Annual Report 1999

Bureau of Economic Geology

W. L. Fisher, Director ad interim

The University of Texas at Austin

Austin, Texas 78713-8924

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Foreword

The Bureau of Economic Geology, established in 1909 as the successor to the Texas Geological Survey and the Texas Mineral Survey, is a research unit of The University of Texas at Austin. It also functions as the State Geological Survey, the Bureau Director representing Texas in the Association of American State Geologists.

Extensive advisory, technical, and informational services relating to the resources and geology of Texas are provided by the Bureau. In addition, the Bureau conducts basic and applied research projects in energy resources, mineral resources and statistics, coastal and environmental studies, land resources, geologic mapping, and a variety of other research programs in areas such as hydrogeology, basin analysis, and geochemistry. Some projects are conducted jointly with other units of the University, as well as with industry and with State, Federal, and local agencies.

The Bureau provides ongoing services to governmental agencies, including reviews of (1) environmental impact statements that are submitted to the Office of the Governor of Texas and (2) permit applications that are submitted to the Surface Mining and Reclamation Division of the Railroad Commission of Texas.

Major reports of the Bureau are published in The University of Texas Publication series; its own series include Reports of Investigations, Geologic Quadrangle Maps, Geologic Atlas Sheets, Environmental Geologic Atlases, Guidebooks, Handbooks, Geological Circulars, Mineral Resource Circulars, and other publications. Publications are sold for a nominal price to recover printing costs. A complete list of publications is available on request.

The Annual Report of the Bureau of Economic Geology outlines the scope and status of current research projects, publications, personnel activities, and services in the area of Texas resources and geology that are available to governmental agencies, industry, and the public.

Cover: Sponsors of Bureau research compiled from records beginning in 1970. The Bureau is grateful for the support provided by these organizations through the years. For a copy of this list, see p. ii.

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ANNUAL REPORT 1999

BUREAU OF ECONOMIC GEOLOGY

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* This list was compiled from records beginning in 1970. We have tried to include as many names as possible. Organizations that underwent name changes may not be included under previous names.

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OVERVIEW

Program Support

In 1999, the Bureau of Economic Geology conducted 91 research projects under an operating budget of $14.5 million (in Federal equivalents) from contracts and grants and line-item State appropriations. Forty-two of these projects were from interagency contracts with State and local governments and 24 from various agencies of the Federal government. Twenty-five contracts were with industry and private institutions. Selected projects are described below.

Industrial Associates Energy Resource Investigations

Development of innovative geologic concepts and strategies for oil and gas exploration and development is the primary emphasis of Bureau energy resource investigations that are supported by industrial consortia. As in previous years, the central theme of 1999's research efforts by the Reservoir Characterization Research Laboratory (RCRL) for carbonate studies was the integration of detailed outcrop-analog studies of major reservoir types with subsurface reservoir studies. The outcrop is the current primary focus of worldwide reservoir- and field-scale analog studies because it provides the only opportunity available to accurately characterize the interwell environment. In addition to its multiyear studies in Permian and Cretaceous carbonates in Texas, New Mexico, and the Middle East, the RCRL initiated a new study of exposed Pennsylvanian carbonate-platform strata flanking the Pedregosa Basin, southwest New Mexico. This data set will be used as an analog for fields in the Permian Basin, such as the Horseshoe Atoll, and the giant fields in the North Caspian Basin. The Applied Geodynamics Laboratory's (AGL) well-established, ongoing program of tectonic modeling is now complemented by a new seismic-based program. Using 2-D and 3-D seismic data, supplemented by well and potential-field data, AGL researchers are investigating salt tectonics along the Angolan margin, West Africa, by examining clearly imaged structural systems to help resolve poorly imaged subsalt structures in the Gulf of Mexico. The Exploration Geophysics Laboratory continued its intensive efforts to develop cutting-edge technologies, particularly of multicomponent data-processing and imaging technologies, that will image reservoirs using all components of the seismic wavefield. Researchers of the Bureau's Fracture Imaging Laboratory (FIL) are striving to understand and successfully characterize, predict, and simulate reservoir-scale structures by means of electron microscope–based imaging devices, quantitative descriptions of how structures of differing scales are related, and innovative geomechanical modeling techniques. The focus of the FIL is on fractures and faults that influence the successful extraction of hydrocarbon resources. The capabilities of the FIL were significantly enhanced in 1999 through the addition of a powerful new scanning electron microscope, elemental mapping tools, and a new highly sensitive cathodoluminescence detector. Testing and perfecting this equipment and associated methodologies using data from commercial wells in active oil and gas plays are key elements of the FIL's research. Several successful tests of new methods were carried out in 1999.

Domestic Energy Resource Investigations

Bureau investigations of domestic siliciclastic and carbonate oil reservoirs continued to stress advanced geological, geophysical, and engineering research approaches to optimize hydrocarbon-recovery strategies. The Offshore Secondary Gas Recovery project, funded by the U.S. Department of Energy (DOE), is identifying additional natural gas re-

sources in a 10,000-ft-thick Miocene section in two adjacent major mature fields (Tiger Shoal and Vermilion Block 50) in the Federal offshore northern Gulf of Mexico through multidisciplinary field- and reservoir-characterization studies. Using a full array of geologic and geophysical data, including total 3-D seismic coverage, the project will ultimately identify new prospects and development opportunities and identify new methodologies to aid in the future search for reserves in mature fields. In another DOE-funded project, Bureau scientists are developing improved engineering and geological methods for characterizing carbonate reservoirs for input into fluid-flow simulators to predict reservoir performance. The project is focused on investigations of excellent Clear Fork outcrops in the Sierra Diablo Mountains, West Texas, and is applying rock-fabric and natural-fracture analyses to the South Wasson Clear Fork reservoir, a major Clear Fork reservoir in the Permian Basin. In an effort to clarify extensional tectonic processes in diverse geologic provinces, researchers are numerically modeling the uniquely well constrained fault system of The Grabens area of Canyonlands National Park, Utah, to enhance understanding of brittle-rock stretching above a ductile layer. The Grabens area records the interaction of propagating extensional faults that are still slipping today above a layer of flowing salt.

Improving recovery from Texas hydrocarbon reservoirs is the objective of three Bureau projects. Now in its third year, the University Lands Advanced Recovery Initiative, which is funded by The University of Texas System and by matching funds from field operators, strives to develop new approaches to the characterization and exploitation of University Lands oil reservoirs in West Texas. During 1999, two reservoir studies of University Block 9 field in Andrews County and one study of the North McElroy Grayburg Unit in Crane County were completed. In 1999, the State of Texas Advanced Oil and Gas Resource Recovery Initiative (Project STARR), with funding from the State of Texas and support from the General Land Office and the Railroad Commission of Texas, continued to identify plays with the best prospects for increased production on extensive acreage owned by the State of Texas. With the support of allied producers, 42 infill wells and 29 recompletions have been drilled, and on the basis of STARR recommendations, 5 fields have added to their total oil and gas reserves. In two fields alone, 8.9 Bcf of gas and 1.9 MMbbl of oil reserves have been added. In a multiyear study of deep-water turbidite sandstone reservoirs funded by DOE, Bureau researchers provided details of the reservoir architecture of two representative fields of the Delaware Mountain Group of West Texas to define cost-effective ways to recover a higher percentage of the original oil in place.

A continuing effort by Bureau researchers to understand and successfully characterize, predict, and simulate reservoir-scale fractures in siliciclastic and carbonate reservoirs composes several projects, one of which is the previously discussed FIL industrial consortium program. Because fractures and many faults are below the limits of seismic resolution and are difficult to characterize adequately using currently available technology, their accurate detection and characterization pose serious challenges for effective reservoir exploration and development. These projects, funded by State and Federal sources, are focused on several issues, such as the relation of fracture characteristics to bedding architecture and fluid flow, the use of geomechanical modeling to improve prediction of fracture attributes in the interwell region, and the relation of microfracture attributes to those of genetically related macrofractures in the same reservoir.

International Energy Resource Investigations

In 1999, the Bureau's international program involved six reservoir-characterization and basin-analysis projects in Austria, Mexico, and Venezuela. The Bureau worked on behalf of OMV Aktiengesellschaft of Austria to help define the remaining unrecovered oil

and gas resource in Matzen field, Vienna Basin, the largest oil and gas field in Central Europe. The project was completed in 1999, and as a result of the findings and specific recommendations made by the research team, OMV has seen tangible improvements in reservoir production. Moreover, OMV reservoir engineers now have a clearer understanding of long-standing anomalous reservoir behavior because of the Bureau research. Maps developed by this study are expected to be the primary guide to reservoir development through the remainder of the life of this giant oil field.

Bureau staff collaborated with The Scotia Group, Inc., to provide technical support for Pemex's exploration and field production optimization projects in the Burgos Basin, Mexico.

Identification and mapping of remaining oil and the development of reservoir-management strategies for more efficient recovery were the primary objectives of four Bureau investigations in Venezuela in 1999. In a new 1999 project funded by Petróleos de Venezuela, S.A., Bureau researchers are using integrated reservoir-characterization techniques to examine reservoirs in pre-Cretaceous basement rocks, Cretaceous carbonates, and Paleocene and Eocene sandstones in the Mara Este (Mara Liviano) field in the Maracaibo Basin, western Venezuela, to identify field-development opportunities in this mature, giant field. Production-optimization projects are also examining Eocene sandstone reservoirs in the Mioceno Norte area of Lake Maracaibo, Venezuela; the Oligocene and Eocene Roblecito and La Pascua reservoirs in the East Guarico Unit, eastern Venezuela, in conjunction with Teikoku Oil de Venezuela; and Oligocene and Miocene strata of the 13/10 area of the Sanvi-Guere Unit in eastern Venezuela.

Hydrogeologic and Environmental Investigations

The Bureau's hydrogeologic and environmental efforts in 1999 addressed a diverse array of domestic and international geoenvironmental research topics, such as the study of regional riparian ecosystems, ground-water management, toxic near-surface contaminants, subsurface waste containment, CO_2 sequestration, and deltaic environmental geology. Using high-resolution videography and multispectral satellite data, Bureau researchers are conducting a multidisciplinary study to delineate the spatial extent of the riparian community in the lower reach of the Rio Grande from Falcon Dam to the mouth of the river. The rapid decline of riparian ecosystems throughout the United States has made riparian conservation a focal issue for the public, Federal and State governments, and private organizations. A major objective of this new 2-year multi-institutional project is to develop a foundation for future analysis of riparian floodplain communities by linking local and remotely sensed regional data using a geographic information system (GIS). In another cooperative project, Bureau researchers and staff from the Texas Water Development Board are applying advanced airborne and ground-based geophysical methods to rapidly and cost-effectively assist South Texas communities in locating new aquifers and assessing the water quality of potential resources. The Rio Grande Water Planning Region, consisting of eight South Texas counties, is subject to severe water shortages during droughts and urgently needs new, shallow ground-water resources to assure adequate water supplies for municipal, agricultural, and industrial uses.

The monitoring of waste-containment sites has become a major national geoenvironmental effort in recent years. The use of noninvasive monitoring techniques has increased rapidly because of the potential risks of destroying the integrity of disposal systems by installing dedicated instruments. Bureau scientists are developing a system based on electromagnetic induction capable of monitoring temporal variability in water content over large areas and of locating zones of high water content that could indicate focused flow into, or leakage out of, disposal cells. The design of effective and reliable engineered covers for waste-

disposal facilities is also receiving much national attention. A proposed low-level radioactive waste disposal facility in the Chihuahuan Desert of West Texas that is no longer being considered for waste disposal is being used as a research facility by Bureau scientists who are developing long-term sets of field data that can be used to verify and validate numerical simulations and to develop a better understanding of the performance of covers in arid environments. Simulations will be used to predict water movement and percolation through the cover under a variety of conditions, including potential future climate scenarios. Results from this study should provide valuable information to waste operators and State and Federal regulatory officials about the monitoring and modeling of cost-effective engineered cover designs for waste containment in arid regions.

Two Bureau projects are evaluating the suitability of hydrocarbon reservoirs that are nearing their apparent economic limit and saline aquifers for sequestering the greenhouse gas, CO_2. Funded by the Electric Power Research Institute, a preliminary Bureau investigation evaluated the suitability of Texas reservoirs for sequestering CO_2 produced by nearby major power plants. Saline aquifers are also recognized as having high potential for long-term sequestration of greenhouse gases, particularly CO_2. However, the same properties that make saline aquifers desirable for sequestration—isolation from the surface and minimal use as a resource—also make them poorly characterized. A Bureau study funded by the DOE is compiling information on geologic properties that affect the usefulness of saline aquifers for CO_2 sequestration for 21 saline formations in the continental United States.

Now in its second year, the Orinoco Delta project, funded by Petróleos de Venezuela, S.A., under the direction of the Coordinación del Desarrollo Armónico de Oriente, continues to describe the active geologic processes, the geologic framework, and the land cover of the fragile and nearly pristine environment of the Orinoco Delta in eastern Venezuela, all part of an effort by Venezuela to encourage responsible development of this environmentally sensitive region. In 1999, after priority reassessment by the funding company, plans are under way to expand the project to focus on studies of biodiversity and physical and environmental controls on habitats and ecosystems of the delta.

Coastal Investigations

Nine projects, several of which are described below, composed the Bureau's coastal investigations program in 1999, which stressed historical trends in coastal shoreline change, wetland creation and preservation, and coastal processes and their influence on coastal management. Bureau coastal scientists are conducting a regional, comprehensive study to characterize and map different shoreline types that occur along the Gulf of Mexico, in the interior bays, and along the Gulf Intracoastal Waterway. The project is funded by the Texas General Land Office as part of the Oil Spill Response and Contingency Planning effort by the natural resource trustee agencies in Texas. Shorelines along the upper and central Texas coast have previously been classified and mapped by the Bureau according to their sensitivity to oil-spill damage. This project, which focuses on the lower coast along Padre Island, Laguna Madre, and Baffin Bay, will complete the shoreline mapping work for the Texas coast. Results of the study will be used by State and Federal agencies responsible for managing Gulf coastal resources. In a related project, the Texas Coastal Management Program is funding a 3-year, joint project involving the Bureau, the Texas Department of Public Safety, and Texas A&M University to develop a Coastal Hazards Atlas of the Galveston Bay and Sabine Lake areas. Inspired by the Bureau's 1974 atlas, *Natural Hazards of the Texas Coastal Zone*, researchers are compiling information on current transportation routes (needed for evacuation planning), hurricane flooding areas, the best available data on shoreline erosion, and new information on subsidence and faulting. Critical information needed by local and State government officials and others interested in coastal-

zone management will be emphasized in a new atlas that will be available on a CD-ROM.

As a result of the passage of Tropical Depression Josephine in October 1996 and Tropical Storm Frances in September 1998, the dunes and beaches along Galveston County, Texas, significantly eroded and put many structures at risk of failure. Using topographic transects of beach profiles and airborne laser terrain mapping (ALTM) surveys, researchers are documenting changes in beach and dune topography to provide base-line present conditions of the Galveston County beach and dune system along the coast to anticipate the effects of the next storm. This project is funded by the Texas Coastal Management Program and the National Aeronautics and Space Administration (NASA).

Barrier islands and spits, among the most dynamic elements of coastal systems, have become highly developed and continue to develop along much of the U.S. coast. This development has altered erosional and depositional patterns of shorelines, placing property and lives at risk from coastal storms, sea-level rise, and long-term erosion. To more fully understand the dynamic processes of coasts, a way to collect detailed and accurate topographic and bathymetric data is critical. Bureau scientists, with funding from NASA, are developing and applying the latest survey technologies, such as ALTM, to study 150 km of the southeast Texas coast. Findings are expected to provide coastal scientists critical guidance in predicting future shoreline change and storm hazards.

HIGHLIGHTS

Scott W. Tinker Appointed Director

Scott W. Tinker, formerly Advanced Senior Geologist at Marathon Oil in Littleton, Colorado, became the eighth Director of the Bureau of Economic Geology on January 26, 2000. He brings to the Bureau strong professional experience focused on managing multidisciplinary reservoir studies involving carbonate sedimentology, sequence stratigraphy, and interpretation of diverse data types. He has been a Distinguished Lecturer for the American Association of Petroleum Geologists and a winner of AAPG's prestigious J.C. "Cam" Sproule Memorial Award, as well as the recipient of many other academic and professional society awards. Tinker holds a Bachelor's degree in geology and business administration from Trinity University, a Master's degree in geology from the University of Michigan, and a Ph.D. in geology from the University of Colorado. Looking forward to serving as the new Director of the Bureau as we enter the new century, Tinker said the 21st century will be "the century of geology: a century that promises to see the positive impact that geologic understanding can bring to bear on issues as varied as climate, hydrology, energy, minerals, land use, and education."

Tinker succeeds Noel Tyler, the seventh Director, who stepped down in June 1999 to return to full-time research and subsequently resigned in January 2000 to pursue opportunities in the private sector. Tyler held the directorship for almost 5 years, during which he led the Bureau into the computer age and, through his foresight and innovative thinking, established the Bureau as a leader in reservoir characterization and visualization. At the request of University Administration, William L. Fisher, the sixth Bureau Director, served as Interim Director during the last half of 1999 and ensured that the period of transition between directors was one of financial stability and professional achievement, a lasting hallmark of both his administrations. When Tinker took over the responsibilities in January 2000, Fisher returned to his other duties of being Director of the Geology Foundation, the Leonidas T. Barrow Centennial Chair in Mineral Resources, and Professor in the Department of Geological Sciences at The University of Texas at Austin.

Altura Donates Geologic Collection to UT

Altura Energy LTD., a Houston-based oil company, has donated 70,000 boxes of geologic materials to The University of Texas at Austin.

The rock material, referred to as core samples, has been collected from oil and gas wells in the Permian Basin of West Texas over several decades. The rock samples were retrieved from depths of 3,000 to 17,000 ft below the earth's surface and will substantially increase the amount of subsurface data available for public study in the Permian Basin area.

Such samples can help scientists and engineers better understand the origins of sedimentary rock layers, the types of porosity or void space necessary for oil and gas reservoirs, and the mechanical properties of the rocks. The samples can provide geologic details through visual inspection, physical analysis and by comparison with other data such as well logs or rock exposures at ground level. This unique geologic collection could have wide interest with industry, government, and academic workers. Possible application could be for hydrogeologic studies, oil and gas development, and advanced geotechnology research.

"Altura and I recognize the importance of preserving these valuable data for future generations," said Bruce Cain, a geologist for Altura, who was instrumental in making the donation of the samples. "Through diligent efforts, we were able to secure a permanent home for the collection."

The Bureau will curate the collection at its Midland facility located at 5310A East Business Interstate 20. The samples will be available for viewing and study to students as well as the general public five days a week from 8 a.m. to 5 p.m.

Interested parties should contact the curator, Rick Richardson, at 915-686-9902 for more information.

Bureau Virtual-Reality Laboratory Enhanced by Donations from Shell Oil Company and Hillcrest Foundations

One of most important roles of the Bureau is distributing the results of our geologic research. In addition to technical publications and technology transfer aimed at geoscience professionals, the development of materials and projects to bring current and scientifically accurate Texas earth science information to K–12 educators and students is a traditional and expanding endeavor of the Bureau.

For teachers and students alike, one of the greatest challenges in geoscience education is visualizing the complex structure of the Earth. At the Bureau, new computer-driven technologies offer the ability to move the learning process beyond the barriers of difficult, abstract concepts through the creation of "virtual worlds."

In February 1999, supported in part by grants from Shell Oil Company Foundation and the Hillcrest Foundation, the Bureau opened the doors of a new large-screen virtual-reality laboratory for the EarthView Texas program. The facility, which is modeled on

the laboratories recently built by Texaco, Exxon, and ARCO for reservoir visualization, is used for educational projects, as well as supporting Bureau research. The virtual images are created by a specialized Silicon Graphics® computer that generates 3-D models and projects stereo images on a large screen. True stereoscopic vision—and the effect of virtual reality—is created for the viewer by LCD glasses that alternate discrete right- and left-eye views in synchrony. In its current configuration, the Virtual Imaging and Visualization Environment, or VIVE, is a 1,500-ft^2 multimode facility that serves as a collaborative work area and an immersive visualization theater.

During the year numerous "virtual" data sets were created to visualize various geoscience concepts. These 3-D models included the Edwards aquifer, Big Bend National Park, the Bolivar Peninsula near Galveston, and the Franklin Mountains surrounding El Paso. Students were able to navigate the subsurface structure of the Edwards aquifer, fly over a barrier island, look at the relationships between topography and geologic units in the Austin area, and take a virtual field trip to Big Bend National Park.

Teachers need instruction and support to use Texas-specific materials in the classroom. For one recent project the Bureau partnered with Southwest Texas Junior College to instruct middle school teachers in rural areas of Southwest Texas in how to extract information of local interest from maps, pamphlets, and the Internet. In particular, this geoscience information is used to understand critical water-resource issues of the area. To bring together research staff in Austin and teachers from widely separated schools, this course is conducted partly by videoconference, E-mail, and the Internet. Hands-on materials, manipulatives, VRML models, and E-mail exchanges are used to support inquiry and foster participant involvement during the videoconference. Field trips, labs, and presentations from resource people in the project area complement the distance learning. This project is supported by a Texas Higher Education Coordinating Board Dwight David Eisenhower Professional Development grant to Southwest Texas Junior College.

Awards and Honors

Stephen E. Laubach won the Jules Braunstein Memorial Award for Best Poster Presentation at the 1999 annual convention of the American Association of Petroleum Geologists for his presentation, "Natural Fracture Analysis using Drilled Sidewall Cores." He was also named an Outstanding Technical Editor by the Society of Petroleum Engineers Editorial Review Committee.

New Research Staff

Eugene M. Kim, who originally worked for the Bureau as a Graduate Research Assistant, has been hired as a Postdoctoral Fellow. His main research interests are reserve-growth studies, play analysis, resource assessment, production analysis, and economic evaluation. He holds a Bachelor's degree in mineral and petroleum engineering from Seoul National University and a Master's degree in energy and mineral resources and Doctorate in geological sciences, both from The University of Texas at Austin.

Staff Promotions

In 1999, the following staff members received promotions:

Jean L. Abernathy to Senior Administrative Associate, **Sigrid J. Clift** to Research Associate, **Dixon E. Coulbourn** to Senior Network Analyst, **L. Morgan Ives** to Senior Operating Systems Specialist, **Enrique Romo** to Administrative Associate, **Ronald L. Russell** to Manager of Computer Operations, and **Bridget R. Scanlon** to Senior Research Scientist.

In Memoriam

David M. Stephens

L. Edwin "Ed" Garner

1935–1999

The Bureau lost a good friend and remarkable resource on Texas geology when Ed Garner died September 3, 1999, at his home in Austin. Ed was born in Stephenville, Texas, on April 19, 1935, the son of Ruth and the late Howard Garner. He earned an Associate in Science degree from Tarleton State University in 1958 and then moved to Austin. It was there at The University of Texas at Austin that he was awarded Bachelor's and Master's degrees in geology and began his life-long career as a geologist.

Ed spent most of his professional life as a Research Associate at the Bureau of Economic Geology. His early work at the Bureau involved fundamental studies of oil and gas reservoirs. He and J. H. McGowen coauthored an early work on this subject, *Physiographic Features and Stratification Types of Coarse-Grained Point Bars: Modern and Ancient* (Bureau, 1975). He also developed a broad understanding of the state's mineral resources and in 1979 compiled the *Mineral Resources of Texas* map. He is perhaps best known for his 1976 Bureau report on the Austin area, coauthored by Keith Young, *Environmental Geology of the Austin Area: An Aid to Urban Planning,* which became an invaluable resource to builders and land developers in Austin.

Besides his many publications, Ed contributed to professional societies and led many field trips in the Austin area. His public service was fully realized in his role as Public Information Geologist at the Bureau. He not only fielded questions from geologists, lawmakers, students, and the general public but also visited schools and delighted children with his "rock concerts." Calling him "one of the best known geologists in the state," William L. Fisher, Bureau Director *ad interim*, whose friendship and professional association with Ed went back to the early 1960's, commented on the wide breadth of knowledge Ed willingly shared with the public: "Ed handled all kinds of inquiries, ranging from the most technical to questions from a school kid wanting information on a specimen collected in the back yard. He handled them all, usually off the top of his head. But if he didn't know the answer, he would track it down and get back to the person quickly. No matter how little mineral potential a piece of property had or how commonplace the rock or fossil specimen might be, Ed knew how to respond in a way that left people thanking him, usually profusely."

Ed left his friends, colleagues, and family all too soon and will be greatly missed. But he left a legacy of good humor, friendship, professionalism, and public service. He was devoted to his parents, his wife, Cheryl, with whom he shared 34 years, his sons, David, Mark, Kevin, and Christopher, and ten grandchildren and six great-grandchildren, as well as his extended family of geologists and interested citizens stretching across the state of Texas and beyond.

ENERGY RESOURCE INVESTIGATIONS

Industrial Associate Programs

Reservoir Characterization Research Laboratory: Characterization of Carbonate Reservoirs

Charles Kerans and F. Jerry Lucia, principal investigators; James W. Jennings, Jr., Kirt A. Kempter, and Stephen C. Ruppel; assisted by Jason W. Rush, Bruno Courme, Rashidul Hassan, and Fatma Akyurek

The Reservoir Characterization Research Laboratory (RCRL) is staffed with an integrated geological/petrophysical/engineering team that has been studying carbonate reservoirs and their outcrop analogs since 1988. The initial focus of the group has been to develop generic methods for describing the 3-D distribution of petrophysical properties in carbonate reservoirs. The overall goal of this research is to provide tools to the industry to improve recovery of hydrocarbons from existing reservoirs. This larger goal is achieved through (1) providing quantified geological and petrophysical models for input into reservoir simulators to improve predictions of reservoir performance and (2) mapping the distribution of remaining hydrocarbons. This research is funded by the following industrial sponsors: Altura Energy Limited; Amerada Hess Corporation; Aramco; ARCO International Oil and Gas; ARCO Permian; BP Exploration; Chevron; Elf Exploration Production; Exxon Production Research Company; Japan National Oil Corporation; Marathon Oil Company; Mobil Corporation; PanCanadian Petroleum Ltd.; Pennzenergy Exploration and Production L.L.C.; Petroleum Development Oman LLC; Southwestern Energy Company; and TOTAL Exploration Production USA, Inc. The program is also supported through software access by GeoQuest, Landmark, GeoMath, and TerraScience.

The integration of realistic images from detailed outcrop-analog studies of major reservoir types with subsurface reservoir studies is the central theme of the RCRL work. The outcrop is important because it provides the only opportunity available to study the interwell environment directly and collect information to characterize this environment geologically and petrophysically. Subsurface reservoir studies provide a means for developing methods of applying this information to analogous reservoirs.

The RCRL is currently active in Permian, Pennsylvanian, and Cretaceous carbonate reservoir strata and is conducting outcrop studies in Texas and New Mexico and reservoir studies in Texas and the Middle East. Permian projects include restricted platform-top reservoirs of the Clear Fork and paleokarst-modified steepened ramps of the Abo. Detailed chronostratigraphic, rock fabric, and petrophysical studies are being conducted to better understand the facies and petrophysical architecture of Clear Fork reservoirs.

Studies of Cretaceous strata are focused on the large Cretaceous reservoirs in the Middle East. Outcrop analogs to the Middle East reservoirs are found in the uppermost Albian in the Pecos River Canyon, which was featured in one of this year's SEPM (Society for Sedimentary Geology) field trips associated with the 1999 annual convention of the American Association of Petroleum Geologists. Cretaceous reservoir studies continue, and new outcrop areas for detailed analysis of complex vuggy porosity in rudist accumulations have been identified.

New this year in the RCRL is a study of Pennsylvanian-age (Canyon-Cisco, or upper Carboniferous [Stephanian]) carbonate-platform and platform-margin strata. The out-

crop area is in southwestern New Mexico flanking the Pedregosa Basin. This data set is to be used as an analog for fields in the Permian Basin such as the Horseshoe Atoll and the giant fields in the North Caspian Basin. This icehouse carbonate data set will fill a gap in the RCRL's data base of carbonate reservoirs, which have until now focused on transitional and greenhouse systems.

Reservoir application studies include the Upper Pennsylvanian limestone reservoir of the Sacroc unit of the Horseshoe Atoll (Pennzenergy is the operator) and dolomitized platform-top facies of the South Wasson Clear Fork unit (Altura Energy is the operator). The study of the karst-modified Abo reservoir at Kingdom field (Pennzenergy is the operator) has focused on seismic modeling using the 3-D survey at the field and comparing it with a synthetic outcrop model from Apache Canyon. A study of the Shuiaba (Aptian, Early Cretaceous) of the Middle East operated by Petroleum Development Oman is in the final stages of completion. A new petrophysical model has been developed for Clear Fork reservoirs and has been incorporated into the sequence-stratigraphic framework to illustrate the rock-fabric approach to modeling Clear Fork reservoirs.

