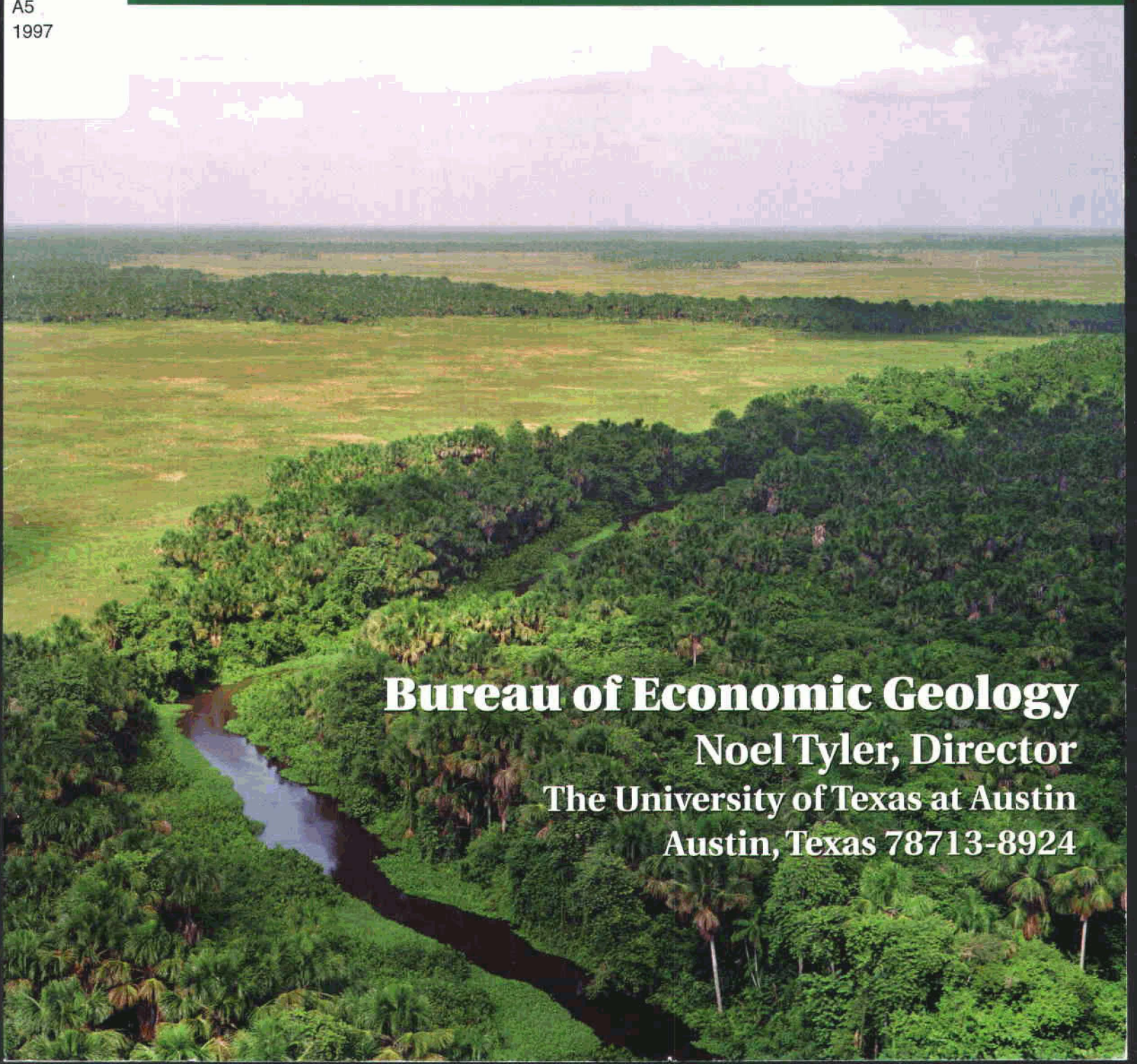
Annual Report 1997



Bureau of Economic Geology
Noel Tyler, Director
The University of Texas at Austin
Austin, Texas 78713-8924

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 and to the Environmental and Consumer Health Protection Division of the Texas Department of Health.

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: A small distributary channel meandering over the northern floodplain of the Orinoco Delta, Venezuela. The Bureau is initiating a baseline geo-environmental characterization of this world-class delta in collaboration with a consortium of Venezuelan universities and Petróleos de Venezuela. Photo by Noel Tyler.

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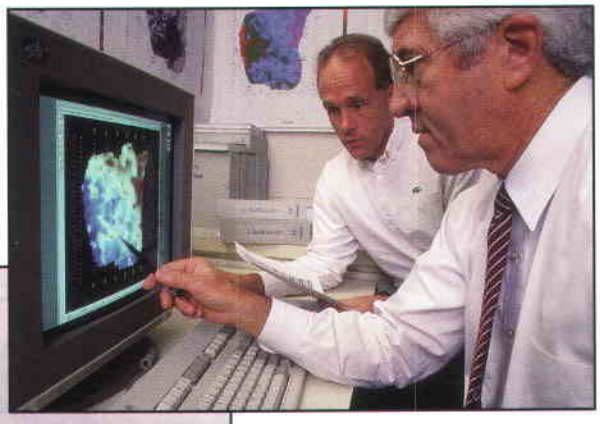
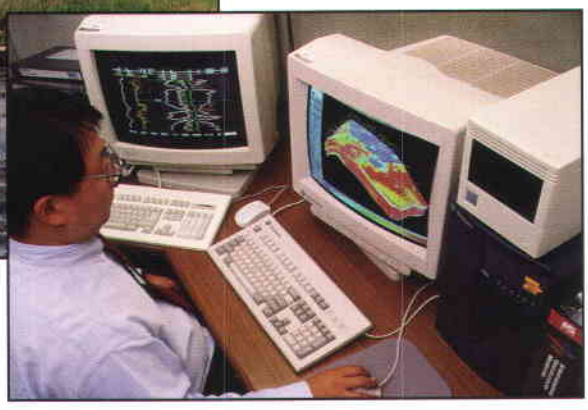
Program Support

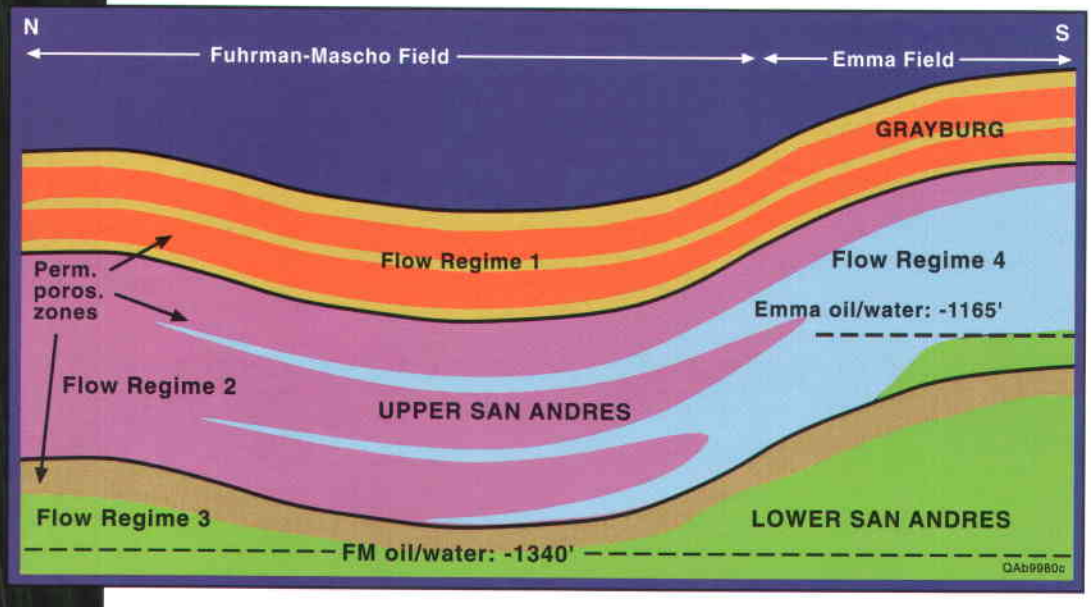
In 1997, the Bureau of Economic Geology's operating budget was $17.8 million (in Federal equivalents) from 89 contracts and grants and line-item State appropriations. Sixty-three of these projects were from interagency contracts with State and local governments and from various agencies of the Federal government. Twenty-six contracts were with the energy industry and private institutions. A complete listing of projects and their funding sources is found in the "Contract and Grant Support" section of this annual report. In 1997, the Bureau conducted 84 research projects, several of which are highlighted herein.





Oil Resource Investigations

In 1997, the Bureau continued its strong emphasis on domestic-oil resource investigations. The goal of the University Lands Advanced Recovery Initiative is to characterize selected reservoirs on extensive acreage owned by The University of Texas System to aid operators in optimizing recovery of their remaining hydrocarbon resources. The ultimate objective is to stem the current decline in University Lands production. Bureau studies indicate that more than 2 billion barrels of remaining mobile oil, about 10 times the remaining reserves, still remains as a target for improved recovery. This project is funded by The University of Texas System and by matching funds from operators of University Lands fields chosen for site-specific studies. The Bureau, with support from the State of Texas, is also providing expertise and advanced geologic and engineering technologies to help recover remaining oil and gas on State Lands. The primary goal of this State of Texas Advanced Oil and Gas Resource Recovery Optimization Initiative (Project STARR) is to increase royalty income of the Permanent School Fund through drilling of targeted infill wells. Several prospects for increased production have been identified and, with the support of



allied producers, are being drilled. In Ozona field in Crockett County, for example, 15 wells have been drilled on STARR-recommended State Lands locations, and early production results show that most of these wells are outperforming other recent Ozona infill wells.

The U.S. Department of Energy (DOE) continued to fund several Bureau investigations designed to discover how to maximize oil recovery from existing U.S. fields. In an ongoing study employing 3-D seismic and subsurface data, Bureau researchers are demonstrating that detailed reservoir characterization of siliciclastic slope and basin reservoirs of the Delaware Mountain Group will lead to cost-effective strategies for recovering a higher percentage of original oil in place. In 1997 the Bureau completed a DOE-funded study that evaluated the potential of recording crosswell tomographic data with a surface-based energy source instead of a conventional downhole energy source. Analysis of field data indicated that surface-source crosswell tomography is an economic and technically viable procedure for evaluating interwell conditions in many reservoir systems.

Natural Gas Resource Investigations

A major 1997 Bureau achievement was the publication of the two-volume series, the *Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs*, which was funded by the Gas Research Institute (GRI), DOE, and Minerals Management Service (MMS), U.S. Department of the Interior. A total of 4 years in preparation, the atlas was a collaborative effort among the Bureau, the Geological Survey of Alabama, the Basin Research Institute (Louisiana State University), and MMS. This series represents the first detailed, comprehensive synthesis of the play framework of all sandstone-body reservoirs in the Federal Outer Continental Shelf and in Alabama, Louisiana, and Texas Offshore State waters. Already one of the Bureau's most popular publications,

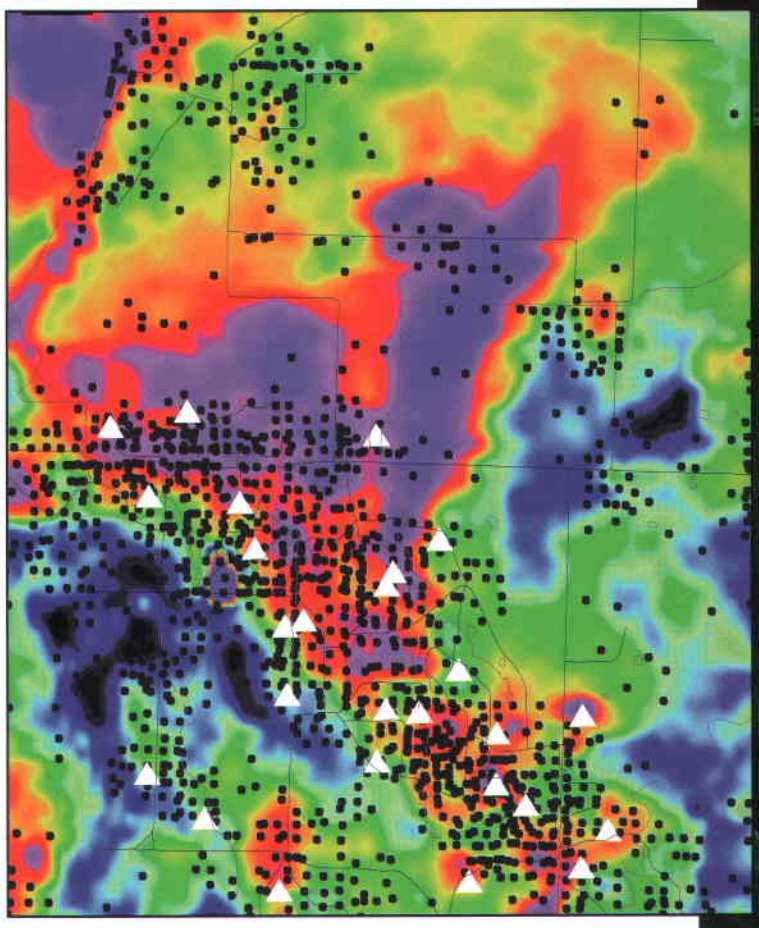
the atlas is described in the "Highlights" section in this annual report.

The objective of studies composing the Carbonate Secondary Gas Recovery program is to develop and demonstrate advanced technologies (3-D seismic-data interpretation and geologic, engineering, and petrophysical modeling) that can be used to evaluate deep, carbonate gas reservoirs, such as the productive Ellenburger interval at Lockridge and Waha fields in West Texas. The program is funded by DOE and GRI.

Another Bureau project funded by DOE currently has scientists developing innovative ways of providing realistic and play-specific methods of measuring natural gas reserve-growth potential. Bureau researchers are assessing the technology necessary to achieve natural gas reserve growth and the economic factors related to natural gas reserve growth in the Gulf Coast Basin. Through such assessment, the longer term potential and economics of natural gas reserve growth as a contributor to the future natural gas supply from the Gulf Coast Basin can be realistically quantified. The methodology of this assessment can be verified and applied more broadly to other natural gas resource areas having significant natural gas reserve-growth potential.

Hydrogeology and Environmental Investigations

The Bureau's hydrogeologic and environmental efforts during 1997 emphasized remediation of toxic near-surface contaminants and geologic study of issues related to subsurface waste containment. The Bureau continued to assist the Railroad Commission of Texas in devising cleanup solutions at eight sites in Texas where the source and subsurface extent of contamination are unknown and where complex subsurface geology will affect remediation efforts. Investigations focused on finding cost-effective remedial solutions and limiting investigation costs by applying nonintrusive and advanced techniques. In a pilot study conducted for the Texas Natural Resource Conservation Commission, Bureau researchers developed a methodology for building a geographic information system (GIS) to merge data on leaking-petroleum-storage-tank sites and hydrogeologic data into a data base to facilitate retrieval and analysis. The study evaluates this technology as a way to enhance evaluation and risk assessment of new sites, as well as to evaluate the effectiveness of site-characterization, risk-assessment, and remediation strategies of old sites.



The Bureau is also investigating the performance of engineered barriers capping waste disposal facilities. In a project funded through the Texas Low-Level Radioactive Waste Disposal Authority,

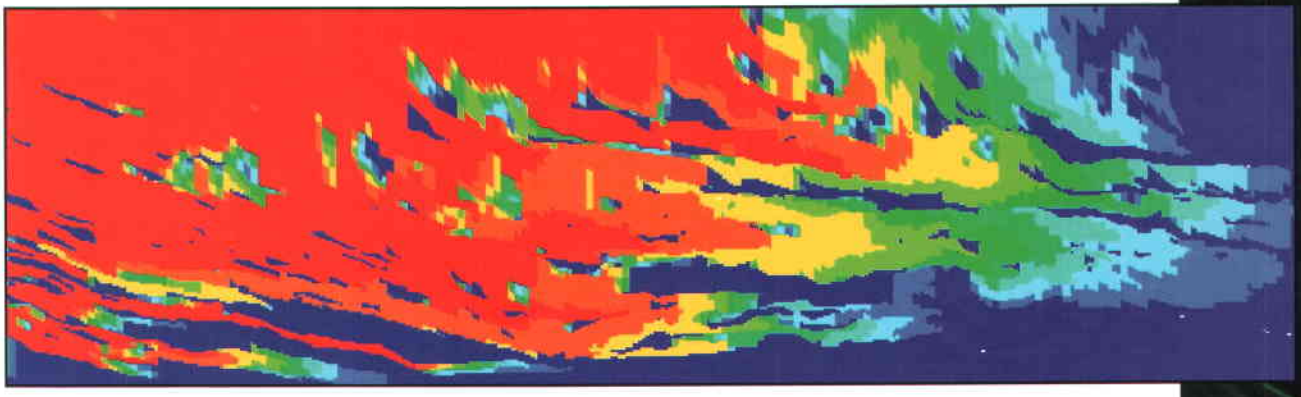
Bureau researchers are documenting the physical, chemical, and mineralogic changes in geologic deposits that have been modified by natural processes for thousands of years. They are examining these deposits as analogs to what might happen to engineered barriers over a long time frame. Results of this study should be applicable to arid-zone disposal sites, as well as to the proposed Texas low-level radioactive waste disposal site in Hudspeth County.

Industrial Associates Programs

In 1997, Bureau projects funded by consortia of industrial associates addressed diverse tasks related to hydrocarbon exploration and production. One major Bureau study is investigating fluvial-deltaic reservoir heterogeneity—specifically the spatial distribution of rock properties at interwell scale in the subsurface. The study's approach is to develop a firm quantitative basis for reservoir modeling by studying extensive, continuous outcrops as reservoir analogs. Outcrop studies provide critical data for modeling sandstone-body architecture, distribution of shales, and permeability structure of strata. The major focus of the project in 1997 was the Frewens Sandstone of the Frontier Formation, central Wyoming, a superbly exposed tide-influenced lowstand delta system and a highly prolific delta type for which few outcrop examples have been documented. In 1997, project researchers also began to study the Sego Sandstone in eastern Utah, a tide-influenced system that differs from the Frewens Castle in stratal architecture, facies patterns, and shale distribution. Outcrop and modeling results will allow contrast of reservoir-production characteristics of two distinctly different tide-influenced delta systems.

The Bureau's Carbonate Reservoir Characterization Research Laboratory is similarly developing new generic methods for describing three-dimensional distribution of petrophysical properties in carbonate-ramp reservoirs. Researchers are combining the study of outcrop analogs of major carbonate-reservoir types with subsurface reservoir studies. Data gathered (1) provide quantified geological–petrophysical models for input into reservoir simulators for improving predictions of reservoir performance and (2) enable mapping of the distribution of remaining hydrocarbons. Extensive investigations have been concluded on Permian Grayburg and San Andres reservoirs and outcrops. The program is currently focused on Permian Clear Fork reservoirs and outcrops in the Sierra Diablo Mountains, West Texas, and on Cretaceous exposures of the Pecos River–Devils River area, southwestern Texas.

Among other innovative projects, the Bureau's Exploration Geophysics Laboratory is developing technologies that will image reservoirs using the complete seismic wavefield, not just the conventional compressional (P) wave component of the wavefield. Researchers hope to create three independent 3-D seismic images of reservoir architecture: the conventional 3-D P-wave image and two distinct shear (S) wave images. By combining the information of these three seismic images, considerably more insight can be gained into petrophysical rock properties; pore structure; type of pore fluid;



sequence relationships; and spatial distributions of lithologies, fractures, and anisotropic reservoir properties of reservoir systems.

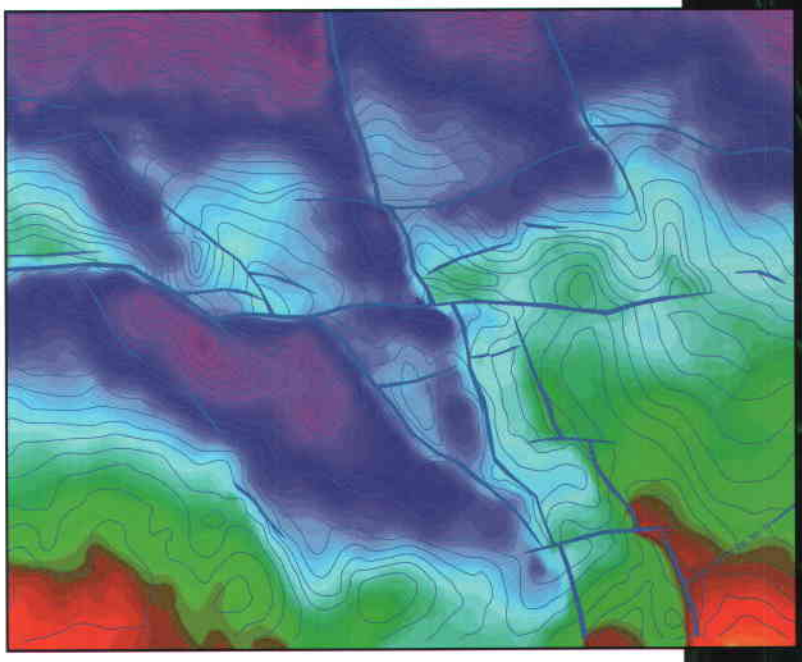
Ongoing studies by the Bureau's Applied Geodynamics Laboratory continue to emphasize mechanical and numerical tectonic modeling for generating new concepts, testing hypotheses, or duplicating specific geologic structures (particularly those involving salt) relevant to the location, mechanics, and evolution of structural traps of oil and gas.

International Research Programs

The Bureau's international program involved seven reservoir characterization and environmental projects in Austria, Belize, and Venezuela in 1997. Scientific collaboration and teamwork among Bureau researchers and their colleagues at supporting international companies and governmental agencies have been key components of the program.

The Bureau is working on behalf of Austria's OMV Aktiengesellschaft to help define remaining unrecovered oil and gas resource in Matzen field, Vienna Basin, that can be tapped by recompletions and infill drilling. Matzen field is the largest oil and gas field in Central Europe. Now 2 years into the project, researchers have developed a high-frequency genetic stratigraphic framework of the productive middle and upper Miocene strata of the field. On this basis, Bureau geoscientists have identified multiple incremental recovery opportunities by means of recompletions and selective infill drilling.

In 1997, Bureau researchers collaborated with geoscientists from the three affiliate companies of the national oil company of Venezuela (Corpoven, S.A., Lagoven, S.A., and Maraven, S.A.) on five projects that employ integrated field studies and advanced reservoir-characterization techniques in various basins in the country. The primary objective of all these projects is to increase oil reserves



and ensure sustained production from the fields, many of which have low recovery efficiencies. The project teams have identified numerous recompletion opportunities and infill-well locations and are using 3-D seismic data and petrophysical and engineering models to obtain better trap resolution. In 1997 Bureau and Lagoven researchers examined Eocene reservoirs in the Mioceno Norte Area, northeast Lake Maracaibo, complementing their 1996 success in identifying more than 180 potential Miocene development-well locations. Faja field, in the Arecuna area, Eastern Venezuela Basin, has a substantial heavy-oil resource base and is in the early stages of primary production. To increase oil reserves, a Bureau–Corpoven team proposed locations for 176 multidirectional wells that target 77 discrete, previously unresolved reservoir compartments in fluvial and deltaic facies of the Oligocene Merecure Formation and the Oligocene–Miocene Oficina Formation. Although the structurally and depositionally complex oil reservoirs of Maraven's VLA-6/9/21 Area, north-central Lake Maracaibo, have posed a significant challenge for optimizing recovery of the remaining oil resource, Bureau and Maraven researchers have identified numerous pay targets.

In an environmentally related international study started in 1997 and funded by the United Nations through the Government of Belize, Ministry of Natural Resources, Bureau environmental scientists are conducting a detailed evaluation of land cover and land use in the southern Belize District. Working in close cooperation with the technical staff of the Belize Ministry of Natural Resources, Bureau staff members have employed Landsat satellite imagery, field studies, and low-altitude aerial surveys to help the Government of Belize develop a current land-use map of the country.

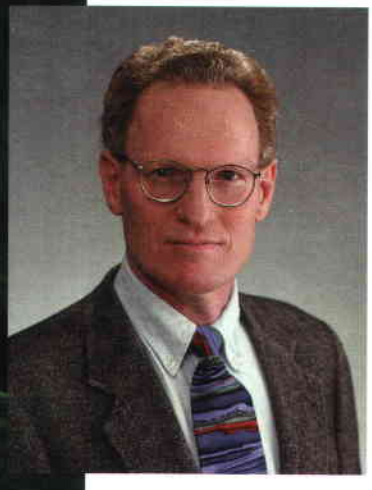
HIGHLIGHTS

Bureau SGR Studies Cited as a Success Story in Report to the President

In the final report submitted by the President's Committee of Advisors on Science and Technology (PCAST), Bureau studies of the onshore Texas Gulf Coast and Fort Worth Basins (composing the Secondary Gas Recovery [SGR] Project) were singled out as examples of a "government–industry success story." The SGR Project, funded by the U.S. Department of Energy, the Gas Research Institute, the State of Texas, and private industry, was designed to improve natural gas recovery from heterogeneous, conventional-permeability reservoirs. President Clinton established the PCAST to provide guidance of Federal energy research and to actively advise the National Science and Technology Council (NSTC) about science and technology issues of national importance. The PCAST serves as the highest level private-sector science-and-technology advisory group to the President and the NSTC. The report, *Federal Energy Research and Development for the Challenges of the Twenty-First Century*, issued by the White House on November 5, 1997, presents a definitive strategy on how to ensure that the United States has a program in place to address the country's energy and environmental needs of the next century.

Martin Jackson Wins Prestigious Award from AAPG

In a letter dated October 23, 1997, American Association of Petroleum Geologists (AAPG) President Edward K. David notified Martin Jackson that he had been chosen to receive the Robert H. Dott, Sr., Memorial Award for Best Special Publication published by AAPG in 1996. Martin and co-editors David Roberts (BP) and Sig Snelson (Shell, retired) will be presented with the award during the opening session of the AAPG annual meeting in Salt Lake City in May 1998.



Martin P. A. Jackson, recipient of the 1997 Robert H. Dott, Sr., Memorial Award for Best Special Publication published by AAPG in 1996. Photo by David M. Stephens.

The book, *Salt Tectonics: A Global Perspective* (AAPG Memoir 65), highlights key advances in salt tectonics that have evolved over the past few decades. The publication presents both landmark regional syntheses of classic areas, such as the Gulf of Mexico and North Sea, as well as preliminary investigations of frontier regions of salt tectonics throughout the world.

The 21 chapters in the book represent the best papers from an AAPG Hedberg Research Conference held in 1993 in Bath, England, which was convened by the editors.

Milo Backus and Bob Graebner Honored by the Society of Exploration Geophysicists

Milo Backus and Bob Graebner of the Bureau's Exploration Geophysics Laboratory were co-recipients of the 1997 Special Commendation Award from the Society of Exploration Geophysicists (SEG). They received the award, which is one of the highest honors bestowed annually to SEG members, at the society's 1997 annual meeting in Dallas. The Special Commendation Award was "established for the purpose of recognizing and giving special commendation by the SEG to deserving persons for meritorious service to the public, the scientific community, or to the [geophysics] profession." Backus and Graebner were two of the "many principals included in the development, application, and marketing of 3-D technology as a commercial system."

Bureau Signs Cooperative Agreement with Costa Rica

Noel Tyler, Luis Barreda (Bureau of Economic Geology), and Juan Sánchez (Associate Vice President for Research, The University of Texas at Austin) traveled to Costa Rica to meet with officials of the Costa Rican government and sign a cooperative agreement. The agreement between The University of Texas at Austin and the Ministerio del Ambiente y Energía (Ministry of Environment and Energy) states that the two institutions "agree to cooperate to identify and provide the opportunity for participation in educational and research programs that are of mutual benefit and interest." Dr. Sánchez signed for the University, and Dr. René Castro-Salazar, the Minister of Environment and Energy of Costa Rica, signed for the Government of Costa Rica. The initial project undertaken as part of this agreement is a cooperative project for preservation of seismic data. This is the first step in building a comprehensive data base for improved assessment of the energy resource potential of Costa Rica. Additional projects involving coastal studies, GIS, and research on environmental and natural resources are being developed.

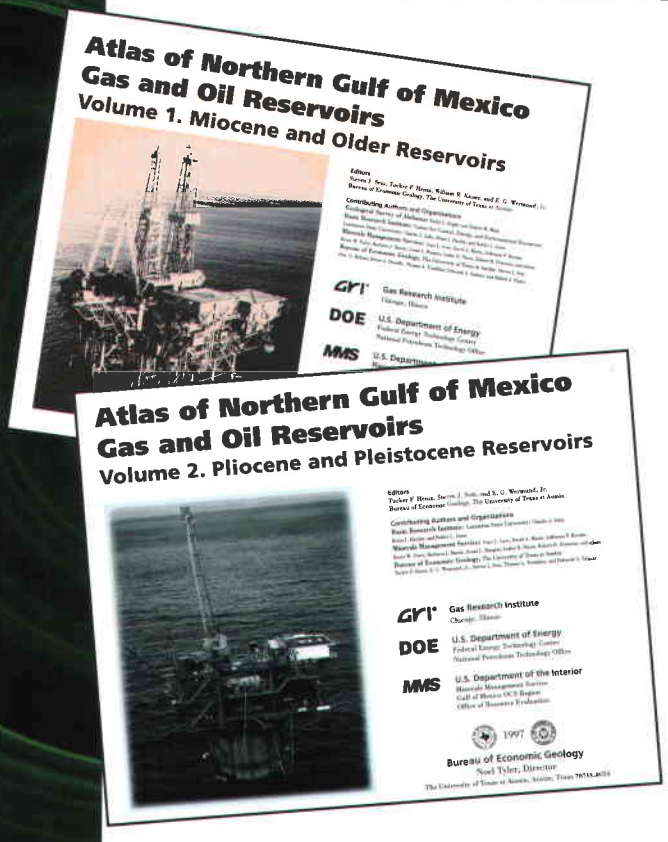
Bureau and Costa Rican officials (left to right): Dr. Luis A. Sánchez-Barreda, Coordinator of the Latin American Program, Bureau of Economic Geology; Dr. René Castro-Salazar, Minister of Environment and Energy of Costa Rica; Dr. Noel Tyler, Director, Bureau of Economic Geology; Dr. Juan M. Sánchez, Associate Vice President for Research, The University of Texas at Austin; and Ing. Walter Robinson Davis, Advisor to the Minister of Environment and Energy of Costa Rica.

Exploration Geophysics Laboratory Established

A new research entity, the Exploration Geophysics Laboratory (EGL), has been created by the Bureau to focus on critical geophysical research topics. The objective of the EGL is to investigate and develop surface-based and borehole-based seismic technologies that can provide high-resolution information on reservoir geometry and petrophysical character. Particular emphasis is being placed on developing seismic vector-wavefield technology that will image reservoir systems having both compressional (P) and shear (S) waves, thereby allowing more reservoir-specific information to be extracted from seismic data.

Both industry-funded and government-funded studies are conducted by the EGL team, headed by Bob A. Hardage. Through a broad base of industry support, several valuable resources have been either donated or made available to the EGL: a 2,000-channel seismic recording system, a large number of single-component and three-component geophone strings, a variety of seismic sources, a fully equipped and fully staffed seismic crew, and a variety of data-processing and data-interpretation software packages. With these resources, the EGL is one of the best-equipped geophysical research groups in the nation.

Atlas of Northern Gulf of Mexico Petroleum Reservoirs Published



In 1997, the Bureau published both volumes of the much-anticipated *Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs*. The atlas represents the first detailed, comprehensive synthesis of the play framework of all Miocene and older reservoirs (volume 1) and all Pliocene and Pleistocene reservoirs (volume 2) in the Federal Outer Continental Shelf (OCS) and in Alabama, Louisiana, and Texas Offshore State waters. It was compiled in collaboration with the Geological Survey of Alabama, the Basin Research Institute (Louisiana State University), and the Minerals Management Service (U.S. Department of the Interior) and was funded by the Gas Research Institute, the U.S. Department of Energy, and the Minerals Management Service.

Publication covers of the latest in the Bureau's series of hydrocarbon atlases: Volumes 1 and 2, composing the *Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs*, which groups the sandstone-body reservoirs of all offshore Gulf of Mexico fields into a play framework.

Leasing activity reached record levels in 1997 in the northern Gulf of Mexico (GOM), emphasizing the region's increasingly important role in supplying domestic energy. Annually the offshore GOM currently produces 14 and 25 percent, respectively, of the nation's oil and gas. Moreover, the Gulf region contains an estimated 17 and 26 percent, respectively, of the nation's undiscovered conventional oil and gas resources. In State and Federal waters, through 1994, 9,947 sandstone-body reservoirs in 1,212 fields produced an estimated 12.1 Bbbl of oil and 134.9 Tcf of gas. Estimated remaining proved reserves are 2.5 Bbbl of oil and 34.2 Tcf of gas.

