, reversing

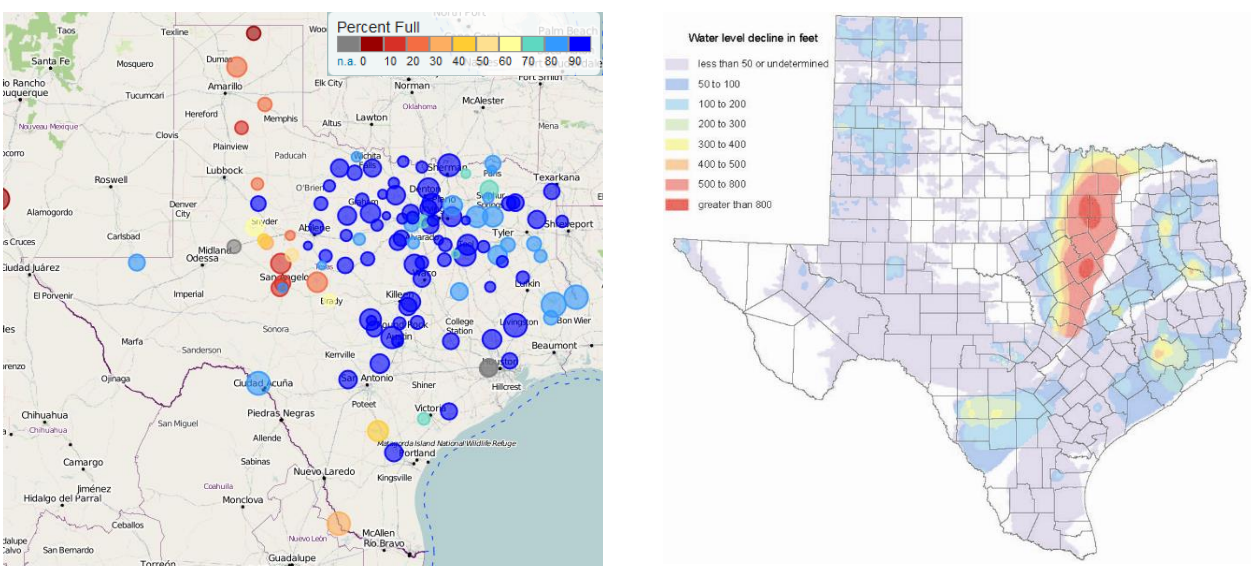

Figure 26. Reservoir levels in Texas on November 21, 2016, showing proximity of full reservoirs and depleted Trinity Aquifer in the vicinity of the Dallas–Fort Worth region. These data demonstrate excellent opportunities for ASR.

previous declining groundwater level trends, increasing reliability of water supplies during drought, and allowing a water market to develop on the basis of highest value uses. This analysis emphasized the importance of demonstration projects to show how subsurface storage works because groundwater is not visible, unlike water stored in surface reservoirs. Since the passage of HB 655, it is now expected that ASR will have a much more significant role in meeting future water supply needs than it has to date. This view is evidenced by late amendments to regional water plans to include ASR as recommended water management strategies to meet projected water supply needs.

List of Products:

Drought

- Verdon-Kidd, D. C., Scanlon, B. R., Ren, T., and Fernando, D. N. (in press), A comparative study of historical droughts over Texas, USA and Murray-Darling Basin, Australia: factors influencing initialization and cessation, *Global Environmental Change*.

- Fernando, D. N., Mo, K. C., Fu, R., Pu, B., Bowerman, A. R., Scanlon, B. R., Solis, R. S., Yin, L., Mace, R. E., Maioduszewski, J., Ren, T., and Zhang, K. (2016), What caused the spring intensification and winter demise of the 2011 drought over Texas? *Climate Dynamics*, *47*(9).

GRACE satellites

- Scanlon, B. R., Zhang, Z. Z., Reedy, R. C., Pool, D. R., Save, H., Long, D., Chen, J. L., Wolock, D. M., Conway, B. D., and Winester, D. (2015), Hydrologic implications of GRACE satellite data in the Colorado River Basin, *Water Resources Research*, *51*(12), 9891–9903.

- Scanlon, B. R., Zhang, Z., Save, H., Wiese, D. N., Landerer, F. W., Long, D., Longuevergne, L., and Chen, J. (in press), Global evaluation of new GRACE mascons productions for hydrological applications, *Water Resources Research.*

Aquifer Storage and Recovery and Managed Aquifer Recharge

- Scanlon, B. R., Reedy, R. C., Faunt, C. C., Pool, D., and Uhlman, K. (2015), Can we mitigate climate extremes using managed aquifer recharge? Case Studies, California Central Valley and South-Central Arizona, USA, *AGU Fall Meeting Abstract H12G-02, invited.*

- Scanlon, B. R., Reedy, R. C., Faunt, C. C., Pool, D., and Uhlman, K. (2016), Enhancing drought resilience with conjunctive use and managed aquifer recharge in California and Arizona, *Environmental Research Letters 11*(3).