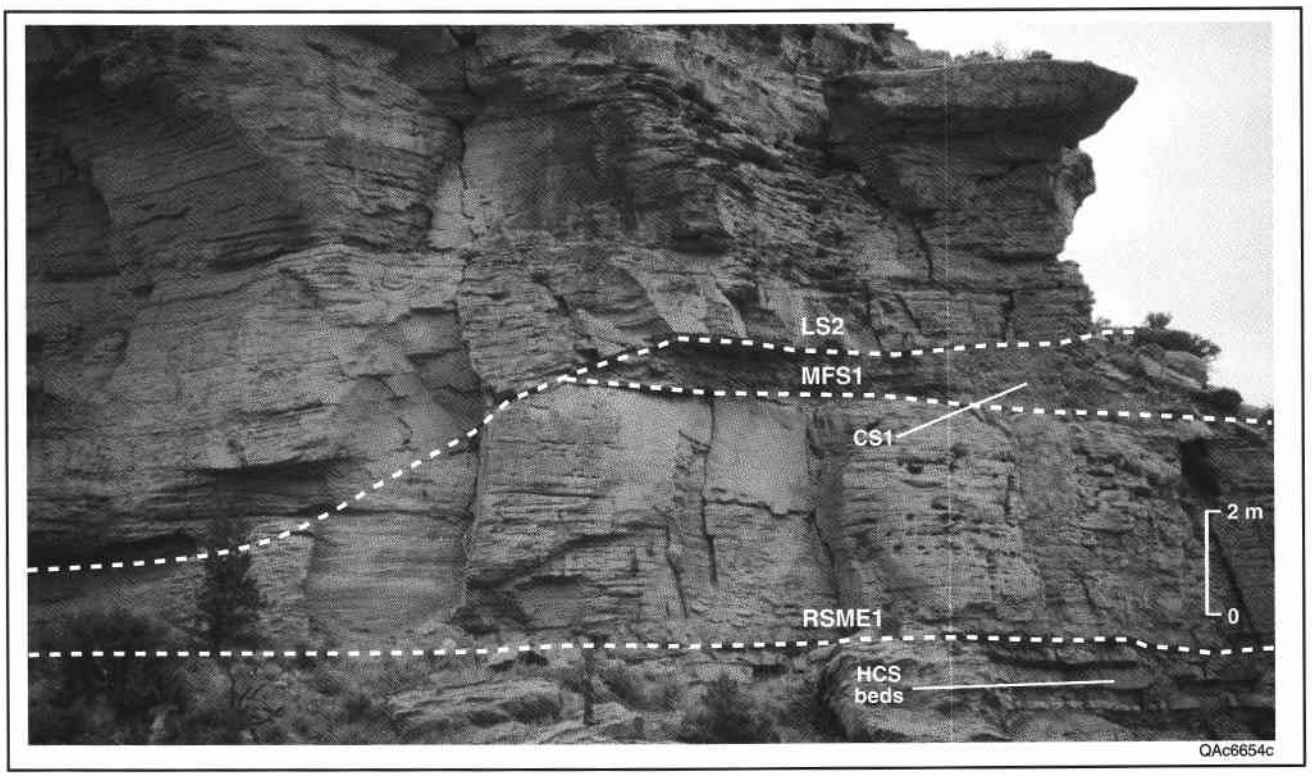
Petrophysical and reservoir studies include (1) the development of a new method for estimating permeability within the oil column using water-saturation and porosity log calculations, (2) analysis of the interrelated effects of small-scale heterogeneity and large-scale permeability trends on fluid flow, and (3) fluid-flow scaleup for improved modeling of reservoir performance. These research results are based on our extensive subsurface and outcrop studies and are directed toward our goal of improving petrophysical characterization of carbonate reservoirs.

Characterization of Heterogeneity Style and Permeability Structure in a Sequence Stratigraphic Framework in Fluvial-Deltaic Reservoirs

Shirley P. Dutton, principal investigator; Christopher D. White, Brian J. Willis, and Lesli J. Wood; assisted by Yugong Gao and Keshav Narayanan

The goal of the Clastic Reservoirs Group (CRG) is to develop improved models of fluvial-deltaic reservoirs using data from well-exposed outcrop analogs. These advanced geologic models quantify internal reservoir architecture, facies dimensions, and spatial variation of permeability, and they can be used to model flow in analogous reservoirs and to formulate recovery strategies. Outcrop data are collected in the context of a regional sequence-stratigraphic framework that allows the application of results to analogous reservoir systems worldwide.

The continued focus of the project this year was tide-influenced systems because ancient outcrop examples of tide-influenced deltas have rarely been documented and few field-scale studies of outcrop analogs exist. The two tidal systems being investigated are the Sego Sandstone in eastern Utah and the Frewens Sandstone of the Frontier Formation in central Wyoming. The Sego Sandstone is a tide-influenced deltaic/estuarine system that was deposited as marine-shelf sands and muds, tidal sand bars, and tidally influenced estuarine sediments. Study of the Sego has included (1) examination of the deposit architecture within a sequence-stratigraphic framework to understand the large-scale depositional setting and to predict exploration uncertainty, (2) construction of detailed maps of bedding, facies, and shale beds, and compilation of a rock-property data base to quantify interwell-scale heterogeneity, (3) evaluation of the sandstone composition and diagenetic alteration to understand relationships between sedimentologic variations and rock-property trends, (4) correlation of sequences, systems tracts, and facies associations in several hundred wells located just behind the outcrop belt to construct a 3-D model of stratal variation and develop methodologies for translating outcrop observations to subsurface data sets, and (5) development of a 3-D data set that can be used to create reservoir models and address exploration and develop-



Maximum lowstand incised valley in Sequence 2 of the Sego Sandstone, eastern Utah, truncates through older shales and into the lowstand shoreface of the underlying Sego Sequence 1. Such homogeneous sandy valley fills form fluid-flow connections between sequences. The basal erosional surface (LS2) of the maximum lowstand incised valley of Sego Sandstone Sequence 2 truncates the underlying condensed section (CS1), through the marine flooding surface (MFS1) of the underlying Sego Sequence 1, and into the lowstand deposits of lower Sego Sequence 1. The regressive surface of marine erosion (RSME1) demarcates the boundary between the bioturbated lowstand deposits and the underlying marine shelf, hummocky cross-stratified (HCS) deposits.

ment uncertainty in these very heterogeneous reservoir systems.

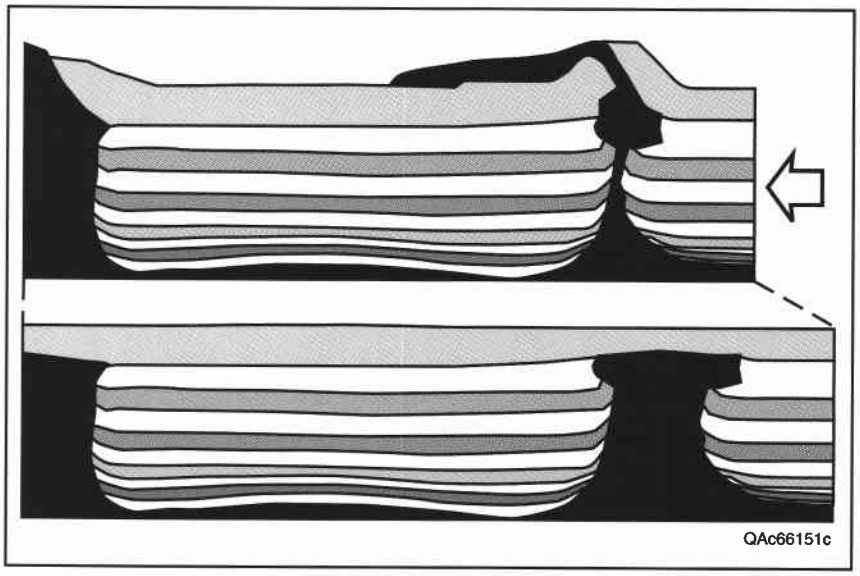
The Frewens Sandstone is a tide-influenced lowstand delta system that prograded into an embayment between more wave-dominated delta lobes. Work this year concentrated on developing a quantitative, structured methodology for collecting outcrop data and carrying those data into reservoir simulation. Simulation studies of high-resolution outcrop data from the Frewens sandstone allowed assessment of the relative importance of different types of geologic variability on flow at the scale of a tidal bar (20 m thick) and a heterolithic bed (1.5 m thick). Estimates of the effects, sensitivities, and interactions of different factors were obtained using experimental design and response surface models.

This program is funded by a consortium of industrial associates comprising the following companies: Chevron Petroleum Technology Company, Intevep S.A., Japan National Oil Corporation, Maxus Energy Corporation, and Statoil. In addition, the program is supported by Computer Modelling Group and Schlumberger/GeoQuest, which provide reservoir-simulation software, and Landmark Graphics Corporation via the Landmark University Grant Program.

Applied Geodynamics Laboratory

Martin P. A. Jackson, principal investigator; Bruno C. Vendeville, laboratory manager; Daniel D. Schultz-Ela and Giovanni Guglielmo, Jr.; assisted by Joel H. Le Calvez and Patrick Walsh

Funded by a consortium of oil companies since 1988, the Applied Geodynamics Laboratory (AGL) investigates tectonic processes relevant to the location, origin, mechanics, and evolution of structural hydrocarbon traps. This



Sequential cross sections in a physical model illustrating the effect of late contraction on passive diapirs and adjacent depocenters, a common occurrence in the lower slope of salt-bearing continental margins. Contraction squeezes the diapirs, forcing the salt to flow upward and spread as a salt tongue.

research has two principal directions: a well-established program of tectonic modeling and a new seismic-based program.

Tectonic modeling covers a wide range of gravity-driven tectonics involving combinations of extension or contraction and mobile salt or shale.

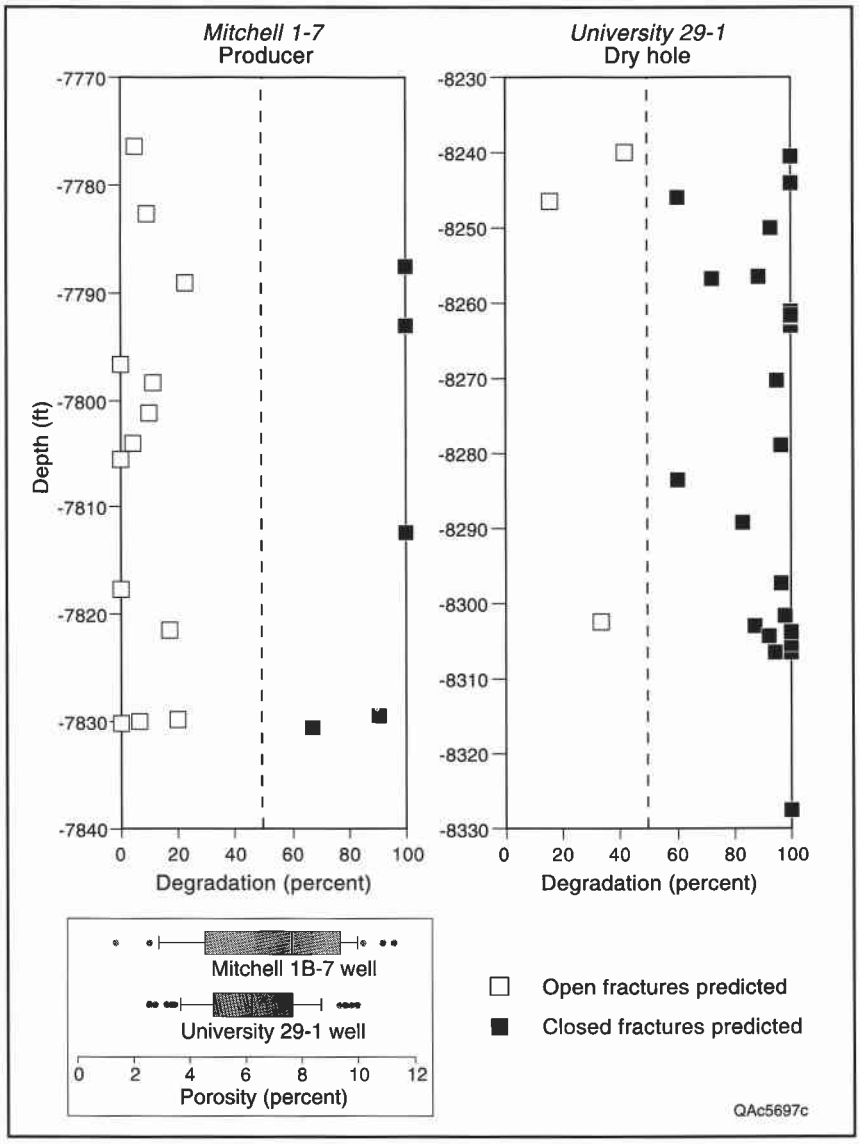
Physical modeling is carried out in the only fully equipped, university-based tectonic modeling laboratory in the United States. Computer-controlled rigs simulate almost any structural style in 2-D or 3-D. Using a combination of overhead photographs, serial sections, time-lapse videos, and CT scans, the evolution of structures in the model can be reconstructed and analyzed.

Mathematical modeling uses *ABAQUS* and *MARC* for forward modeling in 3-D by simulating combined brittle and ductile deformation, large strains, faulting, fluid flow, and thermal effects. *EarthVision*© is used for 3-D visualization, volumetrics, mapping, and creation of data volumes from physical models. Animations and restorations of physical models and mathematical models illustrate structural evolution.

A new AGL project began at the end of 1998 to investigate salt tectonics along the Angolan margin. The project is based on 2-D and 3-D seismic data, supplemented by well and potential-field data. This project complements the parallel modeling program and involves close interaction with several companies in the AGL consortium. The present area of interest is a geotraverse across the center of the Kwanza Basin from onshore to the abyssal Angola Escarpment. Other regions of interest are the Lower Congo Basin to the north and the Benguela Basin to the south. A major goal is to use the clearly imaged, linked structural systems along the Angolan margin as a key to understanding the poorly imaged subsalt structures in the Gulf of Mexico.

Upheaval Dome, Utah, is a breached, subcircular dome that may represent the pinched-off stem of a salt dome. The AGL is currently studying The Grabens, Utah, as a well-exposed and well-constrained example of extensional salt tectonics.

In 1999, the AGL was supported by the following sponsors: Amerada Hess Corporation; Amoco Production Company; Anadarko Petroleum Corporation; BHP Petroleum (Americas) Inc.; BP Exploration and Oil, Inc.; Chevron U.S.A. Production Company; Conoco Inc.; Elf-Aquitaine; ENI-Agip; Exxon Production Research Company; Marathon Oil Company; Mobil; Norsk-Hydro; PanCanadian Petroleum Limited; Petroleo Brasiliero SA; Phillips Petroleum Company; Saga Petroleum ASA; Shell Oil Company; Statoil; Texaco Exploration and Production, Inc.;



Diagnosing whether natural fractures are open or closed is critical in many Texas reservoirs and in oil and gas plays worldwide, yet large subsurface fractures are sparse and challenging to sample systematically. A breakthrough in measuring this key attribute without the necessity to sample large fractures has been achieved in studies carried out by the Fracture Research and Application Consortium, as illustrated by this diagram from a West Texas gas play. Here, a well having mainly open fractures (producer) is distinguished from a well having mostly closed fractures (dry hole) by the use of an indirect sample-based indicator of whether large fractures are open. Inset shows that the wells are not distinguishable on the basis of conventional data. This research illustrates how fundamental advances in understanding of natural fracture systems can also have practical benefits for a key Texas industry.

Total S.A.; and Vastar Resources, Inc.

Seismic Vector-Wavefield Characterization of Complex Reservoirs

Bob A. Hardage, Robert J. Graebner, James L. Simmons, Jr., and Milo M. Backus, principal investigators; Michael V. DeAngelo and Randy L. Remington

The purpose of this program is to develop technologies that will image reservoirs using all components of the seismic wavefield. Research objectives are to develop seismic field-recording techniques and data-processing and data-interpretation software that will result in independent compressional wave (P-wave) and shear wave (S-wave) images of reservoir systems. By combining information from P and S seismic images, more insight can be gained into petrophysical rock properties, pore structure, pore-fluid properties, sequence-stratigraphic relationships, and spatial distributions of lithologies, fractures, and anisotropic properties of complex reservoirs.

Through donations provided by industry sponsors, the Bureau now has equipment for two 2,000-channel seismic recording systems and access to a fully staffed seismic research crew. These Bureau resources are used to record nine-component, 3-D (9C3D) data over selected test properties. More than 40 mi^2 of 9C3D

research data have been recorded, and our research strategy is concentrating on the development of multicomponent data processing and imaging technologies.

Fracture Research and Application Consortium

Stephen E. Laubach, Randall A. Marrett (Department of Geological Sciences, The University of Texas at Austin), and Jon E. Olson (Department of Petroleum and Geosystems Engineering, The University of Texas at Austin), principal investigators; Julia Stowell, Kitty L. Milliken (Department of Geological Sciences, The University of Texas at Austin), and Robert M. Reed; assisted by Eloise H. Doherty, Orlando J. Ortega, and Faustino Monroy

This industry-sponsored research consortium aims to understand and successfully characterize, predict, and simulate reservoir-scale structures. The focus is on fractures and faults that influence the successful extraction of resources. Many faults and fractures are near or below the limits of seismic resolution and are difficult or impossible to characterize adequately using currently available technology. Consequently, fractured reservoirs have been intractable to describe and interpret effectively, posing serious challenges for successful exploration and development.

Research on fundamental fracture and rock properties is the basis for creating methods of obtaining information about subsurface fractures and faults. Testing these concepts involves outcrop, core, image-log, seismic, well test, and modeling studies.

New Methods of Natural Fracture Characterization

Stephen E. Laubach, principal investigator; Sigrid J. Clift and Robert M. Reed; in cooperation with Jon E. Olson (Department of Petroleum and Geosystems Engineering, The University of Texas at Austin) and Randall A. Marrett (Department of Geological Sciences, The University of Texas at Austin)

Advances in analysis of naturally fractured reservoirs—and other reservoirs where the role of natural fractures has been overlooked—have been achieved by means of powerful new scanning-electron-microscope-based imaging devices, quantitative descriptions of how structures of differing scales are related, and innovative geomechanical modeling techniques. This project aims to test and perfect these methods in active oil and gas plays. Part of the testing process is deployment of methods in commercial wells, and project support is from interested companies in the petroleum industry. Several successful tests of new methods were carried out this year. The capabilities of the Fracture Imaging Laboratory at the Bureau's Core Research Center were significantly enhanced through the addition of a powerful new scanning electron microscope; elemental mapping tools; and a new, highly sensitive cathodoluminescence detector.

Domestic Programs

University Lands Advanced Recovery Initiative

Stephen C. Ruppel, principal investigator; Roger J. Barnaby, Jubal G. Grubb, Michael V. DeAngelo, Steve J. Shi, and Robert J. Finley; assisted by J. Greg Ramirez, Jose I. Guzman, and Cengiz T. Vur

Now in its third year, the University Lands Advanced Recovery Initiative (ULARI), which is funded by The University of Texas System and by matching funds from field operators, strives to develop new approaches to the characterization and exploitation of University Lands oil reservoirs in West Texas. During 1999, three reservoir studies were completed. In University Block 9 field in Andrews County, the Pennsylvanian and Wolfcamp units, both operated by Cross Timbers Operating Company, were studied. The North McElroy Grayburg unit in Crane County, which is operated by Apache Corporation, was also examined.

Analysis of the Block 9 Pennsylvanian carbonate succession suggests that the relatively low recovery efficiency

displayed by this reservoir is the result of substantial heterogeneity caused by interrelated stratigraphic and diagenetic processes and by tectonics. Like most icehouse successions, the Pennsylvanian at Block 9 displays the results of high-amplitude rise and fall in relative sea level. These eustatic oscillations have produced a highly cyclic succession of platform carbonates. Diagenesis, involving both leaching and dissolution, and pore-filling cementation are common in the upper parts of cycles. Locally, shales have infilled irregularities at karsted cycle tops, producing local permeability barriers. Faulting of the reservoir has created pressure-isolated compartments that further add to the heterogeneity. Using geologic models derived from core and image-log analysis and 3-D seismic, targets for infill drilling and recompletion have been identified. Initial responses from recompletion of selected zones have shown as much as a three-fold increase in production.

The Block 9 Wolfcamp reservoir displays many of the same stratigraphic and diagenetic controls on heterogeneity seen in the underlying Pennsylvanian. Fault-induced compartmentalization, however, is probably less severe. Cycle-punctuated vertical and lateral changes in rock fabric are key factors in poor reservoir performance. Borehole imaging logs have been shown to be critical tools in defining both facies and cyclicity in the reservoir. These data have formed the basis for detailed mapping and 3-D modeling of porosity and permeability and a reappraisal of reservoir volumetrics. Several opportunities for additional exploitation of the reservoir have been defined on the basis of an integration of 2-D and 3-D models.

Despite its prolific production, recovery efficiency at McElroy field remains relatively low. Bureau studies have shown that the reservoir comprises two very distinct parts, each having very different rock fabrics owing to contrasts in diagenetic style. New approaches to porosity determination have been developed for each of these areas. Targeted infill drilling based on this research has resulted in large volumes of incremental oil production from the field.

The ULARI project, which is expected to continue for at least 2 more years, continues to seek out motivated operators who are interested in developing and applying cutting-edge technology to effecting incremental recovery in University Lands reservoirs.

Application of Advanced Reservoir Characterization, Simulation, and Production Optimization Strategies to Maximize Recovery in Slope and Basin Clastic Reservoirs, West Texas (Delaware Basin)

Shirley P. Dutton, principal investigator; assisted by Jose I. Guzman and Helena H. Zirczy

The objective of this project is to demonstrate that detailed reservoir characterization of slope and basin clastic reservoirs in sandstones of the Delaware Mountain Group in the Delaware Basin of West Texas and New Mexico is a cost-effective way to recover a higher percentage of the original oil in place through geologically based field development. The project focused this year on the East Ford unit, a representative Delaware Mountain Group field that produces from the upper Bell Canyon Formation (Ramsey sandstone). The field, discovered in 1960, is operated as the East Ford unit by Orla Petco, Inc., our industry partner for this project.

Subsurface mapping, study of Bell Canyon sandstones in outcrop, and descriptions of Ramsey sandstone cores from the adjacent Ford Geraldine unit indicate that reservoir sandstones at the East Ford unit were deposited in a deep-water channel-levee and lobe system. Ramsey sandstone channels at the East Ford unit, 1,000 to 1,500 ft wide and 15 to 30 ft thick, are flanked by levee deposits. Lobe facies were deposited at the mouths of channels. The best leases in the field produce from what are interpreted to be channel facies near the center of the unit. Petrophysical characterization of the East Ford unit was accomplished by integrating core and log data and quantifying petrophysical properties from wireline logs. Log-porosity to core-porosity transforms and core-porosity to core-permeability trans-

forms were derived for the East Ford reservoir. The petrophysical data were used to map porosity, permeability, net pay, water saturation, and other reservoir properties.

To estimate the tertiary recovery potential, the results of simulations of a CO_2 flood in the Ramsey sandstone were applied to the East Ford unit. Independent estimates of tertiary recovery from the East Ford unit were made on the basis of the results of the CO_2 flood performed in the south part of the Ford Geraldine unit. Both methods of estimating tertiary recovery in the East Ford unit indicate that a minimum of 10 percent, and as much as 30 percent, of remaining oil in place is recoverable through a CO_2 flood. Original oil in place in the CO_2 flood area within the East Ford unit was approximately 14.7 MMbbl, and of that, 2.5 MMbbl was produced during primary production. Of the 12.2 MMbbl of remaining oil in place in this area, an estimated 1.2 to 3.7 MMbbl is recoverable through CO_2 flood. Tertiary recovery in the East Ford unit by CO_2 injection began in July 1995, and production response to the CO_2 injection was observed in December 1998. In the coming year, production from the East Ford unit will be monitored and compared with predictions made on the basis of flow-model simulations. This comparison will provide an opportunity to evaluate the success of these operations and to test the accuracy of reservoir-characterization and flow-simulation studies as predictive tools in resource preservation of mature fields.

This study of deep-water turbidite sandstone reservoirs is funded by the U.S. Department of Energy as part of the Oil Recovery Field Demonstration Program for Class III (slope and basin clastic) reservoirs. Matching funds for the project were provided by the Texas Office of State-Federal Relations through State Match Pool Funding awarded in a contract titled "Rejuvenating a Dying Oil Play: Benefits to the State, the Permanent School Fund, and the People and Economy of Far-West Texas" and by the State of Texas Advanced Resource Recovery Project.

Architecture of Fluvial-Deltaic Reservoirs, Ferron Sandstone, Utah: Implications for Improved Oil and Gas Recovery Captured on a State-of-the-Art CD-ROM

Noel Tyler, principal investigator; Roger Tyler, Shirley P. Dutton, Christopher D. White, Mark D. Barton, Sigrid J. Clift, Scott D. Rodgers, John R. Andrews, and Kerza P. Prewitt

Hydrocarbon reservoirs typically display a complex stratigraphic architecture that controls paths of fluid migration, recovery efficiency, and the volume of oil and gas left in a reservoir at the time of abandonment. Because recovery of these oil and gas resources requires a detailed understanding of the spatial distribution of the stratigraphic properties that affect fluid flow, this CD-ROM presentation, developed in part with support from the Gas Research Institute, the U.S. Department of Energy, and the State of Texas Advanced Resource Recovery Project (Project STARR), has translated outcrop measurements of geologic heterogeneities into transportable information useful to development and exploration geologists, well-log analysts, and production engineers in their quest to target additional resources. The two-volume CD-ROM focuses on the Upper Cretaceous Ferron Sandstone Member, Utah, as an outcrop analog to heterogeneous fluvial-deltaic reservoirs along the Texas Gulf Coast Basin; the Maracaibo Basin, Venezuela; the North Sea; and other similar high-accommodation fluvial-deltaic petroleum systems around the world that have a large potential for reserve growth. The low hydrocarbon-recovery efficiencies in fluvial-deltaic reservoirs indicate that substantial reserves remain after abandonment, highlighting the need for predicting the spatial distribution of interwell heterogeneities. Exposures of the Ferron Sandstone Member, captured on the CD-ROM, allow one to (1) quantify the 3-D architecture and petrophysical and permeability structural attributes of fluvial-deltaic sandstones within a sequence-stratigraphic framework and (2) document the

expression of such relationships within a subsurface setting. Accordingly, the purpose of this CD-ROM presentation is to develop knowledge and techniques, through the transfer of technology, that will result in the successful exploration and exploitation of potentially vast oil and gas resources worldwide in these types of reservoirs.

State of Texas Advanced Resource Recovery (STARR) Project

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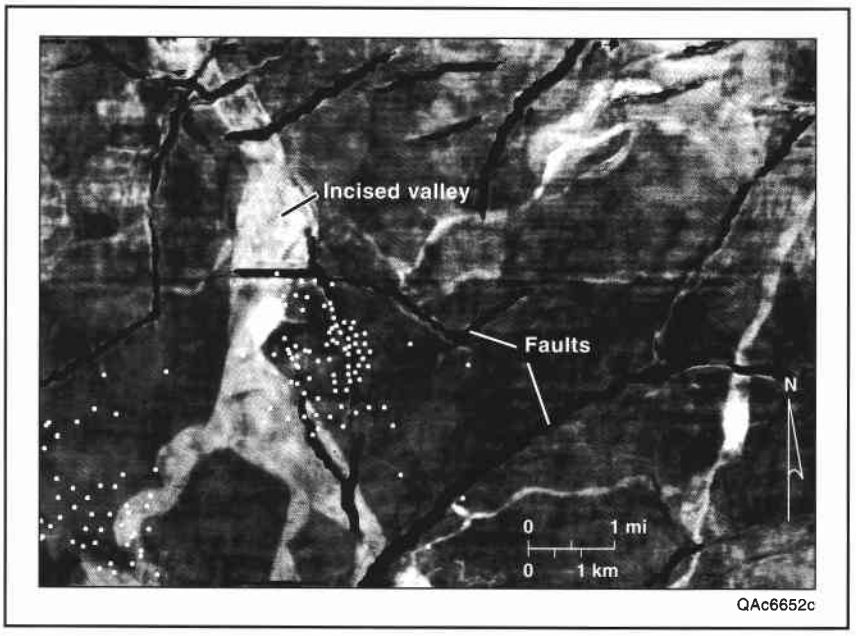
Revenue income to the Permanent School Fund, derived largely from oil and gas royalties from Texas State Lands, has declined over the last decade. However, an enormous hydrocarbon resource base remains on State Lands. In fact, State Lands fields contain more oil and gas than has been recovered over the decades-long history of State Lands production. Rather than being unattainable, however, a large volume of this remaining oil and gas is recoverable through the strategic, or targeted, deployment of advanced recovery technologies. Although advanced technology has historically been the realm of major oil and gas companies, many companies, in pursuing economies of scale, have mostly departed from the mature Texas resource base.

The opportunity thus created has been enthusiastically grasped by the remaining major and independent producers from State Lands fields. Major companies, who have suffered from staff shortages, and independents, who are largely unsupported by the advanced research and development capabilities that the maturing State Lands resource base desperately requires, are requesting reservoir-characterization assistance from the State of Texas Advanced Oil and Gas Resource Recovery Initiative (Project STARR).

The Bureau, with funding from the State of Texas and support from the General Land Office and the Railroad Commission of Texas, is providing that critical technical support. Plays having the best prospects for increased production have been identified and, with the support of allied producers, are being drilled. Project STARR has one major goal—increased royalty income to the Permanent School Fund through the drilling of profitable wells.

To date, 12 fields have been chosen for assessment: Ozona, Geraldine Ford, Ford West, Lockridge, Waha, Waha West, Bar Mar, and Keystone East fields of West Texas; Corpus Christi Bay, Umbrella Point, and Red Fish Bay fields of the Gulf Coast; and Duval County Ranch field in South Texas. Fifteen Texas operators have been involved in Project STARR: Bass Enterprises, Cross Timbers, Conoco, Hallwood Energy, Hanson Corporation, Killam Oil, Mobil, Panaco, Inc., Pi Energy, Pioneer Natural Resources, Royal, Sabco, Shell, Union Pacific Resources, and Vista Resources. Project STARR has recommended 58 infill wells, 56 recompletions, and 3 step-out wells under the current program initiative.

Of the targeted opportunities, 42 infill wells and 29 recompletions have been drilled on State Lands on the basis of STARR recommendations to date. Forty infill wells have been drilled, and twenty-eight recompletions have been undertaken in Ozona and Keystone East fields, and incremental oil and gas reserve growth is estimated at 8.9 Bcf of gas and 1.9 MMbbl of oil. The total revenue generated from the reserves added in these two fields is projected to exceed $48 million. In Umbrella Point field, total gas production from the Panaco 74-10 well exceeded 5.3 Bcf between January and December 1998. In one infill well in Umbrella Point field alone, total revenue between January 1997 and December 1998 to the Permanent School Fund exceeded $1.6 million, directly benefiting the schoolchildren of Texas. Texas State Lands operators are invited to participate in Project STARR by contributing data to the Bureau in exchange for expert technical advice in developing State Lands oil and gas fields.



