State of Texas Advanced Resource Recovery
STARR

Progress Report

December 2014

Researchers

William A. Ambrose, David Smith, Robert G. Loucks, Gregory Frébourg, Tucker F. Hentz, Osareni C. Ogiesoba, Iulia Olariu, Qilong Fu, Hongliu Zeng, Edmond Locke Frost III, H. Scott Hamlin, H. Seay Nance, Bruce L. Cutright, Ian J. Duncan, Ursula Hammes, Harold Rogers III, Sigrid J. Clift, James E. Sivil, Tongwei Zhang, Robert M. Reed, Robert Baumgardner, Ray Eastwood, Caroline Breton, Donnie Brooks, Harry Rowe, David L. Carr, Dallas B. Dunlap, Julia F. W. Gale, and Sheng Peng

Assisted by

Reed Roush, Jinyu Zhang, Rattanaporn Fongngern, Kyle Gabb, Logan Tussey, Angela Eluwa, Rimanda Galvan, Joseph Yeh, Anselmo Jacobo, Haley Loucks, Daniel Ortuño, James Donnelly, Nathan Ivicic, Joshua Lambert, Ben Granau, Cathy Brown, Jamie Coggin, Jana Robinson, Anastasia Grebnova, Jason Suarez, Paula Beard, Stephanie Jones, David Stephens, Joseph Smitherman, Daniel Valencia, Brandon Williamson, Peter Soto-Kerans, Kenneth Edwards, Scott Rodgers, Melissa Garcia, Erin Parr, Amelia Bridges, Julie Duiker, Sophia Ortiz, Valerie Siewert, Amanda Masterson, Dennis Campa, Mark Blount, Linda McCall, Ron Russell, Carlos Garza, Claudia Gerardo, and Jan Braboy

Principal Investigator

William A. Ambrose

Program Director for Energy Research

Eric C. Potter

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 2014

PRINCIPAL INVESTIGATOR
William A. Ambrose

PROGRAM DIRECTOR FOR ENERGY RESEARCH
Eric C. Potter

RESEARCHERS

William A. Ambrose, David Smith, Bruce L. Cutright, Bridget R. Scanlon, Robert C. Reedy, Brent Elliott, Jeffrey G. Paine, Michelle M. Foss, Thomas A. Tremblay, Brad D. Wolaver, Robert G. Loucks, Gregory Frébourg, Tucker F. Hentz, Osareni C. Ogiesoba, Iulia Olariu, Qilong Fu, Hongliu Zeng, Edmond Locke Frost III, H. Scott Hamlin, H. Seay Nance, Ian J. Duncan, Ursula Hammes, Harold Rogers III, Sigrid J. Clift, James E. Sivil, Tongwei Zhang, Robert M. Reed, Robert Baumgardner, Ray Eastwood, Caroline Breton, Donnie Brooks, Harry Rowe, David L. Carr, Dallas B. Dunlap, Julia F. W. Gale, and Sheng Peng

Assisted by

Reed Roush, Jinyu Zhang, Rattanaporn Fongngern, Kyle Gabb, Logan Tussey, Angela Eluwa, Rimanda Galvan, Joseph Yeh, Anselmo Jacobo, Haley Loucks, Daniel Ortuño, James Donnelly, Nathan Ivicic, Joshua Lambert, Ben Granau, Cathy Brown, Jamie Coggin, Jana Robinson, Anastasia Grebnova, Jason Suarez, Paula Beard, Stephanie Jones, David Stephens, Joseph Smitherman, Daniel Valencia, Brandon Williamson, Peter Soto-Kerans, Kenneth Edwards, Scott Rodgers, Melissa Garcia, Erin Parr, Amelia Bridges, Julie Duiker, Sophia Ortiz, Valerie Siewert, Amanda Masterson, Dennis Campa, Mark Blount, Linda McCall, Ron Russell, Carlos Garza, Claudia Gerardo, and Jan Braboy

CONTENTS

FIGURES

EXECUTIVE SUMMARY

The State of Texas Advanced Resource Recovery program (STARR) has been successful in its major objective to increase severance tax income for the State of Texas by means of research projects that promote the drilling of profitable oil and gas wells in the State.

The Bureau of Economic Geology (BEG) currently receives funds from the State to conduct research that assists oil and gas operators in adding new or increasing existing production throughout the State of Texas. STARR is required to be revenue neutral—that is, revenue associated with STARR projects must equal or exceed the amount appropriated to the program by the Legislature. This progress report summarizes and documents in detail the accomplishments of Project STARR over the last two years (September 1, 2012, to August 31, 2014).

Credit to the STARR program for the 2012–2014 biennium, in accordance with methodology approved by the State of Texas Comptroller's office, is $140,766,560 (**table 1**). Relative to total income of $9 million over the current biennium, STARR is revenue positive by a factor of 15.6. To date, the STARR program has completed or is currently working on more than 60 field (reservoir characterization) studies (**figs. 1, 2**). **Figure 2** shows 23 of the most significant new reservoir characterization studies in the 2012–2014 biennium. STARR has also undertaken 8 new regional studies, including the prolific Eaglebine trend on the southeastern Texas Gulf Coast, as well as the Cline Shale and Wolfcamp and Spraberry Formations in the Permian Basin of West Texas (**fig. 3**).

Eight additional program elements within STARR complement the Oil and Gas Resources program. Each of the additional program elements targets research that impacts key economic opportunities or challenges in Texas related to natural resources or geological conditions. Program elements include geothermal resources in Texas, water issues that can threaten the Texas economy, mineral and earth resources of Texas, geological hazards, energy economics, baseline mapping for oil spill response, economic impacts of environmental flows, and analysis of water/energy nexus issues.

Table 1. Summary of royalty and severance tax revenue from September 1, 2012, through July 31, 2014.
Credit to the STARR program is in accordance with methodology approved by the Texas State Comptroller's office.

Regional Studies	Condensate (Bbls)	Oil Well Head Value ($)	Oil Royalty ($)	Oil Severance Tax ($)	Gas (Mcf)	Gas Well Head Value ($)	Gas Royalty ($)	Gas Severance Tax ($)	25% Oil Severance	25% Gas Severance	Total Oil Severance Tax Revenue	Total Gas Severance Tax Revenue
Spraberry/Wolfcamp	71,699,573	7,159,722,354		322,187,506	206,202,667	882,702,239		66,202,668	80,546,876	16,550,667	**80,546,876**	**16,550,667**
Marble Falls	569,571	57,359,871		2,581,194	8,095,150	34,454,453		2,584,084	645,299	646,021	**645,299**	**646,021**
Frio	3,136,057	311,144,690		14,001,511	42,876,863	183,174,512		13,738,088	3,500,378	3,434,522	**3,500,378**	**3,434,522**
Eaglebine	4,206,616	424,079,310		19,083,569	5,542,583	23,724,090		1,779,307	4,770,892	444,827	**4,770,892**	**444,827**
Eagleford	8,228,900	777,713,339		34,997,100	53,268,650	151,815,653		11,386,174	8,749,275	2,846,543	**8,749,275**	**2,846,543**
Bend Conglomorate	372	35,594		1,602	59,003	229,684		17,226	400	4,307	**400**	**4,307**
Field Studies/Partners									100% Oil Severance	100% Gas Severance		
Chesapeake Cleveland Marmaton	794,599	79,766,241		3,589,481	6,798,422	30,132,289		2,259,922	3,589,481	2,259,922	**3,589,481**	**2,259,922**
BBX Operating Austin Chalk	145,657	13,809,074		621,408	4,157,651	14,965,010		1,122,376	621,408	1,122,376	**621,408**	**1,122,376**
Chesapeake Tonkawa	178,719	18,020,447		810,920	635,555	2,766,687		207,502	810,920	207,502	**810,920**	**207,502**
Cobra Marble Falls	631	67,069		3,018	5,462	19,772		1,483	3,018	1,483	**3,018**	**1,483**
Devon Cleveland Marmaton Granite Wash	471,688	46,134,080		2,076,034	11,112,029	45,021,097		3,376,582	2,076,034	3,376,582	**2,076,034**	**3,376,582**
CML E.L. Dismukes	43,656	4,024,810		181,116	6,407	21,169		1,588	181,116	1,588	**181,116**	**1,588**
Newfield Austin Chalk	661,333	65,325,982		2,939,669	3,277,060	12,053,503		904,013	2,939,669	904,013	**2,939,669**	**904,013**
Risco La Sara La Sara Field	708	73,008		3,285	33,348	122,343		9,176	3,285	9,176	**3,285**	**9,176**
Tracker Mississippian Limestone	10,492	1,027,806		46,251	13,649	53,604		4,020	46,251	4,020	**46,251**	**4,020**
Valence Operating Pearsall	92,429	8,953,143		402,891	235,503	877,569		65,818	402,891	65,818	**402,891**	**65,818**
Totals:	90,241,001	$8,967,256,818	$0	**$403,526,557**	342,320,002	$1,382,133,675	$0	**$103,660,026**	$108,887,195	$31,879,365	$108,887,195	$31,879,365
	Condensate Grand Total	Oil Well Head Value Grand Total	Oil Royalty Grand Total	Oil Severance Tax Grand Total	Gas Grand Total	Gas Well Head Value Grand Total	Gas Royalty Grand Total	Gas Severance Tax Grand Total	25% Oil Severance Tax ($)	25% Gas Severance Tax ($)	Total Oil Severance Tax Revenue	Total Gas Severance Tax Revenue
											Total Oil ($)	Total Gas ($)
										Regional Total	$98,213,121	$23,926,887
										Field/Partner Total	$10,674,075	$7,952,478
											Grand Total	**$140,766,560**

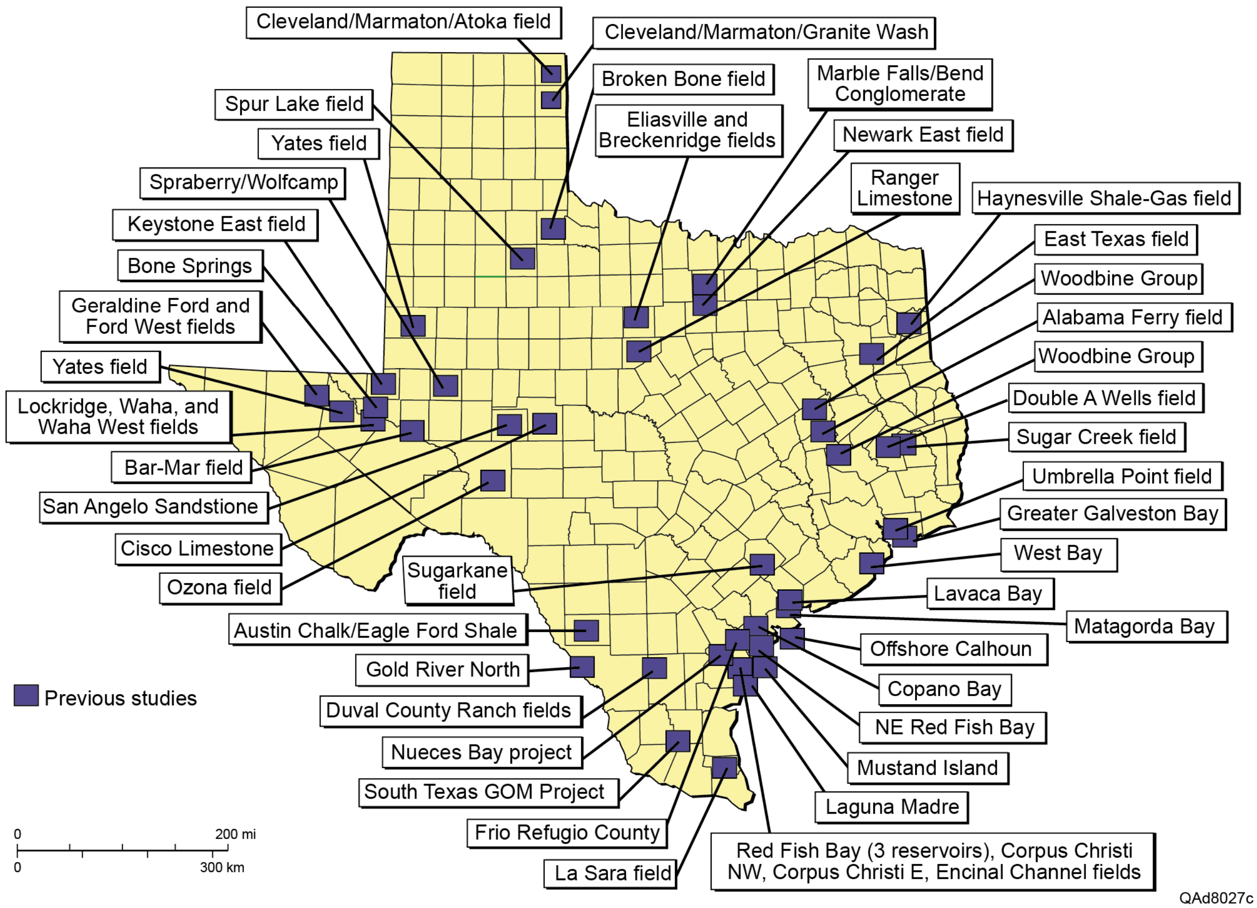

Figure 1. Previous STARR field studies completed prior to the 2012–2014 biennium.

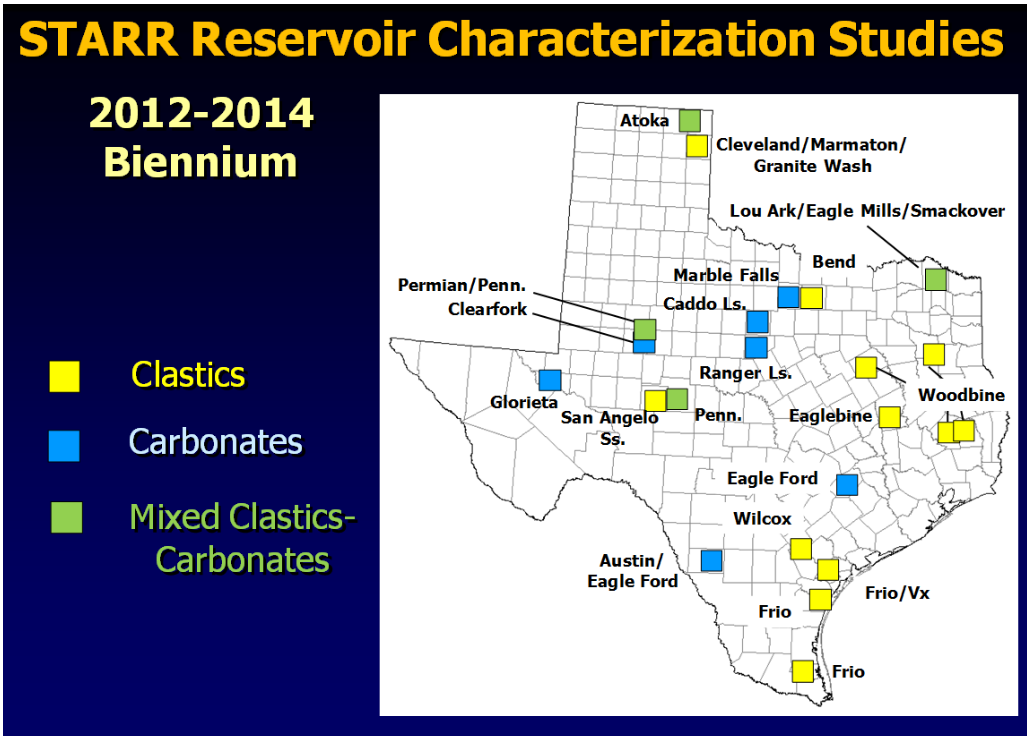

Figure 2. Major new STARR field (reservoir characterization) studies in the 2012–2014 biennium.

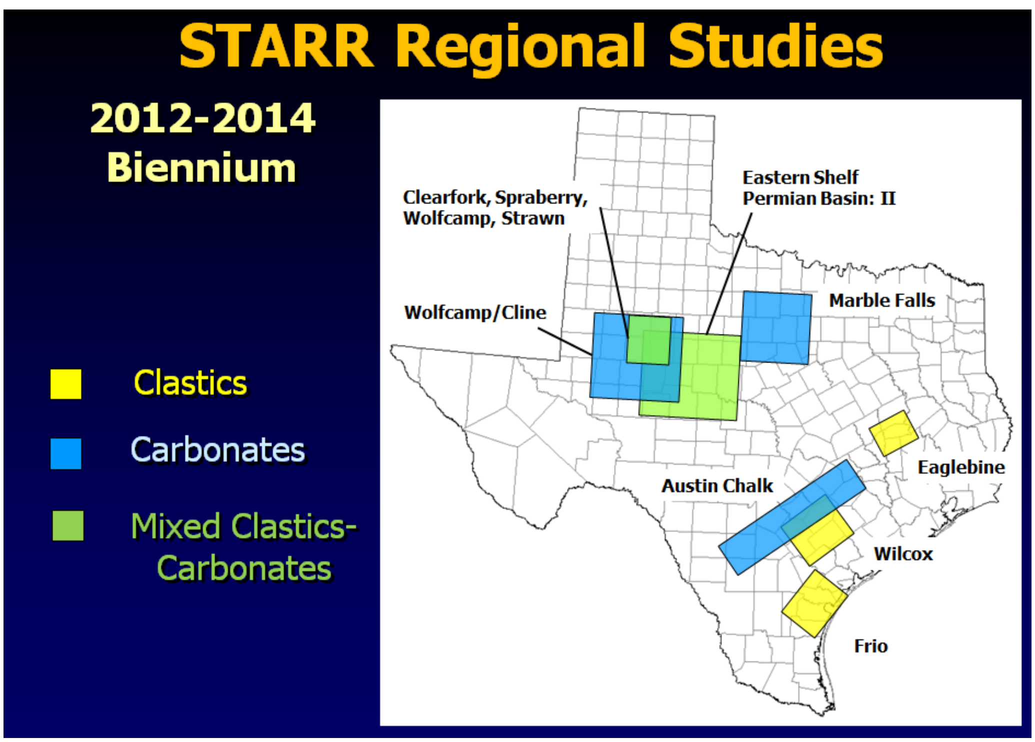

Figure 3. New STARR regional studies in the 2012–2014 biennium.

INTRODUCTION

Texas has produced more oil and natural gas than any other state and remains 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. No other state, or other region worldwide, has been as heavily explored or drilled for oil and natural gas as Texas. As of December 2013, 293,595 active oil wells and 125,157 active gas wells were producing oil and natural gas in the state (**fig. 4**).

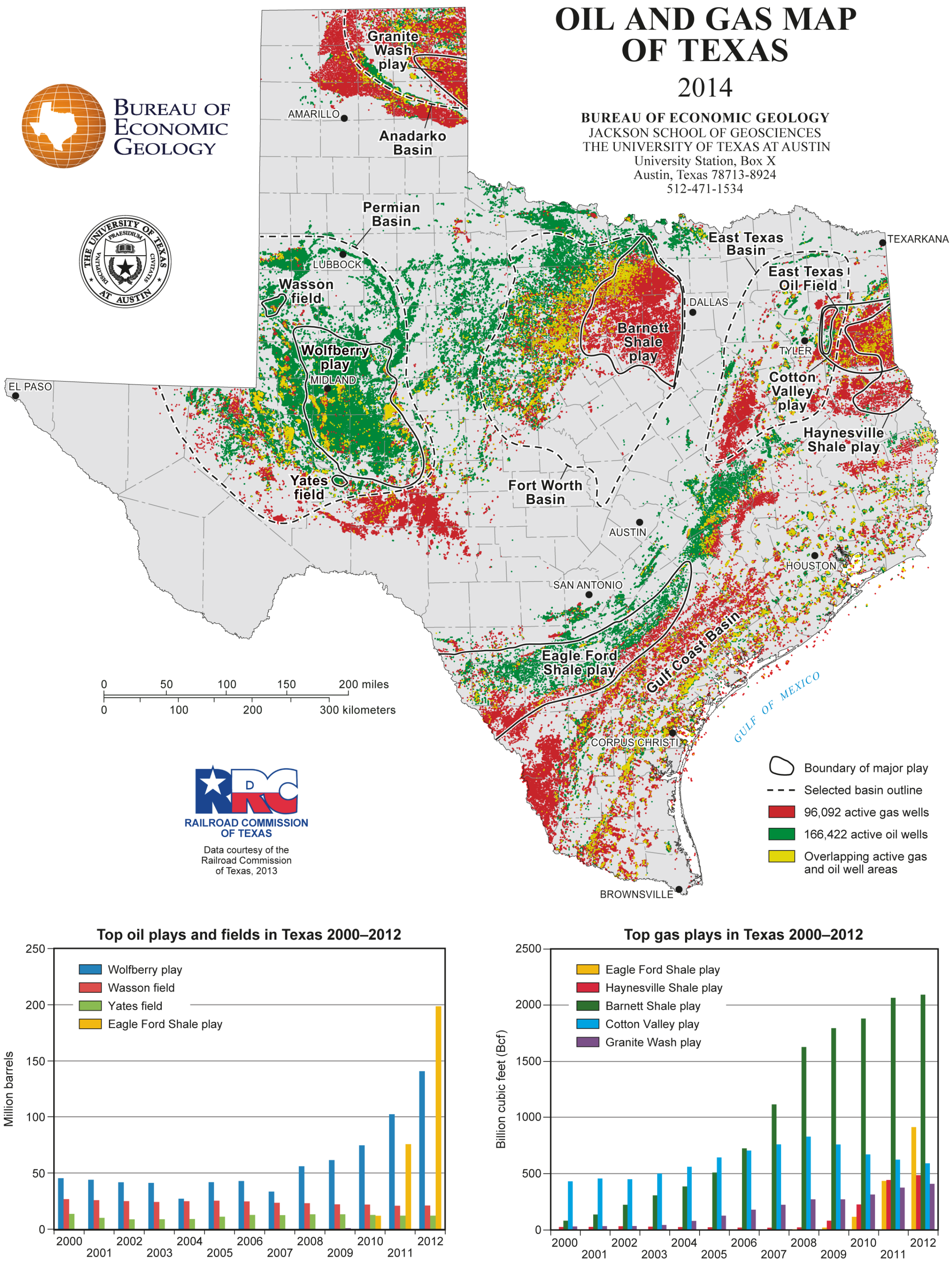

Figure 4. Oil and gas production in Texas, showing distribution and relative rank of top ten oil and gas plays.

The top oil plays in Texas in 2014 include the Eagle Ford Shale in South Texas, the Wolfberry (combined Spraberry and Wolfcamp Formations) in West Texas, and the Wasson and Yates fields in the Permian Basin (**fig. 4**). The Eagle Ford Shale is by far the largest producing oil play in Texas, with production surpassing 1 MMbbl/d in August 2013. Unconventional oil production from shales and other impermeable (tight) reservoirs in the Permian Basin is expected to grow dramatically because of the recent sharp increase in successful horizontal drilling and hydraulic fracturing activity. Mature conventional fields (Wasson, Yates) with access to carbon dioxide for enhanced oil recovery (EOR) operations continue to be major producers. Leading natural gas plays in Texas, measured by current production rate, include the Barnett Shale in North Texas, Eagle Ford Shale in South Texas, Cotton Valley (East Texas), Haynesville Shale (East Texas), and Granite Wash (northern Panhandle) (**fig. 4**). These large gas plays are all products of the application of hydraulic fracturing and horizontal drilling that have enabled economically viable gas production from tight reservoir rocks. The Gulf Coast also continues to produce significant volumes of gas from conventional sandstone reservoirs.

A variety of oil and gas companies request reservoir characterization and exploration assistance from STARR (see Letters of Cooperation, **Appendix A**). 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 2-year period at the time of reporting. For this report, calculations cover the period from September 1, 2012, through July 31, 2014.

STARR has a technology-transfer approach that includes workshops, presentations, publications, website content, and digital data sets. Through technology transfer, we envision that many remaining State Lands oil and gas reserves will be explored and developed in future decades. The award-winning STARR personnel (**Appendix B**) have provided the public with numerous publications, workshops, and lectures (**Appendices C, D**). Since the last biennium report, STARR personnel have produced 22 professional papers, 47 abstracts, 43 presentations, and 4 books and workshop guidebooks (**Appendices C, D**).

During the 2012–2014 biennium, STARR personnel gave a variety of presentations and conducted reviews of core data for industry partners including Devon Energy, T-C Oil Company, Stalker Energy, Cobra Oil and Gas, Apache Energy, Zone Energy, Formosa Petrochemical, Arête Resources, Tracker Resources, Chesapeake Energy, AEATX, and U.S. Enercorp.

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 22-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**.)

Highlights of the present biennium (September 2012–August 2014):

- STARR is revenue positive by a net factor of 15.6. Credit to the STARR program for the 2012–2014 biennium, in accordance with methodology approved by the Texas State Comptroller's office, is $140,766,560. The high positive revenue factor is chiefly because of several thousand successful wells drilled in the highly productive Eagle Ford unconventional oil and shale-gas play in southwest Texas and the unconventional Spraberry-Wolfcamp (Wolfberry) play in the Permian Basin, as well as other active plays such as the Frio Formation of the Gulf Coast.

- A wide variety of new reservoir characterization projects (field studies) (**fig. 2**) and eight new regional studies (**fig. 3**) contributed to the successful completion of new wells and improved oil- and gas-recovery strategies. A partial list of examples includes the Woodbine Group in Cherokee, Rusk, Tyler, Polk, and Navarro Counties; the Marble Falls Formation in Jack County; the Cline Shale and Wolfcamp Formations in Howard and Glasscock Counties; the Glorieta Formation in Ward County; the Eaglebine trend in Leon, Madison, and Fayette Counties; and the Frio Formation in Nueces County and adjacent areas (**table 2**).

- 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 (**Hamlin and Baumgardner, 2012**).

- 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 will be released in an upcoming 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
		1996–1998
Ozona field	Union Pacific Resources (now Anadarko), 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**
	Risco La Sara Operations, Chesapeake	
Woodbine Group (Leon County)	**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)	**Enercorp**	**2013-2015**
Tonkawa, Douglas Formations (Hemphill Co.)	**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**	**2014-2016**

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 2012–2014 biennium, we calculated our revenue neutrality from September 1, 2012, through July 31, 2014. This 2-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) Lands. Severance tax credit accrues from production anywhere in Texas.

Reservoir Characterization Studies

STARR reservoir characterization studies may result in step-out wells, well deepening, recompletions, targeted infill drilling, injection-profile modification, waterflood optimization, and drilling of untested deeper targets in producing fields. Fields characterized by STARR are widely distributed in Texas and include reservoirs in a variety of stratigraphic units (**fig. 2**). Areas in Texas represented by sandstone reservoirs are located in the Gulf Coast and in the East Texas Basin, the Permian Basin in West Texas, and the Anadarko Basin in the Texas Panhandle. Carbonate reservoirs include the Marble Falls Formation, Ranger Limestone, and Caddo Formation in North Texas, and the Glorieta Formation in West Texas. Unconventional reservoirs in southwest Texas (Austin Chalk and Eagle Ford Formation) and the Permian Basin (Spraberry and Wolfcamp Formations) round out the remainder of the field studies.

Regional Studies

STARR regional studies are based on analysis of the sequence-stratigraphic architecture of sedimentary basins, with the goal of delineating and evaluating basin-scale geologic controls on oil and gas production. These studies emphasize trends in new exploration fairways. We use sequence-stratigraphic principles that have been developed by major oil companies over the past three decades and that are illustrated in recent STARR studies in the Gulf of Mexico (**Brown et al., 2004, 2005; Hammes et al., 2007**). Deep to ultradeep reservoirs, such as those in the higher risk, deep-shelf gas play (offshore Tertiary-age sandstone reservoirs between the depths of 15,000 and 35,000 ft) are an example of where new studies are needed to encourage exploration drilling. The regional study of the South Texas Frio Formation (**fig. 3**) is an example of a STARR study that is delineating the geometry and extent of potentially productive sandstones within growth-fault-bounded subbasins, beyond the current limits of existing well control.

STARR conducted a regional study of tight (low-permeability) oil and gas reservoirs in the Pennsylvanian Cleveland Formation and Marmaton Group in the Texas Panhandle. The study demonstrates the need to develop a robust sequence-stratigraphic and depositional-facies framework for a more complete understanding of the controls on reservoir quality and continuity in these low-permeability formations and to help define and extend play fairways into new areas (**Ambrose and Hentz, 2011**).