In order to document the distribution and composition of this valuable resource, the atlas series (1) organizes offshore fields and reservoirs into 91 plays on the basis of geologic and engineering parameters; (2) illustrates and describes each play and typical reservoirs within each play; (3) tabulates 31 geologic, engineering, and volumetric attributes of all sandstone-body reservoirs; and (4) links all play, field, pool, and reservoir data to the spatial location of plays and fields through a computerized geographic information system (GIS) available on an accompanying CD-ROM. These comprehensive data will be particularly useful in (1) identifying areas having the highest concentration of remaining unrecovered hydrocarbons in existing fields and (2) guiding exploration in the deep-water frontier area.

Bureau Study of Benzene Plumes Changes Environmental Policy

A Bureau study conducted in cooperation with the Texas Natural Resource Conservation Commission (TNRCC) and the U.S. Environmental Protection Agency has received national attention and has already changed how contaminated sites are remediated in Texas. The study, published as a Bureau Geological Circular (GC 97-1), focuses on the size, mass, and duration of dissolved hydrocarbon plumes resulting from leaking underground storage tank (LPST) sites. The study demonstrates that benzene plumes have stabilized at most contaminated sites and that plume stabilization is evidence of natural attenuation, that is, naturally occurring chemical, physical, and biological processes that serve to control plume migration. As a result of the study, the TNRCC, Texas' environmental regulatory agency, now considers natural attenuation a viable corrective-action alternative to active ground-water remediation at LPST sites.

The study has gained favorable national attention because of the wide interest in applying natural attenuation at contaminated sites. Besides the requests for information from environmental regulators in California, Washington, and Iowa that have been received, the study has been discussed in the technical periodicals *Civil Engineering* and *The Bio-Cleanup Report.* Bureau staff members have also detailed results of the study at invited talks at the American Geophysical Union, the Industry Council on the Environment, the American Petroleum Institute, the American Institute of Professional Geologists, and the National Ground-Water Association.

Bureau Using Airborne Laser Altimeter Surveys to Monitor Texas Beaches

The Bureau has monitored environmental change along the Texas Gulf Coast for more than 20 years. Our ongoing geologic investigations include studies in beach morphology, shoreline change, and wetlands. In 1997, to further this research, the Bureau initiated state-of-the-art airborne laser altimeter surveys (ALAS) along the southeast Texas coast. This work, supported by a NASA Topography and Surface Change Program grant and a Texas Coastal Management Plan grant, is a joint effort of the Bureau; The Center for Space Research (CSR), The University of Texas at Austin; The University of Florida; the Texas Aircraft Pooling Board; STARLINK Inc. of Austin, Texas; and Optech Inc. of Ontario, Canada, the maker of the laser altimeter system.

ALAS can determine the position of the shoreline and provide geomorphic analysis of barrier-island, dune, and beach-ridge systems with a degree of accuracy and areal coverage greater than that of any previous methods. The data are being used to monitor shoreline changes and barrier-island movement, processes that are of critical importance to public and private interests along the Texas Gulf Coast. The goal of ALAS is to improve the accuracy of topographic mapping significantly in low-relief coastal areas. Using a scanning laser sensor installed in a single-engine aircraft, ALAS can map topography with an accuracy of 10 cm and with horizontal data spacing of less than 5 m. Currently, Bureau mapmakers using this technique are surveying the shoreline from Sabine Pass to Freeport, Texas. In addition to the shoreline swath, they are including the entire Bolivar Peninsula and the San Luis Pass area on the south end of Galveston Island. These data provide the State of Texas with unique topographic information over an environmentally critical portion of the Gulf coast.

Bureau Researchers Awarded Coveted ARP/ATP Grants

Approximately 2,900 proposals statewide were submitted to the 1997 Advanced Research Program/ Advanced Technology Program (ARP/ATP), and 398 awards were granted. Bureau researchers were awarded four grants: (1) "Capacity Building for Resource Assessment and Responsible Development, Texas–Mexico Border Region" (Jay A. Raney, lead investigator of a consortium with UT–Pan American, UT–Brownsville, UT–El Paso, and Texas A&M International Universities), (2) "Numerical Models of Brittle Grabens Forming above Ductile Rock in Canyonlands National Park" (Daniel D. Schultz-Ela, principal investigator), (3) "Scaling of Fractures in Carbonate Reservoirs and Relations with Sequence-Stratigraphic Framework" (Stephen E. Laubach, co-principal investigator), and (4) "Geologic Characterization of Fractured Reservoir Block Size Using Microcrack Data" (Stephen E. Laubach, co-principal investigator). Project details and interim results will appear in next year's annual report.

Bureau Initiates Geo-Environmental Study of the Orinoco Delta

In an exciting new project, the Bureau has contracted with Petróleos de Venezuela to be the lead contractor and coordinating partner of a geo-environmental analysis of the Orinoco Delta in eastern Venezuela. This large project, a continuation of our heritage of coastal and deltaic studies, will extend over 5 years. One of the world's great deltas, the largely pristine Orinoco is a focus of petroleum exploration.

This environmental characterization project will develop baseline information on all aspects—from sedimentological processes to vegetation assemblages—which will be entered into a multiattribute GIS data base. Other participants in this multiuniversity study will be Simón Bolivar and Central Universities, Caracas, and the University of the East—all in Venezuela.

Awards and Honors

Milo M. Backus and **Robert J. Graebner** were co-recipients of the 1997 Special Commendation Award from the Society of Exploration Geophysicists. They received the award at the society's 1997 annual meeting (see feature article on the award in this "Highlights" section). **Alan R. Dutton** won the Bernold M. Hansen Excellence in Presentation Award for best oral presentation, Division of Environmental Geosciences of American Association of Petroleum Geologists (AAPG), for his paper "Application of Environmental Assessment to Remediation of Abandoned Oil Field Sites" presented at the AAPG Annual Convention. The paper was coauthored by **Jeffrey G. Paine** and John J. Tintera (Railroad Commission of Texas). **William L. Fisher** received the William B. Heroy, Jr., Award for Distinguished Service from the American Geological Institute. He also served as the Noël Distinguished Lecturer in Energy, The University of Texas, Permian Basin. **Robert L. Folk** received the Distinguished Educator Award from AAPG. A poster display by **James C. Gibeaut**, K. Clint Slatton (UT–Center for Space Research), Melba M. Crawford (UT–Center for Space Research), and **Roberto Gutierrez**, "Mapping Barrier Islands Using AIRSAR," which was presented at the Fourth International Conference on Remote Sensing for Marine and Coastal Environments, received Honorable Mention. **Bob A. Hardage** was also awarded Honorable Mention for Best Paper in Geophysics in 1996 by the Society of Exploration Geophysicists at its 1997 annual meeting. The paper, "3-D Seismic Evidence of the Effects of Carbonate Karst Collapse on Overlying Clastic Stratigraphy and Reservoir Compartmentalization," was coauthored by David L. Carr, David E. Lancaster, **James L. Simmons, Jr.**, Robert Y. Elphick, Virginia M. Pendleton, and Ronald A. Johns. **Martin P. A. Jackson** was chosen to receive the Robert H. Dott, Sr., Memorial Award for Best Special Publication published by AAPG in 1996 (see feature article on the award in this "Highlights" section). **Stephen E. Laubach** won Best Presentation Award from the Clastic Diagenesis Research Group of SEPM (Society for Sedimentary Geology) for his paper,

Recipients of the 1997 UT Service Awards (left to right): George T. Bush (10 years), Douglas C. Ratcliff (25 years), Lynda A. Miller (10 years), E. G. Wermund, Jr. (25 years), Shirley P. Dutton (20 years), Donna G. Cole (10 years), Jeffrey G. Paine (15 years), Lana Dieterich (10 years), Alan R. Dutton (15 years), Teresa L. Weaver (10 years), Robert A. Morton (25 years), Wanda L. LaPlante (20 years), and Dixon E. Coulbourn (10 years).
Photo by David M. Stephens.

"Diagenesis from a Different Perspective," presented at the AAPG Annual Convention. **Andrew R. Scott** won Best Poster Award from the Energy Minerals Division of AAPG for his paper, "Timing of Cleat Development in Coal Beds," presented at the AAPG Annual Convention as well. **Roger Tyler** won Best Technical Paper of the Geology and Resource Assessment Session and Best Paper of Symposium at the 1997 International Coalbed Methane Symposium for his paper "Defining Coalbed Gas Exploration Fairways in Low-Permeability, Hydrocarbon-Overpressured Basins: An Example from the Piceance Basin, Northwest Colorado." This paper was coauthored by **Andrew R. Scott** and William R. Kaiser.

The West Texas Geological Society awarded George Asquith its Best Paper Award for his paper titled "Petrophysics of the Ramsey Sandstone, Ford Geraldine Unit, Reeves and Culberson Counties, Texas," presented at the 1997 WTGS Fall Symposium. **Shirley P. Dutton**, A. G. Cole, Muhammad Razi, and **Jose I. Guzman** coauthored the paper.

New Research Staff

John R. Andrews joined the Bureau as a GIS specialist working on the Big Bend Ranch State Park and STATEMAP projects. John is completing his M.S. in Geography at The University of Texas at Austin. His thesis explores the application of GIS technologies to conservation planning. **John C. Coyne**, new manager of the Information Technology Services section at the Bureau, has an M.S. in Geophysics from Texas A&M University and more than 19 years' mineral exploration experience. These include 12 years as a geophysicist with Noranda Exploration on both domestic and foreign projects. While with Noranda, John was the Director of Electronic Data Processing for the U.S. exploration group. Before joining the Bureau he was Manager of Information Services for the Ocean Drilling Program at Texas A&M University. **Sarah B. Dale**, a GIS specialist, is working on the Coastal Hazard Atlas and the Tectonic Map of Texas. She has a B.A. in Environmental Science from Rollins College and is completing her M.S. in City Planning at the School of Architecture, The University of Texas at Austin. **Michael V. DeAngelo** has begun working at the Exploration Geophysics Laboratory, where he is developing 3-D seismic technologies that can improve reservoir characterization. He received his M.S. in Geophysics from The University of Texas at El Paso. **Dallas B. Dunlap** is responsible for technical and geophysical support of several of the Bureau's international projects. Before joining the Bureau as a permanent employee, Dallas worked as an undergraduate research assistant for two Bureau international projects. He recently earned a B.S. in Geology from The University of Texas at Austin. **Khaled Fouad** is conducting seismic interpretation on the Lagoven South Lake project as a Research Associate. Originally from Egypt, Khaled received a B.S. in Geology and a Certificate of Higher Studies in Geophysics from Alexandria University. Before joining the Bureau, he worked for Schlumberger Geoquest, providing support for several software packages. He also has more than 12 years' seismic interpretation experience at several oil companies. **Jubal G. Grubb** joined the Bureau's Reservoir Characterization Research Laboratory (RCRL) and became involved in various aspects of subsurface and outcrop

research. He received his B.S. in Geology from The University of Texas at Austin. After a 17-year absence, **C. Robertson Handford** returned to the Bureau as a Senior Research Scientist to participate in international research programs. He is working on characterization of Cretaceous carbonates in Venezuela's Lake Maracaibo, as well as Matzen field (Austria). Robert's expertise is in sequence stratigraphy and depositional-systems analysis. Before rejoining the Bureau, Robert worked at Amoco and ARCO research labs, taught at the University of Arkansas, and worked as a geologic consultant. He received his Ph.D. in Geology from Louisiana State University. **Kirt A. Kempter** joined the Bureau as a Postdoctoral Fellow and is working on RCRL projects in West Texas and southern New Mexico. Kirt received his Ph.D. from The University of Texas at Austin. **Jinhuo Liang** is working on low-level radioactive waste disposal projects. Jinhuo holds degrees in Geology, Engineering, and Petroleum Engineering from Wuhan College of Geology, the Chinese Academy of Sciences, and The University of Texas at Austin, respectively. His research interests include numerical modeling of fluid flow and rock mechanics, rock fracturing, fractured-reservoir characterization, geological data-base management systems, and computer graphics. **Matthew P. Mahoney**, a Research Scientist Associate, is working on the Railroad Commission of Texas (RRC) Abandoned Oil Field project. Matthew received his B.S. in Geology from The University of Texas at Austin and has 16 years' experience as an environmental geologist–geophysicist at several firms in Texas. His professional expertise is in site characterization and subsurface environmental investigations. **Mohammad A. Malik**, a Postdoctoral Fellow, joined the Bureau to conduct computer reservoir simulation of tertiary recovery for the Delaware DOE project. He holds an M.S. and a Ph.D. in Petroleum Engineering from The University of Texas at Austin. His research interests include reservoir flow simulation and reservoir characterization. **Christine R. Martinez** joined the Bureau as a Research Scientist Associate and is working on the International Energy Resources projects. Before coming to the Bureau, Christine worked in Houston as a Processing Geophysicist with Digicon Geophysical Corporation. She has a B.S. in Geology from The University of Texas at Austin. **Mary L. Mercer** conducts reservoir evaluation and characterization for the Matzen field project as a Research Scientist Associate. Before joining the Bureau, Mary was a partner in Mercer Minerals, a petroleum exploration company. She has also worked as a petroleum engineer for Conoco, Inc., and as a technical consultant for the U.S. Environmental Protection Agency. Mary has a B.S. in Petroleum Engineering from the University of Missouri–Rolla. **Courtney Michelle** joined the Bureau as data-base manager of the Matzen field project and coordinator of data transfers from overseas clients. She received her B.A. in Linguistics from The University of Texas at Austin. As a Research Associate, **Robin C. Nava** is active in the RRC Abandoned Oil Field Waste Site Evaluations project. In addition to being a Registered Professional Engineer, Robin has a B.S. in Geological Engineering from the University of Missouri–Rolla and an M.S. in Civil Engineering from the University of Houston. Before joining the Bureau, she worked for Browning–Ferris Industries for 8 years in site development, permitting, construction, and landfill operations in Houston and San Antonio and for Marathon International Oil Company in seismic processing and

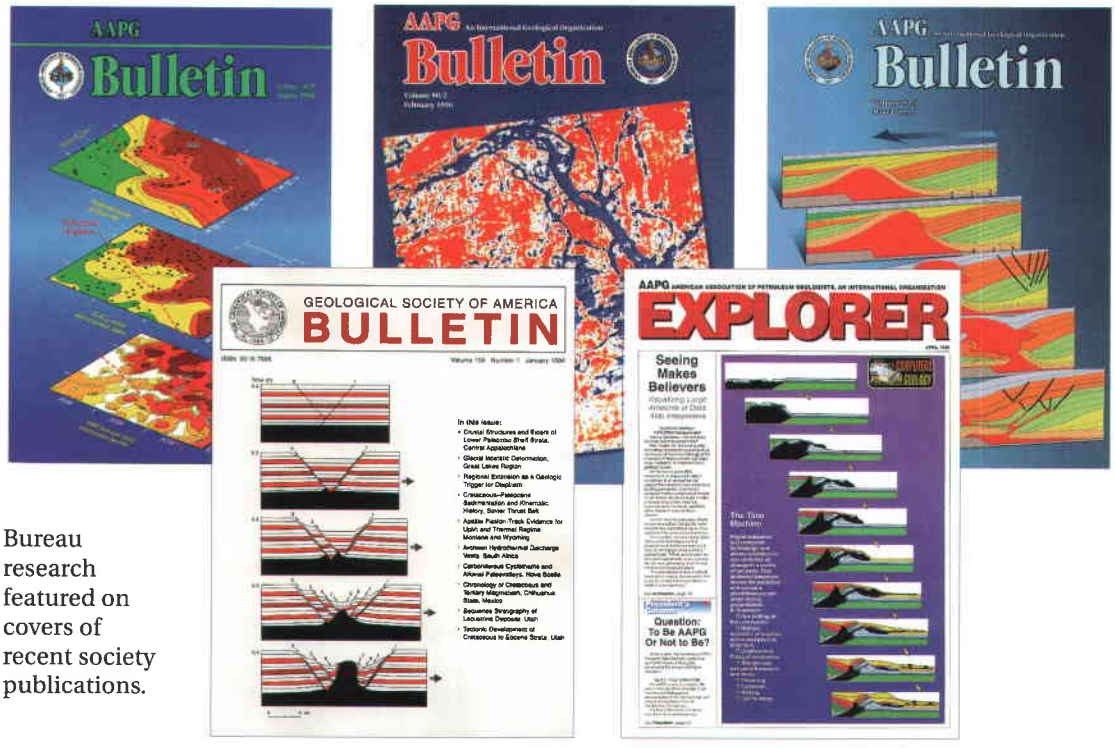
geologic mapping. **Jeffery E. Price** is at work in Information Technology Services as a computer systems development specialist. Mainly supporting Windows® platforms, Jeff has worked in the computer field for about 7 years. Before joining the Bureau, he worked for Dell Computers for 3 years and as an independent consultant for 4 years. He has B.S. degrees in Biology and Chemistry from Hardin–Simmons University. **Robert C. Reedy**, a Research Scientist Associate, is working on the Low-Level Radioactive Waste Disposal Site project. He received his M.S. in Hydrology from New Mexico Tech. Before obtaining his Master's degree, Robert worked for more than 9 years as a digital cartographer–GIS specialist for a civil engineering firm in Albuquerque, New Mexico. **Randy L. Remington**, a Research Scientist Associate, joined the Bureau as a 3-D seismic interpreter with the Exploration Geophysics Laboratory. Randy worked at the Bureau previously as a Research Assistant and returned after 4 years with the Texas Natural Resource Conservation Commission. He has a B.A in Geology from The University of Texas at Austin. **Rebecca C. Smyth**, a Research Scientist Associate, is working on remediation-focused investigations of the waste-contamination sites designated by the RRC in East and Central Texas. Becky received her M.S. in Geology from The University of Texas at Austin. Before joining the Bureau, she worked for the U.S. Geological Survey Water Resources Division and as a hydrogeological consultant. **Mark A. Sparlin** is a Research Associate working on several of the Bureau's international projects. Mark worked 6 years for ARCO Exploration Company studying the Great Basins province of the western U.S. and evaluating offshore leases. Before joining the Bureau, he was employed by Schlumberger as Division Geophysicist in Houston, where he subsequently became Manager of Geophysical Product Development. He has an M.S. in Geophysics from Purdue University. **Enid J. (Jeri) Sullivan** joined the Bureau as a Research Associate, working on sampling plans for the RRC Abandoned Oil Field project. Jeri has an M.S. in Geology from the University of North Carolina, Chapel Hill, and a Ph.D. in Hydrology from New Mexico Institute of Mining and Technology. Jeri's areas of expertise include surfactant chemistry, zeolite surface chemistry, and site and risk assessment. **Eric von Lunen**, a Research Associate, is responsible for geophysical integration of the Bureau's international projects. Before joining the Bureau, Eric worked for Schlumberger, where he was responsible for integration of petrophysics and seismic-character response into interpretations of carbonate and siliciclastic reservoirs in Latin America, Africa, and the Permian Basin. Later, working as a consultant for 8 years, he was involved in onshore 3-D seismic design, processing, and interpretation for reservoir characterization. **Lesli J. Wood** joined the Bureau as a Research Associate and is working on the Deltas Industrial Associates project. She received an M.S. in Geology from the University of Arkansas and a Ph.D. in Earth Resources from Colorado State University. Lesli then joined Amoco Production Company, where she spent 5 years as an explorationist in South America and north Africa and as part of a research team developing tools and methodologies in seismic-attribute analysis. **Wan Yang**, a Research Associate, has been assigned to work on the STARR project. A native Chinese, he has studied petroleum geology, seismic exploration, neotectonics, sedimentology, and stratigraphy at Northwestern University, China;

California State University, Fresno; and The University of Texas at Austin. He worked at Phillips Petroleum Company in international exploration and production for the last 2 years. His interests are in traditional and quantitative outcrop and subsurface sedimentology and stratigraphy.

Hongliu Zeng, a Research Scientist, conducts 3-D seismic visualization studies for several Bureau energy-related projects. Hongliu's expertise is in seismic sedimentology and seismic reservoir characterization. Before joining the Bureau, Hongliu worked for Texaco for 3 years, where he was responsible for the successful introduction of the Stratal-Slicing technique. He has an M.A. in geology from the Petroleum University at Beijing and a Ph.D. in geophysics from The University of Texas at Austin.

Staff Promotions

In 1997, the following members of the Bureau staff received promotions: **Kelly K. Campbell** to Administrative Associate, **Sigrid J. Clift** to Research Scientist Associate III, **Anselmo S. Jacobo** to Administrative Associate, **Robert E. Mace** to Research Associate, **Anne M. Maxim-Kelly** to Administrative Associate, **Glynis G. Morse** to Senior Administrative Associate, **Elizabeth C. Prado** to Administrative Associate, **Lisa E. Remington** to Data-Base Coordinator, **Jana S. Robinson** to Computer Illustrator, **Scott R. Schulz** to Computer Illustrator Technician, **James L. Simmons** to Research Scientist, **Jirapa Skolnakorn** to Research Scientist Associate III, **David M. Stephens** to Computer Illustrator, **Ramón H. Treviño** to Research Scientist Associate III, **Thomas A. Tremblay** to Research Associate, and **Brian J. Willis** to Research Scientist.



Bureau research featured on covers of recent society publications.

Research

Energy Resources Investigations

Petroleum

Reservoir Characterization Research Laboratory: Characterization of Carbonate Reservoirs

F. Jerry Lucia and Charles Kerans, principal investigators; Stephen C. Ruppel, Roger J. Barnaby, and James W. Jennings, Jr.; assisted by Rashidul Hassan, Laura C. Zahm, Kirt A. Kempter, William B. Ward, Jubal G. Grubb, and Eduardo E. Ariza

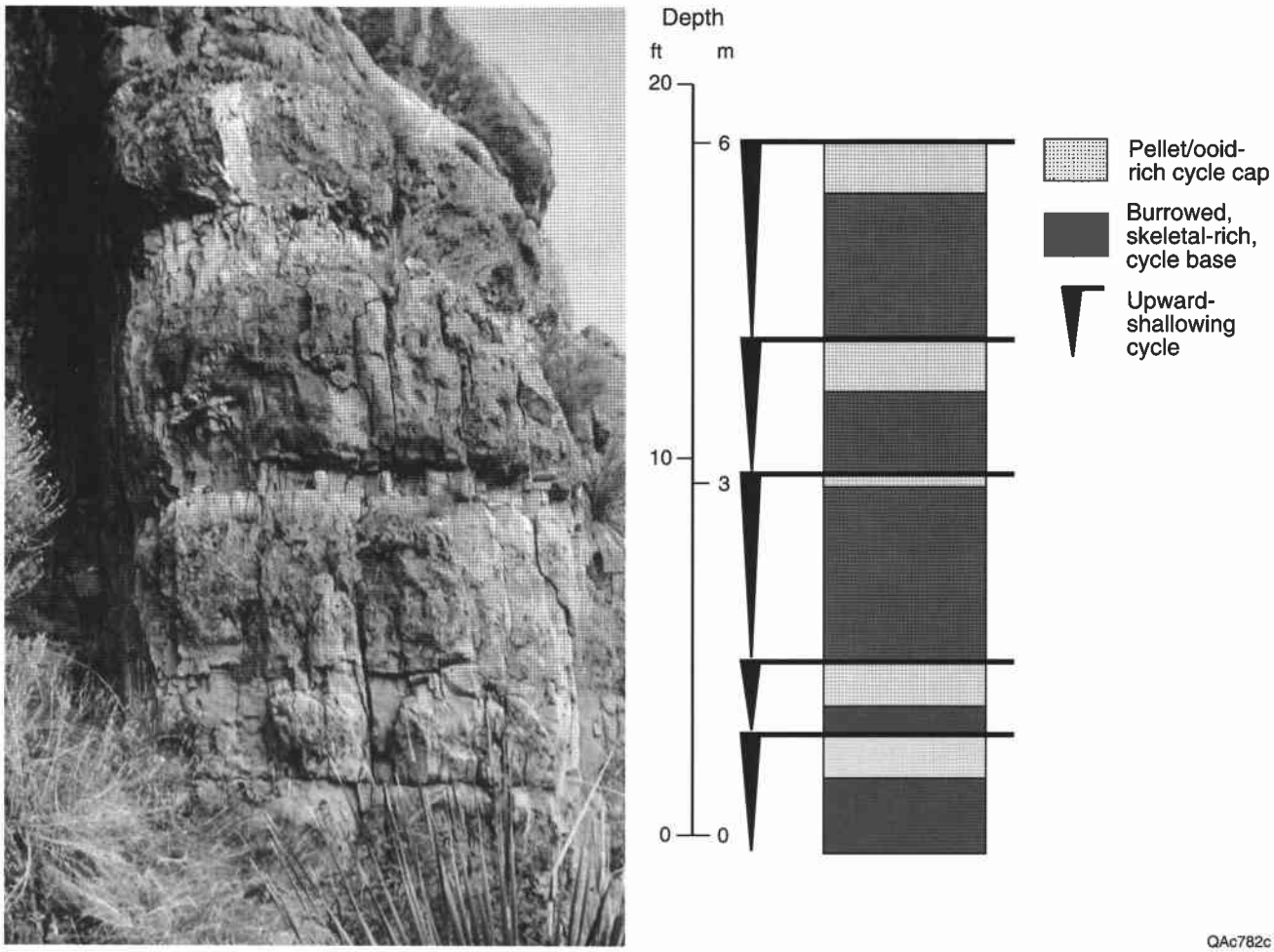
The goal of the Carbonate Reservoir Characterization Research Laboratory (RCRL) is to develop new generic methods for describing the three-dimensional distribution of petrophysical properties in carbonate-ramp reservoirs for the purpose of (1) providing quantified geological–petrophysical models for input into reservoir simulators to improve predictions of reservoir performance and (2) mapping the distribution of remaining hydrocarbons. This research is funded by the RCRL Industrial Associates sponsors, including Altura Energy, Limited; Amerada Hess Corporation; Aramco Services Company; ARCO Exploration and Production Technology; ARCO Permian; BP International Limited; Elf Aquitaine; Exxon Production Research Company; Japan National Oil Corporation; Marathon Oil Company; Mobil New Business Development; Occidental Oil and Gas Corporation; Pennzoil Exploration and Production Company; Petroleum Development Oman LLC; Phillips Petroleum Company; Texaco Inc.; TOTAL; and UNOCAL, Inc. In addition, the program is supported by GeoQuest, Schlumberger, Landmark, GeoMath, and TerraScience, which provide state-of-the-art software.

The approach is to combine the study of outcrop analogs of major reservoir types with subsurface reservoir studies. 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 for applying this information to analogous reservoirs.

Two geological systems are being studied, the Permian and the Cretaceous. The goal of these studies is to develop methods for characterizing the geologic architecture and petrophysical properties in carbonate-ramp reservoirs. Permian-age Grayburg, San Andres, and Clear Fork reservoirs of the Permian Basin, West Texas, have been selected for study because of (1) the vast hydrocarbon resource remaining in these reservoirs and (2) the superb outcrop of these formations in the nearby Guadalupe and Sierra Diablo Mountains. Cretaceous reservoirs have been selected because of the world-class outcrop along the Pecos River, southwest Texas, which serves as an excellent analog for the highly productive Cretaceous fields in the Middle East, South America, and U.S. Gulf of Mexico.

Outcrop studies have shown that rock-fabric facies compose the basic flow unit of carbonate-ramp reservoirs and that the stacking of rock-fabric flow units is systematic within a sequence stratigraphic framework. Subsurface studies have developed methods for using core and log data to describe the sequence stratigraphic framework and to quantify that framework in terms of porosity, permeability, and water saturation by using rock-fabric flow units. Simulation studies have demonstrated the importance of accurately modeling the 3-D distribution of high- and low-permeability rock-fabric units to predict production performance accurately.

The project continues to focus on developing methods and techniques for realistically modeling the 3-D distribution of petrophysical properties. Extensive investigations have been concluded on Grayburg and San Andres reservoirs and outcrops of Permian age. The Permian program is currently focused on Clear Fork reservoirs. Outcrops of the Clear Fork Group in the Sierra Diablo Mountains, West Texas, allow detailed chronostratigraphic, rock fabric, and petrophysical studies to better explain the facies and petrophysical architecture of Clear Fork reservoirs. An ongoing subsurface study of South Wasson Clear Fork field has thus far developed a sequence stratigraphic framework and a petrophysical model by means of core, log, and outcrop data.



Outcrop studies of cycle and sequence stratigraphic architecture in the Permian (Leonardian) Victorio Peak Formation in the Sierra Diablo, West Texas, provide a model for reservoir characterization of subsurface Leonardian Clear Fork reservoirs in the Permian Basin. Photo by Stephen C. Ruppel.

The Cretaceous program has produced a regional and reservoir-scale sequence stratigraphic framework of the Pecos River–Devils River area in southwestern Texas. Two reservoir windows have been described in detail, a grainstone–rudist complex and a packstone–wackestone–rudist-bioherm complex. Petrophysical quantification, according to data from analogous Middle Eastern reservoirs, and flow simulation studies of the grainstone–rudist complex are in progress. Study of a Middle Eastern Cretaceous reservoir located in an outer-ramp facies tract has been completed, demonstrating that the basic sequence stratigraphic–rock-fabric analytic approach that has been successfully applied to West Texas Permian reservoirs can be used to study Middle Eastern Cretaceous reservoirs.

University Lands Advanced Recovery Initiative

Noel Tyler, principal investigator;
Stephen C. Ruppel, Roger J. Barnaby, Jubal G. Grubb, Tucker F. Hentz, Larry Lake, Richard P. Major, and Charles Kerans; assisted by Jennifer L. Beall, Isolda B. Griffiths, Russ K. Johnson, and Neil J. Tabor

The goal of the University Lands Advanced Recovery Initiative (ULARI) is to characterize selected University Lands reservoirs to aid operators in geologically targeting remaining hydrocarbon resources in order to stem the decline in University Lands production.
This project is funded by The University of Texas System and by matching funds from operators of the University Lands fields chosen for site-specific studies.

Three individual site-specific projects have been initiated in the first year of the project (1) Fuhrman-Mascho Block 10 Unit, a San Andres–Grayburg reservoir in Andrews County operated by Arrow Operating Company; (2) University Waddell Devonian field, a Siluro-Devonian reservoir in Crane County operated by Pennzoil; and (3) North McElroy Grayburg field, a Grayburg–San Andres reservoir in Crane and Upton Counties newly acquired by Apache Corporation. Fuhrman-Mascho and University Waddell fields have recovery efficiencies significantly below those of comparable fields within the same geologically based play. McElroy field, although producing at an efficiency above play average, contains an enormous 232 million barrels (MMbbl) of unrecovered mobile oil.

Arrow Operating Company has initiated a 50-well infill-drilling program at Fuhrman-Mascho and has welcomed ULARI as a means of fully assessing opportunities afforded by this development initiative. Indeed, one of the earliest cooperative activities the project began in January 1997 was to core one of these infill wells to provide data for calibrating wireline logs. Stratigraphic relationships in Fuhrman-Mascho field indicate that the reservoir comprises three flow-unit regimes, each with distinct geological, engineering, and field-development significance. Flow Regime 1 constitutes the lower Grayburg, a succession of generally nonporous carbonates and highly continuous, permeable siltstones at the top of the reservoir. This interval has contributed most of the production to date and is highly floodable. Flow Regime 2 consists of the underlying upper San Andres, a succession of shallow-water carbonates with very discontinuous porosity. Because permeability development is highly variable, waterflooding this zone will be complicated; however, untapped compartments are targets for infill wells. Flow Regime 3 consists of a highly continuous porosity zone developed in deeper water carbonates at the top of the lower San And ›s. Although permeability is variable in this zone, its continuity makes it an excellent candidate for waterflooding. Facies changes in Flow Regime 2 from north to south across University Lands Block 10 suggest that the potential for production from this unit may increase in the structurally low parts of the field.

University Waddell Devonian field is operated by Pennzoil. Production is from a Siluro-Devonian reservoir that is currently being waterflooded. Pennzoil, planning an eight-well workover project, will use results of the ULARI to assess modification of the waterflood pattern and, possibly, initiation of a miscible nitrogen or carbon dioxide gas displacement program. Reservoir zones in this field are dominated by thickly laminated to massive cherts that have abundant sponge spicule molds and attendant good reservoir quality. This facies is highly heterogeneous both laterally and vertically, with some key zones clearly not connecting between well bores. The good sorting and sedimentary structures indicate high-energy deposition in submarine channels feeding distal submarine-fan complexes. Gamma-ray response is attenuated throughout the chert and limestone reservoir interval because of the paucity of interbedded siliciclastic rocks. At a detailed level, however, correlation of the minor gamma-ray inflections is more reliable than correlating log-derived porosity. Detailed correlation of gamma-ray logs is crucial to correlating productive reservoir zones accurately at Waddell field. Such correlations demonstrate that among various wells, completed zones in wells previously thought to be in communication are actually isolated reservoir compartments. This lateral and vertical discontinuity of reservoir zones resulted in inefficient waterflood sweep. In most wells, moreover, some zones of high porosity remain untested. Detailed correlation and mapping of these heterogeneous porous units will provide a geologically targeted development strategy of recompletions, infill drilling, and waterflood injection for maximizing hydrocarbon recovery.

The North McElroy Grayburg, recently acquired by Apache Corporation, produces oil from platform carbonates of the Grayburg Formation. As the new operator of this property, Apache has welcomed a cooperative study to identify new production strategies.