Amplitude stratal slice from 3-D seismic data depicting the areal distribution of lowstand incised-valley deposits of an upper Miocene sand reservoir within the greater Starfak and Tiger Shoal field area, offshore Louisiana. Such stratal slices show remarkably focused resolution of depositional and paleophysiographic trends in the study area and serve as accurate guides to facies mapping from well-log data. Stratal slicing is one of several advanced analytic methods that are being used to identify additional natural gas resources in two major mature gas fields in the northern Gulf of Mexico Basin through multidisciplinary field and reservoir characterization study.

Targeting Reserve Growth Opportunities in the Northern Gulf of Mexico Basin: Transferring Secondary Gas Recovery Technology to the Offshore Environment

Lesli J. Wood, principal investigator; Tucker F. Hentz, Hongliu Zeng, Jirapa Skolnakorn, Michael V. DeAngelo, Joseph S. Yeh, Robert J. Finley, and Ramón H. Treviño III; assisted by Cem O. Kilic, Claudia Rassi, Adrian C. Badescu, and Ramiro A. Amaya

The Bureau has been an active partner with industry in improving natural gas recovery efficiency in complex onshore reservoirs since 1988. Research on onshore Gulf Coast sandstones, sandstones of the Fort Worth Basin, and karsted carbonate reservoirs of the Permian Basin has successfully defined secondary, or incremental, gas recovery based on targeting reservoir heterogeneity. Focusing on offshore gas reservoirs, the Offshore Secondary Gas Recovery (Offshore SGR) project began in late 1998 as a 4-year joint research venture between the Bureau and the U.S. Department of Energy (DOE). The project is an outgrowth of a previous DOE-sponsored Bureau project that produced the two-volume *Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs*, which was published in 1997.

The goal of the Offshore SGR project is to identify additional natural gas resources in two major mature fields—Tiger Shoal and Vermilion Block 50 ("Starfak")—in the northern offshore Gulf of Mexico (Federal OCS) through multidisciplinary field- and reservoir-characterization studies. The specific objectives are to (1) fully evaluate the lithostratigraphic, sequence-stratigraphic, structural, petrographic, and engineering attributes of the fields that will lead to additional natural-gas development opportunities, (2) increase reserves, (3) prioritize newly identified prospects and development opportunities, (4) develop and apply new technologies to aid in the future search for reserves, and (5) transfer research methodologies and technologies to the industrial community. Texaco, Inc., the project's industry partner, has operated the study fields since the late 1950's and is providing engineering, production, well-log, and uninterpreted 3-D seismic data.

Starfak and nearby Tiger Shoal fields produce natural gas and oil from a siliciclastic section that spans most of the Miocene Series. The succession grades upsection from slope depositional facies to progradational and retrogradational shelf and shelf-edge facies and finally to dominantly aggradational coastal plain facies just a few hundred feet above the reservoir-bearing interval. As many as 36 potential gas and

oil reservoirs occur in the two fields in proximal to distal shelf and slope sandstones between 6,000 and 16,000 ft.

Development of Active Seismic Vector-Wavefield Imaging Technology for Geothermal Applications

Bob A. Hardage, principal investigator; James L. Simmons, Jr., and Michael V. DeAngelo

A research study funded by the Geothermal Division of the U.S. Department of Energy (DOE) was concluded during the year, and a final report was prepared for the Idaho Operations office. Two new vector-wavefield seismic sources were developed and tested: (1) a vector explosive package that generates a horizontal force vector when deployed in a conventional-size shot hole and (2) vertical vibrators operated in pairs to form a two-element dipole source rather than a two-element monopole source. Each source generates robust shear waves, which is the primary objective of the source development.

Experimental field tests were conducted in South Texas, West Texas, Montana, Pennsylvania, and Oklahoma, and test results are documented in the DOE report. The vector explosive source was developed as a cooperative research effort with Austin Powder Company of McArthur, Ohio, and is commercially available for shear-wave imaging of both geothermal and oil/gas reservoirs.

Devine Test Site

Bob A. Hardage and James L. Simmons, Jr., principal investigators; Milo M. Backus and Robert J. Graebner; James A. Doss, Jr., and George T. Bush, site managers

The Devine Test Site is a 100-acre property in Medina County, Texas, approximately 15 mi west of Devine, Texas, that the Bureau is upgrading into a world-class geophysical field laboratory. Key assets of the property are three wells, each 3,000 ft deep, that have been constructed for the specific purpose of downhole geophysical experimentation. An appealing feature of these wells is that two of them are cased with fiberglass, which allows downhole electromagnetic instruments to function as they would in an uncased hole without the impediment of steel casing. No fluid-exchange processes are occurring in the interwell spaces because the nearest oil production is several miles away.

The Society of Exploration Geophysicists has provided 2 years of financial support to help the Bureau upgrade facilities at the Devine Test Site. Recent site improvements are new fences and entry gates, a water well and a distributed water system to each test well, rural electrical power and electrical outlets at each well pad, and elevated floodlights for night work. Upcoming improvements will be the addition of gravel-based access roads, installation of wireline deployment units at each test well, and construction of a field office.

Petroleum Technology Transfer Program

Andrew R. Scott, principal investigator (January–August), and William L. Fisher, principal investigator (September–December); L. Edwin Garner, Sigrid J. Clift, and Tucker F. Hentz; assisted by Kimberly High

The Bureau is the Texas Regional Lead Organization of the Petroleum Technology Transfer Council (PTTC), a national nonprofit organization formed in 1993 to serve as a national clearinghouse for upstream technology needs of U.S. oil and gas operators. Primarily funded by the U.S. Department of Energy's Office of Fossil Energy through the National Petroleum Technology Office and Federal Energy Technology Center, the main tasks of PTTC are (1) identifying the technological problems of U.S. oil and gas producers and communicating these needs to the research and development community and (2) transferring to domestic producers new and existing upstream technologies that will help them reduce finding costs, improve operating efficiency, improve ultimate recovery, enhance environmental compliance, and add to domestic oil and gas reserves.

The technical information that the PTTC transfers to producers comes from all sectors of the research and develop-

ment community and intermediary providers of technology, including government, universities, DOE, Gas Research Institute, professional and trade societies, national laboratories, private companies, and the service industry. Although not involved directly in any research or development, the PTTC serves as a clearinghouse for improving technology transfer to domestic operators.

The Texas Regional Resource Center began operation in 1995. The Resource Center includes the Bureau's reading room, map room, geophysical log facility, core repositories, and two computer workstations equipped with analytical petroleum software. Programs for contour mapping, reservoir simulation, well-log analysis, log digitizing, and reservoir engineering are available to the public. As the Texas Regional Lead Organization, the Bureau, in cooperation with the Texas Independent Producers and Royalty Owners Association, manages and maintains a home page on the Internet that includes an events calendar; technology news; resource links; and exploration, production, research, and development forums. Workshops are an important part of the technology-transfer process, and a wide range of workshop topics was offered during the year.

The PTTC sponsored a workshop on microbial enhanced oil recovery (MEOR) in Midland. This workshop addressed the concepts behind MEOR and the details of actual case studies. The workshop was designed to inform potential users, particularly independent oil producers, of the scientific basis, design criteria, implementation, costs, and expected results of MEOR. Another workshop in Midland, on use of the Internet, co-sponsored by the American Association of Petroleum Geologists, was designed to train operators in the use of Internet search tools. A mudlogging-technology miniworkshop gave demonstrations on new mudlogging techniques, and PTTC co-sponsored a workshop with the South Texas Geological Society in San Antonio that summarized hydrogeologic factors affecting coalbed methane exploration. Another workshop that updated operators on advanced recovery of oil and gas on State and University Lands was given in Midland.

A new addition to the Texas Region PTTC program was the creation of a mentor program that is designed to promote additional technology and information exchange on a regional scale. The mentor is responsible for developing a network of reliable contacts in the region and answering questions posed by operators in the West Texas area. The program also provides timely information regarding activities in the region, articles for the PTTC regional newsletter or national articles, and information to be placed on the PTTC regional Web site. The development of half-day miniworkshops that cover a broad range of interests has been well received. The success of this test program in the Permian Basin has ensured that the mentor program will continue for at least one more year and possibly expand into other regions within Texas.

Assessment and Forecasting by Play—Natural Gas Ultimate Recovery Growth and Quantifying the Role of Technology Advancements in Reserve-Growth Additions in the Texas Gulf Coast Basin and East Texas

William L. Fisher, principal investigator; Eugene M. Kim

Prediction of natural gas ultimate recovery, the sum of proved reserves and cumulative production up to a specific time, is initially conservative because of a lack of understanding of geological characteristics of the reservoir or field involved. Natural gas ultimate recovery tends, on average, to increase substantially over time and after much drilling, owing to an improved understanding of the geological characteristics of the reservoir or field and the application of advanced technologies. In recent years, natural gas ultimate recovery growth (URG)—the increase in ultimate recovery from fields subsequent to discovery from extensions and infield drilling in existing fields, improved recovery of in-place resources, new pools,

and intrapool completions—has become a major component of total U.S. annual natural gas reserve additions.

The primary research objectives of this project, funded by the U.S. Department of Energy, are to develop new concepts in (1) realistic and play-specific measures of remaining natural gas URG potential, (2) the assessment of the technology necessary and most amenable to realizing natural gas URG, and (3) the assessment of economic factors involved in realizing natural gas URG in the Texas Gulf Coast Basin and East Texas.

When taken as a total, major fields of the Texas Gulf Coast and East Texas Basins are currently experiencing significant URG activity. Disaggregation by play unmasks important play-by-play trend variations in URG obscured by aggregated analysis of broad geological provinces. Field-level ultimate recovery data were disaggregated into 21 and 10 geologically delineated plays in the Texas Gulf Coast and East Texas Basins, respectively. Significant historical URG and future potential in the Texas Gulf Coast and East Texas Basins have been quantified, ranked, and forecasted by plays as a factor of both time and drilling activity.

Undoubtedly, ultimate recovery growth is a large and crucial component in the future natural gas supply of the Texas Gulf Coast and East Texas Basins, as well as of the entire nation. Future research directions include a play-specific economic and technological analysis of currently selected major plays. URG is slowly, but finally, being recognized as one of the most important components of our nation's future natural gas supply.

Scaling of Fractures in Carbonate Reservoirs and Relations with Sequence-Stratigraphic Framework

Randall A. Marrett (Department of Geological Sciences, The University of Texas at Austin) and Stephen E. Laubach, principal investigators; assisted by Orlando J. Ortega, Julia Stowell, and Faustino Monroy

The goals of this project, funded by the Advanced Research Program of the Texas Higher Educational Coordinating Board, include characterization of fracture arrays in carbonate strata, relating the fracture characteristics to fluid-flow observations, and relating fracture characteristics to the bedding architecture of the sedimentary rocks. One study area for this project is in the Sierra Madre Oriental Mountains of northeastern Mexico. Two field campaigns have been carried out, and results of outcrop analyses are being compared with analogous work on core extracted from petroleum wells. We have obtained core samples and associated oil-production data for several wells from Petróleos Mexicanos (Pemex) and completed initial fracture characterization. A pilot study of fracture scaling in carbonate outcrops of Central Texas is also complete. The pilot study has confirmed that fracture apertures in limestone follow power-law scaling across at least four orders of magnitude, comparable to what our previous work demonstrated for sandstone. These results have implications for targeting and simulating fractures in carbonate reservoirs.

Geologic Characterization of Fractured Reservoir Block Size Using Microcrack Data

Jon E. Olson (Department of Petroleum and Geosystems Engineering, The University of Texas at Austin) and Stephen E. Laubach, principal investigators; assisted by Mark Kuncir and Yuan Qiu

Naturally fractured reservoirs represent a large but poorly understood resource in the state of Texas as well as in other hydrocarbon-producing provinces throughout the world. Reservoir-scale fracture networks are difficult to characterize because fracture spacing is typically many times the diameter of a conventional borehole, so that in most cases well bores miss fractures. Because these fractures may nevertheless profoundly influence reservoir behavior, this sampling problem poses a serious challenge to fracture characterization and simulation. This project, funded by the Advanced Technology Program of the Texas Higher Educational

Coordinating Board, involves geomechanical modeling and other advanced modeling and characterization methods to improve prediction of fracture attributes in the interwell region. The project successfully used microstructural fracture proxies to define the location of horizons having conductive fractures on a scale suitable for use in reservoir simulation. These results have been used to specify the vertical dimension of simulator cell blocks. Geomechanical modeling, calibrated with subsurface fracture observations and new rock-property tests, specifies the spacing of fracture clusters in a way that can be used to define the lateral extent of cell blocks. Tests of these methods in several reservoirs are under way.

AGI Web-Based Education

Bob A. Hardage, principal investigator; Scott D. Rodgers and John R. Andrews

The Bureau is working with the American Geological Institute (AGI) to develop Web-based educational modules that cover all aspects of reservoir characterization. The modules will be structured around real data sets that illustrate the principles of reservoir characterization for different depositional environments.

The philosophy of this educational program is to create interactive, game-theory-based modules on the Internet that will allow students to interact with geologic, geophysical, and engineering data; make data interpretations; and then be instructed about the correctness of their answers. The program will be offered by AGI. The Bureau's role is to provide the data required for the instruction, create the text and graphics needed to explain the concepts of reservoir characterization, and structure the material into a series of interactive modules that can be accessed by Web users.

The initial group of modules focuses on reservoir characterization in depositional systems that are dominated by fluvial processes. Subsequent modules will concentrate on reservoir characterization in carbonates, deltaic environments, and slope-basin systems.

Integrated Outcrop and Subsurface Studies of the Interwell Environment of Carbonate Reservoirs: Clear Fork (Leonardian Age) Reservoirs, West Texas and New Mexico

F. Jerry Lucia and Charles Kerans, principal investigators; Stephen C. Ruppel, James W. Jennings, Jr., and Stephen E. Laubach; assisted by Fatma Akyurek, Rashidul Hassan, and Javier G. Moros

This study of carbonate reservoirs is funded by the U.S. Department of Energy and receives matching funds from the Carbonate Reservoir Characterization Research Laboratory. The objective of this project is to investigate and develop improved engineering and geological methods for characterizing carbonate reservoirs for input into fluid-flow simulators to predict reservoir performance. The project is focused on investigations of interwell heterogeneity in Clear Fork reservoirs of the Permian Basin, West Texas and New Mexico. The study addresses three fundamental questions: (1) What effect does the fine-scale heterogeneity located within rock-fabric flow units have on recovery? (2) What is the impact of natural fractures on reservoir performance in Clear Fork reservoirs? (3) What are the best methods of predicting the distribution of high- and low-permeability rock-fabric facies?

Data to answer these questions are being collected and analyzed from the excellent Clear Fork–age outcrops in the Sierra Diablo Mountains, West Texas, and from the South Wasson Clear Fork reservoir, a major Clear Fork reservoir in the Permian Basin, West Texas and New Mexico. The research is organized into three principal tasks. Task 1 is to (1) describe the sequence-stratigraphic framework of the Clear Fork reservoir analog in the Sierra Diablo Mountains, West Texas, and measure dimensions of rock-fabric facies for object modeling; (2) measure the fine-scale petrophysical heterogeneity from selected outcrop rock-fabric facies and test scaleup methods using numerical simulations; and (3) collect detailed fracture information from the outcrop for microscopic and scanning-electron-microscope imaging and construction of a fracture model for input into a fluid-flow simulator. Task 2 is to con-

struct a model of the South Wasson Clear Fork reservoir using core and log data, incorporating models and methods obtained from Task 1. The impact of fractures on production performance will be tested using numerical simulations. Task 3 is to transfer the results of this study to industry through field trips, meetings, publications, and presentations.

Deep-Basin Coal (Lignite) and the Potential for Unconventional Coal Gas Resource Development, Wilcox Group, East-Central Texas

Roger Tyler, principal investigator; assisted by Luciano L. Correa and Tiejun Zhu

Interest in deep-basin coal gas development along the Texas Gulf Coast has increased over the last few years, with numerous independent and major Texas operators requesting information pertaining to coal gas resources and development. Operators have reported "gas kicks" in these deeper Gulf Coast coal seams, which have the potential to produce enough gas to lift oil from productive sandstones to the surface and then, after separation, to fire the heater treater and/or the pumping unit. The Wilcox Group in east-central Texas has been the focus of this project because it contains the largest quantity of deep-basin (220 to 2,000 ft) coal (lignite) in Texas and could potentially hold significant coal gas resources. The east-central Texas region is also strategically located near several cites that may use the deep-basin coal as a gas energy source both for coal-fired power plants and as a potential new exploration target for coal gas resource development. This research is providing the Texas natural gas and coal industry with baseline information, and it may stimulate a new industry in the state.

As part of a cooperative agreement with the U.S. Geological Survey, the Bureau will update the previous deep-basin National Coal Resources Data System resource estimates, with emphasis on developing a coal gas resource data base and investigating the potential for coal gas resource development. As part of the resource development program in east-central Texas, we are applying the coal gas producibility model to east-central Texas and reviewing the potential for coal gas resource development. The coal gas producibility model considers all geologic and hydrologic criteria and data available. Importantly, coal gas producibility and resource volumes are governed by six critical factors: tectonic/structural setting, depositional systems and coal distribution, coal rank, gas content, permeability, and hydrodynamics. Coal beds are both the source and the reservoir for methane; consequently, their distribution and occurrence within a basin are critical in establishing a coal gas resource. High productivity within east-central Texas will be governed by (1) thick, laterally continuous coals, (2) adequate permeability, (3) flow of ground water toward no-flow boundaries (regional hingelines, fault systems, facies changes, and/or discharge areas), (4) generation of secondary biogenic gases, and (5) conventional trapping along those boundaries to provide additional gas beyond that generated in situ during coalification. However, simply knowing the characteristics of the geological and hydrological controls in east-central Texas will not lead to a conclusion about coal gas resources because it is the complex interplay among these controls and their spatial relationships that govern producibility; high coal gas productivity requires a synergistic interplay among these controls. The best potential for coal gas production may lie in conventional or hydrodynamic traps basinward of where outcrop and subsurface coals are in good hydraulic communication. Coal gas research has progressed to the point where understanding the dynamic interaction among these key geologic and hydrologic factors can be used to define areas that may produce coal gas along the Texas Gulf Coast.

Numerical Models of Brittle Grabens Forming above Ductile Rock in Canyonlands National Park, Utah

Daniel D. Schultz-Ela, principal investigator; assisted by Patrick Walsh

The Grabens area of Canyonlands National Park records the interaction of propagating extensional faults that are still slipping today above a

layer of flowing salt. Erosion of the Colorado River canyon down to the salt layer allowed stretching and gravity gliding of the overburden down the gentle regional dip. Numerical modeling of this uniquely well-constrained fault system is enhancing understanding of brittle rock stretching above a ductile layer in other parts of the world.

Our 2-D computer models of the evolution of The Grabens area have tightly constrained the cross-sectional geometry of the faulting and the material properties of the rock. Spacing of grabens depends on the elastic properties. Small flexures localize the location of grabens very early; then a rolling hinge stepping through the layer signals the onset of significant fault growth. We have solved debates about propagation of the faults: they initiate at the top of the overburden as tension fractures and propagate down to become shear fractures. Local flexure controls the simultaneous formation of paired faults that intersect at depth and define grabens. Preliminary 3-D numerical modeling simulates how the faults initiate, propagate, and interact. This type of brittle/ductile system has not been previously modeled.

Field work in The Grabens area provided the accurate input data necessary for meaningful finite-element modeling and served as a check on the results. The results will clarify extensional processes in other areas, such as the Gulf of Mexico, North Sea, Basin and Range province, East African and Rio Grande rifts, midocean spreading centers, and grabens on other planets and moons.

International Programs

Optimizing Hydrocarbon Recovery from the Matzen Field, Vienna Basin, Austria

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The Bureau has been working with OMV Aktiengesellschaft to define the remaining unrecovered oil and gas resource in Matzen field, the largest oil and gas field in Central Europe, located about 30 km northeast of Vienna, Austria. Well deepening, well recompletions, and, potentially, infill drilling based on integrated characterization are all under consideration as part of this study. After completing an overall genetic stratigraphic framework, we subdivided the major oil-producing reservoirs of the Badenian (middle Miocene) into a series of layers representing fourth- and fifth-order sequences. The use of high-frequency genetic stratigraphy and high-quality 3-D seismic data has allowed an improved understanding of complex clinoforms in the 9th Badenian reservoir and clearly documented falling-stage stratal geometries. In each high-frequency layer within the major reservoirs, gross-sandstone trends and well-log-facies analysis have produced paleogeographic reconstructions of the deltaic, shelf, slope, and basin systems that deposited the reservoir sandstones. The resulting understanding of lateral facies, and consequent lateral reservoir-quality variations, explains long-standing reservoir-behavior anomalies and aids in more efficient targeting of unrecovered mobile oil.

A detailed structural analysis of the 105-km^2 3-D seismic volume has included attribute mapping and continuity analysis to identify major and subtle faults in this strike-slip setting. Structural features identified include transtensional trailing-edge imbricate fans, a divergent strike-slip graben, transpressional restraining-bend folds, and extensional duplexes. In addition to the major extensional faults mapped in the northwest area of the field, a series of subtle north- and northeast-trending small-displacement strike-slip features have been identified that appear to influence reservoir behavior and may compartmentalize producing horizons. Time slicing and horizon slicing of 3-D continuity volumes have been extremely useful in identifying these features, as well as in identifying map-view fault patterns in the complex

extensional graben in the northwest area. Seismic surfaces from Landmark SeisWorks software were merged in Landmark Z-Map with reservoir top depths through a flexing algorithm to create accurate subsea-depth structure maps that satisfied all data available.

Petrophysical evaluation has been critical to the construction of a 3-D model of the reservoirs for volumetric mapping. Only a limited number of modern logs containing good porosity information were available in this mature field (developed primarily in the 1950's). Analysis of this newer data, combined with older log data where core material was available and rare modern core data, allowed construction of a 21-layer petrophysical model of the 7 reservoirs studied. To extrapolate good petrophysical information from areas near modern wellbores to the remainder of the field, a transform between modern logs and older spontaneous potential (SP) curves was built to convert the SP curves to pseudo-porosity curves. In the geostatistical modeling, the modern logs were used as hard data, and the pseudo-porosity derived from SP curves was used as soft data. The cokrigging was guided by variogram grids generated from geologically interpreted hand-contoured gross-sandstone maps. This process ensured that computer-based volumetric mapping was guided by a detailed understanding of the depositional facies developed during the stratigraphic mapping phase.

Reservoir performance and sand-production problems identified during this study and related to drilling damage in high-permeability formations led to a Bureau recommendation to initiate pulse-loading completion stimulation techniques developed in the United States and Canada. Perforated intervals are stimulated by a high-pressure gas pulse resulting from the burning of a solid propellant downhole. The three wells stimulated by this technique have yielded severalfold increases in gross-fluid production.

In summary, the understanding of these mature reservoirs developed through the joint OMV-Bureau project has produced tangible improvements in reservoir production and helped OMV reservoir engineers understand long-standing anomalous reservoir behavior. Furthermore, the maps developed by this study are expected to be the primary guide to reservoir development through the remainder of the life of this giant oil field.

Integrated Analysis of the Burgos Basin, Mexico

Noel Tyler,
principal investigator;
William A. Ambrose, Robert E. Barba, L. F. Brown, Jr., and Douglas S. Hamilton

This 9-month project, undertaken in collaboration with The Scotia Group, Inc., is designed to provide technical support for Pemex's exploration and field production optimization projects under way in the Burgos Basin, Mexico. Bureau researchers are working in close partnership with Pemex geologists to establish the stratigraphic framework of the Tertiary section in the Burgos Basin prior to defining exploration fairways. Similarly, Bureau geologists and petrophysicists are defining reservoir architecture and petrophysical attributes in five major fields in the northern Burgos Basin. This project concludes in December.

Optimizing Hydrocarbon Recovery from Mara Este (Mara Liviano) Field, Maracaibo Basin, Venezuela

Noel Tyler, William A. Ambrose, and Andrew R. Scott, project directors;
Edgar H. Guevara, principal investigator; Khaled Fouad, Jirapa Skolnakorn, Stephen E. Laubach, Steve J. Shi, Stephen C. Ruppel, Jubal G. Grubb, L.F. Brown, Jr., Yaguang Gu, Dallas B. Dunlap, Martha L. Romero, C. Robertson Handford, Malcolm P.R. Light, Robert E. Barba, Jr., and Bice Cortiula (Petróleos de Venezuela, S.A.); assisted by Robert F. Keirstead, Ke-Sheng Chan, Alvaro Grijalba, Ramiro A. Amaya, Ruth Y. Pineda, Han-Ching Wu, Liying Xu, and Christi G. Nutter

Phase II of the studies on the Mara Este (Mara Liviano) field in the Maracaibo Basin, Western Venezuela, began in January 1999. This 16-month reservoir characterization study is a continuation of initial data

compilation and assessments conducted in late 1997 and early 1998. The objective of these studies is the identification of field-development opportunities in this mature, giant field that produces from naturally fractured reservoirs in the igneous-metamorphic, pre-Cretaceous basement and in the Cretaceous carbonates section, and from Paleocene and Eocene sandstone reservoirs.

Funding of the project is by Petróleos de Venezuela, S.A., Exploración y Producción (PDVSA EyP), Maracaibo. Integrated geological, geophysical, and petrophysical studies are being conducted at the Bureau. Engineering and production data analyses are being conducted by the Laboratory of Petroleum Technical Services Foundation of La Universidad del Zulia, Maracaibo, Venezuela.

The investigations under way at the Bureau include definition of the regional and fieldwide structural and stratigraphic framework; delineation of the detailed reservoir stratigraphy; characterization of natural fractures using core, log, and production data; and determination of the characteristics and distribution of the petrophysical attributes, using seismic, well, and production data. The data base available to the project comprises a 3-D seismic survey, log and production data from 145 wells, and whole and slabbed core and core analysis from selected wells. The results of these investigations will be the basis for reservoir simulation studies by PDVSA EyP.

Reservoir Characterization, Simulation, and Exploitation Planning for the Eocene "B" Sands: Mioceno Norte Area, Lake Maracaibo, Venezuela

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The goal of this advanced integrated reservoir characterization project was to optimize oil production from the Eocene "B" sandstone reservoirs in the Mioceno Norte area of Lake Maracaibo, Venezuela. The Eocene and Miocene reservoirs in the 100-mi² Mioceno Norte area in the northeast part of Lake Maracaibo have produced more than 265 MMbbl of oil since 1930. However, these reservoirs are estimated to have a recovery efficiency of only 27 percent at the end of primary recovery operations. Multiple poorly contacted reservoir compartments in heterogeneous fluvial-deltaic sandstones cause the low recovery efficiency. Furthermore, a complex pattern of closely spaced faults further complicates reservoir heterogeneity.

Full optimization of the remaining hydrocarbon resource base in the Mioceno Norte area of Lake Maracaibo required integrated reservoir characterization consisting of detailed geologic, geophysical (including 3-D seismic interpretation and virtual reality visualization), petrophysical, and engineering analysis of wells. This analysis was performed to (1) characterize the depositional and structural controls on sandstone geometry and reservoir architecture, (2) identify petrophysical characteristics and fluid distribution across the area, (3) identify geologically and engineering targeted infield development wells to effectively drain bypassed reservoir compartments, (4) identify and map remaining oil, and (5) develop reservoir-management strategies through reservoir-simulation programs, culminating in a comprehensive and ranked inventory of new proposed well locations.

In the Mioceno Norte area, Eocene oil reservoirs all lie within "B-member" sandstones of the Misoa Formation. Most B-member sandstones are relatively thin, progradational fluvial-deltaic deposits. The thicker fluvial sandstones, which range from lenticular to tabular, probably represent

incised valley-fill deposits. Analysis of 3-D seismic data reveals a complicated, highly faulted setting where traps formed associated with major faults and along an angular unconformity that occurs at the base of the Miocene.

A synopsis of the reservoir characteristics and reserve-growth strategies for the B member sandstones was outlined on the basis of this advanced integrated geological and engineering analysis. The recommendations proposed are being tested and reconciled with the simulation characterization carried out by Computer Modelling Group, Ltd. The B member reservoirs are highly compartmented, primarily by faults, and the new 3-D seismic interpretation provides a structural model different from that of the existing structural maps. A consequence of the new structural picture is compartments that are not adequately exploited by current well spacing, thus providing multiple opportunities for infill and step-out drilling. The new structural picture also provides opportunity for recompletions in zones that were initially assumed to be in communication with, and/or depleted by, neighboring wells but that are fault separated and therefore underexploited. Moreover, the new structure defined an exploration play in the northwest part of the Eoceno Norte field area that is approximately one-third the size of the main Eoceno Norte field. Targeted infill drilling and recompletion recommendations in Eocene B sandstone reservoirs added significant volumes to the ultimate recoverable oil in this field.

Hydrocarbon Production Opportunities Defined by Sequence-Stratigraphic Analysis and Depositional Systems Characterization, East Guarico Unit, Eastern Venezuela

Douglas S. Hamilton, principal investigator; Paul R. Knox, Michael V. De Angelo, William A. Ambrose, Noel Tyler, and Roger Tyler; assisted by Luciano L. Correa and Ramiro A. Amaya

In 1999, the Bureau, in conjunction with Teikoku Oil de Venezuela, undertook a detailed sequence-stratigraphic analysis and depositional systems characterization of the East Guarico Unit in Eastern Venezuela. The objectives of the study were to define the seismic and structural framework, depositional systems tracts, and hydrocarbon potential of the Oligocene and Eocene Roblecito and La Pascua reservoirs in the East Guarico Unit, leading to exploration drilling prospects.