Unconventional Resources

Unconventional hydrocarbon resources—such as shale gas, shale oil, tar sands, tight-gas sandstones, and low-pressure gas—continue to be important for the future of Texas. Oil and gas produced from shale constitute some of the most active exploration plays in Texas, with prospects ranging from far West Texas to the Fort Worth Basin and East Texas (**fig. 4**). These plays—including Eagle Ford, Wolfberry, Wolfcamp, Bone Spring, Eaglebine, and Haynesville—affect large areas of State Lands in Texas. STARR is conducting several studies on shale oil and gas to promote these resources. In the upcoming biennium, STARR will investigate other unconventional plays, including the Austin Chalk in the Texas Gulf Coast and the Pennsylvanian Atoka Play in the Texas Panhandle, as well as expand at the regional scale its field study of the Wolfberry and related plays in the Permian Basin in West Texas.

SELECTED PROJECTS IN THE 2012–2014 BIENNIUM

Reservoir Characterization Studies

Cleveland/Marmaton/Granite Wash (Hemphill County)

The unconventional Granite Wash continues to be a leading oil and gas play in the Texas Panhandle (**fig. 4**). The younger Marmaton Group and Cleveland Formation, described in a recent STARR biennium report (**Ambrose and Potter, 2012**), are also important oil- and gas-producing units in the Panhandle. The Cleveland Formation has produced more than 37 MMbbl of oil and more than 1.1 Tcf (trillion cubic feet) of gas since 1956 (**Ambrose et al., 2011**). All of these stratigraphic units are low permeability and require hydraulic fracturing to stimulate production.

A recent STARR study based on core and log data concludes that facies characterization is an important key to understanding reservoir quality in these formations (**fig. 5**). Core data in the Devon No. 44-1H Penelope Moore well (**fig. 5**) indicate that the Granite Wash in southwest Hemphill County is composed of poorly sorted and coarse-grained fan-delta and alluvial deposits, whereas the overlying Marmaton Group is composed of thin (commonly <6-in [<15-cm]), discontinuous tidal-shelf sandstone beds encased in mudstone (**fig. 6**). In contrast, the overlying and more productive Cleveland Formation contains coarse-grained, incised-valley-fill sandstones that grade upward into sandy and muddy tidal-channel and tidal-flat deposits (**fig. 7**). The base of the regionally extensive valley fill in the Cleveland Formation, also recognized and mapped in previous Bureau studies (**Hentz, 1994; Ambrose and Hentz, 2011**), is marked by a coarse-grained erosional lag (**fig. 8**). Recognizing the base of this valley-fill succession is important because greatest reservoir quality and productivity occur in these incised-valley-fill deposits, which follow an east–west trending belt in Lipscomb and Ochiltree Counties (**Ambrose and Hentz, 2011; Ambrose et al., 2011**).

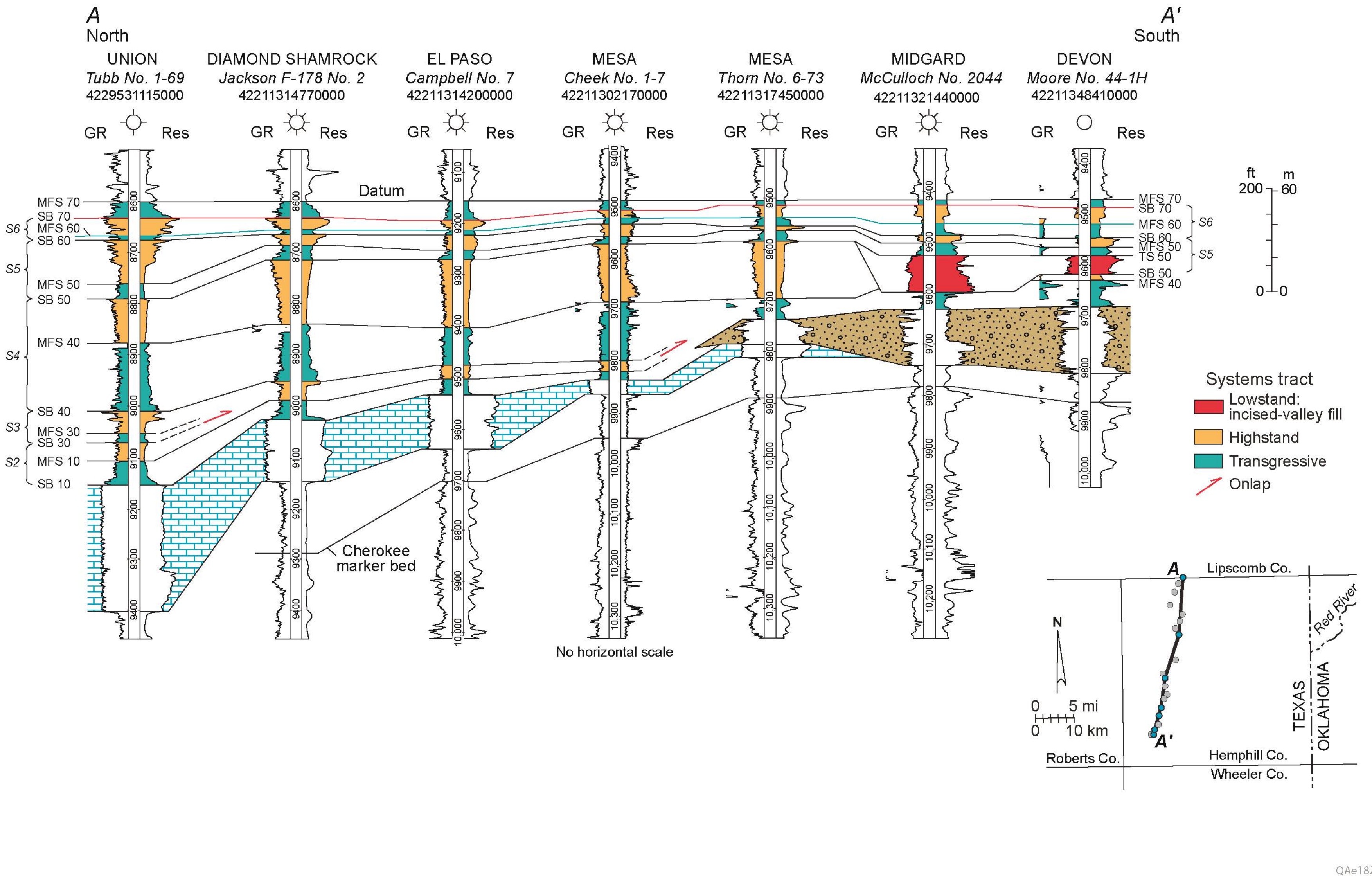

Figure 5. North–south stratigraphic cross section in Hemphill County, displaying the Granite Wash (brown stippled pattern) and overlying Marmaton Group (green and orange stratigraphic units lateral to and above the Granite Wash). Incised-valley-fill deposits in the Cleveland Formation are marked by red stratigraphic units.

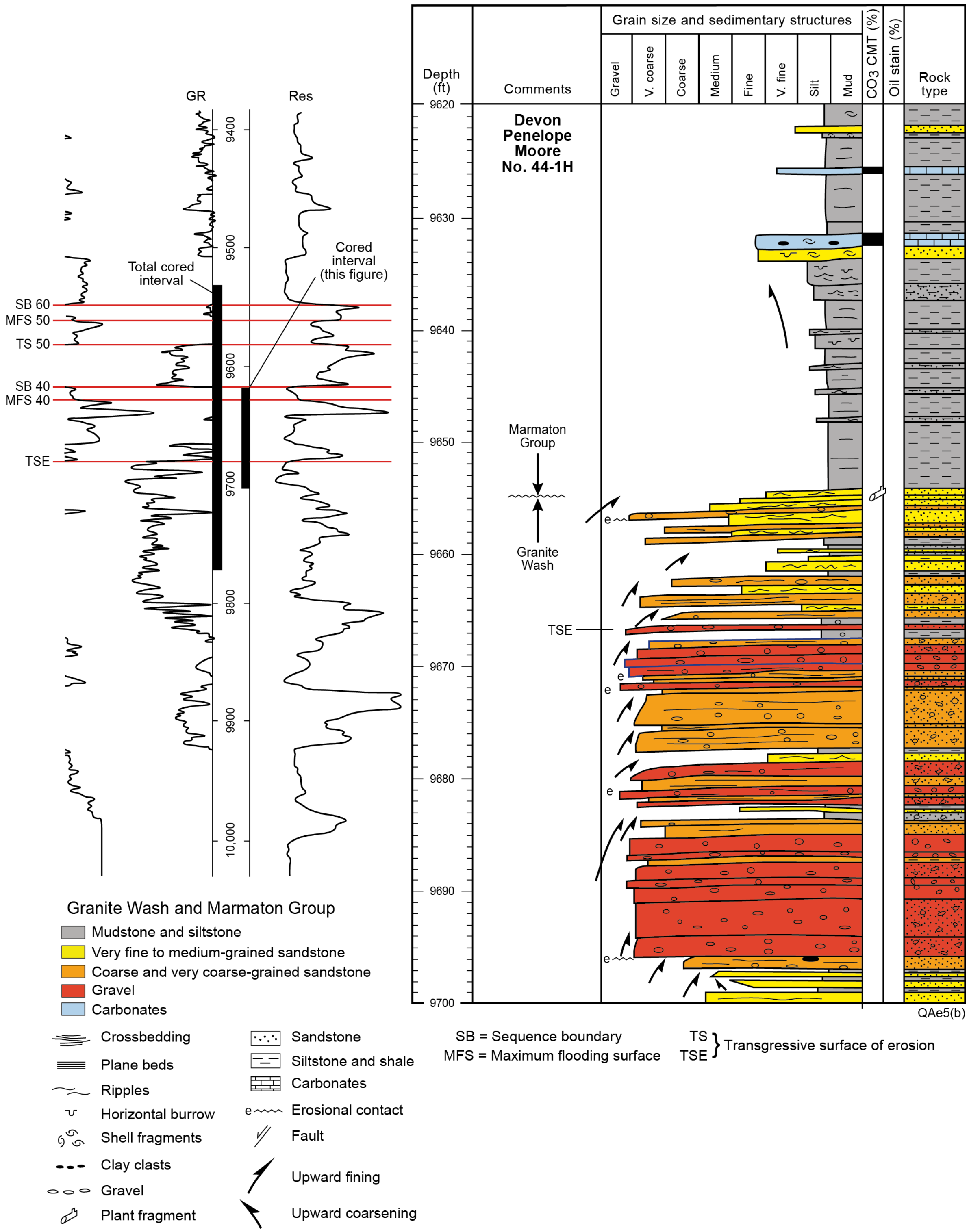

Figure 6. Core description of the Devon No. 44-1H Penelope Moore well in Hemphill County, showing the contact between coarse-grained fan-delta deposits in the Granite Wash and overlying muddy tidal-shelf deposits in the Marmaton Group. Location of well shown in **figure 5**.

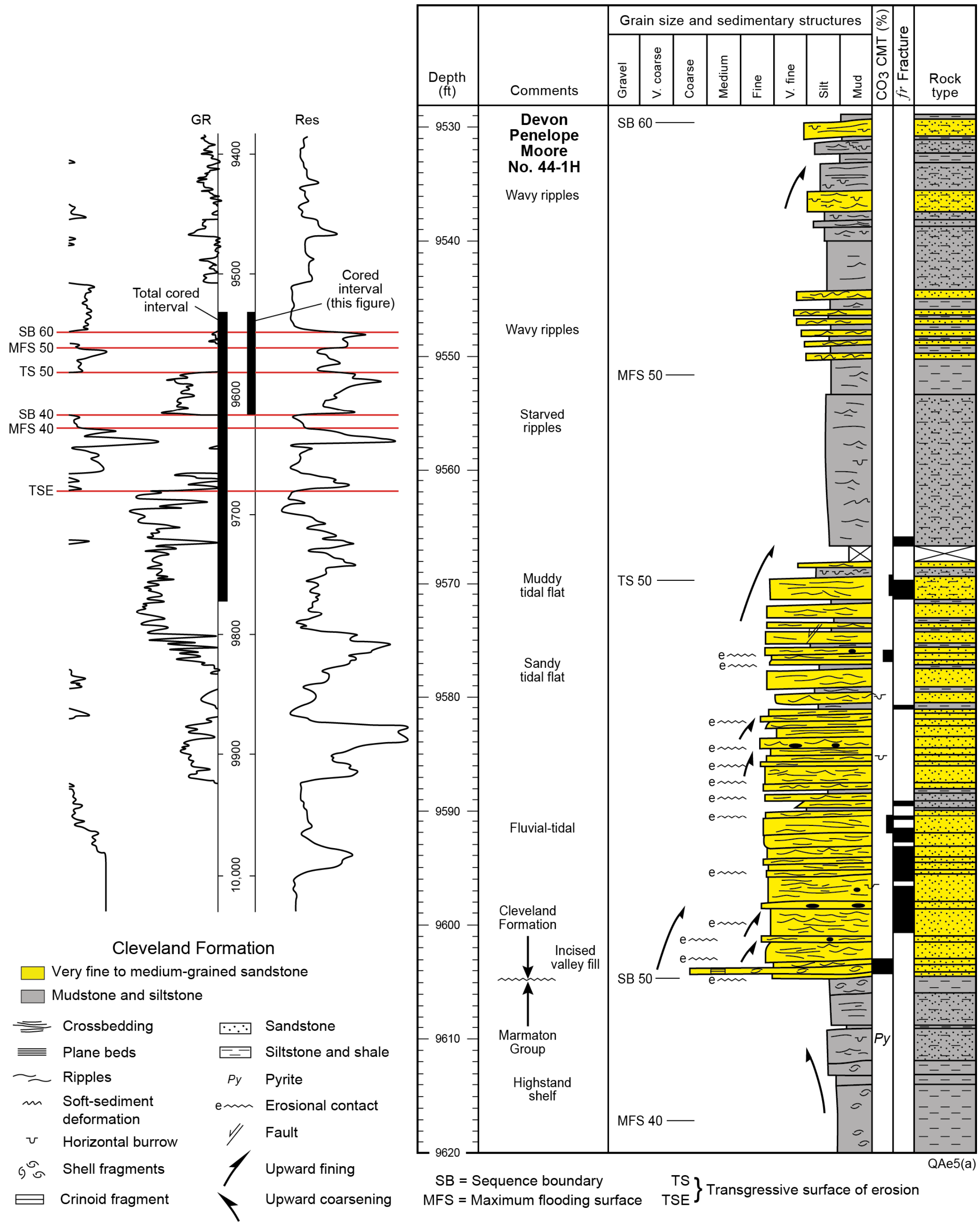

Figure 7. Core description of the Devon No. 44-1H Penelope Moore well in Hemphill County, showing incised-valley-fill and overlying tidal-channel and tidal-flat deposits in the Cleveland Formation. Photograph of basal incised-valley-fill deposits shown in **figure 8.** Location of well shown in **figure 5.**

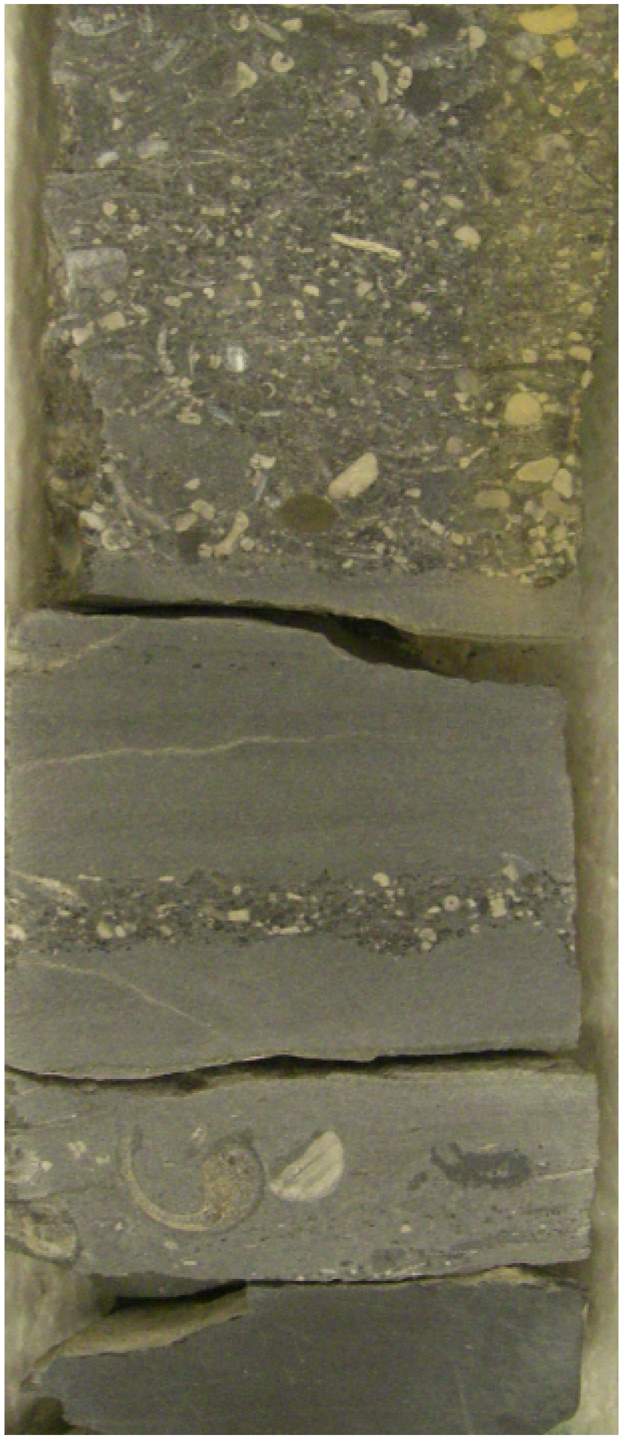

Figure 8. Photograph of basal incised-valley-fill deposits in the Cleveland Formation of the Devon No. 44-1H Penelope Moore well in Hemphill County. Core is approximately 2.2 inches across. Core description shown in **figure 7.** Location of well shown in **figure 5.**

Marble Falls Limestone (Jack County)

The Pennsylvanian Marble Falls Limestone in Jack County, North Texas (**fig. 2**), produces oil and gas mainly from fractures. The Marble Falls Limestone, although composed of low-porosity and low-permeability ramp sponge spicules and carbonate debris-flow deposits, nevertheless has a potential for oil and gas production, owing to locally well-developed natural fractures and total organic carbon (TOC) values that approach 2%. Dominant ramp facies consist of spiculitic wackestones and mudstones with porosity ranging from 1 to 4% and permeability from 0.001 to almost 0.1 md (**fig. 9**). Carbonate debris-flow deposits consist of poorly sorted sections of transported crinoid, mollusk, and mudstone fragments (**fig. 10**). Other Marble Falls lithofacies in the lower part of the section are composed of featureless, dark-gray carbonate mudstones of deepwater origin. The dominant fracture type is defined by vertical to subvertical, postdepositional, and tectonic fractures variably filled with calcite. Although many fractures are closed, zones of continuous, open fractures up to 1.5 ft in length are observed in core; many of these fractures contribute to oil and gas production (**Ambrose et al., 2013**). Cobra Oil and Gas, the operator for a cored well in Jack County (**figs. 9, 10**), has stated that the work by STARR on this core led to the drilling of more than 400 wells in Jack County in the past four years (see Cobra Oil and Gas letter in **Appendix A**).

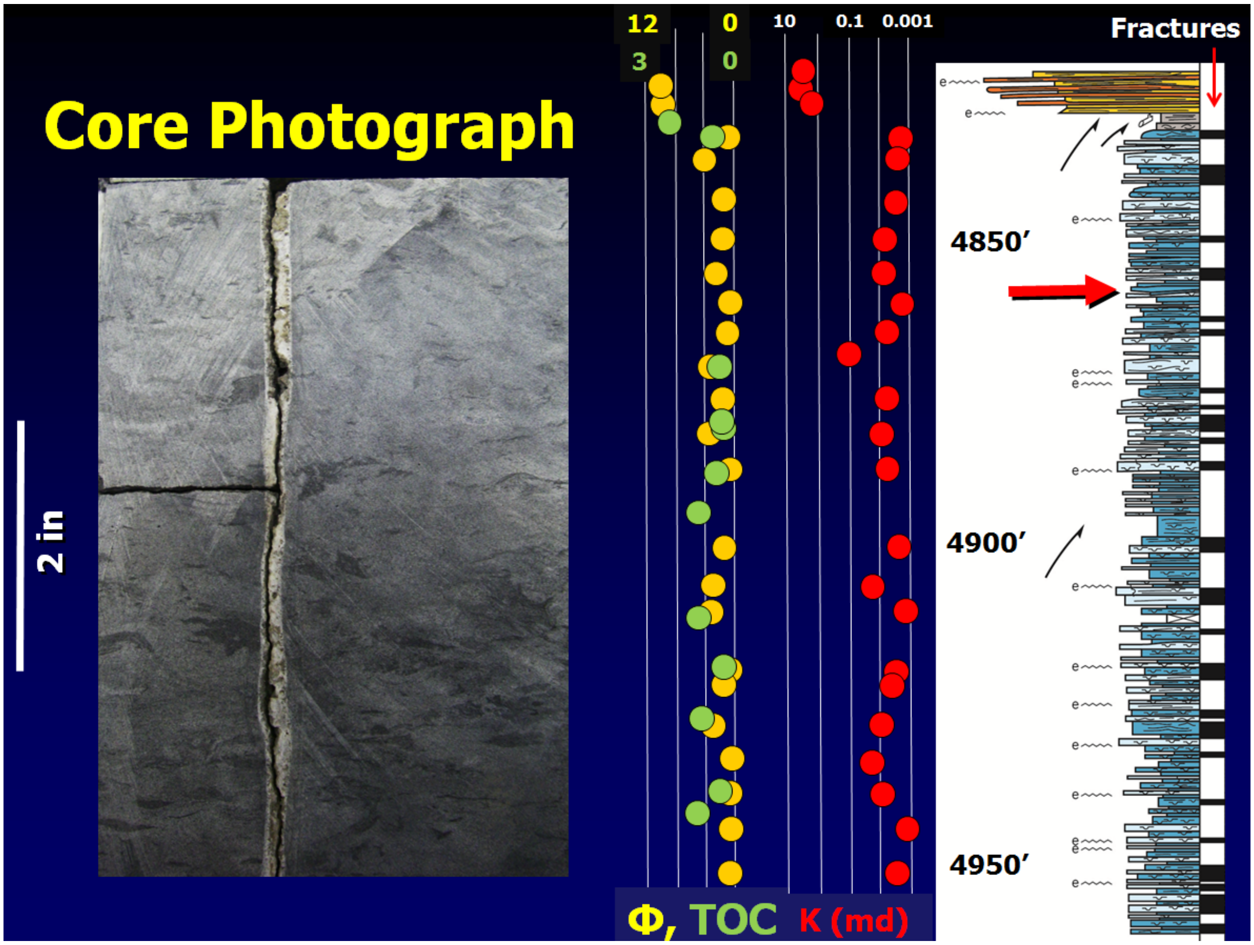

Figure 9. Photograph of naturally fractured sponge-spiculite deposits in the Marble Falls Limestone from a cored well in Jack County. Also shown is core description and porosity (Φ), TOC, and permeability (K) values from core data. The red arrow in the core description indicates footage of the core photograph. Light- and dark-blue beds represent the Marble Falls Limestone, whereas yellow and orange beds correspond to the overlying Bend Conglomerate, described in **Hentz et al. (2012)**. Data from **Ambrose et al. (2013)**.

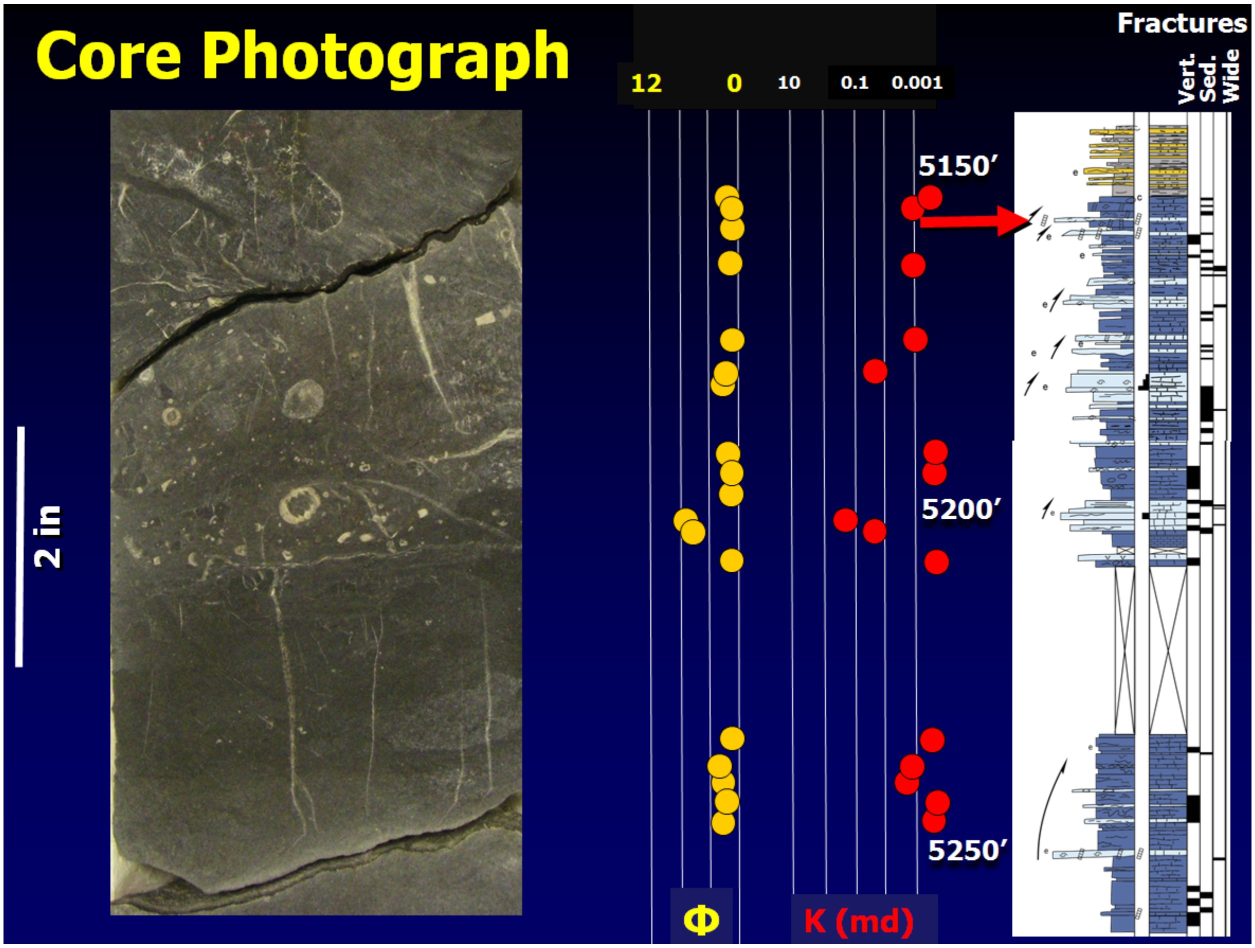

Figure 10. Photograph of carbonate debris-flow deposits in erosional contact with mudstone in the Marble Falls Limestone from a cored well in Jack County. Core description is also shown, displaying porosity (Φ) and permeability (K) values from core data. The red arrow in the core description indicates footage of the core photograph. Light-blue beds represent carbonate grainstones, and dark-blue beds are wackestones and mudstones in the Marble Falls Limestone. Yellow beds are sandstones, and brown beds are mudstone within the overlying Smithwick Shale. Data from **Ambrose et al. (2013)**.

REGIONAL STUDIES

Spraberry/Wolfcamp (Wolfberry) and Cline Shale Regional Study

Permian (Leonardian) Spraberry and Dean sandstones have produced oil in the Midland Basin since the late 1940's. Known as the Spraberry Trend, productive areas extend across 18 counties and contain more than 10 billion barrels (Bbbl) of oil (**fig. 11**). Operators have recently been targeting deeper zones, including the Lower Permian Wolfcamp Formation. The combined Spraberry, Dean, and Wolfcamp productive intervals are collectively called the Wolfberry play. Multiple hydraulic-fracture stimulation stages are applied to these low-permeability formations in a more-than-4,000-ft (1,220-m) vertical interval from depths of 6,000 to 10,000 ft (1,830 to 2,630 m). Since the late 1990's, more than 8,700 Wolfberry oil wells have been completed and have produced 216 MMbbl of oil and 544 Bcf of gas. Initial well production averages 30 to 125 bbl of oil per day, and ultimate per-well recovery is estimated at 100,000 to 140,000 bbl of oil equivalent.