Integrated Geological, Geophysical, and Engineering Characterization of Miocene and Eocene Reservoirs, Mioceno Norte Area, Lake Maracaibo, Venezuela

H. Scott Hamlin and William A. Ambrose, principal investigators;
Regulo A. Alvarez (Lagoven); assisted by Heon Cho, Janaka B. Paulis, Mirtes C. Pessoa, and Martha L. Romero

The goal of this new 2-year project is to optimize production from Eocene and Miocene sandstone

reservoirs by building on a successful study of the Mioceno Norte Area completed in 1996 by the Bureau of Economic Geology and Lagoven, S.A. This new investigation, also undertaken jointly by the Bureau and Lagoven, integrates geological, geophysical, petrophysical, and engineering characterization to identify and map remaining oil and develop reservoir management strategies for more efficient recovery.

Eocene and Miocene reservoirs in the 50-km^2 Mioceno Norte Area in the northeast part of Lake Maracaibo have produced more than 265 MMbbl of oil since 1930. These reservoirs are, however, estimated to have an ultimate primary recovery efficiency of only 27 percent. Multiple poorly contacted reservoir compartments in heterogeneous fluvial-deltaic sandstones are responsible for the low recovery efficiency. Complex patterns of closely spaced faults add a further dimension to reservoir heterogeneity.

A new 174-km^2 3-D seismic survey will permit review and validation of previously proposed well locations targeting Miocene reservoirs. In 1996, a team of Bureau and Lagoven researchers identified more than 180 potential Miocene development-well locations. Now, using the new high-resolution 3-D seismic data for better structural trap resolution, we will confirm previously proposed Miocene drilling locations.

Integrated characterization and reservoir simulation are scheduled for the Eocene reservoirs, which were not included in the previous study. We are conducting high-resolution sequence stratigraphic analysis using the 3-D seismic data, well logs, and more than 1,000 m of core. Seismic structural analysis will define structural traps, and petrophysical analysis will determine fluid saturations and facies-dependent reservoir properties. Log- and core-based sandstone and facies mapping, combined with seismic-facies and attribute mapping, will be used to document depositional controls on reservoir architecture. Remaining oil distribution will be determined by conventional volumetric methods and then verified by reservoir simulation. Finally, we will delineate infield exploration fairways and identify untapped reservoir compartments. The targeted infill drilling and recompletions proposed by this study will add significant volumes to ultimate oil recovery in the Mioceno Norte Area.

Strategic Targeting of Drilling Objectives in the South Lake—Reservoir Characterization, Production Integration, and Reservoir Simulation of Selected Reservoirs at B, C, and E Blocks in Southern Lake Maracaibo, Venezuela

C. Robertson Handford, principal investigator; Robert E. Barba, Jr., Graeme R. Bullen, Khaled Fouad, Douglas S. Hamilton, Mark H. Holtz, Shirley P. Dutton, Ramón H. Treviño, Eric von Lunen, and Carlos Fimlay (Lagoven, S.A.); assisted by Cem O. Kilic and Sandra P. Parra

In 1997, the Bureau of Economic Geology, in conjunction with Lagoven, S.A., an affiliate of Petróleos de Venezuela, S.A., began an integrated study of Tertiary and Cretaceous reservoirs and prospects in Blocks B, C, and E of South Lake Maracaibo. This study began with the expectation of improving hydrocarbon exploitation and justifying the reserves in the area. The primary objective is to formulate a robust integrated geologic model of the Tertiary and Cretaceous reservoirs and prospects using the existing geophysical (3-D seismic), geological, petrophysical, and reservoir engineering data base. Project scientists will conduct a detailed analysis of the structural and stratigraphic components of the reservoir framework and identify and quantify the location of remaining oil reserves. The South Lake project, of 16-month total duration, has been divided into two phases. Phase 1 is a 10-month geological reservoir characterization study, and Phase 2 is a simulation study of selected Tertiary reservoirs. The data base consists of a 3-D seismic survey, geophysical data from approximately 45 wells, and core data from 2 wells. Seismic and well log interpretations are being conducted by means of Landmark software.

Oil in the study area is produced from Tertiary-age incised valley-fill sandstones of mainly fluvial to estuarine origin and from Cretaceous shallow-marine carbonates and glauconitic sandstones. These facies occur in combination structural–stratigraphic traps. According to previous studies, the Lake Maracaibo area has been subjected to several major tectonic events, an early Tertiary extensional phase followed by two different compressional phases. As a result, tectonics has played a major role in controlling depocenters and depositional systems tracts.

The first activity conducted for the project was a quick interpretation of a fast-track seismic data set from Block E to review and recommend several well locations to be drilled by Lagoven. A final, processed version of the Block E seismic data is to be received and thoroughly analyzed by the spring of 1998. In the meantime, thorough integrated studies will be conducted on reservoirs in Blocks B and C. This activity includes simultaneous interpretation of seismic and well log data. A high-resolution sequence stratigraphic framework will provide detailed segregation of the complex vertical and lateral assemblages of carbonate and sandstone reservoirs. The stratigraphy will be digitally documented through a detailed cross-section network making use of all existing wells. The high-frequency stratigraphic framework will include the Cretaceous Cogollo Group, the B and C intervals of the Misoa, and the Santa Barbara intervals. Productive reservoir intervals will be identified and mapped. Structural analysis of each of the key reservoirs and delineated prospects will be documented on maps and cross sections.

Characterization of Eocene Reservoirs: VLA-6/9/21 Area, Lake Maracaibo, Venezuela

William A. Ambrose and Edgar H. Guevara, principal investigators;
Ramón H. Treviño, M. Saleem Akhter, Robert E. Barba, Jr., Fred P. Wang, Shirley P. Dutton, and Linda K. Colvin;
Dan Parker and Virginia M. Pendleton (consultants);
assisted by Martha L. Romero, Jorge E. Nieto, and Janaka B. Paulis

This 28-month reservoir characterization of Maraven's VLA-6/9/21 Area, occupying a 23.2-mi² (60-km²) area in north-central Lake Maracaibo, was concluded in 1997. This study was an integrated analysis including genetic sequence stratigraphy, 3-D seismic interpretation, petrophysics, petrography, and production engineering. The objective of the study was to provide Maraven, S.A., with a variety of new drilling opportunities in order to increase oil recovery from tidal-shelf and estuarine-fill deposits in the C Members of the Lower Eocene Misoa Formation.

Oil reservoirs in the VLA-6/9/21 Area are extremely heterogeneous as a result of a complex structural setting and the heterolithic nature of the reservoir sandstones. Optimizing recovery of the remaining oil resource requires understanding of structural

Water-cut map of the C4 Member, Lower Misoa Formation, in the VLA-6/9/21 Area, Lake Maracaibo, Venezuela, illustrates the structural complexity of this productive lower Eocene unit. Northwest-trending wrench faults between the strike-slip Icotea and Eastern Boundary Faults control abrupt changes in water-cut values and are inferred to segment the field into multiple, large-scale poorly drained reservoir compartments.

and stratigraphic controls on reservoir architecture and mapping of fluid distribution.

Faults provide the main structural controls on reservoir architecture in the VLA-6/9/21 Area, which occupies a structurally high area between two transpressional, left-lateral strike-slip faults having dip-slip displacement. The interior part of the VLA-6/9/21 Area is divided into multiple structural compartments by numerous, primarily northwest-trending normal faults. These normal faults are interpreted as extensional features that formed during transpression and are inferred to be fluid-flow barriers because of abrupt changes in water-cut values and pressure data from nearby water-injection wells.

Reservoir sandstone-body architecture in the VLA-6/9/21 Area is primarily controlled by the original tide-dominated depositional environment. Depositional axes in many submembers, 50 to 150 ft (15.2 to 45.7 m) thick, commonly occur as narrow (less than 2,000-ft [< 600-m]) dip-parallel and upward-coarsening sandstones separated by muddy areas. Many of these depositional axes extend for more than 4 mi (>6.4 km), dividing the field into multiple narrow zones of contrasting reservoir quality.

Unrecovered hydrocarbon resources in the VLA-6/9/21 Area were documented by a variety of methods, including identification of unperforated pay by petrophysical analysis, observation of anomalies on maps of RMS amplitudes by means of 3-D seismic data, delineation of abrupt changes in values of water cut and reservoir pressure across faults, and computation of remaining oil in individual wells. Improved petrophysical characterization of the VLA-6/9/21 Area by means of a Standard Simandoux model resulted in significant upward revision of the original-oil-in-place value from approximately 2.0 BSTB (billion stock tank barrels) to 3.8 BSTB.

This study identified recompletion opportunities in approximately 240 unperforated pay zones in 71 existing wells and 66 new infill locations. In addition to the major pay zones, numerous minor pay zones were identified, along with numerous laminated zones that should produce economic quantities of hydrocarbons. Recompletions were identified from zones of unperforated pay having favorable petrophysical parameters, such as low bulk-volume water, low water saturation, and high porosity.

New proposed infill wells were selected mainly in structurally high areas of high remaining oil, inferred from areas having high SoPhiH values and low production from nearby wells. These new infill wells were also located in areas of low water cut, where reservoirs were inferred to be poorly swept. Fifteen first-priority wells with recompletions and 13 first-priority infill wells, located in structurally high areas in the field having high remaining-oil and low water-cut values, are estimated to recover more than 80 MMSTB (million stock tank barrels). The remaining 56 wells having recompletion targets and 53 infill wells, together with approximately 30 proposed water-injection wells to provide pressure support for poorly swept areas, are proposed for most of the 634 MMSTB of remaining oil.

Targeting High-Potential Exploration Objectives in the South Lake: An Integrated Sequence Stratigraphic, Structural, and Hydrocarbon Habitat Analysis of the Tertiary of South Lake Maracaibo, Venezuela.

Noel Tyler, principal investigator;
Edgar H. Guevara, project coordinator;
Hongliu Zeng, Mark A. Sparlin, Khaled Fouad, Eric von Lunen, Robert E. Barba, Jr., Mark H. Holtz, Graeme R. Bullen, Christine R. Martinez, Dallas B. Dunlap, and Lisa E. Remington; Carlos Luis Camposano, Mauro Moya, and Maria Salomon de Salazar (Lagoven, S.A.); Gerhard Brink, N. J. S. van Wyk, Randall Etherington, and H. Roice Nelson, Jr. (consultants); assisted by Sandra P. Parra, Cem O. Kilic, and John M. Marks

This 1-year project funded by Lagoven, S.A., an affiliate company of Petróleos de Venezuela, S.A., identified and documented exploration opportunities, particularly stratigraphic and combination stratigraphic–structural traps, in southern Lake Maracaibo, western Venezuela. The northwestern part of the South Lake area, covered by a 3-D seismic survey encompassing approximately 1,000 km² was emphasized. The data base comprises 2-D seismic lines and well log, engineering, and production data from about 40 wells. Analysis and integration of the geophysical, geological (stratigraphic, biostratigraphic, structural, and geochemical), petrophysical, and engineering information allowed determination of the high-frequency sequence stratigraphic framework, structure, and hydrocarbon habitat, with emphasis on the Paleocene–lower Miocene interval. The study resulted in a portfolio of ranked prospects and leads for use in exploration and reexploration plans.

Integrated Reservoir Characterization and Volumetric Analysis of the Arecuna Area of Faja Field, Venezuela

Douglas S. Hamilton, principal investigator;
M. Saleem Akhter, Mark H. Holtz, Robert E. Barba, Jr., and Joseph S. Yeh; Milagro Rodriguez, Marel A. Sanchez, Jose J. Castillo, and Pedro Calderon (Corpoven, S.A.);
H. Roice Nelson, Jr. (consultant);
assisted by Felix A. Diáz, Pedro J. Leon, and Senira S. Kattah

This 5-month project, funded by Corpoven, S.A. (an affiliate of Petróleos de Venezuela, S.A.) and completed in February 1997, was a reservoir characterization study that concluded with volumetric and economic analyses. The primary objective of the study was to define a development plan for a horizontal-well drilling program to increase oil reserves and ensure sustained production from the substantial heavy-oil resource base of Faja field, Arecuna area, Eastern Venezuela Basin. Faja field is in the early stages of primary production. The project team comprised Bureau and Corpoven reservoir geologists, petrophysicists, geophysicists, and petroleum engineers.

Oil in the study area is produced from sandstone reservoirs that are composed mostly of fluvial and deltaic facies forming part of the Oligocene Merecure Formation and the Oligocene–Miocene Oficina Formation. Oil accumulations are combination stratigraphic–structural, normal-fault-related traps.

The project data base comprised a 100-mi^2, 3-D seismic survey, digitized well logs from approximately 40 wells that include directional and horizontal boreholes, core data from 1 well, and production data spanning about 15 years. Data were analyzed by means of Landmark and TerraScience software installed on workstations.

The total original oil in place in the study area was estimated to be 2.8 billion barrels residing in 77 discrete compartments. A field-development plan was constructed to maximize exploitation of this resource. A total of 176 wells were proposed for the Arecuna area. Of these 176 target wells, 58 are multilateral wells (116 targets), 43 are horizontal wells (43 targets), 14 are vertical wells (14 targets), and 1 is a trilateral well (3 targets). These wells are located on 70 different pads. The economic assessment of the development plan was performed to (1) determine and evaluate the investment return for each proposed location well type on the basis of projected production rates and costs and (2) determine the economic feasibility of the different well types (vertical, horizontal, and multilateral) by means of preliminary production and cost figures. Considering the conservative assumptions made, the overall economics for the Arecuna development plan was extremely favorable, indicating a tremendously profitable opportunity. The economic analysis also helped in designing the type of well to be used for each proposed drilling location.

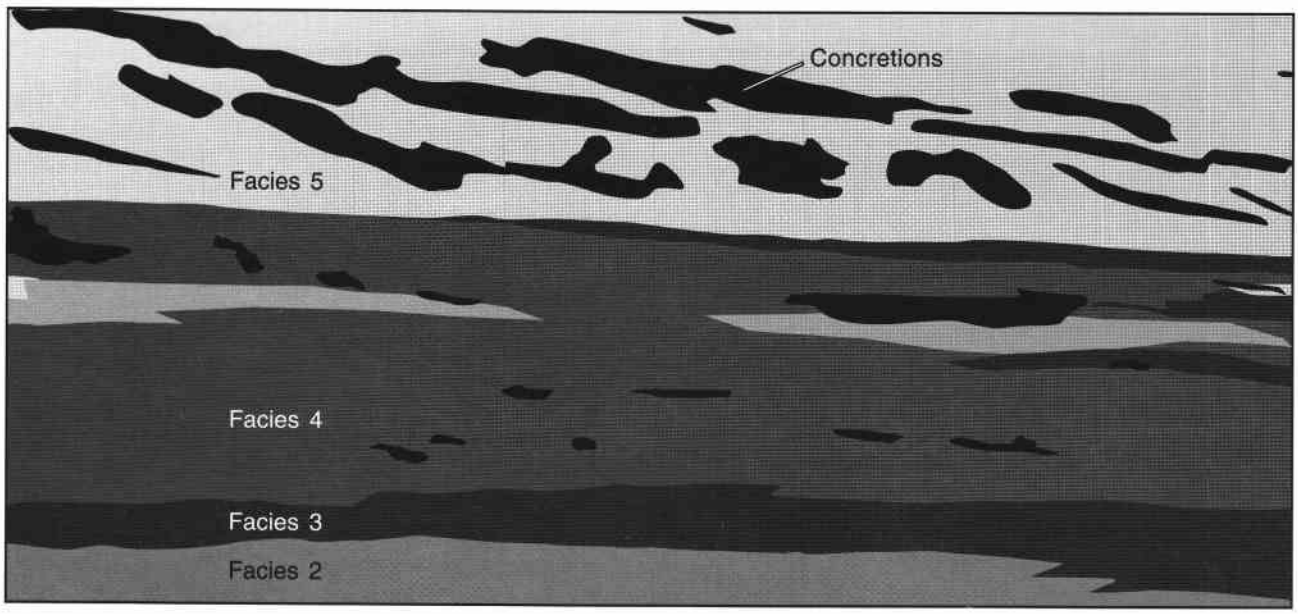
Characterization of Heterogeneity Style and Permeability Structure in a Sequence Stratigraphic Framework in Fluvial-Deltaic Reservoirs

Shirley P. Dutton and Christopher D. White, principal investigators; Janok P. Bhattacharya, Brian J. Willis, and Lesli J. Wood;
assisted by Qing Fang, Sharon L. Gabel, Yugong Gao, Keshav Narayanan, and Matthew M. Uliana

This reservoir characterization program, funded by a consortium of Industrial Associate companies, focuses on fluvial-deltaic systems because of the worldwide importance of resources in this reservoir type. Characterization of fluvial-deltaic reservoir heterogeneity holds great potential for improving production by increasing the efficiency of recovery processes. Because of the difficulty of determining the spatial distribution of rock properties at the interwell scale in the subsurface, our approach is to develop a firm quantitative basis for reservoir modeling through study of extensive, continuous outcrops as reservoir analogs.

Outcrop studies provide data on sandstone-body architecture, stacking patterns, and continuity; the distribution and length of shales; and the permeability structure of strata. Permeability and architectural data collected from outcrops improve reservoir models that predict fluid flow behavior. These models test the effects of geologic variability on different recovery processes and demonstrate how outcrop data can be meaningfully and generally incorporated into reservoir models. Outcrops are studied from within a sequence stratigraphic framework to provide a context that allows the application of results to analogous reservoir systems worldwide.

A major focus of the project this year was the Frewens sandstone of the Frontier Formation in central Wyoming, a superbly exposed tide-influenced lowstand delta system. This study provides an important contribution to our understanding of the attributes of this class of deltaic reservoir because few examples from



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Outcrop model of the Frewens sandstone, which represents tide-influenced deltaic deposits that prograded into the Cretaceous Western Interior Seaway. The influence of cemented zones comprising calcite concretions (black) on subsurface flow has been modeled using reservoir-simulation methods developed at the Bureau. As a result of a reduction in permeability, localized cemented regions within the high-permeability facies may improve the vertical sweep efficiency of displacements. The calcite cement, however, significantly reduces effective permeability (and thus injectivity and productivity) and reduces hydrocarbons in place.

this highly prolific reservoir type have been documented. The goals of the study are to (1) develop an understanding of facies variations, sandstone geometries, and stratigraphic patterns, all of which have important implications for both reservoir exploration predictions and development strategies in tide-influenced deltas and (2) conduct quantitative outcrop descriptions of geologic variations over a hierarchy of bedding scales and use these data in flow models to determine the relative importance of bedding, facies, shales, and diagenetic cements as controls on subsurface fluid flow behavior.

In addition, a new study of the Sego Sandstone was begun in eastern Utah, a tide-influenced system that differs from the Frewens in stratal architecture, facies patterns, and distribution of shales. The work on the Sego this year focused on several kilometer-scale outcrop segments of the lower Sego with contrasting internal facies and ratios of sandstone to shale. The goal is to provide a quantitative data set of 2-D and 3-D deposit-architecture and rock properties, detailed genetic interpretations of the depositional system, 2-D and 3-D seismic models of stratal relationships, and reservoir-analog flow models from different types of deposits within the Sego. These results will allow us to contrast reservoir production implications of two distinctly different tide-influenced systems—the Frewens and Sego sandstones.

This program is funded by a consortium of industrial associates comprising the following companies: BP International Limited, Chevron Petroleum Technology Company, Elf Exploration Production, Exxon Production Research Company, Intevep S.A., Japan National Oil Corporation, Maxus Energy Corporation, Oryx Energy Company, Saga Petroleum ASA, and Statoil. In addition, the program is supported by Computer Modeling Group and Schlumberger/GeoQuest, which provide reservoir-simulation software.

3-D Description and Reservoir Modeling of Architectural Elements in a Deep-Water Sandstone High-Frequency Cycle

Mark D. Barton and Christopher D. White, principal investigators; Joseph S. Yeh

In this project sponsored by Den norske stats oljeselkap a.s. (Statoil), the Bureau is using outcrop data to construct a detailed three-dimensional model of a turbidite sandstone cycle within the Bell Canyon Formation of West Texas. The Bell Canyon is a 300-m-thick, cyclically interbedded, sandstone-rich succession that has minor

carbonate zones. Within the Bell Canyon, high-frequency cycles 15 to 40 m thick are bounded by thin organic-rich siltstones. The high-frequency cycles represent submarine-fan-lobe and fan-channel-levee systems that initially prograded, then aggraded and backstepped; autocyclic lobe-switching caused additional complexity.

Two major dissecting canyons near Cow Mountain provide both strike and dip views of the Bell Canyon Formation. Photographs and detailed measured sections have been used to construct a three-dimensional stratigraphic framework in this area, which is approximately 4.5 × 2 km. A number of channel-form sandstone bodies and levees are incised into interbedded lutite, siltstone, and sandstone. Bedding geometry and lithofacies are being mapped.

Investigators are assembling maps of depositional unit thickness and facies into a three-dimensional model using commercial and custom software packages. The final model will consist of a fine areal grid (approximately 50-m grid spacing) having variable thickness cells used to model changes in depositional thickness and erosion. This cornerpoint data format can be imported into existing reservoir-simulation programs.

Architecture of Fluvial-Deltaic Reservoirs: Extension of Outcrop Studies into 3-D Using Ground-Penetrating Radar

Brian J. Willis and Mark D. Barton, principle investigators; Richard T. Buffler; assisted by Georgios P. Tsoflias and James E. Lundy

An advanced understanding of complex stratal architectures and the distribution of heterogeneities that control subsurface fluid flow is required to improve reservoir development strategies and increase recovery efficiencies. In recent years, detailed 2-D outcrop studies of fluvial-deltaic deposits have been used to document between-well-scale complexities that can influence reservoir production behavior. Explaining fluid flow during reservoir development is fundamentally a 3-D problem, however, and the next generation of reservoir models must therefore be based on records of stratal geometry and heterogeneity documented in three dimensions. The objective of this 2-year project, funded by the Advanced Technology Program of the Texas Higher Educational Coordinating Board, is to use ground-penetrating radar (GPR) to interpolate the 3-D geometry and facies of sediment bodies behind outcrops of channel and shoreface deposits in the Cretaceous Ferron Sandstone.

GPR profiling is similar to seismic reflection, except that it is based on reflection of electromagnetic radiation. In the Ferron deposits, GPR provided images of the strata at decimeter resolution to depths of 7 to 15 m. Profiles across fluvial sandstones clearly resolved channel-bar and channel-fill deposits and their internal bedding geometry. Kilometers-long profiles spanning the transition from fluvial to deltaic deposits showed pronounced changes in bedding-architecture styles and radar facies. Multiple, hundreds-of-meters-long profiles aligned both parallel and perpendicular to several outcrop faces provided serial cross sections through selected sediment bodies. Sediment-body shapes and facies can be interpolated among these cross sections. This study provides detailed templates for fine-scale reservoir analog models that can predict 3-D patterns of subsurface fluid flow through these heterogeneous deposits.

A Robust Economic Technique for Crosswell Seismic Profiling

Bob A. Hardage, principal investigator; James L. Simmons

Traditionally, crosswell profiling data are recorded by means of a downhole receiver array in one well and a downhole seismic energy source in a second well. The Bureau completed a DOE-funded study that evaluated the potential of recording crosswell tomographic data by means of a surface-based energy source rather than a conventional downhole energy source.

In this new approach to crosswell profiling, a standard seismic energy source, such as a vibrator, is positioned on the earth surface so that its radiated wavefield sweeps past downhole receiver arrays that are positioned in two inline wells. The crosswell traveltimes are measured as this wavefield propagates across the interwell space between receiver stations in these two inline wells. These traveltimes can be used to construct a crosswell velocity tomogram in the same way that the crosswell traveltimes measured between downhole source stations and downhole receiver stations in these same two inline wells would be used.

In this Bureau study, surface-source crosswell data were recorded in wells at Texaco's Borehole Geophysics Test Site at Humble, Texas. Analysis of these data led Bureau scientists to conclude

The first field activity of the industry-sponsored seismic vector-wavefield research project. Two horizontal vibrators (foreground) and a conventional P-wave vibrator (background) are being used to generate nine-component VSP calibration data inside the first prospect area that will be evaluated by 3-D nine-component data. A downhole three-component geophone was positioned in the well to record the VSP data. Photo by Bob A. Hardage.

that surface-source crosswell tomography is an economic and technically viable procedure for evaluating interwell conditions in many reservoir systems. These Bureau findings are being prepared for publication.

Seismic Vector-Wavefield Characterization of Complex Reservoirs

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

A fundamental objective of the Bureau is to expand and enhance the technologies that are used to characterize oil and gas reservoirs. This philosophy has led to the establishment of industry-sponsored research involving seismic vector-wavefield characterization of complex hydrocarbon reservoirs. The purpose of this program is to develop technologies that image reservoirs using the complete seismic wavefield, not just the compressional (P) wave component of the wavefield as is commonly done.

The immediate objectives of this project are to develop equipment and software that will create three independent 3-D seismic images of reservoir architecture: the conventional 3-D P-wave image that is used throughout the industry, as well as two distinct shear (S) wave images that are commonly referred to as fast-S and slow-S images. By combining the information of these three seismic images, considerably more insight can be gained into petrophysical rock properties, pore structure, type of pore fluid, sequence relationships, and spatial distributions of lithologies, fractures, and anisotropic reservoir properties of reservoir systems.

Eighteen companies sponsor this seismic vector-wavefield research. Through donations provided by these sponsors, the Bureau has a fully equipped seismic crew that records 3-D nine-component data continuously over a variety of prospects and can have these data processed by a variety of commercial entities.

Advanced Oil-Recovery Technologies for Improved Recovery from Slope and Basin Clastic Reservoirs, Nash Draw Brushy Canyon Pool, Eddy County, New Mexico

Bob A. Hardage, principal investigator; James L. Simmons, Jr.; Virginia M. Pendleton (consultant)

One of the reservoir types being evaluated in the U.S. Department of Energy (DOE) Class III Oil Recovery Field Demonstration Program is the Brushy Canyon turbidite successions, such as those produced by Strata Production Company at Nash Draw field, Eddy County, New Mexico. The Bureau assisted Strata Production in reservoir characterization by interpreting the 3-D seismic

data that were recorded across the Nash Draw field as a part of this DOE study.

The Brushy Canyon reservoirs at Nash Draw are complex assemblages of thin-bed reservoirs. The Bureau's 3-D seismic interpretation established an empirical relationship between reflection amplitude and the net pay within the major producing turbidite successions. Target-location data derived from this empirical relationship have been used to site two successful production wells. Other seismic-based relationships established by the Bureau are being used by reservoir-simulation members of the Strata team to estimate 3-D distributions of porosity-feet and fluid transmissivity within the reservoir system.

State of Texas Advanced Resource Recovery (STARR) Project

Richard P. Major and Roger Tyler, principal investigators; Mark D. Barton, Sigrid J. Clift, Shirley P. Dutton, H. Scott Hamlin, Douglas S. Hamilton, Mark H. Holtz, Mark R. Vining, and Fred P. Wang; assisted by Syed A. Ali, Ke Sheng Chan, Jianchun Dai, Juan C. Jimenez, Toribio Jimenez, Hye Won Kim, Chengshu Wang, and Tiejun Zhu

Although revenue income to the Permanent School Fund, largely derived from oil and gas royalties from State Lands, has declined over the past decade, an enormous hydrocarbon resource still remains on State Lands. In fact, State Lands fields contain more oil and gas than have been recovered over the decades-long history of State Lands production. Rather than being unattainable, a large volume of this remaining oil and gas is recoverable through the strategic, or targeted, deployment of advanced recovery technologies.

The Bureau, with funding from the State of Texas, is providing technical support to State Lands operators in the form of integrated geologic, 3-D seismic, and engineering studies. The primary goal of th·s State of Texas Advanced Oil and Gas Resource Recovery Optimization Initiative (Project STARR) is to increase royalty income to the Permanent School Fund through drilling of targeted infill wells. Some of the best prospects for increased production in the fields being studied have been identified and, with the support of allied producers, are being drilled. To date, 11 priority fields are being assessed, including Ozona, Geraldine Ford, Ford West, Lockridge, Waha, West Waha, Keystone East, and Bar Mar fields of West Texas and Umbrella Point, Trinity River Delta, and Duval County Ranch fields of the Gulf Coast. In Ozona field in Crockett County, for example, 15 wells have been drilled on STARR-recommended State Lands locations by Union Pacific Resources Company. Early production results show that the STARR-recommended wells are outperforming other recent Ozona infill wells by an average of almost two to one. In another example, geologic study (including interpretation of 3-D seismic data) and production analysis by Bureau researchers have located prospects in virgin Vicksburg and mature Frio sandstones within Umbrella Point field, operated by Panaco in Chambers County.

Texas operators that are currently involved in the STARR initiative include Union Pacific, Conoco, Shell, Mobil, Chevron, Bass Enterprises, Hallwood Energy, Parker and Parsley, Vista Resources, Panaco, Hamman Oil, Killam Oil, and Hanson Corporation.

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; Mark D. Barton, Sigrid J. Clift, and Mohammad A. Malik; assisted by Jose I. Guzman and Janaka B. Paulus

The Bureau of Economic Geology has completed Phase 1 of a cooperative agreement funded by the U.S. Department of Energy Class III Oil Recovery Field Demonstration Program. The Bureau's partner in this project is Conoco, Inc. Matching funds for the project are 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. 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 original oil in place through strategic placement of infill wells and geologically based field development. The study focuses on the Ramsey sandstone, Bell Canyon Formation, in the Ford Geraldine unit, Reeves and Culberson Counties, Texas.

A key component of the reservoir characterization was investigation of well-exposed outcrop analogs of subsurface reservoirs in order to interpret the

Exposure of a submarine-channel (massive sandstone) and levee (thin beds at top) deposits in the Upper Permian Cherry Canyon Formation, Delaware Mountain Group, exposed in Willow Draw, Culberson County, West Texas. A key component of the Delaware Basin project is investigation of well-exposed outcrop analogs of subsurface reservoirs to interpret the processes that deposited the reservoir sandstones in the Ford Geraldine unit. Stratal relationships in outcrop indicate that Delaware Mountain Group sandstones were deposited by high- and low-density turbidity currents in a basinal deep-water setting. Photo by Mark D. Barton.

processes that deposited the reservoir sandstones in the Ford Geraldine unit and to develop a depositional model that could be used to interpret the subsurface data. Stratal relationships in outcrop indicate that upper Bell Canyon sandstones were deposited by high- and low-density turbidity currents in a basinal deep-water setting. The fundamental depositional element is the channel with attached levees and lobes. This model was used to interpret the processes that deposited the Ramsey sandstone reservoirs at the Ford Geraldine unit and to map the geometry and dimensions of the architectural elements within them. On the basis of core descriptions, subsurface mapping, and outcrop information, the Ramsey sandstones were interpreted as a basin-floor channel-levee and lobe system. Reservoir sandstones consist of sheetlike lobe deposits overlain and incised by lenticular 1,200-ft-wide channels flanked by levee deposits.

Special techniques were used to maximize the information that could be derived from the old geophysical logs at the Ford Geraldine unit. Core-analysis and petrophysical data were used to construct maps of porosity, permeability, net pay, water saturation, porous hydrocarbon volume, and other reservoir properties. The 3-D seismic survey acquired for this project was designed specifically to target Delaware Mountain Group reservoirs. Ramsey sandstone thickness in the Ford Geraldine unit is 1/4 wav elength of the seismic data and is therefore considered a thin bed. The amplitude family of attributes had the highest correlations with average porosity and porosity × thickness. Interpretation of the data included coherence cube evaluation to highlight discontinuities; this technique was effective in delineating the field outline.

The northern end of the Ford Geraldine unit was chosen as the proposed demonstration area for Phase 2 of the project. During Phase 2, a geologically designed, enhanced-recovery program (CO_2 flood) and well-completion program will be implemented. To estimate the tertiary recovery potential of the demonstration area, flow simulations were performed for a CO_2 flood, one using layered permeabilities and the other using stochastic permeabilities generated by conditional simulation. Results of the simulations indicate that a minimum of 10 percent of the remaining oil in place, or 1 MMbbl, is recoverable through CO_2 flood.