The data base available for study included 1,000 line kilometers of 2-D seismic data, 8 checkshot surveys, 61 well bores, and production information from existing fields. A sequence-stratigraphic framework was established using the well-bore information and the seismic lines. Mapping of the depositional systems and facies variability was undertaken primarily from the well control, but seismic attributes and inversion analysis from the 2-D seismic data were integrated into the mapping process. The structural framework was defined by the 2-D seismic data and constrained by available well-bore control. Production information was then integrated into the geological and structural framework. The principal hydrocarbon trapping mechanism throughout the unit, in which structural dip is to the north, is considered to be v-shaped fault closure, created wherever the northeast-trending faults branch, resulting in a "v" that is closed in the updip direction. Some known accumulations, however, were not well explained by this mechanism, and some contribution from stratigraphic pinch-out was suspected, increasing the importance of stratigraphic analysis to successful exploration.

Depositional settings of the Roblecito and La Pascua reservoirs, initially thought to be dominantly marine, were identified from core description, log facies, and FMI data as bedload and mixed-load fluvial systems and rare delta-front systems. Sediment transport directions during deposition were principally parallel to regional dip, from southeast to northwest, but in several well-documented instances, fluvial channels were deflected to the northeast, coincident with the northwest edge of horst blocks, indicating subtle structural control on depositional patterns. Geophysical investigations clarified structural patterns and identified an increased number of northeast-trending faults. At-

tribute analysis and inversion modeling were carried out to identify the distribution of fluvial-channel bodies more accurately.

Integration of geophysical and sedimentological analysis confirmed that some accumulations in the East Guarico Unit are the result of combination structural-stratigraphic traps. A total of 15 prospective areas containing 60 reservoir objectives, a number of which were high-priority combination style traps, were identified by the joint study and ranked to provide a drilling portfolio for Teikoku's exploration efforts for 2000 and beyond.

Hydrocarbon Production Opportunities Defined by Integrated Reservoir Characterization, Sanvi-Guere 13/10 Area, Eastern Venezuela

Douglas S. Hamilton, principal investigator; William A. Ambrose, Robert E. Barba, Jr., Michael V. De Angelo, Noel Tyler, Joseph S. Yeh, and Dallas B. Dunlap; assisted by Luciano L. Correa and Ramiro A. Amaya

Following a successful 1998 joint study with Teikoku Oil de Sanvi-Guere to identify exploratory drilling locations, the Bureau undertook a joint study in 1999 to carry out integrated characterization of developing reservoirs in the 13/10 area of the unit. The intent of this study was to incorporate more detailed geological and geophysical analysis with available reservoir engineering and production performance data from discovered reservoirs to identify future development potential. The integration effort was designed to support the construction of a 3-D reservoir visualization model incorporating fault-seal analysis.

Detailed stratigraphic correlation, description of core obtained in the 1998 drilling program, and analysis of FMI data were used to predict the sandstone distribution of bedload and mixed-load fluvial systems and wave-dominated delta and barrier-strandplain systems away from current well control and identify possible stratigraphic compartmentalization. A more detailed interpretation of available 2-D seismic data was carried out to refine the fault model for use in the reservoir visualization model and to identify possible structural compartmentalization. Petrophysical and engineering data such as porosity, permeability, initial and residual saturation, oil-water contacts, lowest known oil, and highest known water were investigated to evaluate productivity of various facies and identify reservoir compartments. Structure, sandstone-thickness and facies maps, and petrophysical characteristics were incorporated into the 3-D model to evaluate cross-fault seal and compartmentalization.

The reservoir section of the Oficina and Merecure Formations was subdivided into 18 depositional units, 16 intervals of which were evaluated. Structural and stratigraphic compartments were documented through the recognition of faults and the mapping of previously unidentified sandstone axes. More than 10 drilling locations in at least 8 stratigraphic intervals were identified and ranked to provide targets for Teikoku Oil de Sanvi-Guere's development drilling in 2000 and beyond.

LAND, WATER, AND ENVIRONMENTAL RESOURCE INVESTIGATIONS

Environmental, Geologic, and Hydrogeologic Studies

Regional Ecological Resource Assessment of the Rio Grande Riparian Corridor: A Multidisciplinary Approach to Understanding Anthropogenic Effects on Riparian Communities in Semiarid Environments

Jay A. Raney, principal investigator; William A. White and Thomas A. Tremblay; Melba Crawford and Amy Neuenschwander (Center for Space Research, The University of Texas at Austin); Frank Judd and Robert Lonard (The University of Texas–Pan American); Gene Paull (The University of Texas at Brownsville)

Funded by the U.S. Environmental Protection Agency,

this multidisciplinary study of riparian communities along the Lower Rio Grande Valley is a cooperative investigation by the Bureau and the Center for Space Research at The University of Texas at Austin, the Earth Science and Biology Departments of The University of Texas at Brownsville, and the Geology and Biology Departments of The University of Texas–Pan American.

Riparian ecosystems of the southwestern United States are characterized by high species diversity and are among the most productive ecosystems of North America. The rapid decline of riparian ecosystems throughout the United States has made riparian conservation a focal issue for the public, Federal and State governments, and private organizations. Among the objectives of this approximately 2-year study are to (1) acquire and analyze high-resolution remotely sensed data from multiple sensors, (2) integrate existing and new field data and remotely sensed data into a geographic information system (GIS), (3) ascertain whether the native communities are maintaining themselves and identify the topographic, edaphic, and other ecological factors that perpetuate these communities, (4) interpret spatial variations in riparian habitats, including comparisons of the northern and southern banks of the Rio Grande, (5) analyze temporal changes at specific locations, and (6) develop a foundation for future analysis of riparian floodplain communities by linking local and remotely sensed regional data using GIS.

The study area includes the lower reach of the Rio Grande from Falcon Dam to the mouth of the river. Detailed local-scale ecological transects of dominant riparian vegetation will be correlated with high-resolution videography and multispectral data to delineate the spatial extent of the riparian community. This correlation will provide ground truth for the classification output from high-resolution (4 to 7 m) hyperspectral and synthetic aperture radar data. Classification output from high-resolution imagery will in turn provide the class mixtures for medium-resolution (20 to 30 m) Landsat thematic mapper (TM) and SPOT multispectral data that cover the entire study area, on both sides of the Rio Grande.

Data on geology, soils, water quality and hydrology, and topographic information from Topographic Synthetic Aperture Radar, as well as laser altimetry data acquired for the study, will be investigated as additional inputs into the classification process and used to help explain temporal and spatial changes in ecological resources indicated in the remotely sensed data. GIS-based spatial models and statistical modeling results will be used to predict the expected future effects of landscape change on plant distribution, biodiversity, and functional organization at multiple scales of resolution. The developed methodologies will help to guide future assessments of riparian regions.

Plume Research Group: Integrated Regional, Site-Specific, and Theoretical Studies of Ground-Water Contaminant Plumes

Bridget R. Scanlon, principal investigator; Rebecca C. Smyth and Alan R. Dutton

An industrial associates group has been established to characterize ground-water contaminant plumes so that contaminated sites are managed and regulated in a logical, timely, and cost-effective manner. The objective of the program is to evaluate the behavior of ground-water contaminant plumes in a variety of hydrogeologic settings. The work is important because of the ongoing need to use data derived from studies of contaminated sites to guide (1) environmental regulation, (2) risk-based corrective action, (3) reliance on natural attenuation, (4) remediation and closure of contaminated sites, and (5) siting of facilities that may impact ground water. The model for this program is based on the study of benzene plumes beneath leaking petroleum storage tanks in Texas conducted by the Bureau. The results of this study convinced regulators to consider natural attenuation as an alternative to active remediation. The Bureau conducted a similar study on methyl tertiary butyl ether (MTBE) plumes in Texas that provided valuable information about the size and potential impact of these plumes on the environment. The primary goal of this program is to provide useful and defensible research to

support decision-making related to the management of plumes at contaminated sites. Our current research is focused on investigating the temporal behavior of MTBE plumes, generating case studies of MTBE plumes, and modeling MTBE plumes to better understand the processes and environmental properties that affect migration.

Evaluation of Electromagnetic Induction as a Noninvasive Technique for Monitoring Water Movement into and beneath Waste Disposal Facilities

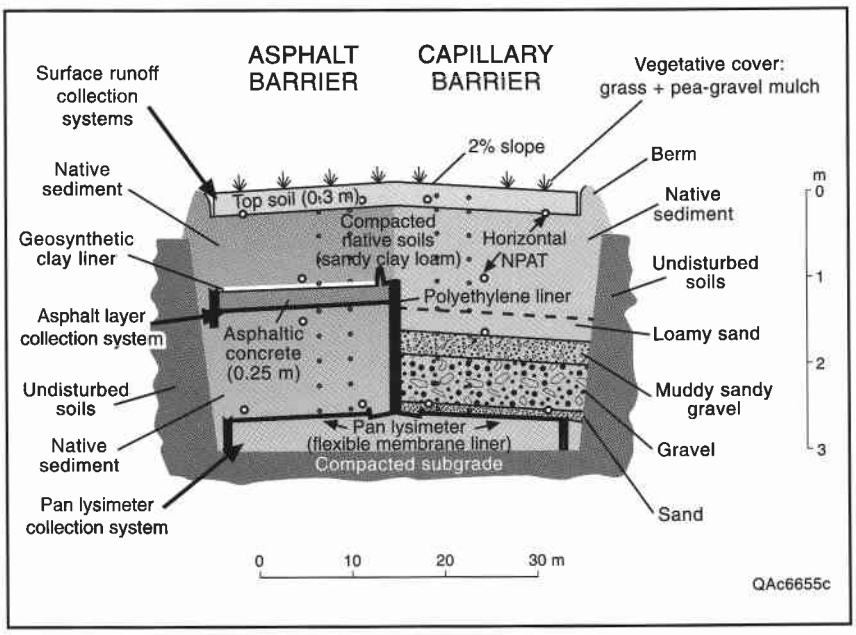
Bridget R. Scanlon, principal investigator; Robert C. Reedy

Interest in noninvasive monitoring techniques such as electromagnetic induction has increased rapidly in the past several years because of the potential risks of destroying the integrity of disposal systems by installing dedicated instruments. In addition, use of noninvasive techniques in contaminated sites avoids creating further contamination through drilling that may provide pathways for contaminant migration. The objective of the proposed research is to develop a system to monitor temporal variability in water content that is noninvasive, capable of integrating over large areas, and capable of locating zones of high water content that could indicate focused flow into, or leakage out of, disposal cells. The proposed monitoring system includes electromagnetic induction, which measures a weighted-average apparent electrical conductivity that varies with water content and other parameters. Monitoring water movement is critical for evaluation of contaminant transport because water moving into disposal facilities or contaminated areas may ultimately leach contaminants into underlying aquifers. Monitoring water movement beneath disposal or contaminated areas may help determine the source of contaminants. This research proposes to extend the use of noninvasive electromagnetic techniques to evaluate spatial and temporal variability in water movement in disposal facilities. The results of the electromagnetic surveys will be tested on the ground with data from conventional water-content monitoring instruments such as neutron probes and time-domain reflectometry systems. The research is being conducted on engineered barriers that were installed near Sierra Blanca, Texas. The site consists of asphalt and capillary barrier systems that are heavily instrumented with time-domain reflectometry probes and neutron-probe access tubes. Monthly monitoring is being conducted with the neutron probe and the electromagnetic induction system. An EM38 meter is being used, and apparent electrical conductivity is being measured. Results of this study should be of great value in studies where noninvasive monitoring is required.

Evaluation of Design, Monitoring, and Modeling Issues Related to Engineered Covers for Waste Containment

Bridget R. Scanlon, principal investigator; Robert C. Reedy and Jinhuo Liang

The purpose of this study is to evaluate design, monitoring, and modeling issues related to engineered covers. The information from this study will be valuable to operators who want to install cost-effective engineered covers and to regulators who need to evaluate proposed cover designs. Engineered covers have been installed in the Chihuahuan Desert of Texas as part of a proposed low-level radioactive waste disposal facility. The site is no longer being considered for waste disposal and can be used as a research facility for this study. The cover designs being evaluated represent alternatives to the traditional RCRA Subtitle C and D covers and include two end-member designs: a restrictive barrier that consists of a geosynthetic clay liner on asphalt at 1.3-m depth and a conductive barrier that consists of a capillary barrier at 2-m depth. These covers have been vegetated and may also be considered evapotranspiration covers. If water movement is restricted to the shallow part of either cover, the designs may be considered similar to monolithic covers. The proposed research will include detailed analysis of monitoring strategies, including comparison of various types of instru-



Cross section of engineered covers for waste containment. The cover on the left consists of a resistive barrier (geosynthetic clay liner overlying asphalt), whereas that on the right is a capillary barrier. These engineered covers are designed to overcome limitations with existing covers that rely on low-permeability clay to reduce infiltration. Such clays generally dry and crack in semiarid regions, resulting in preferential flow through the covers.

mentation, examination of installation issues with respect to development of preferred pathways, and optimization of monitoring programs (instrumentation density and temporal intervals for monitoring). Uncertainty with respect to leak detection will be evaluated using different monitoring designs. Water movement will be monitored under ambient and enhanced precipitation.

A wide variety of computer codes are available to model the performance of engineered covers. Lack of multiyear field data to verify and validate the computer codes used in the numerical simulations limits certainty in model predictions and confidence in simulation results. This facility will develop long-term sets of field data that can be used to verify and validate numerical simulations and to develop a better understanding of the performance of covers in arid environments. Sensitivity and uncertainty analyses of both conceptual models and hydraulic parameters will be investigated. The simulators will be used to predict water movement and percolation through the cover under a variety of conditions, including potential future climate scenarios. Results from this study should provide valuable information to waste operators and State and Federal regulatory officials about the monitoring and modeling of cost-effective engineered cover designs for waste containment in arid regions.

Evaluation of Interplaya Recharge on the Southern High Plains

Bridget R. Scanlon, principal investigator; Robert C. Reedy; assisted by Jinhuo Liang

The objective of this project is to quantify infiltration in response to precipitation events at two interplaya settings located at the Pantex Plant near Amarillo, Texas. We are evaluating data gathered from a site adjacent to Playa 5 located in the southeast area of the Pantex Plant and at the inter-playa recharge monitoring installation located adjacent to the main Pantex Plant facility (Pantex installation). Monitoring adjacent to Playa 5 is restricted to water potential and temperature, whereas water potential, matric potential, temperature, water content, and bulk conductivity are monitored in the Pantex installation. Precipitation data are recorded by Pantex personnel at locations near the monitoring installations. Monitoring adjacent to Playa 5 has been ongoing since 1994 and shows that the subsurface remained dry from mid-1994 to mid-1996 but has been getting progressively wetter. Rapid increases in water potentials at 1.7 and 2.9 m immediately after rainfall events suggest preferential flow to these depths. The most recent monitoring shows that the soils were wetted to 1.7 m. The Pantex recharge monitoring station has been fully operational since October 1998. Thermocouple

psychrometers show rapid infiltration occurred to at least 1 m depth and water redistribution occurred to at least 1.4 m and less than 3.1 m. Water content and bulk-conductivity data monitored with time-domain reflectometry probes were similar to matric potential monitored with the heat dissipation sensors and water potential monitored with thermocouple psychrometers.

Estimates of infiltration in interplaya settings provided by this monitoring program will be an important component of an environmental impact statement that will be required of any new missions at the Pantex Plant. This work is being funded by the U.S. Department of Energy.

A Ground-Water Management Model for the Edwards Aquifer, Barton Springs Segment

Bridget R. Scanlon, principal investigator

The purpose of this project is to develop a user-friendly numerical ground-water flow model to guide the management of the Barton Springs segment of the Edwards aquifer. This model will be an important tool for developing a regional water plan in support of the State Senate Bill 1 planning process. The model will be used to evaluate the impact of current and future pumping and recharge rates on water levels and spring flow to help guide management and conservation policy. This model will be better than existing models because it will be designed to follow fault boundaries, consider vertical variations in permeability, and incorporate results of more recent studies on flow paths, permeability, pumping, and recharge. Aquifer information will be organized in a geographic information system before being loaded into a preprocessor for a finite-difference model. Once the model is calibrated with historical recharge, water-level, and spring flow data, we will use it to make predictions of water levels and spring flow for the regional water plan.

Analysis of Soil Remediation Requirements of Abandoned Centralized and Commercial Drilling-Fluid Disposal Sites

Alan R. Dutton, principal investigator; Rebecca C. Smyth; assisted by Liying Xu and Susan Palachek

Drilling fluids from oil and gas exploration and production activities are sometimes contaminated with saltwater, crude oil, or drilling additives and are disposed of instead of recycled. A small percentage of spent drilling fluid is sent to centralized or commercial sites. Although current practices limit soil contamination at permitted offsite disposal locations, many older centralized commercial sites used for disposal of spent drilling fluid were abandoned without proper closure, leaving some uncertainty as to the extent and character of contaminants. Costs for assessment and remediation of abandoned sites are borne by states when responsible parties are not located or are insolvent.

This new study for the U.S. Department of Energy will provide a synthesis of the data generated and lessons learned from assessment and remediation activities at abandoned oil-field waste-disposal sites in Louisiana, New Mexico, Oklahoma, and Texas. Better documentation and understanding of the relationships among soil contamination, waste constituents, drilling fluids, and constituents of concern will provide a basis for application of risk-based models to oil and gas waste and will make State regulation and State-funded cleanup of these abandoned sites more cost effective.

Capacity Building for Resource Assessment and Responsible Development, Trans-Mexico Border Area

Jay A. Raney, principal investigator; Thomas A. Tremblay, E. Jeri Sullivan, and Robin C. Nava; assisted by Maria Bondarenko, Wan-Joo Choi, and Han-Ching Wu

The purpose of this project is to produce digital maps of the Texas-Mexico border area that can be used as a foundation for other scientific and engineering studies in the region. The Bureau is the lead organization for this collaborative project that includes researchers, staff, and students of the major universities in the Border area: The University of Texas at Brownsville, The Uni-

versity of Texas–Pan American at Edinburg, The University of Texas at El Paso, and Texas A&M International University at Laredo. An important aspect of the project is providing an opportunity for students of the Border institutions to be trained in geographic information systems (GIS) as well as practical geographic and geologic skills. This project has also upgraded the GIS facilities of the Border universities.

Many existing maps of the Border region are commonly available only as printed maps and are specific to Texas or Mexico but end at the Rio Grande. This project is producing digital maps that are then merged into a seamless binational data base. Each of the Border universities has concentrated its efforts on digitizing geologic maps of regions of Mexico that are adjacent to its campus. Using its Geologic Atlas of Texas, the Bureau has produced digital geologic maps of large regions of the Border area in the Lower Rio Grande Valley and Laredo and El Paso regions. These Texas maps are being merged with the digital geologic maps of Mexico produced by the Border institutions to develop seamless geologic maps that have common units on both sides of the border. Additional data sets are being developed by each of the participants.

During the 2 years of this project, the participants have attended review meetings and field trips to discuss various technical issues and facilitate coordination. These meetings have encouraged sharing of technical expertise as well as approaches to solving the various issues unique to this project. Students working on the project have attended and presented the results of their efforts. A major project meeting in El Paso will be the first public presentation of the maps and will provide an opportunity for participants to discuss the final activities planned for this project. This project has produced important results that benefit the Border area and has provided training opportunities for many students.

Comprehensive State Ground Water Protection Program: Core Assessment Project

Alan R. Dutton, principal investigator; Robin C. Nava

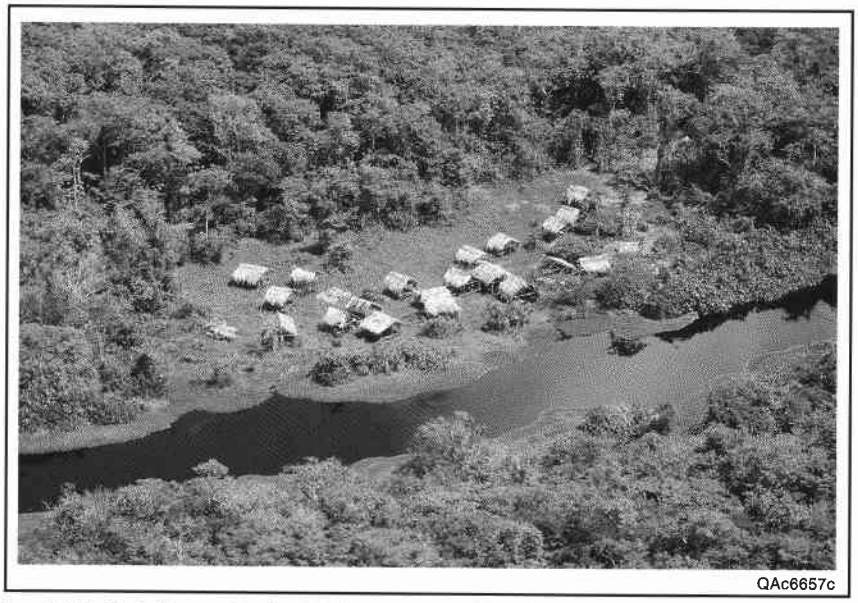
The U.S. Environmental Protection Agency (EPA) encourages states to adopt an approach to ground-water protection described as the Comprehensive State Ground Water Protection Program (CSGWPP). The Texas Natural Resource Conservation Commission (TNRCC), the State agency responsible for enforcing ground-water protection in Texas, requested that the Bureau evaluate how the state meets the CSGWPP program requirements, using the TNRCC's petroleum storage tank (PST) program as an example. The Bureau's review included summarizing the role of various State agencies involved in ground-water management, the TNRCC's efforts to implement a core CSGWPP program, a summary description of the PST program, and a comparison of the PST program to the EPA-specified activities of a CSGWPP program.

Geo-Environmental Characterization of the Delta del Orinoco, Venezuela

Noel Tyler, project director; Edgar H. Guevara and Jay A. Raney, principal investigators; Andrew G. Warne, Andres Aslan, James C. Gibeaut, William A. White, Thomas A. Tremblay, Rebecca C. Smyth, and John R. Andrews; Melba M. Crawford and Solar S. Smith (Center for Space Research, The University of Texas at Austin); Pavel Rodriguez (Petróleos de Venezuela, S.A.); assisted by Asif Muzaffar

This project, funded by Petróleos de Venezuela, S.A., Coordinación Desarrollo Armónico de Oriente (PDVSA/DAO), is an interdisciplinary study of the modern Orinoco delta in northeastern Venezuela. These studies form part of PDVSA's program to encourage responsible development of this environmentally sensitive region. Venezuelan organizations also participate in the project, and researchers at The University of Texas at Austin Center for Space Research work closely with Bureau scientists in imagery processing and computer analysis.

The objective of the Bureau's work is to describe active geologic processes, the geologic framework, and the land cover of this fragile and nearly pristine environment. These in-



Small, tidally influenced caño (blackwater stream) and abandoned native Warao village on the lower Orinoco Delta, Venezuela. Many caños of the delta are characterized by water rich in organics derived from adjacent forested and herbaceous swamps. These blackwater caños contrast with brownwater caños that transport Orinoco water and sediment. The Warao abandon sites and clear and rebuild new sites on a regular basis. Photo by Jay A. Raney.

vestigations are to be integrated with topical studies conducted by the Venezuelan researchers collaborating on the project. The Bureau has developed a data base of environmental baseline information from both our own studies and those of collaborators in Venezuela and worked closely during the year with DAO in the overall coordination of these activities. During the course of this 5-year project, a digital atlas of the delta, including a multiattribute geographic information system data base, will be developed that will benefit all who are concerned about the natural resources and sustainable development of this region.

Studies during 1999, the second year of the project, focused on the northwestern part of the delta, where most of the activities of the petroleum companies exploring or operating in the area occur. Project activities during the year included four field expeditions to this part of the delta, compilation, review, and synthesis of existing information, acquisition and processing of satellite imagery (Landsat, Radarsat, JERS), and detailed mapping of geoenvironments in the northwest delta. The regional geomorphology and depositional systems of the Orinoco Delta and northeastern South America were evaluated to identify and evaluate critical physical processes controlling delta ecosystems.

During the field expeditions, shallow borings at selected sites were excavated, described, and sampled to evaluate the late Holocene evolution of the delta. Transects were made to characterize the size and geometry of distributary and tidal channels, and vegetation inventories and detailed descriptions were also made at selected sites for geoenvironmental mapping. Airplane reconnaissance flights were made across the delta to evaluate geoenvironments initially identified in satellite imagery, obtain a photographic record of otherwise locally inaccessible areas, and identify and map different coastal environments. Differential Global Positioning Satellite data collected during the expeditions allowed georeferencing of the satellite imagery and precise identification of sampling locations and airplane flyover and boat track lines.

Remediation-Focused Hydrogeological Investigations of Abandoned Oil Field Cleanup Sites

Alan R. Dutton, principal investigator; Robin C. Nava, Jeffrey G. Paine, Rebecca C. Smyth, E. Jeri Sullivan; assisted by Wan-Joo Choi, William H. Doneghy, Jordan W. Forman, Jr., Andy M. Graham, and Susan Palachek

The Railroad Commission of Texas (RRC) oversees the cleanup of abandoned oil field sites throughout Texas to protect public health and safety and the environment. The Bureau's investigations focused on defining the subsurface source and extent of contamination, applying, to the largest extent possible, low-cost, nonintrusive, and state-of-the-art hydrogeological models and investigation techniques.

Since 1995, 15 oil field sites have been studied for the RRC.

Work during 1999 focused on three sites having saltwater or crude-oil contamination. Research at a saltwater site in an unincorporated area on Houston's northeast side followed a phased approach: tracking saltwater contamination using electromagnetic geophysics; proving up the geophysics results using a truck-mounted hydraulic probe to core, log, and sample the shallow subsurface; and constructing monitoring wells in the inferred saltwater plume. At the other two sites, crude oil has been found seeping out of the banks of two rivers. At one site we cored 12 boreholes and constructed monitoring wells to assist the RRC in identifying which operator might be responsible for the oil seep. At the other we conducted a contaminant-vapor soil-gas survey (using a hydraulic probe to get soil-gas samples for field analysis on a gas chromatograph) and drilled more than seven core holes to identify the position and most likely source of the oil plume.

Salt Cavern Development in Bedded Salt Areas: An Analysis of Industry Experience in a Geologic Context

Susan D. Hovorka, principal investigator; Robin C. Nava; assisted by Susan Palachek

Solution-mined caverns in salt are low-cost, low-risk, large-volume facilities that can be adapted for a variety of uses. This study, funded by the U.S. Department of Energy through the Salt Cavern Research Partnership documents the long-term industry experience with solution-mined caverns in bedded salt of the Permian Basin of Texas. This compilation will serve regulators and the solution-mining industry by documenting, making readily available, and preserving industry experience to help reduce environmental and financial risks during future cavern development.

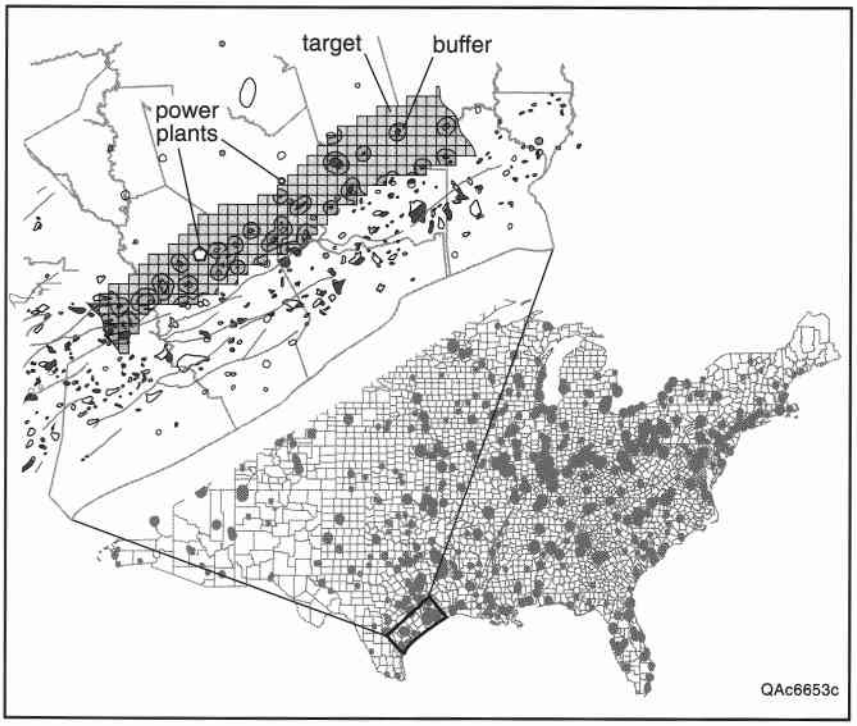
The data base of cavern experience compiled from Railroad Commission of Texas files and industry sources is linked to detailed stratigraphic and structural studies of salt in the Midland Basin and Panhandle field areas. Available historical and descriptive data include information on well construction, cavern development, use, monitoring history, and maintenance of storage and brine-production caverns. Geologic data (including a detailed stratigraphic and facies analysis of the salt-host material, description of above-salt anhydrite used for casing seats, characteristics of the above-salt interval, and characterization of the hydrologic setting) were compiled and analyzed. New detailed geologic data for Carson, Gray, Potter, Moore, and Hutchinson Counties of the Texas Panhandle show the geologic context for caverns sited in multiple salt beds having complex geometries. Analysis and integration of cavern history with the detailed geologic setting data allow extrapolation of cavern-performance expectations throughout the salt areas of the Permian Basin and permit comparison between the performance of these salts and bedded salt in other basins.

Optimal Geological Environments for Carbon Dioxide Disposal in Saline Water-Bearing Formations (Aquifers) in the United States

Susan D. Hovorka, principal investigator; Paul R. Knox, Martha L. Romero, and Thomas A. Tremblay

Saline aquifers have been widely recognized as having high potential for very long term (geologic-scale) sequestration of greenhouse gases, particularly CO_2. The same properties that make saline aquifers desirable for sequestration—isolation from the surface and minimal use as a resource—make them typically poorly characterized.