The Wolfberry is a resource play characterized by heterogeneous rock types, low-permeability values, and reservoirs and source rocks in close proximity. The paleogeographic setting is a deep ocean basin surrounded by shallow carbonate platforms. Basin-floor stratigraphy comprises alternating layers of continuous calcareous and siliciclastic deposits. In siliciclastic intervals, such as the Spraberry and Dean, turbidite sandstones and laminated siltstones are interbedded with organic-rich mudrocks (**fig. 12**). In calcareous intervals, such as the lower Leonard and the Wolfcamp Formation, carbonate debris flows are interbedded with carbonate turbidites and organic-rich, calcareous mudrocks.

Exploration in the southern part of the Midland Basin has recently focused on the Cline Shale in the lower Wolfcamp Formation (**fig. 13**). The Cline Shale is an organic-rich mudrock (**fig. 14**) composed predominantly of siliciclastic-rich facies, interbedded with thin carbonate beds (**Roush et al., 2014**). The Midland Basin was a passively subsiding, asymmetric basin dipping to the west during Cline deposition (**Frenzel et al., 1988)**. Slow sedimentation rates and periodic oceanic oxygen depletion controlled accumulation and preservation of organic matter, important in generating oil and gas resources (**Adams, 1951**). The Cline is an example of the evolution of the Wolfberry Play towards mostly horizontal drilling in selected target intervals, rather than continuing the vertical completions. These horizontal drilling targets inlcude the Wolfcamp A, B, and D (Cline) plus some deeper and shallower intervals. These horizontal targets will be the subject of future STARR research projects.

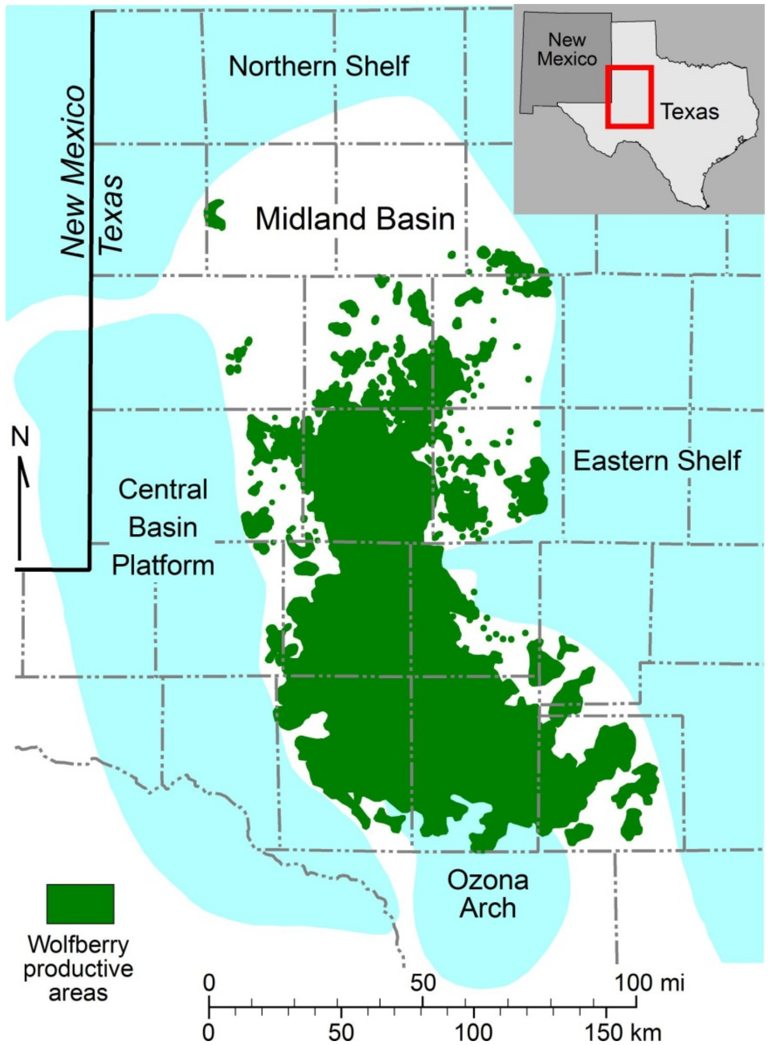

Figure 11. Map of the Midland Basin in West Texas showing Wolfberry productive areas in green. (The Wolfberry play is located within a Permian deepwater ocean basin. Surrounding shallow-water carbonate platforms are shown in blue.) From **Hamlin and Baumgardner (2012)**.

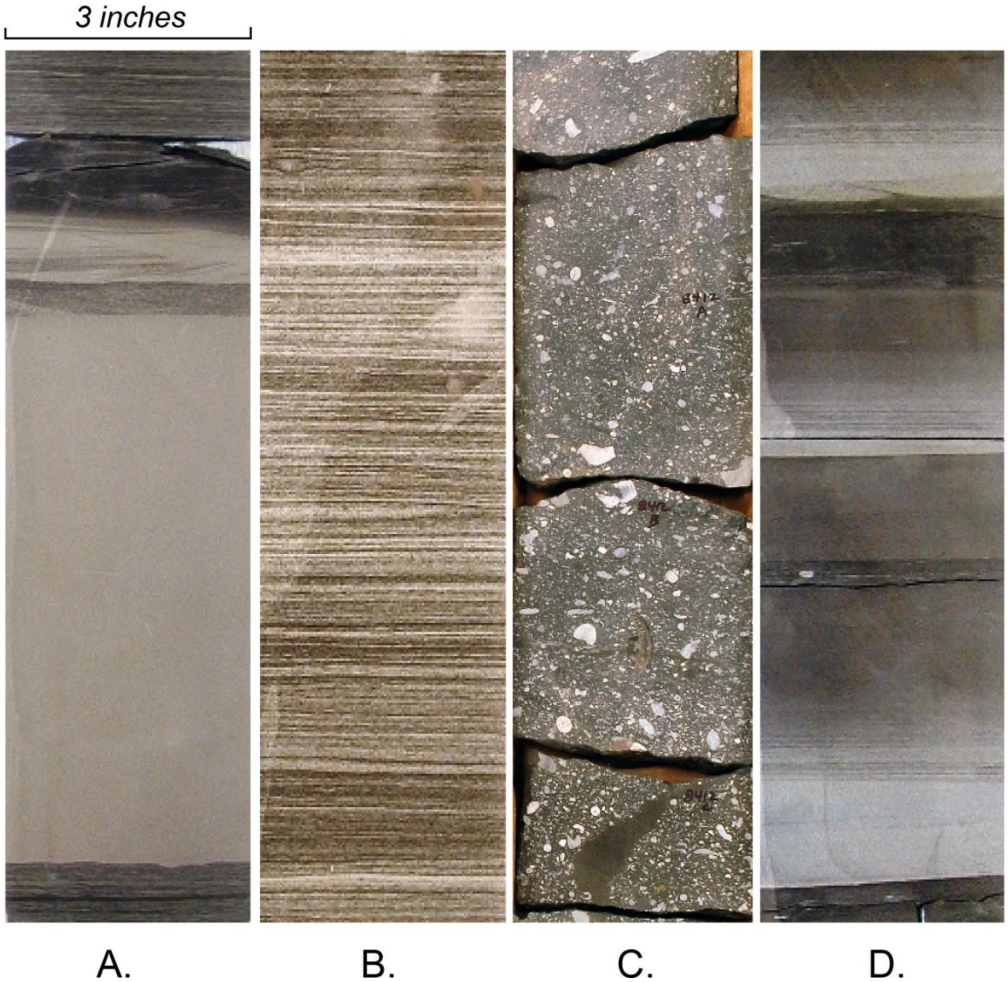

Figure 12. Core photographs of Wolfberry lithofacies. (a) Complete turbidite sandstone enclosed in laminated siltstone, Dean. (b) Laminated siltstone, Spraberry. (c) Muddy debris flow with carbonate lithoclasts and bioclasts, Wolfcamp. (d) Thin carbonate turbidites interbedded with organic-rich mudrock. Slabbed cores are 3 inches wide. From **Hamlin and Baumgardner (2012)**.

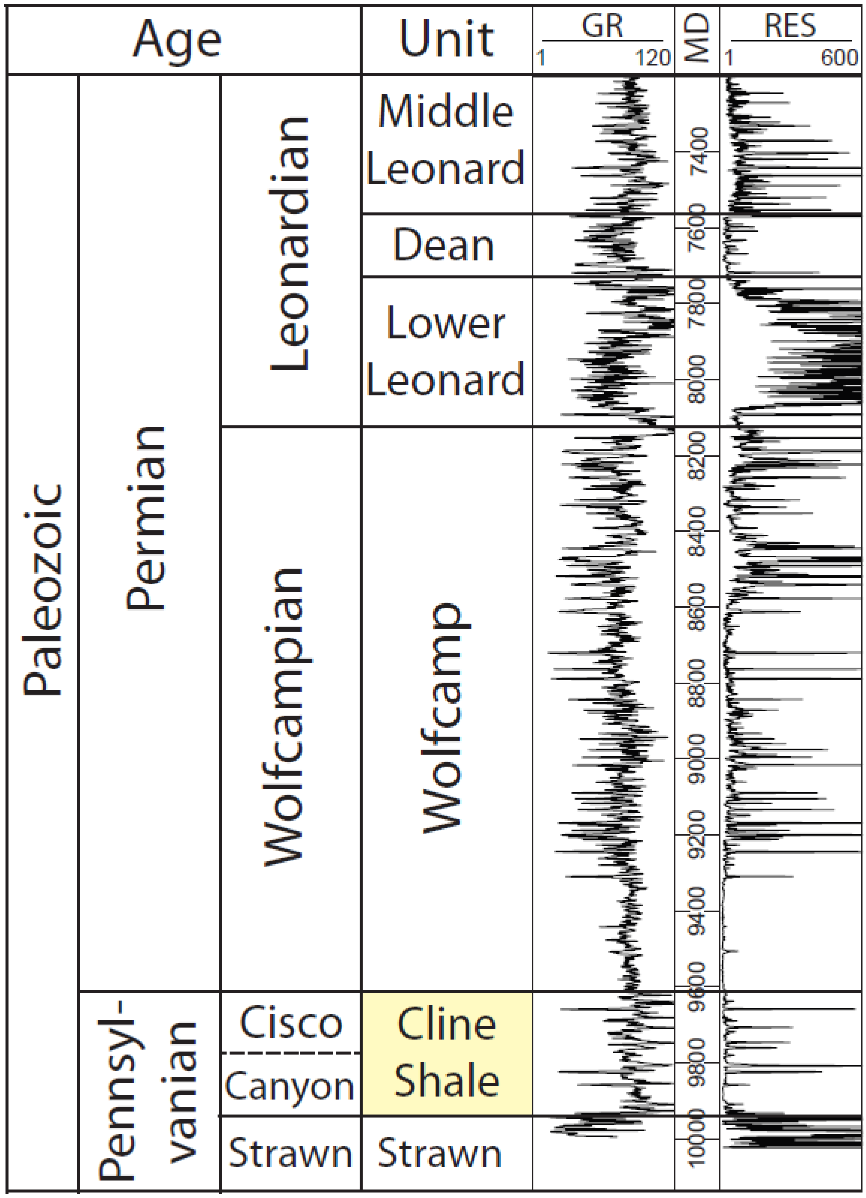

Figure 13. Type log of the Cline Shale. From **Roush et al. (2014)**.

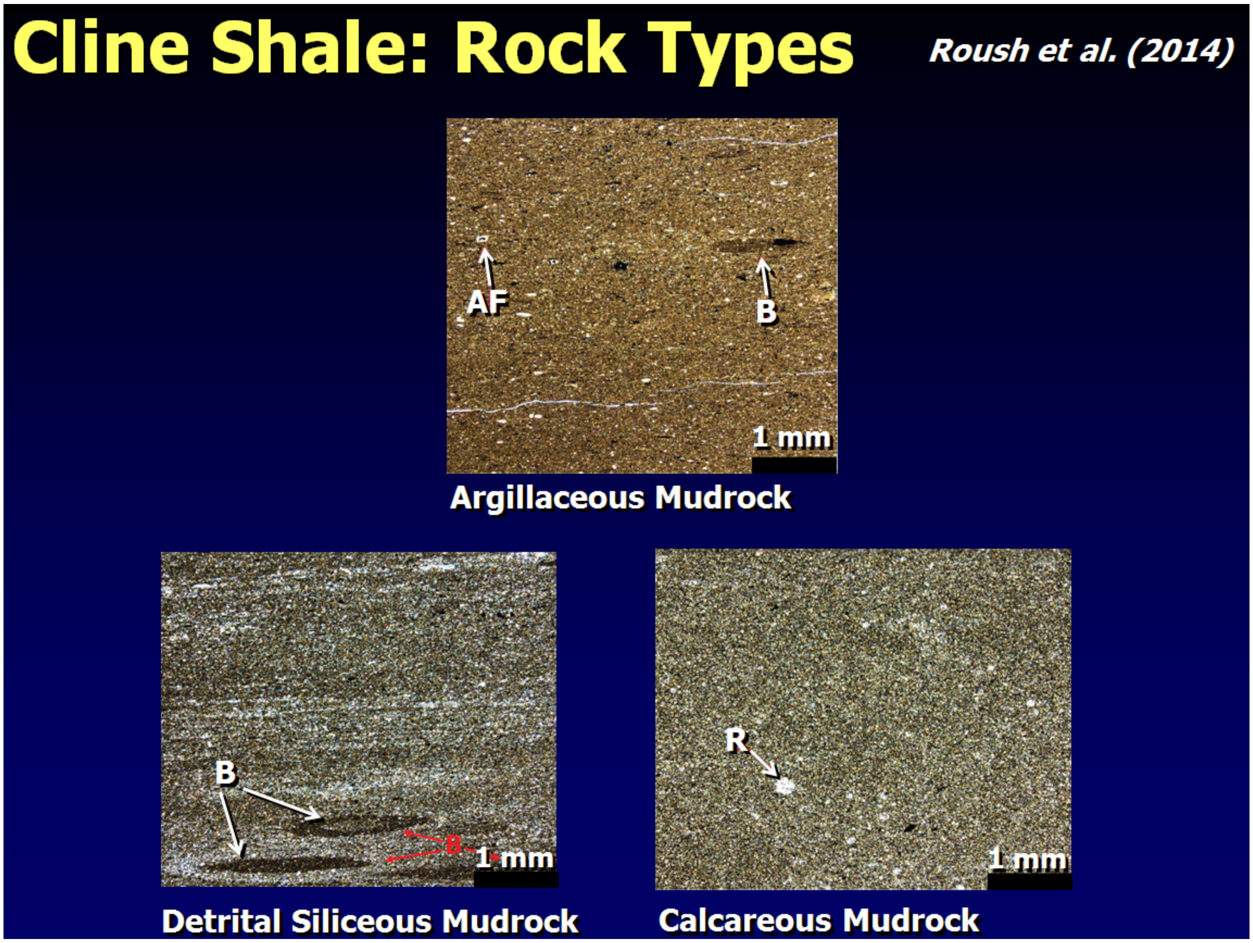

Figure 14. Rock types in the Cline Shale. AF = Agglutinated foraminifera. B = Burrows. R = Radiolarians. Photomicrographs modified from **Roush et al. (2014)**.

Eagle Ford Shale and Eaglebine Regional Studies

The Eagle Ford Shale, which extends across the Texas Gulf Coast (**fig. 15**), is the leading shale-oil play in Texas and the U.S. (**fig. 4**). Containing a significant carbonate content (as much as 70% in southwest Texas), the Eagle Ford Shale is brittle and amenable to hydraulic fracturing. It is also the primary source rock for the Austin Chalk and the giant East Texas field in the East Texas Basin (**Ambrose et al., 2009**). Oil production in the Eagle Ford Shale in the period from January to July 2014 alone consisted of almost 900,000 bbl (**fig. 17**). The Eagle Ford Shale also produces significant amounts of natural gas (**figs. 18**, **19**).

The Eaglebine trend, encompassing parts of Brazos, Robertson, Grimes, Walker, Leon, and Madison Counties (**fig. 16**), consists of deltaic and shelf deposits in the Maness Shale, Woodbine Group, and overlying Eagle Ford Shale (**fig. 20**). A recent regional STARR study (**Hentz et al., in press**) shows that Woodbine sandstone beds in the trend are typically narrow and discontinuous, having been deposited in a fluvially dominated deltaic system (**fig. 21**). Exploration in the Eaglebine play is driven by recent advances in horizontal-drilling and multistage hydraulic-fracturing methods to maximize hydrocarbon production in stratigraphic traps, although production has historically come from Woodbine fields with structural and combination traps associated with salt structures (**Jackson and Seni, 1984; Wescott and Hood, 1994**). These stratigraphic traps are represented by facies pinchouts or diagenetic barriers in thin (<25-ft [8-m]) sandstone beds (**Siemers, 1978; Foss, 1979**). Most current Eaglebine wells target upper Woodbine sandstones just below the base of the Eagle Ford Group. **Powell Shale Digest (2013)** reports that ~200 horizontal wells drilled by 27 different operators in the Eaglebine trend are producing oil and gas. Peak-month daily oil production in these wells averages 314 bbl, ranging from 238 bbl (Robertson County) to 417 bbl (Madison County). Peak-month daily gas production averages 288 thousand cubic feet (Mcf) but ranges widely from 73 Mcf/d (Robertson County) to 548 Mcf/d (Grimes County).

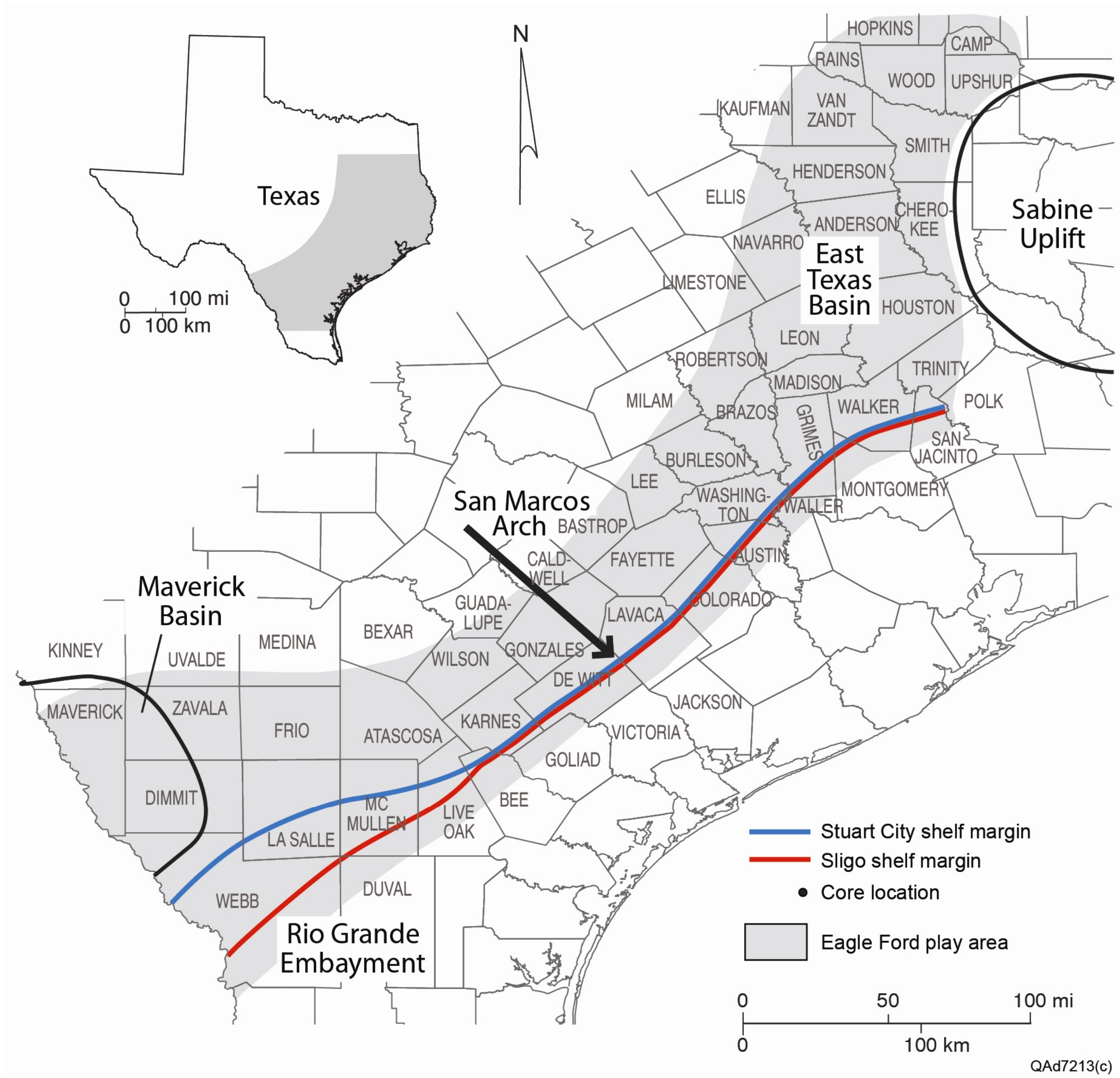

Figure 15. Regional extent of Eagle Ford Play in Texas. From **Hentz and Ruppel (2010)**.

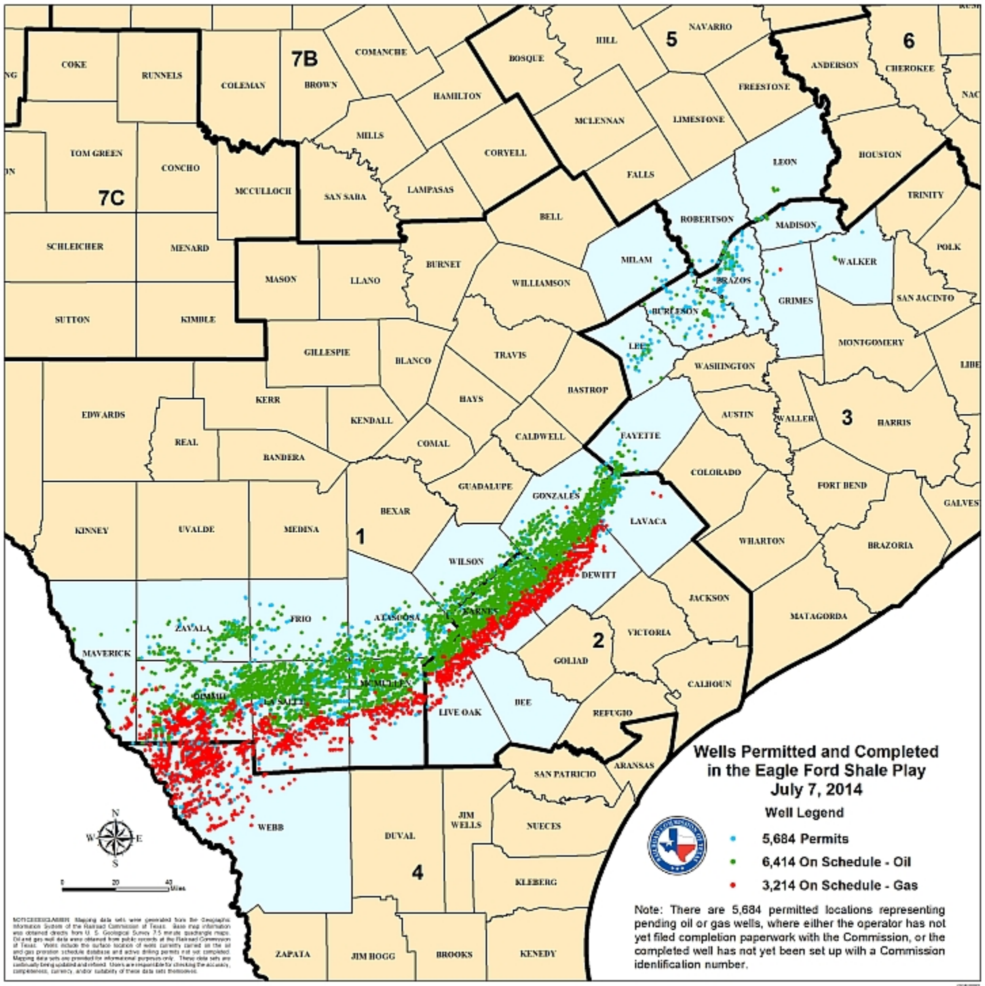

Figure 16. Distribution of oil and gas production in the Eagle Ford Play in Texas, updated to July 2014. From the **Railroad Commission of Texas (2014a)**.

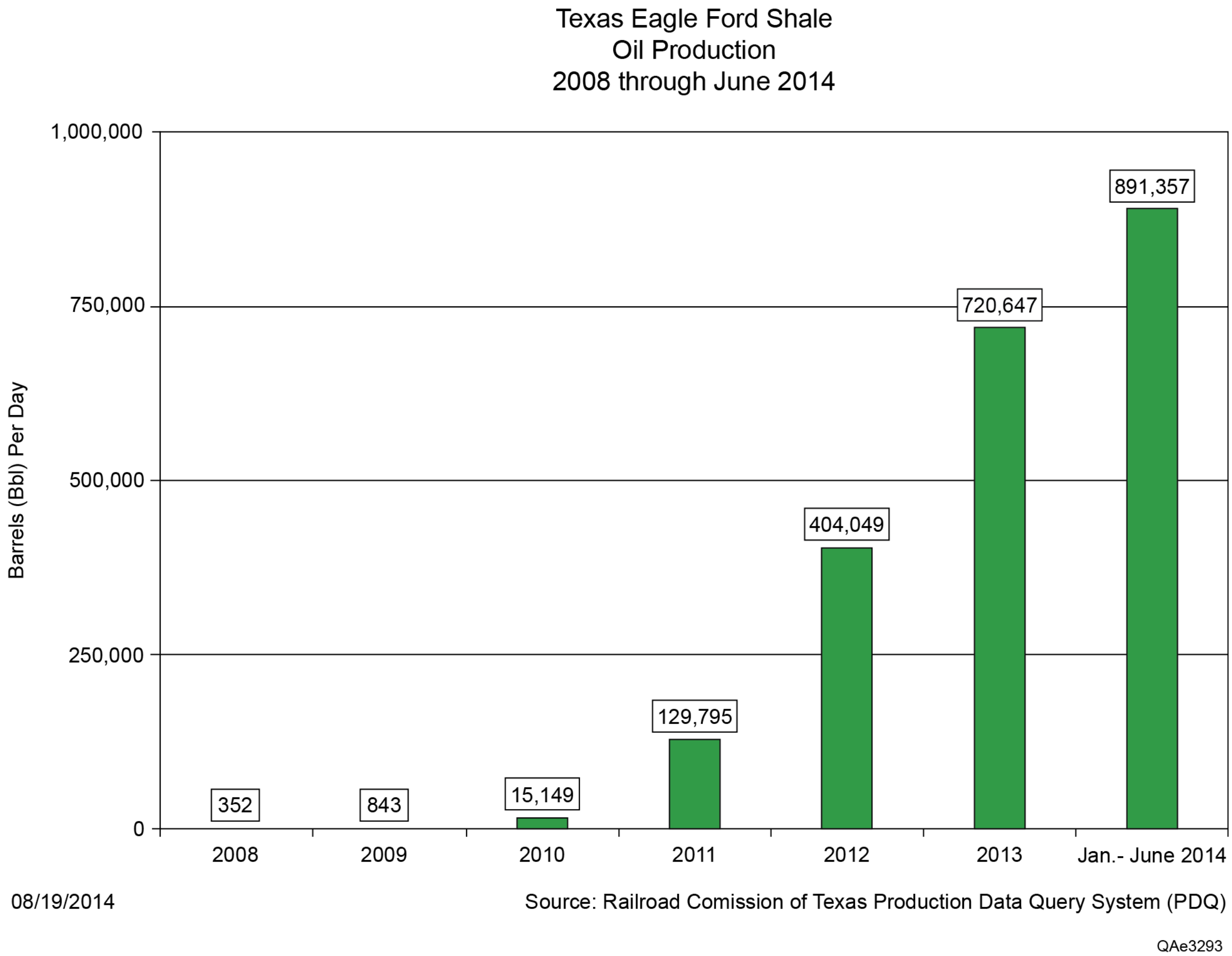

Figure 17. Average daily oil production in the Eagle Ford Formation in Texas, updated to July 2014. From the **Railroad Commission of Texas (2014b)**.