Optimizing Hydrocarbon Recovery from Matzen Field, Vienna Basin, Austria

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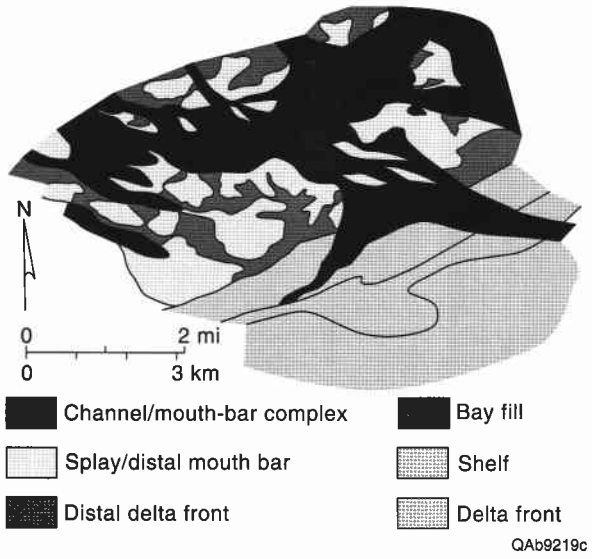
Eric von Lunen, Mary L. Mercer, Mark H. Holtz, Joseph S. Yeh,
Graeme R. Bullen, Sigrid J. Clift, Ramón H. Treviño,
Courtney Michelle, and Chun-Yen Chang;
Panos Baltas, Marion Jarnik, and Claudia E. M. Rassi
(OMV Energie); assisted by Jinghua Chen, Dallas B. Dunlap,
Ke Sheng Chan, Cem O. Kilic, Sandra P. Parra, and Syed A. Ali

Matzen field, the largest oil and gas field in Central Europe, is located in the Vienna Basin about 30 km northeast of the city of Vienna, Austria. Discovered in 1949, the field contains about 1.3 billion barrels of oil in place. The Bureau is working on behalf of OMV Aktiengesellschaft to help define the



Facies map of an upper Miocene reservoir zone of Matzen field, Austria. Delta-distributary-channel and mouth-bar facies in these mature fluvial-dominated deltaic reservoirs are a key pathway for edgewater influx. Splay facies commonly represent low-risk recompletion opportunities even when they lie structurally low to watered-out wells in channel facies.

remaining unrecovered oil and gas resource in the field that is amenable to recompletions and infill drilling. A high-frequency genetic stratigraphic framework has been established for the middle and upper Miocene strata of the field through identification of major and minor flooding surfaces. Work in 1997 focused on the southeast part of the field, where four third-order cycles in the Badenian were found to be dominated by delta progradation, at least three third-order cycles in the Sarmatian to be dominated by fluvial incision, and one third-order cycle in the Unter Pannonian also to be dominated by delta progradation. These differences have led to key variations in reservoir geometry in the field that must be exploited to improve overall recovery efficiency.

Pronounced reservoir cyclicity in the 8th and 9th Badenian, for example, has led to subdivision of the original reservoir functional units into multiple layers. In the 8th, strongly dip oriented channel and mouth-bar systems provide high-permeability pathways that are well swept by both a natural water drive and by injected water. Most remaining unrecovered oil is marginal to these preferred pathways in splay deposits or remains in layers immediately above or below high-permeability sandstones. A different geometry prevails in the 9th Badenian. In addition to channel-mouth-bar facies, a series of clinoforms is identified as a prograding delta front having about 100 m of relief on the delta wedge.

Incremental recovery opportunities occur in recompletions and selective infill drilling and possibly from adjustment of waterflood patterns. Wells outside the preferred axes of water encroachment offer access to unrecovered oil in splay facies; carefully conceived completion techniques designed to avoid potential water zones are necessary because of the highly layered character of the Miocene sandstone reservoirs. Other opportunities will come from completing untapped clinoforms and from selective recompletion in updip positions formerly avoided because of an inferred gas cap. The Bureau will continue working on this project into 1998 to address remaining challenges related to production in the field.

Petroleum Technology Transfer Program

Richard P. Major and Andrew R. Scott, principal investigators; L. Edwin Garner and Mark H. Holtz

The Bureau of Economic Geology 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 United States oil and gas operators. Its main missions are to (1) identify the technological problems of U.S. oil and gas producers and to communicate these needs to the research and development community and (2) transfer 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 development community and intermediary providers of technology, including government, universities, the U.S. Department of Energy (DOE), the Gas Research Institute (GRI), 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 was developed and 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 examples of software that are available to the public. As Texas Region Lead Organization (RLO), the Bureau, in cooperation with Texas Independent Producers and Royalty Owners Association (TIPRO), also established a home page on the Internet that includes an events calendar; technology news; exploration, production, research and development forums; and resource links. An informational brochure describing the Texas Region of the PTTC was developed, and several hundred copies were distributed at technology transfer workshops, trade shows, and conventions throughout the year. Other program activities included two continuing education focused technology workshops on (1) the Permian Deep-Water Sandstones of the Bell Canyon Formation, Geraldine Ford Area, in the Delaware Basin, West Texas (presented in Midland) and (2) the Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs (held in Houston). The Texas RLO also co-sponsored a short course with the PTTC and the American Association of Petroleum Geologists, "Finding Oil and Gas on the Internet," presented by Bill Crowley in Houston.

Using Microstructure Observations to Quantify Fracture Properties and Improve Reservoir Simulations

Stephen E. Laubach, William R. Rossen (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), principal investigators; Sigrid J. Clift, Jon E. Olson, and Larry Lake; assisted by Yaguang Gu, Orlando J. Ortega, and Robert M. Reed

Despite the critical role that natural fractures commonly play in governing reservoir fluid flow, fractures are rarely accounted for adequately in reservoir simulations. This results not only from both the severe observational challenges that prevent satisfactory fracture characterization, but also the time limitations for discrete fracture simulation. This project, sponsored by the U.S. Department of Energy, working through BDM–Oklahoma, Inc., is developing new fracture characterization approaches and new methods for incorporating this information into fractured reservoir simulators. It is a collaborative project among the Bureau, Department of Petroleum and Geosystems Engineering, and Department of Geological Sciences at The University of Texas at Austin.

During 1997, the research team successfully used unique core-analysis methods to document fracture orientations in reservoir rocks, including a blind test of the method on samples from the Spraberry trend of West Texas. Breakthroughs in quantitative scaling of fracture populations were achieved, and this information was successfully integrated into the new reservoir simulator protocol.

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, supported by Chevron U.S.A. Production Company; Conoco, Inc.; Exxon Production Research Company; Maxus Energy Corporation; Mobil Exploration and Producing Technical Center; and Union Pacific Resources; with in-kind support from Oxford Instruments, aims to test and perfect these methods in active oil and gas plays.

Gas

Integrated Strategies for Reserve Growth in Carbonate Reservoirs: An Example from the Ellenburger Group, Permian Basin, West Texas

Bob A. Hardage and Richard P. Major, principal investigators; James L. Simmons, Jr., Hongliu Zeng, Daniel D. Shultz-Ela, Tucker F. Hentz, and Charles Kerans; Virginia M. Pendleton (consultant)

The objective of the Carbonate Secondary Gas Recovery (SGR) program is to develop and demonstrate technology that can be used to evaluate deep carbonate gas reservoirs, such as the productive Ellenburger facies at Lockridge and Waha fields in West Texas. The Bureau is the

lead contractor of this study, which is funded by the U.S. Department of Energy (DOE) and the Gas Research Institute (GRI). S. A. Holditch and Associates provides reservoir engineering support, and Landmark Graphics Corporation assists the technology transfer phase of the project.

A major phase of the study has been the acquisition, processing, and interpretation of 176 mi^2 of 3-D seismic data that image Lockridge and Waha fields and extend across parts of Reeves, Ward, and Pecos Counties in West Texas. The seismic data acquisition and processing costs were equally funded by DOE, GRI, Altura Energy, and Mobil Exploration and Production U.S., Inc.

A team of Bureau-led scientists interpreted the 3-D seismic data and integrated these seismic interpretations with geologic, engineering, and petrophysical models of the Ordovician, Devonian, and Mississippian carbonate reservoirs that produce at Lockridge, Waha, and West Waha fields. These integrated reservoir characterization studies have confirmed the existence of extensive overturned and repeated sections and unique fault patterns that will help operators improve their exploration and exploitation of deep carbonate gas reservoir systems of the Delaware Basin.

A Guide to Targeting Coalbed Methane Exploration Fairways

Roger Tyler, principal investigator; Andrew R. Scott; assisted by Ronald G. McMurry and Juan C. Jimenez; in cooperation with Carol M. Tremain (Colorado Geological Survey)

Although methane from coal beds is a potentially important source of natural gas worldwide, to date successful exploitation of coalbed methane resources has been limited to several coal basins in the United States. Triggered by success in the United States, however, exploration for coal gas has begun in coal-rich areas of the United Kingdom, eastern and western Europe, China, South Africa, Zimbabwe, and Australia. What has not been widely recognized about the U.S. experience is that although coalbed methane resources in some basins have been successfully exploited, other basins with seemingly similar geologic and hydrologic attributes have proven to be disappointing methane producers.

The traditional view of production from coal reservoirs is inadequate to explain the contrasts in coalbed methane producibility among coal basins. In the traditional view, coal gases are generated in situ during coalification and sorbed on the large internal surface area of the coal. Sorption is pressure dependent and is promoted by increasing pressure. Gas production is then achieved by reducing reservoir pressure through depressuring (dewatering), thereby liberating gases from the coal surface for diffusion to the fracture (cleat) system for subsequent flow to the well bore. The traditional view is oversimplified because it fails to recognize the need for additional sources of gas, beyond that generated initially during coalification, to achieve high gas content following basinal uplift and cooling. Conventionally migrated and hydrodynamically trapped gases, in-situ-generated secondary biogenic gases, and solution gases are required to achieve high gas contents or fully gas-saturated coals for consequent high productivity. To delineate the presence and origin of these additional sources of gas, the Bureau has developed a coalbed methane producibility model that can act as a guide for exploration and development. Importantly, application of the producibility model requires an understanding of the interplay among tectonic and structural setting, depositional systems and coal distribution, coal rank, gas content, permeability, and hydrodynamics to target exploration fairways.

Our understanding of the controls on coalbed methane producibility is based on comprehensive geologic and hydrologic studies of the San Juan, Sand Wash, Greater Green River, and Piceance Basins, funded by Gas Research Institute and reconnaissance studies of several other producing and prospective coal basins in the United States and worldwide. The San Juan Basin, in which cumulative production exceeds 1 Tcf (28 Bm^3), is the world's most prolific coalbed methane basin. Our basin-scale model for coalbed methane producibility has evolved out of a comparison of the prolific San Juan Basin and the marginally productive Sand Wash, Greater Green River, and Piceance Basins and is now being applied to coalbed methane frontier basins in Alaska. Bureau Report of Investigations No. 244, *The Application of a Coalbed Methane Producibility Model in Defining Coalbed Methane Exploration Fairways and Sweet Spots: Examples from the San Juan, Sand Wash, and Piceance Basins*, by Roger Tyler, A. R. Scott, W. R. Kaiser, and R. G. McMurry, describing the steps to coalbed methane resource evaluation and target generation, is now available.

Alaskan Coalbed Methane Resource Development

Roger Tyler and Andrew R. Scott, principal investigators; in cooperation with James G. Clough (Alaskan Division of Geological and Geophysical Surveys); assisted by Juan C. Jimenez and Greg J. Ramirez

The purpose of the Coalbed Methane Cooperative Research Agreement between the Alaskan Department of Natural Resources, Division of Geological and Geophysical Surveys, and the Bureau is to investigate the potential for rural Alaskan coalbed methane resource development utilizing the Bureau's basin-scale exploration model. This cooperative agreement is designed to select coalbed methane exploration fairways near several rural Alaskan villages for the purpose of drilling and testing their potential for power generation and home heating. Although Alaska's potential for coalbed methane resources may be as high as 1,000 Tcf, the actual number of methane-bearing coal basins is mostly unknown and the extent and magnitude of producible gas is untested.

Coalbed methane exploration and development in Alaska have progressed to the point where exploration fairways that have potentially high coalbed methane productivity have been defined. All rural Alaskan basins are considered coalbed methane exploration and development targets. On the basis of geologic and hydrologic criteria, the Northern Alaska Province (Colville Basin), Upper Yukon Province (Yukon Basin), and Alaska Peninsula Province (Chignik Basin) can make a significant contribution to the rural Alaskan gas supply. The Yukon–Koyukuk Province (Kobuk, Upper Koyukuk, and Lower Koyukuk Basins) and Nenana Province (Minchumina Basin) have secondary importance.

Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs

William L. Fisher, principal investigator; Tucker F. Hentz, Steven J. Seni, Thomas A. Tremblay, and E. G. Wermund, Jr.; assisted by Kamran Durrani and Naresh D. Sen; subcontracts to the Basin Research Institute (Louisiana State University) and the Geological Survey of Alabama

In collaboration with the Minerals Management Service, the Basin Research Institute of Louisiana State University, and the Geological Survey of Alabama, the Bureau completed the atlas of gas and oil reservoirs (Federal and State offshore waters) of the northern Gulf of Mexico. The two-volume series has been published and is available for purchase. The U.S. Department of Energy (DOE), Minerals Management Service (MMS), and Gas Research Institute (GRI) initiated funding of the 4-year program beginning in the fall of 1992 and the spring of 1993. The atlas folios include a comprehensive data base of geologic, engineering, and volumetric attributes to the sandstone-body reservoir level and geographic information system (GIS) spatial data on a CD-ROM. Aggregated digital data of plays, fields, and reservoir pools are also available through the Internet on the home pages of the Bureau, GRI, MMS, and DOE. A Technical Advisory Group consisting of ARCO Oil and Gas Company; CNG Producing Company; Conoco, Inc.; Marathon Oil Company; Oryx Energy Company; Shell Offshore Inc.; Texaco USA; and UNOCAL, Inc., provided industry liaison and technical support.

The northern Gulf of Mexico is currently receiving much attention from the oil and gas industry for field extension and infill drilling in mature areas of the basin and for frontier exploration in deeper parts of the Gulf. In 1997, leasing activity reached record levels for both the northern and western Gulf of Mexico, emphasizing the region's increasingly important role in supplying domestic energy. The Gulf of Mexico offshore region currently produces 14 and 25 percent, respectively, of the nation's annual production of oil and gas. In addition, the Gulf region contains an estimated 17 and 26 percent, respectively, of the Nation's undiscovered conventional oil and gas resources. Through 1994 in State and Federal waters, 9,947 sandstone-body reservoirs in 1,212 fields produced an estimated 12.1 billion barrels of oil and 134.9 Tcf of gas.

We delineated 91 reservoir plays in Federal and State waters of the Gulf of Mexico, typically using age and depositional style as the key defining attributes of a play. We identified plays by integrating regional patterns of hydrocarbon occurrence and patterns of depositional style and structure with engineering reservoir data. Various elements of geologic and engineering data were synthesized to determine the boundaries of plays.

Systematic compilation of Gulf of Mexico reserves and production data within a reservoir play-defined framework will help to assess the most important combinations of trap types and producing facies. Digital data provided on the CD-ROM can be used to (1) identify the areas of greatest potential with the highest concentration of remaining unrecovered hydrocarbons in

existing fields and (2) guide frontier exploration in ultradeep water on the basis of analysis of submarine-fan and slope-apron facies encountered beneath the shallower adjacent continental shelf. Regional reservoir play analysis thus provides a logical basis for simultaneously evaluating both field reserve growth potential and opportunities for extension exploration in mature plays. The result will be reduced exploration risk and improved efficiency.

Assessment and Forecasting—by Play, Natural Gas Reserve Appreciation, and Quantifying the Role of Technology Advancements in Reserve-Growth Additions in the Gulf Coast Basin

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

In recent years, reserve growth has become a major component of total U.S. annual natural gas reserve additions. Further, by adding reserves within existing infrastructure and commonly by inexpensive recompletion technology in existing wells, reserve growth has become the dominant factor in providing an ample low-cost natural gas supply. Although there is a wide range in natural gas reserve-growth potential by play and that potential is a function of the drilling and technology applied, current natural gas reserve-growth studies are gross (averaging wide ranges), disaggregated by broad natural gas provinces, and calculated as a function of time.

The primary research objectives of this project, funded by the U.S. Department of Energy, are developing new concepts in (1) realistic and play-specific measures of remaining natural gas reserve-growth potential, (2) assessment of technology necessary and most amenable to realizing natural gas reserve growth, and (3) assessing the economic factors of realizing natural gas reserve growth in the Gulf Coast Basin. Through such assessment, the longer term potential and economics of natural gas reserve growth as a contributor to the future natural gas supply from the Gulf Coast Basin can be determined and quantified. The methodology of such an assessment can be verified and applied more broadly to other natural gas resource areas that have significant natural gas reserve-growth potential.

To date, most research has focused on literature surveys, compilation and review of data, data-base construction, and preliminary estimates of reserve growth by plays as a function of time since discovery. Past resource-assessment and reserve-growth studies have been reviewed and compared in order to delineate the current state of research and problems needed to be resolved. A field data base and corresponding play-level data base for the Federal Offshore Gulf of Mexico have been constructed and integrated with the Bureau's offshore atlas play data bases. Preliminary analysis of aggregated total fields revealed that natural gas reserve appreciation in the Federal Offshore Gulf of Mexico has occurred steadily, along with an increase in the number of fields, within a 17-year time frame.

Because of problems with insufficient data to allocate reserves to the play level in the Federal Offshore Gulf of Mexico, Railroad Commission of Texas (RRC) District 4 will be initially reviewed and analyzed to determine the suitability of the proposed methodology. RRC District 4 was selected on the basis of its role as a major natural-gas-producing district, where significant technological advancements have been routinely applied, and its historical production data maintained on a reservoir level. A preliminary determination of annual reserve growth by field and aggregation to already established plays, as well as a translation to reserve growth as a factor of time, has been undertaken.

Major future tasks involve (1) estimation of reserve growth potential by play, (2) estimation of reserve growth potential by heterogeneity class and determination of volume, (3) extrapolation of future reserve-growth potential and comparison with volumetric estimates to verify statistical versus volumetric assessments, and (4) establishment of a methodology that integrates volumetric estimates and statistically extrapolated historical reserve growth.

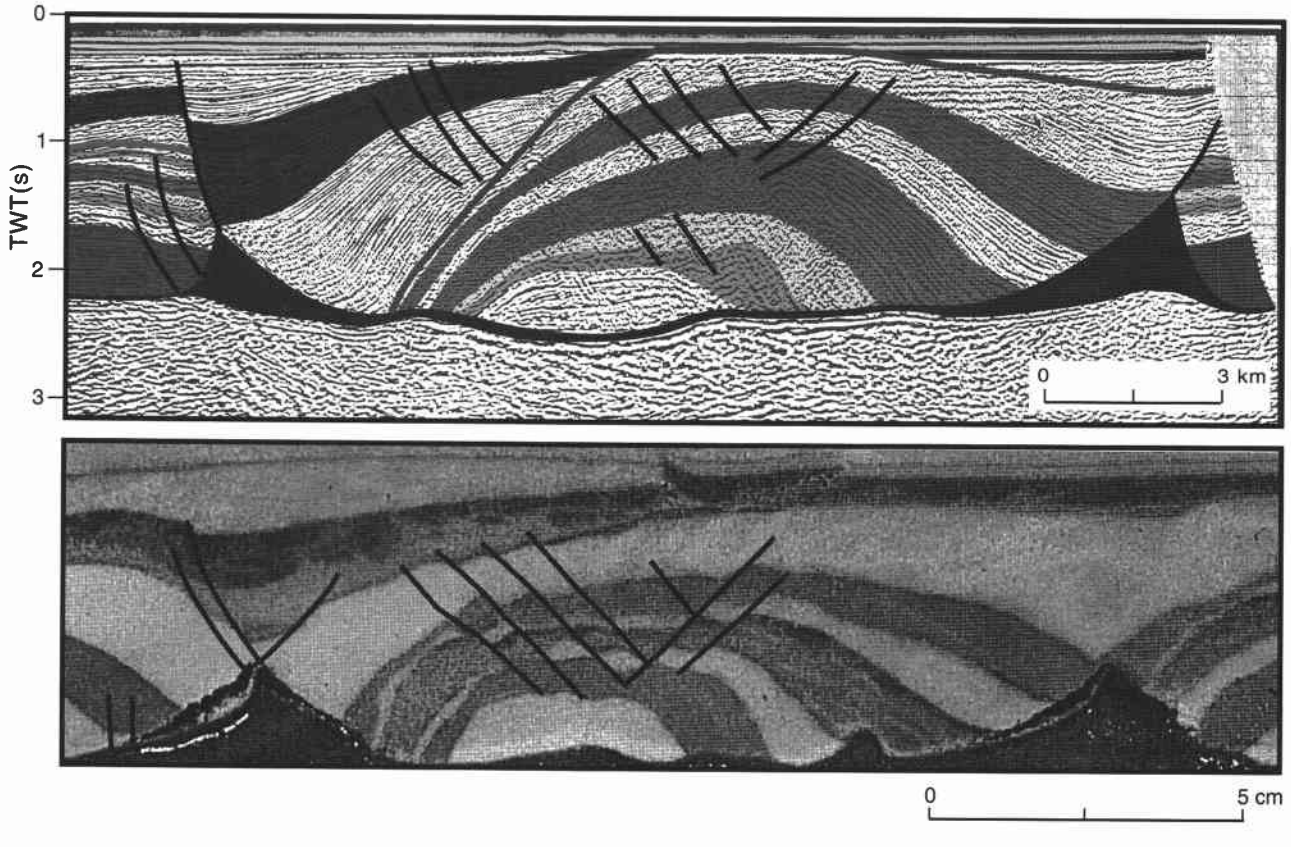
Experimental and Applied Tectonics Investigations

Applied Geodynamics Laboratory

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

The Applied Geodynamics Laboratory (AGL) carries out mechanical tectonic modeling to generate new concepts, test hypotheses, or duplicate specific geologic structures relevant to the location, origin, mechanics, and evolution of structural traps for oil and gas. Research is funded by the Texas Higher Education Coordinating Board and by the following consortium of oil companies: Agip S.p.A.; Amoco Production Company; Anadarko Petroleum Corporation; ARCO Exploration and Production Technology and Vastar Resources, Inc.; BHP Petroleum (Americas) Inc.; BP Exploration Inc.; Chevron Petroleum Technology Company; Conoco and Du Pont Corporation; Exxon Production Research Company and Exxon Exploration Company; Louisiana Land and Exploration Company; Marathon Oil Company; PanCanadian Petroleum Limited; Petroleo Brasileiro, S.A.; Phillips Petroleum Company; Saga Petroleum ASA; Shell Oil Company; Statoil; Texaco, Inc.; and TOTAL Minatome Corporation.

Two sites on the World Wide Web provide releasable research results, including multimedia hypertext publications comprising animations; high-resolution, full-color 3-D images; and searchable text. A public site (http://www.utexas.edu/depts/beg/agl) includes funding sources, research staff, a list of publications, samples of released research, and channels of communication. Another site for only



Seismic profile (above) and comparative physical model (below) of a turtle-structure anticline. Gravity-driven regional extension laterally stretched the turtle-structure anticline between sagging, triangular diapirs (black). Growth wedges in the anticline indicate that its right-hand (landward) limb sagged before its left-hand (basinward) limb.

the Industrial Associates includes an interactive version of our latest contract report, new animations, samples of ongoing research, and abstracts of preprints and recent reprints.

Experimental modeling was carried out in a normal gravity field. Deformation rigs, which allow almost any structural styles to be simulated and superposed, are driven by stepper motors controlled by electronic indexers and a computer. Modeling is also possible in an accelerated gravity field by means of a high-speed, high-capacity centrifuge. Experimental research focused on the following main topics: (1) progradation and deformation of an entire divergent continental margin, (2) gravity gliding against rigid pluglike obstacles, (3) formation of counterregional "growth faults," and (4) three-dimensional effects of progradation above an allochthonous salt tongue.

Numerical modeling and computer visualization uses several Macintoshes and digitizers and two Silicon Graphics workstations. Mathematical simulation combines brittle and ductile deformation, large strains, faulting, sedimentation, and erosion. The following topics were systematically investigated: (1) control of synkinematic sedimentation and salt interbeds on structural style of thin-skinned contraction above salt, (2) evolution of grabens by thin-skinned gravity gliding above autochthonous salt, and (3) effects of feeder stems and variable sedimentary loading on structural style of allochthonous sheets.

Earthvision® is used for full three-dimensional visualization, volumetrics, and mapping of structural traps from digitized cross sections of physical models. It was applied to the following physical models: (1) extension followed by shortening of salt sheets and diapirs, (2) breakout of allochthonous salt during progradation over an arcuate basinward pinch-out of salt, and (3) subsidence of diapiric walls induced by regional extension.

The AGL also carried out research on the basis of geologic data, such as a classification of salt-related fault families and fault welds in the Gulf of Mexico (with the University of Colorado), an investigation of the origin of The Needles grabens in Canyonlands National Park (with the University of Nevada), an examination of diachronous structural regimes in prograding margins (with Elf Aquitaine), and a comparison of petroleum systems in Angola and the Gulf of Mexico (with TOTAL).

Computer Modeling of Hydrocarbon Traps Formed around Deformed Salt Sheets in the Gulf of Mexico

Daniel D. Schultz-Ela, principal investigator; assisted by Ryan J. Mann

Although revised concepts of salt deformation combined with technological advances have rejuvenated oil exploration in the Gulf of Mexico, success requires an understanding of the interaction of salt deformation and sedimentation. Funded by the Advanced Technology Program of the Texas Higher Educational Coordinating Board, our project models the mechanics of sediment loading and salt-sheet deformation to simulate the formation of hydrocarbon traps and conduits. We attempt not only to answer *what* has happened but also *why*. Modeling with unique, state-of-the-art finite-element software allows variation of density, strength, salt viscosity, and deposition patterns and rates. Understanding the effects of each variable, as well as the shape of a salt sheet and presence of regional extension, reveals the critical controls on deformation and, therefore, the evolution of migration pathways and traps needed for hydrocarbon accumulation.

A wide array of properties have been systematically varied to explain the mechanics of sediment loading and salt-sheet deformation. We have identified a number of key findings: (1) regional extension strongly enhances segmentation of the sediment layer lying on the salt; (2) localized sediment loads from migrating channels interact with subsalt topography to control salt uplift; (3) fault scarps beneath the salt create zones of salt upwelling; and (4) a feeder connected to the stock collapses as the sheet inflates, causing uplift of the salt roof rather than the subsidence found in other models. Presence of a feeder substantially changes the results in runs, varying location and rate of sedimentation, regional slope, regional extension, initial salt bulge, and sediment density. Active structures below the salt link weakly to structures above it. The strength of the linkage depends on sheet thickness, loading rate, and regional deformation. Some types of suprasalt structures provide better clues to subsalt structure than others.

Land, Water, and Environmental Resources Investigations

Environmental, Geologic, and Hydrogeologic Studies

Hydrologic and Geologic Studies of the Texas Low-Level Radioactive Waste Disposal Site, Eagle Flat Region, Hudspeth County

Bridget R. Scanlon and Jay A. Raney, principal investigators; Edward S. Angle, Edward W. Collins, Alan R. Dutton, John F. Gamble, Robert E. Mace, William F. Mullican III, and Robert C. Reedy; assisted by Jiunnren Lai

Site characterization and monitoring of the State's proposed low-level radioactive waste disposal site in Northwest Eagle Flat basin continued in 1997. Planning and instrumentation for the ground-water monitoring program, to be conducted by staff from the Bureau and the Low-Level Radioactive Waste Disposal Authority, have been finalized, and the program is now operational. Additional ground-water monitor wells have been installed and all have been retested. Final expert testimonies were written in support of upcoming hearings for the site, scheduled to begin in January 1998. This effort has been supported by the Texas Low-Level Radioactive Waste Disposal Authority and the U.S. Department of Energy.

A significant part of the operational and postclosure monitoring of the disposal trenches will occur in a prototype trench cap constructed during 1997. The trench cap was built according to design specifications of the facility's proposed trench caps and was monitored by a wide variety of instruments to determine how much water infiltrates through the trench cap into the subsurface. The trench cap comprises two parts: an asphalt barrier based on the design of the proposed repository and a capillary barrier. The asphalt barrier includes a layer of asphalt at a depth of 4.3 ft (1.3 m), similar to the traditional resistive barriers or clay liner barriers that minimize downward water flux by means of a low-permeability layer. The asphalt layer avoids the disadvantages associated with the use of clay liners in traditional EPA covers, however, such as desiccation and cracking. The capillary barrier design, including a capillary break or course layer at a depth of 6.6 ft (2.0 m), increases the storage capacity of the overlying material so that the water can later be removed by evapotranspiration.

Geologic studies at the low-level site were conducted to support engineering and hydrologic investigations and included describing the basin-fill stratigraphy exposed in a ~30-ft-deep exploratory trench. Basin-fill deposits exposed in the >800-ft-long trench compose three multicomponent sediment packages that are separated by calcic paleosol horizons. An upper sediment package is made up of sand, silt, and some gravel. A middle package consists of sand and gravel. A lower, clay-rich sediment package contains mostly intervals of sandy clay and clayey and silty sand. The calcic paleosol horizons are almost laterally continuous along the trench walls. Locally either paleoerosion has scoured away small parts of these horizons or the paleosols did not develop.

Remediation-Focused Hydrogeological Investigations of Abandoned Oil-Field Cleanup Sites

Alan R. Dutton, principal investigator; James C. Gibeaut, Susan D. Hovorka, Matthew P. Mahoney, Robin C. Nava, Jeffrey G. Paine, Rebecca C. Smyth, Enid J. Sullivan; assisted by Martina U. Blüm, Wan-Joo Choi, William H. Doneghy, Jordan W. Forman, Jr., Andy M. Graham, and Susan Palachek

The Railroad Commission of Texas (RRC) has statutory responsibility under S.B. 1103 (72nd Legislature, 1991) for oversight of the cleanup of abandoned oil-field sites throughout Texas to protect public health and safety and the environment. During 1997 the Bureau continued to assist the RRC in devising cleanup solutions at sites where previous investigations had not been able to define the source of contamination, where the subsurface extent of the contaminant is unknown, and where complex subsurface geology will affect remediation feasibility. Our investigations focus on finding cost-effective remedial solutions and limiting investigation costs, by applying, to the largest extent possible, nonintrusive, state-of-the-art techniques.

During 1997 the Bureau completed work on eight sites across Texas, including three sites containing

spent drilling fluids, two sites contaminated by oil and two sites contaminated by saltwater, and one site containing natural gas.

Investigations at the sites containing spent drilling fluids focused on defining the thickness and levels of contamination of the pit fluids and determining whether contaminants have leached into surrounding soil, ground water, or surface water. In addition to sampling and analyzing pit fluids, we conducted electromagnetic geophysical surveys to test for subsurface salinization and constructed and sampled monitoring wells to evaluate ground-water quality. We prepared recommendations for remedial solutions on the basis of risk-based calculations of exposure to contaminants.

Of particular interest is one site that has a subsurface oil plume that has impacted two private water-supply wells. We delineated the plume and collected soil samples by drilling with solid-stem and hollow-stem augers, having determined that a direct-push soil probe survey would be unsuccessful. We made on-site gas chromatograph measurements of water, oil, and borehole vapor samples and conducted hydrologic and chemical tests in monitoring wells. We found that the source of the oil was most likely a spill of 125 to 500 bbl sometime during the 1960's that seeped down to the water table. The 76,000-ft^2 oil plume is surrounded by a methane plume because of natural biodegradation of the oil. CO_2 and CH_4 are elevated, and O_2 is decreased, in soil vapors associated with the oil plume. Remedial solutions include removing the recoverable free product, active venting of subsurface methane, and air sparging to remove and immobilize remaining crude oil.

Another special site involves extensive salinization near the Red River that has produced barren cropland. Reconnaissance electromagnetic geophysical surveys found that multiple possible sources of the salt water exist. We decided the most cost-effective way to map subsurface salinity at this site is by an airborne electromagnetic survey. The survey tracked the main axis of the salinity plume from the barren ground to an oil field that has been in operation since the 1920's. The main body of salt water appears to coincide with the location of brine-disposal pits that had been active in the field up until 1969. Integrated information on the three-dimensional volume of the plume, ground-water chemical composition, hydrological properties, and discharge rates are being used to evaluate cost-effective solutions to the expansion of the barren ground and the long-term potential of discharge of salt water to the Red River.

Reevaluation of Ground-Water Resources on State Lands in Eastern El Paso County, Texas

William F. Mullican III, principal investigator; Alan R. Dutton and Robert E. Mace; assisted by Martina U. Blüm

The State of Texas owns many large blocks of land in West Texas, from which any profits are dedicated to the Permanent School Fund. Because of declining surface- and ground-water supplies in the region, the value of land is mostly determined by the availability of potable water in the area. The Texas General Land Office (GLO) is the State agency responsible for the management of State-owned lands and for any income that may be generated by these vast holdings. In eastern El Paso County, the GLO is responsible for approximately 115 sections (73,600 acres) of mostly undeveloped land. In an effort to evaluate the value of this extensive land holding properly, the Bureau worked with the GLO to reevaluate the potential for developing additional local ground-water resources in eastern El Paso County that could be used to enhance the value of State-owned lands.

Using ground-water conceptual models developed by the Bureau over the last decade while working in the Trans-Pecos region and data compiled for this effort, we identified three areas in eastern El Paso County as having potential for significant ground-water resources. Plans are being considered for following up this initial screening effort with more in-depth studies to evaluate the potential of the area further. The successful development of additional water resources in eastern El Paso County would significantly increase the value of State-owned lands in the area.

Evaluation of Interplaya Recharge on the Southern High Plains Recharge

Bridget R. Scanlon, principal investigator; Edward S. Angle, William F. Mullican III, and Robert C. Reedy; assisted by Jinhuo Liang

The objective of this project is to develop a monitoring station to quantify infiltration in an interplaya setting at the Pantex Plant near Amarillo, Texas. Estimates of infiltration in interplaya settings will be an important component of a sitewide environmental impact statement that will be required for any new missions at the Pantex Plant. This work is being conducted in cooperation with the Department of Civil Engineering, Texas A&M University.