This study, funded by the U.S. Department of Energy, is compiling information on geologic properties that affect the usefulness of a saline formation for CO_2 sequestration for 21 saline units in the continental United States. Six formation properties that affect optimal injectivity are depth, permeability, formation thickness, net-sand thickness, percent shale, and sand-body continuity. Effective trapping is necessary to isolate the CO_2 from the atmosphere to prevent contamination of potable water and catastrophic leaks of CO_2 that might endanger hu-



One of the options to reduce atmospheric emissions of the greenhouse gas carbon dioxide is to capture it before it is released and to inject it back into the subsurface. This figure demonstrates using geologic data in a geographic information system to identify optimal geologic formations for carbon dioxide injection beneath fossil fuel–burning electric-power-generation plants in an area of the Texas Coastal Plain. Dot size indicates calculated 1996 carbon consumption at each plant. The demonstration target is high-permeability Frio deltaic sandstones at subsea depths of 4,000 to 6,000 ft. Buffer zones of about 2 mi in diameter around features that could cause potential conduits of leakage, such as faults, domes, and producing oil fields, were delineated and eliminated from the target area.

man health and safety. Eight formation properties related to effective trapping are being inventoried: top-seal thickness, continuity of top seal, hydrocarbon production from interval, fluid-residence time, flow direction, CO_2 solubility in brine (pressure, temperature, and salinity), rock/water reaction, and porosity.

We are using reservoir characterization and geologic play approaches to extend our knowledge from well-known areas (saline formations closely associated with hydrocarbon production) to poorly known areas (potential large-volume, unproductive saline formation targets for sequestration) by applying conceptual geologic and hydrologic models. Reservoir characterization and play approaches are standard techniques for hydrocarbon exploration and development but require adaptation to explore for optimal hydrogeologic settings for CO_2 injection in various types of geologic environments.

Water and the Environment in Southwest Texas

Blaine Bennett (South West Texas Junior College), principal investigator; Susan D. Hovorka and Violetta Lien (Department of Education, The University of Texas at Austin)

This goal of this project is to instruct middle school teachers in rural areas of southwest Texas in how to extract information from maps, pamphlets, and the Internet to apply geoscience concepts to understanding critical water-resource issues of the area. The project is funded by a grant from the Texas Higher Education Coordinating Board, Eisenhower Professional Development Program to SWETnet, a consortium of 21 rural public schools managed by Southwest Texas Junior College. To bring together research staff in Austin and teachers from widely separated schools, this course was conducted partly by videoconference, E-mail, and the Internet. Hands-on materials, manipulatives, VRML models, and E-mail exchanges were used to support inquiry and foster participant involvement during the videoconferences. Field trips, labs, and presentations from resource people in the project area complemented the distance learning.

Using GIS Technology to Explore Earth Systems and a Virtual Tour of the Edwards Aquifer

Bricolage Interactive Design, Inc; Susan D. Hovorka, John R. Andrews, and Scott D. Rodgers

This project, in partnership with Bricolage Interactive Design, Inc., and funded by a Texas Education Agency Technology Integration into Education grant is developing Web-based methods for supplying materials and the expertise to apply them in the classroom to teachers in distant parts of the state.

We are developing Internet-based instructional materials for public school students to investigate two topics. One data set supplies digital sets and needed background for students to examine the relationships among geology, topography, land use, and soils in various parts of the state. The second data set lets students experiment with a manipulatable 3-D model of the Edwards aquifer. Through this medium, students can observe the impact of various recharge and water-use scenarios on water levels and spring flow in the aquifer.

Estimating Depth to Bedrock

Jeffrey G. Paine, principal investigator

This project, funded by the Texas Department of Transportation (TxDOT), represents a cooperative effort by the Bureau and the Center for Transportation Research at The University of Texas at Austin to estimate depth to bedrock across the state of Texas using available soil and geologic data along with rapid geophysical tests. Depth-to-bedrock estimates, which are necessary for assessing pavement condition, are currently based on analysis of falling-weight deflectometer data without the benefit of the abundance of information available on near-surface soils and rocks. Considerable effort has been expended over the last few decades by earth scientists to produce maps, cross sections, and soil profiles that focus on the upper few meters of the subsurface, a critical zone for roadway design and performance. These data provide a semiquantitative basis for determining regional and local differences in expected bedrock rigidity and depths to bedrock across Texas. Further, they can complement field measurements of depth to bedrock by allowing optimized test design for anticipated bedrock depths and by providing a geological context for site-specific test data.

During 1999, Bureau researchers designed, built, and tested a prototype seismic refraction instrument (the Seismic Refraction Bedrock Analyzer, or SRBA) to rapidly acquire more accurate information on bedrock depth and physical properties beneath pavement than can be obtained from geologic maps alone. TxDOT employees will be trained to use this instrument routinely to monitor pavement and substrate condition. Potential geological uses of the SRBA include bedrock mapping in areas of poor exposure, detecting sinkholes, and establishing physical properties of rock types for engineering design and construction.

Review of Data on Hydrogeology and Related Issues in Andrews County, Texas

Jay Raney, principal investigator; Alan R. Dutton

With the 1998 denial of a license application by the State for a low-level radioactive waste repository in Hudspeth County, attention moved to consideration of one or more commercially operated waste-disposal sites in Andrews County. The Bureau was asked by the Texas Low-Level Radioactive Waste Disposal Authority to review ground-water issues for licensing a site to receive low-level radioactive wastes generated in Texas. Licensing requirements are spelled out in State regulations (TRCR Part 45). Our review consisted of looking at published information on the hydrogeology of Andrews County and documents compiled by the operators of two waste sites. We looked at data on the extent of the High Plains aquifer, its saturated thickness, and features affecting recharge and discharge of ground water.

Andrews County lies at the southern limit of the High Plains aquifer, which includes the Ogallala Formation as well as parts of older formations, and the aquifer material tends to be thinner in Andrews County than to the north. The aquifer is thinnest or possibly absent in one area in the western part of Andrews County along the border with New Mexico and another area in the south-central part of the county near the border with Ector and Winkler Counties. Our review found that additional scientific data would be needed to confirm the absence of the High Plains aquifer in these areas and address site-suitability requirements for licensing.

Training on Use of Numerical Models of Ground-Water Flow

Robert E. Mace, principal investigator

During 1999, Bureau staff provided on-site training on the use of numerical models of ground-water flow to members of the Water Resources Planning Division (Availability Section) of the Texas Water Development Board. The training included workshops on the use of modeling software, including Visual MODFLOW and Processing MODFLOW, and the linkage between modeling and geographic information system software. The workshops focused on using the software to develop a model of ground-water flow in the Trinity aquifer of Central Texas.

A Permeability and Storativity Data Base for the Carrizo-Wilcox Aquifer in Texas

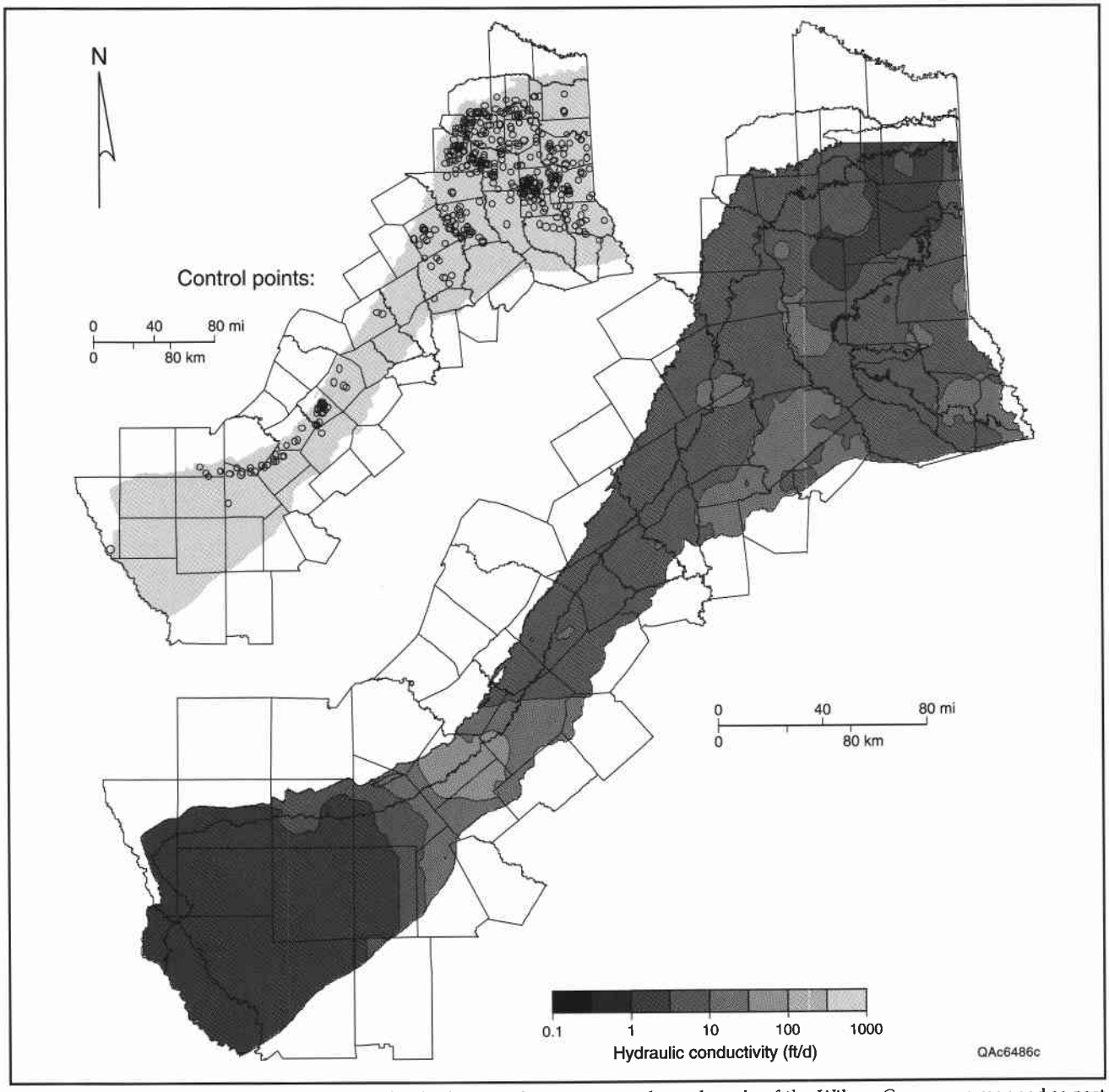
Robert E. Mace, principal investigator; John R. Andrews and Rebecca C. Smyth; assisted by Liying Xu and Jinhuo Liang

Transmissivity and hydraulic conductivity describe the general ability of an aquifer to transmit water (over the entire saturated thickness for transmissivity and over a unit thickness for hydraulic conductivity) and are among the most important hydrogeologic data needed for managing ground-water resources. To support initiatives of the Texas Water Development Board, the Bureau used numerous sources to develop a data base of more than 7,400 estimates of hydrogeologic properties for the entire Carrizo-Wilcox aquifer in Texas. The Carrizo-Wilcox aquifer provides water to all or part of 60 Texas counties along a band that parallels the Gulf Coast between the Rio Grande and the Sabine River. Measurements were compiled from approximately 4,450 wells. Transmissivity and hydraulic conductivity for all tests in the Carrizo-Wilcox aquifer were found to be log-normally distributed. Transmissivity ranges from about 0.1 to 10,000 $ft^2\ d^{-1}$ and has a geometric mean value of about 300 $ft^2\ d^{-1}$; hydraulic conductivity ranges from about 0.01 to 4,000 $ft\ d^{-1}$ and has a geometric mean value of about 6 $ft\ d^{-1}$. Transmissivity and hydraulic conductivity vary spatially in the Carrizo-Wilcox aquifer. Semivariograms show that transmissivity and hydraulic conductivity values in the Carrizo Sand and undivided Wilcox Group are spatially correlated with local-scale heterogeneity.

Ground-Water Availability in the Carrizo-Wilcox Aquifer in Central Texas

Alan R. Dutton, principal investigator; Gregory J. Jeffers, Robert E. Mace, Robin C. Nava, Bridget R. Scanlon, and Rebecca C. Smyth; assisted by Jeffrey S. Beckage, Wan-Joo Choi, Susan Palachek, and Thomas A. Tremblay

In late 1998 San Antonio Water System (SAWS), Alcoa, Inc., and San Antonio's City Public Service announced a contract for SAWS to receive as much as 40,000 to 60,000 acre-ft/year of ground water pumped from the Carrizo-Wilcox aquifer at existing and proposed lignite mines in Central Texas. Previous hydrogeologic investigations of this part of the aquifer have been regional in perspective. To assess the general availability of ground water in the Carrizo-Wilcox aquifer between the Colorado and Brazos Rivers, the Texas Water Development Board (TWDB) asked the Bureau to develop a ground-water simulation model to look at ground-water availability in light of the contract as well as of other anticipated increases in ground-water withdrawal.



Hydraulic conductivity, which is the ease with which ground water moves through rock, of the Wilcox Group was mapped as part of a state-wide study of the Carrizo-Wilcox aquifer.

The TWDB set up an Advisory Group that included interested parties and technical experts outside the Bureau. The Advisory Group identified five scenarios of ground-water withdrawal for the period 2000 through 2050 to be studied. On the basis of the calibrated model, ground water in the Carrizo-Wilcox aquifer in the study area was predicted to remain available to meet the five withdrawal scenarios through the year 2050. The aquifer units were forecast to remain fully saturated except for near the centers of major pumping areas. Simulated rate of decline of water levels, however, remained constant through 2050, and continued drawdown would be expected as long as such rates of pumping continued. Since completion of the study, the ground-water simulation model has been used outside the Bureau to begin the process of designing the actual locations and pumping rates of well fields.

Support of the State Energy Conservation Office in Environmental Oversight of the U.S. Department of Energy Pantex Plant

Alan R. Dutton, principal investigator; Robin C. Nava and Bridget R. Scanlon

Since 1995 the Bureau has participated with other State agencies in supporting the State Energy Conservation Office in environmental oversight of the U.S. Department of Energy's (DOE) Pantex Plant near Amarillo, Texas. During 1999 the Bureau's main activities have included assisting in the State review of DOE and Pantex documents and presenting an overview of the hydrology of the Ogallala aquifer in the vicinity of the Pantex Plant as part of a public information workshop titled "Groundwater 101."

Hydrologic Needs Assessment and Technical Support for the Panhandle Regional Water Planning Area

Robert E. Mace and Alan R. Dutton, principal investigators; Robert C. Reedy and Bridget R. Scanlon; assisted by Jinhuo Liang, Susan Palachek, and Liying Xu

Senate Bill 1 was enacted in the 75th Texas Legislature to provide the basis for developing a broad-based water-use and management plan for both surface water and ground water for the entire State by 2001. For the Panhandle Regional Water Planning Area, the Bureau is providing support that includes assessing groundwater availability and evaluating the effects of alternative water demand scenarios. A major part of the effort involves building a detailed groundwater simulation model of the northern part of the Texas Panhandle; model boundaries extend into New Mexico, Oklahoma, and Kansas. A geographic information system is being used to prepare spatial data for loading into the model. In 2000, the calibrated model will be transferred for use as a planning tool by members of the Regional Planning Group while the Bureau completes its study of aquifer resources and management strategies.

Mapping Near-Surface Salinization Using Long-Wavelength AIRSAR

Jeffrey G. Paine, principal investigator

Recent Bureau tests of high-resolution, airborne electromagnetic induction (EM) mapping of near-surface salinization revealed that the method is technically successful but impractically expensive when applied over large areas. Less expensive methods are needed to identify priority areas within major watersheds where soil and water salinization has occurred. This 3-year project, funded by the National Aeronautics and Space Administration (NASA), will examine whether NASA's airborne synthetic aperture radar (AIRSAR) can be used to rapidly screen watersheds for salinization hotspots, which will allow high-resolution airborne and ground-based EM surveys to be focused on those areas where problems are likely to exist.

We are assessing the utility of the radar method by acquiring long-wavelength AIRSAR reflectivity images at two Texas test sites (one in the Red River watershed near Lake Texoma and another in the Colorado River watershed near San Angelo) where extensive airborne and ground-based EM surveys have already been conducted. These reflectivity images, which are affected by both the roughness of the surface imaged and the electrical properties of the near-surface materials, may reveal an electrical conductivity signature related to the large increase in ground electrical conductivity that accompanies salinization. The first AIRSAR flights over the test areas were completed in May 1999 and are currently being analyzed.

Rapid Geophysical Identification and Assessment of Ground Water for the Lower Rio Grande Valley

Jeffrey G. Paine, principal investigator

The Rio Grande Water Planning Region, consisting of eight South Texas counties, is subject to severe water shortages during droughts and urgently needs new, shallow ground-water resources to assure adequate water supplies

for municipal, agricultural, and industrial uses. These additional resources will provide both immediate and long-term relief to a region that needs assured access to reliable water supplies. In a cooperative project funded by the Texas Water Development Board (TWDB), Bureau and TWDB staff are applying advanced airborne and ground-based geophysical methods to rapidly and cost-effectively assist South Texas communities in delineating promising water-bearing subsurface units, estimating depth to water, and assessing water quality of potential resources.

Recent work by the Bureau on behalf of the TWDB and the Railroad Commission of Texas has demonstrated the effectiveness of airborne and ground-based applications of the electromagnetic induction (EM) method in water-resource investigations. This method, long in use in minerals exploration, has been adapted successfully to identify salinized soil and water in West and North-Central Texas and the Panhandle. The EM method detects changes in the electrical conductivity of the ground that are caused by variations in rock type, water saturation, and water chemistry.

Water prospecting in the Rio Grande region using EM exploits several known relationships. In this part of the Gulf Coastal Plain, near-surface sediments consist of interbedded sand, silt, and clay units deposited in the ancestral Rio Grande delta and associated coastal depositional systems. The most abundant water resources are found in the sand-rich units. These sand bodies and the adjacent clay-rich units are likely to have differing electrical conductivities, enabling water-bearing strata to be detected laterally and vertically with EM equipment. Once the locations and shapes of these sand bodies are delineated with airborne or ground-based instruments, their measured electrical conductivities can be used to estimate water quality. High-total-dissolved-solids water has high electrical conductivity; fresh water has low electrical conductivity.

Principal products will include a summary report and a geographic information system data base that will include conductivity maps at selected depths, surface geology, water-well locations, and interpreted water-resource quality and availability. The summary report will describe the methods used, present the results of the geophysical surveys, interpret water-resource quality and availability in the study areas, and evaluate the usefulness of the EM method and its potential application elsewhere in Texas.

CO_2 Sequestration in Abandoned Hydrocarbon Reservoirs

Robert J. Finley and Mark H. Holtz, principal investigators; assisted by Carlos A. Rodney

Emissions of industrial greenhouse gases have increased the total load of carbon in the atmosphere. Although the long-term consequences of these emissions are hotly debated, one possible outcome is the alteration of global climate as greenhouse gases trap heat at the Earth's surface. The electricity-generation industry is currently a major source of atmospheric CO_2 emissions, and one industry challenge in the coming decades may be to profitably employ advanced technology that reduces CO_2 output while maintaining generation availability and reliability. There are likely to be many different strategies applied to new generation additions, but the viable alternatives for existing facilities are relatively limited. Capture and sequestration of CO_2 in mature oil reservoirs appear to be one important management alternative for the existing generating unit.

The likelihood that CO_2 disposal in hydrocarbon reservoirs will become economically feasible is greatly increased if the disposal process provides readily quantifiable ancillary benefits, such as enhanced oil recovery (EOR) through CO_2 injection. Whereas the benefits of reducing CO_2 emissions are long term, global, and potentially difficult to quantify, the benefits of enhanced oil recovery are immediate and quantifiable. The proximity of large power plants to oil and gas reservoirs, many of them nearing their apparent economic limit, makes Texas the logical geographic area to test the feasibility of this method of greenhouse-gas sequestration in the United States. Funded by the Electric Power Research Institute, this preliminary Bureau investigation evaluated

the suitability of Texas reservoirs for sequestering CO_2 produced by major power plants. Preliminary analyses indicate that CO_2 capture for lignite- and coal-fired plants in Texas may be cost effective when compared with fuel-switching these same boilers to natural gas. From a policy standpoint, it may be desirable to encourage CO_2 capture retrofit initially, as opposed to fuel switching, to achieve overall lower levels of CO_2 emissions at a comparable cost.

Previous research indicated that a primary target for EOR in Texas is estimated at 74 billion stock-tank barrels (BSTB) of residual oil. This study finds that 8 BSTB of this resource is within a 90-mi (145-km) radius of the candidate coal- or lignite-fired plants in Texas. Additional oil resources beyond this 8 BSTB are also available from oil fields located near natural-gas-fired facilities, but additional CO_2-effluent-management issues need to be addressed with these facilities. Factors influencing the recovery of these resources include CO_2 production cost and availability, generation-unit characteristics, transportation cost, environmental regulations, and oil prices.

Modeling conducted in this study indicates that CO_2 flooding can produce oil that would not otherwise be recovered, at an incremental cost between $6 and $16 per stock-tank barrel. In addition, it is likely that between 12 and 20 years of CO_2 production from the candidate lignite- or coal-fired boilers can be sequestered from these generation facilities. Therefore, we conclude that there is substantial potential for using utility plant boiler effluent as a CO_2 supply source for flooding and using mature oil reservoirs for CO_2 sequestration. Development of this potential resource base may be facilitated through further research and policy initiatives.

Coastal Studies

Investigation of Shoreline Change in the Vicinity of Rollover Pass

James C. Gibeaut, principal investigator; William A. White, Roberto Gutiérrez, and Thomas A. Tremblay; assisted by Hai Dong

The Bureau is providing technical support to the Office of the Attorney General for the State of Texas and the Texas Parks and Wildlife Department in determining the amount and cause of shoreline retreat in the vicinity of Rollover Pass on Bolivar Peninsula. Rollover Pass is a small, artificial tidal inlet connecting the Gulf of Mexico and East Galveston Bay. It was cut in 1954 to enhance fishing in the area, and it is currently stabilized with bulkheads and short jetties. There is concern, however, that the pass has increased beach erosion along the Gulf of Mexico shoreline. This project is investigating shoreline changes before and after the pass was cut to help determine the effect of the pass on the adjacent beaches. The Bureau is using several types of surveys to measure the shoreline changes, including (1) historical vertical aerial photography, (2) beach profiles (topographic ground surveys), (3) Global Positioning Satellite shoreline surveys, and (4) airborne laser altimeter surveys. All data are being combined so that shoreline movement and beach volume changes can be compared for various time periods.

Classifying and Mapping Shoreline Types along the Lower Texas Coast

William A. White, principal investigator; Thomas A. Tremblay and James C. Gibeaut

Funded by the Texas General Land Office, this project is part of the Oil Spill Response and Contingency Planning effort by the natural resource trustee agencies in Texas. The purpose of this regional, comprehensive study is to characterize and map different shoreline types that occur along the Gulf of Mexico, in the interior bays, and along the Gulf Intracoastal Waterway. Shorelines along the upper and central coast have been previously classified and mapped by the Bureau. This project, which focuses on the lower coast along Padre Island, Laguna Madre, and Baffin Bay, will complete the shoreline mapping work for the Texas coast. Results of the study will be used by State and Federal agencies responsible for managing coastal resources.

Shoreline along the mainland side of south Laguna Madre characterized by riprap and bulkheads. These features are among approximately 20 shoreline types that are classified in terms of their sensitivity to oil impacts and the relative difficulty of cleanup activities. Marshes and mangroves are ranked the highest in terms of their sensitivity to environmental damage. Photo by William A. White.

Shorelines are classified and ranked according to their sensitivity to oil-spill damage. For example, hard, manufactured structures such as seawalls exposed to high-energy waves generally have low sensitivities to oil-spill cleanup activities, whereas wetlands (marshes and swamps) have high sensitivities. The classification scheme also incorporates shore morphologies, slopes, composition, and wave exposure. Shoreline types are determined from low-altitude color video surveys and aerial photographs, delineated on 1:24,000-scale topographic maps, and field checked from the air and on the ground. The mapped shorelines are then digitized, and the data formatted in a geographic information system. Final products of the project include digital files of the shoreline classifications and a report that describes the shoreline types and presents examples from the study area.

Integrity of Houston Ship Channel Archeological Sites

Jeffrey G. Paine, principal investigator

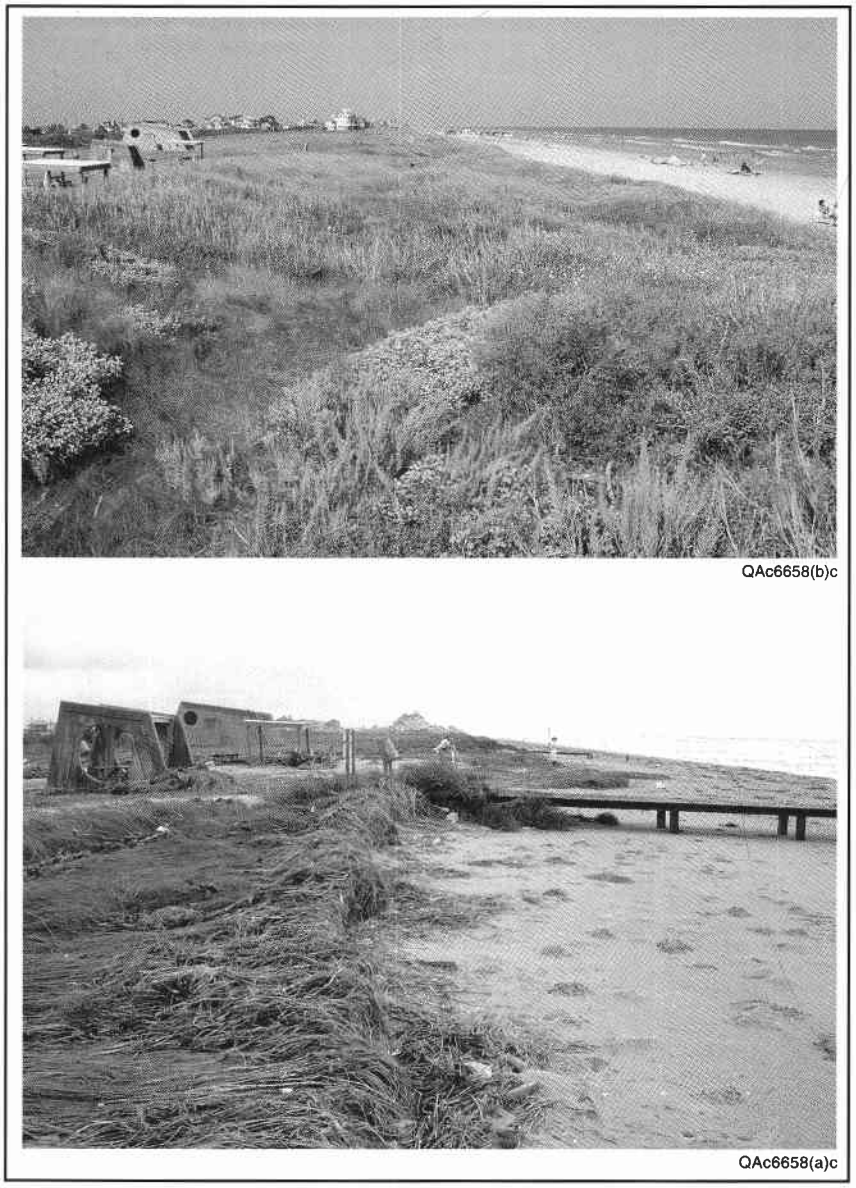
This joint project with the Texas Archeological Research Laboratory was funded by the Galveston District, U.S. Army Corps of Engineers. Bureau researchers conducted geomorphological studies and analyzed historical aerial photographs to determine the likelihood that archeological sites reported along the Houston Ship Channel over the last few decades remain intact. Galveston Bay is one of the most altered and rapidly changing coastal areas in the United States. In addition to natural inundation caused by relative sea-level rise, extensive dredging and disposal activities, hydrocarbon exploration and production, and groundwater withdrawal have caused further subsidence, land-use changes, and modification of near-surface sediments that make assessment of archeological site integrity challenging.

In this project, completed during 1999, Bureau researchers assisted archeologists by determining whether reported sites are likely to be either intact, submerged by rising sea level, eroded as shorelines have retreated, covered by subsequent dredge material, or reworked remnants of material dredged from nearby ship channels. This information allowed archeologists to focus labor-intensive excavation efforts on those sites that are most likely to be intact and significant.

Dune and Beach Dynamics in Galveston County: Critical Information for Coastal Management

James C. Gibeaut, principal investigator; Roberto Gutierrez; assisted by Robin C. Nava

During the passage of Tropical Depression Josephine in October 1996 and Tropical Storm Frances in September 1998, the dunes and beaches along Galveston County, Texas, significantly eroded and put many structures at



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Photographs of the beach at the State Park on Galveston Island, Texas. The top photo was taken on August 8, 1998. The Gulf of Mexico is on the right, and two vegetated dunes are behind the wide sandy beach. The bottom photo shows the same location on September 16, 1998, 5 days after Tropical Storm Frances struck. Frances completely removed the dunes and caused dramatic beach erosion. Bureau scientists are conducting ground and airborne laser terrain mapping surveys to track and gain a better understanding of the recovery of beaches and dunes after large storms. Photos by James C. Gibeaut.

risk of failure. After Frances, 107 houses were determined by the Texas General Land Office to be seaward of the vegetation line and hence on the public beach. This project, which is funded by the Texas Coastal Management Program and the National Aeronautics and Space Administration, is providing critical information for the monitoring and management of the coastal dune and beach system along the Galveston County shoreline.

Changes in beach and dune topography were documented by comparing topographic transects oriented perpendicular to the shoreline (beach profiles) at 32 locations. All profiles were measured in September 1994 and again in November 1997. Subsets of the profiles were measured in 1995, 1996, and within weeks before and after Tropical Storm Frances in September 1998. Data on ocean level, waves, wind, and surface currents were compiled for the period to examine the response of the shoreline to certain conditions. In conjunction with this study, airborne laser terrain mapping (ALTM) surveys were conducted in November 1997, August 1998, and September 1998.