Connection to Neutrality and Value to Texas:

- Quantifying past droughts, understanding controls on initiation and cessation of droughts, and linking meteorological, agricultural, and hydrologic droughts are keys to developing a predictive understanding of future vulnerability of Texas to droughts. Improving drought prediction helps maximize effective response when an event occurs and minimize its impact through better planning. STARR funds supplemented program funds from the National Oceanic and Atmospheric Administration (NOAA) to assess droughts in the state.

- Significant advances in remote sensing tools provide an objective large-scale monitoring of water resources in the state that can be used to assess vulnerability of the system to droughts and floods. Enhancing applications of these satellite-based tools should improve our monitoring system in the state. Texas can be a leader in state-of-the-art development and applications of remote sensing tools for drought and flood monitoring in the state that should enhance drought preparedness and reduce economic losses related to these climate extremes. These programs leverage from NASA funding to the University to advance remote sensing in the state.

- Increased understanding of the value of storing water underground in aquifers should reduce vulnerability of regions to water scarcity related to drought and enhance drought resilience. With increased potential applications of ASR to facilitate water storage in aquifers, water supply variability related to droughts and floods should be evened out. Reviewing applications of subsurface storage projects in Arizona and California provided valuable insights into the efficacy of such storage, the legal and regulatory aspects of developing aquifer storage, and the potential for water markets to develop to provide water to the higher value users.

APPENDIX A

Letters of Cooperation

The following selected letters are from partner companies with whom the STARR program has recently collaborated. These letters document the strong interaction between STARR and the oil and gas industry.

Dr. William Ambrose

Project Director STARR Project
Bureau of Economic Geology
The University of Texas at Austin
P.O. Box X, UT Station
Austin, Texas 78713

December 23, 2015

Dear Dr. Ambrose:

On behalf of Haimo Oil & Gas LLC, I would like to thank you as well as the other STARR team for the contributions made to our Howard County, Allar 17 oil and gas exploration and production program.

The available data provided by the William Ambrose on the Amerada Hess-1 Robinson and Texaco-1-d Sterling cores, along with Scott Hamlin and Robert Baumgardner's 2012 Publication, *Wolfberry (Wolfcampian-Leonardian) Deep-Water Depositional Systems in the Midland Basin: Stratigraphy, Lithofacies, Reservoirs, and Source Rocks*, Dr. Qilong Fu's 2015 PBS-SEPM presentation, provided valuable data that enabled us to better understand Wolfberry production trends and identify new prospective exploration areas and new well sites within our acreages.

Extensive geological discussions, meetings with STARR team and IT supports from Joseph Yeh and Poe Chen at Bureau of Economic Geology, led to the drilling success of our Allar 17#2 and Allar 17#3 wells in Howard County. Dr. Tongwei Zhang provided valuable geochemical suggestions and is carrying out IsoTube and IsoJar samples analysis for Haimo. Encouraged by these results, not only Haimo, but other offset independent companies are going to drilling more wells to achieve the most economic recoveries of oil and gas in the area. Without these consistent assistances and supports from STARR folks, the Allar 17 program may have never reached the maximum exploitation evident today.

The Bureau's STARR program is a valuable resource available for all oil and gas companies operating in Texas, but it is especially valuable for small independents like Haimo because the program provides access to data and technical expertise that would otherwise only available to larger companies.

The economic impact from oil and gas discovery, development and exploitation not only benefits the exploration companies but also stimulates our vast state's economy. The funding for the STARR Project is vital to our industry and the state's economy. I hope that the State of Texas will continue to provide funding to the STARR program so that small companies like Haimo can remain competitive in the effort to discover new reserves in the State of Texas.

Sincerely,

Rongsheng Yang

Principal Geologist
Haimo Oil & Gas LLC
2901 Wilcrest Drive, Suite 285
Houston, TX 77042

To: Representative Todd Hunter
District 32,
Texas House of Representatives
May 19, 2016

Todd,

We briefly discussed this at your talk to the CC Geological Society. The STARR (State of Texas Advanced Oil and Gas Resource Recovery), http://www.beg.utexas.edu/starr/ program is a BEG program whose objective is to increase severance tax income for the State of Texas and be revenue neutral (equal to or better than the legislative appropriations. They do this by working on problems that industry identifies and in which the BEG has particular skill sets in. For instance, regional geological studies, ie Wilcox which I am involved in and core studies.