Findings based on previous interplaya studies conducted near the Pantex Plant suggest negligible water movement in this setting under natural conditions. A multidisciplinary approach to monitor hydraulic parameters and measure the subsurface distribution of environmental tracers is being used to quantify infiltration. Thermocouple psychrometers will be installed in two boreholes to a maximum depth of 24 m to monitor temporal variations in water potential, and temperature- and time-domain reflectometry probes will be used to monitor water content. The monitoring station will provide information on infiltration in response to ambient precipitation. The distribution of environmental tracers, such as chloride and stable isotopes of oxygen and hydrogen, will be used to test hypotheses regarding flow developed from the monitoring station and to provide information on longer term net water fluxes. It is important to establish a monitoring system as early as possible to provide long-term data on the response of flow in the unsaturated zone to variations in precipitation. Information on infiltration rates is critical because infiltration drives analyses of all subsurface pathways for contaminants.

Monitoring Techniques Related to Subsurface Gas Transport

Bridget R. Scanlon, principal investigator; Edward S. Angle and John F. Gamble

Upward and downward migration of gases, such as the volatile contaminants ^{3}H, ^{14}C, and ^{222}Rn, from waste disposal facilities is a critical issue for low-level radioactive waste disposal. Transport mechanisms for gases include not only diffusion but also advection. The purpose of this study is to evaluate different techniques of estimating gas transport parameters and of monitoring subsurface gas migration. The work is being conducted at the Maricopa Agricultural Center in collaboration with the University of Arizona and is funded by the U.S. Nuclear Regulatory Commission.

This study includes evaluation of subsurface pressure response to barometric pressure fluctuations. Computer simulations suggest that air from the surface can move several meters into the ground during typical barometric pressure cycles. Boreholes were drilled and gas ports were installed at different depths to evaluate atmospheric breathing through the unsaturated zone. The response of the subsurface to diurnal and longer term (~4 d) variations in atmospheric pressure was recorded. Minimum vertical air permeabilities can be calculated from these data. Results of this monitoring can also be used to show the importance of barometric pressure cycles for optimizing sampling of gases that are transported by atmospheric breathing. Pneumatic pressure tests were used to provide information on both vertical and horizontal air permeabilities at different levels. Air was injected in a central well, and pneumatic pressure was recorded in monitoring wells. We conducted pumping tests using different injection or extraction rates. We evaluated the data using analytical or numerical techniques. Information obtained in these tests was used to examine the importance of advective flow of gases. The results of this study provided valuable information on subsurface gas transport processes and on the methodology of measuring gas transport parameters required for simulation of such processes. These data are required for performance assessment calculations.

Implementation of Test Plan for Ward Valley, California, Recharge Studies

Bridget R. Scanlon, principal investigator; Edward S. Angle, Jinhuo Liang, William F. Mullican III, Robert C. Reedy

Ward Valley is the proposed low-level radioactive waste disposal facility in the Mojave Desert, 30 km west of Needles, California. The site is on a low-relief alluvial surface that slopes gently toward Homer Wash. A National Academy of Sciences (NAS) panel was convened in 1994 to evaluate seven issues related to recharge at the Ward Valley site. This study is being conducted to address recommendations made by the NAS with respect to recharge at that site.

A test plan was developed that outlines how each of the issues is to be addressed. Surface electromagnetic (EM) induction surveys conducted perpendicular to the small drainages and in interdrainage settings showed that apparent conductivities were very low, indicating dry sediments. There was no evidence of higher water contents beneath the small drainages. These reconnaissance data were used to locate boreholes that will be drilled by augers according to ODEX (reverse air circulation) techniques. Procedures have been developed for drilling and sampling the boreholes. Borehole depths will range from 30 to 213 m (depth of water table). Samples from these boreholes will be analyzed for (1) hydraulic parameters to evaluate current rates of water movement and (2) environmental tracers to evaluate long-term net water fluxes. Hydraulic

parameters include soil texture, water content, and water potential. These data will help determine the direction of water movement. Environmental tracers such as chloride, stable isotopes of oxygen and hydrogen, tritium, and chlorine-36 will also be analyzed to determine rate of water movement. Isotopic tracers will be analyzed in the liquid and gas phases. Integration of hydraulic, chemical, and isotopic data should provide a comprehensive understanding of unsaturated flow processes at the site.

This project is funded under contract to ERM Program Management Company for the California Department of Health Services. The Bureau is collaborating with other companies such as Tracer Research, D. B. Stephens & Associates, and Miami Tritium Laboratory to conduct this work.

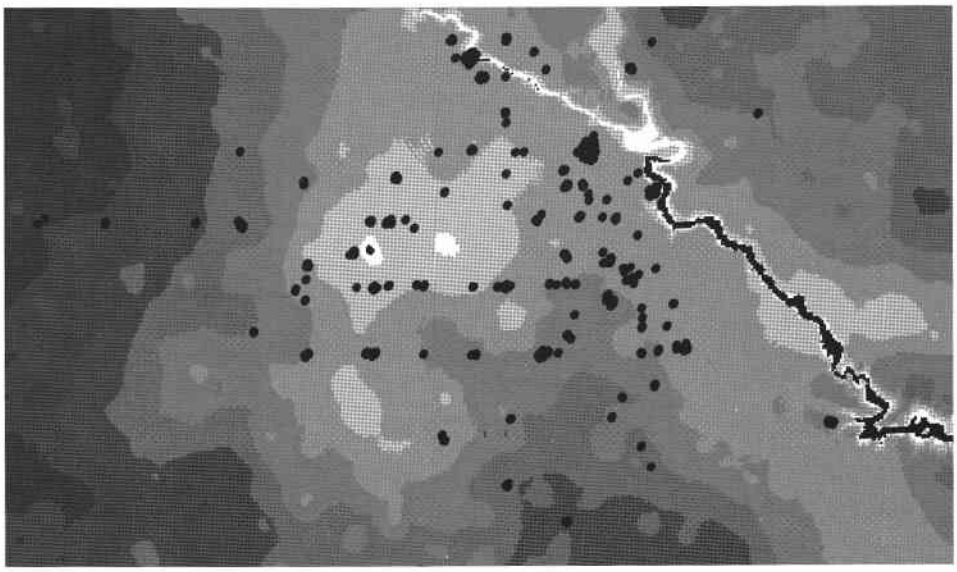
Lubbock County Pilot Study for Development of a Hydrogeologic Geographic Information System (HGIS) to Support TNRCC Implementation of Risk-Reduction Rules

Susan D. Hovorka, principal investigator;
Robert E. Mace;
assisted by Susanne Porterfield and Sandra P. Parra

In the past decade, a great deal of information has been collected by the Texas Natural Resource Conservation Commission (TNRCC) as part of the leaking-petroleum-storage-tank (LPST) and ground-water protection program. Our pilot study demonstrated a methodology for building a geographic information system (GIS) for merging site-specific and hydrogeologic data into a data base to facilitate retrieval and analysis. The study evaluates the use of this technology to provide context information for new site evaluation and risk assessment, as well as to evaluate the effectiveness of past site-characterization, risk-assessment, and remediation strategies. Methods and costs of producing the data base in this pilot study were described.

Several analyses of these data were presented as a demonstration of the uses of this tool. The heterogeneity within the unsaturated zone was characterized spatially and statistically. Hydrologic variables, including water level and hydraulic conductivity from well tests, were mapped. The effect of the observed variability on Risk-Based Corrective Action (RBCA) calculations was assessed. The evolution of contaminant plumes can be viewed and relationships between plumes and water-supply wells quantified.

This pilot study demonstrates an application of GIS technology to a moderate-size data set of contaminated-site information. The demonstration is intended not only to provide information about the Lubbock County study area but to serve as a prototype and feasibility study for application of this technology to other large contaminated-site data sets, including LPST-site



Thickness of the unsaturated zone in and around Lubbock, Texas, recreated by Geographic Information System (GIS) software, Arc GRID®, to subtract the potentiometric surface of the Ogallala aquifer from the USGS Digital Elevation Model. Black shading shows areas of ground-water discharge into Yellowhouse Draw and Maxey Lake playa; gray represents depth to water from a minimum of less than 10 ft (white) grading to a maximum of 150 ft (dark gray). This image, used in a pilot study to demonstrate the uses of GIS technology for supporting implementation of TNRCC risk-reduction rules, shows the relationship between leaking-petroleum-storage-tank sites (dots) and shallow ground water.

Deforested area in central Belize showing relatively recent vegetation growth among the charred stumps of a cleared broadleaf forest. The Bureau and UT–Center for Space Research, in cooperation with the Belize Ministry of Natural Resources, are currently involved in a land-cover mapping project of central Belize. Photo by Jay A. Raney.

data in other major urban areas, other types of contaminated sites, and industry applications.

Remote Sensing Analysis of Land Cover and Land Use in the Southern Belize District, Belize

Jay A. Raney and William A. White, principal investigators; Thomas A. Tremblay; Melba M. Crawford and Solar S. Smith (UT–Center for Space Research)

Funded by the United Nations through the Government of Belize, Ministry of Natural Resources, this project is a follow-up to a previous nationwide study in which the Bureau determined extent and rates of deforestation. The present study is a more detailed evaluation of land cover and land use in the southern Belize District. It supports the efforts by the Government of Belize to develop a current land-use map of Belize.

Working in close cooperation with the technical staff of the Belize Ministry of Natural Resources, Bureau staff will first review existing data and imagery of the southern Belize District. The Government of Belize will also provide office accommodations and ground transportation in Belize. The study is based on analysis of 1996 Landsat Thematic Mapper imagery. The project area has been selected because it is relatively cloud free in the best available imagery and includes a large percentage of the coastal and upland land-cover and land-use units that are present elsewhere in Belize. Interpretation of the Landsat imagery will be based on our previous experience in Belize and will be verified by limited field studies and low-altitude aerial surveys. This study will be the basis for image classification that can be used elsewhere in Belize. At the conclusion of the study, a workshop will be presented in Belize that describes the methodology used and the results of the land-cover and land-use classification. A final report, including maps of land cover and land use in the southern Belize District, will be prepared for the Ministry.

Geologic Analogs of Engineered Barriers: Natural Examples of Very Long Term Performance of Layered Geologic Materials

Susan D. Hovorka, principal investigator

Materials in the vadose zone are modified through time by a number of processes. These processes have the potential of adversely affecting the performance of engineered barriers capping waste disposal facilities. The project, funded through the Texas Low-Level Radioactive Waste Disposal Authority, documents the physical, chemical, and mineralogic changes in geologic deposits that have been modified by natural processes for thousands of years as analogs to what might happen to engineered barriers over a long period of time. The role of fine-grained clays and marls in limiting vertical permeability and the extent to which in situ gravels function as capillary barriers to flow in

the unsaturated zone were of particular interest. Results of this study are intended to apply to other arid-zone disposal sites, as well to the proposed Texas low-level radioactive waste disposal site in Hudspeth County, Texas.

Alteration of layered natural materials has been investigated at 10 sites containing fluvial and lacustrine deposits that range in age from 500 to 22,000 years. Fine-grained materials include clay, silty clay, diatomite, and calcareous lake deposits. Coarse-grained materials include gravel, gravel with sand matrix, and gravel with mud matrix. Climatic parameters were used to define the geographic areas suitable for analogs to the Texas site. Modification of sediments includes penetration by roots; cracking of fine-grained materials in response to shrink–swell activity of clays; infiltration of fines into gravel; precipitation of carbonate, limonite, and manganese oxides and hydroxides, and gypsum and halite; and oxidation and reduction of iron associated with fine-grained sediments. The two main variables that can be related to intensity of alteration are (1) geomorphic setting and (2) composition of fine-grained materials. Most alteration was observed in deposits now in topographic lows; deposits on hillsides underwent the least alteration. Clayey deposits showed more evidence of shrink–swell and cracking than did diatomites. Topographic effects and mineralogy have more influence on the amount of alteration than do the age of the deposits.

Because all deposits examined during this study underwent substantial modification since deposition, this complex evolution limits determination of timing and rates of alteration. Future analog studies might focus on very young deposits (for example, mine ponds and tailings) to determine rates of alteration. Lake deposits including diatomites and carbonates are fine-grained alternatives to silts and clays. Marl deposits appear to be structurally more stable under shrink–swell and weathering than deposits containing clay. Inspection of sites suggests that marls may serve as fine-grained units in capillary barrier systems; however, quantitative and experimental data are needed.

Salt Cavern Studies — Regional Map of Salt Thickness in the Midland Basin

Susan D. Hovorka, principal investigator

Salt caverns in bedded and domal salt are used for product storage and waste disposal. This reconnaissance study, funded by the National Petroleum Technology Center, U.S. Department of Energy, provides basic data needed for siting, development, and regulation of salt caverns in an area of intense industry activity.

Regional variation in the thickness, depth, and structure of the major bedded salt-bearing interval of West Texas, the Salado Formation, was mapped in a 28-county area of the Midland Basin according to about 500 wireline logs. Areas of reduced and variable salt thickness and relatively shallow depths to the top of the salt are identified on the Eastern Shelf of the Midland Basin in Garza, Borden, Howard, Glasscock, and Reagan Counties; along the Pecos River in Crockett, Upton, Crane, and Pecos Counties; and along the west edge of the Central Basin Platform in Ward and Winkler Counties. Reconnaissance data suggest that salt may be locally or regionally actively dissolving from these areas. Salt thinning in areas where the top of salt is relatively deep (>1,500 ft) is noted south of the Matador Arch in Cochran, Hockley, Lubbock, and Crosby Counties and locally along the east edge of the Central Basin Platform in Gaines, Andrews, and Ector Counties. The thinning in these areas is tentatively interpreted as dominantly the result of deposition of thin salt or Permian salt dissolution. In all areas of thinning, sedimentary patterns suggest that facies changes may also change the quality of the salt (salt purity, water content, bed thickness) over short distances.

In other areas within the Midland and Delaware Basins, salt-thickness changes are gradual. The potential for local areas of salt dissolution not identified in this regional study, however (for example, those that may be beneath saline lakes), may impact the suitability of salt as host strata in these areas. This project provided a starting point from which additional description of engineering and environmental attributes of salt will be added during the next year.

Estimating Depth to Bedrock

Jeffrey G. Paine, principal investigator

This project, funded by the Texas Department of Transportation, represents a cooperative venture by the Bureau and the Center for Transportation Research (CTR) 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 roadway design, are currently based on analysis of falling weight deflectometer data without benefit of the abundance of information available on near-surface soils and rocks.

Considerable effort has been expended over the last few decades by geologists, soils scientists, engineers, and geomorphologists to produce maps, cross sections, and soil profiles that focus on the upper few meters of the subsurface, a critical zone for roadway design. These data may provide a semiquantitative basis for determining regional and local differences in expected 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.

In this project, the Bureau and CTR are (1) evaluating the utility of existing soils and geological maps in estimating depth to bedrock; (2) establishing regional variations in near-surface rock and soil properties that might allow the state to be subdivided into regions of similar physical properties; (3) establishing soil- and rock-type variations within a region that allow definition of units having similar physical properties and depth-to-bedrock ranges; (4) developing guidelines for survey design, acquisition parameters, and analysis of proven seismic refraction technology for accurate depth-to-bedrock estimates; and (5) developing procedures that would allow a project engineer to estimate bedrock depths on the basis of the project region and geologic and soil units within the region, select appropriate sites for seismic refraction surveys if more detail is necessary, and optimize the acquisition parameters for the refraction survey on the basis of the qualitative depth-to-bedrock estimates from geologic and soil maps.

Environmental Restoration at the U.S. Department of Energy, Pantex Plant, Texas Panhandle

Jay A. Raney, principal investigator;
William F. Mullican III, Jeffrey G. Paine, and Bridget R. Scanlon

The Bureau assists the Governor's Office and State agencies in their oversight responsibilities for the U.S. Department of Energy's (DOE) Pantex Plant near Amarillo, Texas. This work is funded through an Agreement in Principle (AIP) between the DOE and the State of Texas. The Bureau previously conducted a 5-year characterization study of the geology and hydrogeology of the plant and surrounding region. Based on this experience, we participated in the AIP by reviewing documents and providing technical comments on environmental issues related to the geology and hydrogeology of the area, such as geochemistry and ground-water models.

Integrity of Houston Ship Channel Archeological Sites

Jeffrey G. Paine, principal investigator

This joint project of the Bureau and the Texas Archeological Research Laboratory is funded by the Galveston District, U.S. Army Corps of Engineers. Bureau researchers are conducting geomorphological studies and analyzing 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 spoiling activities, hydrocarbon production, and ground-water 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, Bureau researchers are assisting archeologists by determining whether reported sites are likely to be intact, submerged by rising sea level, eroded following shoreline retreat, covered by subsequent dredge material, or reworked as remnants of material dredged from nearby ship channels. Such determination allows archeologists to focus labor-intensive excavation on those sites that are most likely to be intact and significant. Prefield activities included detailed analysis of historical aerial photographs and topographic maps at the reported site locations to establish depositional environment and rates of shoreline erosion. Field activities included trench and borehole studies, collection and analysis of vibracore samples from submerged sites, and soil-profile analyses. Products will include detailed maps of individual sites that depict the changing geomorphic setting from the time earliest maps were made to the date of most recent aerial photographs.

Coastal Studies

Mapping Shoreline Types of the Central Texas Coast

Robert A. Morton, principal investigator;
William A. White, Thomas A. Tremblay, and L. Edwin Garner

This 2-year 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. The purpose of this regional, comprehensive effort is to characterize and map the different shoreline types that occur along the Gulf of Mexico, in the interior bays, and along the Gulf Intracoastal Waterway between East Matagorda Bay (Sargent Beach) and Corpus Christi. Results of the study will be used by State and Federal agencies responsible for managing coastal resources.

In 1997, the Bureau classified and ranked shorelines 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 were determined from low-altitude color video surveys and aerial photographs, delineated on 1:24,000 topographic maps, and field checked from the air and on the ground. The mapped shorelines were then digitized, and the data were formatted in a geographic information system (ARC/INFO).

High-Accuracy Bathymetric Surveying and Real-Time GPS Positioning System

James C. Gibeaut and Bob E. Schutz (UT–Center for Space Research) co-principal investigators; Roberto Gutierrez and Robert A. Morton; assisted by Eric M. Matzel, Cheng-Fang Lo, and Sung Byun

This project, funded by the Texas Higher Education Coordinating Board through the Advanced Technology Program, continues the development of a high-accuracy bathymetric surveying system begun under an earlier funded project titled "Shallow Water, High-Accuracy, High-Resolution Bathymetric Surveying System." It is a joint project between the Bureau and the Center for Space Research at The University of Texas at Austin. The primary focus is to develop and integrate with our bathymetric surveying system a method to obtain horizontal and vertical positions with an accuracy of 2 to 3 cm in "real time" while the survey vessel is moving. This robust positioning component, which will use the global positioning system (GPS), is required to meet our goals for bathymetric surveying, but it will also have a variety of commercial and research applications. In addition, we are continuing the refinement of the entire bathymetric surveying system through further testing. We are improving data-logging software and portability and adding the capability to precisely measure the speed of sound in water.

Three-dimensional (X, Y, Z) GPS positioning accurate to 2 to 3 cm is critical to achieving our survey goals. Our kinematic differential GPS software currently requires static initialization to estimate the phase biases. To initialize land kinematic surveys, the GPS rover remains stationary near the GPS base station for 20 to 30 minutes at the beginning of the survey. It is difficult, however, to keep a vessel stationary, and if the static initialization is attempted at dock side, a considerable number of useless GPS data are collected while the vessel travels to the survey area. The answer to this limitation imposed by the static initialization is to develop kinematic software with the ability to estimate phase biases "on-the-fly" (OTF), that is, while the vessel is in motion. In addition to the OTF enhancement, we are developing a "real-time" GPS positioning capability for our bathymetric system. Real-time GPS requires that the phase data from the base stations be broadcast to the GPS rover via a radio link. There are three major advantages of real-time GPS positioning for bathymetric surveying: (1) the position is immediately available for producing an accurate chart and for checking for spurious data; (2) extremely accurate navigation information is provided, allowing precise vessel positioning and speed control; (3) data processing is simplified because the bathymetry and positioning information can be immediately integrated.

Detecting Small-Scale Topographic Changes and Relict Geomorphic Features on Barrier Islands Using Airborne Synthetic Aperture Radar (AIRSAR)

James C. Gibeaut and Melba M. Crawford (UT–Center for Space Research), principal investigators; Roberto Gutierrez; assisted by K. Clint Slatton, Amy Neuenschwander, and Michael R. Ricard

The shapes, elevations, and sediment and vegetation distributions of barrier islands may change dramatically over a short period of time, such as during a storm. Even between storms, sediment is constantly shifting to and from these islands and between different areas of the islands at varying rates and in varying amounts. This 3-year project, which is funded by the National Aeronautics and Space Administration (NASA) and

Bureau and Optech Inc. personnel readying the Texas Cessna 206 aircraft for a laser altimeter topographic mapping mission on the upper Texas coast. Photo by David M. Stephens.

jointly conducted by the Bureau and the Center for Space Research at The University of Texas at Austin, is developing the use of airborne synthetic aperture radar (AIRSAR) to map coastal topography and sedimentary environments. The AIRSAR instrument is operated by NASA's Jet Propulsion Laboratory and is flown on a DC-8 aircraft. The study area lies along the Texas coast between Sabine Pass and Freeport.

We are evaluating the use of AIRSAR to detect old features, such as storm scarps, storm channels, former tidal inlets, and beach ridges, that have been obscured by vegetation, erosion, deposition, and artificial filling. We are also modeling polarimetric multiband radar signatures on the barrier island–spit systems. This modeling aids interpretation and automated classification of images into subenvironments. Methods developed during this project will provide coastal geologists with an unprecedented tool for detecting and understanding sedimentological changes. Overall coastal management policies will improve, and the effects of natural and human-induced coastal hazards will be reduced.

Topography in the form of digital elevation models (DEM's) are obtained from the AIRSAR data according to interferometric techniques. The method is based on the concept that radar signals received by two antennas are processed at the same Doppler frequency to form images. Assuming that the two antennas are within the scattered beam of the same ground-resolution cell, then the signals reflected from a scatterer on the ground will interfere with one another. The phase difference between the two paths are then used to derive ground elevation. Using this technique, we had hoped to be able to detect topographic change of 30 cm or less. It appears, however, that we will not be able to obtain vertical resolution of better than about 60 cm. We nonetheless expect that the radar-derived DEM's will greatly enhance the classification of sedimentary environments when combined with the polarimetric radar signatures and optical remote sensing data. To address the need for higher resolution DEM's to detect topographic change, NASA has provided additional support to fly an airborne laser altimeter mission. The altimeter data have a vertical resolution of 10 cm or better and horizontal spacing of data points of 2 to 5 m.

In 1995 and 1996, we obtained polarimetric multiband radar data and radar-derived DEM's. In 1996, we also obtained calibrated Airborne Multispectral Scanner (CAMS) data and simultaneous color infrared photography of Galveston Island and Bolivar Peninsula. We have shown that radar can discriminate sedimentary subenvironments on barrier-island systems. L-band (wavelength of 24 cm) appears to best delineate beach-ridge and swale morphology and different wetland environments. L- and P-band (wavelength of 68 cm) appear to indicate extensions of tidal creeks and faults cutting across the islands that may not be visible on aerial photography. L- and P-band can also delineate former breaches caused by storms and dredging. C-band (wavelength of 5.7 cm) provides the

greatest detail related to vegetation. In addition, AIRSAR data can image subtidal features, wave refraction, and current patterns in shallow (<4 m) tidal-inlet systems. We are currently combining AIRSAR (polarimetric and DEM data) and CAMS data in statistical classification routines.

Responses of Fluvial, Estuarine, and Barrier-Island Systems to Climate and Sea-Level Change—Central Texas

Michael D. Blum (University of Nebraska—Lincoln) and Robert A. Morton, principal investigators

This 2-year collaborative research project, which is funded by the National Science Foundation, combines expertise from several scientific disciplines, including fluvial geomorphology, coastal geology, micropaleontology, and archaeology. The purpose of the project is to document how fluvial, estuarine, and barrier-island environments of the Central Texas Coast responded to climatic and eustatic changes during the last 150,000 years. An improved understanding of the interaction between coastal evolution and threshold values of sea-level rise will provide better predictions of possible future changes in coastal environments and natural resources.

In 1997, personnel from the Bureau and the U.S. Geological Survey Coastal Division (St. Petersburg, FL) conducted high-resolution seismic surveys in three parts of the bay–lagoon system (1) immediately seaward of the highstand fluvial-deltaic deposits (Nueces Bay) and down the axis of the incised valley (Corpus Christi Bay), (2) within an adjacent lagoon that occupies an interfluve position (Redfish Bay), and (3) within another unfilled incised valley that was excavated by a minor coastal-plain stream (Copano Bay). The digital seismic profiles recorded during these surveys image the incised valleys and postglacial fills, as well as older fluvial-deltaic sediments deposited during an older highstand in sea level. The seismic profiles also provide a stratigraphic framework for correlating surfaces of subaerial exposure and marine erosion with similar surfaces observed in auger cores and vibracores taken across the valley and within the fill. The sequence stratigraphic analysis based on the seismic and available core data is being completed. Additional vibracores were collected from the barrier–lagoon system in 1997. Integration of the seismic profiles and cores provides a basis for interpreting the geologic history of the region and how sediment loads, river discharge, and channel patterns evolved as climate and sea level changed during the last glacio-eustatic cycle.

Mapping of Erosion Hazard Areas along the Gulf Shorelines of Galveston and Brazoria Counties

Robert A. Morton, principal investigator; Edward S. Angle; assisted by Erica M. Boghici

Determining the future position of the Gulf shoreline in Texas is of vital concern to State and Federal agencies and coastal planners responsible for maintaining the existing infrastructure and promoting economic development of the region. This study of the Gulf shoreline between High Island and the Brazos River is being conducted for the Texas General Land Office and the Federal Emergency Management Agency. It involves GPS (global positioning system) mapping of the 1996 position of the Gulf shoreline, comparing that position to others mapped in 1974 and 1990, calculating the rate of shoreline retreat or advance, and plotting the historical positions of the Gulf shoreline to establish trends and to predict future positions of the Gulf shore. This analysis served as the basis for calculating long-term average annual erosion rates and predicting the position of the shoreline during the next 60 years. This information provides a scientific method of projecting where coastal flooding zones and erosion hazard areas will be in the future.

A major accomplishment of the project was completion of an electronic data base of historical shoreline positions, monitoring transects, and other layers in ARC–INFO that permit rapid analyses of shoreline movement. The digitized shorelines span the time interval from the mid-1860's to 1996. Electronic results of this effort have been used by universities and by State and Federal agencies in a variety of applications. Results of the study were published in the Bureau's Geological Circular 97-3 entitled *Gulf Shoreline Movement between Sabine Pass and the Brazos River, Texas: 1974 to 1996.*

Sediment Characteristics, History, and Recent Transport, Laguna Madre, Texas

Robert A. Morton, principal investigator; Edward S. Angle and James R. Doss; assisted by James E. Lundy

The U.S. Army Corps of Engineers is responsible for maintaining navigable depths in the Gulf Intracoastal Waterway (GIWW), a dredged channel that traverses the shallow waters of Laguna Madre in South Texas. Placement of the dredged material in areas where sediment reworking is minimized

will lower costs of channel maintenance by reducing the frequency of future dredging and will also protect the aquatic habitats that are important to the commercial and recreational fisheries industries.

The Bureau investigation of Laguna Madre focuses on regional sediment characteristics, sediment budget, sources of fine-grained sediments, and historical changes in bathymetry and sediment types. It is one of several investigations being conducted by universities and Federal agencies that are intended to address environmental concerns regarding sediment suspension around islands of dredged material and its possible adverse impact on seagrasses, which are an important component in the ecosystem. The Bureau study emphasizes physical factors that may contribute to historical changes in marine grasses, such as storms, climate variations, internal transfers of sediment within the lagoon, and reworking and redistribution of material dredged from the GIWW. Laboratory and field work is concentrated on placement areas of dredged material where historical losses of marine grasses have been significant or where substantial dredging is necessary to maintain the waterway.

The technical approach includes compilation and synthesis of historical data, such as aerial photographs, topographic maps, hydrographic charts, climate records, records of upland runoff and freshwater inflow, documents pertaining to significant engineering projects, summaries of dredging records, and data on major hurricanes impacting the area. Each technical task has both field and laboratory components that integrate geological observations, physical measurements, and historical changes derived from morphological and sedimentological analyses.

In 1997 we completed a sediment budget for Laguna Madre that estimated the long-term average annual volume of sediment supply from dune migration and eolian suspension, hurricane washover, tidal inlets, upland runoff, internal reworking, and precipitation of authigenic sediments. We also described and interpreted 21 fixed-piston cores and 27 vibracores (total of 48 cores) and determined the thickness of dredged material and depth of the predredging lagoon floor. Total cumulative volume of sediment dredged from specific segments of the GIWW were compared with volumes of sediment remaining in the adjacent disposal sites. This comparison is intended to provide an estimate of the degree of resuspension and transport of dredged material from the disposal area and back into the navigation channel. Greatest reworking of dredged material occurs where the GIWW crosses the transition zones between the shallowest and deepest parts of Laguna Madre. The degree of reworking of dredged material is directly related to water depth and to the surface area of dredged material exposed to waves and currents. On the mud flats of the Land Cut and across the shoals of Laguna Madre, reworking of dredged material is minimal, but reworking increases as water depth increases.

Analysis of Current Status and Historical Trends of Selected Estuarine and Coastal Habitats in the Corpus Christi National Estuary Program Study Area

William A. White, principal investigator; Thomas A Tremblay and E. G. Wermund, Jr.

This project is part of the Corpus Christi Bay National Estuary Program (CCBNEP) funded by the U.S. Environmental Protection Agency and the Texas Natural Resources Conservation Commission. The Bureau is the primary contractor in this cooperative study with the Texas Parks and Wildlife Department (TPWD) and Texas A&M University—Corpus Christi.

The CCBNEP area encompasses an extensive, biologically productive estuarine and lagoonal system composed of numerous diverse and essential habitats. Major objectives of this study are to determine the status and trends of wetlands, wind-tidal flats, and riparian woodlands; to classify and map hardened and natural shorelines; to characterize estuarine and palustrine emergent wetlands in terms of their prevalent plant associations; and to determine the trends in vegetation cover on natural and dredged-material rookery islands. These types of data are critical to developing sound and comprehensive management practices for this nationally recognized estuarine system.

The project area for the study is defined by 30 7.5-minute quadrangles that encompass Corpus Christi and Aransas Bays and secondary bays including Copano, Nueces, Mesquite, and Redfish Bays and upper Laguna Madre. Barrier islands that are part of the study area include south Matagorda, San José, Mustang, and North Padre Islands. Wetlands status and trends are being determined by geographic information systems analysis of U.S. Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI) maps of wetlands and

aquatic habitats interpreted from 1950's, 1979, and 1992 aerial photographs. Hardened and natural shorelines are being mapped from high-quality, 1997 low-altitude aerial videotape surveys. Aerial photographs, USFWS NWI maps, TPWD land-cover maps, and field surveys are the primary sources of information for analysis of riparian woodlands. Prevalent wetland plant associations and rookery island vegetation are being characterized from field surveys, maps, aerial photographs, and existing reports. Results of the study will provide information on the health of the bay system and will be incorporated in the CCBNEP comprehensive conservation management plan.

Preliminary findings of habitat status and trends in the study area indicate that salt–brackish marshes and fresh (or interior) marshes were almost equal in total area in the early 1990's. Since the mid-1950's, net gains have occurred in both of these resources. Gains in salt marsh are partly the result of rising sea levels that have flooded tidal flats and contributed to the spread of marshes dominated by *Spartina alterniflora* in frequently flooded areas and seagrass beds in permanently submerged areas. Correspondingly, there has been a reduction in the total area of estuarine tidal flats since the 1950's.

Evaluation of Marsh Creation and Restoration Projects and their Potential for Large-Scale Application, Galveston–Trinity Bay system

Robert A. Morton and William A. White, principal investigators

The study to evaluate marsh creation and restoration projects is being conducted in cooperation with the Texas General Land Office (TGLO) and is funded by TGLO and the U.S. Environmental Protection Agency. Researchers at the Bureau are working closely with Tom Calnan, TGLO project manager. The major objectives of this investigation are to inventory and evaluate marsh restoration and creation projects in the Galveston–Trinity Bay System in terms of achieving project objectives and potential for large-scale application. In an area where thousands of acres of marshes have been lost since the mid-1950's, there is a need for planning and implementing marsh restoration and creation at a much larger scale than a few tens of acres. Marsh restoration and creation are important goals for the State of Texas, especially in areas where large-scale losses in marsh habitat have occurred as a result of both natural processes and human activities.