From 1994 to 1998, eight tropical storms and hurricanes affected the northwestern Gulf of Mexico. Of these eight storms only Josephine in October 1996 and Frances in September 1998 caused significant changes in the dunes and beaches of the upper Texas coast. Conditions generated by Josephine appear to have just exceeded the threshold above which significant episodic erosion occurs along the upper Texas coast, particularly in areas with high long-term shoreline erosion rates. On the basis of conditions during Josephine and other storms that did not cause significant erosion, it is estimated that the threshold condition is an ocean level that exceeds 0.9 m above sea level, coincident with wave heights that exceed 3 m for at least 12 hours. Lower threshold conditions apply if the beaches and dunes have not fully recovered from a previous storm.

Frances caused significantly more erosion than Josephine did. Vegetation-line retreat caused by Josephine was 5 to 15 m along West Beach on Galveston Island, and for Frances it was 15 to 25 m. Frances also completely eroded foredunes that rose 2.5 m above the beach-berm tops and caused overwash, whereas Josephine only removed or cut back 1.5- to 2-m-high incipient dunes and sand piles. Preliminary data show that Frances did not erode any washover dunes that were more than 3 m above the beach berm tops or where the dune system was more than about 40 m wide. These areas are on the west end of Bolivar Peninsula and 11 to 14 km northeast of San Luis Pass on West Beach, where long-term shoreline retreat rates are relatively low. Additional data will be collected in 1999 to better define the effects of Frances.

Josephine was 500 km south of Galveston Bay when water levels and wave heights peaked along the Galveston County shoreline. Maximum wind speed at this time was only 30 kn. Coastal residents and managers should note that such a weak and distally tracking storm can cause significant beach and dune changes and concomitant property damage and management issues. Real-time data on water levels and wave heights are available for the Galveston area, and emergency responders could monitor these data during a storm to get an indication of what damage to expect. Officials should also be aware of the present conditions of the beach and dune system along the coast to anticipate the effects of the next storm.

Coastal Hazards Atlas of Texas: A Tool for Hurricane Preparedness and Coastal Management

James C. Gibeaut, principal investigator; Thomas A. Tremblay, Sarah B. Dale, and Gregory J. Jeffers

The Texas Coastal Management Program is funding this 3-year joint project of The University of Texas at Austin, the Texas Department of Public Safety, and Texas A&M University to develop a Coastal Hazards Atlas of the Galveston Bay and Sabine Lake area. The information provided by the Atlas is needed by local governments, State agencies, the general public, and others concerned about responsible development, environmental protection, and emergency preparedness. The Atlas was inspired by the atlas that was published by the Bureau in 1974, *Natural Hazards of the Texas Coastal Zone*. We are completely revising and updating this atlas to include current transportation routes (needed for evacuation planning), hurricane flooding areas, the best available data on shoreline erosion, and new information on subsidence and faulting. The text will be rewritten to emphasize critical information needed by local and State government officials and others interested in coastal zone management. All map data and text will be available on a CD-ROM to allow users to make custom maps with a personal computer and geographic information system (GIS) browsing software.

In 1999, we finished compiling the data for the Galveston Bay and Sabine Lake areas and produced a report and a CD-ROM with GIS files. We also produced 1:24,000-scale maps that depict the average annual rate of shoreline change along the Gulf of Mexico and that show the 1956 and projected 2056 shorelines overlain on 1995 color-infrared photographs. Subdivisions and in-

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Digital elevation model (DEM) of a portion of Bolivar Peninsula on the southeast Texas coast textured with an infrared digital orthophoto. The Gulf of Mexico is on the right. Vegetation shows in various darker shades, whereas barren areas, such as the beach, are shown in lighter shades. White buildings and dark trees show as sharp protrusions because vertical exaggeration is about 15×. This perspective distinctly shows the beach, foredunes, secondary dunes, and subtle ridge-and-swale topography. The DEM is developed from data acquired during an airborne laser terrain mapping (ALTM) survey. The Bureau and The University of Texas at Austin's Center for Space Research are combining highly detailed and accurate topography from ALTM surveys with other remote sensing imagery to map coastal environments and monitor topographic change.

dividual homes visible on these maps dramatically place shoreline change in context for the user. The third year of the project, which began in September 1999, is focusing on the middle coast from the Brazos River to Corpus Christi Bay.

The Texas High School Coastal Monitoring Program: A Project in Education, Public Awareness, and Coastal Management

James C. Gibeaut, principal investigator; Roberto Gutierrez and Brenda Kirkland-George (Department of Geological Sciences, The University of Texas at Austin)

The Texas Coastal Monitoring Program engages coastal residents in the study of their natural environment. High school students, teachers, and scientists work together to gain a better understanding of dune and beach dynamics on the Texas coast. Scientists from The University of Texas at Austin (UT) provide the tools and training needed for scientific investigation. Students and teachers learn how to measure the topography, map the vegetation line and shoreline, and observe weather and wave conditions. By participating in an actual research project, the students gain an enhanced science education. Furthermore, public awareness of coastal processes and the Texas Coastal Management Program is heightened. The students' efforts also provide coastal communities with valuable data on their changing shoreline.

The Texas Coastal Management Program, Conoco, and the Exxon Foundation fund the program, which is in its third year. During 1998/1999, Ball High School completed its second year in the program, and in 1999 Port Isabel and Port Aransas High Schools were added to the program. We envision developing a network of coastal high schools conducting scientific studies of the beaches and exchanging their observations with other schools and the public through the Internet. More information is available at the program's Web site, http://www.utexas.edu/research/beg/thscmp/index.html.

Patterns of Shoreline Change and Hurricane Washover on Barrier Islands

James C. Gibeaut, principal investigator; Roberto Gutierrez; Melba M. Crawford and Bob E. Schutz (Center for Space Research, The University of Texas at Austin)

Despite the erosional nature of barrier islands and spits, they have become highly developed and continue to develop along much of the U.S. coast. This activity has altered erosional and depositional

patterns of shorelines. Development has placed property and lives at risk from coastal storms, sea-level rise, and long-term erosion and has affected coastal habitats. To understand the dynamics of coasts, we need to measure the exchange of sediment between dune, beach, and nearshore environments. What has been lacking, however, is a way to collect detailed and accurate topographic and bathymetric data rapidly along tens of kilometers of shoreline. Recent advances in airborne laser ranging and the application of the Global Positioning Satellite (GPS) can overcome this survey problem.

This 3-year project, funded by the National Aeronautics and Space Administration beginning in 1998, is developing and applying the latest survey technologies to study 150 km of the southeast Texas coast. This shoreline has both natural and developed areas, and its characteristics are typical of barrier coasts, making techniques developed during this project applicable to sandy barrier coasts around the world. We will coordinate four topographic surveying methods: (1) airborne laser altimeter surveys having horizontal and vertical accuracy of 10 to 15 cm will provide continuous coverage of the dune and upper beach, (2) kinematic GPS surveys using a vehicle will provide coverage of the upper and lower beach with an accuracy of 1 to 3 cm, (3) conventional total station surveys will extend selected transects from landward of the foredune into the surf zone, and (4) nearshore GPS/echo sounder surveys will extend selected transects to approximately 7 m of water depth at an accuracy of 5 cm. Overlap areas of the different survey data will be compared to evaluate accuracy. We will merge these various data into an optimal digital elevation model.

Researchers conducted airborne laser terrain mapping (ALTM) missions along the southeast Texas coast in November 1997, August 1998, and September 1998. From August 6, 1998, to August 9, 1998, the survey of Bolivar Peninsula, begun in November 1997, was completed. In August 1998 we also acquired data along the Galveston Island shoreline. Three detailed beach profiles (topographic transects oriented normal to the shoreline) were measured within two days of the ALTM flights using an Electronic Total Station (ETS). Vegetation height was recorded along each profile for later comparison with ALTM data. On September 10, 1998, Tropical Storm Frances caused 20 to 30 m of shoreline retreat, completely eroded foredunes, and severely damaged many structures along the southeast Texas coast. On September 17, we conducted an ALTM survey of the shoreline from Sabine Pass to the Brazos River (190 km). We also measured 11 beach profiles within two days of that post-storm ALTM survey.

For the ALTM surveys, we installed an Optech Inc. ALTM-1020 laser altimeter in a Cessna 206 single-engine aircraft operated by the Texas State Aircraft Pooling Board. The Optech ALTM-1020 system combines a pulsed, solid-state laser, an inertial motion unit (IMU), and a geodetic GPS receiver in a compact and modular configuration. The IMU (accelerometers and gyroscopes) monitors the aircraft attitude, and the GPS receiver provides aircraft position data. Rotating optics in the instrument's sensor head scans the laser across the ground, illuminating a swath under the aircraft. The laser pulses up to 5,000 times per second.

Results show that we can efficiently and accurately acquire beach and dune surveys along hundreds of kilometers of coast using ALTM. Vertical precision is 8 to 15 cm (root mean square error). Absolute accuracy is also 8 to 15 cm after subtracting a bias error determined by comparing ALTM data with GPS road surveys. Data-point spacing for these surveys is 2 m, and the mapping swath width is about 200 m, which covers the beach, foredune, secondary dunes, and structures. During the second year of the project, we will compare ALTM surveys acquired at different times.

Accurately mapping shoreline position and calculating rates of shoreline change have been a problem addressed by coastal geologists for decades. Usually, shoreline position is mapped using vertical aerial photographs. The shoreline is interpreted and drawn on the photograph and then transferred to a base map for comparison with earlier shorelines. Typically, the boundary between wet and dry sand on the

beach, which is displayed as a tonal contrast on the photographs, is used as the shoreline. This boundary, however, is affected by recent water level and wave activity and may not be a reliable indicator of shoreline position. There is also error introduced to the shoreline position when it is transferred to the base map. Because ALTM surveys are GPS based, data do not have to be transferred to a base map. Furthermore, we can use a contour line as the shoreline, eliminating the ambiguity present in the wet sand–dry sand boundary. Our results show that a single swath of ALTM data appears adequate to define a contour line as the shoreline. The GPS-based ALTM data, however, are produced as heights above the ellipsoid and what should be mapped as the shoreline is an elevation that is related to local sea level. We are continuing research to adjust the ALTM data to be relative to local sea level and, therefore, to significant beach morphology features such as scarps or berm crests.

We will analyze the survey data to reveal topographic and geomorphic relationships to past shoreline change and hurricane washover patterns. When the annual surveys are combined with weather, water-level, and wave data, we will gain a better understanding of the overall response of the coast to particular conditions. We expect that we will find quantifiable relationships among coastal erosion patterns, wave-refraction patterns, topography, and geomorphology. These relationships will provide us with guidance in predicting future shoreline change and storm hazards.

Coastal Erosion Planning and Response Act, July 1999 Public Meetings

James C. Gibeaut, principal investigator

In June, Texas Governor George W. Bush signed into law the Coastal Erosion Planning and Response Act. This act provides $15 million over the next 2 years for coastal erosion projects. It authorizes the Texas General Land Office (GLO) to implement a comprehensive coastal erosion response program that can include designing, funding, building, and maintaining erosion projects. The Bureau is named in the Act as the entity that will determine shoreline change rates and assist the GLO in identifying critical erosion areas. In July, the Texas General Land Office held 13 public meetings to present and gather input on the Act. At these meetings, the Bureau made a presentation and answered questions from the public regarding how shoreline change rates are determined, what the current status of shoreline mapping is, and what the regional shoreline change rates are. The Bureau will continue to work with the GLO on implementing the Act over the next 2 years.

Recent Changes in Gulf Shoreline Position, Mustang and North Padre Islands, Texas

James C. Gibeaut, principal investigator; Thomas A. Tremblay and Roberto Gutierrez

This project, which is funded by the Texas Coastal Management Program, is determining the historical rate of shoreline change along the Gulf coast on Mustang and North Padre Islands. The project is providing up-to-date information regarding beach conditions for managing natural resources, planning and protecting shorefront development, and minimizing property damage. Because the physical setting varies along this part of the coast, management stategies need to be prepared for accreting, stable, and eroding beach segments.

The primary objectives of this project are to map the Gulf shoreline position in Nueces and Kleberg Counties using Global Positioning Satellite techniques, to evaluate shoreline movement since 1974, and to calculate the long-term rate of shoreline change using a combination of shorelines since the 1930's. Previously mapped shoreline positions will be digitized and compiled in a geographic information system so that change calculations and the projection of future shoreline positions can be automated. In 1999, we mapped the shoreline and began digitizing the earlier shorelines.

MAPPING INVESTIGATIONS

STATEMAP Project: Geologic Mapping to Support Improved Data-Base Development and Understanding of Critical Aquifers of Texas

Edward W. Collins and Jay A. Raney, principal investigators; assisted by Thomas A. Tremblay and Gregory J. Jeffers

The objective of this program is to produce geologic maps that augment the Texas and national geologic data base. The project, part of the U.S. Geological Survey's (USGS) STATEMAP program, is funded jointly by the USGS and the Bureau.

One subproject involves the geologic mapping of 7.5-minute quadrangles to support responsible development in karst aquifer areas in south-central Texas. The purpose of this project is to develop geologic base maps that are sufficiently detailed and accurate to meet the needs of a variety of professionals who must respond to the demands placed on the environment and resources of a south-central Texas region that is undergoing rapid urban growth. An improved geologic base map is needed for studies of ground-water recharge and flow in the Edwards limestone aquifer, which is crucial to the economic well-being of the region, and for responsible urban development and construction needs. Engineers, developers, and planners need detailed maps of the geology for land-use planning and design of construction projects. Geologic maps produced for this project may eventually be compiled in a digital format and utilized at a base scale of 1:100,000.

Mapping for this 3-year south-central Texas subproject was done in three geologically critical areas. All three areas are within the Balcones Fault Zone, which is the main structural control on the geology of the region and the Edwards aquifer. The west San Antonio corridor is within an intensely faulted part of the Balcones Fault Zone and within the San Antonio segment of the Edwards aquifer and recharge zone, the sole-source aquifer for the San Antonio urban area. Mapping of the west San Antonio corridor was finished during the first part of 1999 with the completion of Comanche Waterhole, Flat Rock Crossing, Sabinal, and Seco Pass Quadrangles. Fourteen 1:24,000-scale quadrangles previously completed for this 18-quadrangle study area are the Bandera, Castroville, D'Hanis, Hondo, Murphy School, Mustang Valley, Quihi, Riomedina, Sabinal NE, Tarpley, Tarpley Pass, Texas Mountain, Timber Creek, and Twin Hollow Quadrangles.

The Austin-Georgetown corridor is within the Austin region's northern segment of the Edwards aquifer, an urban growth corridor that is undergoing some of the most rapid development in Central Texas. This 16-quadrangle study area includes the towns of Round Rock, Georgetown, and Salado along Interstate 35. Mapping of the Austin-Georgetown corridor was finished during the first part of 1999 with the completion of the Briggs, Liberty Hill, Mahomet, and Nameless Quadrangles. Geologic maps of 12 quadrangles—Cobbs Cavern, Ding Dong, Florence, Georgetown, Hutto, Jarrell, Leander, Leander NE, Round Rock, Salado, Weir, and Youngsport—were completed during previous years.

The Del Rio corridor is within the southern part of the Edwards Plateau aquifer region and western extension of the Balcones Fault Zone. It is traversed by U.S. Highway 90, a major transportation route from Mexico to San Antonio that is contributing to the growth and development of this area. Mapping of the Del Rio Corridor was finished during the first part of 1999 with the completion of the Flat Rock Creek SW, Mud Creek North, and Mud Creek South Quadrangles. Geologic maps of six quadrangles, Del Rio NE, Del Rio NW, Del Rio SE, Del Rio SW, Rough Canyon, and Rough Canyon SE, were completed for this nine-quadrangle

study area during previous years.

Another subproject produced geologic maps of four quadrangles that are in areas of special environmental concern. Mapping was completed during the first part of 1999. The map areas include Magers Crossing and Sabinal Canyon Quadrangles, which are along the Edwards and Trinity aquifer recharge zones and contain State parks, and Luling and Prairie Valley School Quadrangles, where local aquifers and rivers are potentially being contaminated by leaking oil wells, pits, or pipelines. Improved geologic information in these areas can impact development, land use, public education, and the economy.

A third subproject is the digital compilation (1:100,000) of geologic mapping (1:24,000) of the Hueco Bolson aquifer and adjacent recharge and urban growth areas, El Paso County, Texas. Digital compilation of this 16-quadrangle area was completed during the first part of 1999. This project is important because of the rapid growth of the U.S.-Mexico border area, diminishing water resources, environmental issues associated with development, and the presence of large areas of public access lands (Franklin Mountains and Hueco Tanks) whose management will benefit from having digital geologic data available for planning, development, and improved public awareness of geologic processes and geologic history.

Also during 1999, two new mapping projects began. Geologic maps to be produced in the East Austin corridor and the northeast Uvalde area–Edwards aquifer recharge zone will address issues related to urban growth, land use and earth resources, water quality, groundwater management, construction practices, engineering properties of near-surface materials, and public education regarding utilization of earth resources and good environmental practices. Quadrangles mapped during 1999 and ones that will be mapped in early 2000 are the Bastrop, Bastrop SW, Coupland, Elgin East, Elgin West, Lake Bastrop, Utley, and Structure Quadrangles of the East Austin corridor. Northeast Uvalde area–Edwards aquifer recharge-zone quadrangles mapped during 1999 and to be mapped in early 2000 are Blanco Lake, Trio, Utopia, and Vanderpool Quadrangles.

OTHER GEOLOGIC INVESTIGATIONS

Geomorphic Studies of Archeological Sites

L. Edwin Garner, principal investigator

The Texas Department of Highways and Public Transportation has contracted with the Bureau to provide services as needed to perform geomorphic studies for archeological investigations. The required work includes field investigations and drilling programs for selected locales, analysis of soils data, and short reports of observations and conclusions.

The geomorphic studies are conducted to determine the geomorphologic character of locales, the influences on past human activities, and the effects of natural processes on deposits of cultural materials. Investigations during 1999 included thin-section examination of archeological materials and drilling projects in Brazoria, Nueces, DeWitt, and Williamson Counties.

CONTRACT AND GRANT SUPPORT

The Bureau maintains formal and informal cooperative arrangements with several governmental entities. Parts of the Bureau's research program are conducted under The University of Texas at Austin contracts and grants with Federal, State, and private organizations.

Contract-management personnel prepare proposals and budgets, negotiate contracts, and monitor expenditures. During the contract period, technical and financial reports are distributed at monthly, quarterly, and annual intervals. In 1999, the following 91 contracts, each of which had reporting requirements, were active at the Bureau:

Federal

"Analysis of Soil Remediation Requirements of Abandoned Centralized and Commercial Drilling-Fluid Disposal Sites": supported by the U.S. Department of Energy.

"Application of Advanced Reservoir Characterization, Simulation and Production Optimization Strategies to Maximize Recovery in Slope and Basin Clastic Reservoirs, West Texas (Delaware Basin)": supported by the U.S. Department of Energy.

"Assessment and Forecasting, by Play, Natural Gas Reserve Appreciation and Quantifying the Role of Technology Advancement in Reserve Growth Additions in the Gulf Coast Basin": supported by the U.S. Department of Energy.

"Deep Basin Coal (Lignite) and the Potential for Unconventional Coal Gas Resource Development, Wilcox Group, East-Central Texas": supported by the U.S. Geological Survey, U.S. Department of the Interior.

"Detecting Small-Scale Topographic Changes and Relict Geomorphic Features on Barrier Islands Using SAR": supported by the National Aeronautics and Space Administration.

"Development of Active Seismic Vector-Wavefield Imaging Technology for Geothermal Applications": supported by the U.S. Department of Energy.

"Development of a Monitoring Station for Estimating Interplaya Recharge": supported by the U.S. Department of Energy through the Amarillo Natural Resources Center for Plutonium.

"Evaluation of Design, Monitoring, and Modeling Issues Related to Engineered Covers of Waste Containment": supported by the U.S. Environmental Protection Agency.

"Geological Mapping to Support Improved Database Development and Understanding of Critical Aquifers of Texas": supported by the U.S. Geological Survey, U.S. Department of the Interior.

"Geological Mapping to Support Improved Database Development and Understanding of Urban Corridors and Critical Aquifers of Texas": supported by the U.S. Geological Survey, U.S. Department of the Interior.

"Integrated Outcrop and Subsurface Studies of the Interwell Environment of Carbonate Reservoirs: Clear Fork (Leonardian Age) Reservoirs, West Texas and New Mexico": supported by the U.S. Department of Energy.

"Interdisciplinary Approaches to Ecosystem Restoration": supported by the U.S. Army Corps of Engineers.

"Mapping Near-Surface Salinization Using Long-Wavelength AIRSAR": supported by the National Aeronautics and Space Administration.

"Midland Core Repository": supported by the U.S. Department of Energy.

"Optimal Geological Environments for Carbon Dioxide Disposal in Saline Aquifers in the United States": supported by the U.S. Department of Energy.

"Patterns of Shoreline Change and Hurricane Washover on Barrier Islands": supported by the National Aeronautics and Space Administration.

"Reduction of Greenhouse Gas Emissions through Underground CO_2 Sequestration in Texas Oil and Gas Reservoirs": supported by the U.S. Department of Energy through Electric Power Research Institute.

"Regional Ecological Resource Assessment of the Rio Grande Riparian Corridor: A Multidisciplinary Approach to Understanding Anthropogenic Effects on Riparian Communities in Semi-Arid Environments": supported by the U.S. Environmental Protection Agency.

"Salt Cavern Development: An Analysis of Industry Experience in a Geologic Context": supported by Sandia National Laboratories.

"Secondary Natural Gas Recovery in the Appalachian Basin: Application of Advanced Technologies in a Field Demonstration Site, Henderson Dome, Western Pennsylvania": supported by the U.S. Department of Energy through West Virginia University Research Corporation.

"Targeting Reserve Growth Opportunities in the Northern Gulf of Mexico Basin: Transferring Secondary Gas Recovery Technology to the Offshore Environment": supported by the U.S. Department of Energy.

"Technical Review for Pacific Northwest National Laboratory": supported by the Battelle Memorial Institute.

"Texas Regional Change Program": supported by the National Aeronautics and Space Administration.

"A Technology Transfer Program, Texas Region of the Petroleum Technology Transfer Council": supported by the Petroleum Technology Transfer Council.

State and Local

"A Ground-Water Management Model for the Edwards Aquifer, Barton Springs Segment": supported by the Lower Colorado River Authority.

"A Permeability and Storativity Data Base for the Carrizo-Wilcox Aquifers in Texas": supported by the Texas Water Development Board.

"Applying Numerical Ground-Water Flow Models to Water-Resources Issues": supported by the Texas Water Development Board.

"Archeological Projects—Assistance to the Texas Department of Transportation": supported by the Texas Department of Transportation (two contracts).

"Assessment of Possible Impacts on Surface Water and Ground Water in Bastrop, Lee, and Milam Counties, Texas, Resulting from Proposed Groundwater Extraction by San Antonio Water System": supported by the Texas Water Development Board.

"Capacity Building for Resource Assessment and Responsible Development, Trans-Mexico Border": supported by the Texas Higher Education Coordinating Board.

"Coastal Hazards Atlas of Texas: A Tool for Hurricane Preparedness and Coastal Management (three volumes)": supported by the Coastal Coordination Council (Texas General Land Office) (three contracts).

"Colorado River Seep Site Investigation, Wharton County, Texas": supported by the Railroad Commission of Texas.

"CSGWPP Core Assessment Project": supported by the Texas Natural Resource Conservation Commission.

"Current Hydrocarbon Reserves and Future Reserve Growth on University Lands: Quantification and Economic Evaluation": supported by The University of Texas System.

"Dune and Beach Dynamics in Galveston County: Critical Information for Coastal Management": supported by the Coastal Coordination Council (Texas General Land Office).

"Dyersdale Site Saltwater Investigation, Harris County, Texas": supported by the Railroad Commission of Texas.

"Edwards Rules Maps Digitization": supported by the Texas Natural Resource Conservation Commission.

"Environmental Investigations of Abandoned Oil Field Cleanup Sites": supported by the Railroad Commission of Texas.

"Estimating Depth-to-Bedrock Feasibility Study": supported by the Texas Department of Transportation through the Center for Transportation Research.

"Evolution of Monitoring Programs for Engineered Barriers for Waste Disposal": supported by the Texas Low-Level Radioactive Waste Disposal Authority.

"High School Beach Monitoring Program: A Pilot Project in Education, Public Awareness, and Coastal Management (Years 2 and 3)": supported by the General Land Office through Galveston Independent School District (two contracts).

"Implementation of Test Plan for Ward Valley Recharge Studies": supported by ERM Program Management Company for the California Department of Health Services.

"Investigation of Shoreline Change in the Vicinity of Rollover Pass": supported by the Texas Parks & Wildlife Department.

"Numerical Ground-Water Model for the Panhandle Water Planning Area": supported by the Panhandle Regional Planning Commission.

"Numerical Models of Brittle Grabens Forming above Ductile Rock in Canyonlands National Park": supported by the Texas Higher Education Coordinating Board.

"Participation by the Bureau of Economic Geology in Public Meetings on the Coastal Erosion Bill": supported by the Texas General Land Office.

"Rapid Geophysical Identification and Assessment of Ground Water for the Lower Rio Grande Valley": supported by the Texas Water Development Board.

"Recent Changes in Gulf Shoreline Position, Mustang, and North Padre Islands, Texas": supported by the Texas General Land Office.

"Review of Data on Hydrology and Related Issues in Andrews County, Texas": supported by the Texas Low-Level Radioactive Waste Disposal Authority.

"Review of Documents and Dissemination of Environmental Geologic Information Related to Environmental Restoration at the U.S. Department of Energy's Pantex Plant, Carson County, Texas": supported by the Office of the Governor of the State of Texas.

"San Marcos River Site Investigation, Guadalupe County, Texas": supported by the Railroad Commission of Texas.

"Shoreline Types of the South Texas Coast": supported by the Texas General Land Office.

"Sierra Blanca Ranch Project": supported by the Texas General Land Office (two contracts).

"Supplementary Study of Inferred Fault to Support License Application": supported by the Texas Low-Level Radioactive Waste Disposal Authority.

"Technology Center for Oil and Gas Recovery Optimization on Texas State Lands": supported by the State of Texas.

"Texas High School Coastal Monitoring Program: Port Aransas High School, Year 1": supported by the Texas General Land Office through the Port Aransas Independent School District.

"Texas High School Coastal Monitoring Program: Port Isabel High School, Year 1": supported by the Texas General Land Office through the Point Isabel Independent School District.

"Using GIS Technology to Explore Earth Systems/A Virtual Tour of the Edwards Aquifer": supported by Fabens Independent School District.

"University Lands Advanced Recovery Initiative": supported by The University of Texas System.

"Water and the Environment in Southwest Texas": supported by Southwest Texas Junior College.

"Update of Oil and Gas Plays": supported by the U.S. Geological Survey, U.S. Department of the Interior.

Private

"Applied Geodynamics Laboratory": supported by Amerada Hess Corporation; Amoco Production Company; Anadarko Petroleum Corporation; BHP Petroleum (Americas) Inc.; BP Exploration and Oil, Inc.; Chevron U.S.A. Production Company; Conoco Inc.; Elf-Aquitaine; ENI-Agip; Exxon Production Research Company; Marathon Oil Company; Mobil; Norsk-Hydro; PanCanadian Petroleum Limited; Petroleo Brasiliero SA; Phillips Petroleum Company; Saga Petroleum ASA; Shell Oil Company; Statoil; Texaco Exploration and Production, Inc.; Total S.A.; and Vastar Resources, Inc.

"Characterization of Heterogeneity Style and Permeability Structure in a Sequence Stratigraphic Framework in Fluvio-Deltaic Reservoirs": supported by Chevron Petroleum Technology Company; Intevep, S.A.; Japan National Oil Corporation; Maxus Energy Corporation; and Statoil.

"Characterization of San Andres and Grayburg Reservoirs": supported by Altura Energy Limited; Amerada Hess Corporation; Aramco; ARCO International Oil and Gas; ARCO Permian; BP Exploration; Chevron; Elf Exploration Production; Exxon Production Research Company; Japan National Oil Corporation; Marathon Oil Company; Mobil Corporation; PanCanadian Petroleum Ltd.; Pennzenergy Exploration and Production L.L.C.; Petroleum Development Oman LLC; Southwestern Energy Company; and TOTAL Exploration Production USA, Inc.

"Description and Interpretation of the Depositional Environments and Sequence Stratigraphy of the Arab-D Formation in the Haradh Area of Ghawar Field, Saudi Arabia": supported by Integrated Reservoir Characterization Group, Inc.

"Development of Seismic Imaging Applications for Optimally Characterizing Depositionally Heterogeneous Reservoirs": supported by ARCO Permian; Dell Computing; Fairfield Industries; Input/Output, Inc; Landmark Graphics Corporation; Maxus/YPF; Oyo Geospace Corporation; Phillips Petroleum Company; Schlumberger; Seismic Micro-Technology; Seitel Data; Syntron; Vastar Resources, Inc.; and Visos Energy Corporation.

"EarthView Texas": supported by the Hillcrest Foundation and the Shell Foundation (two contracts).

"Evaluation of Electromagnetic Induction as a Noninvasive Technique for Monitoring Water Movement": supported by the Electric Power Research Institute.

"Feasibility Study for the Establishment of a National Geoscience Data System": supported by the American Geological Institute.

"Fracture Research and Application Consortium": supported by Chevron Petroleum Technology Company; Conoco, Inc.; YPF Maxus International; and Sanchez Oil and Gas Corporation.

"Geo-Environmental Characterization of the Orinoco Delta": supported by Petróleos de Venezuela, S.A., Coordinación Desarrollo Armónico de Oriente.

"Hydrocarbon Production Opportunities Defined by Integrated Reservoir Characterization, Guarico 13/10 Area, Eastern Venezuela": supported by Teikoku Oil de Sanvi-Guere, C.A.