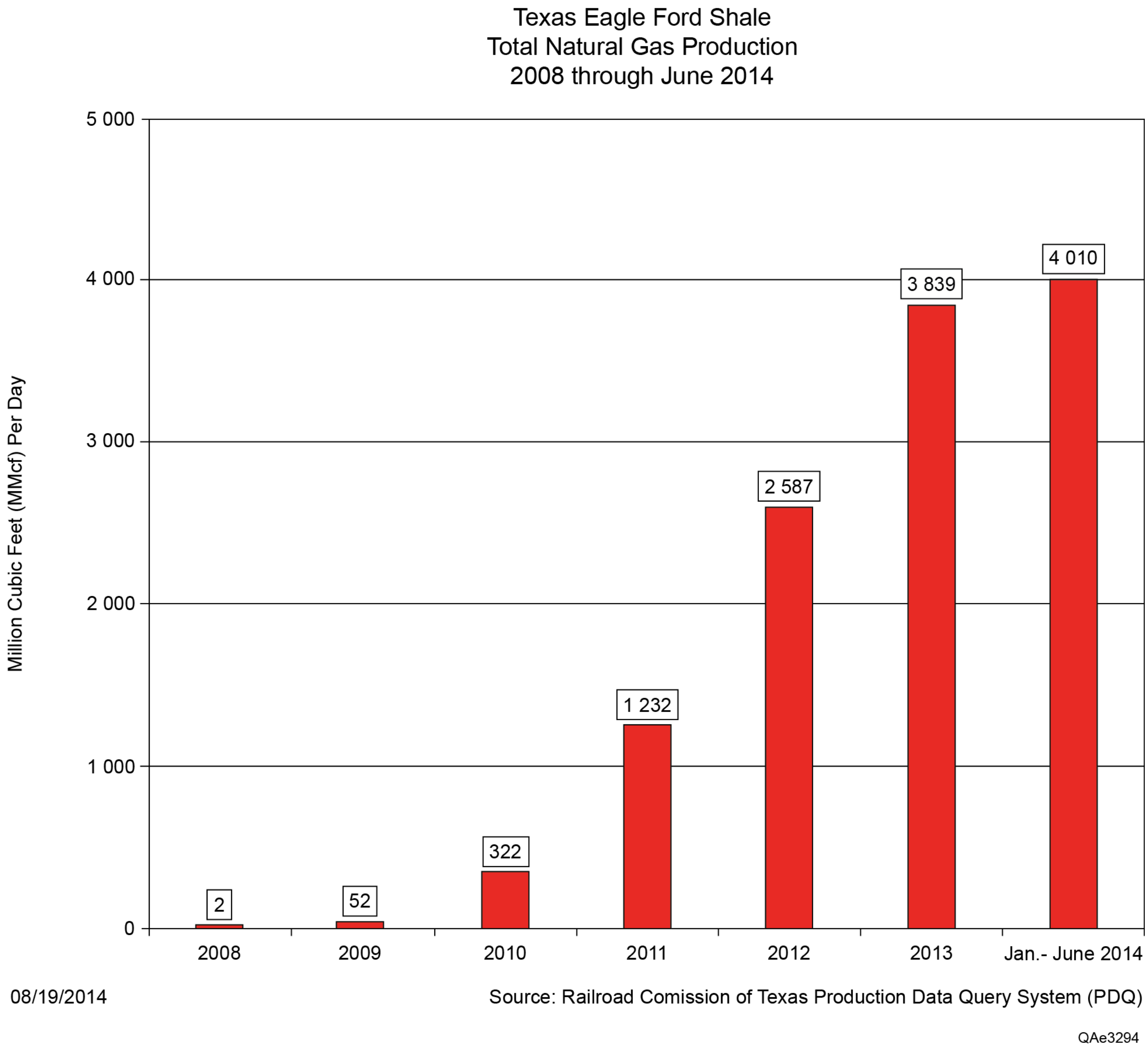

Figure 18. Average daily gas production in the Eagle Ford Formation in Texas, updated to July 2014. From the **Railroad Commission of Texas (2014c)**.

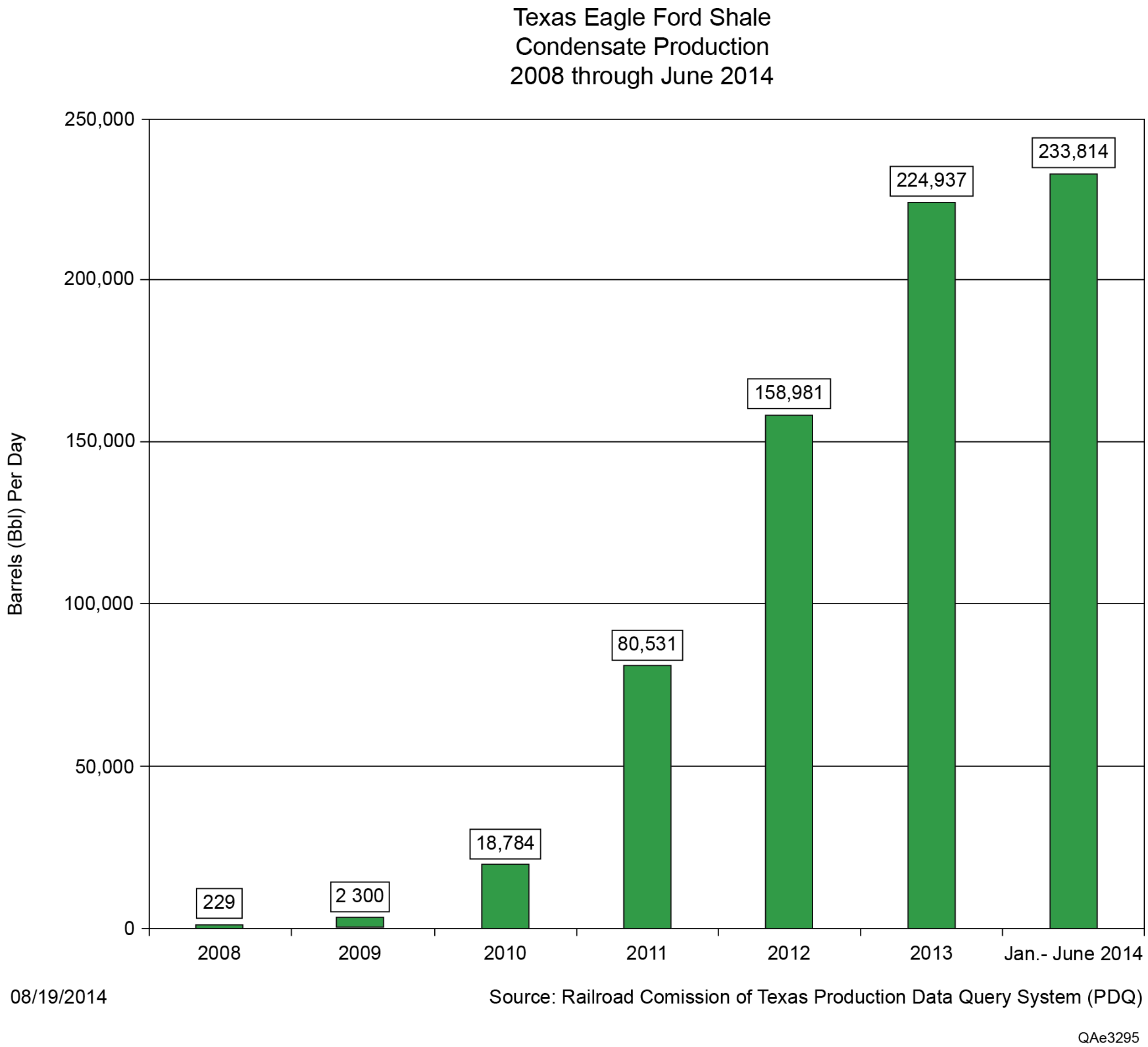

Figure 19. Average daily condensate production in the Eagle Ford Formation in Texas, updated to January–July 2014. From the **Railroad Commission of Texas (2014d)**.

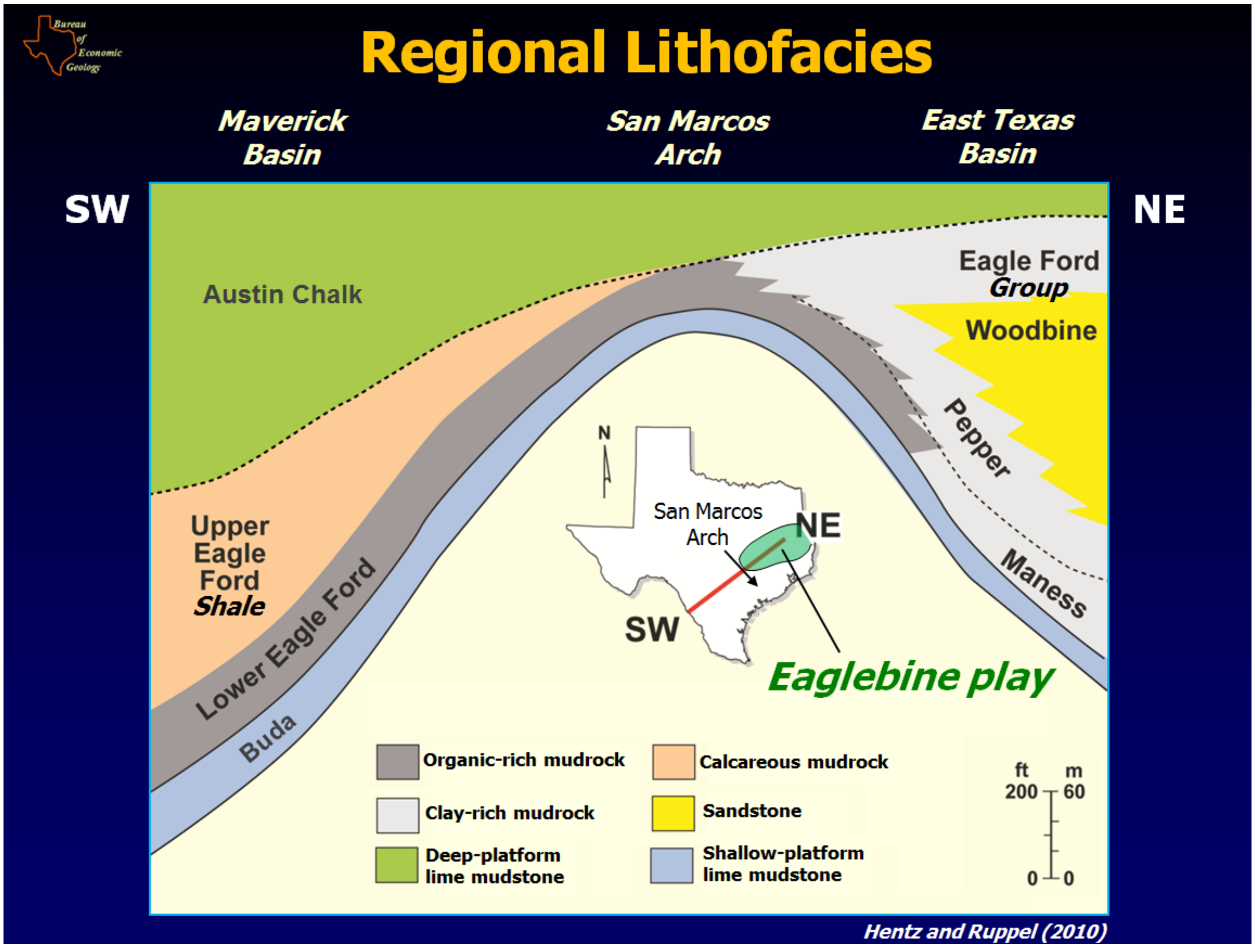

Figure 20. Regional lithofacies and stratigraphic complexity in the Buda Limestone to Austin Chalk interval that includes the Eagle Ford Formation. Modified from **Hentz and Ruppel (2010)**.

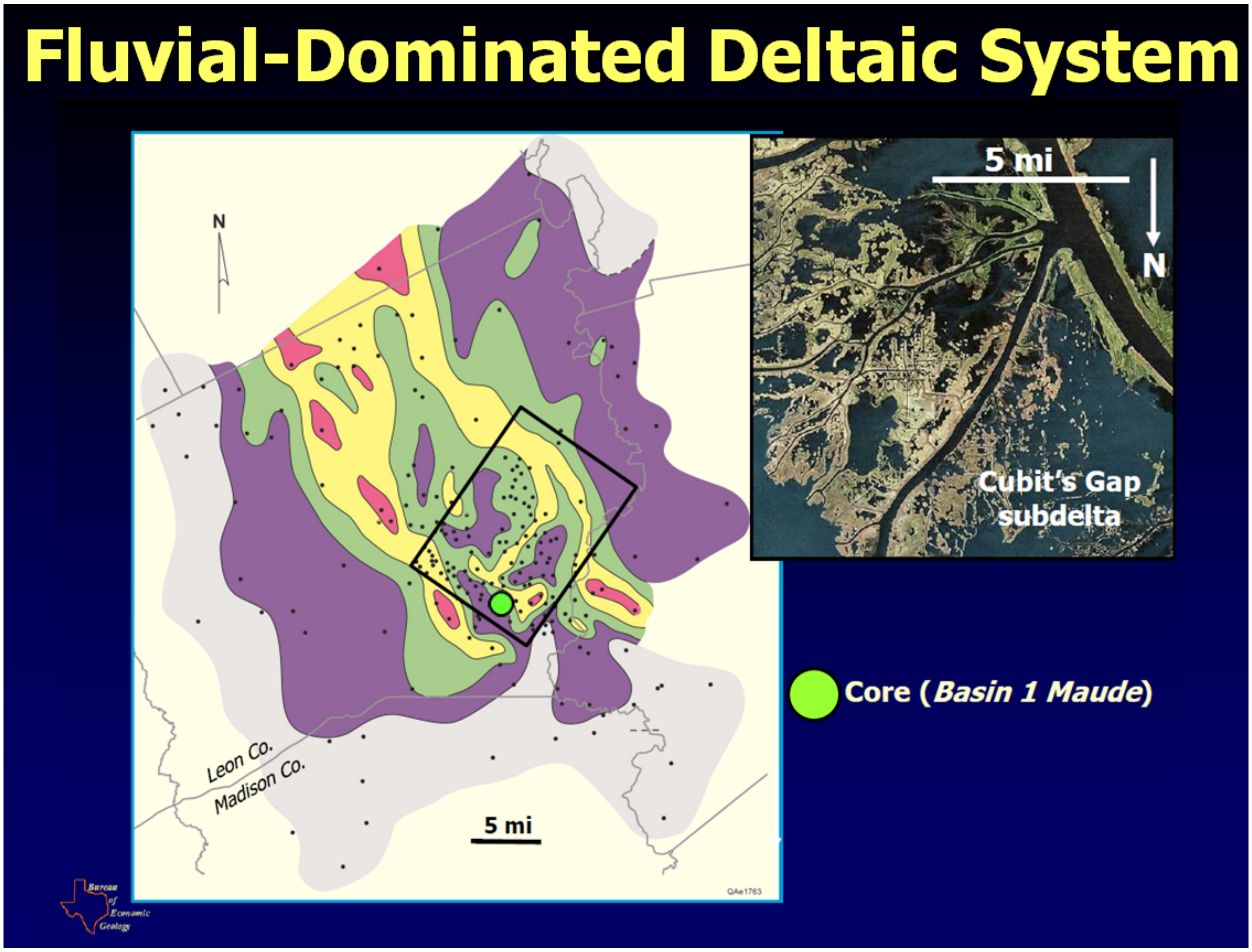

Figure 21. Depositional setting of Woodbine sandstone bodies in the Eaglebine trend in Leon and Madison Counties in southeast Texas. Inset shows a modern analogue, a portion of the Mississippi Delta. Modified from **Hentz et al. (in press)**.

REFERENCES CITED

Adams, J. E., Frenzel, H. N., Johnson, D. P., and Rhodes, M. L., 1951, Starved Pennsylvanian Midland Basin: AAPG Bulletin, v. 35, p. 2600–2607.

Ambrose, W. A., Hammes, U., and Potter, E. C., 2010, State of Texas Advanced Oil and Gas Resource Recovery (STARR) progress report: The University of Texas at Austin, Bureau of Economic Geology, report on the 2008–2010 biennium prepared for the Texas State Comptroller of Public Accounts, 88 p. + CD-ROM.

Ambrose, W. A., and Hentz, T. F., 2011, Depositional systems and facies variability in tidally modified shelf and estuarine systems in the Pennsylvanian Cleveland Formation, Anadarko Basin, North Texas and western Oklahoma, *in* Ambrose, W. A., ed., Sequence stratigraphy, depositional systems, and hydrocarbon play analysis of the Pennsylvanian Cleveland Formation and Marmaton Group, Anadarko Basin, North Texas and western Oklahoma: The University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No. 275, p. 35–66.

Ambrose, W. A., Hentz, T. F., Bonnaffé, F., Loucks, R. G., Brown, L. F., Jr., and Wang, F. P., 2009, Sequence stratigraphic controls on complex reservoir architecture of highstand fluvial-dominated deltaic and lowstand valley-fill deposits in the Woodbine Group, East Texas field: regional and local perspectives: AAPG Bulletin, v. 93, p. 231–269.

Ambrose, W. A., Hentz, T. F., Carr, D. L., and Sprowl, J., 2011, Oil- and gas-production plays and trends in the Pennsylvanian Marmaton Group and Cleveland Formation, Anadarko Basin, North Texas and western Oklahoma, *in* Ambrose, W. A., ed., Sequence stratigraphy, depositional systems, and hydrocarbon play analysis of the Pennsylvanian Cleveland Formation and Marmaton Group, Anadarko Basin, North Texas and western Oklahoma: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 275, p. 67–98.

Ambrose, W. A., Loucks, R. G., Hooker, J. N., Frost, E., Reynolds, C., McDavid, A., Dawson, D., and Walker, B., Jr., 2013, Facies variability, fracture heterogeneity, and reservoir properties of the Marble Falls Limestone, Jack County Texas (abs.): AAPG Southwest Section Convention Program and Abstracts, unpaginated.

Ambrose, W. A., and Potter, E. C., 2012, STARR program progress report: The University of Texas at Austin, Bureau of Economic Geology, prepared for the State of Texas, 65 p. + CD-ROM.

Brown, L. F., Jr., Loucks, R. G., and Treviño, R. H., 2005, Site-specific sequence-stratigraphic section benchmark charts are key to regional chronostratigraphic systems tract analysis in growth-faulted basins: American Association of Petroleum Geologists Bulletin, v. 89, no. 6, p. 715–724.

Brown, L. F., Jr., Loucks, R. G., Treviño, R. H., and Hammes, U., 2004, Understanding growth-faulted, intraslope subbasins by applying sequence-stratigraphic principles: examples from the South Texas Oligocene Frio Formation: American Association of Petroleum Geologists Bulletin, v. 88, no. 11, p. 1501–1522.

Foss, D. C., 1979, Depositional environment of Woodbine sandstones, Polk County, Texas: Gulf Coast Association of Geological Societies Transactions, v. 29, p. 83–94.

Frenzel, H. N., et al., 1988, The Permian Basin region, *in* Sloss, L. L., ed., Sedimentary cover, North American craton: Boulder, Colorado, Geological Society of America, Geology of North America, v. D-2, p. 261–306.

Hamlin, H. S., and Baumgardner, R. W., Jr., 2012, Wolfberry (Wolfcampian-Leonardian) deep-water depositional systems in the Midland Basin: stratigraphy, lithofacies, reservoirs, and source rocks: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 277, 62 p. + 4 pls. in pocket.

Hammes, U., Loucks R. G., Ambrose W. A., Treviño R. H., Brown, L. F., Jr., Zeng, H., Hentz, T. F., Gale, J. F. W., Wang, F., Bonnaffé, F., Wright, W. R., Eastwood, R., Moscardelli, L., Johnson, B. E., and Ruppel, S., 2008, Project STARR: State of Texas Advanced Oil and Gas Resource Recovery: The University of Texas at Austin, Bureau of Economic Geology, progress report, 90 p.

Hammes, U., Loucks, R. G., Brown, L. F., Jr., Treviño, R. H., Montoya, P., and Remington, R. L., 2007, Reservoir geology, structural architecture, and sequence stratigraphy of a growth-faulted subbasin: Oligocene lower Frio Formation, Red Fish Bay area, South Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 272, 28 p.

Hardage, B. A., Ambrose, W. A., Barba, R. E., Brown, L. F., Jr., Castillo, J., Clift, S. J., Correa, L., Fouad, K., Fimlay, C., Gu, Y., Holtz, M. H., Treviño, R., and Tyler, R., 2000, Project STARR: State of Texas Advanced Oil and Gas Resource Recovery: The University of Texas at Austin, Bureau of Economic Geology, progress report, 49 p.

Hentz, T. F., 1994, Sequence stratigraphy of the upper Pennsylvanian Cleveland Formation: a major tight-gas sandstone, western Anadarko Basin, Texas Panhandle: AAPG Bulletin, v. 78, no. 4, p. 569–595.

Hentz, T. F., Ambrose, W. A., and Carr, D. L., 2012, Reservoir systems of the Pennsylvanian lower Atoka Group (Bend Conglomerate), northern Fort Worth Basin, Texas: high-resolution facies distribution, structural controls on sedimentation, and production trends: AAPG Bulletin, v. 96, no. 7, p. 1301–1332.

Hentz, T. F., Ambrose, W. A., and Smith, D. C., in press, Eaglebine play of the southwestern East Texas Basin: Chronostratigraphic and depositional framework of the Upper Cretaceous (Cenomanian-Turonian) Woodbine and Eagle Ford Groups: AAPG Bulletin.

Hentz, T. F., and Ruppel, S. C., 2010, Regional lithostratigraphy of the Eagle Ford Shale: Maverick Basin to East Texas Basin: Gulf Coast Association of Geological Societies Transactions, v. 60, p. 325–337.

Jackson, M. P. A., and Seni, S. J., 1984, Atlas of salt domes in the East Texas Basin: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 140, 102 p.

Loucks, R. G., Treviño, R. H., Hammes, U., Brown, L. F., Jr., Sakurai, S., and Zeng, H., 2004, Project STARR: State of Texas Advanced Oil and Gas Resource Recovery: The University of Texas at Austin, Bureau of Economic Geology, progress report, 65 p.

Loucks, R. G., Treviño, R. H., Hammes, U., Brown, L. F., Jr., Zeng, H., Ruppel, S. C., Gale, J., Wang, F., Bonnaffé, F., McDonnell, A., Wright, W., Sakurai, S., Kane, J., and Fouad, K., 2006, Project STARR: State of Texas Advanced Oil and Gas Resource Recovery: The University of Texas at Austin, Bureau of Economic Geology, progress report, 83 p.

Loucks, R. G., Treviño, R. H., Remington, R. L., Brown, L. F., Jr., Sakurai, S., Kane, J., Correa Vivar, L., Montoya, P., Acevedo, J., Mendez, D., and McDavid, A., 2002, Project STARR: State of Texas Advanced Oil and Gas Resource Recovery: The University of Texas at Austin, Bureau of Economic Geology, progress report, 60 p.

Powell Shale Digest, 2013, Texas potential Eaglebine shale wells: v. 1, no. 45, p. 14–19.

Railroad Commission of Texas, 2014a**,** Wells permitted and completed in the Eagle Ford Shale play to July 7, 2014: http://www.rrc.state.tx.us/media/22358/eaglefordshaleplay071514-lg.jpg, accessed September 9, 2014.

Railroad Commission of Texas, 2014b**,** Texas Eagle Ford shale oil production, 2008 to June 2014: http://www.rrc.state.tx.us/media/7078/eaglefordproduction_oil_perday.pdf, accessed August 21, 2014.

Railroad Commission of Texas, 2014c, Texas Eagle Ford total natural gas production, 2008 to June 2014: http://www.rrc.state.tx.us/media/7079/eagleford_totalnaturalgas_perday.pdf, accessed August 21, 2014.

Railroad Commission of Texas, 2014d**,** Texas Eagle Ford condensate production, 2008 to June 2014: http://www.rrc.state.tx.us/media/7077/eaglefordproduction_condensate_perday.pdf, accessed August 21, 2014.

Roush, R., Hamlin, H. S., and Rowe, H., 2014, Regional stratigraphic and core-based characterization of the upper Pennsylvanian Cline Shale, Midland Basin and Eastern Shelf, Texas (abs.): AAPG Southwest Section Annual Convention, Midland, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90190sws/abstracts/rou.html.

Siemers, C. T., 1978, Submarine fan deposition of the Woodbine-Eagle Ford interval (Upper Cretaceous), Tyler County, Texas: Gulf Coast Association of Geological Societies Transactions, v. 28, p. 493–533.

Tyler, R. Barnaby, R. J., Clift, S. J., Dai, J., Dutton, S. P., Hamilton, D. S., Hamlin, H. S., Holtz, M. H., Major, R. P., Vining, M. R., and Yang, W., 1998, Project STARR: State of Texas Advanced Oil and Gas Resource Recovery: The University of Texas at Austin, Bureau of Economic Geology, progress report, 42 p.

Wescott, W. A., and Hood, W. C., 1994, Hydrocarbon generation and migration routes in the East Texas Basin: AAPG Bulletin, v. 78, p. 287–307.

ADDITIONAL PROGRAM ELEMENTS

Eight additional program elements within STARR complement the Oil and Gas Resources program. Each of the additional program elements targets research that impacts key economic opportunities or challenges in Texas related to natural resources or geological conditions. A summary of these programs and progress within them is presented here.

1. Project Title: Geothermal Energy Resources

Overview and Goals of Project

The STARR Geothermal Research Program focuses on three main areas: (1) identifying, assessing, and defining the magnitude of the extractable geothermal resources in the State of Texas; (2) making the economic factors related to the development and production of geothermal energy in the State available to both public and private entities; and (3) assisting public and private entities in assessing specific projects or prospects for the production and operation of geothermal energy.

The Bureau of Economic Geology began geothermal research for power production in the State of Texas in the early 1970’s. This research was originally funded by the Energy Research and Development Administration, the predecessor agency of the U.S. Department of Energy (DOE). In 1982, the Bureau's map “Geothermal Resources of Texas” (**Woodruff, et al. 1982**) offered the first comprehensive presentation of geothermal prospects for Texas. Since then, the Bureau has produced numerous publications, maps, and focused reports, in addition to leading a decade-long geothermal research program on Gulf Coast geothermal resources. This program, in conjunction with the DOE and the Gas Research Institute, was instrumental in carrying out the Pleasant Bayou Pilot Project. This project developed a geothermal-energy production well located in Brazoria County that produced nearly one megawatt of power for 121 days to demonstrate the practicality of commercial-scale electrical energy from geothermal-geopressured zones along the Texas Gulf Coast. The DOE provided additional funds beginning in 2009 to compile and make available through the National Geothermal Data System geothermal-related information applicable to the investigation and development of geothermal energy. Almost all of the 50 states contributed to this data set, with Texas providing more information and data than any other state in the Union.

From 2012 to 2014, the Bureau has continued the geothermal research program, with funding provided by the STARR program, DOE Geothermal Technologies Program Office, Statoil Petroleum AS, Lawrence Berkeley National Labs, and BP Alternative Energy North America. Most importantly, however, funds from the STARR program have enabled the Bureau geothermal program to continue its activities supporting large and small energy businesses interested in starting up geothermal companies, providing data sets and analyses to major petroleum-producing companies that have a need for heat-flow related data, and supporting several student degrees.

Results and Findings

The DOE funding during the 2009 to 2013 period provided the foundational support necessary to organize and make available raw geologic information pertinent to geothermal energy. Using this initial data-assembly effort, STARR funds have supported the detailed analysis of over 55 different potential geothermal reservoirs and 138 cross-sectional slices showing reservoir parameters, as well as the application of the DOE Geothermal Electricity Technology Evaluation Model (GETEM) to representative reservoirs to illustrate economic factors related to the production of geothermal energy and detailed geothermal gradient maps for the entire State. New and significant findings from these programs include the identification of areas of significantly higher geothermal gradients in the Sabine Uplift area of East Texas, expansion of the geothermal fairways along the Gulf Coast (originally identified by Bureau Researchers Don Bebout and Robert Loucks in 1982), and significant new geothermal prospects in the Trans-Pecos Region of West Texas. Previous studies had not identified the Anadarko Basin of the Texas Panhandle as having any significant geothermal potential. However, the recent petroleum drilling activity focused on the Granite Wash areas of the Panhandle provided new and very useful data and demonstrated that North Texas and the Anadarko Basin have the potential to contribute to the overall estimate of extractable geothermal resources for the State. **Table 4**, taken from a recent STARR Geothermal Team publication (**Zafar and Cutright, 2014**), provides an estimate of the geothermal resources from the four major geographic regions of the State.