Numerous efforts have been made by many agencies, including Federal, State, local, and private entities, to restore, enhance, and create wetlands in the Galveston–Trinity Bay system. Unfortunately, most of these efforts have been uncoordinated and carried out at a relatively small scale. In addition, most completed projects have not been systematically monitored and evaluated on a long-term basis to determine their success in meeting performance goals and creating productive, functional wetlands. There is a need to inventory and evaluate wetland restoration, enhancement, and creation projects in terms of their original design criteria, success in meeting performance goals, and feasibility for large-scale application. Plans for large-scale restoration of wetlands will assist the State of Texas in achieving the goal of no overall net loss of State-owned wetlands. In addition, the Galveston Bay Plan considers wetlands loss and degradation the number-one management problem in the Galveston–Trinity Bay system, and, therefore,

Marsh-creation site at the Bayland Park Marina in Baytown, Texas. The Bureau and the Texas General Land Office are conducting studies of seven marsh restoration–creation sites around the Galveston Bay system to evaluate their potential for large-scale application. Photo by William A. White.

gives a high priority to increasing the quality and quantity of wetlands, setting as a goal expansion of the area of vegetated wetlands in the Galveston Bay area by 15,000 acres within 10 years. Among the goals of this study are to evaluate and synthesize primary physical criteria for large-scale marsh creation.

Detailed field data are being collected at seven marsh restoration–creation sites located around the Galveston Bay system. The study sites include former upland areas that have been scraped and graded and subtidal areas that have been filled with dredged material to achieve intertidal elevations. Vegetation planted at the sites is primarily cordgrasses, *Spartina alterniflora*, and *Spartina patens*. Among the objectives of the study are to develop a matrix of site characteristics and design criteria that help define the best techniques available for large-scale marsh creation and restoration.

Assistance to State Agencies Regarding Coastal Issues

Robert A. Morton, principal investigator

In 1997, the Bureau conducted several short-term projects that were designed to assist natural resource agencies in Texas with their missions. Researchers accomplished this task by reviewing pertinent technical reports and historical documents, such as maps and aerial photographs; conducting field investigations at specific sites; conducting historical analyses of coastal geomorphology and site stability; meeting with agency representatives, natural resource specialists, and other experts to discuss issues; and preparing brief reports that describe physical characteristics and coastal processes at the site.

We assisted the Texas General Land Office Coastal Division by providing technical information and participating in the preparation of a training video. The video is designed to train personnel in coastal counties who are responsible for removing trash and debris from the recreational beaches along the Texas Gulf shore. The video describes several recommended beach-cleaning techniques and discusses how some beach maintenance activities could be harmful to the dunes and vegetation. We also assisted the Texas Attorney General's Office by explaining the geological setting and historical changes in shoreline position for several segments of the Gulf shore. Topics including land surface subsidence and storm erosion of wetlands were discussed with the Texas General Land Office, Texas Parks and Wildlife Department, National Marine Fisheries, the U.S. Fish and Wildlife Service, and The Nature Conservancy, who are all considering wetlands restoration or protection in Galveston Bay and Corpus Christi Bay. Rates of shoreline retreat and causes of beach erosion and potential shoreline stabilization at the McFaddin Wildlife Refuge (Highway 87) were discussed with the U.S. Fish and Wildlife Service.

Analysis of Water Levels and Beach Features

Robert A. Morton, principal investigator; assisted by Allison J. Goldberg

This project, funded by the Conrad Blucher Institute of Science and Surveying at Texas A&M University—Corpus Christi simultaneously examined beach profiles, actual water levels on the beach, and the elevations of water levels recorded at nearby tide gauges. Beach profiles and water-level measurements were made by surveyors from the Texas General Land Office at North Padre Island within the National Seashore 18 times within a year. This detailed data base was supplemented by surveyors' measurements at East Beach, Galveston Island, and Follets Island.

The study demonstrated that tide gauges systematically underestimate the position of high water on sandy beaches because the gauges are designed to eliminate high-frequency fluctuations in water level and do not account for the horizontal runup of breaking waves. The discrepancies between measured and actual water levels is greatest on low-gradient sandy beaches along a microtidal-wave-dominated coast such as the Gulf of Mexico. In these microtidal settings, the mean higher high water (MHHW) line consistently plots in the middle of the wet beach and far seaward of the berm crest. The wet-beach–dry-beach boundary commonly mapped on aerial photographs as the shoreline is an ephemeral nonmorphological feature that undergoes large-scale, high-frequency fluctuations. It should, consequently, be used neither to delineate the shoreline nor to predict future shoreline stability. Despite widespread use of the wet-beach–dry-beach boundary in the past, accuracy of data sets and future predictions can be improved by monitoring morphological features that are linked to the long-term movement of the beach but are relatively insensitive to high-frequency fluctuations in water level. In the examples from Texas, the strip of beach above the level of MHHW that is regularly inundated by marine water (State-owned submerged land, by definition) but that is surveyed as private property ranges from 1 to 4 hectares per kilometer of coast, depending

Students measuring the beach and dunes on Galveston Island. The students are from the Marine Science Honors Class of Ball High School, Galveston, Texas. The Bureau is working with students and teachers to collect data and make observations using methods consistent with ongoing coastal research at the Bureau. Photo by James C. Gibeaut.

on whether the strip is measured from the MHHW line to the berm crest or to the vegetation line. The seasonal cyclicity of beach changes could result in a systematic bias in the position of the legal boundary depending on whether surveys were conducted during the winter or summer. Surveys conducted in the late summer would tend to minimize the ambulatory nature of the MHHW boundary, but they would favor the upland property owner in terms of land area.

High School Beach-Monitoring Program: A Pilot Project in Education, Public Awareness, and Coastal Management

James C. Gibeaut, principal investigator; Roberto Gutierrez and Brenda Kirkland-George (UT–Department of Geological Sciences)

Scientists from the Bureau and the Department of Geological Sciences, The University of Texas, are working with students from Ball High School in Galveston, Texas, on this coastal research project. Researchers are training teachers and students in the Marine Science class to monitor dune and beach changes on Galveston Island. The students are measuring beach and dune topographic profiles and making observations on weather conditions, sea state, rate of longshore drift, and dune vegetation. They will analyze these data and compare them with earlier data acquired by the Bureau. Through their collaboration with scientists working on an actual research project, the students are obtaining enhanced science instruction and insight into the scientific method. This project will increase public awareness of natural coastal processes and coastal management issues. The information will also enhance the efforts of State and Local officials and the public to manage the protective dunes and beaches on Galveston Island. We are currently developing a curriculum, classroom materials, equipment, and field techniques. We have completed field and classroom training of the teachers and have conducted our first field trip with the Marine Science class. The class will make several more trips to the beach during the year. This project is serving as a model for a Texas-wide high school beach-monitoring program.

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

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

This joint project of The University of Texas, the Texas Department of Public Safety, and Texas A&M University is developing a coastal hazards atlas of the Galveston Bay 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 of Coastal Hazards* that was published by the Bureau in 1974. We are completely revising and updating the previous 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. A key part of this effort is the production of the atlas in a Geographic Information System that will allow integration of the coastal atlas with other digital maps of the

coastal zone. It will also encourage Local government to input site- and area-specific data as they become available.

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

James C. Gibeaut, principal investigator; Roberto Gutierrez

During the passage of Tropical Depression Josephine in October 1996, the dunes and beaches along Galveston County, Texas, significantly eroded and put many structures at risk of failure. This project will provide information critical to the monitoring and management of the coastal dune and beach system along the Galveston County shoreline. We are resurveying 32 dune and beach topographic transects established in 1994 as part of the Texas Natural Resources Inventory. In addition, the National Aeronautics and Space Administration is providing funds for a state-of-the-art laser altimeter survey that is expected to yield topographic data with a vertical resolution of 4 inches or better and essentially continuous horizontal coverage. These measurements will provide quantitative data of the shoreline, and, when compared with earlier and subsequent measurements, will tell us how the dunes and beaches have responded to coastal processes. We expect to find relationships among processes, physical setting, and dune and beach morphology that will aid State and Local planners and residents in their decision making and design of erosion-mitigation projects. To this end, the project will present data and interpretations in a form accessible to Local government and interested citizens.

Mapping Investigations

STATEMAP Project: Digital Geologic Map of New Braunfels, Texas

Jay A. Raney, principal investigator; Edward W. Collins, Sarah B. Dale, and John R. Andrews

The purpose of this completed project was to compile a digital geologic map of the New Braunfels, Texas, 1:00,000-scale quadrangle from new 1:24,000-scale geologic maps. This project, part of the U.S. Geological Survey's (USGS) STATEMAP program, is funded jointly by the USGS and the Bureau. The geology of the area was recently mapped for the STATEMAP program as 32 open-file geologic maps at 1:24,000 scale. The New Braunfels 1:100,000-scale quadrangle includes a large part of the Edwards aquifer and recharge zone, a complex part of the Balcones Fault Zone, and a large part of the rapidly developing San Antonio-to-Austin growth corridor. Many environmental issues related to economic and resource development, including management of the Edwards aquifer and recharge zone, require a high-quality baseline of geologic information as the foundation for intelligent decision making. The availability of a digital geologic map of the area will enhance the utility of the geologic data presented by the 32 open-file maps and the cost effectiveness of their application to the many environmental, developmental, and policy issues that are critical to San Antonio and adjacent communities.

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

Jay A. Raney and Edward W. Collins, principal investigators

This project consists of two subprojects that will fulfill project goals 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 that are undergoing rapid urban growth. The purpose of this ongoing 3-year mapping 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 is needed for studies of recharge and hydraulic flow in the Edwards limestone aquifer, which is crucial to the economic well-being of the region and is also critical 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. Expansive clays are a major problem

associated with some of the Cretaceous units, and other units host high-quality limestone that is actively being quarried at many localities. Geologic maps produced for this project are intended ultimately to be compiled in a digital format and used at a base scale of 1:100,000.

Mapping for this south-central Texas subproject is being done in three geologically critical areas that are undergoing rapid urban growth and that contain a portion of the Edwards karst aquifer and recharge zone. 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 rapidly expanding San Antonio urban area. Six 1:24,000-scale quadrangles have been completed for this 18-quadrangle study area. They are the Bandera, 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 along Interstate 35 of Round Rock, Georgetown, and Salado. Geologic maps of six quadrangles, Cobbs Cavern, Georgetown, Hutto, Jarrell, Round Rock, and Weir, are completed. The Del Rio corridor is within the south part of the Edwards Plateau aquifer region and west 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. Geologic maps of three quadrangles, Del Rio NW, Del Rio SW, and Rough Canyon, are completed for this nine-quadrangle study area.

The second subproject will produce geologic maps of two quadrangles, Lake Theo and Fortress Cliff, that include two State parks, Caprock Canyons and Palo Duro Canyon, in the Texas Panhandle. Within the map areas are some of the best public exposures of the geologic framework of the High Plains (Ogallala) aquifer, which is the sole-source aquifer for most of the region and is of vital importance to the economy of the State. The State parks afford an opportunity for the public to have access to undeveloped lands and an opportunity for the Bureau to provide educational materials to improve public awareness of geologic processes, geologic hazards, and the geologic setting.

Texas Parks and Wildlife Support of Mapping Projects

Jay A. Raney, principal investigator; John R. Andrews, Edward W. Collins, Sara B. Dale, L. Edwin Garner, and Thomas A. Tremblay

The Bureau continues to work closely with the staff of the Texas Parks and Wildlife Department (TPWD) on a variety of projects. Funding provided by TPWD has allowed us to digitize our recently completed geologic maps of quadrangles that include Franklin Mountains State Park (El Paso County) and Hueco Tanks State Park (Hudspeth County) in Trans-Pecos Texas. These maps will assist TPWD in the management of the parks. We have continued to work on the geologic map and reports on Big Bend Ranch State Park, and digital files of these maps have been transferred to TPWD. Bureau staff also prepared a brief report on the geology of Galveston Island at the request of TPWD. On the basis of suggestions from technical staff of TPWD, who serve on the advisory board for the Texas STATEMAP project, we have included preparation of geologic maps of Palo Duro Canyon State Park and Caprock Canyons State Park in this year's activities. TPWD staff also provided reviews and comments on *Down to Earth at McKinney Falls State Park*, the Bureau's first publication to be produced as part of a new public information series.

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 studies are conducted to determine the geomorphic character of locales, the influences on past human activities, and the effects of natural processes on deposits of cultural materials. Investigations during 1997 included thin-section examination of archeological materials and providing maps for background geological information.

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 1997, the following 89 contracts, each of which had reporting requirements, were active at the Bureau:

Federal

"Advanced Oil Recovery Technologies for Improved Recovery from Slope Basin Clastic Reservoirs, Nash Draw Brushy Canyon Pool, Eddy County, New Mexico": supported by Strata Production Company through 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.

"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.

"Digital Geologic Map of New Braunfels, Texas Quadrangle 1:100,000 Scale": supported by the U.S. Geological Survey, U.S. Department of the Interior.

"Geologic Characterization of Bedded Salt in the Midland Basin": supported by the U.S. Department of Energy.

"Geologic Mapping of 7.5-Minute Quadrangles to Support Responsible Development in Karst Aquifer Areas Undergoing Rapid Urban Growth, South Central Texas": supported by the U.S. Geological Survey, U.S Department of the Interior.

"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.

"Geoscience/Engineering Characterization of the Interwell Environment in Carbonate Reservoirs Based on Outcrop Analogs, Permian Basin, West Texas, and New Mexico": supported by the U.S. Department of Energy.

"Integrated Strategies for Carbonate Reserve Growth: An Example from the Ellenburger Group, Permian Basin, West Texas": supported by the U.S. Department of Energy and Gas Research Institute (2 contracts).

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

"Monitoring Techniques Related to Subsurface Gas Transport": supported by the Nuclear Regulatory Commission through the University of Arizona.

"Offshore Northern Gulf of Mexico Oil and Gas Resources Atlas Series": supported by the Minerals Management Service, U.S. Department of the Interior; the U.S. Department of Energy; and Gas Research Institute (2 contracts).

"Physical and Environmental Assessment of Sand Resources—Texas Continental Shelf": supported by the Minerals Management Service, U.S. Department of the Interior.

"Prehistoric Site Testing, Houston–Galveston Navigation Channels": supported by the U.S. Army Corps of Engineers.

"Preparation of a Regional Salt Thickness Map in Support of Salt Cavern Site Selection / Development in a Critical Salt Cavern Area": supported by the U.S. Department of Energy.

"Responses of Fluvial, Estuarine, and Barrier-Island Systems to Climate and Sea-Level Change—Central Texas": supported by the National Science Foundation.

"A Robust Economic Technique for Crosswell Seismic Profiling": supported by the U.S. Department of Energy.

"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.

"Secondary Natural Gas Recovery—Infield Reserve Growth Joint Venture: Applications in Midcontinent Sandstones": supported by the U.S. Department of Energy and Gas Research Institute (2 contracts).

"Sediment Characteristics, History, and Recent Transport, Laguna Madre, Texas": supported by the U.S. Army Corps of Engineers.

"Studies to be Conducted by the Continental Margins Committee (Years 9 and 10)": supported by the Minerals Management Service, U.S. Department of the Interior (two contracts).

"A Technology Transfer Program, Texas Region of the Petroleum Technology Transfer Council": supported by BDM–Oklahoma, Inc., through the Petroleum Technology Transfer Council.

"Using Microstructure Observations to Quantify Fracture Properties and Improve Reservoir Simulations": supported by BDM–Oklahoma, Inc.

State and Local

"Analysis of Current Status and Historical Trends of Selected Estuarine and Coastal Habitats in the Corpus Christi National Estuary Program Study Area": supported by the Texas Natural Resource Conservation Commission.

"Analysis of Short-Term Beach Stability, North Padre Island, Texas": supported by Texas A&M University—Corpus Christi.

"Archeological Projects—Assistance to the Texas Department of Transportation": supported by the Texas Department of Transportation.

"Architecture of Fluvial-Deltaic Reservoirs: Extension of Outcrop Studies into 3-D Using Ground-Penetrating Radar": supported by the Texas Higher Education Coordinating Board.

"Bacterially Mediated Carbonate Precipitation: The Link between Organic and Inorganic Crystallization": supported by the Texas Higher Education Coordinating Board.

"Brazos River Erosion Assessment": supported by the Texas Parks and Wildlife Department.

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

"Computer Modeling of Hydrocarbon Traps Formed around Deformed Salt Sheets in the Gulf of Mexico": supported by the Texas Higher Education Coordinating Board.

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

"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.

"Evaluation of Marsh Creation and Restoration Projects and Their Potential for Large-Scale Application, Galveston–Trinity Bay System": supported by the Texas General Land Office.

"Geologic and Hydrologic Studies of the Eagle Flat Area, Texas": supported by the Texas Low-Level Radioactive Waste Disposal Authority (two contracts).

"High-Accuracy Bathymetric Surveying and Real-Time GPS Positioning System": supported by the Texas Higher Education Coordinating Board.

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

"Identification of Geologic Analogs for Engineered Barriers": supported by the Texas Low-Level Radioactive Waste Disposal Authority.

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

"Investigation of Shallow Class V Injection Wells at TxDOT Maintenance Sections": supported by the Texas Department of Transportation.

"Lubbock County Pilot Study for Development of a Hydrogeologic Geographic Information System

(HGIS) to Support TNRCC Implementation of Risk-Reduction Rules": supported by the Texas Natural Resource Conservation Commission.

"Mapping of Erosion Hazard Areas Along the Gulf Shorelines of Galveston and Brazoria Counties": supported by the Texas General Land Office.

"Planning and Coordination Services for Water Resources Information for Ground-Water Management System along the Texas–Mexico Border": supported by the Texas General Land Office.

"Predicting the Extent, Mass, and Duration of Hydrocarbon Plumes from Leaking Petroleum Storage Tanks in Texas": supported by the Texas Natural Resource Conservation Commission.

"Rejuvenating a Dying Oil Play: Benefits to the State, the Permanent School Fund, and the People and Economy of Far West Texas": supported by the Texas Office of State–Federal Relations.

"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.

"Scientific and Economic Analysis of Various Natural Resource Issues Related to Designated Real Property Assets of the Permanent School Fund": supported by the Texas General Land Office.

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

"Targeting Alaskan Coalbed Methane Exploration Fairways and Sweet Spots Based on a Basin-Scale Producibility Model": supported by the Alaska Department of Natural Resources, State of Alaska.

"Technical Assistance to the General Land Office Related to Beach Maintenance Practices": supported by the Texas General Land Office.

"Technical Support to the Natural Resource Damage Assessment Trustee in the Evaluation of Shamrock Island Erosion and Wetland Loss": supported by the Texas General Land Office.

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

"Texas Parks and Wildlife Support": supported by the Texas Parks and Wildlife Department.

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

Private

"Applied Geodynamics Laboratory": supported by Agip, S.p.A.; Amoco Production Company; Anadarko Petroleum Corporation; ARCO Exploration and Production Technology/Vastar Resources, Inc.; BHP Petroleum (Americas) Inc.; BP Exploration Inc.; Chevron Petroleum Technology Company; Conoco/Dupont Inc.; Exxon Production Research Company and Exxon Exploration Company; Louisiana Land and Exploration Company; Marathon Oil Company; PanCanadian Petroleum Limited; Petroleo Brasileiro, S.A.; Phillips Petroleum Company; Saga Petroleum ASA; Shell Oil Company; Statoil; Texaco, Inc.; and TOTAL Minatome Corporation.

"Characterization of Fractured Cretaceous Reservoirs for Development and Production Optimization in the Tampico Area, Mexico": supported by PEMEX Exploration & Production.

"Characterization of Heterogeneity Style and Permeability Structure in a Sequence Stratigraphic Framework in Fluvio-Deltaic Reservoirs": supported by BP International Limited; Chevron Petroleum Technology Company; Elf Aquitaine Production; Exxon Production Research Company; Intevep, S.A.; Japan National Oil Corporation; Maxus Energy Corporation; Oryx Energy Company; Saga Petroleum ASA; and Statoil.

"Characterization of San Andres and Grayburg Reservoirs": supported by Altura Energy Limited, Amerada Hess Corporation, Aramco Services Company, ARCO Exploration and Production Technology, ARCO Permian, Elf Aquitaine Production, Exxon Production Research Company, Japan National Oil Corporation, Marathon Oil Company, Mobil New Business Development, Occidental Oil and Gas Corporation, Pennzoil Exploration and Production Company, Petroleum Development Oman LLC, Phillips Petroleum Company, Texaco Inc., and TOTAL.

"Characterize Miocene Reservoirs That Are Found in the Mioceno-Norte Area of Maracaibo Lake": supported by Lagoven, S.A.

"Contracting of Services to Transfer Seismic Data from Tapes to Compact Disks": supported by the Costa Rica Ministry of Environment and Energy (MINAE).

"Detailed Characterization Study for the Eocene Reservoirs of the VLA-6/9/21 Area, Block I, Lake Maracaibo Field": supported by Maraven, S.A.

"Develop Digital Map and Database of Spraberry Depositional Trends": supported by Parker & Parsley Development L.P.

"Development of Seismic-Imaging Applications for Optimally Characterizing Depositionally Heterogeneous Reservoirs": supported by Amoco Production Company; Aramco Services Company; Maxus Energy Corporation; Mercury Exploration Company; Phillips Petroleum Company; Vastar Resources, Inc.; and VISOS Energy Corporation.

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

"Gulf of Mexico Subsalt Structure Study": supported by Agip Petroleum S.p.A.

"Integrated Reservoir Characterization and Volumetric Analysis of the Arecuna Area of Faja Field, Venezuela": supported by Corpoven, S.A.

"Integrated Studies in the Eoceno Norte and South Lake": supported by Lagoven, S.A.

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

"New Methods of Natural Fracture Characterization": supported by Chevron U.S.A. Production Company, Conoco Inc., Exxon Production Research Company, Maxus Energy Corporation, Mobil Exploration & Producing Technical Center, and Union Pacific Resources Company.

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

"Planning and Preparation of a Reconnaissance Trip to the Ferron Sandstone and the Sego Formation in Utah": supported by Statoil.

"Precambrian Tectonics": supported by BHP Minerals.

"A Project to Establish a Relationship between Rock-Fabrics, Petrophysical Properties, and Wireline Logs Specific to the Arab in the Ghawar Field, Saudi Arabia": supported by Aramco Services Company.

"Remote Sensing Analysis of Land Cover/Land Use of the Southern Belize District": supported by the Government of Belize, Ministry of Natural Resources.

"Reservoir Characterization of the Potrerillos Formation and Enhanced Petroleum Recovery Project in the Barrancas Norte Deposit": supported by YPF, S.A.

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

"Targeting High-Potential Exploration Objectives in the South Lake": supported by Lagoven, S.A.

"Technical Assistance to Parker & Parsley": supported by Parker & Parsley Development Corporation.

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

"3-D Description and Reservoir Modeling of Architectural Elements in a Deep-Water Sandstone High-Frequency Cycle": supported by Statoil.

Publications

In its role as a public geological research unit, the Bureau of Economic Geology disseminates the results of research projects and programs primarily through its own publication series. During its 88-year history, the Bureau has published nearly 2,300 reports, bulletins, circulars, maps, and other publications covering major aspects of the geology and natural resources of Texas. Bureau publications also report research results of international projects and U.S. projects conducted outside Texas. In addition to publishing traditional printed reports and maps, the Bureau continues its efforts to serve the geological community via the Internet (http://www.utexas.edu/research/beg/). Summaries of Bureau publications and information about the Bureau's programs may be viewed on our home page.

To date, more than 1.7 million publications have been distributed worldwide, mostly through direct sales but also through charitable donation. In 1997, more than 24,000 titles were distributed. The Bureau issued the following publications in 1997:

Reports of Investigations

RI 241. Oil and Gas on Texas State Lands: An Assessment of the Resource and Characterization of Type Reservoirs

by R. P. Major (editor). G. B. Asquith, R. J. Barnaby, K. T. Barrow, D. G. Bebout, G. L. Causey, J. C. Fiduk, W. M. Fitchen, M. H. Gardner, C. M. Garrett, Jr., D. S. Hamilton, M. H. Holtz, P. R. Knox, R. P. Major, D. R. Prezbindowski, J. U. Ricoy, Q. Ye, J. S. Yeh, and H. Zeng (contributing authors).
166 p., 14 chapters, 114 figs., 9 tables, $11.50

This volume comprises a series of 14 technical papers that review the results of the State Lands Energy Resource Optimization project (Project SLERO), which was a 4-year study of hydrocarbon resources on Texas State Lands. This interdisciplinary project aimed at a thorough explanation of the geological controls on production in State Lands reservoirs. The specific fields chosen for detailed study were selected within the play-analysis framework, and chosen fields typify plays that encompass large portions of the remaining State Lands resource. Geologic, engineering, and geophysical data on reservoirs span the range of reservoir types in Texas, from relatively young fields in the deep Tertiary sandstones of the Texas Gulf Coast to mature oil reservoirs in the limestones and dolomites of the Permian Basin. Eleven State Lands reservoirs and two subregional study areas were the subject of reservoir-characterization research and formed the basis for identifying bypassed and uncontacted hydrocarbon resources.

RI 242. Playas and Recharge of the Ogallala Aquifer on the Southern High Plains of Texas—An Examination Using Numerical Techniques

by W. F. Mullican III, N. D. Johns, and A. E. Fryar.
72 p., 29 figs., 9 tables, $5.50

Much recent hydrologic, geologic, and chemical evidence suggests that the numerous playa lakes on the Southern High Plains of Texas and New Mexico are the focal points of recharge to the Ogallala aquifer, the main source of ground water in this important agricultural region. In this study, the authors evaluated the hydrologic plausibility of this playa-focused recharge theory through construction of a finite-difference ground-water flow model that simulates a part of the Ogallala aquifer underlying 11 Texas counties on the Southern High Plains. A smaller part of the Ogallala aquifer and five playas at the U.S. Department of Energy's Pantex Plant, near Amarillo and near the study area, were also simulated by means of a particle-tracking procedure in

order to evaluate potential contaminant movement within the aquifer.

The results of the steady-state simulations establish that the playa-focused recharge theory is hydrologically entirely plausible. The results of the particle-tracking procedure at the Pantex Plant indicate that a particle entering the Ogallala aquifer would reach wells to the north and northeast of the plant at a traveltime of several tens to hundreds of years.

RI 243. Spatial Variability in Unsaturated Flow beneath Playa and Adjacent Interplaya Settings and Implications for Contaminant Transport, Southern High Plains, Texas

by Bridget R. Scanlon, Richard S. Goldsmith, and William F. Mullican III.
68 p., 27 figs., 7 tables, 5 appendices, $5.50

The status of water movement beneath playas in the Southern High Plains has been the subject of considerable debate. Conceptual models regarding the role of the playas as recharge or discharge zones have varied over the past few decades. This study examines unsaturated flow and transport beneath playas and adjacent interplaya areas. A total of 39 boreholes from 7 playa and adjacent interplaya settings on the Southern High Plains of Texas were sampled for hydraulic and hydrochemical parameters.

Small-scale variability in solute transport associated with roots and desiccation cracks was examined by applying tracers such as bromide and organic dyes. Results show that recharge is focused beneath playas, as evidenced by high water contents, high water potentials, low chloride and high tritium concentrations in pore water, and low carbonate contents in sediment. Water fluxes estimated from chloride and tritium data ranged from 60 to 120 mm yr^{-1}. In addition to focused recharge beneath playas, applied tracer experiments showed preferential flow of bromide and dye along roots and desiccation cracks through structured clays in playas. Frequent ponding in playas and the structured nature of the clay sediments predispose this system to preferential flow.

In contrast to playas, unsaturated water flux in natural interplaya settings under current climatic conditions is negligible, as indicated by low water contents, low minimum water potentials, upward water potential gradients, high peak chloride concentrations in pore water, and high carbonate contents in sediment. Upward water potential gradients suggest net upward water movement in the top 5 to 10 m of the sediment. The chloride profiles suggest very low water fluxes (0.1 mm yr^{-1}) during the past 2,000 to 5,000 yr. Spatial focusing of recharge beneath playas and preferential flow through macropores greatly increase the transport rate of contaminants through the unsaturated zone.

RI 244. The Application of a Coalbed Methane Producibility Model in Defining Coalbed Methane Exploration Fairways and Sweet Spots: Examples from the San Juan, Sand Wash, and Piceance Basins

by Roger Tyler, A. R. Scott, W. R. Kaiser, and R. G. McMurry.
59 p., 37 fig., 1 table, $7.50

This publication details a basin-scale coalbed methane producibility and exploration model that is based on a decade of Gas-Research-Institute–supported research at the Bureau. Using conclusions drawn from comprehensive Bureau geologic and hydrologic studies of the San Juan, Sand Wash (Greater Green River), and Piceance Basins and on reconnaissance studies of several other producing and prospective coal basins in the U.S., the authors discussed application of the producibility model in defining coalbed methane exploration fairways and sweet spots in U.S. coal basins. The model indicates that tectonic and structural setting, depositional systems and coal distribution, coal rank, gas content, permeability, and hydrodynamics are controls critical to coalbed methane producibility. Another key conclusion of this report is that knowledge of geologic and hydrologic characteristics alone will not lead to a realistic view of a basin's coalbed methane producibility. Rather, it is the interplay among geologic and hydrologic controls on production and their spatial relation that

governs producibility. This synergism is exemplified in discussions about the prolific San Juan Basin and the marginally producing Sand Wash and Piceance Basins.

The authors' producibility model also has direct application to worldwide coalbed methane exploration and development. Triggered by successes in the United States, exploration for coalbed methane has begun in coal-rich areas of the United Kingdom, eastern and western Europe, China, South Africa, Zimbabwe, and Australia.

RI 245. Quaternary Faults within Intermontane Basins of Northwest Trans-Pecos Texas and Chihuahua, Mexico

by Edward W. Collins and Jay A. Raney.
59 p., 31 figs., 2 tables, $7.50

This report details the occurrence, geometries, scarp morphology, and paleorupture histories of Quaternary faults within Cenozoic intermontane basins of northwest Trans-Pecos Texas and northern Chihuahua, Mexico. This area encompasses a part of the east margin of the Southern Basin and Range–Rio Grande rift tectonic province. Pre-Cenozoic tectonism and its influence on Cenozoic structural history is also reviewed. Basins studied in this report include the Hueco, Red Light, Northwest and Southeast Eagle Flat, Green River, Salt, Wild Horse, Lobo Valley, and Ryan Flat Basins. Aerial photographs and outcrops were analyzed in conjunction with borehole and seismic data to evaluate the region's structural and stratigraphic framework and the attributes of the Quaternary faults.

Knowledge of the structural setting and Quaternary tectonism of the studied basins and associated faults provides clues about these basins' structural development, as well as the structural history of the southeast margin of this extensional tectonic province. These studies are also useful in seismic risk studies related to designing critical facilities such as the proposed Eagle Flat low-level radioactive waste repository.

RI 246. Conceptual Breakthroughs in Salt Tectonics: A Historical Review, 1856–1993

by M. P. A. Jackson.
51 p., 41 figs., $7.50

This report reviews the chief conceptual breakthroughs in the understanding of salt tectonics from the period 1856 through 1993. The text is an expanded version of the opening chapter in *Salt Tectonics: A Global Perspective (AAPG Memoir 65)*, which was awarded the Robert H. Dott, Sr., Memorial Award for Best Special Publication published by AAPG in 1996 (see "Highlights" section in this annual report for award details). The book was based on the Hedberg International Research Conference on Salt Tectonics held in September 1993 in Bath, England. At that conference, an oral review of the rapidly evolving lexicon and existing conceptual framework of salt tectonics was conducted. Report of Investigations No. 246 covers the conceptual evolution of salt tectonics until early 1993, before abstracts for the Hedberg conference were first submitted.

The report divides the history of salt tectonics into three parts: the Pioneering Era (1856 to 1933), the Fluid Era (1933 to ~1989), and the Brittle Era (~1989 to present). The approach of the report is to highlight the few source papers that seem to have wielded major influence on salt tectonics in each era by elucidating or catalyzing major conceptual breakthroughs. Many of these achievements were impelled or permitted by technological advances, such as seismic processing and modeling techniques.

Geological Circulars

GC 97-1. Extent, Mass, and Duration of Hydrocarbon Plumes from Leaking Petroleum Storage Tank Sites in Texas

by Robert E. Mace, R. Stephen Fisher, David M. Welch, and Sandra P. Parra.
52 p., 24 figs., 7 tables, 4 appendices, $4.50

More than 19,000 examples of leaking petroleum storage tanks (LPST) were documented in Texas as of August 1996. The sheer number of regulated facilities and their wide geographic distribution throughout the state have made gaining a regional perspective on hydrocarbon plumes difficult. This study is the first attempt to quantify the general site, soil, hydrogeologic, and plume characteristics throughout Texas and in different regions of the state. This circular summarizes information for 605 LPST sites compiled from files at the Texas Natural Resource Conservation Commission, including chemical and water-level data on more than 4,000 monitoring wells. This data base is used to quantify the size, mass, and duration of dissolved FHC (benzene) plumes in Texas and to determine (in order to assist in exposure assessments) dimensions of benzene plumes, predictability of plume concentrations and lengths, rates at which plumes self-remediate, and classification of plume behavior. Using monitoring-well location, water level, and chemical data, the authors determined hydraulic gradients, ground-water flow directions, average plume benzene concentrations, and benzene plume dimensions over time for different hydrogeologic and climatic regions of Texas. Site-descriptive data are summarized by means of nonparametric statistics, histograms, and pie charts.