"Hydrocarbon Production Opportunities Defined by Sequence Stratigraphic Analysis and Depositional Systems Characterization, East Guarico Unit, Eastern Venezuela": supported by Teikoku Oil de Venezuela, C.A.

"Integrated Analysis of the Burgos Basin, Mexico": supported by Pemex through The Scotia Group, Inc.

"Integration of 3-D Seismic Mioceno-Norte Area": supported by Petróleos de Venezuela, S.A.

"LIDAR-Derived Digital Elevation Model for Lakewood Area, California": supported by Optech, Inc.

"Maintenance of Borehole Geophysics Test Site: The University of Texas at Austin": supported by the Society of Exploration Geophysicists.

"New Methods of Natural Fracture Characterization": supported by Chevron Petroleum Technology Company; Conoco, Inc.; Japan National Oil Company; Maxus; and Sanchez Oil and Gas Corporation.

"Optimizing Hydrocarbon Recovery from the Mara Liviano (Mara Este) Field, Maracaibo Basin, Venezuela": supported by Petróleos de Venezuela, S.A.

"Optimizing Hydrocarbon Recovery from the Matzen Field, Vienna Basin, Austria": supported by ÖMV Aktiengesellschaft.

"Plume Research Group: Integrated Regional, Site-Specific, and Theoretical Studies of Ground-Water Contaminant Plumes": supported by the Mobil Foundation.

"Seismic Vector-Wavefield Imaging": supported by Visos Energy Corporation.

"Sequence Stratigraphy, Salt Tectonics and Prospect Definition in the Area of the Coast of Coatzacoalcos and the Gulf of Campeche, Mexico": supported by Universidad Nacional Autónoma de México.

"Spatial and Temporal Variability of MTBE Plumes in Texas": supported by the American Petroleum Institute.

"Technical Cooperation Agreement": supported by Intevep, S.A.

RESEARCH STAFF ACTIVITIES

Lectures and Public Addresses

Sigrid J. Clift

"Texas oil and gas": presented to students from Eden Park Academy, Austin, Texas.

"Bureau of Economic Geology's science education outreach programs": presented to U.S. Environmental Protection Agency Roundtable Meeting, Dallas, Texas, and to TMRA/Alcoa Teachers' Workshop, Rockdale, Texas.

Edward W. Collins

"Geologic maps of urban growth areas within the Edwards aquifer area of Central Texas": presented to the Austin Geological Society, Austin, Texas.

Alan R. Dutton

"Results of a post audit of a flow model—lower Gulf Coast aquifer": presented to SB 1 Regional Planning Group K, Bastrop, Texas.

"Hydrogeology of the Ogallala and perched aquifers, Pantex area": presented to Ground Water 101 workshop hosted by the Governor's Office, Panhandle, Texas.

Shirley P. Dutton

"Outcrop studies of diagenesis of deltaic sandstones": presented to Anadarko Petroleum Corporation, Houston, Texas.

"Clastic Reservoirs Group Industrial Associates project": presented to Enron Oil and Gas Company, Austin, Texas.

"Clastic Reservoirs Group outcrop and subsurface characterization of fluvial-deltaic reservoirs": presented to Enron Oil and Gas Company, Austin, Texas.

William L. Fisher

"Growing the reserve: the challenge of reservoir characterization": keynote address presented at Gulf Coast Section Society of Economic Paleontologists and Mineralogists Foundation 19th Annual Bob F. Perkins Research Conference, Houston, Texas.

"Global oil supply: technology versus depletion": presented to U.S. National Labs Energy R&D Working Group, Washington, D.C.

"U.S. natural gas: making the 30-Tcf future": presented to North American Gas Strategies Conference, Houston Texas.

"Future of the geoscience: change like we have never seen": banquet address presented at Corporate-Academic Affiliates Conference, American Geological Institute, Houston, Texas.

"System, sequences, and regimes": keynote address presented at Symposium on Depositional Systems, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

"Future direction of global oil supply and price": luncheon address presented to Central Texas Section, Society of Independent Earth Scientists, Austin, Texas.

"Technology in old field revitalization": presented to workshop on Old Field Revitalization, sponsored by Brazilian Ministry of Mines and Energy, Salvador, Brazil.

"Energy resources into the 21st century": presented at U.S. Geological Survey and National Research Council Symposium on Natural Resources and Hazards: Challenges for the 21st Century; in honor of Michel T. Halbouty; The National Academies, Washington, D.C.

"Our changed perception of energy resources in the past 20 years": presented at The Haney Symposium on Two Decades of Geology in the Public Interest: Kentucky Society of Professional Geologists, University of Kentucky, Lexington, Kentucky.

"Systems, sequences, and regimes": presented at Society of Exploration Geophysicists, Annual Meeting, by special invitation, Houston, Texas.

"Citation for Charles J. Mankin, Ben H. Parker Medalist": presented at American Institute of Professional Geologists, Annual Meeting, Anchorage, Alaska.

"Citation for Don R. Boyd, Special Commendation Award": presented at Gulf Coast Association of Geological Societies, Annual Meeting, Lafayette, Louisiana.

William E. Galloway

"Depositional architecture and hydrocarbon productivity of autochthonous slope systems": presented to Corpus Christi Geological Society, Corpus Christi, Texas, and as part of T. M. Stout Lecture Series, University of Nebraska, Lincoln, Nebraska.

"Cenozoic sediment dispersal patterns, Gulf of Mexico continental margin": poster presented at American Association of Petroleum Geologists Hedberg Research Conference, Carlsbad, New Mexico.

James C. Gibeaut

"Applying airborne LIDAR to beach studies": presented at the LIDAR Workshop convened by the Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas.

"Mapping shoreline change in Texas": presented at 13 public meetings convened by the Texas General Land Office along the Texas coast.

"Topographic mapping of coastal zones using airborne laser and radar systems": presented at the U.S. Geological Survey, Center for Coastal Geology, Saint Petersburg, Florida.

Bob A. Hardage

"Using petrophysics and cross-section balancing to interpret complex structure in a limited-quality 3-D seismic image": presented to Abilene Geological Society, Abilene, Texas.

"Principles of geophysics": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 330K), Austin, Texas.

"Using shaped explosives as a seismic energy source for vertical seismic profiling": presented to Petroleum Technology Transfer Council short course, Pittsburgh, Pennsylvania.

"Interpretation of deep complex structure in a limited-quality 3-D seismic image": presented at U.S. Department of Energy, 1999 Oil and Gas Conference, Dallas, Texas.

"Examples of field activity associated with seismic data recording": presented at National Association of Royalty Owners, Annual Convention, San Angelo, Texas.

"3-D seismic stratal concepts": presented at Sixth International Congress of the Brazilian Geophysical Society, Rio de Janeiro, Brazil.

"Seismic interpretation of complex structures in the Delaware Basin": presented at The University of Texas at El Paso, monthly technical seminar.

"Seismic vector-wavefield characterization of complex reservoirs": presented to industrial sponsors of the Exploration Geophysics Laboratory, Austin, Texas.

"P-wave and S-wave applications for improved prospect evaluation": presented to Society of Independent Professional Earth Scientists chapter, Austin, Texas.

"3-D seismic stratal-surface concepts": presented at Flagship Users Forum, Houston, Texas.

Susan D. Hovorka

"Aquifer in a tank": Hands-on fourth-grade experiment presented for filming by Texas Education Agency *Eye on Earth* program, Austin, Texas; also presented to Earth Camp, City of Austin environmental education training program for teachers, Austin, Texas.

"Bureau professional development programs": presented at CAST Informal Science Association Showcase, Lubbock, Texas.

Martin P. A. Jackson

"Overview of AGL research for 1999": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

"Salt-tectonic provinces of Kwanza and Benguela Basins": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

"Monocline province: draping and translation caused by basement uplift": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

"Diapir province: you name it, we've got it": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

"Some causes and effects of Tertiary uplift of the Angolan Margin": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

"Thickened salt and wedge provinces: inflation of salt and buckling of roof": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

James W. Jennings, Jr.

"Carbonate permeability heterogeneity and fluid-flow modeling": presented at annual fall meeting of the Center for Subsurface Modeling Industrial Associates, Austin, Texas.

"Multiple scales of permeability heterogeneity in Permian carbonates, outcrop statistics and implications for fluid flow modeling": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 391), Austin, Texas.

"Outcrop permeability studies and implications for subsurface modeling": presented at annual review meeting of the Reservoir Characterization Research Laboratory Industrial Associates, Carlsbad, New Mexico.

"Permeability trend models and their effects on fluid flow": presented at annual review meeting of the Reservoir Characterization Research Laboratory Industrial Associates, Carlsbad, New Mexico.

"Imaging vuggy pore space in a Cretaceous caprinid buildup": presented at annual review meeting of the Reservoir Characterization Research Laboratory Industrial Associates, Carlsbad, New Mexico.

"Statistical analysis, flow modeling, and scaleup in Permian and Cretaceous carbonate outcrops: implications for subsurface reservoir modeling": presented to Total Exploration and Production, Paris, France; Elf Aquitane Exploration and Production, Pau, France; and BP Amoco Exploration, Sunbury, UK.

"Geostatistical analysis and flow modeling in Permian outcrops of West Texas and New Mexico": presented to The University of Texas at Austin, Department of Petroleum and Geosystems Engineering (Petroleum and Geosystems Engineering 383), Austin, Texas.

"Fourier filtering for fast and accurate stochastic simulation of correlated random fields": presented at The University of Texas at Austin, Texas Institute for Computational and Applied Mathematics seminar, Austin, Texas.

Charles Kerans

"Sequence stratigraphic analysis for reservoir characterization, how carbonates fit": presented at Elf Aquitaine Exploration/Production Research and Total Exploration/Production Research, Pau, France, and Paris, France.

"Carbonate sequence stratigraphy of Cretaceous and Permian systems": presented at IFP School, Paris, France.

"Advanced methods of carbonate reservoir characterization": presented at Southwestern Energy, Houston, Texas.

"Quantification of carbonate systems for flow modeling": presented at

Gordon Research Conference on Flow in Porous Media, invited theme paper, Andover, New Hampshire.

"Carbonate reservoir characterization": series of three lectures presented to The University of Texas at Austin, Department of Geological Sciences (Geology 383R), Austin, Texas.

"Tools of carbonate sequence stratigraphy": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 390N), Austin, Texas.

"Carbonate facies dimensions in a sequence stratigraphic framework": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 390N), Austin, Texas.

"Application of carbonate sequence stratigraphic concepts to reservoir studies": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 390N), Austin, Texas.

"Developing an integrated database for carbonate stratigraphic, petrophysical, and engineering data": presented at annual review meeting of the Reservoir Characterization Research Laboratory Industrial Associates, Carlsbad, New Mexico.

"Icehouse carbonate reservoirs of the Horseshoe Atoll, Permian Basin": presented at annual review meeting of the Reservoir Characterization Research Laboratory Industrial Associates, Carlsbad, New Mexico.

"Stratigraphic framework of carbonate reservoir analog strata, Big Hatchet Range, southwestern New Mexico": presented at annual review meeting of the Reservoir Characterization Research Laboratory Industrial Associates, Carlsbad, New Mexico.

"Predicting stratigraphic layering schemes for reservoir modeling": presented to Petroleum Development Oman, Muscat, Oman.

"Carbonate object modeling for advanced reservoir characterization": presented to Chevron Intercompany Technology Group on Carbonates, Chevron USA, New Orleans, Louisiana.

"A methodologic approach to sequence stratigraphic reservoir model construction": presented to Chevron Intercompany Technology Group on Carbonates, Chevron USA, New Orleans, Louisiana.

"Carbonate reservoir database for prediction of reservoir architecture and reservoir heterogeneity styles": presented to Chevron Intercompany Technology Group on Carbonates, Chevron USA, New Orleans, Louisiana.

"Carbonate reservoir characterization with a focus on Permian fields of the Permian Basin": presented to Anadarko Petroleum Company, Houston, Texas (with F. Jerry Lucia).

Paul R. Knox

"Waltzes, wine, and oil: toward the revitalization of Matzen field": presented to the Austin Geological Society, Austin, Texas.

Stephen E. Laubach

"Rapid prediction of fracture fluid flow": presented to U.S. Department of Energy workshop, Geologic Studies of Fractures in Reservoirs, Midland, Texas.

"Identifying productive fairways in structured reservoirs": presented to research symposium, Conoco, Inc., Midland, Texas.

"Bone Springs play: insights from structural and reservoir quality analysis": presented to University Lands and West Texas operators meeting, Midland, Texas.

"Structural diagenesis: a key to reservoir quality prediction": presented to Marathon Oil Company, Littleton, Colorado.

"Structural geology and the petroleum industry": presented to Society of Independent Professional Earth Scientists, Austin, Texas.

F. Jerry Lucia

"Carbonate reservoir geology" presented to The University of Texas at Austin, Department of Geological Sciences (Geology 330K), Austin, Texas.

"Carbonate reservoir characterization with a focus on Permian fields of the Permian Basin": presented to Anadarko Petroleum Company, Houston, Texas (with Charles Kerans).

"Rock-fabric reservoir model for middle Clear Fork, South Wasson Clear Fork field": presented at annual review meeting of the Reservoir Characterization Research Laboratory Industrial Associates, Carlsbad, New Mexico.

"Rock-fabrics, petrophysical rock typing, and wireline logs in carbonate reservoirs": presented at Petroleum Development Oman, Muscat, Oman.

"Rock-fabric approach to estimating permeability in carbonate reservoirs from common wireline logs": presented at BP-Amoco Sunbury Office, London, England.

"Rock-fabric and petrophysical characterization of carbonate reservoirs": presented at Elf Aquitaine Office, Pau, France; and at TOTAL Offices, Paris, France.

Jeffrey G. Paine

"Near-surface geophysical methods in hydrogeological investigations": lecture and field demonstration presented to The University of Texas at Austin, Department of Geological Sciences (Geology 376L), Austin, Texas.

"Delineating Colorado River salinization sources using reconnaissance airborne EM": presented to Clean Rivers Program Steering Committee, San Angelo, Texas; and Big Spring, Texas.

"Assessing salinization sources and extent using EM methods": presented at The University of Texas at Austin, Department of Geological Sciences, Hydrogeology Brown Bag, Austin, Texas.

Stephen C. Ruppel

"Integrated outcrop and reservoir studies of Clear Fork facies and cycle architecture": presented at the Carbonate Reservoir Characterization Research Laboratory annual meeting, Carlsbad, New Mexico.

Bridget R. Scanlon

"Evaluation of unsaturated flow in arid settings": presented to the Department of Hydrology, Rehovot, Israel.

"Spatial and temporal variability in unsaturated flow in arid regions:" presented to the U.S. Salinity Laboratory, Riverside, California.

"Evaluation of alternative, engineered covers in an arid setting in the Chihuahuan Desert, Texas": presented to the Texas Natural Resource Conservation Commission Environmental Trade Fair, Austin, Texas.

"Analysis of design, monitoring, and modeling issues related to engineered covers for waste containment": presented to the U.S. Environmental Protection Agency Headquarters, Washington, D.C.

"Evaluation of subsurface flow based on analysis of water potential data in semiarid regions": presented to the U.S. Department of Energy, Washington, D.C., and Desert Research Institute, Las Vegas, Nevada.

Daniel D. Schultz-Ela

"Graben initiation: evolution of stress fields and controls on spacing": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

"Behavior of interlayers during thickening of Angolan-type salt plateau": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

"Upheaval Dome in Utah's Canyonlands: result of a sudden smack or a slow squeeze?": presented to Southern Methodist University, Department of Geological Sciences, Dallas, Texas.

"Sliding on a slippery slope: numerical modeling and salt tectonics applied to The Grabens in Canyonlands National Park": presented to Southern Methodist University, Department of Geological Sciences, Dallas, Texas.

Andrew R. Scott

"A review of a coalbed methane exploration model": presented at Louisiana State University's First Coalbed Methane Conference, sponsored by the Louisiana Geological Survey and the Basin Research Institute, and the Petroleum Technology Transfer Council, Central Gulf Region; and at Petroleum Technology Transfer Council, Technology Transfer Workshop, Developing a Model for Coalbed Methane Exploration Fairways and Gas-in-Place Analysis in Texas, San Antonio, Texas.

"Review of Petroleum Technology Transfer Council activities": presented at the Texas Independent Producers and Royalty Owners Association summer policy meeting, Galveston, Texas.

"Petrographic evaluation of the Eoceno Norte area, Lake Maracaibo, Venezuela": presented to Petróleos de Venezuela, S.A., Maracaibo, Venezuela.

"Application of virtual reality technology and demonstration for Eoceno Norte area": presented to Petróleos de Venezuela, S.A., Maracaibo, Venezuela.

"Introduction to the preliminary results of Eoceno Norte reservoir modeling": presented to Petróleos de Venezuela, S.A., Maracaibo, Venezuela.

"Developing a coalbed methane producibility model for Texas Gulf Coast coals": presented at South Texas Geological Society, monthly meeting, San Antonio, Texas.

"Summary of key hydrogeologic factors affecting coalbed methane producibility": presented at workshop sponsored by the Petroleum Technology Transfer Council, Norman, Oklahoma.

James L. Simmons, Jr.

"Nine-component, 3-D seismic reflection data: the next step?": presented to Purdue University, Department of Earth and Atmospheric Sciences, Lafayette, Indiana.

"Radial-transverse (SV-SH) coordinates for 9-C 3-D seismic reflection data analysis": presented to Industrial Associates meeting, Seismic Vector-Wavefield Consortium, Austin, Texas.

"Case history: 3-D shear-wave processing and interpretation in radial-transverse (SV-SH) coordinates": presented to Industrial Associates meeting, Seismic Vector-Wavefield Consortium, Austin, Texas.

Noel Tyler

"Assessment of mature fields in a competitive oil and gas environment: the Venezuelan initiative": presented at Cempes, Petrobras Research Laboratory, Rio de Janeiro, Brazil.

"Increasing oil and gas recovery in depositionally complex reservoirs": presented as Dean McGee Distinguished Lecture Tour sponsored by the American Association of Petroleum Geologists to Sociedad Venezolana de Geologos, PDVSA (Guaraguao), Caracas, Venezuela; Sociedad Venezolana de Geologos, PDVSA (E&P Headquarters), Caracas, Venezuela; Sociedad Geologica del Peru, Lima, Peru; Instituto de Investigaciones Geologicas, La Paz, Bolivia; Yacimientos Petroliferos Fiscales Bolivianos (YPFB), Santa Cruz, Bolivia; Associado Brasileira de Geologos de Petroleo, Rio de Janeiro, Brazil; Petrobras E&P, Campos Basin Division, Macae, Brazil; Asociacion Geologica Argentina and Asociacion Argentina de Geologica y Geof., Buenos Aires, Argentina.

"Architectural controls on recovery response in deltaic reservoirs in foreland basin settings": presented as Dean McGee Distinguished Lecture Tour sponsored by the American Association of Petroleum Geologists to Associado Brasileira de Geologos de Petroleo, Rio de Janeiro, Brazil; Geological Society of Trinidad and Tobago, Port of Spain, Trinidad, West Indies; Asociacion Geologica Argentina and Asociacion Argentina de Geologica y Geof., Buenos Aires, Argentina.

"Production optimization in fluvial-deltaic reservoirs": presented at the 50th Anniversary Meeting of the Asociacion Mexicana de Geologos Petroleros, Veracruz, Mexico.

Roger Tyler

"A beginner's guide to the geology of Texas": presented to the kindergarten classes at Saint Theresa School, Austin, Texas.

"Developing coalbed methane exploration fairways in a basin with limited data: an example from the

North Slope of Alaska": presented at Louisiana State University's First Coalbed Methane Conference, sponsored by the Louisiana Geological Survey and the Basin Research Institute, and the Petroleum Technology Transfer Council, Central Gulf Region, Baton Rouge, Louisiana.

"The application of a producibility model in defining coalbed methane exploration": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 383R), Austin, Texas.

Bruno C. Vendeville

"Revisiting Trusheim's classic concept of salt-diapir evolution": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

"Back-and-forth propagation of thrusts and folds above salt": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

"Formation of salt canopies during coeval contraction and extension of minibasins": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

"Structural evolution of delta lobes and channels above salt": presented at the Applied Geodynamics Laboratory Industrial Associates meeting, The University of Texas at Austin, Austin, Texas.

"Salt tectonics": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 381E), Austin, Texas.

"Experimental tectonic modeling and its applications to understanding salt structures": presented to Baylor University, Geology Department, Waco, Texas.

Bureau of Economic Geology Seminars

William L. Fisher

"Energy—The next 100 years"

Edgar H. Guevara

"Mara Este: Integrated fractured reservoir study"

Bob A. Hardage

"Recent advances in multicomponent seismic technology"

Susan D. Hovorka

"K–12 educational elements within research projects"

Martin P. A. Jackson

"Salt tectonics provinces and superposed deformation across the continental-oceanic boundary, offshore Angola"

Charles Kerans

"Predicting carbonate platform and reservoir architecture"

Stephen E. Laubach

"Degradation beyond the emergent threshold"

Stephen C. Ruppel

"Applications of borehole image logs to carbonate reservoir characterization"

Daniel D. Schultz-Ela

"Sliding on a slippery slope: models of graben formation in Canyonlands National Park"

Lesli J. Wood

"Outcrop data—use it or lose it: integrating outcrop and subsurface research for improved clastic reservoir analogs with focus on the falling-stage tidal-bar complexes and incised valleys of the Sego Sandstone, Upper Cretaceous, Utah"

Hongliu Zeng

"Seismic sedimentology—Mioceno Norte example"

Committee Services, Offices, and Other Professional Responsibilities

William A. Ambrose

Co-chairman, "Latin American exploration plays and development," AAPG technical and poster sessions, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Sigrid J. Clift

Chairperson, Texas Environment Awareness Network (TEAN), representing the Bureau of Economic Geology.

Volunteer, The University of Texas at Austin, College of Natural Sciences Interactive "Science Fun Day."

Co-chairman, "Applications of visualization technologies from pore to reservoir scales," SEPM poster session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Edward W. Collins

President, Austin Geological Society, spring 1998–summer 1999.

Past President, Austin Geological Society, spring 1999–summer 2000.

Alan R. Dutton

Member, Ground-Water Protection Committee, Texas Natural Resource Conservation Commission, representing the Bureau of Economic Geology.

Member, Technical Advisory Group, Edwards Aquifer Authority, for developing an Edwards aquifer optimization program.

Associate Editor, *Hydrogeology*.

Shirley P. Dutton

Associate Editor, *Journal of Sedimentary Research*, SEPM (Society for Sedimentary Geology).

Convenor, "Advances in clastic diagenesis," technical session, American Association of Petroleum Geologists, 2000 Annual Convention, New Orleans, Louisiana.

Co-chairman, "Role of fluid flux in diagenesis," SEPM technical and poster sessions, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

William L. Fisher

Director, Geology Foundation, The University of Texas at Austin.

Chair, Faculty Review Committee, Department of Geological Sciences, The University of Texas at Austin.

Chair, Exploration Geophysicists Search Committee, Department of Geological Sciences, The University of Texas at Austin.

Member, Board of Directors, Texas Low-Level Radioactive Waste Disposal Authority.

Foundation Trustee, American Geological Institute.

Trustee, Southwest Research Institute.

Trustee Associate, American Association of Petroleum Geologists Foundation.

Member, Research Committee, Interstate Oil and Gas Compact Commission.

Member, Committee on Future Roles, Challenges, and Opportunities for the U.S. Geological Survey, National Research Council, Board on Earth Sciences and Resources.

Member, Hedberg Award Committee, Institute for the Study of Earth and Man.

Member, Advisory Council, Gas Research Institute.

Member, Science and Technology Committee, Gas Research Institute.

Member, University Advisory Board, Center for Legislative Energy and Environmental Research, South/West Energy Council.

Member, Advisory Board, World Energy Update.

Member, Committee on Resources, American Association of Petroleum Geologists.

Member, Steering Committee, National Geoscience Data Repository System.

Member, National Petroleum Council.

Member, National Academy of Engineering.

Member, U.S. National Committee for World Petroleum Congress.

Member, Board on Energy and Environmental Systems, National Research Council.

Member, Peer Committee, Petroleum, Mining, and Geological Engineering Section, National Academy of Engineering.

Member, Energy Resource Committee, Interstate Oil and Gas Compact Commission.

Member of the Corporation, American Association of Petroleum Geologists Foundation.

Chair, Bureau of Economic Geology Director Search Committee, The University of Texas at Austin.

Member, Past President's Council, American Geological Institute.

Member, Honorary Member Committee, Association of America State Geologists.

Member, Coastal Processes Committee, Association of America State Geologists.

Member, Continental Margins Committee, Association of America State Geologists.

Member, Digital Geological Mapping Committee, Association of America State Geologists.

Member, Energy and Mineral Policy Committee, Association of America State Geologists.

Member, Environmental Affairs Committee, Association of America State Geologists.

Liaison to U.S. Potential Gas Committee, Association of America State Geologists.

William E. Galloway

Member, Bureau of Economic Geology Director Search Committee, The University of Texas at Austin.

Member, Bureau of Economic Geology Senior Research Scientist Promotion Committee, The University of Texas at Austin.

Member, Research Committee, Society of Economic Paleontologists and Mineralogists.

Chairman, SEPM Program, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Co-chairman, "Depositional systems from reservoirs to basins: overview," SEPM/AAPG technical session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

James C. Gibeaut

Member, Texas Geographic Information Council, Texas Department of Information Resources and Texas Natural Resources Information System, representing the Bureau of Economic Geology.

Member, Texas Mapping Advisory Committee, representing the Bureau of Economic Geology.

Co-chairman, "Techniques for analyzing modern environmental processes and change and impacts," SEPM poster session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Edgar H. Guevara

Co-chairman, "Latin American exploration plays and development," AAPG technical session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Roberto Gutiérrez

Co-leader, "Beach processes and patterns of shoreline change along the upper Texas coast, Galveston Bay area," SEPM/SC field trip, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Douglas S. Hamilton

Co-chairman, "Depositional systems from reservoirs to basins: shore-zone and shelf," SEPM/AAPG technical and

poster sessions, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

C. Robertson Handford

Co-chairman, "Depositional systems from reservoirs to basins: carbonate platform systems," SEPM/AAPG poster session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Bob A. Hardage

Book Editor, *Planning Land 3-D Seismic Surveys*, Society of Exploration Geophysicists.

Member, Publications Committee, Society of Exploration Geophysicists.

Member, Exploration Geophysicists Search Committee, Department of Geological Sciences, The University of Texas at Austin.

Tucker F. Hentz

Editor, Advanced Reservoir Characterization for the Twenty-First Century: Gulf Coast Section Society of Economic Paleontologists and Mineralogists Foundation 19th Annual Bob F. Perkins Research Conference, Houston, Texas.

Susan D. Hovorka

Chairman, SEPM Awards Committee, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Volunteer, The University of Texas at Austin, College of Natural Sciences Interactive "Science Fun Day."

Co-chairman, "Techniques for analyzing modern environmental processes and change and impacts," SEPM poster session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Martin P. A. Jackson

Co-convenor, "Salt dynamics and sedimentation," SEPM/AAPG technical session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Chairman, "Salt tectonics," AAPG/SEPM poster session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

James W. Jennings, Jr.

Technical editor, *SPE Reservoir Evaluation and Engineering*, Society of Petroleum Engineers.

Charles Kerans

Member, Distinguished Lecture Committee, American Association of Petroleum Geologists.

Member, Development Geology Committee, Society of Petroleum Engineers.

Co-chairman, "Advances in carbonate sequence stratigraphy," AAPG/SEPM poster session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Co-leader, "Sequence framework and facies architecture of a Cretaceous carbonate ramp: late Albian of the Pecos River, West Texas," SEPM field trip, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Co-chairman, Best of American Association of Petroleum Geologists/Society of Exploration Geophysicists for Society of Petroleum Engineers.

Leader, "Pennsylvanian stratigraphic framework and distribution of reservoir facies, Big Hatchet Mountains, southwestern New Mexico," Reservoir Characterization Research Laboratory field trip, Bureau of Economic Geology, The University of Texas at Austin.

Chair, Senior Research Scientist Promotion Committee, Bureau of Economic Geology, The University of Texas at Austin.

Co-chairman, "Geologic models and reservoir simulation," Advanced Reservoir Characterization for the Twenty-First Century: Gulf Coast Section Society of Economic Paleontologists and Mineralogists Foundation 19th Annual Bob F. Perkins Research Conference, Houston, Texas.

Paul R. Knox

Co-chairman, "Depositional systems from reservoirs to basins: shore-zone and shelf," SEPM/AAPG technical and poster sessions, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Stephen E. Laubach

Co-chairman, "Exploration and exploitation of fractured reservoirs—I and II," AAPG technical and poster sessions, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Member, Board of Associate Editors, American Association of Petroleum Geologists *Bulletin*.

Chair, Research Group—Reservoir Deformation, American Association of Petroleum Geologists.

Member, Research Committee, American Association of Petroleum Geologists.

Member, Editorial Board, *SPE Reservoir Evaluation & Engineering*.

Member, Technical Editor Board, Society of Petroleum Engineers.

Jerry W. Mullican

Member, Ground Water Protection Council.

President, Ground Water Protection Research Foundation.

Member, Salt Cavern Research Partnership, representing Bureau of Economic Geology.

Member, Environmental Affairs Committee, Interstate Oil and Gas Compact Commission.

Jeffrey G. Paine

Associate Editor, *Geophysics, Environmental & Engineering Geoscience*, a journal published by the Association of Engineering Geologists and the Geological Society of America.

Review Panelist, National Aeronautics, and Space Administration Earth Science Enterprise Program, Solid Earth and Natural Hazards Panel.

Stephen C. Ruppel

Member, Program Advisory Committee, Advanced Reservoir Character-

ization for the Twenty-First Century: Gulf Coast Section Society of Economic Paleontologists and Mineralogists Foundation 19th Annual Bob F. Perkins Research Conference, Houston, Texas.