Table 4. Estimate of geothermal resources from four major geographic regions of Texas

	Area (Sq km)	Total Energy (Joules)	Total Energy (BBls of oil equivalent)	Total Energy in MWh	Total Thermal Energy in MW hours
Gulf Coast	9.06E+03	9.42E+21	1.56E+12	2.64E+12	1.88E+12
East Texas	8.84E+03	8.34E+21	1.37E+12	2.32375E+12	1.65193E+12
West Texas	1.29E+04	8.66E+21	1.42E+12	2.41274E+12	1.71519E+12
North Texas	1.29E+04	3.85E+21	6.34E+11	1.07337E+12	7.63047E+11
Total	4.37E+04	3.03E+22	4.99E+12	8.45E+12	6.01E+12

These estimates continue to be refined as new subsurface data become available and as additional studies related to refining methods of estimating the extractable portion of contained heat in the deep sedimentary units are completed. We are also working cooperatively with Lawrence Berkeley National Labs (LBNL) to refine estimates of extractable thermal energy using supercritical carbon dioxide as the heat mining fluid. Carbon Dioxide is being used extensively in enhanced oil recovery operations in the Permian Basin and other areas of the State, and is of interest in climate studies assessing the utility of storing excess carbon dioxide underground in geologic repositories. Based on model studies by LBNL and the Bureau, it also appears that CO_2 may increase the efficiency of heat extraction from lower-temperature reservoirs and lower-permeability reservoirs by as much as 50 percent above the use of geothermal brines in the same situation. This is an active area of research for the geothermal STARR program, and we look forward to having more definitive information for the next reporting period.

Obstacles to Development

Despite the magnitude of the identified resource and competitive levelized cost of energy (LCOE), geothermal energy extraction from sedimentary basins remains slow to emerge in Texas and other regions. Several obstacles to development explain the delayed embrace of geothermal energy in Texas. The first is a lack of reliable, detailed resource information at the reservoir scale. While our research efforts have demonstrated that a massive thermal resource is present, other characteristics are vital to identifying and exploiting potential reservoirs. Permeability and reservoir heterogeneity must be well known and well defined in order to confidently estimate flow rates and sustainability of potential projects. Currently, the Bureau's STARR Geothermal Research Program is addressing these issues through additions to the Bureau's IGOR database, publications in widely read technical journals, and presentations in industry forums and conferences. We also continue to make Texas data available through the National Geothermal Data System web link.

Additionally, there are opportunities for improving the technology for defining, extracting, and using most of the recoverable resources for power generation. While there have been substantial advancements in power generation from thermal energy, mainly from developments in binary turbine generation systems, these systems have significant areas for improvement, particularly in the area of cooling-systems efficiencies. The Bureau has worked extensively with manufacturers that are developing these technologies to help identify potential locations for demonstration sites and create partnerships between private companies, municipalities, research institutions, and government agencies to design demonstration projects.

Finally, an uncertain regulatory and economic environment in the burgeoning geothermal industry is a major obstacle to attracting capital and getting projects off the ground. Geothermal has not enjoyed the same level of renewable energy tax credits that the wind and solar energy industry have received, and there are greater uncertainties in obtaining tax credits for geothermal energy production relative to tax credits for other energy sources. Uncertainties also remain in how mineral leasing regulations will apply to development projects, such as whether the same surface and mineral rights ownership policies apply as in the oil and gas industry. Regulations and policies vary widely depending on land ownership status, such as private land compared to government-owned land previously leased to oil and gas producers. It also remains somewhat unclear how “rule of capture” would apply to geothermal energy production. The Bureau continues to work with Texas State Agencies and U.S. regulatory agencies such as the DOE to help develop a clear regulatory framework and encourage tax policies that will favor geothermal energy production in Texas and other areas.

Associated with the regulatory issue are uncertainties in possible environmental impacts and regulations related to fracture stimulation for geothermal energy production. One issue, for example, is how geothermal brines containing high levels of dissolved heavy metals and other minerals would be handled. The Bureau is contributing to solving this issue by analyzing the geochemistry of brines of potential regions and examining the possibility of economically extracting these minerals for commercial exploitation. The Bureau is also analyzing reinjection of geothermal fluids within a geopressured environment to better understand the feasibility and sustainability of closed-loop systems, preventing contamination of potable aquifers or land surface with geothermal brines.

Future Focus

We anticipate continuing our work on resource definition within Texas and supporting Statoil and BP in their interest in developing geothermal energy along the Texas Gulf Coast. We have also had interest expressed by the Port Authority of Corpus Christi, the City of Galveston, The University of Texas Medical Branch at Galveston, the Corpus Christi Naval Air Station, the City of McAllen, Texas, and several private companies, including Valero, in meeting some of their power needs with geothermal energy. Our research focus will continue to be on refining our methodologies for determining extractable geothermal energy; defining critical reservoir properties that affect the efficiency of developing geothermal energy; and working cooperatively with other State institutions, such as the Public Utilities Commission and the Texas General Land Office, on geothermal-related research in the State.

As a precursor to some of the research that we anticipate completing and publishing during the next biennium, we include here a thermal-conductivity map and a heat-flow map of the State, developed using 49,000 wells from our database (**fig. 22**). These figures have not been published as of this date but represent a new methodology for deriving heat-flow data from multiple wells that will significantly improve our ability to derive heat-flow data for areas throughout the United States.

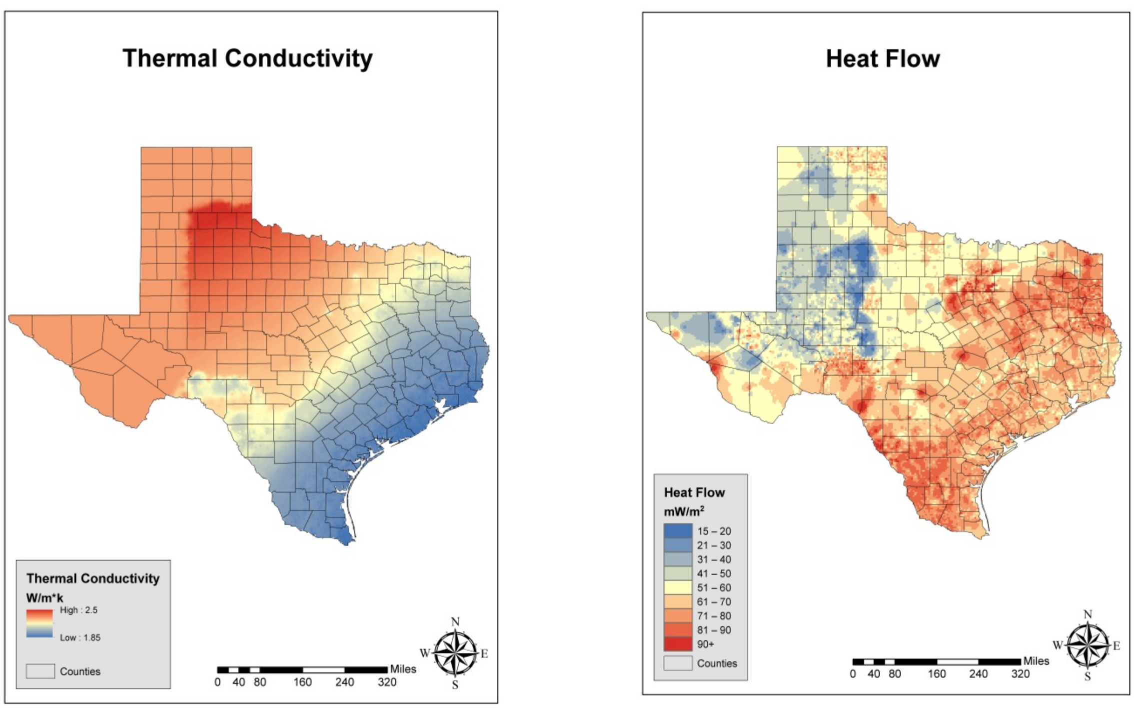

Figure 22. Thermal-conductivity and heat-flow maps of Texas.

The thermal-conductivity map was created using average subsurface thermal conductivity values at 449 points, determined through well-core analysis. These 449 points provided the thermal-conductivity parameter and were then extrapolated across the 49,000 wells where we had thermal-gradient information. While the thermal-conductivity points were scattered across the state, data density was highest in the Gulf Coast and East Texas regions and most sparse in the West Texas and Anadarko/Panhandle regions. Because of the lack of data density in the west and north regions, the values are highly generalized and show only regional heat-flow trends; they do not reflect the fine geologic detail that will be developed as more data points are gathered. The greater the regional density of measured values for thermal conductivity, the more these heat-flow values are expected to reflect the variation of geological units across the area.

Connection to Neutrality and Value to Texas

The United States has over 3,300 MW of installed geothermal-generating capacity. Texas, rivaled only by California, contains more potentially extractable geothermal energy resources than any of the remaining States. Unfortunately, while California, Colorado, Oregon, Utah, Nevada, New Mexico, North Dakota, and Wyoming have active geothermal energy projects, Texas has lagged behind commercial development, largely because of ample supplies of natural gas, oil, and coal and a highly subsidized wind and solar market. The STARR Geothermal Research Program is working to make Texas more competitive by (1) providing high-quality information on geothermal prospects to interested parties, (2) quantifying the economics of developing geothermal energy and providing comparative cost information so that independent power producers may intelligently chose among power-generation methods, and (3) enhancing public awareness of the advantages of geothermal energy by accepting public-speaking opportunities and assisting in information dissemination.

The State of Texas has more than 10,000 MW of easily accessible sustainable geothermal energy that can be produced at a cost that is competitive with other fossil-fuel and renewable-energy sources of power generation. **Figure 23** presents data compiled by the Electric Reliability Council of Texas (ERCOT) and the U.S. Department of Energy, Energy Information Agency, and released in their 2013 annual energy report for the levelized cost of energy (LCOE) comparison of power-generation methods. The geothermal data illustrated in this chart is based on both binary-cycle and flash-steam generators cost data for plants in the United States. Most areas in Texas are more suitable to binary-cycle generators, which are usually slightly lower in overall cost of operation than flash-steam generators. As clearly illustrated in the left portion of the figure, geothermal power production LCOE is competitive with other sources of generation, whether renewable or traditional fossil-fuel sources.

The average retail consumer price of electricity within Texas is between 8.6 and 12 cents per kilowatt-hour. As illustrated in the right-hand portion of the figure, over 5.2 million customers pay more than 10 cents per kilowatt-hour. Expansion of electrical-energy production using geothermal energy as the generation source could substantially reduce the overall power cost to consumers while at the same time providing an opportunity to reduce greenhouse-gas emissions without onerous taxes or penalties on fossil-fuel plants.

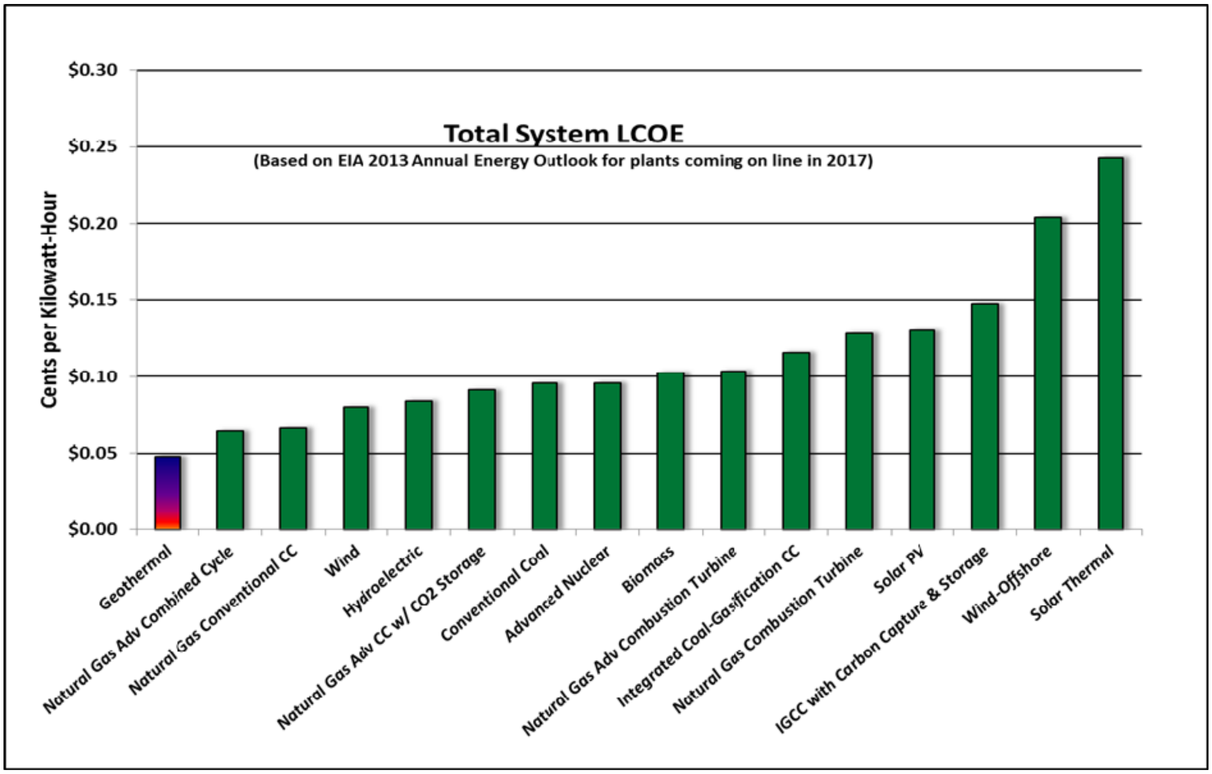

Figure 23. (a) Levelized cost of energy comparison for various generating methods in the U.S.

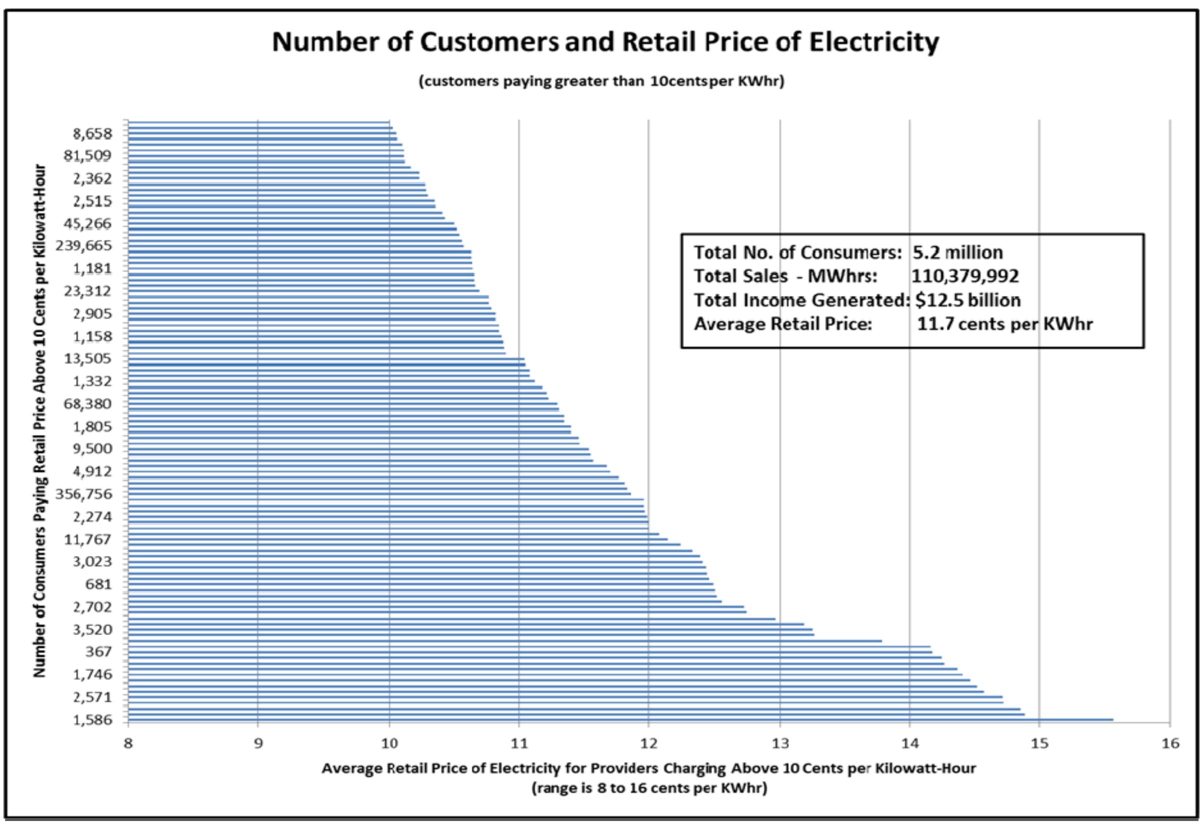

Figure 23. (b) Retail consumer price of electricity in Texas.

95% Availability Installed Capacity	Input MWhr/yr	KWhr/yr	Annual Gross Revenue from Sales (retail sales price, $ per KWhr) 0.05	0.06	0.07	0.08	0.1	0.12
1MW	8,327	8.E+06	$ 416,374	$ 499,648	$ 582,923	$ 666,198	$ 832,747	$ 999,297
10MW	83,275	8.E+07	$ 4,163,736	$ 4,996,483	$ 5,829,230	$ 6,661,978	$ 8,327,472	$ 9,992,966
50MW	416,374	4.E+08	$ 20,818,680	$ 24,982,416	$ 29,146,152	$ 33,309,888	$ 41,637,360	$ 49,964,832
100MW	832,747	8.E+08	$ 41,637,360	$ 49,964,832	$ 58,292,304	$ 66,619,776	$ 83,274,720	$ 99,929,664
200MW	1,665,494	2.E+09	$ 83,274,720	$ 99,929,664	$ 116,584,608	$ 133,239,552	$ 166,549,440	$ 199,859,328
500MW	4,163,736	4.E+09	$ 208,186,800	$ 249,824,160	$ 291,461,520	$ 333,098,880	$ 416,373,600	$ 499,648,320
1000MW	8,327,472	8.E+09	$ 416,373,600	$ 499,648,320	$ 582,923,040	$ 666,197,760	$ 832,747,200	$ 999,296,640

95% Availability Installed Capacity	Input MWhr/yr	KWhr/yr	Projected Revenue to State from Geothermal Power Generation Activities (assuming a 3.5% royalty on total revenues) 0.05	0.06	0.07	0.08	0.1	0.12
1MW	8,327	8.E+06	$ 14,573	$ 17,488	$ 20,402	$ 23,317	$ 29,146	$ 34,975
10MW	83,275	8.E+07	$ 145,731	$ 174,877	$ 204,023	$ 233,169	$ 291,462	$ 349,754
50MW	416,374	4.E+08	$ 728,654	$ 874,385	$ 1,020,115	$ 1,165,846	$ 1,457,308	$ 1,748,769
100MW	832,747	8.E+08	$ 1,457,308	$ 1,748,769	$ 2,040,231	$ 2,331,692	$ 2,914,615	$ 3,497,538
200MW	1,665,494	2.E+09	$ 2,914,615	$ 3,497,538	$ 4,080,461	$ 4,663,384	$ 5,829,230	$ 6,995,076
500MW	4,163,736	4.E+09	$ 7,286,538	$ 8,743,846	$ 10,201,153	$ 11,658,461	$ 14,573,076	$ 17,487,691
1000MW	8,327,472	8.E+09	$ 14,573,076	$ 17,487,691	$ 20,402,306	$ 23,316,922	$ 29,146,152	$ 34,975,382

Figure 24. Potential income from geothermal energy for the State of Texas.

We have also examined the potential income to the State that would be available from severance taxes and royalties on the production of geothermal energy (**fig. 24**). A small 100-MW plant would generate gross income from $40 to $80 million annually, assuming a retail price of from 5 to 10 cents per kilowatt-hour. A 3.5 percent severance tax would generate from $1.4 to $2.9 million of revenue for the State. Although these numbers are small compared to what the oil and gas industry generates, the subsidiary benefits include low land-use area required, no carbon dioxide emissions, no fuel costs, and low base-load generation capacity. These factors result in significant operational benefits to the load management personnel. If build-out capacity of geothermal reaches the 1,000-MW level that is easily within reach, the income to the State from severance taxes alone would exceed $300 million annually.

We also anticipate continuing our research on the advantages of using supercritical carbon dioxide as a heat-extraction fluid. To date, we have developed a cost model that allows us to compare the advantages of using carbon dioxide versus geothermal brines for power generation. There is additional work to be completed on the transition period during which a brine-filled reservoir is gradually filled with supercritical CO_2, and on developing options for handling the excess brine produced at the surface. We believe we will have definitive answers to most of these questions during the next biennium period.

Table 5 was developed jointly by the Bureau's STARR Geothermal research group and Barry Friefield's research team at Lawrence Berkeley National Laboratory to illustrate the advantages of geothermal energy extraction using supercritical CO_2 as the heat extraction fluid.

Table 5. Advantages of geothermal energy extraction using supercritical CO_2.

Heat Extraction	Rate of heat extraction when using supercritical CO_2 is estimated from modeling efforts to be 50% greater than that when using geothermal brines
Wellbore Hydraulics	Lower viscosity substantially improves wellbore fluid flow rates and reduces friction head losses
Chemical Interactions	Rock-fluid interactions are reduced because of the anhydrous nature of CO_2
➢ **Fluid Losses**	Unavoidable losses result in permanent storage of CO_2

List of Publications and Presentations

The following presentations, abstracts, interviews, and published reports have been produced during the current biennium:

Airhart, M. 2011, A second look: sizing up the potential for geothermal energy in Texas: The University of Texas at Austin Jackson School of Geosciences Newsletter.

Andrews, J., Dallas, D., Standen, A., Averett, A., Cutright, B. L. and Murphy, S., 2013, An immersive 3D presentation of Permian Basin geology: a web portal prototype for accessing online geologic data: presented at the West Texas Geological Society Fall Symposium, September 26.

Blackwell, D., Golm, M., Cutright, B. L., Gosnold, W., Kay, M., Nagihara, S., Smith, E., and Tester, J., Recovery act: geothermal data aggregation: submission of information into the National Geothermal Data System. Accessible at: http://geothermaldata.org/ or http://geothermal.smu.edu/gtda/.

Blackwell, D., Moerchen, F., Cutright, B. L., Gosnold, W., Kay, M., Nagihara, S., Robinson, C., and Tester, J., 2011 Data integration into the National Geothermal Data System: Geothermal Resources Council Transactions, v. 35, p. 1539–1544.

Cutright, B. L., 2012, The impact of transformational technologies in power generation from geothermal energy: presented to the Southwest Texas Electric Cooperative, El Dorado, Texas, October 2.

Cutright, B. L., 2012, Renewable energy from the petroleum industry: leveraging 150 years of capital investment from the petroleum industry to produce renewable geothermal energy: invited presentation to the Hill Country Geoscientists, Kerrville, Texas, September 17.

Cutright, B. L., 2012, The renewable energy resource assessment: geothermal energy from co-produced fluids: invited presentation to the Gulf Coast Regulatory and Environmental Affairs Association, Houston, Texas, September 13.

Cutright, B. L., 2012, The transformation of hydrofraced reservoirs to thermal energy production: AAPG Search and Discovery Article No. 90142: presented at the AAPG Annual Convention and Exhibition, Long Beach, California, April 22–25.

Cutright, B. L., 2013, Geothermal opportunities and challenges in Central America: presented at the Latin American Forum VIII, The University of Texas at Austin, April 15.

Cutright, B. L., 2013, Geothermal potential in Victoria County, South Texas Gulf Coast: presented to Statoil Alternative Energy Resources, Austin, Texas, April 18.

Cutright, B. L., 2013, Geothermal resource assessment and the potential for geothermal energy development in China: invited presentation at the McCombs School Visiting Scholars Program, The University of Texas at Austin, June 22.

Cutright, B. L., 2013, Geothermal resources from resource definition to power production in Texas: presented at the conference on Geothermal Energy and Waste Heat to Power: Utilizing Oil and Gas Plays, Southern Methodist University, Dallas, Texas, March 13.

Cutright, B. L., 2013, Geothermal resources from resource definition to power production in Texas: presented at the Southern Methodist University Conference on Co-Produced Fluid Resources, Dallas, Texas, March 14.

Cutright, B. L., 2013, Latin American geothermal energy and water resources: presented at the Latin American Forum VIII on Energy and the Environment, The University of Texas at Austin, March 4–5.

Cutright, B. L., 2013, Latin American geothermal energy and water resources: invited presentation to the STRATFOR Strategic Latin American Group, Austin, Texas, March 22.

Cutright, B. L., 2013, A new assessment of the extractable geothermal energy from deep sedimentary formations in Texas: Proceedings, Gulf Coast Association of Geological Societies, 63rd Annual Convention, New Orleans, LA October 6.

Cutright, B. L., 2013, Transformational opportunities in water supply and treatment with geothermal energy: invited presentation at the Carollo Engineers Conference on Water Treatment and Desalination, Austin, Texas, July 25.

Dunlap, D., Andrews, J., Standen, A. A., Cutright, B. L., and Murphy, S., 2013, A three dimensional geologic model and geo-referenced database for Texas (3-D-T): presented at the West Texas Geological Society Fall Symposium, Midland, Texas. September 26, 2013.

Freifield, B., Zakim, S., Cutright, Bruce L., Sheu, M., Pan, L., Doughty, C., and Held, T., 2013, Geothermal energy production coupled with CCS: a field demonstration at the SECARB Cranfield Site, Cranfield, Mississippi, USA: Energy Procedia, v. 37, p. 6595–6603.

Kampa, K., 2013, An energy return on investment for a geothermal power plant on the Texas Gulf Coast, The University of Texas at Austin, Master’s thesis, 63 p.

Morris, A., and Sheets, A., 2013 Geothermal systems: systems types, applicability and environmental impacts, Contributions by Bruce L. Cutright, Bureau of Economic Geology *in* The University of Texas School of Architecture Center for Sustainable Design, Meadows Foundation Funded Projects Digital Repository. Available at http://hdl.handle.net/2152/13326.

O'Neil, K., and Cutright, B. L., 2012, A portfolio approach to geothermal financing and innovation: invited presentation to the Navy Geothermal Program Office (GPO) at an industry forum in support of a DOD-wide geothermal program, Reno, Nevada, December 13.

Pan, L., Freifeld, B., Doughty, C., Zakem, S., Sheu, M., Cutright, B. L., and Terral, T., in press, Fully coupled wellbore-reservoir modeling of geothermal heat extraction using CO_2 as the working fluid: Geothermics, v. 53, p. 100–113.

Smith, C., Uddenberg, M., Setchko, A., Cutright, B. L., Stater, A., Bello, S.and Kampa, K., 2012, Geothermal energy from mature gas reservoirs: an analysis of the Frio and Vicksburg formations, South Texas, Hidalgo County: AAPG Search and Discovery Article No. 80235. Presented at AAPG Annual Convention, Houston Texas, 2012.

Terrall, T. R., Cutright, B. L., Zafar, S. D., and Freifeld, B. M., 2013, Potential in the contiguous United States for carbon capture and storage combined with geothermal heat extraction utilizing supercritical CO_2 as the circulating fluid: Geological Society of America Abstract No. 217277, GSA South Central Section, 47th Annual Meeting, Austin, Texas, April.

Terrall, T. and Cutright, B., 2014. A geospatial characterization of the geothermal resource potential of America's sedimentary basins utilizing innovative GIS methods. Presented at the 2014 GSA Annual Meeting, Vancouver, British Columbia. 19-22 October, 2014.

Uddenberg, M., 2012, An assessment of value for deep sedimentary geothermal resources in Texas, The University of Texas at Austin, Master's thesis.

Woodruff, C. M., Jr., Dwyer, L. C., and Gever, C. 1982. Geothermal Resources of Texas 1982. Map Produced by Ronald H. Smith through the National Geophysical Data Center National Oceanic and Atmospheric Administration for the Geothermal and Hydropower Technologies Division, United States Department of Energy.