GC 97-2. Electrical Imaging Catalog: Microresistivity Images and Core Photos from Fractured, Karsted, and Brecciated Carbonate Rocks

by Ursula Hammes.
40 p., 32 figs., $5.50

Electrical images in boreholes are used widely in a variety of applications in reservoir evaluation. Modern borehole-imaging tools produce excellent electrical microconductivity images of the formation encountered in a well bore. These images provide valuable information on fault and fracture orientation, aperture height, porosity, rock type, borehole shape, and sedimentological structure. When images are calibrated with cores, their 3-D display benefits reservoir evaluation by extending core data to other wells and by improving the determination of core azimuth, the calibration of core depth, the description of sedimentary structures, and the calibration of images created under poor borehole conditions. Electrical images displayed and described in this circular are a comprehensive collection of carbonate features seen in electrical microresistivity images as compared with carbonate cores of the Lower Ordovician Ellenburger Group of West Texas. The images and cores show depositional and diagenetic features characteristic of the Ellenburger Group, which is a fractured, karsted, and brecciated carbonate reservoir that serves as an example of similar carbonate reservoirs.

GC 97-3. Gulf Shoreline Movement between Sabine Pass and the Brazos River, Texas: 1974 to 1996

by Robert A. Morton.
46 p., 10 figs., 4 tables, 3 appendices, $7.00

State and Federal agencies having coastal management responsibilities currently rely on average rates of shoreline movement and projected future shoreline positions for regulatory purposes. As a result of this dependency on scientific data, regional studies of shoreline movement are now regarded as important sources of information for formulating coastal management policies and long-range planning. Changes in shoreline position along the southeastern Texas Gulf coast between 1974 and 1996 were documented by conducting a kinematic real-time differential global positioning system field survey in 1996 and comparing that shoreline with other shorelines archived in a geographic information system. Results show that (1) beach morphology, shoreline

movement, and regional geological framework are closely interrelated, (2) Gulf beaches are generally retreating, and (3) the rates of retreat have accelerated locally.

GC 97-4. A Practical Use of Vertical Seismic Profiles—Stratigraphic Calibration of 3-D Seismic Data

by Bob A. Hardage.
11 p., 5 figs., $3.50

Vertical seismic profiling (VSP) is a measurement procedure in which a seismic sensor is lowered by wireline to a sequence of selected depths in a well, and at each of these downhole receiver stations, that sensor then records both the downgoing and the upgoing seismic wavefields produced by a surface-positioned source. In conventional horizontal seismic profiling, only upgoing seismic wavefields are recorded; the important information of the downgoing wavefields is unavailable to assist seismic data processors and interpreters, particularly those working with 3-D seismic data. The objective of this circular is to illustrate how VSP data can provide invaluable support to 3-D seismic interpretation. Specifically the objective is to show that VSP data commonly allow a more reliable depth-to-time calibration than do velocity check shots or synthetic seismograms. The important thin-bed calibration that VSP data provide to 3-D interpreters must be balanced by the fact that acquisition of VSP data imposes an additional cost on the seismic evaluation of a prospect. In this circular, such cost considerations are also discussed in relation to the potential cost-effective benefits that VSP data provide.

GC 97-5. Principles of Onshore 3-D Seismic Design

by Bob A. Hardage.
23 p., 13 figs., $4.00

Three-dimensional seismic imaging has become one of the most important technologies that oil and gas operators use to evaluate prospects and manage producing properties. Although much information about 3-D seismic design is available, there is still a need for a concise, well-illustrated description of the principles of onshore 3-D seismic design that can be used by people who are not skilled in the theories of geophysics. The purpose of this circular is to provide such a description. The target audience is nongeophysicists, primarily aggressive independent operators who wish to know more about 3-D seismic technology, geologists and petroleum engineers who have to make decisions about acquiring 3-D seismic data, and investors and financiers who are presented opportunities to participate in 3-D seismic programs.

GC 97-6. Basin Morphological Controls on Submarine-Fan Depositional Trends: Spraberry Sandstone, Permian Basin, Texas

by Noel Tyler, J. Crispin Gholston, and Edgar H. Guevara.
43 p., 30 figs., $4.75

The Lower Permian (Leonardian) Spraberry Formation is a major oil-producing unit of the Permian Basin, accounting for more than 700 million barrels of oil produced from heterogeneous submarine-fan reservoirs. This circular addresses the basinwide architecture of the Spraberry fan complex. Several thousand wells have penetrated the Spraberry, providing a rich data set from which the depositional framework and sediment-dispersal trends could be determined, from the feeder canyons of the platform margin to the distal fan sediments 150 mi basinward. The extensive exploration and development of the Spraberry and deeper reservoirs provide the opportunity to establish the sedimentary evolution of a fan cone fed only by relatively small rivers and windblown sediment in a tectonically inactive setting.

Because the Spraberry is not exposed, the study utilized a rich subsurface data base of more than 1,200 well logs developed in pursuit of the 10 billion barrels of oil discovered in the fan cone. Entrapment of this oil is almost entirely stratigraphic, most of the resource being captured in the midfan to distal fan

sediments in the distal Midland Basin more than 100 mi basinward of the Leonardian shelf edge. The analysis of controls on depositional trends in the Spraberry had an immediate goal of providing a framework for continued exploration of the unit. Taken in a broader context, however, the Spraberry provides a superb analog for fine-grained, mud-rich fan systems, which are a high-priority, global target for exploration and development.

Atlas

Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs: Volume 1. Miocene and Older Reservoirs

by Steven J. Seni, Tucker F. Hentz, William R. Kaiser, and E. G. Wermund, Jr. (editors).
199 p., 646 figs., 3 plates, 2 appendices, 1 CD-ROM, $295.00

Volume 2. Pliocene and Pleistocene Reservoirs

by Tucker F. Hentz, Steven J. Seni, and E. G. Wermund, Jr. (editors).
78 p., 203 figs., 3 plates, $195.00 (site license for volumes 1 and 2 available for $5,000.00)

The *Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs* is a two-volume series that documents principal geologic, engineering, and volumetric characteristics of natural gas and oil reservoirs of the offshore northern Gulf of Mexico basin. The atlas represents the first detailed, comprehensive synthesis of the play framework of all Pleistocene and older reservoirs in the U.S. Gulf of Mexico.

Volume 1 surveys 4,325 Miocene and older reservoirs in the Federal Outer Continental Shelf (OCS) and offshore waters of Alabama, Louisiana, and Texas. The reservoirs in 645 fields have been organized into 72 plays and subplays primarily on the basis of age, depositional environment, and structure. Volume 2 examines 5,622 Pliocene and Pleistocene reservoirs in the Federal OCS and Louisiana Offshore State waters. The reservoirs, occuring in 567 fields, have been grouped into 19 plays and subplays.

For the first time, geologic, engineering, and production data from all Mesozoic through Pleistocene reservoirs in State and Federal offshore waters have been compiled and presented in a unified format. Each folio-size atlas volume provides details of defining attributes, depositional facies, production history, and other characteristics of each play and its type State and Federal fields and reservoirs. Reservoir attributes and GIS data are conveniently tabulated on a CD-ROM that accompanies each volume of the atlas. The data files include (1) 31 geologic, engineering, and volumetric attributes of sandstone-body reservoirs, pools, fields, and plays and (2) GIS files of the boundaries of fields and plays, the shoreline, State–Federal areas, and area boundaries.

Although staff at the Bureau of Economic Geology coordinated the project, compilation of information in this atlas was a cooperative effort among the Geological Survey of Alabama; the Basin Research Institute, Louisiana State University; the Minerals Management Service, U.S. Department of the Interior; and the Bureau of Economic Geology. The Gas Research Institute, the U.S. Department of Energy, and the Minerals Management Service provided the funding for the project.

"Down to Earth" Series

Down to Earth at McKinney Falls State Park, Texas

by Jay A. Raney.
31 p., 23 figs., $6.00

Written in a popular style for a nontechnical audience, this publication provides an entertaining synopsis of the geologic features and historical background of McKinney Falls State Park, which is located just south of Austin, Texas. Much of the text takes the reader on a "McKinney Falls Walkabout" by describing many of the amazing sights that the park has to offer the visitor. Part guidebook and part geologic text, the publication introduces the reader to such features as the fossils, faults, volcanic history, scenic erosional structures, and ground-water aspects that can be viewed or imagined while visiting the park. Learn about Pilot Knob, the McKinney Gristmill, the Balcones Fault Zone, natural potholes, the Smith Rockshelter, "Old Baldy," and the waterfalls themselves. This publication is ideal for geology buffs and park enthusiasts of all ages.

Miscellaneous Map

MM 38. Structure Map of the San Antonio Segment of the Edwards Aquifer and Balcones Fault Zone, South-Central Texas: Structural Framework of a Major Limestone Aquifer: Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties

by Edward W. Collins and Susan D. Hovorka.
Oversize color map (scale 1:250,000) and booklet (14 p., 6 figs.), $5.50

Normal faults of the Balcones Fault Zone are the principal structural control on the important Edwards limestone aquifer and recharge zone, currently the sole source aquifer of San Antonio, Texas, and many other municipalities in Central Texas. The San Antonio segment of the aquifer, extending over an area of approximately 3,000 mi^2 in Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties, is the main water resource for residential, agricultural, and industrial use in Bexar, Medina, and Uvalde Counties.

The map of the aquifer depicts the subsurface structure of the base of the Del Rio Formation (approximate top of the confined part of the aquifer), the Edwards Group outcrop belt (aquifer recharge area and unconfined part of the aquifer), faults, large relay ramps, and the approximate interface between fresh and saline water. The map builds on many previous studies of the structure and stratigraphy of the Edwards aquifer. The authors used an updated subsurface data base and recent comprehensive surface geologic mapping conducted by the senior author, however, to illustrate the structure at a scale that provides more detail than that of any map previously available. The authors are thus able to make new interpretations on fault occurrence, throw, and geometry. The accompanying booklet summarizes key elements of the Edwards aquifer's structural framework and describes structural attributes that affect aquifer recharge, ground-water flow, areal extent, and depth.

Other

A Resource Development Manual for Secondary Natural Gas Recovery in Conventional-Permeability Sandstone Reservoirs

by Robert J. Finley, Bob A. Hardage, and James R. Ballard. 123 p., 23 figs., 2 tables, $35.00

This manual is designed to guide the natural gas producer in improving the recovery efficiency of natural gas from depositionally heterogeneous, conventional-permeability reservoirs in known fields. It is based on experience gained from the Bureau's Secondary Gas Recovery project, which evaluated incremental recovery opportunities in fluvial and deltaic reservoirs of the Texas Gulf Coast and valley-fill and deltaic reservoirs in the Fort Worth Basin of North-Central Texas. The approach of the manual is generic, however, and should be applicable to assessing heterogeneous gas reservoirs in many basinal settings, after accounting for facies differences, subsidence rates, source-material differences, and other factors that define sedimentary environments.

The manual focuses on helping the producer develop a detailed understanding of depositional, and to a lesser extent, diagenetic, controls on unrecovered gas. Procedures outlined emphasize integration of geology, reservoir engineering, geophysics, and formation evaluation–petrophysics. Discussion proceeds from reservoir screening to reservoir development by recompletions or infill drilling. This manual is not a comprehensive reference to the application of any one of these disciplines and therefore must be supplemented by the producer's expertise in a given area and by new information that the producer will want to acquire.

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Vining, M. R., 1997, Progress report: STARR reservoir characterization study of the Frio Formation, Umbrella Point field, Chambers County, Texas: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for State of Texas, 20 p. + appendices.

Young, M. H., Wierenga, P. J., Warrick, A. W., Hofmann, L. L., Musil, S. A., and **Scanlon, B. R.,** 1997, Field testing plan for unsaturated zone monitoring and field studies: University of Arizona, Department of Soil, Water and Environmental Science, and The University of Texas at Austin, Bureau of Economic Geology, contract report prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-6462, 49 p.

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 the largest public collection 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 ft², houses nearly 50 linear miles of shelving. Roughly 10 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 is large enough to display as much as 1,800 ft of conventional core. Approximately 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) 1997, the CRC received more than 250 visitors, who made transactions involving CRC inventory that included materials from more than 430 wells and required the transfer of more than 8,255 boxes of core to and from viewing and shipping areas.

New acquisitions in 1997 totaled 113 new core samples, in excess of 1,066 boxes and nonconventional (cuttings, sidewall, unwashed cuttings, and outcrop) core samples from 70 wells, totaling 286 boxes, as well as 45,000 thin sections. Donations were received from British Borneo; Mike Blum; and the Bureau of Economic Geology from the following projects: Texas Department of Transportation Archaeology; NSF Sea Level Change; Railroad Commission—Vinson; Railroad Commission—Wharton; CC Company; Chevron Resources; Enserch Exploration, Inc.; Parker & Parsley Development L.P.; Petro Hunt Corporation; Shell E&P Technology Co.; United Oil and Minerals, Inc.; the University of Oklahoma; The University of Texas—James Rich Kyle; and Clayton Williams Energy, Incorporated. The MCRC is also administered by the Bureau. The facility, a 32,700-ft² building on 3.7 acres in Midland, Texas, has a core examination room, a processing room for slabbing core, and office space.

The MCRC's collection contains about 259,000 boxes of samples and core, most of which come from wells drilled in Texas, although it also contains material from several other states. The Curator is Robert (Rick) Richardson, who can be reached at (915) 686-9902.

The MCRC is open between 8 a.m. and 5 p.m. (CST), Monday through Friday. Materials are organized according to protocols followed by the CRC in Austin. The MCRC collection's data are incorporated into the Bureau's existing data base, which will allow patrons of the new facility to access these data, as well as those of the CRC in Austin.

Public Information

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

Extensive data and information are available at 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. During 1997, approximately 1,500 such requests were handled by L. Edwin Garner, the Public Information Geologist. In addition to direct inquiries, Bureau staff have directly contributed to educational programs by making presentations to public school classes in the Austin area.

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 L. Edwin Garner, 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 houses 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 public. Topographic and geologic maps, aerial photographs, and Landsat images are also available. Subsurface data files include well logs for more than 150,000 wells in Texas and 8,000 wells in adjacent states; microfiche copies of well logs for more than 40,000 wells in West Texas, New Mexico, and Oklahoma; scout tickets and well records for more than 200,000 Texas wells and 30,000 New Mexico wells; drillers' logs for about 400,000 Texas wells; and completion cards for more than 300,000 Texas wells.

The Reading Room staff cataloged, indexed, shelved, and entered into a computer data base more than 1,800 items. More than 1,200 items were received from other states and countries through the Bureau's publication-exchange program. Most of the exchange volumes were transferred to the Department of Geological Sciences library, the Elizabeth C. and Joseph C. Walter, Jr., Geology Library.

Geophysical Log Facility

The Geophysical Log Facility (GLF), managed by L. Edwin Garner, 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 with at least one copy of a well log for each new, deepened, or plugged well. A subsequent agreement with the Railroad Commission designated the Bureau as the entity responsible for providing public access to these logs. The Railroad Commission supplies paper or microfiche copies of the well logs and three different cumulative indexes to the logs. They are then filed at the GLF by district number and API number. Users of the facility include commercial companies, independent researchers, and Bureau scientists. Patrons may examine well logs using the GLF's microfiche readers. Requests for log copies can be made in person or by mail, telephone, fax, or E-mail.

By the end of 1997, the facility had accumulated approximately 180,000 well logs of various types from the Railroad Commission of Texas, at a rate of 800 logs per month. All logs are entered into the GLF's computer data base.

Research Staff Activities

Lectures and Public Addresses

Robert E. Barba, Jr.

"Increasing recoverable reserves in multiple zone environments": presented to the Society of Petroleum Engineers, Dallas, Texas.

Roger J. Barnaby

"Facies architecture of ooid grainstone-dominated cycles in a sequence stratigraphic framework: Grayburg Formation, New Mexico": presented at the U.S. Department of Energy Annual Review Meeting, Houston, Texas.

"Sequence stratigraphic framework, high-frequency cyclicity and three-dimensional heterogeneity: Grayburg Formation, Brokeoff Mountains, New Mexico": presented to the West Texas Geological Society, Midland, Texas.

Mark D. Barton

"Application of advanced reservoir characterization, simulation, and production optimization strategies to maximize recovery in slope and basin clastic reservoirs, West Texas (Delaware Basin)": presented at the U.S. Department of Energy Project Review Meeting, Houston, Texas.

"Characterization and quantification of geologic and petrophysical heterogeneity in fluvial-deltaic reservoirs": presented at the Gas Research Institute, Basic Research and Project Review Meeting, Chicago, Illinois.

"Midland core repository: year 2 plan": presented to the Petroleum Technology Transfer Council (Texas region), Houston, Texas.

Edward W. Collins

"Status of geologic mapping of critical areas in Texas": presented at the Soil Survey and Land Resource Workshop, Texas A&M University, College Station, Texas.

"Introduction to geology": presented to Scout Pack 98, Webolos group, Austin, Texas.

Alan R. Dutton

"Application of soil-gas surveys to site assessment—case study at Chiltipin Creek, Texas": presented at The University of Texas at Austin, Department of Geological Sciences, Hydrogeology Brown Bag Lecture, Austin, Texas.

"Hydrology of the unsaturated zone": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 382C), Austin, Texas.

Shirley P. Dutton

"Reservoir characterization of a deep-water channel-levee and lobe system, Bell Canyon Formation, Ford Geraldine unit, West Texas (Delaware Basin)": presented at Texas Tech University, Department of Geosciences Technical Sessions, Lubbock, Texas.

William L. Fisher

"Technology and the revitalization of the natural gas industry": presented to the Energy Forum, City College of New York Graduate School, New York.

"Technology in the restructured oil and gas industry": presented to Energy Daily, First Annual Utility R&D Conference, Washington, D.C.

"Oil and gas plays of the Gulf of Mexico": presented to the U.S. Department of Energy, Annual Gas Conference, Houston, Texas.

"Oil and gas exploration and production technologies": presented at Resources for the Future, Workshop on Technology Impacts, Washington, D.C.

"The energy situation in Texas and the nation": presented to the Austin Geological Society, Austin, Texas.

"A current look at energy": presented to The University of Texas at Austin Ex-Students Association, Alumni Update 1997, Austin, Texas.

"Changing perceptions of the U.S. and global oil and natural gas resource base": presented to the American Association of Petroleum Geologists, Division of Professional Affairs, Annual Meeting, Dallas, Texas.

"Energy in transition": presented to The University of Texas, Permian Basin, Noël Lecture, Midland–Odessa, Texas.

"Energy use, population, and the environment": presented to The University of Texas, Permian Basin, Midland–Odessa, Texas.

"Concentrating the mind: the turnaround in domestic oil and gas": presented to the American Association of Petroleum Geologists, Southwest Section, Keynote Address, San Angelo, Texas.

"Update on oil and gas in the U.S.": presented to the Society of Independent Professional Earth Scientists, Austin, Texas.

"Will technology save us?": presented to the Society of Petroleum Engineers, Dallas, Texas.

"New elements in the Nation's energy policy": presented to the South Texas Geological Society, San Antonio, Texas.

Robert L. Folk

"Comparison of putative nannobacteria on Earth and Mars": presented to The University of Texas at Austin, Astronomy Department and Department of Geological Sciences, Austin, Texas.

"Bahaman ooid sands: role of nannobacteria in creation and diagenesis": presented to The University of Texas at Austin, Department of Geological Sciences, Soft-Rock Seminar, Austin, Texas.

"When good things happen to bad rocks": presented to The University of Texas at Austin, Department of Geological Sciences, Hard-Rock Seminar, Austin, Texas.

"Nannobacteria and mineral precipitation, Earth and Mars": presented to the Austin Gem & Mineral Society, Austin, Texas.

"Nannobacteria and you": presented to the Lakeway Men's Breakfast Club, Austin, Texas.

"Nannobacteria and geochemistry of the Earth": presented to E. T. H. University, Geology Department, Zurich, Switzerland.

"Nannobacteria are alive on Earth as well as Mars" (with F. Leo Lynch): presented at the Society of Photo-Optical Engineering Annual Meeting, San Diego, California.

Nannobacteria and Mars": presented as part of a documentary television program on the Martian meteorite, broadcast by BBC, London, England.

"Viterbo hot springs, discovery site for nannobacteria": presented as part of a documentary on nannobacteria made for Netherlands TV.

William E. Galloway

"Depositional processes, regime variables, and development of siliciclastic stratigraphic sequences": presented to the Venezuelan Petroleum Association, Caracas, Venezuela.

James C. Gibeaut

"Mapping barrier islands using AIRSAR": presented at the Fourth International Conference on Remote Sensing for Marine and Coastal Environments, Orlando, Florida.

Douglas S. Hamilton

"Fluvial sedimentology and its application to reserve growth opportunities in depleting hydrocarbon reservoirs": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 391), Austin, Texas.

H. Scott Hamlin

"Flow-unit characterization and recovery optimization of a braid-delta sandstone reservoir, Tirrawarra oil field, South Australia": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 391), Austin, Texas.

Bob A. Hardage

"Seismic imaging of Ellenburger karsted reservoirs": presented to the Society of Independent Professional Earth Scientists, Austin Chapter, Austin, Texas.

"Visualization requirements for 3-D seismic interpretation of reservoirs": presented at the Virtual Environment Technology Conference, University of Houston, Houston, Texas.

"Applications of seismic P and S data in prospect evaluation": presented at the Texas Independent Producers and Royalty Owners Association Annual Meeting, San Antonio, Texas.

"Seismic imaging of thin-bed reservoirs in the Fort Worth Basin": presented at the American Institute of Professional Geologists Conference, Houston, Texas.

"Seismic vector-wavefield technology": presented at the Independent Petroleum Association of America Annual Meeting, Houston, Texas.

Tucker F. Hentz

"Atlas of northern Gulf of Mexico gas and oil reservoirs": presented at the Gas Research Institute, Natural Gas Supply Project Advisors Group Meeting, Oklahoma City, Oklahoma.

"The northern Gulf of Mexico atlas project: play synthesis of 10,000 offshore reservoirs": presented to the Austin Geological Society, Austin, Texas.

"Incentive for offshore gas and oil production: the offshore atlas project": presented to the Production Incentives and Technology Transfer Seminars, sponsored by the Petroleum Technology Transfer Council and the Railroad Commission of Texas, Corpus Christi, Texas.

James W. Jennings, Jr.

"Geostatistical analysis and simulation of petrophysical data from carbonate outcrops": presented at the Fourth SIAM Conference on Mathematical and Computational Issues in the Geosciences, Albuquerque, New Mexico.

"Geostatistical analysis and simulation of petrophysical data from carbonate outcrops": presented to The University of Texas at Austin, Department of Petroleum and Geosystems Engineering, Graduate Seminar, Austin, Texas.

Stephen E. Laubach

"The new paradigm in core analysis": presented to the Department of Geology, New Mexico Tech University, Socorro, New Mexico.

"Diagenetic controls on fracture permeability": presented to the 36th U.S. Rock Mechanics Symposium, Columbia University, New York.

"Fracture properties from rock microstructure" and "Introduction to the new AAPG Reservoir Deformation Research Group": presented at the American Association of Petroleum Geologists Hedberg Research Conference, Bryce, Utah.

"Using core analysis to characterize fractures and calibrate seismic data": presented to the Gas Research Institute technical advisory group, Denver, Colorado.

"Diagenesis from a different perspective": presented at the SEPM (Society for Sedimentary Geology) Clastic Diagenesis Research Group Meeting, Dallas, Texas.

"Uncovering fractures": keynote address presented at the Imaging Systems dinner, American Association of Petroleum Geologists Annual Convention, Dallas, Texas.

"Structural geology in support of reservoir engineering in modern reservoir management": presented to The University of Texas at Austin, Department of Petroleum and Geosystems Engineering, Austin, Texas.

"Métodos revolucionarios de análisis de muestras de testigos para yacimientos fracturados [Revolutionary core analysis methods for fractured reservoirs]": keynote address presented as part of the 32nd anniversary celebration of the founding of the Instituto Mexicano del Petróleo, Mexico City, Mexico.

F. Jerry Lucia

"Carbonate rock fabrics: a key to integrated reservoir characterization": presented to the Society of Explorationists in the Emirates, Abu Dhabi, United Arab Emirates, and to the Dhahran Geological Society, Dhahran, Saudi Arabia.

"The scale of superpermeability and its impact on core descriptions and flow simulations": presented to the First Super K Forum, Dhahran, Saudi Arabia.

"Petrography of carbonate pore space": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 383M), Austin, Texas.

F. Leo Lynch

"Nannobacteria are alive on Earth as well as Mars" (with Robert L. Folk): presented at the Society of Photo-Optical Engineering Annual Meeting, San Diego, California.

Robert E. Mace

"Bugs and benzene: a regional scale study of plumes beneath leaking-petroleum-storage-tank sites in Texas": presented at The University of Texas at Austin, Department of Geological Sciences, Hydrology/Hydrogeology Brown-Bag Seminar, Austin, Texas.

"Measurement and analysis of fracture roughness" and "Conducting hydrogeologic studies in fractured rocks: an example from the Austin Chalk": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 391), Austin, Texas.

"The past, present, and future of plume studies at the Bureau of Economic Geology": presented to the American Petroleum Institute Soil/Groundwater Division Technical Advisory Panel, Austin, Texas.

"Plume studies at the Bureau of Economic Geology": presented to the U.S. Environmental Protection Agency, Dallas, Texas.

"Developing conceptual ground-water flow and contaminant transport models in fractured rock": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 391C), Austin, Texas.

"Natural stabilization of hydrocarbon plumes": presented to The Industry Council on the Environment, Austin, Texas.

R. P. Major

"The Petroleum Technology Transfer Council, Texas regional lead organization—technology clearinghouse for the independent oil and gas industry": presented to the technology transfer seminar sponsored by Pampa Economic Development Corporation, Texas Comptroller of Public Accounts, and Southwestern Public Service Company, Pampa, Texas.

"Predicting reservoir quality at the development scale: methods for quantifying remaining hydrocarbon resource in diagenetically complex carbonate reservoirs": presented to the Society of Independent Professional Earth Scientists, Austin, Texas, and the South Texas Geological Society, San Antonio, Texas.

"Geochemical tracers of dolomitizing fluids—a tool for predicting diagenetically controlled porosity on a reservoir scale": presented to the Society of Independent Professional Earth Scientists, San Antonio, Texas.

"Introduction to the Texas regional lead organization of the Petroleum Technology Transfer Council": presented to the Technology Transfer Seminar—Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs, sponsored by the Petroleum Technology Transfer Council and the Bureau of Economic Geology, Houston, Texas.

"Coral reefs of the Caribbean Sea—scuba diving geologists collect research samples": presented to The University of Texas at Austin, Bring Your Child to Work Day, Austin, Texas.

"Introduction to research programs at the Bureau of Economic Geology, The University of Texas at Austin": presented to Iqbal Mahmud, Vice-Chancellor, Bangladesh University of Engineering and Technology, Austin, Texas.

"Review of the State Lands project": presented to the Texas State Senate Interim Committee on Funding, Austin, Texas.

"Modern carbonate sediment facies heterogeneity at the development scale—an example from Joulters Cays, Bahamas": presented to the Society of Independent Professional Earth Scientists, Dallas, Texas.

Mohammad A. Malik

"Simulations for improved recovery by CO_2 flood in Ford Geraldine unit, West Texas": presented to the Second CO_2 Oil Recovery Forum, New Mexico Institute of Mining and Technology, Socorro, New Mexico.

Robert A. Morton

"Coastal trends in Texas—a physical perspective" and "Beach cleaning practices in Texas": presented to the Coastal Issues Conference sponsored by the Texas General Land Office, Corpus Christi Texas.

"Coastal geology and public policy—basic scientific solutions for new environmental problems": presented to the Austin Geological Society, Austin, Texas.

Jeffrey G. Paine

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

"Identifying salinity sources in West Texas using geophysical methods": presented at the Upper Colorado

River Authority, Board of Directors meeting, San Angelo, Texas.

"Application of research in geology, geologic processes, and geophysics to Texas transportation issues": presented to the Center for Transportation Research Symposium, Kerrville, Texas.

"Combining high-resolution airborne and ground-based geophysical methods to identify salinity sources in West Texas": presented to The University of North Texas, Center for Remote Sensing, Denton, Texas.

"Wells, springs, pits, and seeps—identifying brine sources with geophysics": presented to the Society of Independent Professional Earth Scientists, 34th Annual Convention, Austin, Texas.

"Estimating depth-to-bedrock feasibility study": presented at the Texas Department of Transportation Research Management Committee Meeting, Austin, Texas.

"Near-surface applications of seismic reflection and electromagnetic induction methods": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 465K), Austin, Texas.

Jay A. Raney

"Down to Earth at McKinney Falls State Park": presented to the Texas Earth Science Teachers Association, Austin, Texas.

"Methods, results, and applications of coastal studies by the Bureau of Economic Geology, Texas Gulf Coast": presented to the University of Northern Baja California, Ensenada, Baja California, Mexico.

"Regional and site-specific geologic setting of proposed site for Texas low-level radioactive waste disposal facility and summary of vadose zone studies": presented to the National Technical Review Committee of the Low-Level Radioactive Waste Forum, El Paso, Texas.

"Rates of deforestation in Belize 1989/92 to 1994/96": moderator of workshop presented to the U.S. Agency for International Development, Belize Ministry of Natural Resources, Government of Belize, nongovernmental organizations, and the public, Belmopan, Belize.

Bridget R. Scanlon

"Evaluation of focused recharge beneath playas and implications for agricultural practices": presented to the Texas Agricultural Extension Service, Lubbock, Texas.

"Overview of unsaturated zone hydrologic studies related to radioactive waste disposal in Texas": presented to The University of Texas at El Paso, Department of Geological Sciences, El Paso, Texas.

Daniel D. Schultz-Ela

"Numerical modeling of the geologic evolution of salt-related structures: interactions of brittle and ductile rocks": presented to Centric Engineering Systems, Sunnyvale, California.

Andrew R. Scott

"Introduction to the Texas regional lead organization of the Petroleum Technology Transfer Council": presented at the technology transfer seminar, "Effect of Ellenburger karsting and collapse structure on reservoir compartmentalization in overlying Bend Conglomerate (Atoka Group), Boonsville field," sponsored by the Petroleum Technology Transfer Council and Bureau of Economic Geology, San Antonio, Texas.

"Annual review of Gulf Coast region activities": presented to the Energy Minerals Division of the American Association of Petroleum Geologists, Dallas, Texas.

"Introduction to Petroleum Technology Transfer Council": presented at the technology transfer seminar, "Advanced applications of wireline logging for improved oil recovery," sponsored by the Petroleum Technology Transfer Council and BDM Oklahoma, Midland, Texas.

"Integrated approach to reservoir characterization": presented to the Production Incentives and Technology Seminar, sponsored by the Petroleum Technology Transfer Council and Railroad Commission of Texas, Abilene, Texas.

"Review of annual Petroleum Technology Transfer Council activities": presented at the Petroleum Technology Transfer Council Project Advisors Group Meeting, Houston, Texas.

"Summary of recent Gulf Coast Region activities": presented to the Energy Minerals Division of the American Association of Petroleum Geologists, Tulsa, Oklahoma.

E. Jeri Sullivan

"Microcalorimetry of cationic surfactant sorption onto clinoptilolite zeolite": presented to the American Chemical Society Colloid and Surface Science Symposium, Newark, Delaware.

"Development of surfactant-modified zeolites for use in permeable barriers": presented to the Soil Science Society of America, Anaheim, California.

Roger Tyler

"State of Texas advanced oil and gas resource recovery program": presented to the Society of Independent Professional Earth Scientists, Austin, Texas.

Mark R. Vining

"Reserve growth in the Frio Formation of Umbrella Point field, Chambers County, Texas: a reservoir study for the STARR and PTTC programs of Texas": presented to the Corpus Christi Geological Society, Corpus Christi, Texas.

"Long-term forward hydrologic fluvial system evolution model": presented to Texas Tech University, Department of Geosciences, Lubbock, Texas.

"Review of STARR project reservoir characterization": presented to the General Land Office, Austin, Texas.

Christopher D. White

"Stratigraphically oriented reservoir modeling": presented to The University of Texas at Austin, Center for Petroleum and Geological Engineering, Austin, Texas.

"Translating outcrop data for reservoir simulation": presented to the Integrated Reservoir Modeling Workshop, Chevron International Petroleum, Inc., San Ramon, California.

William A. White

"Evaluation of marsh restoration projects in the Galveston Bay System": presented to the Natural Resources Uses Subcommittee of the Galveston Bay Estuary Program, Webster, Texas.

Brian J. Willis

"Sedimentology and stratigraphy of valley fills: Cretaceous Fall River Formation": presented to the Department of Earth Sciences, State University of New York at Oswego, Oswego, New York.

Lesli J. Wood

"Sequence stratigraphy and tectonostratigraphic development of the Columbus Basin, Trinidad and Tobago, West Indies": presented to The University of Texas at Austin, Department of Geological Sciences, Soft Rock Seminar, Austin, Texas.

"Seismic attribute analysis and interpretation": presented to The University of Texas, Department of Geological Sciences (Geology 391), Austin, Texas.