Chairman, Publications Committee, Austin Geological Society.

Delegate, American Association of Petroleum Geologists.

Luis A. Sánchez-Barreda

Co-chairman, Oral session IV, "Revitalization of petroliferous fields and provinces," Revitalización de provincias petrolíferas maduras, Tercera Conferencia Internacional Conjunta, Asociación Mexicana de Geólogos Petroleros and American Association of Petroleum Geologists, Veracruz, Mexico.

Bridget R. Scanlon

Associate Editor, *Reviews of Geophysics*, American Geophysical Union.

Member, Committee on Unsaturated Zone Hydrology, American Geophysical Union.

Member, National Academy of Sciences Panel on Review of Subsurface Contamination at Department of Energy Complex Sites: Research Needs and Opportunities.

Member, Committee on Water Cycle Study Group, U.S. Global Climate Change Program.

Technical Reviewer for U.S. Department of Energy, "Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment."

Theme Session Organizer and Convenor, "Measurement techniques and modeling of spatial and temporal variability in groundwater recharge in response to past, present, and future climates," Geological Society of America, 1999 Annual Meeting, Denver, Colorado.

Andrew R. Scott

Associate Editor, American Association of Petroleum Geologists *Bulletin*.

Vice President, Energy Minerals Division, American Association of Petroleum Geologists.

Councilor, Gulf Coast Section, Energy Minerals Division, American Association of Petroleum Geologists (1995–July 1999).

Member, Research Committee, American Association of Petroleum Geologists.

Co-chairman, "Gas hydrate exploration and development," technical session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Chairman, Gas Hydrates, Energy Minerals Division, American Association of Petroleum Geologists.

Chairman, Website, Energy Minerals Division, American Association of Petroleum Geologists (1997–July 1999).

Chairman, Energy Minerals Division, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Short Course Chairman, Energy Minerals Division, American Association of Petroleum Geologists, 2000 Annual Convention, New Orleans, Louisiana.

Member, Unconventional Reservoirs Subcommittee, American Association of Petroleum Geologists.

Chairman, Member Services, Energy Minerals Division, American Association of Petroleum Geologists.

James L. Simmons, Jr.

Associate Editor, *Amplitude-versus-Offset (AVO)*, Geophysics.

Admissions and Awards Committee, Department of Geological Sciences, The University of Texas at Austin.

Co-chairman, "Applications of visualization technologies from pore to reservoir scales," SEPM poster session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Noel Tyler

Member, Environmental Practices Committee, Division of Environmental Geosciences, American Association of Petroleum Geologists.

Member, Committee on Earth Resources, National Research Council.

Member, National Research Council Panel to Review United States Geological Survey Coastal Program (1998–1999).

Member, Committee on Earth Resources, National Research Council (1994–present).

Member, Committee on Basic Research Opportunities in the Earth Sciences, National Research Council (1998–2000).

Session Director, 17th Congress of the World Energy Council, Houston, Texas.

Member, University Advisory Board, Energy Council.

President's Advisory Committee for Vice President for Research, The University of Texas at Austin.

Member, Geophysicists Search Committee, Department of Geological Sciences, The University of Texas at Austin.

Chair, Continental Margins Committee, Association of American State Geologists.

Member, Coastal Processes Committee, Association of American State Geologists.

Member, Energy and Minerals Policy Committee, Association of American State Geologists.

Member, Environmental Affairs Committee, Association of American State Geologists.

Member, Digital Mapping Committee, Association of American State Geologists.

Member, Texas Mapping Advisory Committee.

Member, Faculty Review Committee, Department of Geological Sciences, The University of Texas at Austin.

Co-chairman, Program Advisory Committee, Advanced Reservoir Characterization for the Twenty-First Century: Gulf Coast Section Society of Economic Paleontologists and Mineralogists Foundation 19th Annual Bob F. Perkins Research Conference, Houston, Texas.

Roger Tyler

Co-convenor, "Unconventional reservoirs," EMD/AAPG technical

session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Gulf Coast Councillor, Energy Minerals Division (EMD) of American Association of Petroleum Geologists (AAPG), 1999–2000.

Bruno C. Vendeville

Member, Editorial Committee, *Bulletin de la Société Géologique de France*, 1999–present.

William A. White

Member, Bessie Heights Marsh Restoration Planning Team, 1998–1999.

Brian J. Willis

Co-chairman, "Depositional systems from reservoirs to basins: alluvial systems," SEPM/AAPG technical and poster sessions, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Co-chairman, "Depositional facies and surfaces of falling-stage systems tracts," SEPM technical session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

Lesli J. Wood

Co-chairman, "Seismic imaging and modeling of depositional systems and facies," SEPM poster session, American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas.

University Teaching/ Continuing Education

Alan R. Dutton

"Introduction to hydrogeology": short course presented to Master's class, Universidad Iberoamericana, Campus Leon, Guanajuato, Mexico.

William L. Fisher

"Introduction to petroleum workstations" (Geology 391 and 171C): The University of Texas at Austin, Department of Geological Sciences (with William E. Galloway), Austin, Texas.

"Sequence stratigraphy" (Geology 380N): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

"Research in basin analysis" (Geology 394): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

"Reservoir geology and advanced recovery" (Geology 383R): The University of Texas at Austin, Department of Geological Sciences (with Noel Tyler), Austin, Texas.

"Introduction to petroleum workstations" (Geology 391): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

William E. Galloway

"Research in depositional systems" (Geology 394): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

"Depositional systems: terrigenous clastics" (Geology 383): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

"Introduction to petroleum workstations" (Geology 391 and 171C): The University of Texas at Austin, Department of Geological Sciences (with William L. Fisher), Austin, Texas.

Bob A. Hardage

"Exploration geophysics and reservoirs" (Geology 391): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

"Field techniques in exploration geophysics" (Geology 391): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

Susan D. Hovorka

"Water and the environment in Southwest Texas": professional development course in earth science presented to southwest Texas middle school teachers via videoconference, Austin, Texas.

James W. Jennings, Jr.

"Practical characterization and modeling of San Andres and Grayburg reservoirs": short course presented to the Society of Petroleum Engineers and the West Texas Geological Society, Midland, Texas (with F. Jerry Lucia).

Charles Kerans

"Sequence stratigraphy and characterization of carbonate reservoirs": co-leader of SEPM short course presented at American Association of Petroleum Geologists, 1999 Annual Convention, San Antonio, Texas (with S. W. Tinker).

Stephen E. Laubach

Instructor, Fractured Reservoirs School: American Association of Petroleum Geologists, Austin, Texas.

F. Jerry Lucia

"Geological/engineering characterization of carbonate reservoirs" (Geology 391): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

"Practical characterization and modeling of San Andres and Grayburg reservoirs": short course presented to the Society of Petroleum Engineers and the West Texas Geological Society, Midland, Texas (with James W. Jennings, Jr.).

"Carbonate rock-fabrics and reservoir model construction": short course presented to Anadarko Petroleum Company, Houston, Texas.

Stephen C. Ruppel

"Modern approaches to reservoir characterization of Permian platform carbonates in the Permian Basin": short course presented to the Permian Graduate Center, Midland, Texas.

Andrew R. Scott

"Defining coalbed methane exploration fairways and resources": co-coordinator (with Roger Tyler) of coalbed methane short course, held in

conjunction with College of Continuing Studies, The University of Alabama, '99 International Coalbed Methane Symposium, Tuscaloosa, Alabama.

"Introduction to microbial options for increasing oil recovery": workshop sponsored by the Petroleum Technology Transfer Council and the U.S. Department of Energy, Midland, Texas.

"Coalbed methane exploration strategies": workshop sponsored by the Oklahoma Geological Survey and the Petroleum Technology Transfer Council, Norman, Oklahoma.

Noel Tyler

"Characterization of heterogeneous reservoirs": short course presented at the 50th Anniversary Meeting of the Asociacion Mexicana de Geologos Petroleros, Veracruz, Mexico.

"Introduction to basin and play analysis": short course presented to Pemex, northern district, Reynosa, Mexico.

"Optimizing production from mature fields in Trinidad's business climate": workshop presented for Petrotrin, Trinidad.

"Reservoir geology and advanced recovery" (Geology 383R): The University of Texas at Austin, Department of Geological Sciences (with William L. Fisher), Austin, Texas.

"Research in reservoir geology" (Geology 394): The University of Texas at Austin, Department of Geological Sciences, Austin, Texas.

Roger Tyler

"Defining coalbed methane exploration fairways and resources": co-coordinator (with Andrew R. Scott) of coalbed methane short course, held in conjunction with College of Continuing Studies, The University of Alabama, '99 International Coalbed Methane Symposium, Tuscaloosa, Alabama.

"Developing coalbed methane exploration fairways in a basin with limited data: examples from the Piceance Basin, Colorado, and North Slope of Alaska": presented at Petroleum Technology Transfer Council, Technology Transfer Workshop, Developing a Model for Coalbed Methane Exploration Fairways and Gas-in-Place Analysis in Texas, San Antonio, Texas.

PUBLICATIONS

In its role as a public geological research unit, the Bureau of Economic Geology disseminates the results of its research programs primarily through its publications. Bureau publications cover major aspects of the geology and natural resources of Texas as well as the results of research for international projects and U.S. projects conducted outside of Texas. In addition to publishing traditional printed reports and maps, the Bureau continues to serve the geological community through use of the Internet. Information about the Bureau's research programs and publications may be viewed at our home page: **http://www.utexas.edu/research/beg/.**

The following publications were issued in 1999:

Reports of Investigations

RI 254. Twin Vertical-Seismic-Profile (VSP) Simulation of Crosswell Seismic Tomography

by James L. Simmons, Jr.
35 p., 19 figs., $10.00

This report found that the twin-vertical-seismic-profile simulation of cross-well (TVSC) tomography algorithm is a viable approach for simulating a crosswell-tomography experiment. In work funded by the U.S. Department of Energy, researchers used field data acquired at Texaco's Borehole Test Site near Humble, Texas, to image interwell velocity fields. The TVSC tomography method uses first-arrival times from wavefields generated by a number of surface sources positioned inline with two receiver wells. The differential traveltimes between receiver wells are used to estimate interwell velocities. TVSC tomography is evaluated on synthetic and real data. Use of the model covariance matrix illustrates the trade-off between data fit and model reasonableness. The authors recommended that a TVSC ex-

periment be applied at a site where valid sonic logs, true cross-well data, and zero-offset vertical seismic profiles are available.

RI 255. Geologic and Engineering Characterization of Turbidite Reservoirs, Ford Geraldine Unit, Bell Canyon Formation, West Texas

by Shirley P. Dutton, Mark D. Barton, George B. Asquith, Mohammad A. Malik, Andrew G. Cole, John Gogas, Jose I. Guzman, and Sigrid J. Clift
88 p., 74 figs., 7 tables, $9.00

This report summarizes results of an integrated geological, geophysical, petrophysical, and engineering study of a representative Delaware Mountain Group field to identify constraints on producibility in this deep-water sandstone reservoir exhibiting low primary recovery efficiency. The Ramsey sandstone interval of the Bell Canyon Formation was characterized in the Ford Geraldine unit, Culberson and Reeves Counties, Texas, using data from outcrops, subsurface logs and cores, and a 3-D seismic survey. Facies relationships determined from depositional processes interpreted from outcrop analogs exposed in Culberson County suggest that the sandstones were deposited by turbidites in a basin-floor system of channels and levees having attached lobes. The depositional model developed from outcrop can be widely applied by operators to other reservoirs that produce from Delaware sandstones. The study was funded primarily by the U.S. Department of Energy and the State of Texas.

RI 256. Groundwater Availability in the Carrizo–Wilcox Aquifer in Central Texas—Numerical Simulations of 2000 through 2050 Withdrawal Projections

by Alan R. Dutton
53 p., 23 figs., 5 tables, 2 apps., $5.00

In anticipation of the increased demand for groundwater in the Carrizo-Wilcox aquifer between the Colorado and Brazos Rivers, this study, conducted for the Texas Water Development Board, involved the simulation of five groundwater-development scenarios. A calibrated model was developed to predict water-level change related to the amount of groundwater withdrawal, its concentration in an area, hydrogeologic properties, and model characteristics. The results showed that groundwater in the study area is likely to remain available to meet demand through 2050.

RI 257. Using Airborne Geophysics to Identify Salinization in West Texas

by Jeffrey G. Paine, Alan R. Dutton, and Martina U. Blüm
69 p., 59 figs, 2 tables, 3 apps., $10.00

In this study of an oil field and agricultural area in Runnels County, airborne and ground-based geophysical surveys and chemical analyses were integrated to identify soil and water salinization and determine its origin. Salinization, a chronic problem in arid regions, is caused by natural processes as well as oil-field and agricultural activities. This work focused on the Hatchel area, where more than 700 oil and gas wells have been drilled since the 1920's. Conductivity and magnetic anomalies detected by airborne instruments were combined with well locations to identify oil-field salinization without requiring ground surveys at every well. This cooperative study was funded by the Railroad Commission of Texas with contributions from the Lower Colorado River Authority and the Colorado River Municipal Water District.

Geological Circular

GC 99-1. 3-D Seismic Interpretation of Deep, Complex Structures in the Delaware Basin, West Texas

by Bob A. Hardage, Virginia M. Pendleton, and George B. Asquith
42 p., 31 figs., 1 table, $12.00

With support from the U.S. Department of Energy and Gas Research Institute, researchers conducted this multidisciplinary reservoir-characterization study of the Ellenburger Group to determine whether productive Ellenburger facies could be detected and mapped by

using surface-recorded seismic data. The study area—a 176-mi^2 3-D seismic grid in Pecos, Reeves, and Ward Counties in the southern Delaware Basin of West Texas—comprised Lockridge, Waha, and West Waha fields and parts of Worsham-Bayer and Coyanosa fields, which have produced 1.3 Tcf of natural gas since their discoveries in the 1960's. Seismic time-structure and depth maps were generated for the tops of the Bone Spring-3, Mississippian, Devonian (Woodford), and Ellenburger. Structural maps created across the image area are thought to be some of the most accurate depictions of the subsurface structure of this area of the Delaware Basin that are publicly available. No seismic attribute could be found, however, that exhibited any significant correlation with Ellenburger production. The best production in the Lockridge-Waha region was found to be associated with reverse faults and overturned sections, making the best sites for wells where they will penetrate the maximum number of fractured strata.

Page-sized Map

Land Resources of Texas

by E. G. Wermund, Jr.
scale: 1 inch = 100 mi,
$0.25 each

Next in the Bureau's series of page-sized maps, this summary of land resources depicts the fundamental physical and geomorphic properties that characterize these resources in Texas. Units are generalized from the Bureau's 1:500,000-scale *Land Resources of Texas* map.

Contract Reports

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SERVICES

Core Research Centers

The Bureau of Economic Geology manages two core research facilities, the Core Research Center (CRC) and the Midland Core Research Center (MCRC). The CRC, located adjacent to the Bureau of Economic Geology Research and Administration Office, houses one of the largest public collections of subsurface geological materials in the United States and is open Monday through Friday from 8:00 a.m. to 5:00 p.m. (CST). The Curator is George Bush. The repository, approximately 103,000 ft^2, houses nearly 50 linear miles of shelving. Ten percent of the repository is isolated and climate controlled for storing unstable core materials.

Other CRC services include gamma-scan facilities, photography lab, sawroom, and general core processing. Facilities for holding core seminars are also available. Advance notice is requested for CRC services.

A brochure describing the CRC, its policies, procedures, and price list is available upon request. Customized printouts of CRC holdings are available for purchase. Printouts can be generated on the basis of county, operator, lease name, or sample range. The entire CRC data base, listing all CRC holdings, may also be purchased by contacting James Donnelly, Data-Base Manager.

Visitors may view cores or cuttings in the Main Viewing Room, which can display as much as 1,800 ft of conventional core; 16,440 core samples and 74,560 drill cuttings from wells are available for study at the CRC. Geologic specimens housed at the CRC represent 34 countries and 880 counties or parishes within 36 states. Patrons are asked to provide results of analyses of sampled materials within 1 year of completion of their studies, which then become part of the CRC's reference material.

During (fiscal) 1999, the CRC received more than 250 visitors, who made transactions involving CRC inventory that included materials from more than 600 wells and required the transfer of more than 16,000 boxes of core to and from viewing and shipping areas.

New acquisitions in 1999 totaled 100 new core samples, in excess of 1,975 boxes. Donations were received from the following Bureau projects: Texas Department of Transportation—Archeology; Railroad Commission of Texas—Wharton and Beals Creek Sites; and Pantex AIP. Donations were also received from Chevron Petroleum Technology Company; Pioneer Natural Resources; Strand Energy; and Texaco Incorporated. Altura Energy Ltd. has donated 70,000 boxes of core that will be delivered to the CRC in 2000.

Public Information

Requests for information about the geology, energy, mineral, and land resources of Texas come to the Bureau from geologists, engineers, educators, students, landowners, industry, governmental agencies, and other organizations and interested individuals.

Extensive data and information are available from the Bureau's Reading Room/Data Center, and members of the Bureau's research staff provide advisory and technical services in their areas of expertise. The Bureau's Public Information Geologist maintains files on mineral resources (both energy and nonenergy minerals) and general geology of specific areas of the state and assists patrons in locating answers to questions. In addition to dealing with these direct-inquiry responses, the Public Information Office, as well as other Bureau staff, has also made a commitment to K–12 education by (1) developing presentations and activities for the classroom, (2) providing professional development for teachers, and (3) offering instructional tours for classrooms at the Bureau.

Ed Garner served as the Bureau's Public Information Geologist for many years until his death in September 1999 (see *In Memoriam*, p. 8). Sigrid Clift has assumed the duties of Public Information Geologist and also manages, with the assistance of Amanda R. Masterson, the Bureau's Reading Room/Data Center.

Publication Sales

Best-selling publications in 1999 were our page-sized maps, our Geologic Atlas of Texas Sheets, and our Guidebooks, notably Guidebook 27, *Geology of the Big Bend Ranch State Park, Texas*. Another popular series, part of our Open-File collection, consists of more than 100 black-and-white geologic quadrangle maps at a scale of 1:24,000 prepared by E. W. Collins and Jay A. Raney; please contact us for a list of available quadrangle maps.

The Publications Sales office is managed by Amanda Masterson, assisted each semester by students. This year's student assistant was Wendy Zinke.

For our U.S. customers' convenience, we offer a toll-free phone number (1-888-839-4365) and a toll-free fax number (1-888-839-6277).

We continue to maintain our Web site, http://www.utexas.edu/research/beg/pub.html, which features an online order form.

Located on the first floor of the Bureau's Research and Administration building on the J. J. Pickle Research Campus, the office is open from 8:00 a.m. to 4:30 p.m., Monday through Friday, and at other times by advance notice. We accept cash, checks, money orders, international wire transfers, and most major credit cards.

Reading Room/ Data Center

The Bureau's Reading Room/Data Center provides a wide range of geological data and information to staff members, students, and visitors interested in Texas geology. The facility, supervised by Sigrid Clift assisted by Amanda R. Masterson, is open to the public for reference use from 8:00 a.m. to 5:00 p.m., Monday through Friday.

The Reading Room houses a collection of more than 5,000 monographs and serials and about 50 periodicals. Included in the collection are extensive reports and open-file materials received from the U.S. Geological Survey, the U.S. Bureau of Mines, and the U.S. Department of Energy.

The Data Center also contains an extensive collection of surface and subsurface geological data pertaining to Texas and adjacent states. Open-file document storage data consisting of original maps, cross sections, and other data used in preparing Bureau publications are available to staff and the public. Topographic and geologic maps, aerial photographs, and Landsat images are also available.

Geophysical Log Facility

The Geophysical Log Facility (GLF), managed by Sigrid Clift assisted by Daniel Ortuño, is housed in the Bureau's Reading Room/ Data Center. The facility was established by State legislation, effective September 1, 1985, that requires that all operators of oil, gas, and geothermal wells provide the Railroad Commission of Texas (RRC) with at least one copy of a well log for each new, deepened, or plugged well. A subsequent agreement with the RRC designated the Bureau as the entity responsible for providing public access to these logs. The RRC supplies paper copies of each well log and an index to the logs. They are filed at the GLF by accession number and API number. Users of this facility include commercial companies, independent researchers, and Bureau scientists. Patrons may examine well logs at the GLF facility. Requests for log copies can be made in person, by mail, telephone, fax, or E-mail.

The GLF has received approximately 284,000 well logs of various types from the RRC. Historical logs (prior to 1985) from the RRC are also in the process of being stored at the GLF.

Additionally, the GLF has a collection of more than 750,000 geophysical well logs that have been acquired for Bureau research projects and from various donations. The GLF also stores more than 240,000 microfiche copies of well logs, 500,000 scout tickets and well records, 400,000 driller's logs, and 300,000 completion cards for Texas wells.

SUPPORT STAFF

Administrative

The administrative staff, supervised by Wanda L. LaPlante, Executive Assistant, handles the daily management requirements for the Bureau. These tasks include payroll and personnel, accounts payable and receivable, publication sales, purchasing, travel arrangements and reimbursements, correspondence, receptionist duties, and coordination of meetings with outside agencies. Each year this group processes more than $5 million in purchases, $6 million in personnel appointments, and another $4 million in other cost categories.

Editing

The Editing staff, supervised by Chief Editor Susann V. Doenges, handle editing, word processing, desktop publishing, and proofreading of manuscripts for Bureau publications, contract reports, and other documents. They support the text-processing needs of the research staff and work closely with the Graphics section to produce publications that are made available to the public and to sponsors of Bureau research. During 1999, the staff prepared 6 Bureau publications and 51 contract reports. In addition, 41 papers and 62 abstracts by Bureau authors were published by professional journals and publishers.

Graphics

The Graphics section, under the direction of Graphics Manager Joel L. Lardon, is responsible for producing text illustrations and presentation materials, manual and digital photography, design and layout of Bureau publications and reports, as well as map design and finishing. In 1999, the Graphics section's 7-person full-time staff digitally produced 3 full-color plates, 1 black-and-white plate, 1,439 text illustrations, and 2,965 presentation graphics (35-mm slides, posters, and overhead transparencies).

All illustrations, including color and black-and-white plates, are produced entirely on computers. High standards are practiced to maintain the Bureau's reputation for quality. The Graphics section utilizes a 1200-dpi black-and-white laser printer, a dye-sublimation color printer, one high-resolution large-format color desktop printer, a 300-dpi color ink-jet desktop printer, four 36-inch-wide color ink-jet printers, a 36-inch-wide hot laminator, two high-resolution film recorders, a 300-dpi monochrome scanner, and a high-resolution color scanner for opaque and transparent originals.

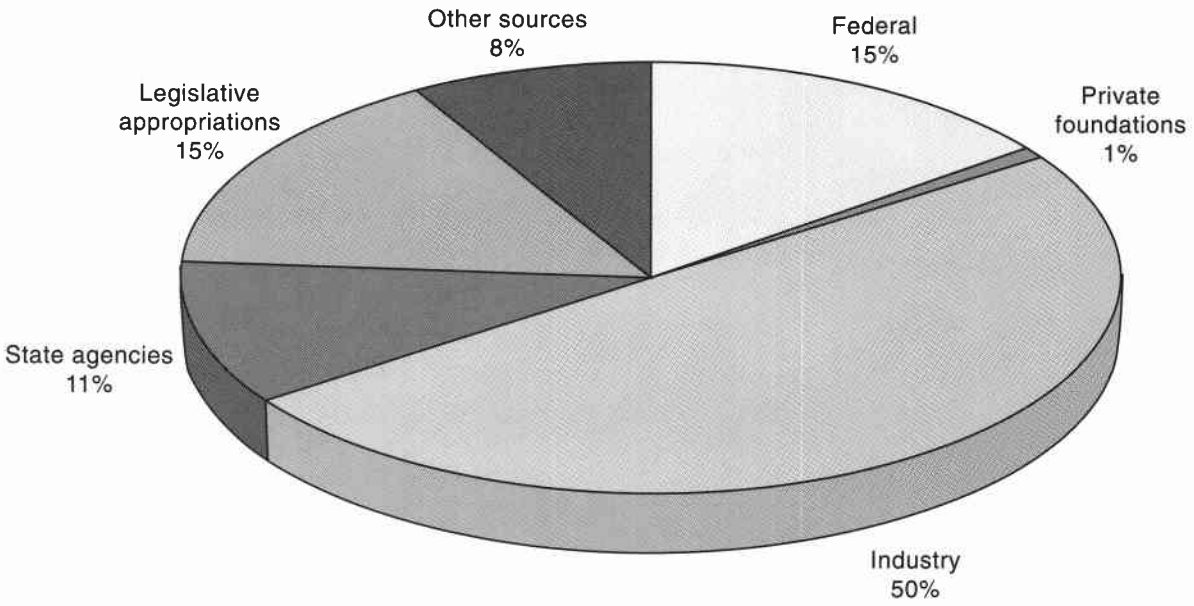
Information Technology Services

Information Technology Services (ITS) provide technical resources and services to Bureau scientists and support staff to assist research in interpretation, 3-D modeling, visualization, reservoir characterization, computer mapping, programming, data-base applications, and statistical and graphical analysis of data. Scott Rodgers is the Manager of Media Technologies, and Ron Russell is the Manager of Computer Services.

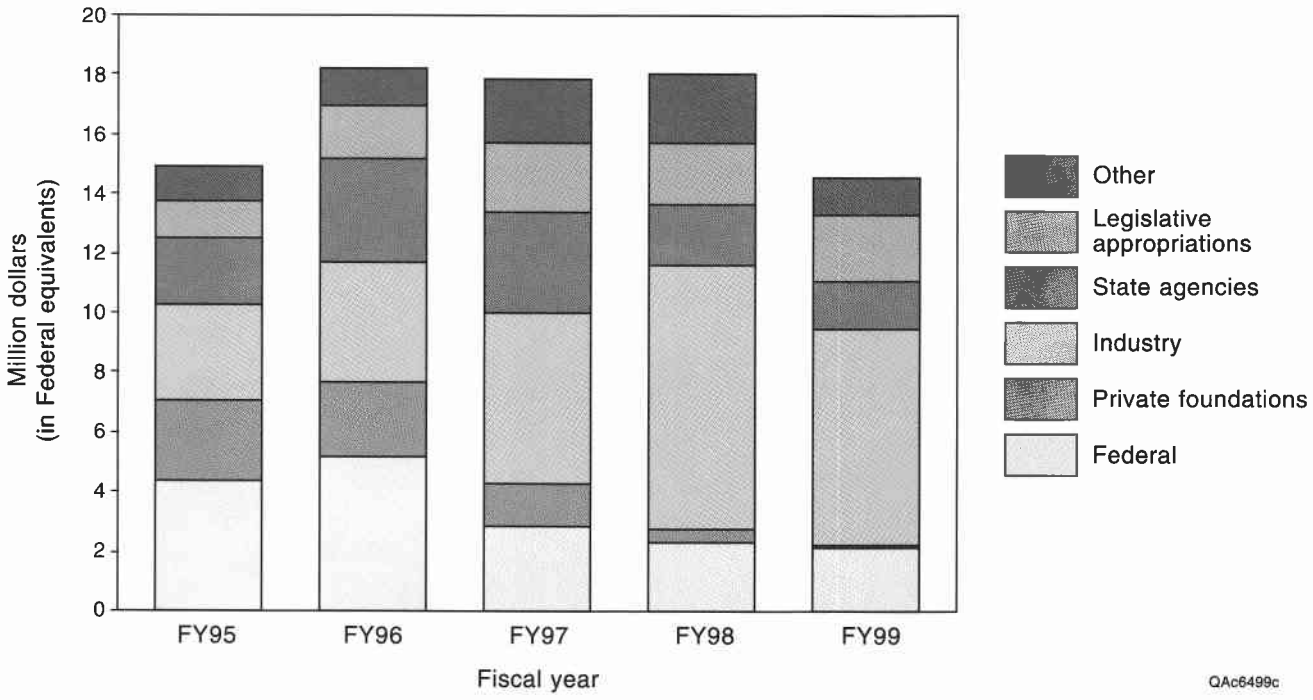
With maintenance support from ITS, the Media Technologies group operates the Bureau's Virtual Imaging and Visualization Environment, or VIVE, which is a multimode facility that serves as a collaborative work area and an immersive visualization theater. The system is also designed to support the Bureau's *EarthView Texas* educational outreach program and is capable of remote large-screen virtual reality presentations. ITS is also responsible for systems and network design, as well as the purchasing, testing, installation, and training for these systems. Services are provided by a state-of-the-art computing environment composed of Unix, Windows PC's, and Macintosh computers. The computing equipment is connected by a LAN within the Bureau and through a T-1 circuit to the University and the Internet. Print, file, E-mail, and application services are provided by various servers to the desktop across the 10/100 MB Ethernet LAN. A total of 33 Unix workstations, 94 Macintoshes, and 116 Windows PC's make up the computing resources. The Bureau's virtual imaging environment employs Silicon Graphics® Onyx 2 and O_2 computers to generate and visualize complex 3-D models and projects using active stereo technologies on a large rear-projection screen. Color-printing and plotting services are provided by a 36-inch Versatec electrostatic plotter, one HP 1055CM plotter, four HP 755CM plotters, one LaserMaster ColorMark plotter, one HP2500CM printer, and four HP 1600CM printers. Additional hardware consists of 25 laser printers and 3 scanners. The University's IBM, Unix, VAX, and Cray computer systems are also available to Bureau researchers. Major geoscience software packages from Dynamic Graphics, ER Mapper, ESRI, GeoGraphix, Geomath, GeoQuest, Green Mountain Software, GX Technology, Hampson-Russell, Landmark Graphics, MathWorks, Micro Seismic Technology, Neuralog, Paradigm Geophysical, Parallel Geoscience, PetCom Inc., PetroSoft, and Smedvig Technologies are installed on the appropriate platforms. Office-productivity software is installed on all desktops.

SOURCES OF FUNDING AND BUDGET TRENDS

FY 99 SOURCES OF FUNDING



FIVE-YEAR BUDGET TRENDS



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