Zafar, S. D., and Cutright, B. L., 2014 Texas' geothermal resource base: a raster-integration method for estimating in-place geothermal energy resources using ArcGis: Geothermics, Volume 50, April 2014 pages 148-154., doi:10.1016/j.geothermics.2013.09.003.

Zafar, S. D., and Cutright, B. L., 2013, Thermal energy in-place: a novel method for estimating accessible geothermal power with existing oil and gas wells using ArcGis®: presented at the Geological Society of America South-Central Meeting, Austin, Texas, April 5.

Zafar, D. and Cutright, B. L., 2012, An assessment of Texas' geothermal resources and economic potential: presented at the Geological Society of America Annual Meeting and Exposition, Charlotte, North Carolina, November 4–7.

2. Project Title: Evaluation of Water Issues That Can Threaten the Economy of Texas: Drought Vulnerability of Power Generation

Overview and Goals of Project

Because of the extreme drought in 2011 and concerns about water shortages for thermoelectric generation, we evaluated the drought vulnerability of power generation in Texas (**fig. 25**). The goals of the study were to

- quantify water consumption and withdrawal for thermoelectric generation; and
- compare water demand for power generation with water supplies to assess drought vulnerability.

Results and Findings

Our study found that water consumption for energy production is controlled primarily by

- generator technology, which is related to thermal efficiency; and
- cooling-system design, with up to 50% higher consumption in cooling towers relative to ponds.

Water demands are controlled primarily by the cooling system, with once-through cooling having water withdrawals about two orders of magnitude greater than cooling towers. Natural gas combined-cycle plants have the highest thermal efficiency.

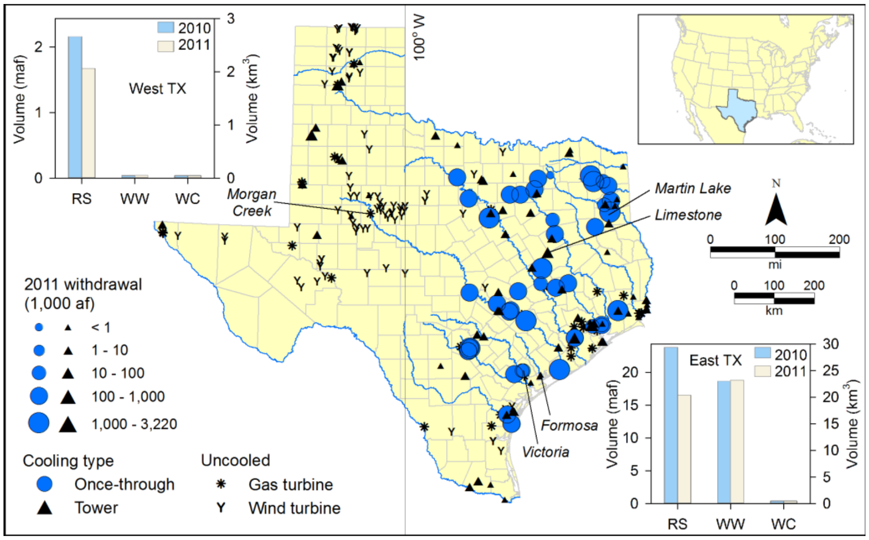

Figure 25. While water scarcity is often used to infer drought vulnerability, this study shows that power plants in semiarid West Texas were not necessarily more drought vulnerable because they are generally pre-adapted to low water availability and had more-reliable water sources (groundwater and municipal wastewater) than power plants in East Texas, dependent on surface water.

Although the 2011 drought resulted in only a 6% increase in net power generation with a corresponding 9% increase in water consumption when compared to 2010, water availability decreased sharply, with a 30% decline in monitored reservoir storage for power-plant cooling. Power plants adapted by switching from once-through cooling to cooling towers, switching from steam turbines to gas combustion turbines, and piping additional water to the power plant.

Water withdrawal is projected to decrease in the future with replacement of once-through cooling systems with cooling towers, and water consumption is projected to increase slightly because of slightly higher water consumption in cooling towers relative to once-through systems.

Other Funded Research

We examined drought vulnerability indicators, including GRACE satellite data. Other water availability and economic research supported over the past year included an analysis of the shadow price of water related to irrigated agriculture in the Texas High Plains. We evaluated data for 2010 and 2011 to estimate the cost/acre-ft based on expected and actual net revenues from the production of corn, cotton, wheat, soybeans, and sorghum. The lowest positive shadow price of water was found for corn ($5.13/acre-ft) in the southern High Plains, and the highest price was found for cotton ($865.99/acre-ft) in the northern High Plains.

Desalination is a prospective solution for mitigating future water shortages in Texas. While investment, maintenance, and total capital costs per unit water are considered as factors determining viability of a desalination plant, we evaluated a broader picture of socioeconomic impacts related to the construction project itself. As of 2010, 46 municipal brackish-water desalination plants were operating in Texas, with an estimated total desalination capacity of about 120 million gallons per day (2.3% of State water use). This study presented an Input-Output model for the brackish-water desalination plant in San Antonio. The analysis shows that constructing the desalination plant could create 2,050 jobs in the San Antonio region, while also adding 316 more jobs in other regions of Texas by 2016. Construction would also create US $133.9M of total added value in the San Antonio region and US $36.6M in the remainder of Texas.

List of Publications and Presentations

Long, D., Scanlon, B. R., Longuevergne, L., Sun, A. Y., Fernando, D. N., and S. Himanshu, S., 2013, GRACE satellites monitor large depletion in water storage in response to recent drought in Texas: Geophysical Research Letters, v. 40, p. 3395–3401.

Scanlon, B. R., Duncan, I., and Reedy, R. C., 2013, Drought and the water-energy nexus in Texas: Environmental Research Letters, v. 8, no. 4, doi:10.1088/1748-9326/8/4/045033.

Scanlon, B. R., Reedy, R. C., Duncan, I., Mullican, W. F., III, and M. H. Young, M. H., 2013, Controls on water use for thermoelectric generation: case study Texas, U.S.: Environmental Science & Technology, v. 47, 11326–11334.

Ziolkowska, J. R., 2014, Evaluating the shadow price of water for irrigation—a case of the High Plains: Poster presentation at the Agricultural & Applied Economics Association Annual Meeting, Minneapolis, Minnesota, July 27–29.

Ziolkowska, J. R., Scanlon, B. R., and Young, M., 2013, Perspectives and challenges for water desalination—a socio-economic multi-regional analysis and a case study for Texas: Abstract #H51U-02, American Geophysical Union Fall Meeting, San Francisco, December 9–13.

Connection to Neutrality and Value to Texas

The availability of water—and the cost of making water available for power generation, irrigated crop production, and municipal supply—is the keystone of the Texas economy. STARR funds were leveraged to build internal capacity to address ongoing drought concerns and to identify the resilience, and vulnerability, of Texas water resources.

3. Project Title: Geologic Mapping and Mineral/Earth Resources of Texas

Overview and Goals of Project

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 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 used for construction and in the hydrocarbon exploration/production industry, as well as minerals used in chemical industries, 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.

The STARR Geologic Mapping and Mineral/Earth Resources of Texas project complements the STARR Hazards Mapping and Response project and the 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, with coordination from the Bureau of Economic Geology. Geologic mapping during the September 2013–August 2014 fiscal year was conducted in the Texas Gulf of Mexico Coast and Coastal Plain, South Central Texas, North Central Texas, and the Trans-Pecos area of West Texas.

Results and Findings

- 1 geologic map, produced for South Texas area, with geologic units of potential industrial and/or hydraulic fracturing sand resources (**Elliott, 2014c**). Co-mapping for Texas STATEMAP Program and STARR.
- 2 geologic maps produced for areas with geologic units of potential rare earth elements (**Elliott, 2014a, b**). Co-mapping for Texas STATEMAP Program and STARR.
- 1 geologic map, produced for North Central Texas area, with geologic units of potential industrial and/or hydraulic fracturing sand resources and limestone aggregate resources (**Collins, 2014**). Co-mapping for Texas STATEMAP Program and STARR.

- 2 geologic maps, produced for middle Texas Gulf of Mexico Coast area, of sensitive coastal environments, potential sand resources, and ongoing evaluation of coastal erosion (**Paine and Collins, 2014a, b**). Co-mapping for Texas STATEMAP Program and STARR.
- 1 geologic map produced for geologic data applicable to earth and water resources and engineering projects of population corridor (**Woodruff, in review**).
- Collection of lidar data set covering Shafter silver district, Red Hills copper-molybdenum area, F-U-REE-Be mineralization around Round Top, and gold-silver-lead-zinc prospects around the Quitman Mountains (**Elliott, 2014a**).
- Continued development and updates to the Texas Mineral Resources Map through the BEG website http://igor.beg.utexas.edu/txmineralresources/ (**Elliott, 2014**).
- Promotion of industry connections and fostering of relationships with organizations and agencies that maintain valuable resource-related data, including the U.S. Geological Survey, U.S. Department of Energy, 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 (**Elliott, 2014**).
- Information and assistance with numerous inquiries about mineral occurrences, deposits, data, and available publications, many from companies and consultants looking for resource-location information. These inquiries ranged from public questions on rocks/minerals and regional/local geology, to questions about salt deposits with possible culinary applications, to resource-specific questions concerning uranium, sand, and gravel; hydraulic-fracturing sand and high-quality industrial sands; natural clay materials; rare-earth elements; silver resources; sulfur and graphite deposits; crushed limestone; trap-rock (gabbro/diabase) and aggregate resources; and heavy sands with possible titanium, zirconium, and niobium associations (**Elliott, 2014**).
- Information and assistance with inquiries concerning engineering geology and geologic hazards in Central Texas (**Woodruff, in review**).
- Research posters and oral presentations at regional and national meetings of the Society of Economic Geology, Geological Society of America, and Society of Mining and Engineering, as well as at the Bureau of Economic Geology–hosted Industry Day (**Collins, 2014; Elliott, 2014**; **Woodruff, in review**). Some presentations relate to Jackson School of Geosciences student supervision and training (**Elliott, 2014**).

List of Publications and Presentations

Bhagwat, S. B., and Ipe, V. C., 2000a, The economic benefits of detailed geologic mapping to Kentucky: Illinois State Geological Survey Special Report 3, 39 p.

Bhagwat, S. B., and Ipe, V. C., 2000b, What are geologic maps worth?: Geotimes, December 2000, p. 36–37.

Collins, E. W., 2014, Geologic map of the Hood quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Elliott, B. A., 2014a, 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., 2014b, Geologic map of the Lasca quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Elliott, B. A., 2014c, Geologic map of the Losoya quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Paine, J. G., and Collins, E. W., 2014a, Geologic map of the Bayside quadrangle: Aransas Delta and Copano Bay Area, 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., and Collins, E. W., 2014b, Geologic map of the Mission Bay quadrangle: Mission Delta and Copano Bay Area, Texas Gulf of Mexico Coast: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, scale 1:24,000.

Woodruff, C. M., Jr., in review, Geologic map of the Smithwick 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 Geologic Mapping and Earth/Mineral Resources of Texas integrates much of its work 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 awarded Federal funds ($141,053) for the STATEMAP Program of the July 2013–June 2014 project work year.
- STARR funds accounted for most of the required Cost Share for awarded Federal funds ($129,152) for the STATEMAP Program of the July 2014–June 2015 project work year.
- Geologic maps and related charts, diagrams, and texts are a type of product that has been documented to have immense economic and societal value, ranging from 25 to 39 times the cost of the mapping (**Bhagwat and Ipe, 2000a, b**).

4. Project Title: STARR Hazards Mapping and Response

Overview and Goals of Project

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; to assess the threat hazards pose; and, ultimately, to produce an atlas of geologic hazards that is accessible to emergency responders, planners, and citizens.

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 the following:

- **An airborne lidar topographic survey of the Wink sinkhole area in Winkler County, West Texas, to assess current and historic 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 airborne survey has been completed and data have been processed to produce a high-resolution elevation model, which was compared to that determined in the 1960's to show areas of historic subsidence (**fig. 26**). Planned activities include a gravity survey along county roads undergoing subsidence to assess collapse risk. STARR funds leverage funds donated by industry to support ongoing sinkhole studies. Winkler County officials have expressed an interest in helping fund future studies to the extent possible.

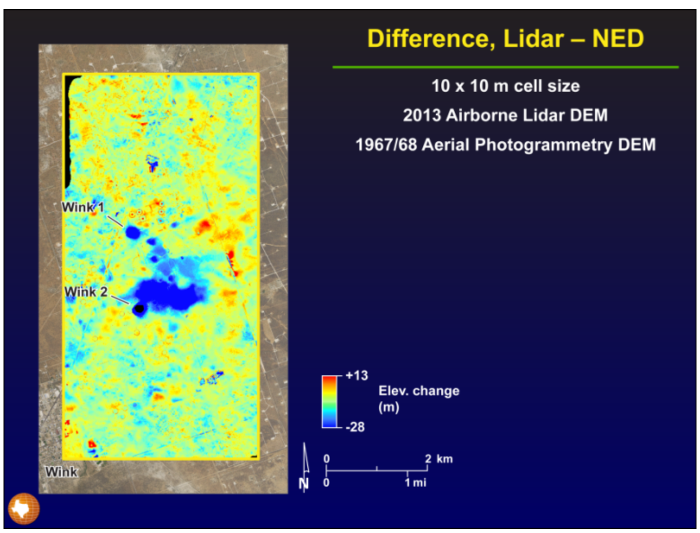

Figure 26. Elevation change in the Wink sinkhole area determined by comparing airborne lidar-derived elevations from a STARR-supported survey in 2013 with those determined by the U.S. Geological Survey in the 1960's. Blue areas indicate subsidence at rates as great as 1 inch per month.

- **Airborne and ground mapping on the Texas Coastal Plain to assess onshore sand resources needed to support restoration projects in response to sea-level rise, storm damage, and shoreline erosion.** STARR Hazards funds supplement externally funded projects, allowing us to conduct airborne lidar and ground-based investigations, complementary to project objectives in the San Antonio Bay and Copano Bay areas on the central Texas coast. Sand deposits are potential resources for future energy extraction, beach nourishment, and marsh restoration. In addition, STARR-supported surveys have identified previously unknown surface faults in the Copano Bay area. Planned FY2015 activities include additional airborne lidar and ground-based mapping projects to supplement state-sponsored mapping and hazards assessments in the Copano Bay and Matagorda Bay areas.

List of Publications and Presentations

Principal products from STARR-supported activities include presentations at conferences and stakeholder meetings, maps available to the public, interviews, reports, and articles such as the following:

Quadrangle-scale maps showing sand distribution in five quadrangles surrounding San Antonio Bay and two quadrangles in the Copano Bay area. Two more Copano Bay quadrangles will be completed before the end of FY2015. These products are jointly produced from STATEMAP, STARR, and General Land Office projects.

Presentations on sinkholes and coastal geologic hazards:

- Wink sinkholes to Winkler County officials, Kermit, Tex.
- Wink sinkholes at the 2014 SAGEEP conference, Boston, Mass.
- Wink sinkholes at Texas Legislature campus visit, The University of Texas, Austin
- Coastal hazards to Nueces County, Corpus Christi, Tex.
- Coastal hazards to the General Land Office, Austin, Tex.
- Coastal hazards to the 2013 ASBPA conference, S. Padre Island, Tex.
- Texas geologic hazards at Earth Science Week, The University of Texas, Austin

Reports and publications on geologic hazards:

- Geomorphology journal article on active fault motion on the Texas Coastal Plain
- Abstracts on sinkhole hazard assessment at two international conferences (SAGEEP and AGU) and on coastal hazards studies at another (GSA).
- Contract reports to GLO on coastal erosion (2) and to USGS on coastal mapping (2) in the San Antonio Bay and Copano Bay systems.

Journal Article

Feagin, R. A., Yeager, K. M., Brunner, C. A., and Paine, J. G., 2013, Active fault motion in a coastal wetland: Matagorda, Texas: Geomorphology, v. 199, p. 150–159.

Abstracts

Paine, J. G., Caudle, T., and Andrews, J. R., 2014, Historical to recent Texas Gulf shoreline movement and its postglacial context (abs.): Geological Society of America Abstracts with Programs, Geological Society of America Annual Meeting, Vancouver, BC, October 19-22, 2014, 1 p.

Paine, J., Saylam, K., Yang, Dochul, A., John, Averett, A., Caudle, T., and Collins, E., 2014, Quantifying monthly to decadal subsidence rates and magnitudes near the Wink sinkholes, west Texas, using airborne lidar and radar interferometry: 27th Symposium on the Application of Geophysics to Engineering and Environmental Problems, Boston, Massachusetts, 1 p.

Paine, J., Collins, E., Yang, D., Andrews, J., Averett, A., Caudle, T., and Saylam, K., 2014, Quantifying monthly to decadal subsidence and assessing collapse potential near the Wink sinkholes, west Texas, using airborne lidar, radar interferometry, and microgravity: American Geophysical Union Annual Meeting, San Francisco, California, 1 p.

Contract Reports

Caudle, T., Tremblay, T. A., Paine, J. G., Andrews, J. R., and Saylam, K., 2014, Final report: Beach and dune analysis using Chiroptera imaging system, South Padre and Brazos Islands, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology, report to the Texas Coastal Coordination Council pursuant to NOAA Award No. NA12NOS4190021, final report prepared for General Land Office under contract no. 13-030-000-6895, June 2014, 68 p., 34 figs., 3 tables.

Collins, E. W., and Paine, J. G., 2014, Project 1: Geologic mapping of the Aransas and Mission Deltas, Texas Gulf Coast, in Collins, E. W., Paine, J. G., and Elliott, B. A., Texas STATEMAP Program FY13 (2013-2014): The University of Texas at Austin, Bureau of Economic Geology, final report prepared for U.S. Geological Survey, under contract no. G13AC00178, p. 4-12 p.

Collins, E. W., and Paine, J. G., 2013, Project 1: Geologic Mapping of the Guadalupe River Delta, Texas Gulf Coast, in Collins, E.W., Paine, J.G., and Elliott, B.A., Texas STATEMAP Program FY12 (2012-2013) Final Report: The University of Texas at Austin, Bureau of Economic Geology, contract report prepared for U.S. Geological Survey under Cooperative Agreement No. G12AC20287, p. 1-–12.

Paine, J. G., Andrews, J., Saylam, Kutalmis, Tremblay, T., Young, M. H., Abolt, C., Bradford, B., Caudle, T., Meyer, T., and Neuenschwander, A., 2013, Determining wetlands distribution, lake depths, and topography using airborne lidar and imagery on the North Slope, Deadhorse area, Alaska: Bureau of Economic Geology, The University of Texas at Austin, Final Technical Report prepared for Great Bear Petroleum Operating LLC under Sponsored Research Agreement UTA12-0000752, 76 p.

Paine, J. G., Andrews, J., Saylam, Kutalmis, Tremblay, T., Young, M. H., Abolt, C., Bradford, B., Caudle, T., Meyer, T., and Neuenschwander, A., 2013, Determining wetlands distribution, lake depths, and topography using airborne lidar and imagery on the North Slope, Deadhorse area, Alaska: Draft Technical Report: Bureau of Economic Geology, The University of Texas at Austin, Draft Technical Report prepared for Great Bear Petroleum Operating LLC under Sponsored Research Agreement UTA12-0000752, 71 p.

Paine, J. G., Caudle, T., and Andrews, J., 2013, Shoreline, beach, and dune morphodynamics, Texas Gulf coast: Bureau of Economic Geology, The University of Texas at Austin, Final Report prepared for General Land Office under contract no. 09-242-000-3789, 64 p.

Paine, J. G., Caudle, T., and Andrews, J., 2014, Shoreline movement along the Texas Gulf coast, 1930's to 2012: Bureau of Economic Geology, The University of Texas at Austin, Final Report prepared for General Land Office under contract no. 09-074-000, 52 p. + CD-ROM.

Published interviews on STARR-supported hazards studies, including interviews on coastal erosion for EarthSky, and on the Wink sinkhole studies for the Odessa, Texas, CBS television affiliate.

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 used to conduct sinkhole hazard studies in West Texas, as well as supplementing numerous State and Federal grants (GLO and NOAA 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.

5. Project Title: STARR Energy Economics (STARR EE)
Oil and Gas Value Creation

Overview and Goals of Project

We investigate the myriad paths to commercialization of oil and gas resources in the State and in the United States as a whole. Our main focus is deployment of new production of oil, condensates (wellhead), natural gas liquids (NGL's; plant tailgates), and methane. Our goal is to understand emerging markets for the array of molecules in Texas and U.S. production streams, as well as the challenges in developing midstream infrastructure (pipelines, processing, fractionation, storage, export facilities) and downstream (refining, petrochemicals, power generation) investment to foster value creation. Our objectives are to explore implications for economic benefits as well as for upstream sustainability, in particular for Texas oil and gas production, supply–demand balances, and complex interactions of policy/regulatory drivers and constraints. Our approach is to build a robust, ongoing analytics and modeling platform consisting of high-integrity bottom-up databases to capture and track midstream and downstream projects (the majority of investment in Texas and along the Gulf Coast) and test assumptions about price, market conditions, and policy/regulatory effects using modeling tools that can mimic dynamics such as electric power dispatch.

Results and Findings

Our main results and findings for this biennial cycle are concentrated in two areas, as shown in the **figs. 27, 28**.

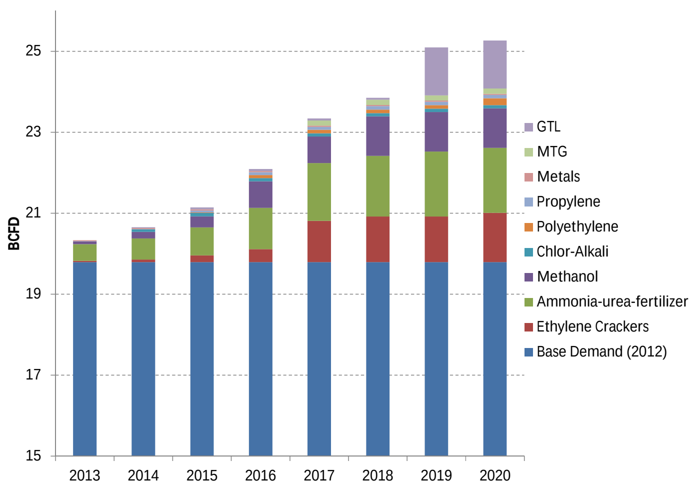

Figure 27. Potential growth in industrial demand for natural gas. Our analysis of roughly 140 projects being undertaken in the United States indicates that demand response to competitively priced, substantial volumes of methane and NGL is large and could reach levels exceeding those generally assumed for longterm U.S. energy outlooks. Thus far we have two scenarios: a reference" case of 23.5 billion cubic feet per day (Bcf/d), a 19 percent increase in industrial gas utilization above the 2012 U.S. industrial base demand; and a "high" case of 26 Bcf/d, a 31 percent increase above the 2012 base (with gas-to-liquids, or GTL, projects included).

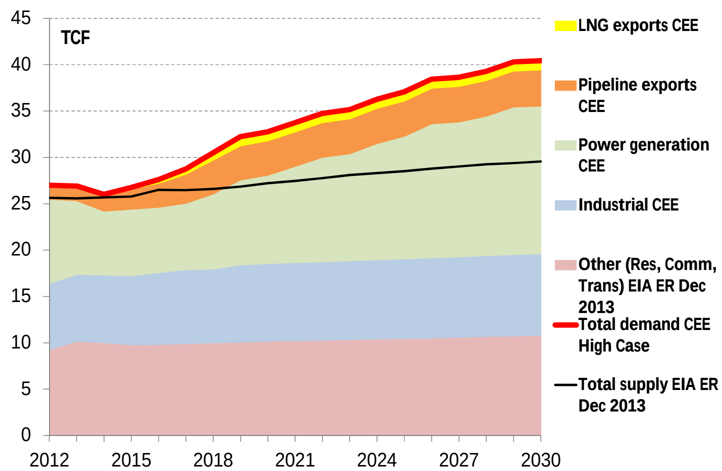

Figure 28. Potential growth in gas-fired power generation. Our analysis and modeling of generation responses to natural-gas supply growth in Texas and the United States, along with industrial demand, yield an overall scenario of natural-gas utilization with exports included (40 trillion cubic feet, or Tcf, by 2030) that far surpasses U.S. government projections of both demand and total supply during the study time frame.

The results obtained thus far demonstrate the power of combining ground-up empirical research to identify contributions to oil and gas utilization and modeling to project possible future outcomes (in the case of the electric power sector). We are continuing to refine empirical inputs and beginning to more closely explore growth factors (such as availability and pricing of oil and gas production for feedstocks), policy/regulatory drivers (such as clean-air rules that could both spur natural gas for electric power and impact supply attainment), and key issues (such as emerging export opportunities from Texas ports and value chains associated with international trade). Our work on oil and gas value creation will be combined with BEG research on shale resource assessments for a fuller, more in-depth look at supply–demand balances and implications for Texas and the United States.

List of Publications and Presentations

All works in progress are publicly available from the BEG/Center for Energy Economics (CEE) website, http://www.beg.utexas.edu/energyecon/thinkcorner/. During the course of the biennium, we released short "snapshots" that covered (1) possible U.S. liquefied natural gas (LNG) exports; (2) the 40-Tcf demand scenario for natural gas (above right chart); (3) midstream infrastructure buildout and NGL economics; (4) natural gas storage; (5) power plant retirements (a component of gas use for power generation); (6) industrial gas demand (above left chart); and (7) how oil and gas infrastructure is being re-shaped to accommodate new production locations (using Bakken rail pipeline transport as the example).

Our power sector approach and modeling results were used to address issues within the Electric Reliability Council of Texas (ERCOT) region, with a research paper entered into the Public Utility Commission of Texas (PUCT) docket on proposed energy price-cap adjustments and a peer-reviewed paper published in *The Electricity Journal* (August/September 2013). A two-part article on our overall analytics, modeling assumptions, and observations was published by *Oil & Gas Investor* (August/September 2013).

We have made numerous presentations at industry, professional, and public meetings and conferences, sharing results within the State through meetings and other exchanges, including expert testimony at the August 15 hearing (held by PUCT and attended by members of the Texas Railroad Commission and Texas Commission on Environmental Quality) on the U.S. Environmental Protection Agency's proposed clean power rule (PUCT project 42636). Analysis and modeling of the Texas and U.S. gas market and electric power are being used by PUCT to build the State's response to EPA request for comments. Results also are being shared with the U.S. Energy Information Administration at a variety of levels, including the directorate. Papers and reports in progress include a full review of industrial demand; electric-power model refinements and revisions; and papers on special topics including oil and gas production taxes, midstream issues and trends, and North American natural-gas markets.

Connection to Neutrality and Value to Texas

- We procured external funding to match more than half of the STARR EE budget in order to expand and extend research tools and outputs.
- We receive large and robust in-kind support from companies, research organizations, trade associations, and other external sources, ranging from access to information via meetings and data sharing to peer review and feedback. Interactions during the course of the biennium included two annual and two mid-year meetings to disseminate results and obtain feedback.
- Our work has identified capital investment of about $121 billion in industrial projects in Texas and the Gulf Coast region, which translates into economic benefits for the State and region well in excess of direct expenditures.
- The State's electric power sector benefits strongly from natural-gas production; supply growth and availability have helped, and are helping, to moderate power prices to Texas consumers and customers. The competitive power market in Texas is a magnet for inbound investment and supports the observed industrial expansion.