This program is very important to small businesses (independents) that drill the bulk of wells in Texas. We do not have a research department, like one that I worked with at Getty Oil back in the 70's. All the majors have these departments, but no longer explore onshore Texas. They left in the early 90's and have only recently returned to pick up Shale plays that independents started and drilled. South Texas directly benefited from BEG studies of the Eagleford, providing data that everyone could use. In my own area the staff has taken on the task of describing core. In particular they have also helped to identify whether or not shale filled canyons in the Wilcox formation are subaerial canyons like the Grand canyon or submarine canyons like we have offshore. These provide information that we can use to better understand the complex systems that we are drilling into and develop ideas of trapping potential and source rocks.

I hope you will urge your colleagues in the legislature to continue funding this very useful and productive program. As always, we are grateful that you have your ear tuned into business and are a great ally to South Texas. We really appreciate the work you do for us.

--
Frank G Cornish
Imagine Resources, LLC
615 N. Upper Broadway, Ste1770
Corpus Christi, Tx 78401--0773
361-883-0923 361-654-2070 direct
fx 361-883-7102
imagineresourcesllc.com

JONES
ENERGY

Mr. William Ambrose
Project Director
STARR Project
Bureau of Economic Geology
Jackson School of Earth Sciences
The University of Texas at Austin
P. O. Box X, UT Station
Austin, Texas 78713

October 24th, 2016

Dear Mr. Ambrose:

I would like to acknowledge the contributions made to our oil and gas exploration programs in the Texas Panhandle by research carried-out and published by the State of Texas Advanced Resource Recovery project (STARR) at the Bureau of Economic Geology. Through the STARR program's core workshops, as well as published and unpublished research, we at Jones Energy have broadened our geologic understanding of numerous Pennsylvanian-age hydrocarbon prospects in the western Anadarko Basin. Staff members on the STARR project a proven record of expertise in the study of depositional systems, sequence stratigraphy, diagenesis and other controls on reservoir quality --and their work reflects that.

The STARR project is a great resource for those actively exploring for, and developing oil and gas in the state of Texas and I hope that they remain able to operate in perpetuity.

Kind regards,

Logan Tussey
Geologist
Jones Energy, Inc.

William Ambrose
Project Director
STARR Project
Bureau of Economic Geology
Jackson School of Earth Sciences
The University of Texas at Austin
P. O. Box X, UT Station
Austin, Texas 78713

October 26, 2016

Dear Mr. Ambrose:

I would like to acknowledge the contributions made to our oil and gas exploration program in both the Eastern Shelf and the Permian Basin by research carried out and published by the State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology. The published and unpublished work by STARR has helped in a variety of areas:

1) Tucker Hentz's original research carried south from Frank Brown's 1990 Report of Investigations No. 197, has allowed for greater understanding of shelf margin development along the Eastern Shelf.

2) Independent work and research conducted by Tucker Hentz at the BEG, has allowed independent operators, with limited exploration budgets and staff, to cross check their own research with the BEG.

3) The Lower Permian to Upper Pennsylvanian Sequence Stratigraphic framework research has aided in correctly naming and identifying formation tops along the Eastern Shelf.

4) Continued professional contacts at the BEG has made it possible for the inflow and outflow of knowledge.

5) The work carried out at the BEG allows for further, in the greater regional context, on how the developments of major leading stratigraphic and structural geologic settings develop away from my own research.

6) One of the best examples of collaboration was when I talked with Tucker Hentz at the SWS-AAPG in Abilene, Texas back in 2016. His research, conducted 100% independent of my research on the Eastern Shelf, we both found that designated shelf margin outlines, and formation tops were comparable throughout the project database. Not only did his research provide confidence in my picking and data base building, it reinforced Tucker Hentz's work that independent oil and gas geologists were on the "Same track" as his work conducted at the BEG. This not only supports and reinforces our efforts to keep building our database correctly, it allows the BEG to directly bridge independent works from academia to industry.

In summary, the BEG's presentations, publications, research, and studies have provided an education and insight to many recent advances in petroleum exploration that has been successfully applied to our areas of interests. This specifically demonstrates the STARR program's ability to turn academic studies into economic success. The BEG's continued interest in depositional systems in Texas, will only prove time and time again, that the research conducted at the BEG is financially beneficial to all areas of academia and to the petroleum industry.

Respectfully submitted,

Nicolas O. Brissette, CPG 6211
Petroleum Geologist
Delta Oil and Gas

November 10th, 2016

Dr. William Ambrose
Project Director
STARR Project
Bureau of Economic Geology
Jackson School of Earth Sciences
The University of Texas at Austin
P. O. Box X, UT Station
Austin, Texas 78713

November 10, 2016

Dear Dr. Ambrose:

I would like to acknowledge the contributions made to our Ellenburger oil project in Nolan County, Eastern Shelf Permian basin by research carried out by the State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology. Work carried out to interpret the 3D seismic, review image and log data and to compare with analog research projects has assisted greatly in refining the geological model in our area and highlighting uncertainties from the data which when further evaluated will help to improve our understanding of the entire Ellenburger section in our area and it's production potential.