Bureau of Economic Geology Seminars

William A. Ambrose

"Oil recovery opportunities in tide-dominated estuarine-fill sequences in the Lower Misoa Formation (lower Eocene), Maraven Bloque 1 area, Lake Maracaibo, Venezuela"

Roger J. Barnaby

"Strontium isotopic signatures of subsurface brines: key to identifying interreservoir hydraulic connectivity"

"Sequence stratigraphic framework, high-frequency cyclicity and facies architecture of a mixed carbonate–siliciclastic, shallow-water platform succession: Grayburg Formation, New Mexico"

Alan R. Dutton

"Environmental assessment of abandoned oil field cleanup sites in Texas"

Shirley P. Dutton

"Reservoir characterization of channel-levee and lobe deposits, Bell Canyon Formation, Geraldine Ford field, West Texas (Delaware Basin)"

James C. Gibeaut

"High-accuracy bathymetric surveys for coastal research"

Ursula Hammes

"Calibrating the rock record—electrical images from microresistivity logs in fractured, brecciated, and karsted carbonate rocks"

C. Robertson Handford

"Sequence stratigraphy and stratigraphic trap potential of the Villeta Formation (Cretaceous), Putumayo Basin, Colombia"

Tucker F. Hentz (with Thomas A. Tremblay)

"Northern Gulf of Mexico gas and oil atlas: a significant new tool for offshore producers"

Mark H. Holtz

"3-D geocellular modeling of a Frio fluvial-deltaic reservoir"

Susan D. Hovorka

"Salt dissolution in the Permian Basin: timing, processes, and implications for waste storage in salt"

Charles Kerans

"Cretaceous ramp carbonates from the Pecos River Canyon: analogs for Cretaceous reservoirs in the Middle East"

Stephen E. Laubach

"Progress in fracture characterization"

F. Jerry Lucia

"Locating remaining oil in existing carbonate reservoirs"

Robert E. Mace

"Evidence of natural attenuation from a regional study of benzene plumes from leaking-petroleum-storage-tank sites in Texas"

Robert A. Morton

"Coastal geology and public policy—basic scientific solutions for new environmental problems"

Bridget R. Scanlon

"Future research areas in unsaturated zone hydrology"

Andrew R. Scott

"Geochemical and production heterogeneity in coal reservoirs"

E. Jeri Sullivan

"Development of surfactant-modified zeolites for use in permeable barriers"

Thomas A. Tremblay (with Tucker F. Hentz)

"Northern Gulf of Mexico gas and oil atlas: a significant new tool for offshore producers"

Mark R. Vining

"Hydrologic fluvial system evolution model with application to coastal sequence stratigraphy"

William A. White

"Submergence of Texas coastal wetlands along active faults"

Congressional, Legislative, and Special Testimony

Jay A. Raney

"State's proposed site for a low-level radioactive waste disposal facility": presented to the Texas House/Senate Appropriations Conference Committee, Austin, Texas.

"In support of a new State project to sample the submerged lands of Texas": presented to the Coastal Coordination Council, Austin, Texas.

Noel Tyler

"Recent production history and remaining resources in East Texas field": presented to the Energy Committee, Texas State House of Representatives.

Committee Services, Offices, and Other Professional Responsibilities

Robert E. Barba, Jr.

Lecturer (1995–1997), Speakers Bureau, Society of Petroleum Engineers.

Mark D. Barton

Leader of field trip, "Field trip to the Bell Canyon Formation: a submarine channel-levee system with attached lobes," BEG/DOE/STARR/PTTC Technology Transfer Workshop, "Reservoir characterization of Ford Geraldine unit: Permian Bell Canyon Formation, Delaware Basin, West Texas," Culberson County, Texas.

Sigrid J. Clift

Leader of field trip, Llano Uplift, McNeil High School Geology classes, Austin, Texas.

Edward W. Collins

President-Elect, Austin Geological Society.

Alan R. Dutton

Editor, *The Hydrogeologist*, Geological Society of America, Hydrogeology Division.

Judge, AAPG Division of Environmental Geology Technical Sessions, American Association of Petroleum Geologists Annual Convention.

Shirley P. Dutton

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

Convenor, "Results of joint DOE/industry programs," technical session, American Association of Petroleum Geologists Annual Convention.

Robert J. Finley

Member, Committee on Development Geology, American Association of Petroleum Geologists.

William L. Fisher

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

Chairman, Honors and Awards Committee, American Institute of Professional Geologists.

Chair, Faculty Review 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, Advisory Council, Gas Research Institute.

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

Member, Faculty Council, The University of Texas at Austin.

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, Commission on Geosciences, Environment, and Resources, National Research Council.

Member, National Academy of Engineering.

Member, Technical Program Committee, World Energy Conference.

Member, Texas Press Committee, The University of Texas at Austin.

Member, President's Council of Advisors on Science and Technology, R&D Panel.

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.

Member, Honors and Awards Committee, Gulf Coast Association of Geological Societies.

James C. Gibeaut

Member, Topography and Surface Change Investigators Working Group, National Aeronautic and Space Administration.

Member, Texas Geographic Information Council, Texas Department of Information Resources and Texas Natural Resources Information System.

Bob A. Hardage

Chairman, Publications Committee, Society of Exploration Geophysicists.

Editor-in-Chief, *Journal of Petroleum Science and Engineering.*

Member, Editorial Board, *Journal of Seismic Exploration.*

Martin P. A. Jackson

Session Chairman, "Analog and physical models of reservoir-scale deformation," American Association of Petroleum Geologists Hedberg Research Conference on Reservoir-Scale Deformation: Characterization and Prediction, Bryce, Utah.

Session Chairman, "Geometry and interpretation of extensional and diapiric structures," American Association of Petroleum Geologists Annual Convention, Dallas, Texas.

Member, International Union of Geological Sciences Commission on Tectonics.

James W. Jennings, Jr.

Co-leader of field trip, "Leonardian platform deposits of the Sierra Diablo: cycle stratigraphy and petrophysics of Clear Fork reservoir analogs," Reservoir Characterization Research Laboratory Annual Meeting, West Texas.

Charles Kerans

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

Member, Development Geology Committee, Society of Petroleum Engineers.

Co-chairman, 1998 Carbonate Reservoirs of the World International Conference, Gulf Coast Section, Society of Economic Paleontologists and Mineralogists.

Co-chairman, "Climatic and biologic signals in sequence stratigraphy," technical session, American Association of Petroleum Geologists Annual Meeting.

Second Vice-President, Permian Basin Section, SEPM (Society for Sedimentary Geology).

Paul R. Knox

Session Co-Chair, "Reservoir models," Fourth International Reservoir Characterization Technical Conference, sponsored by the U.S. Department of Energy, BDM–Oklahoma, Inc., and the American Association of Petroleum Geologists.

Stephen E. Laubach

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

Member, Research Committee, American Association of Petroleum Geologists.

Member, Editorial Board, *SPE Formation Evaluation.*

Member, SPE Technical Editor board, Society of Petroleum Engineers.

Convenor, "New technology in the exploration and exploitation of fractured reservoirs," technical session, American Association of Petroleum Geologists Annual Convention.

Convenor, "New developments in formation evaluation techniques and technology," technical session, American Association of Petroleum Geologists Annual Convention.

F. Jerry Lucia

Member, Production Geology and Geophysics Committee, Society of Petroleum Engineers.

Convenor, "Best of AAPG," technical session, Society of Petroleum Engineers Annual Convention.

Leader of field trip, "Interplay of karst, fractures, and permeability in the Cretaceous Edwards aquifer: analogs for fractured carbonate reservoirs in the Lake Medina and New Braunfels area," Society of Petroleum Engineers Annual Convention, San Antonio, Texas.

Robert E. Mace

Co-moderator, "MTBE: Occurrence and Remediation," workshop, Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Remediation Conference, American Petroleum Institute and National Ground Water Association.

R. P. Major

Secretary, Gulf Coast Section, SEPM (Society for Sedimentary Geology).

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

Member, Graduate Admissions and Support Committee, Department of Geological Sciences, The University of Texas at Austin.

Robert A. Morton

Member, Working Group, Scientific Committee on Problems of the Environment and International Union of Geological Sciences, Earth Surface Processes, Materials Use and Urban Development; Understanding the Human Contribution to Global Geomorphic Change.

Member, Editorial Board, *Journal of Coastal Research*, Coastal Education and Research Foundation.

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

Leader of field trip, "Geologic evolution of the Central Texas coast: a look at the past and the future," Fourth Symposium on Studies Related to Continental Margins—A Summary of Year-Nine and Year-Ten Activities, sponsored by the Minerals Management Service, Corpus Christi, Texas.

William F. Mullican III

Member, Texas Groundwater Protection Committee.

Member, Texas Oil and Gas Forum.

Jeffrey G. Paine

Associate Editor, *Environmental & Engineering Geoscience*, Association of Engineering Geologists and Geological Society of America.

Review Panelist, Solid Earth and Natural Hazards Panel, National Aeronautic and Space Administration Mission to Planet Earth Program.

Jay A. Raney

Member, GIS Planning Council for the Department of Information Resources, representing the Bureau of Economic Geology.

Member, Natural Resources Section, Board on Natural Resources, National Association of State Universities and Land-Grant Colleges, representing The University of Texas at Austin.

Member, Committee on Geologic Mapping, Scale, and Accuracy, American Association of State Geologists.

Participant, environmental oversight of the Pantex Plant at the request of the Governor's Office, Agreement in Principal between the State of Texas and the U.S. Department of Energy.

Lisa E. Remington

Secretary, Austin Geological Society.

Stephen C. Ruppel

Chairman, Publications Committee, Austin Geological Society.

Bridget R. Scanlon

Associate Editor, *Ground Water*, Association of Ground Water Scientists and Engineers.

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

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

Convenor, "Use of noninvasive techniques for evaluating parameters in unsaturated systems," technical session, American Geophysical Union Annual Meeting.

Technical Reviewer for U.S. Department of Energy: Analysis of ^{36}Cl results from the high-level nuclear waste site at Yucca Mountain.

Daniel D. Schultz-Ela

Co-convenor, "Numerical and physical structural modeling," technical session, American Association of Petroleum Geologists Annual Convention.

Andrew R. Scott

Technical Chairman, Energy Minerals Division, 1999 American Association of Petroleum Geologists Annual Convention.

Councilor, Gulf Coast Section, Energy Minerals Division, American Association of Petroleum Geologists.

Co-convenor, "Coals into the 21st Century," technical session, American Association of Petroleum Geologists Annual Convention.

Member, Operation Subcommittee, Task Force for the Registration of Geologists, Geophysicists, Soil Scientists in Texas.

Member, Organizing Committee, International Conference on Coal Seam Gas and Oil.

James L. Simmons, Jr.

Associate Editor of Amplitude-Versus-Offset (AVO), *Geophysics*, Society of Exploration Geophysicists.

Noel Tyler

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

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

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

Member, Environmental Affairs, Association of American State Geologists.

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

Member, Committee on Earth Resources, National Research Council.

Member, Texas Oil & Gas Forum.

Member, World Energy Conference, Technical Program Review Panel.

Roger Tyler

Member, South African Council for Natural Scientists.

Member, Fossil Fuel Foundation, Geological Society of South Africa.

Convenor, "Oil fields revitalized," technical session, Gulf Coast Association of Geological Societies, Annual Convention, New Orleans, Louisiana.

Convenor, "Coalbed methane and Texas coal," technical session, Energy Mineral Division, American Association of Petroleum Geologists Annual Convention, Dallas, Texas.

Bruno C. Vendeville

Member, Editorial Board, Tectonophysics.

Guest Editor, Special issue of *The Leading Edge* on

Exploring in Complex Structural Regimes, Society of Exploration Geophysicists.

Convenor, "Numerical and physical structural modeling," poster session, American Association of Petroleum Geologists Annual Convention.

Judge, "Origin and interpretation of diapirs and extensional structures," poster session, American Association of Petroleum Geologists Annual Convention.

Mark R. Vining

Judge, "Fluid migration and diagenesis," poster session, Gulf Coast Association of Geological Societies, Annual Convention, New Orleans, Louisiana.

E. G. Wermund, Jr.

Chairman, Awards Committee, Austin Geological Society.

Member, Texas Mapping Advisory Committee.

Member, Texas Natural Resources Information System Task Force.

Member, Scientific and Technical Advisory Committee, Corpus Christi Bay National Estuary Program.

Member, HOSTS program, Ortega Elementary School.

Judge of Science Fair, Ortega Elementary School.

Christopher D. White

Member, Fluid Mechanics and Recovery Processes Technical Committee, Society of Petroleum Engineers.

Session Chairman, "Pore structure characterization / geomechanical mechanisms," Society of Petroleum Engineers Annual Technical Conference and Exhibition.

University Teaching/ Continuing Education

Robert E. Barba, Jr.

"Economical fracture optimization for 3-D models": short course presented to Halliburton Energy Institute, Duncan, Oklahoma.

Mark D. Barton

"Description of architecture elements within a high-order cycle, Bell Canyon Formation, West Texas: a submarine channel-levee system with attached lobes": co-lecturer of the West Texas Geological Society Continuing Education Short Course, "Reservoir characterization of Permian deep-water sandstones, Bell Canyon Formation, West Texas (Delaware Basin)," Midland, Texas.

"Facies architecture of Bell Canyon Sandstones: a submarine channel-levee system with attached lobes," co-lecturer of the BEG/DOE/STARR/PTTC Technology Transfer Workshop, "Reservoir characterization of Ford Geraldine unit: Permian Bell Canyon Formation, Delaware Basin, West Texas," Carlsbad, New Mexico.

Sigrid J. Clift

"Core display of Ramsey sandstone cores, Geraldine Ford field": co-lecturer of the West Texas Geological Society Continuing Education Short Course, "Reservoir characterization of Permian deep-water sandstones, Bell Canyon Formation, West Texas (Delaware Basin)," Midland, Texas.

"Presentation of Ramsey sandstone cores, Geraldine Ford field": co-lecturer of the BEG/DOE/STARR/PTTC Technology Transfer Workshop, "Reservoir Characterization of Ford Geraldine unit: Permian Bell Canyon Formation, Delaware Basin, West Texas," Carlsbad, New Mexico.

Shirley P. Dutton

"Introduction to the technology transfer workshop," "Reservoir characterization of Geraldine Ford field," and "Short course summary and conclusions": co-lecturer of the West Texas Geological Society Continuing Education Short Course, "Reservoir characterization of Permian deep-water sandstones, Bell Canyon Formation, West Texas (Delaware Basin)," Midland, Texas.

"Introduction to the workshop and field trip" and "Reservoir characterization of Geraldine Ford field": co-lecturer of the BEG/DOE/STARR/PTTC Technology Transfer Workshop, "Reservoir characterization of Ford Geraldine unit: Permian Bell Canyon Formation, Delaware Basin, West Texas," Carlsbad, New Mexico.

Robert J. Finley

"Geological characterization of heterogeneous reservoirs": co-lecturer of short course presented at the American Association of Petroleum Geologists Annual International Meeting, Vienna, Austria (with Noel Tyler).

William L. Fisher

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

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

"Petroleum workstations": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 391), Austin, Texas (with William E. Galloway).

"Natural resources and the environment": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 379K), Austin, Texas (with Mark P. Cloos).

William E. Galloway

"Depositional systems and sequences in exploration for sandstone reservoirs": AAPG Continuing Education Short Course, American Association of Petroleum Geologists Annual Convention, Dallas, Texas.

Douglas S. Hamilton

"Effect of Ellenburger karsting and collapse structure on reservoir compartmentalization in overlying Bend Conglomerate (Atoka Group), Boonsville field, Jack and Wise Counties, Texas": co-lecturer of short course presented to the South Texas Geological Society, San Antonio, Texas.

C. Robertson Handford

"Carbonate depositional systems and sequence stratigraphy": short course presented on behalf of the Indonesian Association of Geologists, Cirebon, Indonesia.

"High-resolution well-log sequence stratigraphy—application to exploration and production": co-lecturer of short course presented to the American Association of Petroleum Geologists, Denver, Colorado.

Bob A. Hardage

"3-D seismic imaging and interpretation of complex reservoir systems": short course presented on behalf of the Society of Exploration Geophysicists, Jakarta, Indonesia.

"3-D seismic technology applications in slope and basin thin-bed reservoirs": short course presented on behalf of the U.S. Department of Energy Class III Reservoir Characterization Program, Hobbs, New Mexico.

"Effect of Ellenburger karsting and collapse structure on reservoir compartmentalization in overlying Bend Conglomerate (Atoka Group), Boonsville field, Jack and Wise Counties, Texas": co-lecturer of short course presented to the South Texas Geological Society, San Antonio, Texas.

Tucker F. Hentz

"Atlas of northern Gulf of Mexico gas and oil reservoirs": co-lecturer of workshop sponsored by the Petroleum Technology Transfer Council and the Bureau of Economic Geology, Houston, Texas.

Charles Kerans

"Sequence stratigraphy and characterization of carbonate reservoirs": co-lecturer of short course presented at the American Association of Petroleum Geologists Annual Meeting, Dallas, Texas.

"AAPG current processes and technologies: recent advances in sequence stratigraphy for reservoir characterization": short course presented at the American Association of Petroleum Geologists Annual Meeting, Dallas, Texas.

F. Jerry Lucia

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

Robert E. Mace

"Benzene and methyl tert-butyl ether (MTBE) aqueous-phase plume studies in Texas": co-lecturer of workshop ("MTBE: Occurrence and Remediation") presented at the Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Remediation Conference, American Petroleum Institute and National Ground Water Association, Houston, Texas.

R. P. Major

"Effect of Ellenburger karsting and collapse structure on reservoir compartmentalization in overlying Bend Conglomerate (Atoka Group), Boonsville field, Jack and Wise Counties, Texas": co-lecturer of short course presented to the South Texas Geological Society, San Antonio, Texas.

Mohammad A. Malik

"Stochastic permeability characterization and preliminary enhanced recovery projection for Geraldine Ford field": co-lecturer of the West Texas Geological Society Continuing Education Short Course, "Reservoir characterization of Permian deep-water sandstones, Bell Canyon Formation, West Texas (Delaware Basin)," Midland, Texas.

"Simulations of a CO_2 flood in Ford Geraldine unit, West Texas": co-lecturer of the BEG/DOE/STARR/PTTC Technology Transfer Workshop, "Reservoir characterization of Ford Geraldine unit: Permian Bell Canyon Formation, Delaware Basin, West Texas," Carlsbad, New Mexico.

Robert A. Morton

"Amenazas naturales y planificacion," "Geoindicadores costeros y monitoreo ambiental," "Geología y políticas de desarrollo costero," "Alteraciones humanas en sistemas naturales," and "Geología para el manejo de zonas litorales, principios basicos y aplicaciones": topics of short course presented to the Centro de Educación Continua y Departamento de Geología, Universidad EAFIT, Medellin, Colombia.

"Errores y sus consecuencias en el desarrollo costero": short course presented to the Departamento Administrativo del Sistema de Prevención, Atención y Recuperación de Desastres, Medellin, Colombia.

Stephen C. Ruppel

"Modern approaches to characterization of Permian shallow platform reservoirs in the Permian Basin": co-lecturer of short course presented to the Permian Basin Graduate Center, Midland, Texas.

Bridget R. Scanlon

"Physical and environmental tracer data to quantify spatial and temporal variability in unsaturated flow": short course presented to the Summer School on European Water Resources and Climate Change Processes, Civil Engineering Department, University College Cork, Cork, Ireland.

"Unsaturated zone hydrology, organic contaminant transport, and groundwater modeling": short course presented to the University College Cork, Civil Engineering Department, Cork, Ireland.

Andrew R. Scott

"Defining coalbed methane exploration fairways and resources": co-lecturer of short course presented to the International Coalbed Methane Symposium, Tuscaloosa, Alabama.

"Unconventional gas resources": short course presented to the Midwest Region of the Petroleum Technology Transfer Council, Grayville, Illinois.

James L. Simmons, Jr.

"Geophysical modeling and inversion": presented to The University of Texas at Austin, Department of Geological Sciences (Geology 384M), Austin, Texas.

Thomas A. Tremblay

"Atlas of northern Gulf of Mexico gas and oil reservoirs": co-lecturer of workshop sponsored by the Petroleum Technology Transfer Council and the Bureau of Economic Geology, Houston, Texas.

Noel Tyler

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

"Geological characterization of heterogeneous reservoirs": co-lecturer of short course presented to the American Association of Petroleum Geologists Annual International Meeting, Vienna, Austria (with Robert J. Finley).

Roger Tyler

"Defining coalbed methane exploration fairways and resources": short course presented to the International Coalbed Methane Symposium, Tuscaloosa, Alabama.

Bruno C. Vendeville

"Introduction to experimental modeling of tectonic processes": short course presented to the AAPG Students Chapter, American Association of Petroleum Geologists Annual Convention, Dallas, Texas.

Support Staff

Administrative

Administrative staff members handle the general management of the Bureau, which includes payroll and personnel, accounts payable and receivable, purchasing, travel arrangements and reimbursements, correspondence, receptionist duties, secretarial responsibilities, and coordination of meetings. The Bureau's involvement in numerous contracts and research projects results in numerous transactions to allocate staff time properly among funding sources. This section, controlling more than $5 million in purchases and subcontracts each year, is supervised by Wanda L. LaPlante, Executive Assistant.

Editing

The members of the Editing staff, supervised by chief editor Susann V. Doenges, handle editing, word processing, typesetting and layout, 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 1997, the staff prepared 17 Bureau publications, and 40 contract reports. In addition, 71 papers and 68 abstracts by Bureau authors were published by professional journals and publishers.

Graphics

The Graphics section, under the direction of Senior Computer Illustrator Joel L. Lardon, is responsible for producing text illustrations and visual aids, manual and digital photography, design and layout of Bureau publications and reports, as well as map design and finishing. In 1997, the Graphics section's 16-person full-time staff digitally produced 16 full-color maps, 2,472 text figures, and 3,709 visual aids (35-mm slides, posters, and overhead transparencies).

All illustrations, including color and black-and-white maps and plates, are produced entirely on the computer. High standards are practiced to maintain the Bureau's reputation for quality. The Graphics section utilizes two 600-dpi black-and-white laser printers, a dye-sublimation color printer, two 36-inch-wide color ink-jet plotters, a 36-inch-wide hot laminator, a high-resolution 35-mm film recorder, a 300-dpi monochrome scanner, and a high-resolution color scanner for opaque and transparent originals—all of which support Macintosh computers.

Information Technology Services

The Bureau has state-of-the-art computing hardware and software, which its Information Technology Services staff use to support Bureau scientists in interpretation, 3-D modeling, visualization, reservoir characterization, computer mapping, programming, data-base applications, and statistical and graphical analysis of data. The Bureau's research staff also has access to the University's IBM, UNIX, VAX, and Cray computer systems.

The Bureau's computer environment includes VAX, UNIX, Windows PC's, and Macintosh computers—all on an Ethernet LAN. A three-node VAX cluster provides VMS services. The UNIX machines are one Silicon Graphics Onyx Reality Engine server, seven SGI workstations, a Sun Ultra Enterprise 2 server, nine Sparc workstations, and seven UltraSparc workstations. A total of 4 departmental Windows NT servers host the Bureau's Intranet and FTP sites and provide file and printer sharing to 125 Macintoshes and 75 IBM-compatible PC's. Additional hardware resources include 25 LaserWriter printers, 5 color ink-jet printers, 1 Versatec 36-inch electrostatic plotter, 3 Hewlett-Packard 36-inch DesignJet plotters, 1 LaserMaster ColorMark plotter, 1 photo-quality dye-sublimation printer, 1 film recorder, 2 high-resolution color scanners, and 1 36-inch-wide sheet scanner. All computer systems on the Bureau's Local Area Network are connected at 10 MB or 100 MB to an Ethernet backbone that is in turn connected via a T-1 circuit to the UT campus and other Internet sites worldwide.

Publications Sales

The Publications Sales Office, managed by Amanda R. Masterson with assistance from Timothy M. Medrano and Kristin E. Neilson, reported an outstanding year. Sales in 1997 totaled more than $170,000, which represents a 41-percent increase over last year in total sales. Addition of new corporate standing-order customers and availability of new publications, notably Volumes 1 and 2 of the *Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs*, contributed to the increase in sales during 1997. The best-selling publications of the year were the page-sized maps and guidebooks. The new "Down to Earth" series, designed for the general public, was inaugurated in 1997 with the publication of *Down to Earth at McKinney Falls State Park, Texas*, a popular guidebook available at State Park visitor centers and the Bureau. The Publication Sales office is located at the J. J. Pickle Research Campus,

10100 Burnet Road, Building 130, in northwest Austin. Office hours are 8:00 a.m. to 4:30 p.m., Monday through Friday. For our U.S. customers' convenience, we offer toll-free phone (1-888-839-4365) and fax (1-888-839-6277) numbers and a Web site (http://www.utexas.edu/research/beg/pub.html).

Quality Assurance

The Bureau has maintained a formal quality assurance program since 1979. The program is documented in written instructions that address research activities, analytical procedures, and methods for verifying and documenting the achievement of quality. The Bureau's quality assurance program conforms to requirements and standards provided by Congress, such as 10 CFR 50, Appendix B, by professional entities such as ANSI/ASME Nuclear Regulatory Documents, and as directed by contract. The Bureau's QA program meets the requirements of both the U.S. Department of Energy and the U.S. Environmental Protection Agency.

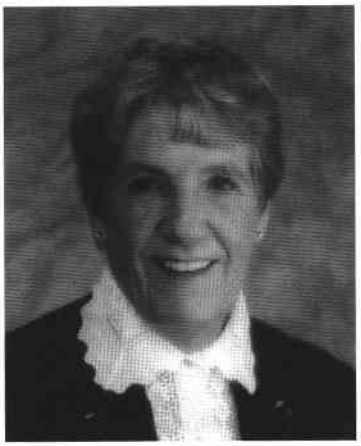
During 1997, quality assurance personnel participated on three Bureau research projects. In addition to providing guidance to researchers on quality assurance issues, the QA staff continued to update and revise the Bureau's QA Program and Procedures. James Donnelly, Quality Assurance Specialist, organized an 8-hour Basic Health and Safety Course that was taught by the U.S. Environmental Protection Agency. Twenty-four Bureau researchers and one employee from UT's Center for Electromechanics participated in this course, which renews employees' knowledge of health and safety regulations when working in the field.

In Memoriam: Barbara M. Hartmann (1934–1997)

The Bureau has long been known for the exceptionally fine quality of products produced by its cartographic and computer graphics section. Although that group of professionals has made and continues to make a superb platform for Bureau presentations and publications with slides and other graphics, their key legacy is the many full-colored maps they produce. Among the best of these map makers was Barbara M. (Babs) Hartmann. She had all the technical skills in executing a map, but she also had the talent and flair of an artist in selecting and melding colors. Her maps were not only cartographically precise but also pleasing to the eye; these are her legacies.

Babs Hartmann immigrated to the U.S. from Hamburg, Germany. She joined the Bureau as a cartographer in 1957 and retired 38 years later in 1995, taking a leave in the interim to raise her children.

Babs worked on several major mapping projects at the Bureau, including the *Energy Resources of Texas* map, the *Mineral Resources of Texas* map, the *Atlas of Major Texas Oil Reservoirs*, six *Geologic Atlas of Texas* sheets, three maps for the *Environmental Geologic Atlas of the Texas Coastal Zone*, two quadrants of the *Land Resources of Texas* map, the *Geologic Map of Texas*, and the *Submerged Lands of Texas* atlases. In 1987 she was awarded a certificate of merit for the Brownsville–Harlingen area *Submerged Lands of Texas* map in a design contest sponsored by the American Congress on Surveying and Mapping in cooperation with the American Cartographic Association. Her award was for "Best in Category—Series Maps and Charts, 1986." In 1987 she also received the prestigious UT Excellence Award from President William Cunningham for "consistent, high-level" performance.



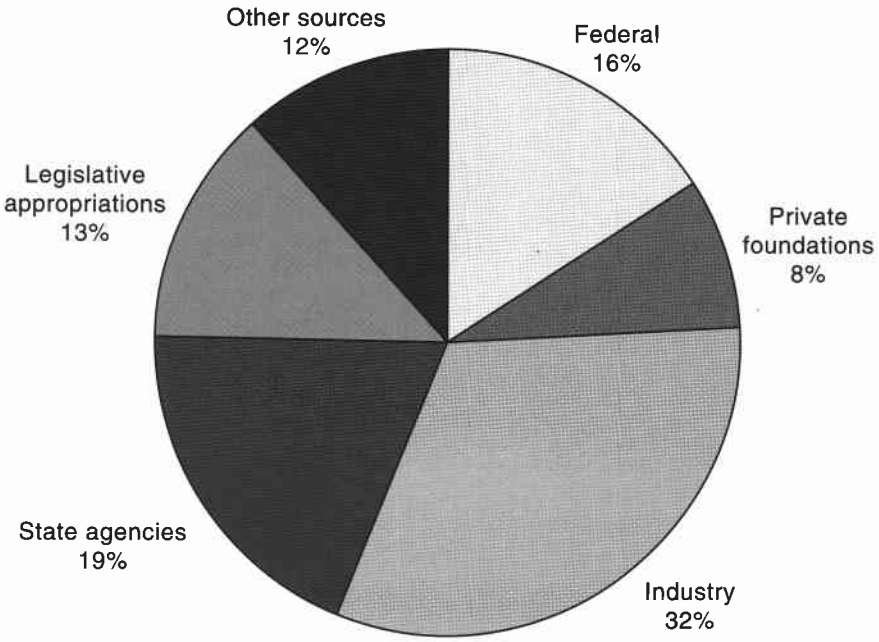
Babs is survived by her husband Helmut, her daughter Heike, and son Klaus. I first met Babs in the fall of 1960, when the Bureau was on the Little Campus, and for nearly 4 decades we were colleagues and friends. I always respected her skills, but I also enjoyed her sense of humor, fun, and zest for living. Those of us who date back some years will never forget the delightful, but potent, fruit punch of hers that highlighted the cartographic section's Christmas party.

On the occasion of Babs' UT Excellence Award 10 years ago, I described her as "the epitome of the dedicated and talented Bureau staffer: the kind of person that gives us the fine reputation we enjoy." She was that and more. We miss her, but her maps and her memory will live on.

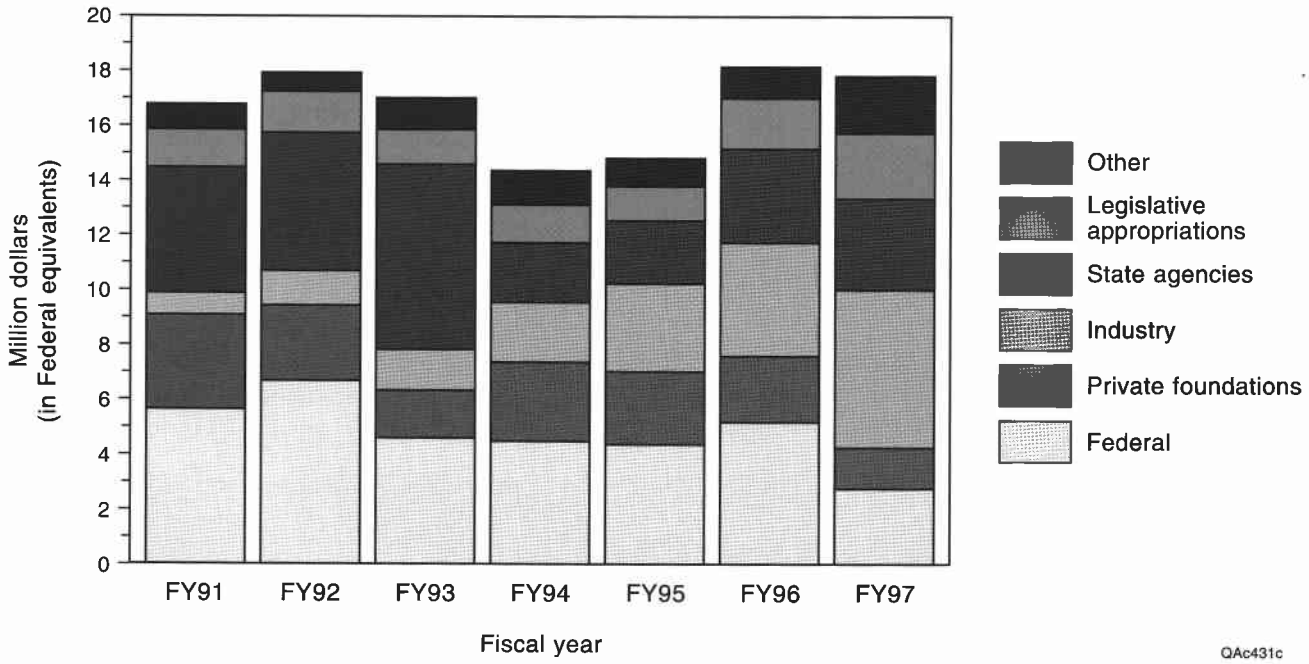
—William L. Fisher

Sources of Funding and Budget Trends

FY 97 SOURCES OF FUNDING



SEVEN-YEAR BUDGET TRENDS



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