6. Project Title: Colonial Waterbird Rookery Island Geoenvironmental Mapping for Oil Spill Response

Overview and Goals of Project

Natural and dredged-material islands are utilized by many species of colonial waterbirds. Natural rookery islands are rare along the Texas coast, and where found, often suffer from erosion and habitat degradation. Presently, a detailed comprehensive inventory of rookery islands on the Texas coast doesn't exist. This study, requested by the Oil Spill Prevention and Response Division of the Texas General Land Office (GLO), will locate, characterize, and provide detailed baseline information for monitoring of Texas waterbird rookery habitat. The primary objective of this project will be to supply an integrated, GIS-based database that will enhance the ability of the Oil Spill Prevention and Response Program to locate environmentally sensitive rookery islands and identify those islands most susceptible to oil spill contamination. The database will form the basis for rookery island health monitoring. Data collected in future surveys will be compared to this data set to determine rates of shoreline change and identify islands subject to erosion and storm damage. Topographic information can be applied to predictive models to ascertain the effects of sea-level rise on colonial waterbird rookery islands. Status, trends, and future modeling studies are needed to ensure that GLO wetland restoration efforts are based on sound science. The project will be conducted in 2 phases. The first phase (Year 1) will cover the lower Texas coast; the second phase (Year 2) will cover the upper Texas coast. The database will focus on the following:

- Rookery island inventory
- Digital Elevation Model (DEM)
- Rookery island characterization

Coastal marshes are essential natural resources that are highly productive biologically and chemically and are part of an ecosystem on which a variety of flora and fauna depend. Mangroves, primarily the black mangrove (*Avicennia germinans*), are an increasingly abundant component of saltmarshes along the Texas Coastal Bend. Mangroves are sensitive to oil spills, receiving the highest environmental sensitivity index (ESI) rank of 10, which represents shorelines *most likely to be damaged* by oiling. Recent studies have shown that mangroves, considered an invasive species in some arenas, may provide improved resistance to sea-level rise and may be more resistant to erosion than saltmarsh cordgrass (*Spartina alterniflora*). Saltmarsh cordgrass is the preferred habitat of the blue crab, a significant food source for the whooping crane (*Grus americana*), which was placed on the endangered species list in 1967 and remains listed today.

This study, funded through the Coastal Management Program of the GLO, will provide a baseline from which to monitor the spread of mangroves in the Coastal Bend area. A previous wetland study (**White et al., 2006**) within the barrier system of the Coastal Bend found that 665 ha (1,643 acres) of mangroves in 1979 had expanded to 837 ha (2,068 acres) by 2004.

Reference

White, W. A., Tremblay, T. A., Waldinger, R. L., and Calnan, T. R., 2006, Status and trends of wetland and aquatic habitats on Texas barrier islands, Coastal Bend: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas General Land Office and National Oceanic and Atmospheric Administration, under GLO contract no. 05-041, 64 p.

Results and Findings

Results from Year 1 of the rookery study were compiled in an annual report that included a table with statistics for 53 colonial waterbird rookeries and figures illustrating rookery characteristics. Results for Year 1 of the mangrove study were presented at the 2014 Texas Bays and Estuaries Meeting (TBEM).

Year 2 of the study will map and characterize the lower Texas coast. Results of this study will address two critical issues: (1) baseline mapping for monitoring of mangrove habitat, and (2) establishment of methods and procedures to monitor mangrove habitat in a consistent and timely manner through the use of hyperspectral imaging. The results and findings of Year 2 will be presented at the 2015 TBEM and will be summarized in a *Southwestern Naturalist* article.

List of Publications and Presentations

- Annual report delivered to GLO Oil Spill Response Division on August 31, 2014
- GIS database for upper Texas coast compiled and in final stages of documentation
- Poster, “Multiplatform Mangrove Mapping in the Coastal Bend, Texas Gulf Coast,” discussing results of initial mapping of mangroves in the Texas Coastal Bend presented at 2014 TBEM

Connection to Neutrality and Value to Texas

The rookery island study will locate, characterize, and provide detailed baseline information for monitoring of Texas waterbird rookery habitat. This investigation will aid the Texas GLO Oil Spill Prevention and Response Program in locating environmentally sensitive rookery islands and identifying those islands most susceptible to oil spill contamination. Accurate and comprehensive information will contribute to effective oil spill response and help determine strategies for conservation and restoration of these essential habitats.

7. Project Title: Potential Economic Impacts of Environmental Flows for Central Texas Freshwater Mussels

Overview and Goals of Project

Texas water resources, already taxed by drought and population growth, could be further stressed by possible listings of endangered aquatic species. The U.S. Fish and Wildlife Service is considering several freshwater unionid mussel species for possible inclusion on the Federal list of endangered species. Of concern are potential economic impacts caused by reductions or reallocations of water for mussel habitats. This study estimated potential economic impacts of environmental flows for five freshwater unionid mussels in three Central Texas basins (Brazos, Colorado, and Guadalupe–San Antonio Rivers; **fig. 29**) that encompass 36% of Texas (~246,000 km^2). A water-availability model projected reductions in water supply to power, commercial and industrial, municipal, and agriculture sectors in response to possible environmental flows for mussels. Single-year economic impacts were calculated using publicly available data with and without water transfers.

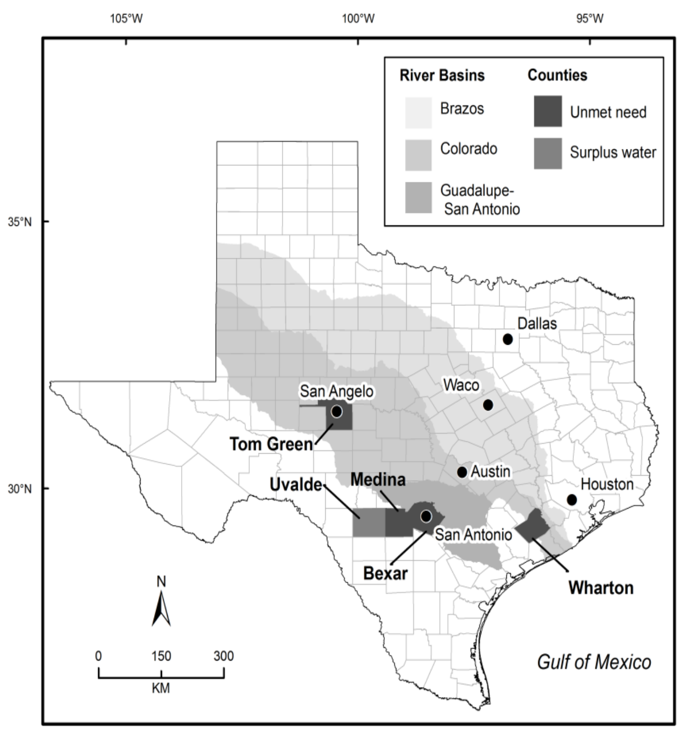

Figure 29. Freshwater mussels are found throughout Central Texas in the Brazos, Colorado, and Guadalupe-San Antonio River basins. Four counties have baseline water shortages that become more severe under environmental flow restrictions (dark gray polygons). Tom Green County includes the city of San Angelo, Wharton County is in an agricultural region, and Bexar County includes the city of San Antonio. Medina County, west of San Antonio, only has shortages during droughts and with high environmental flow requirements. Uvalde County (light gray polygons) has surplus agricultural water that may be used to mitigate impacts of environmental flows in Bexar County. The Brazos River basin is not substantially affected by possible environmental flows.

Results and Findings

- Potential economic losses resulting from a listing of Central Texas freshwater mussels were highest during droughts, but nominal (<$1 million) in wetter years—even with elevated environmental flows.
- During drought, three counties with pre-existing water issues would experience surface water shortages exacerbated by environmental flows for freshwater mussels.
- Reduced supplies to San Antonio-area power plants caused worst-case impacts of a single-year shutdown up to $107 million (M) during drought; however, potential losses to the power sector would be mitigated through operational best practices. For other sectors in the study area, water transfers reduced worst-case losses from $80M to $11M per year.
- Implementing innovative water management strategies such as water markets, conjunctive use of surface water and groundwater, aquifer storage and recovery could mitigate economic impacts if mussels—or other widely distributed aquatic species—were listed.
- This freshwater mussel study has been completed and results published. However, the Texas economy could benefit from future Texas endangered species research such as the following:
  - Defining strategies for mitigating economic impacts of environmental flows, while maintaining deliveries to power, commercial and industrial, municipal, and agricultural water users.
  - Estimating economic benefits of environmental flows for widely distributed aquatic species, such as gains to water supply and water quality, recreation, fisheries, and local economic development
  - Understanding the effects of dams (small and large) on stream fragmentation and how reservoir operation may need to be modified to provide habitat for the American eel, should it be listed

List of Publications and Presentations

Papers

Wolaver, B. D., Cook, C. E., Sunding, D. L., Hamilton, S. F., Scanlon, B. R., Young, M. H., Xu, X., and Reedy, R. C., 2013, Potential economic impacts of environmental flows following a possible listing of endangered Texas freshwater mussels: Journal of the American Water Resources Association, Paper [http://onlinelibrary.wiley.com/doi/10.1111/jawr.12171/abstract]. Supporting Information [http://onlinelibrary.wiley.com/doi/10.1111/jawr.12171/suppinfo].

Presentations

Hydrologic characterization of Texas freshwater mussel habitat: talk presented at 3rd Annual Texas Freshwater Mussel Symposium and Workshop, Kerrville, Texas, August 2014.

Water for Texas aquatic species: economics of environmental flows for freshwater mussels: poster presented at Austin Geological Society, Austin, Texas, May 2014.

Water for Texas aquatic species: economics of environmental flows for freshwater mussels: poster presented at BEG Industry Day, Austin, Texas, April 2014.

Potential economic impacts of environmental flows for aquatic species: invited talk presented at Tulane University, Dept. of Earth and Environmental Sciences, New Orleans, Louisiana, November 2013.

Potential economic impacts of environmental flows following a possible listing of endangered Texas freshwater mussels: talk presented at University of Texas at Austin Hydro Brown Bag, September 2013.

Connection to Neutrality and Value to Texas

This study calculates potential economic impacts of environmental flows for Central Texas freshwater mussels following a possible federal listing as endangered. Utilizing the water management strategies presented in this study would provide the State of Texas a value as great as $107M per year in avoided economic losses, should the mussels be federally listed. This study also was leveraged to acquire funding for the spot-tailed earless lizard ($233,531), plains spotted skunk ($102,579), and western chicken turtle ($46,922). An important goal of these ongoing studies is to generate the science needed to understand and mitigate potential effects of federal listings on energy and water resources so that the Texas economy continues to be robust and growing.

8. Project Title: STARR Water/Energy Nexus

Overview and Goals of Project

Texas energy resources require water to extract, and water requires energy for pumping and treating—these resources are inextricably linked. Though the rainfall during this reporting period is near normal, reservoir storage west of I-35 is significantly below normal and could remain so. At the same time, because high-intensity exploration of (unconventional) energy sources is not currently conveniently being conducted in wetter areas of Texas, smarter choices are needed in how water resources are quantified, used, treated after use, and predicted. We also need a wider understanding of different sources and quality of water (including brackish water), thereby helping stakeholders and industry decide how water use can be optimized. Finally, with substantial exploration activity in the Eagle Ford, and other endangered-species issues that could influence economic activity in the State, we have also assessed above-ground impacts from oil and gas operations, focusing first on La Salle County and then across the entire Eagle Ford play.

STARR funds were also used as a 1:1 match for two competitive grant proposals, one submitted and approved by the DOE RPSEA program, and the other submitted and approved by the DOE Office of Science (OS). The goal of the RPSEA grant is to understand the causes, extent, and severity of stray methane gas in the high-focus plays in Texas, including Barnett and Permian Basin. The goal of the OS grant is to understand the geomechanics and failure mechanisms of reservoir seals, which is the source rock being explored in unconventional plays. STARR funds have supported these scientifically focused tasks to improve our understanding of this complicated water/land/energy nexus.

Results and Findings

Water/Energy (**Scanlon et al., 2013, 2014**)

- Though focus is now on hydrocarbon liquids versus natural gas in the Eagle Ford, results showed that water used for hydraulic fracturing is half for oil versus gas based on production to date and more similar based on expected ultimate recovery (EUR).
- Hydraulic-fracturing water use, when compared in terms of water intensity per unit of energy (e.g., volume water/volume oil) is about 3.5 times higher based on production to date and 2 times higher based on EUR in the Eagle Ford Formation than estimated in the Bakken play. Oil production and geological setting explain the differences.
- Overall water use in Eagle Ford unconventional reservoirs (0.2–1.4 gal water/gal oil) is in the lower range of water use in conventional reservoirs (0.1–5 gal water/gal oil) across the United States. See **figs. 30, 31**.

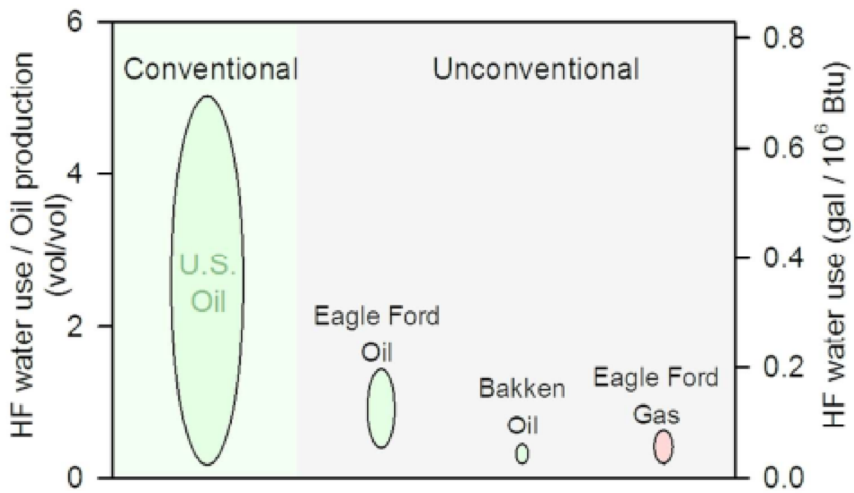

Figure 30. Eagle Ford water use.

Land/Energy (**Pierre et al., 2014**)

- Changes in land classification were based on pipeline and drill-pad locations from the start of recent Eagle Ford activity.
- Contiguous core landscapes (>2 km^2) were reduced in area by ~550 m^2. The majority of land disturbance comes from pipeline construction.
- Results suggest that reducing set-asides and coordinating field infrastructure could reduce land impacts, potentially reducing erosion and flooding risks.

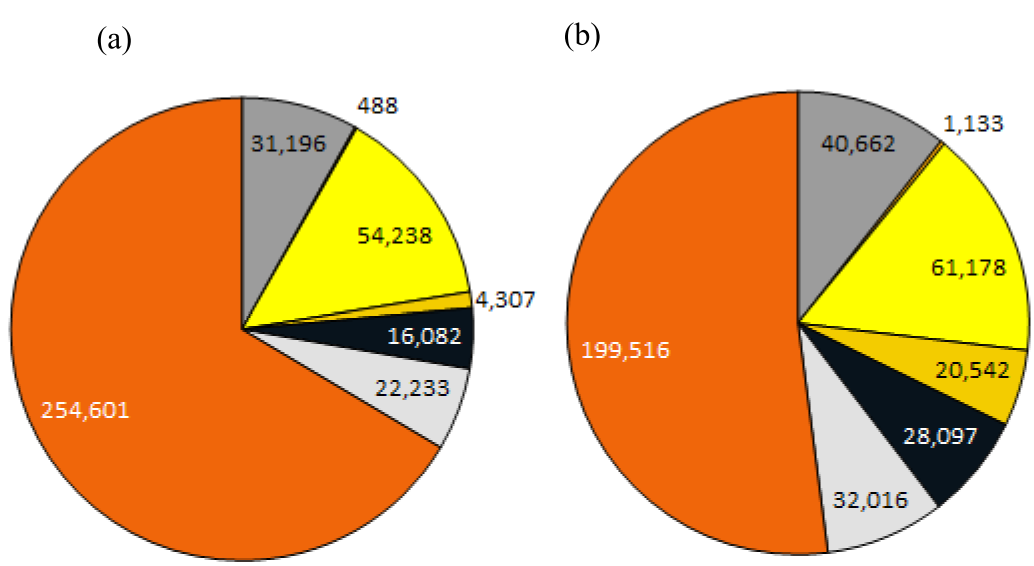

Figure 31. Change in area of landscape classes after 12 years of Eagle Ford (EF) development in La Salle County, Texas. (a) 2001 pre-EF conditions and (b) 2012 EF conditions Units are hectares (ha).

Water Resources

- The drought of 2011 has reduced flow to reservoirs and recharge to aquifers, mainly because of lack of soil-moisture data.
- Analyses have shown that soil-water loss in 2011, from natural evaporation and plant water use, explains 20–80% of all water lost to Texas during the drought.
- We show that monitoring soil-water status and storage can provide substantial levels of predictability for the reservoir stage; this in turn provides higher confidence in decisions for release volumes.

List of Publications and Presentations (partial list)

- Nicot, J. P., B. R. Scanlon, R. C. Reedy, and R. A. Costley (2014), Source and Fate of Hydraulic Fracturing Water in the Barnett Shale: A Historical Perspective, Environmental Science & Technology, 48(4), 2464-2471.
- Pierre, J. P., Abolt, C. J., and Young, M. H., 2014, Impacts from above-ground activities in the Eagle Ford Shale play on landscapes and hydrologic flows, La Salle County, Texas: Journal of Environmental Management, in preparation.
- Scanlon, B. R., Reedy, R. C., Duncan, I. J., Mullican, W. F., and Young, M. H., 2013, Controls and trends in the water footprint of thermoelectric generation: case study Texas, U.S.: Environmental Science and Technology, v. 47, p. 11326–11334, doi: 10.1021/es4029183.
- Scanlon, B. R., Reedy, R. C., and Nicot, J.-P., 2014, Comparison of water use for hydraulic fracturing for shale oil and gas production versus conventional oil: Environmental Science and Technology, v. 48, no. 20, p. 12386–12393, doi: 10.1021/es502506v.
- Scanlon, B. R., R. C. Reedy, and J.-P. Nicot (2014), Will water scarcity in semiarid regions limit hydraulic fracturing of shale plays?, Environmental Research Letters.
- Young, M. H., 2014, Seismic Experiences in Texas: presented at the IPAA 84th Midyear Meeting and Land Access and Environmental Issues Conference, Colorado Springs, Colorado.
- Young, M. H., Nicot, J.-P., and Scanlon, B. R., 2014, Experiences in Texas: Water, Land and Unconventional Fossil Energy Exploration: presented at the 79th North American Wildlife and Natural Resources Conference, Denver, Colorado.
- Young, M. H., Nicot, J.-P., Scanlon, B. R., and Pierre, J. P., 2014, Water/Land/Energy Nexus for Unconventional Energy in Texas: presented at the University of Minnesota Biosystems Engineering Seminar Series.
- Young, M. H., Nicot, J.-P., Scanlon, B. R., and Pierre, J. P., 2014, Water/Land/Energy Nexus for Unconventional Energy in Texas: presented at the Air and Waste Management Association Fall 2014 Symposium on Energy and the Environment: Progress and Possibilities, Austin, Texas.

Connection to Neutrality and Value to Texas

Funds have been used to match two external grants, both from the DOE and together totaling more than $2M. These grants seek to address issues crucial to Texas and its economy: What is the potential for stray methane to reach potable groundwater, and what are the mechanisms that impact the fracturing of rock seals overlying/underlying reservoirs? In addition, the funds have helped to increase understanding of the potential long-term impacts of above-ground activity on land-use change, which can lead to procedures that will maintain land productivity after exploration in the play is completed. Water-resource sustainability in Texas is one of the most important goals of the day, impacting nearly every facet of life in the State, from future industrial activity to energy exploration to maintaining the State's quality of life for current and future citizens.

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
Jackson School of Earth Sciences
The University of Texas at Austin
P. O. Box X, UT Station
Austin, Texas 78713

September 18, 2014

Dear Dr. Ambrose:

I would like to acknowledge the contributions made to our oil and gas exploration programs in both the Gulf Coast Region of Texas 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 projects:

1) Work in South Texas and on the San Marcos Arch (Dimmit, La Salle, McMullen, Karnes, Dewitt, Lavaca, and Fayette counties) has aided in our drilling Devon operated wells in Lavaca county and BHP/ Devon operated wells (in which we have an approximate half interest) in Dewitt county.
2) Work in East Texas Basin on the Woodbine has helped us understand our secondary recovery operations and drill wells in Leon, Houston, Madison, and Grimes counties.
3) Work in other parts of East Texas helped with our recent divesture to Linn Energy of acreage worth a total of $2.3 Billion in which significant portions were in South and East Texas in the Cretaceous and Cenozoic parts of the stratigraphic section.
4) Work on the Cline formation helped us drill better Devon operated wells and understand our positions in and around Sterling, Mitchell, Nolan, Fisher, Scurry and Haskell Counties.
5) Work on the Wolfcamp formation helped us drill Devon operated wells in and around Reagan, Crockett, and Irion counties.

The Bureau's studies, publications and presentations have provided an education and insight to many recent advances in petroleum exploration that has been successfully applied to our areas of interest. This demonstrates the STARR program's ability to turn academic studies into economic success.

Respectfully,
David C. Hull
Strategic Geologist
Devon Energy

COBRA
OIL & GAS CORPORATION
2201 Kell Blvd
Wichita Falls, TX 76308
940-716-5100 off.
Mailing Address - P. O. Box 8206
Wichita Falls, TX 76307

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

September 23, 2014

Dear Dr. Ambrose:

I would like to thank you for introducing Cobra Oil & Gas Corporation to the State of Texas Advanced Resource Recovery Project (STARR) at the Texas Bureau of Economic Geology. The research performed on the Cobra-Geer #1 Marble Falls core in Jack County, Texas, significantly impacted the exploration for this highly fractured and water productive formation in North Texas. Extensive geological discussions, based on the results from the Marble Falls STARR core study, led other independent companies to explore the formation and achieve the most economic recoveries of oil and gas. Without this research, the Marble Falls play may have never reached the maximum exploitation evident today in a minor sub-basin within the larger Fort Worth Basin. Companies the size of Cobra do not maintain the in-house staff and laboratories required to perform this type of research that the STARR Project provides for us. 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 Bureau's specific research based on the Cobra-Geer #1 core in the Marble Falls formation, has led to approximately 400 wells being drilled and completed in Jack County, Texas, alone during the past 4 years.

The funding for the STARR Project is vital to our industry and the state's economy.

Best regards,

Craig Reynolds
Exploration Manager
Cobra Oil & Gas Corporation

U.S.ENERCORP LTD.
EXPLORATION & PRODUCTION

William Ambrose
Project Director
STARR Program
Bureau of Economic Geology
The University of Texas at Austin
P. O. Box X
University Station
Austin, Texas 78713-8924

September 12, 2014

Dear Mr. Ambrose:

I would like to acknowledge the contributions made to our oil and gas exploration programs in the upper Cretaceous by research carried out by the State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology. The core and diagenesis research by the Bureau has contributed to our understanding of controls on reservoir quality and hydrocarbon accumulation in key areas in southwest Texas. We hope that the STARR program will continue to receive funding from the State of Texas. We and other independent companies do not have the benefit of major geologic research programs and therefore, results of the Bureau's research on various methods of exploitation and exploration has been very helpful in our efforts to discover additional reserves in in the state.

The Bureau's studies, publications and presentations have provided an education and insight to many recent advances in petroleum exploration that has been successfully applied to our areas of interest. The STARR program continues to help companies like us turn academic studies into economic success.

Respectfully,

Bruce Gates
U.S. Enercorp, Ltd.

8610 N. New Braunfels, Suite 405, San Antonio, TX 78217
P: 210-829-4888 F: 210-824-3950

ZONE
Energy

September 23, 2014

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

Dear Dr. Ambrose:

On behalf of Zone Energy, LLC, I want to thank you for the assistance and interaction that has occurred during the last several years between our staff and research associates of the STARR program. Through the information that has been shared and the open exchange and discussion of technically related concepts, we have greatly enhanced our understanding and ultimately the EUR of our ongoing water flood efforts in the East Texas field. Further, the relationships we have built as part of the program have "fast tracked" our efforts in other new venture areas that will result in additional investment in the near future. We see this ongoing interaction between the Bureau, STARR, and our organization as economically beneficial and one that we anticipate to continue going forward.

Respectfully,

Bill Hogenson
Vice President, Geosciences

Zone Energy, LLC 8 Greenway Plaza, Suite 800 Houston, TX 77046 713.877.9920 713.877.9921 Fax www.zone-energy.com

Arete Resources LLC.
1310 South 1st St. Ste 110
Austin, TX

October 2, 2014

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

Dear Dr. Ambrose:

I would like to thank you as well as the other STARR team for the contributions made to our Ochiltree County, Atokan 13 Fingers oil and gas exploration program.

The available data provided by the Bureau of Economic Geology on the EOG Ferguson #42-3 core, along with Gregory Frebourg's 2014 AAPG presentation on the 13 Fingers, provided valuable data that enabled us to better understand Atoka production trends and identify new prospective exploration areas.

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 Arete because the program provides access to data and technical expertise that would otherwise only available to larger companies.

I hope that the State of Texas will continue to provide funding to the STARR program so that small companies like Arete can remain competitive in the effort to discover new reserves in the State of Texas.

Sincerely,
Eric S. Rhoden
Principal/Geoscientist
Arete Resources, LLC.

STALKER ENERGY, L.P.

Mr. William Ambrose
Project Director
STARR Project
Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin
P. O. Box X, UT Station
Austin, Texas 78713-8924

November 15, 2012

Dear Mr. Ambrose:

I would like to acknowledge the contributions made to our oil and gas exploration programs in the Bend Arch - Fort Worth Basin by research carried out and published by the State of Texas Advanced Resource Recovery project (STARR) at the Bureau of Economic Geology. The research conducted by the Bureau has contributed significantly to our exploration efforts in several counties in the Bend Arch petroleum province. We hope that the STARR program will continue to receive funding from the State of Texas. Stalker Energy L.P. (Stalker), as well as many other smaller independent companies do not have the benefit of major geologic research programs and therefore, results of the Bureau's scientific research has been very helpful in our efforts to pursue and discover new reserves in Texas. This type of specific scientific assistance would otherwise be unavailable to small E&P companies which contribute significantly to the overall hydrocarbon production in the State of Texas.

The Bureau's studies, publications and presentations have provided an education and insight to many recent advances in petroleum exploration and development. These concepts and techniques are currently being applied in our areas of interest. This demonstrates the STARR program's ability to turn academic studies into economic success. Stalker is grateful for the STARR program and hopes it will continue to receive funding from the State of Texas.

Respectfully,

A. Dax McDavid
Geologist
Stalker Energy L.P.

1717 W. 6th Street, Suite 230
Austin Texas, 78703

BASA Resources Inc.
14875 Landmark, Suite 400
Dallas, Texas 75254
214-559-4200

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 7, 2012

Dear Dr. Ambrose:

I would like to acknowledge the contributions made to our oil and gas exploration programs in the Eliasville Field by research carried out and published by the State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology. The core and seismic research by the Bureau has contributed to our understanding of oil in Stephens County, Texas. We hope that the STARR program will continue to receive funding from the State of Texas. We and other independent companies do not have the benefit of major geologic research programs and therefore, results of the Bureau's research on various methods of exploitation and exploration has been very helpful in our efforts to discover additional reserves in Texas.

The Bureau's studies, publications and presentations have provided an education and insight to many recent advances in petroleum exploration that has been successfully applied to our areas of interest. The STARR program continues to help companies like BASA Resources turn academic studies into economic success.

Respectfully,

Jim Barton
Vice President of Geosciences
BASA Resources, Inc.

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

October 14, 2014

Dear Dr. Ambrose:

I would like to acknowledge the contributions made to our oil and gas exploration programs in the Camp Hill Field, Leon County, Texas and Carrizo formation in the Maverick 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 research by the Bureau has contributed to our continued exploration for medium and heavy oils in Leon County and the Maverick Basin. Boardman Energy Partners, LLC (BEP), and other smaller independent companies do not have the benefit of major geologic research programs and therefore, results of the Bureau's research on various methods of exploration has been very helpful in our efforts to pursue and discover new reserves in Texas. This type of specific scientific assistance would otherwise be unavailable to small E&P companies which contribute significantly to the overall hydrocarbon production in the State of Texas.

The Bureau's studies, publications and presentations have provided an education and insight to many recent advances in petroleum exploration that has been successfully applied to our areas of interest. This demonstrates the STARR program's ability to turn academic studies into economic success. BEP is very grateful for the STARR program and hopes and respectfully request that it continue to receive adequate funding from the State of Texas.

Respectfully,

Timothy A. Boardman
Managing Partner

APPENDIX B

Project STARR Awards

Distinguished Service Award: Tucker F. Hentz. Gulf Coast Association of Geological Societies, 2013.

Distinguished Fellow: Tucker F. Hentz. Geological Society of America, 2013.

A. L. Cox Best Poster Award: Reed Roush, H. Scott Hamlin, and Harry Rowe. Regional Stratigraphic and Core-Based Characterization of the Upper Pennsylvanian Cline Shale, Midland Basin and Eastern Shelf, Texas, AAPG Southwest Section Annual Conference, 2014.

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.