In addition through access to publications and insights from research team members over the course of the project the Bureau has provided an education of the latest research into karst petroleum systems which has been of great benefit to independent companies such as ourselves who do not have the benefit of access to major geologic research programs.

Best Regards,

Neville Henry
MD/CEO
Winchester Energy Limited

Cc: file

Australian Office: Level 1, 100 Havelock Street, West Perth WA 6005 Australia | PO Box 641 West Perth WA 6872
Tel +61 1300 133 921 | Fax +618 6160 5901 | ABN 21 168 586 445
USA Office: Two Riverway, 17th Floor, Suite 1700, Houston, Texas USA 77056 | Tel +1 713 728 6315

APPENDIX B

Project STARR Awards

I. A. Levorsen Memorial Award for best technical presentation: William A. Ambrose, Tucker F. Hentz, and Logan Tussey, Southwest Section, American Association of Petroleum Geologists, for “Tidal Depositional Systems in Pennsylvanian Strata in the Anadarko Basin, Northeast Texas Panhandle” 2016.

Charles J. Mankin Memorial Award: H. Scott Hamlin and Robert W. Baumgardner, Association of American State Geologists for “Wolfberry (Wolfcampian-Leonardian) Deep-Water Depositional Systems in the Midland Basin: Stratigraphy, Lithofacies, Reservoirs, and Source Rocks,” 2014.

APPENDIX C

One of the major goals of Project STARR is to disseminate results and new concepts developed by the program. During this reporting biennium (2014–2016), STARR researchers generated a wide variety of articles, abstracts, BEG publications and reports, presentations, workshops, and guidebooks.

ARTICLES

William A. Ambrose

Ambrose, W. A., Hentz, T. F., and Smith, D. C., 2014, Facies variability and reservoir quality in the shelf-to-slope transition, Upper Cretaceous (Cenomanian) Woodbine Group, northern Tyler and southeastern Polk Counties, Texas, U.S.A: GCAGS Journal, v. 3, p. 1–19.

Ambrose, W. A., Hentz, T. F., and Tussey, L., 2015, Tidal depositional systems in Pennsylvanian strata in the Anadarko Basin, northeast Texas Panhandle: AAPG Search and Discovery, no. 10742, 27 p.

Ambrose, W. A., Loucks, R. G., and Dutton, S. P., 2015, Sequence-stratigraphic and depositional controls on reservoir quality in lowstand incised-valley-fill and highstand shallow-marine systems in the Upper Cretaceous (Cenomanian) Tuscaloosa Formation, Louisiana, U.S.A.: GCAGS Journal, v. 4, p. 43–66.

Ambrose, W. A., Breton, C., Nuñez-López, V., and Gülen, G., 2015, EOR potential from CO_2 captured from coal-fired power plants in the Upper Cretaceous (Cenomanian) Woodbine Group, East Texas Basin, and southeastern Texas Gulf Coast, USA: Natural Resources Research, v. 24, no. 2, p. 161–188.

Hackley, P. C., Warwick, P. D., Ambrose, W. A., Hammes, U., et al., 2015, Unconventional Energy Resources: 2015 Review: Natural Resources Research, v. 24, no. 4, p. 443–508.

Robert Baumgardner

Baumgardner, R. W., Jr., DiMichele, W. A., and de Siqueira Vieira, N., 2016, An early Permian coastal flora dominated by *Germaropteris martinsii* from basinal sediments in the Midland Basin, West Texas: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 459, p. 409–422.

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Gregory Frébourg

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Frébourg, G., Ruppel, S. C., Loucks, R. G., and Lambert, J., 2016, Depositional controls on sediment body architecture in the Eagle Ford/Boquillas system: Insights from outcrops in West Texas, United States: AAPG Bulletin, v. 100, no. 4, p. 657–682.

Qilong Fu

Fu, Q., Horvath, S., Potter, E., Roberts, F., Tinker, S. W., Ikonnikova, S., Fisher, W., and Yan, J., 2015, Log-derived thickness and porosity of the Barnett Shale, Fort Worth Basin, Texas: implications for assessment of gas shale resources: AAPG Bulletin, v. 99, no. 1, p. 119–141.

Yawen He

He, Y., Zeng, H., Kerans, C., and Hardage, B. A., 2015, Seismic chronostratigraphy at reservoir scale: statistical modeling: Interpretation, v. 3, no. 2, p. SN69–SN87.

Christopher Hendrix

Hendrix, C., 2016, A core based chemostratigraphic study of the upper Cretaceous Buda Limestone and Austin Chalk, south Texas, USA: AAPG Search and Discovery, no. 90249, 1 p.

Tucker Hentz

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