EMD (Energy Minerals Division of AAPG) Honorary Membership: William A. Ambrose. Presented at the 2014 Annual AAPG Convention, Houston, Texas, April 9, 2014.

APPENDIX C

One of the major goals of Project STARR is to disseminate results and new concepts developed by the program. During the last reporting biennium (2012–2014), STARR researchers generated a wide variety of articles, abstracts, presentations, and books.

ARTICLES

William A. Ambrose

Ambrose, W. A., Breton, C., Núñez-López, V., and Gülen, G., 2012, Geologic and economic criteria for siting clean-coal facilities in the Texas Gulf Coast, USA: Natural Resources Research, v. 21, no. 4, p. 461–481.

Ambrose, W. A., and Hentz, T. F., 2012, Shelf-edge deltaic depositional systems in the upper Woodbine succession, Double A Wells field, Polk County Texas: GCAGS Transactions, v. 62, p. 3–12.

Ambrose, W. A., Loucks, R. G., and Dutton, S. P., 2013, Depositional systems and controls on reservoir quality (determined from core data) in deeply buried Tertiary strata in the Texas-Louisiana Gulf of Mexico: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 278, 80 p.

Rattanaporn Fongngern

Fongngern, R., and Ambrose, W. A., 2012, Variability of sandstone architecture and bypass systems of the Miocene Oakville and lower Lagarto Formations in the Carancahua Bay area, Texas Gulf Coast: GCAGS Transactions, v. 62, p. 131–144.

Edmond Locke Frost III

Budd, D. A., Frost, E. L., Huntington, K. W., and Allwardt, P., 2013, Syndepositional deformation features in high-relief carbonate platforms: long-lived conduits for diagenetic fluids: Journal of Sedimentary Research, v. 83, no. 1, p. 12–36.

Frost, E. L., Budd, D. A., and Kerans, C., 2012, Syndepositional deformation in a high-relief carbonate platform and its effect on early fluid flow as revealed by dolomite patterns: Journal of Sedimentary Research, v. 82, no. 11, p. 913–932.

Frost, E. L., Budd, D. A., Kerans, C., Huntington, K. W., and Allwardt, T., 2012, Syndepositional deformation and its effect on fluid-flow though reflux dolomitization, burial, and exhumation, *in* Kerans, C., and Bellian, J. A., eds., Digital geospatial context for 3-D source-to-sink models: new insights into the classic shelf to basin system of the Guadalupe and Delaware Mountains: Proceedings, SEPM Research Conference, Carlsbad, New Mexico, p. 101–108.

Kerans, C., Bellian, J. A., Playton, T. E., Harman, C. A., Rush, J., and Frost, E. L., 2012, 3-D sequence framework of Leonardian to Guadalupian shelf-to-basin successions of the Guadalupe Mountains, *in* Kerans, C., and Bellian, J. A., eds., Digital geospatial context for 3-D source-to-sink models: new insights into the classic shelf to basin system of the Guadalupe and Delaware Mountains: Proceedings, SEPM Research Conference, Carlsbad, New Mexico, p. 45–58.

Qilong Fu

Browning, J., Tinker, S. W., Ikonnikova, S., Gülen, G., Potter, E., Fu, Q., Horvath, S. C., Patzek, T., Male, F., Fisher, W. L., Roberts, C., and Medlock, K., 2013, Barnett study determines full-field reserves, production forecast: Oil and Gas Journal, v. 111, no. 11, p. 88–95.

Scott Hamlin

Hamlin, H. S., and Baumgardner, R. W., Jr., 2012, Wolfberry (Wolfcampian-Leonardian) deep-water depositional systems in the Midland Basin: stratigraphy, lithofacies, reservoirs, and source rocks: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 277, 62 p. + 4 pls. in pocket.

Hamlin, H. S., and Baumgardner, R. W., Jr., 2012, Wolfberry play, Midland Basin, West Texas: AAPG Search and Discovery Article No. 10419.

Ursula Hammes

Hammes, U., Hamlin, H. S., and Ewing, T. E., 2013, Geologic analysis of the Upper Jurassic Haynesville Shale in east Texas and west Louisiana: Reply: AAPG Bulletin, v. 97, no. 3, p. 529.

Robert G. Loucks

Loucks, R. G., and Hull, D. C., 2012, Depositional significance of siliciclastic component of the Lower Cretaceous Pearsall Cow Creek Limestone Member in the western Maverick Basin, South Texas: GCAGS Transactions, v. 62, p. 253–264.

Loucks, R. G., Lucia, F. J., and Waite, L., 2013, Origin and description of the micropore network within the Lower Cretaceous Stuart City Trend tight-gas limestone reservoir in Pawnee Field in South Texas, GCAGS Journal, v. 2, p. 29–41.

Lucia, F. J., and Loucks, R. G., 2013, Micropores in carbonate mud: Early development and petrophysics: GCAGS Journal, v. 2, p. 1–10.

Osareni Ogiesoba

Ogiesoba, O. C., and Eastwood, R., 2013, Seismic multiattribute analysis for shale gas/oil within the Austin Chalk and Eagle Ford Shale in a submarine volcanic terrain, Maverick Basin, South Texas: Interpretation, v. 1, no. 2, doi: 10.1190/INT-2013-0019.1.

Ogiesoba, O. C., and Hammes, U., 2012, Seismic interpretation of mass-transport deposits within the upper Oligocene Frio Formation, south Texas Gulf Coast: AAPG Bulletin, v. 96, no. 5, p. 845–868.

Iulia Olariu

Olariu, M. I., Hammes, U., and Ambrose, W. A., 2013, Depositional architecture of growth-fault related wave-dominated shelf edge deltas of the Oligocene Frio Formation in Corpus Christi Bay, Texas: Marine and Petroleum Geology, v. 48, p. 423–440.

Olariu, M. I., Hammes, U., Ambrose, W. A., and Loucks, R. G., 2012, Facies variability of the Oligocene Frio Formation in growth-faulted compartments in Corpus Christi Bay, Texas: GCAGS Transactions, v. 62, p. 331–343.

Hongliu Zeng

Zeng, H., Zhu, X., and Zhu, R., 2013, New insights into seismic stratigraphy of shallow-water progradational sequences: Subseismic clinoforms: Interpretation, v. 1, no. 1, p. SA35–SA51.

Zeng, H., 2013, Frequency-dependent seismic-stratigraphic and facies interpretation: AAPG Bulletin, v. 97, no. 2, p. 201–221.

Tongwei Zhang

Zhang, T., Ellis, G. S., Ruppel, S. C., Milliken, K., and Yang, R., 2012, Effect of organic-matter type and thermal maturity on methane adsorption in shale-gas systems: Organic Geochemistry, v. 47, p. 120–131.

ABSTRACTS

William A. Ambrose

Ambrose, W. A., Loucks, R. G., Hooker, J., Frost, E. L., Reynolds, C., McDavid, A. D., Dawson, D., and Walker, B., Jr., 2013, Facies variability, fracture heterogeneity, and reservoir properties of the Marble Falls Limestone, Jack County Texas (abs.): AAPG Southwest Section Convention Program and Abstracts, unpaginated.

Robert W. Baumgardner, Jr.

Baumgardner, R. W., Jr., and Hamlin, H. S., 2013, Core-based geochemical study of mudrocks in basinal lithofacies in the Wolfberry Play, Midland Basin, Texas (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/baumg.htm.

Baumgardner, R. W., Jr., Hamlin, H. S., and Rowe, H. D., 2013, Geochemical and geomechanical study of basinal facies in the Wolfberry Play, Midland Basin, Texas (abs.): presented at the West Texas Geological Society Fall Symposium, Midland, Texas, September 25–27, p. 98–99.

Cortez, M., III, Baumgardner, R. W., Jr., Hamlin, H. S., and Rowe, H., 2012, Chemostratigraphy of the Pennsylvanian-Permian section of the Midland Basin of West Texas with focus on the Wolfcamp Series: developing a mudrock correlation and paleo-depositional framework (abs.): GCAGS Transactions, v. 62, p. 697.

Bruce L. Cutright

Andrews, J. R., Dunlap, D. B., Standen, A. R., Averett, A. R., Cutright, B. L., and Murphy, S., 2013, An immersive 3D presentation of Permian Basin geology: a web portal prototype for accessing online geologic data (abs.): presented at the West Texas Geological Society Fall Symposium, Midland, Texas, September 26.

Cutright, B. L., 2013, A new assessment of the extractable geothermal energy from deep sedimentary formations in Texas (abs.): Proceedings, GCAGS 63rd Annual Convention, October 6, 2013.

Zafar, D. S., and Cutright, B. L., 2013, Thermal energy in-place: a novel method for estimating accessible geothermal power with existing oil and gas wells using ArcGis®: presented at the Geological Society of America South-Central Meeting, April 5, Austin, Texas.

Rattanaporn Fongngern

Fongngern, R., and Ambrose, W. A., 2012, Sequence stratigraphy, sandstone architecture, and depositional systems of the lower Miocene succession in the Carancahua Bay area, Texas Gulf Coast (abs.): AAPG Annual Convention and Exhibition, Long Beach, California: http://www.searchanddiscovery.com/abstracts/html/2012/90142ace/abstracts/fong.htm.

Gregory Frébourg

Frébourg, G., Carr, D. L., Ambrose, W. Ruppel, S. C., Smith, A. N., and Rhoden, E. S., 2014, Sedimentary processes and depositional dynamics of the Atokan (Lower Pennsylvanian) 13 Fingers Formation in eastern Texas Panhandle, Anadarko Basin, Texas, USA (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/1841156.html.

Frébourg, G., Ruppel, S. C., and Loucks, R. G., 2013, Bottom current deposition and sediment reworking in the Boquillas/Eagle Ford Fm: Val Verde County, West Texas, USA (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/fre.htm.

Edmond Locke Frost III

Frost, E. L., 2013, Syndepositional fault and fracture controls on diagenetic fluid-flow, Tansill carbonates (Permian), Dark Canyon, Guadalupe Mountains, New Mexico (abs.): Abstracts of the Geological Society of America South-Central Section, 47th Annual Meeting, Austin, Texas, April 4–5.

Frost, E. L., 2014, New carbonate plays in the Mississippian Lime of the Bend Arch area, Texas (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/1841613.html.

Frost, E. L., Hunt, D., Simo, T., and Labrana, G., 2014, Variations in syndepositional fault properties as a function of stratigraphic position in high-relief carbonate platforms (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/1841613.html.

Qilong Fu

Fu, Q., Horvath, S. C., Potter, E., Roberts, F., Tinker, S. W., and Fisher, W. L., 2013, Sweet spot mapping of the Barnett Shale play, Fort Worth Basin, Texas (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/fu.htm.

Julia Gale

Gale, J. F. W., 2013, Quantifying natural fracture spatial organization: application in shales (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/g.htm.

Gale, J. F. W., Frohlich, C., Eichhubl, P., Olson, J., Fan, Z. Q., Gono, V., Horvath, S. C., Breton, C., and Davis, M. H., 2014, Relationships between induced seismicity and fluid injection: development of strategies to manage injection (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/ 1842062.html.

Tucker F. Hentz

Dokur, M., and Hentz, T. F., 2012, Reservoir characterization of the Upper Cretaceous Woodbine Group in Northeast East Texas Field, Texas (abs.): AAPG Southwest Section Convention Program and Abstracts, unpaginated.

Hentz, T. F., and Ambrose, W. A., 2012, High-resolution facies distribution, structural controls on sedimentation, and production trends of the Pennsylvanian Bend Conglomerate, Boonsville field, Fort Worth Basin, Texas (abs.): SIPES/DGS 2012 Dallas E & P Forum.

Hentz, T. F., and Ambrose, W. A., 2013, High-resolution facies distribution, structural controls on sedimentation, and production trends of the Pennsylvanian Bend Conglomerate, Boonsville field, Fort Worth Basin, Texas: (abs.): AAPG Southwest Section Convention Program and Abstracts, unpaginated.

Hentz, T. F., and Ambrose, W. A., 2013, Sandstone trends, sequence framework, and depositional settings of the Upper Cretaceous Woodbine Group: “Eaglebine” play, southern East Texas Basin (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/hent.htm.

Robert G. Loucks

Brown, A. A., and Loucks, R. G., 2013, Subsurface Seven Rivers (Guadalupian) anhydrite-dolomite transition, Eddy Co., New Mexico, USA: modification of a depositional facies change by Permian meteoric dissolution (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/brown.htm.

Hull, D. C., Phelps, R. M., Loucks, R. G., and Milliken, K. L., 2014, Sedimentological and geochemical record of oceanic anoxic events (OAE's) in the Aptian-Albian Pearsall Formation of South Texas (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/1842058.html.

Loucks, R. G., Frébourg, G., and Ruppel, S. C., 2014, Evidence of below storm-wave base, deeper water depositional setting for the Upper Cretaceous, Boquillas (Eagle Ford) carbonate dominated A-Member (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/1834257.html.

Loucks, R. G., Rowe, H. D., and Frébourg, G., 2014, Origin and analysis of the nano/micropore network in the Upper Cretaceous Ozan and Annona Chalks in the Caddo/Pine Island field in northwest Louisiana (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/1833330.html.

Loucks, R. G., Sullivan, P. A., Zahm, L., and Kerans, Charles, 2013, The other Lower Cretaceous carbonate shelf-margin trends in the Gulf of Mexico: Winn and Calvin Limestones (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/lou.htm.

Lucia, F. J., and Loucks, R. G., 2014, Transformation of depositional lime mud to microrhombic calcite (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/1834317.html.

Zahm, C., Loucks, R. G., and Kerans, C., 2014, Albian Sunniland Formation in southwest Florida and lower Glen Rose Formation in central Texas: spectrum of depositional facies (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/1841270.html.

Seay Nance

Nance, H. S., and Rowe, H., 2013, Chemostratigraphy of mudrocks: Bone Spring Formation, Delaware Basin, West Texas (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/na.htm.

Nance, H. S., Rowe, H., and Ruppel, S. C., 2013, Characterization of mudrock by integrating core description, XRF chemostratigraphy, organic matter pyrolysis, and isotope analysis (abs): presented at the American Association of Petroleum Geologists International Convention and Exhibition, Cartagena, Colombia, September 9.

Osareni Ogiesoba

Ogiesoba, O. C., Eastwood, R., Ambrose, W. A., and Hammes, U., 2013, Seismic inversion for shale gas/oil within the Austin Chalk and Eagle Ford Shale, Maverick Basin, South Texas (abs.): AAPG Annual Convention and Exhibition, Pittsburg, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/og.htm.

Iulia Olariu

Olariu, M. I., and Ambrose, W., 2014, Depositional trends in the Paleogene Lower Wilcox Guadalupe Delta, South Texas Gulf Coast (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/1840970.html.

Olariu, M. I., Hammes, U., Ambrose, W. A., and Ogiesoba, O. C., 2013, Growth-faulted compartments of the Oligocene Frio Formation in proximity of the shelf edge in Corpus Christi Bay, Texas (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/olar.htm.

Eric C. Potter

Browning, J., Ikonnikova, S., Gülen, G., Potter, E., Medlock, K., Male, F., Horvath, S. C., Patzek, T., Fu, Q., Roberts, F., and Tinker, S. W., 2012, Barnett Shale production model and economics (abs.): GCAGS Transactions, v. 62, p. 671–672.

analysis for “bottom up” shale gas production forecasting: Unconventional Resources Technology Conference Panel, Denver, Colorado.

Robert M. Reed

Reed, R. M., 2013, How common are naturally occurring microfractures in organic-rich mudrocks? Observations from samples prepared with Ar-ion cross-section polishing (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/ree.htm.

Reed, R. M., and Loucks, R. G., 2013, Scanning electron microscope observations of the nature of pore-containing organic matter in thermally mature mudrocks: Geological Society of America Abstracts with Programs, v. 45, no. 7, p. 242.

Reed, R. M., and Ruppel, S. C., 2012, Pore morphology and distribution in the Cretaceous Eagle Ford Shale, South Texas, USA (ext. abs.): GCAGS Transactions, v. 62, p. 599–604.

Reed Roush

Roush, R., Hamlin, H. S., and Rowe, H., 2014, Regional stratigraphic and core-based characterization of the Upper Pennsylvanian Cline Shale, Midland Basin and Eastern Shelf, Texas (abs.): AAPG Southwest Section Annual Convention, Midland, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90190sws/abstracts/rou.html.

Harry Rowe

Rowe, H., Mainali, P., and Ruppel, S. C., 2012, Some chemostratigraphic insights on the Haynesville-Bossier System (abs.): GCAGS Transactions, v. 62, p. 783.

Rowe, H., Ruppel, S. C., and Moran, L., 2013, A Cenomanian-Age deep continental shelf record of cyclical anoxia, Gulf of Mexico, South Texas (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/rowe.htm.

Hongliu Zeng

He, Y., and Zeng, H., 2013, Chronostratigraphy at the seismic scale: rethinking Vail et al.'s basic assumption (ext. abs.): 2013 SEG Technical Program Expanded Abstracts, p. 1456–1461.

Zeng, H., 2013, Shingled reservoirs without a shingled reflection pattern: origin and recognition (ext. abs.): 2013 SEG Technical Program Expanded Abstracts, p. 1379–1383.

Zeng, H., Ambrose, W., Yin, Z., He, Y., Xu, W., and Huang, P-H., 2014, Seismic sedimentology of incised valley, lowstand delta, and slope fan systems in the Eocene Wilcox Group, central south Texas coast (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/1840620.html.

Zeng, H., Xu, L., Wang, G., and Pu, X., 2013, Influence of tectonic geomorphology on sedimentary geomorphology: applied to prediction of ultrathin sandstones (ext. abs.): 2013 SEG Technical Program Expanded Abstracts, p. 1519–1523.

Jinyu Zhang

Zhang, J., and Ambrose, W. 2014, Tectonic-controlled stratal architecture and decameter-scale cycle variability of shelf-edge, growth faulted deltaic systems: a case study from the Frio Formation in Corpus Christi Bay, South Texas (abs.): AAPG Annual Convention and Exhibition, Houston, Texas: http://www.searchanddiscovery.com/abstracts/html/2014/90189ace/abstracts/1841323.html.

Zhang, J., Ambrose, W. A., and Olariu, M. I., 2013, Sequence-stratigraphic and depositional framework of wave-influenced deltaic systems in the Lower and Middle Frio Formation, Redfish Bay, Corpus Christi, Texas (abs.): AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania: http://www.searchanddiscovery.com/abstracts/html/2013/90163ace/abstracts/zhang3.htm.

Tongwei Zhang

Zhang, T., Ellis, G. S., Ruppel, S. C., Milliken, K., and Xun, S., 2013, Effect of organic matter properties, clay mineral type and thermal maturity on gas adsorption in organic-rich systems (ext. abs.): Unconventional Resources Technology Conference (URTeC), Denver, Colorado, no. 1583690.

PRESENTATIONS

William A. Ambrose

Shelf-edge deltaic depositional system in the upper Woodbine succession, Double A Wells field, Polk County Texas: presented at the 62nd GCAGS Conference, Austin, Texas, October 23, 2012.

Incised-valley and estuarine deposits in the Pennsylvanian Cleveland Formation, western Anadarko Basin: presented at Bureau of Economic Geology research seminar, Austin, Texas, January 11, 2013.

BEG clean-coal projects and prospects: presented to University of Queensland, Australian Delegation, Austin, Texas, February 11, 2013.

Facies variability, fracture heterogeneity, and reservoir properties of the Marble Falls Limestone, Jack County Texas: presented at the annual AAPG Southwest Section Convention, Fredericksburg, Texas, April 10, 2013.

Oil and gas fields in Texas: new life from old plays, new frontiers: presented at the 2013 annual TCEQ Environmental Trade Fair and Conference, Austin, Texas, May 1, 2013.

The future of clean coal in Texas: presented at Highland Lakes Energy Group, Marble Falls, Texas, August 2, 2013.

Woodbine depositional systems and oil-recovery potential in East Texas field: presented at Core Workshop: Sequence stratigraphy, depositional systems, and facies complexity in the Woodbine Group in East Texas field: Bureau of Economic Geology, Austin, Texas, May 19, 2014.

Reservoir architecture and geologic controls on CO_2-EOR: presented at Workshop: Technical and business risks associated with carbon capture, utilization and storage (CCUS) and expanding CO_2-EOR in Texas and beyond: Bureau of Economic Geology and Center for Energy Economics, Houston, Texas, August 8, 2014.

Bruce Cutright

The renewable energy resource assessment; geothermal energy from co-produced fluids: presented to the Gulf Coast Regulatory and Environmental Affairs Association, Houston, Texas, September 13, 2012.

Renewable energy from the petroleum industry; leveraging 150 years of capital investment from the petroleum industry to produce renewable geothermal energy: presented to the Hill Country Geoscientists, Kerrville, Texas, September 17, 2012.

An assessment of the geothermal energy potential of the Southwest Texas area: presented to Statoil, Austin, Texas, April 18, 2013.

Rattanaporn Fongngern

Variability of sandstone architecture and bypass systems of the Miocene Oakville and Lower Lagarto Formations in the Carancahua Bay Area, Texas Gulf Coast: presented at the 62nd GCAGS Conference, Austin, Texas, October 23, 2012.

Gregory Frébourg

Sedimentary processes and depositional dynamics of the Atokan (Lower Pennsylvanian) 13 Fingers Formation in eastern Texas Panhandle, Anadarko Basin, Texas, USA: presented at the AAPG Annual Convention and Exhibition, Houston, Texas, April, 2014.

Edmond Locke Frost III

New carbonate plays in the Mississippian Lime of the Bend Arch Area, Texas: presented at the AAPG Annual Convention and Exhibition, Houston, Texas, April 2014.

Variations in syndepositional fault properties as a function of stratigraphic position in high-relief carbonate platforms: presented at the AAPG Annual Convention and Exhibition, Houston, Texas, April 2014.

Julia Gale

Quantifying natural fracture spatial organization: application in shale: presented at the AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 2013.

Qilong Fu

Sweet spot mapping of the Barnett Shale Play, Fort Worth Basin, Texas: presented at the AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 2013.

Scott Hamlin

Wolfberry oil play of West Texas: presented at Real Estate, Oil and Gas Conference, San Antonio, Texas, February 2013.

Wolfberry (Wolfcampian-Leonardian) deep-water depositional systems in the Midland Basin: stratigraphy, lithofacies, reservoirs, and source rocks: presented to Permian Basin Section SEPM, Midland, Texas, March 2013.

Wolfberry (Wolfcampian-Leonardian) deep-water depositional systems in the Midland Basin: stratigraphy, lithofacies, reservoirs, and source rocks: presented at the Bureau of Economic Geology Research Symposium, Austin, Texas, September 2013.

Tucker F. Hentz

Regional Lower Atoka (Bend Conglomerate) log correlations, depositional trends, and core expression: Fort Worth Basin, north Texas: presented to Vantage Energy LLC, Austin, Texas, October 6, 2012.

Woodbine reservoir facies of East Texas field and the "Eaglebine" area, East Texas Basin: presented to Zone Energy, Austin, Texas, October 30, 2012.

High-resolution facies distribution, structural controls on sedimentation, and production trends of the Pennsylvanian Bend Conglomerate, Boonsville field, Fort Worth Basin, Texas: invited paper presented to the 2012 Dallas E & P Forum, Farmer's Branch, Texas, November 1, 2012.

High-resolution facies distribution, structural controls on sedimentation, and production trends of the Pennsylvanian Bend Conglomerate, Boonsville field, Fort Worth Basin, Texas: presented to the Southwest Section AAPG annual convention, Fredericksburg, Texas, April 10, 2013.

Regional Woodbine facies tracts, central East Texas Basin to Edwards shelf edge: correlation challenges and effects of base-of-Austin Chalk unconformity: presented to Apache Corporation, Austin, Texas, April 17, 2013.

Depositional settings of the Upper Cretaceous Woodbine Group: "Eaglebine" play, southern East Texas Basin: presented to Society of Independent Professional Earth Scientists (SIPES), Austin Chapter, Austin, Texas, October 3, 2013.

Regional sequence stratigraphic model of the Woodbine Group and East Texas field: presented at Core Workshop: Sequence stratigraphy, depositional systems, and facies complexity in the Woodbine Group in East Texas field: Bureau of Economic Geology, Austin, Texas, May 19, 2014.

Robert G. Loucks

The other Lower Cretaceous carbonate shelf-margin trends in the Gulf of Mexico: Winn and Calvin Limestones: presented at the AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 2013.

Distinguishing organic matter pores associated with in-place organic matter versus migrated organic matter in mudrocks: presented at EMD/AAPG Unconventional Research Group Meeting, Houston, Texas, April 8, 2014.

How modern karst studies lead to understanding the development and burial evolution of paleokarst reservoirs: presented at Karst Water Institute Award Banquet, Houston, Texas, March 1, 2014.

Petrographic controls on reservoir quality in East Texas field, Upper Cretaceous Woodbine Sandstone: presented at Core Workshop: Sequence stratigraphy, depositional systems, and facies complexity in the Woodbine Group in East Texas field, Bureau of Economic Geology, Austin, Texas, May 19, 2014.

Seay Nance

Chemostratigraphy of mudrocks: Bone Spring Formation, Delaware Basin, West Texas: presented at the AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 2013.

Osareni Ogiesoba

Seismic inversion for shale gas/oil within the Austin Chalk and Eagle Ford Shale, Maverick Basin, South Texas: presented at the AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 2013.

Iulia Olariu

Growth-faulted compartments of the Oligocene Frio Formation in proximity of the shelf edge in Corpus Christi Bay, Texas: presented at the AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 2013.

Depositional trends in the Paleogene Lower Wilcox Guadalupe Delta, South Texas Gulf Coast: presented at the AAPG Annual Convention and Exhibition, Houston, Texas, April 2014.

Eric C. Potter

East Texas oil field, history and basics: presented at Core Workshop: Sequence stratigraphy, depositional systems, and facies complexity in the Woodbine Group in East Texas field: Bureau of Economic Geology, Austin, Texas, May 19, 2014.

Robert M. Reed

How common are naturally occurring microfractures in organic-rich mudrocks? Observations from samples prepared with Ar-ion cross-section polishing: presented at the AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 2013.

Reed Roush

Regional stratigraphic and core-based characterization of the upper Pennsylvanian Cline Shale, Midland Basin and Eastern Shelf, Texas: presented at the AAPG Southwest Section Annual Convention, Midland, Texas, May 2014.

Harry Rowe

A Cenomanian-Age deep continental shelf record of cyclical anoxia, Gulf of Mexico, South Texas: presented at the AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 2013.

Hongliu Zeng

Seismic sedimentology of incised valley, lowstand delta, and slope fan systems in the Eocene Wilcox Group, central south Texas coast: presented at the AAPG Annual Convention and Exhibition, Houston, Texas, April 2014.

Jinyu Zhang

Sequence-stratigraphic and depositional framework of wave-influenced deltaic systems in the Lower and Middle Frio Formation, Redfish Bay, Corpus Christi, Texas: presented at the AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 2013.

Tectonic-controlled stratal architecture and decameter-scale cycle variability of shelf-edge, growth faulted deltaic systems: a case study from the Frio Formation in Corpus Christi Bay, South Texas: presented at the AAPG Annual Convention and Exhibition, Houston, Texas, April 2014.

Tongwei Zhang

Geochemical controls on gas adsorption and preservation in organic-rich shale systems: Theme 1: Unconventionals II (EMD/AAPG) poster presented at the AAPG Annual Convention, Pittsburgh, Pennsylvania, May 2013.

BOOKS

William A. Ambrose

Ambrose, W. A., Loucks, R. G., and Dutton, S. P., 2013, Depositional systems and controls on reservoir quality (determined from core data) in deeply buried Tertiary strata in the Texas-Louisiana Gulf of Mexico: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 278, 80 p.

Tucker F. Hentz

Hentz, T. F., ed., 2012, Transactions: Gulf Coast Association of Geological Societies, v. 62, 665 p. + 68 p. front matter (CD-ROM).

APPENDIX D

Workshops and Guidebook Chapters

William A. Ambrose

Ambrose, W. A., Hentz, T. F., Loucks, R. G., Frébourg, G., and Potter, E. C., 2014, Sequence stratigraphy, depositional systems, and facies complexity in the Woodbine Group in East Texas field: Workshop No. SW0020, Bureau of Economic Geology, The University of Texas at Austin, variously paginated.

Scott Hamlin

Upper Pennsylvanian (Cline) cores from the Midland Basin: presented to Devon Energy, Austin, Texas, December 2013.